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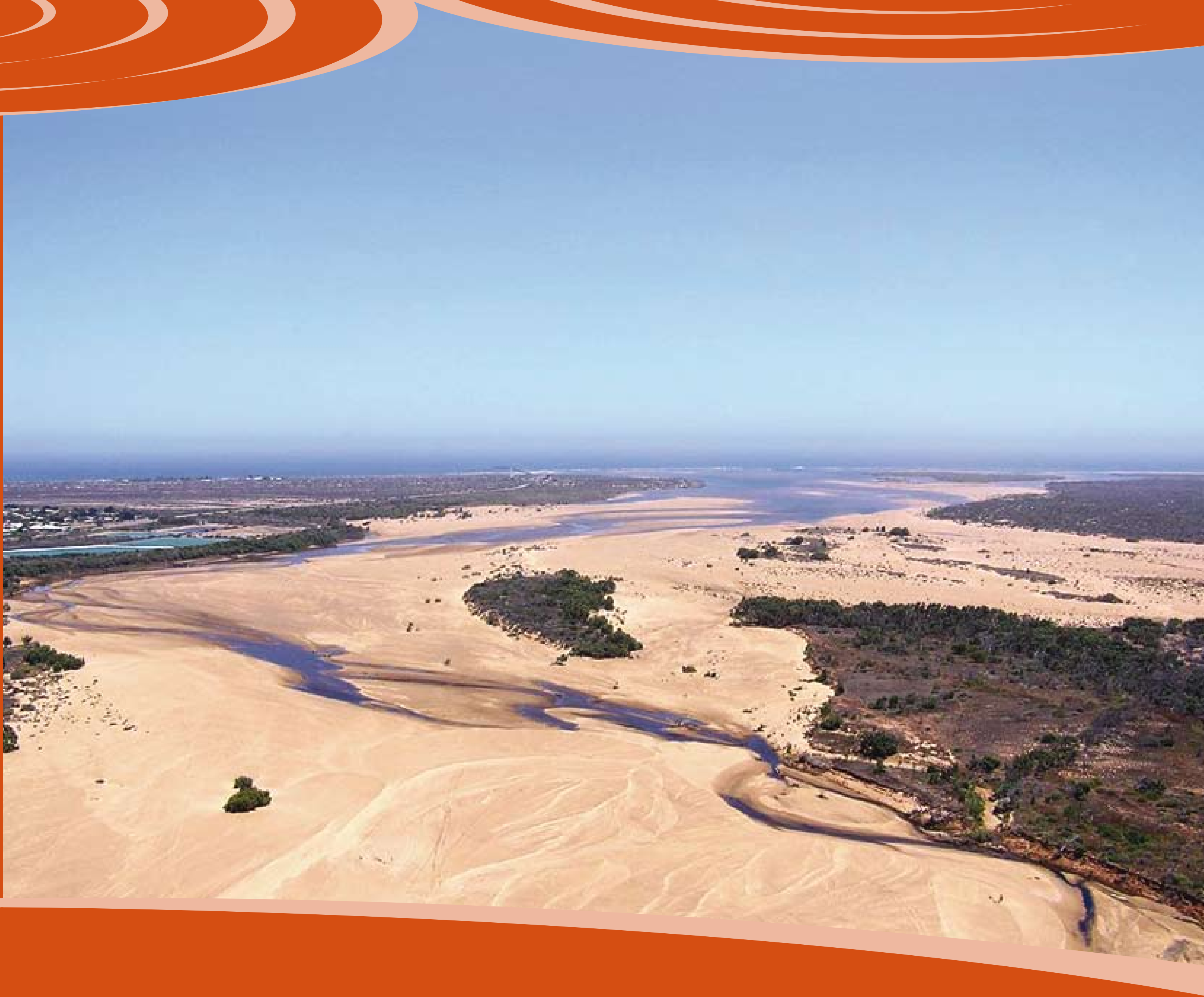

Groundwater recharge from the Gascoyne River, Western Australia

Hydrogeological record series

Report no. HG 32
May 2009

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Cover photo: Gascoyne River, Western Australia

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Abstract

The Gascoyne River is ephemeral and drains a catchment of roughly 73 400 km^2 in the arid mid-northwest of Western Australia. There is a great variation in surface water volume and duration of flow along the Gascoyne River as a consequence of the size of the catchment and the climatic conditions that deliver rainfall to the area. Fresh groundwater occurs within the floodplain sediments beneath the Gascoyne River to a depth of 60 m below the ground, but is surrounded by brackish groundwater. River flow is the main source of recharge to the floodplain sediments and the groundwater is used to supply the needs of the horticultural industry and the town of Carnarvon.

The fresh groundwater resource occurs in an area with regulated limited water supply. Government policies on the sustainable abstraction and quality protection of the resource have been implemented to prevent any deterioration of the resource. The importance of estimating a sustainable yield for the social, economic and environment benefits of the community have necessitated a thorough understanding of the groundwater flow system, the magnitude of recharge resulting from river flow and the water quality.

This report represents a synthesis of groundwater investigations, water quality and watertable monitoring conducted over the last 30 years. It establishes the hydrologic, geological and hydrogeological framework for the Gascoyne River floodplain aquifer. This framework was represented by a transient, quasi three-dimensional, finite-difference groundwater flow model for quantification of the groundwater resources. A probability distribution function of recharge from river flow after the simulation of eight historical flow events over seven years gave an expected recharge volume of 17 GL, and an 80% probability of recharge between 3.4 and 28.5 GL per river flow. The expected recharge volume exceeds the current rate of abstraction and implies potential for increased groundwater abstraction.

1 Introduction

Ephemeral rivers and associated groundwater resources represent an enormous opportunity for water supply development in arid regions of the northwest of Western Australia. This report presents an analysis of the groundwater flow system of the Gascoyne River floodplain aquifer, in the arid mid-northwest of Western Australia, which has substantial groundwater development and monitoring to facilitate a comprehensive understanding of the recharge process associated with ephemeral river flow.

1.1 Historical setting

At the mouth of the Gascoyne River lies the town of Carnarvon, located on the Indian Ocean coastline. The town was founded in 1883 to serve a fledgling pastoral industry in the region, the original water supply being derived from shallow wells located along the south arm of the river. However, increases in salinity, causing abandonment of wells furthermost from the river, began in the vicinity of the town site as early as 1919. Thus, the fundamental importance of understanding the groundwater flow system for the viability of Carnarvon was realised from the outset.

The first banana suckers were planted in the region in 1928 (Findlay, 1984), and the horticultural industry began. However, obtaining an adequate, low salinity and dependable water supply has occupied the energy of the horticulturalists and government agencies ever since. The horticulturalists were able to draw fresh water from the Gascoyne River adjacent to their plantations and from shallow wells sunk into the riverbed or its banks. However, flow in the Gascoyne River is intermittent, and the volume of each flow highly variable; consequently doubts about the sustainable nature of the water supply have dogged the industry from the earliest days.

To address the water shortage issue government agencies have conducted many investigations into water supply options in addition to the extensive drilling exploration conducted by horticulturalists, beginning with a drilling program in 1938, when 60 wells were sunk along the river to assist growers in locating water, with 35 being successful. In 1946 another drilling program sank 50 wells to locate ‘second water’ beneath the riverbed, of which 22 were successful. After failure of the river to flow in 1954 another government drilling program completed 40 wells to investigate the floodplain for suitable quality groundwater beneath the plantation area. However, only one well was successful, the rest being too saline, leading to the conclusion that, ‘*there is no general body of suitable groundwater under the plantation areas away from the riverbed sand*’ (Ellis, 1954).

A subsequent report in 1955 by government geologist H. A. Ellis, after reviewing the drilling results from government and private wells, was even more pessimistic, stating, ‘*beyond any doubt whatever that, upstream of the clay crossing* (Bibbawarra

Crossing?) *there is no general widespread body of groundwater suitable for continuous irrigation purposes*'. The report recommendations included constructing a clay barrier to slow the natural depletion of groundwater from the riverbed sand, and that '*if nothing is done to alleviate the water position*…. *then the next best thing could possibly be some control to ensure a more equable distribution of the water which is available*' (Ellis, 1955). Interestingly, the report also noted the existence of '*shoe-string sands*' within the floodplain sediments and that if connected to the riverbed they may contain freshwater.

After many debates, judging by the magnitude of correspondence on file, a clay barrier was constructed across the river in 1956 to slow the natural groundwater depletion, but it was breached by floodwater during 1957. By 1960, the government was exercising control over the allocation of groundwater for the horticulture industry at the request of the plantation owners. The aim was to reduce the risks of increasing salinity and safeguard the town water supply.

A complicated set of 'rules of the river' were developed through historical practice and precedents. Prolongations were drawn from the edge of plantation boundaries to the centre of the river, where a northern prolongation boundary would meet a southern plantation prolongation, and the respective proprietors were allowed to draw a specified allocation from within that area alone. After each river flow the allocation amount would be reset, and from time to time re-assessed with each failure of river flow. After long periods of no flow however, the natural depletion of groundwater coupled with abstraction resulted in the deterioration of water quality.

In 1962 construction of a pilot public irrigation scheme upstream of the plantation area began. The scheme demonstrated that it was feasible to pipe water from upstream wells to the plantation area in times of drought, if a significant volume of freshwater could be located. By the early 1970s the plantation wells were under threat from rising salinity as the river failed once more. Groundwater abstraction from around Water Supply Island for the town water supply had resulted in the ingress of saline water as groundwater pumping had drawn waterlevels below sea level. Some plantations on the north side of the river were abandoned because wells had become too saline and low salinity water for irrigation could not be obtained.

In 1974 a major expansion of the pilot scheme began with the extension of the wellfield to 50 km inland, after no river flow coupled with rising salinity within the Water Supply Island wellfield had restricted water supply the previous year. Water exploration drilling had shown that the floodplain sediments did contain fresh groundwater upstream of the plantation area, and the volume stored represented a viable option for water supply to the town and also for the horticultural industry. A public water supply area was proclaimed, but doubts about the sustainable yield of the scheme and the downstream impacts on private wells persisted, owing to the unpredictable nature of river recharge and limited knowledge of the groundwater reserves. Accordingly, in 1980, a moratorium on increasing allocations was enforced and remains to this day.

Over the last 40 years there has been steady exploration, well boring and construction in the public water supply area. This has increased the water supply scheme capacity and added greatly to the knowledge and understanding of the groundwater flow system in the area. Waterlevel and salinity monitoring extend back decades, along with abstraction data, river flow levels from two stream gauging stations and climate data. This wealth of monitoring provides an unprecedented opportunity to study the groundwater flow system of an ephemeral river in an arid environment. This project provides water resource managers with the confidence to allocate the maximum sustainable yield from the groundwater flow system for the social and economic benefit of the Carnarvon community, while ensuring adequate resources for the groundwater dependent environment.

The ‘shoe-string’ sands of the floodplain, first alluded to by H.A. Ellis in his 1955 summary, are now a very important component of the water supply issue for Carnarvon.

1.2 Location

The town of Carnarvon is the regional centre for the lower Gascoyne district. It lies at longitude 113°39' and latitude 24°53' at the mouth of the Gascoyne River, bordered by the Indian Ocean to the west and the arid mid-northwest region of Western Australia to the east (Fig.1). The major industries in Carnarvon are horticulture, fishing and tourism, while regional industries are predominantly pastoral and mining. At one time, the town was also a whaling station. The important horticultural industry supplies fresh fruit and vegetables for local and international markets.

The town water supply wellfield extends from east of Nine Mile Bridge up to Rocky Pool, 56 km above river mouth (ARM). A private wellfield exists between Nine Mile Bridge and Water Supply Island to the west, with a small extension east of the bridge along McGlades Road on the north side of the river.

1.3 Climate

The region has an arid climate with hot summers and mild winters. Inland climatic conditions are more extreme than those experienced at the coast. January is typically the hottest month in the inland catchment with a mean daily maximum temperature of 41°C. February is typically the hottest month for the coastal area with a mean daily maximum temperature of 33°C. Cooling onshore breezes result in significant temperature gradients in near coastal areas in the summer months (Bureau of Meteorology, 1998). The coolest month for the inland catchment is July, the mean daily maximum temperature for Gascoyne Junction (176 km ARM) is 23°C, and for Carnarvon it is 22°C (Table 1).

There are four major rain-producing mechanisms for the Gascoyne River catchment:

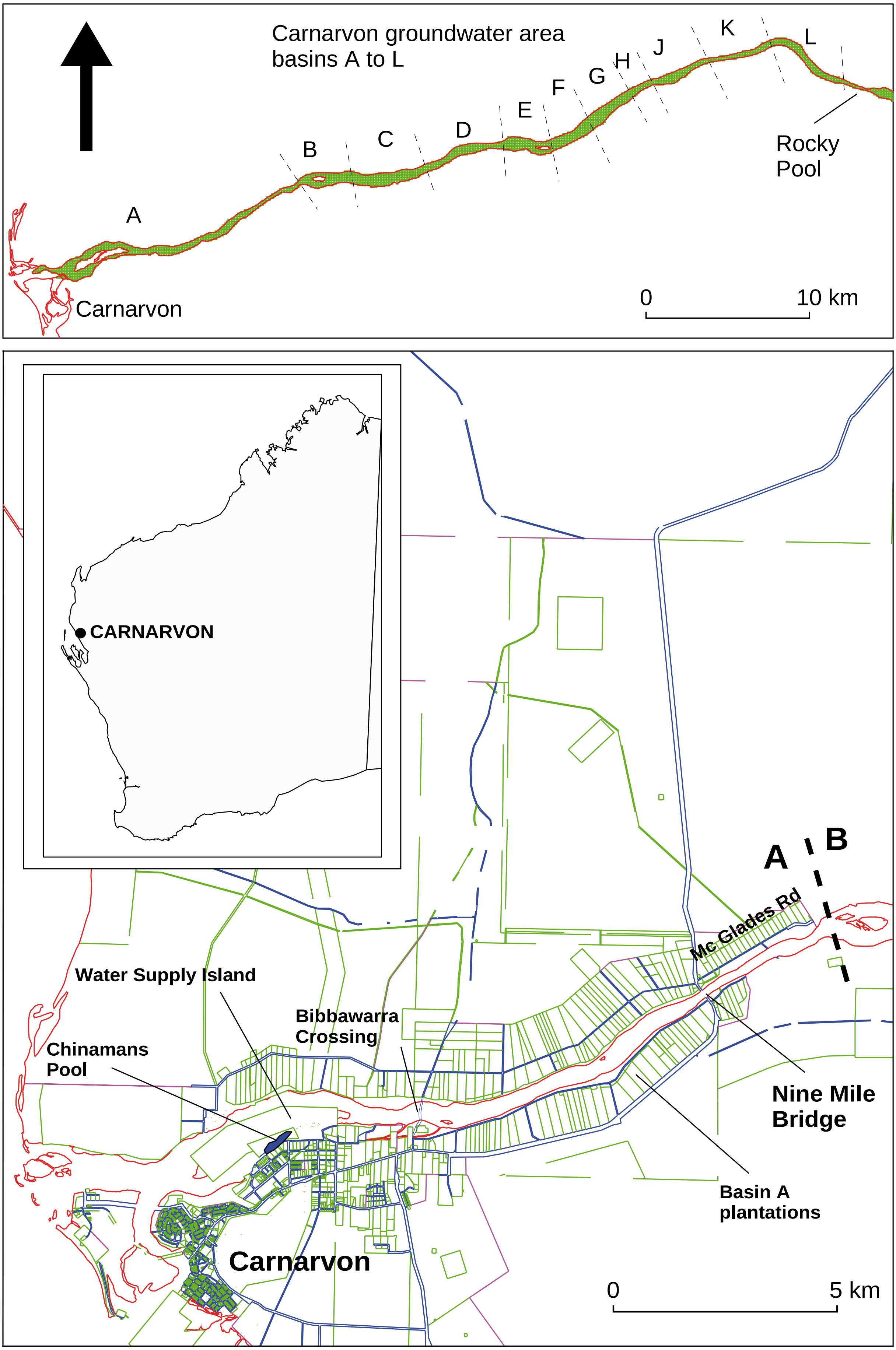

Figure 1 Location

- northwest Australian cloudbands,
- cold fronts,
- tropical depressions, and
- troughs and lows with easterly winds.

Northwest Australian cloudbands develop the elongated, coherent mass of middle and high level cloud, that forms off the northwest coast of Australia and extends southeastwards across the continent (Bureau of Meteorology, 1998). These cloudbands produce rainfall in the cooler months from April to October. However, not all cloudbands are sufficiently developed to produce rainfall. Often northwest Australian cloudbands and cold fronts occur together and may combine to produce significant rainfall, as in 1980, when the yearly average rainfall occurred between May and June.

Cold fronts mainly occur during the cooler months and sweep across Western Australia from west to east; however, most fronts pass to the south of Carnarvon. Rainfall associated with cold fronts declines inland, away from the coast. Strong fronts cause rainfall inland, but usually a front requires interaction with moisture from northwest cloudbands to generate significant rainfall over the inland catchment of the Gascoyne Region (Bureau of Meteorology, 1998).

Tropical depressions (lows and cyclones) are the primary mechanism for heavy rainfall in the warmer months and are the main cause of flooding in the region (Bureau of Meteorology, 1998). These systems are most common in February and March, but can occur from December through to May. From 1910 to 2000, 27 cyclones delivered significant rainfall to the catchment, approximately one every three and a half years. The heaviest rainfalls occur along the track of the tropical lows or cyclone paths, but the rainfall varies with the size, speed and direction of movement of each system.

Troughs and lows with easterly winds can generate significant rainfall in exceptional cases. The rain-bearing systems are divided into two types: either thunderstorm-producing heat troughs in warmer months or mid-level lows in the cooler months (Bureau of Meteorology, 1998). The thunderstorm-producing heat troughs generally impact inland catchment areas and generate damaging winds and intense, localised rainfall, that may result in small river flows in the upper catchment. Mid-level lows generally affect the coastal area as they form offshore and move slowly inland.

Annual rainfalls for three Gascoyne River catchment meteorological stations are shown in Figure 2. Rainfall is highly variable and unreliable from year to year; other than the dry interior, it is much less reliable than any other part of Western Australia (Bureau of Meteorology, 1998). Generally it is less variable in the cooler months as opposed to the summer months. The mean yearly rainfall for Carnarvon is 233 mm, and at Gascoyne Junction the yearly mean is 214 mm. The highest yearly total at Carnarvon is 557 mm in 1963, and at Gascoyne Junction it is 550 mm in 1923; the lowest yearly rainfall at Carnarvon is 75 mm in 1966, however at Gascoyne Junction it is 7 mm in 1957. The highest daily total rainfall recorded within the catchment is

293 mm in 1943 at Jimba Jimba, near Gascoyne Junction, and this was associated with a cyclone (Bureau of Meteorology, 1998). Gascoyne Junction rainfall correlates better with river flow periods than at the downstream stations, particularly over the last 5 years (Fig. 2).

Evaporation has been recorded using a Class A pan evaporimeter fitted with a bird guard at Carnarvon, Brickhouse Station (approximately 17 km ARM) and Gascoyne Junction. Evaporation is typically highest in January, whilst the same minimum occurs in June and July. High daily evaporation rates occur in hot windy conditions, while negligible daily evaporation occurs on unusually cool, wet, humid days. The mean annual potential evaporation rate for Carnarvon is 2613 mm, and inland at Brickhouse House Station it is 2946 mm, and at Gascoyne Junction it is 2977 mm.

1.4 Physiography

The catchment physiography can be divided into two distinct areas: an inland, etched, granitic plain; and the Carnarvon Basin, consisting of the Kennedy Range plateau, and a flat coastal plain (Fig. 3). The total catchment area is approximately 74 000 km^2.

The topography of the granitic plain rises to approximately 700 m AHD (Australian Height Datum) on isolated peaks, but averages about 400 m AHD and slopes gently to the west to an elevation of about 280 m AHD. The drainage channels are generally broad and ill defined by large flood-ways within very wide valleys. The granitic terrain comprises about three-quarters of the total catchment area and is generally of very low relief.

The Carnarvon Basin lies westwards from the granite terrain and is divided into three broad physiographic zones: a coastal, a transitional and an inland zone (Hocking, Moors and van de Graaff, 1987). The coastal zone consists of flat lying, aggrading alluvial to deltaic plains and sand dunes derived from reworked alluvium. The inland zone consists of erosional landforms of dissected duricrust plateaus with greatest relief. Some areas, such as the Kennedy Range, are virtually undissected plateaus above 300 m AHD, protected from erosion by an extensive sandplain. The transitional zone lies between the two, and consists of both low-lying constructional and erosional landforms.

The groundwater area of the model occurs over part of the flat, lowland coastal plain, from the coast to Rocky Pool, a distance of roughly 56 km. The elevation at Rocky Pool is approximately 40 m AHD, from where the coastal plain slopes gently down to the Indian Ocean where mean sea level is 0.865 m AHD[1]. This area consists of numerous unlithified, sparsely vegetated longitudinal dunes as much as 3 m above the surrounding lowland. Interspersed between the dunes are deflation clay pans that are periodically inundated after severe flooding or heavy rainfall. The clay pans

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[1] Data courtesy of the National Tidal Facility, Flinders University of South Australia

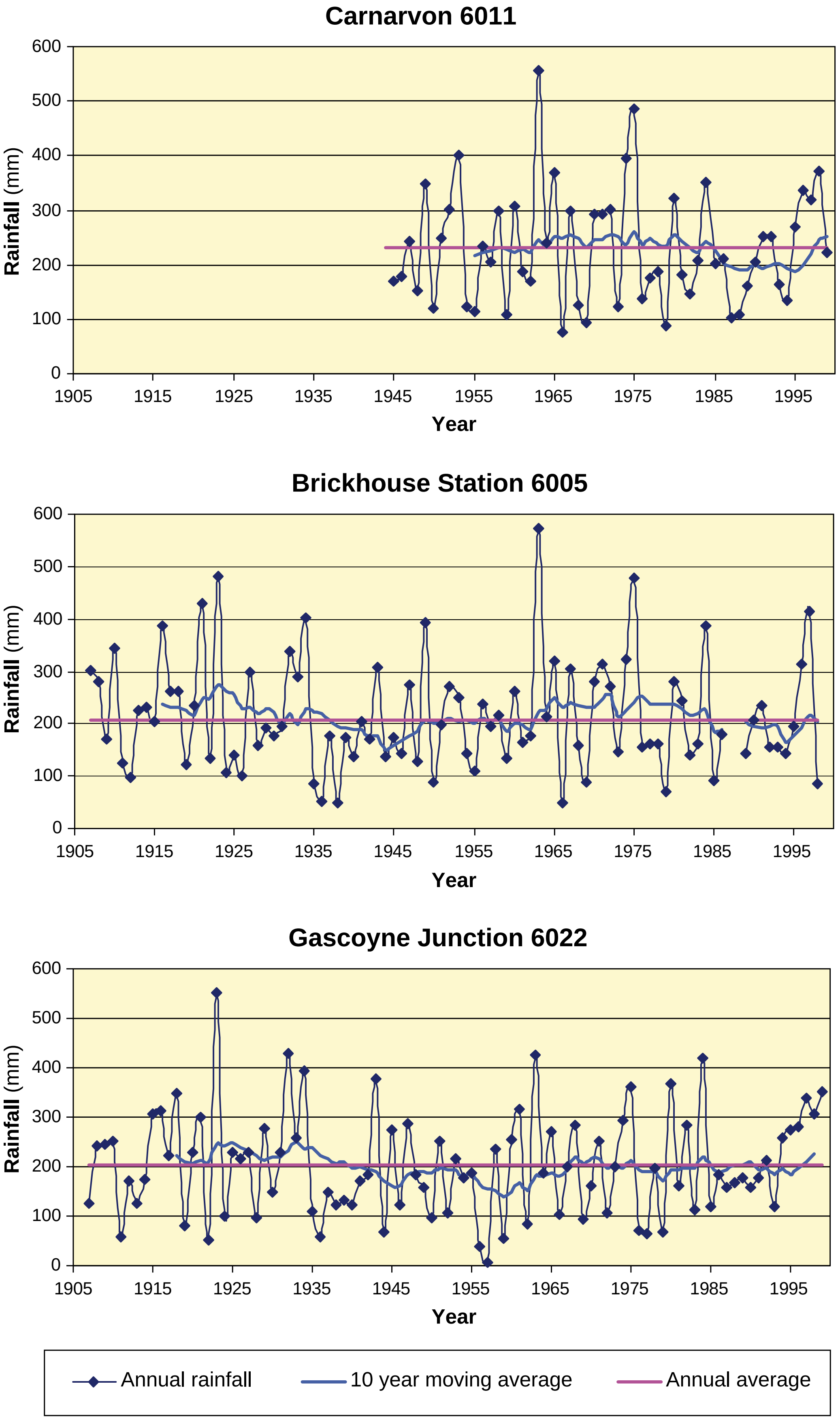


Figure 2 Gascoyne River catchment rainfall (Source: Bureau of Meteorology)

west of Rocky Pool receive runoff from small tributaries that drain surrounding areas, but rarely link up with the Gascoyne River to drain their water owing to the relatively higher levee banks of the river. As a consequence, much of the floodplain is not negotiable after heavy rainfall.

Table 1 Climatic data for the Gascoyne River catchment

	J	F	M	A	M	J	J	A	S	O	N	D	Annual average
Mean monthly rainfall (mm)													
Carnarvon Airport 3 km ARM	12	21	16	14	38	48	47	19	6	6	4	2	233
Brickhouse Station 17 km ARM	19	31	15	18	32	42	56	20	5	11	5	2	256
Gascoyne Junction 120 km ARM	23	29	31	14	29	33	28	13	3	5	3	4	214
Three Rivers ~550 km ARM	31	40	37	22	25	26	13	8	2	5	8	18	234
Mean maximum daily temperature (°C)													
Carnarvon Airport 3 km ARM	31	33	31	29	26	23	22	23	24	26	27	29	
Brickhouse Station 17 km ARM	36	37	35	31	28	24	23	24	27	29	31	35	
Gascoyne Junction 120 km ARM	41	40	37	33	27	23	23	24	28	32	35	39	
Three Rivers ~550 km ARM	40	38	36	30	25	21	21	23	28	32	35	38	
Mean minimum daily temperature (°C)													
Carnarvon Airport 3 km ARM	22	23	22	19	15	12	11	12	14	16	19	21	
Brickhouse Station 17 km ARM	21	23	21	17	13	11	10	9	11	14	17	20	
Gascoyne Junction 120 km ARM	24	24	22	18	14	10	9	10	12	15	18	21	
Three Rivers ~550 km ARM	24	23	21	16	10	7	5	6	10	14	18	22	
Mean daily and annual pan evaporation (mm)													
Carnarvon Airport 3 km ARM	10	10	9	6	5	4	4	5	6	8	9	10	2613
Brickhouse Station 17 km ARM	12	12	10	7	5	4	4	5	7	9	10	12	2946
Gascoyne Junction 120 km ARM	13	12	10	7	5	3	3	5	7	10	11	12	2977

Source: Bureau of Meteorology

At the coast the Gascoyne River has built three small deltas during the Quaternary (Johnson, 1982). The present delta is dominated by wind and wave erosion and its location suggests that the Gascoyne River delta has migrated slowly northwards during the Quaternary (Hocking, Moors and van de Graaff 1987). Southeast of Carnarvon lies Brown Range, rising to 30 m AHD, that probably represents an older beach-ridge complex associated with an earlier delta of the Gascoyne River (Hocking, Moors and van de Graaff, 1987). Coastal dunes and saline coastal marshes occur north of the river mouth.

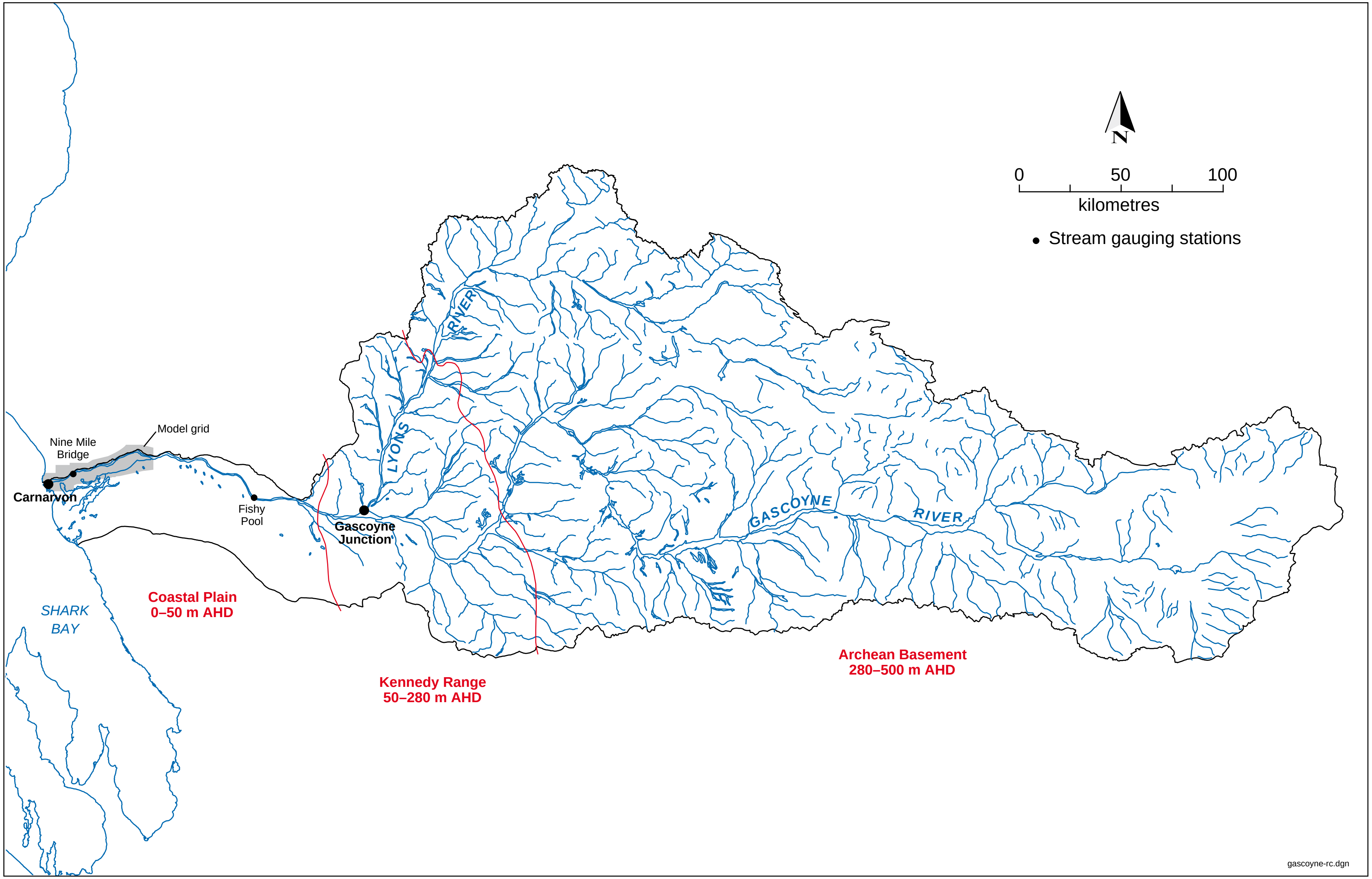


Figure 3 Gascoyne River catchment

1.4.1 Drainage

The Gascoyne River extends about 700 km inland from the coast. Its upper tributaries consist of broad flat flood-ways that drain the inland Archaean basement of the arid interior. The eastern part of the Carnarvon Basin is of greater relief than the coastal plain and the drainage is better defined than in the arid interior, with small tributaries draining the Kennedy Range. The other major tributary within the catchment is the Lyons River, that joins the Gascoyne River near Gascoyne Junction at the western margin of the Kennedy Range (Fig.3). The Lyons River drains mainly the Kennedy Range area and has higher rainfall and lower evaporation than the interior eastern Gascoyne River. Its contribution to the stream flow of the coastal plain is considered significant, however there are no rating curves developed for the Lyons River gauging stations to confirm this theory.

From the western margin of the Kennedy Range the coastal plain has little relief, and gently slopes from approximately 60 m AHD down to the Indian Ocean over a distance of about 140 km, a gradient of the order of 10^{-4}. On this plain the Gascoyne River has a singular, low-sinuosity channel, up to 1200 m wide, incised 3 to 5 m into the floodplain and containing vegetated sand islands. Rainfall over the inland catchment is the source for surface flow, as the floodplain is lacking significant tributaries. Once a surface flow leaves the incised channels of the Kennedy Range it is more likely to branch and spread out across the floodplain, if the stage height is sufficient to overflow the levee banks, as various overflow channels leave the main watercourse.

1.5 Vegetation

The vegetation of the low-lying coastal plain is sparse; much of the area consists of bare clay pans, gravel and shingle patches or sand dunes. Where vegetation occurs, it consists of grass plains of spinifex, interspersed with a mixture of low acacia scrub consisting mainly of snakewood (Beard, 1975). Near Carnarvon, saltbush and bluebush around clay pans dominate the coastal marshes, and very wet areas contain halophytes, such as samphire. Low sand dunes and high ground, such as Brown Range, contain sparse, low acacia shrubs and herbaceous small woody plants. The vegetation assemblages indicate predominantly alkaline soils (Beard, 1975).

Along the Gascoyne River a gallery of predominantly river red gums (*Eucalyptus camaldulensis*) with other eucalypt species and some acacia trees occurs. The density of trees is sparse, ranging from 10–40%, which indicates that the trees survive in less than ideal conditions. Mature red gum trees are up to 12 m tall, and through their life cycle utilise a combination of surface water, soil moisture and groundwater stored within the riverbed and banks for survival. The eucalypts survive nowhere else on the coastal plain, except where stunted trees, 6–8 m tall, line small creeks and waterways.

The river red gum is the most widely distributed of all eucalypt species, occurring across Australia from 12.5–38°S. It grows under a large range of environmental conditions, from sub-tropical to arid; the mean annual rainfall range over its distribution is mostly within 150–1250 mm (Harwood et al., 2001).

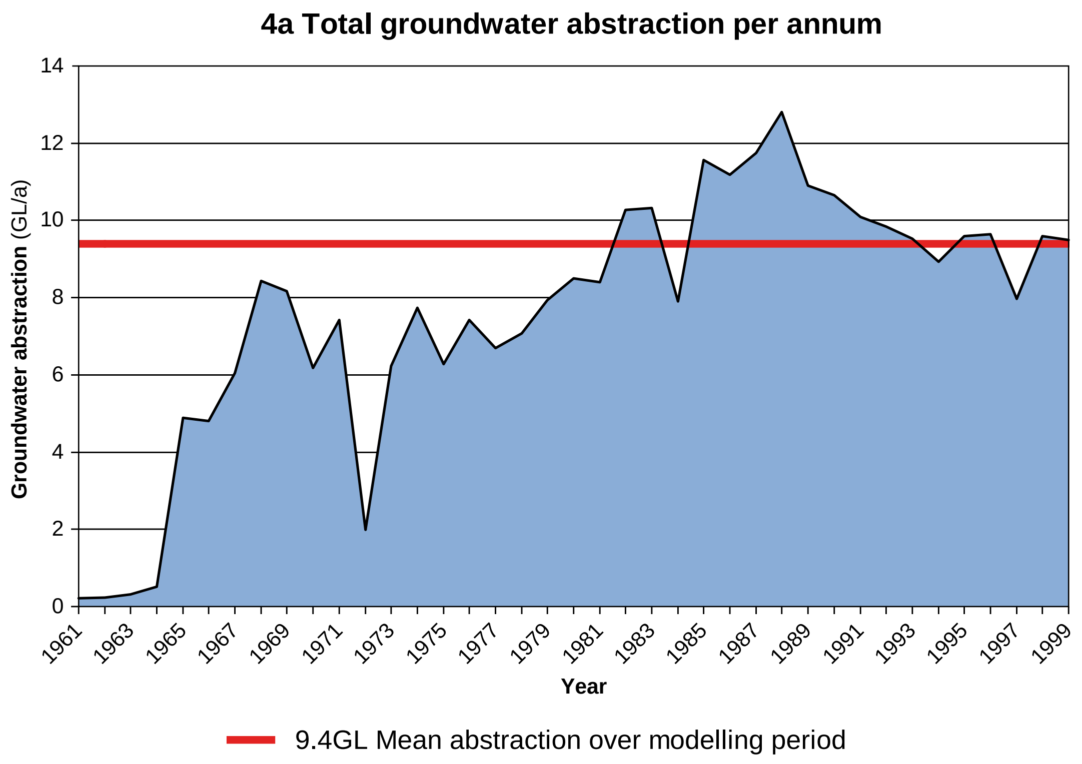
1.6 Land use

Land use within the inland catchment is predominantly pastoral and mining. Horticultural plantations line the Gascoyne River from approximately 5 km ARM to just east of the Northwest Coastal Highway along McGlades Road. Owing to previous water shortages, the plantations use relatively economical irrigation practices, such as trickle irrigation, plastic laid flat to reduce evaporative losses and large areas of shade cloth. There are no comprehensive studies or estimates of groundwater returns from irrigation to the watertable within the Carnarvon plantation area. However, owing to the depth of the watertable (generally > 10 m) and the clayey nature of the soils, irrigation returns to the watertable are assumed small.

1.7 Water supply

The water supply for Carnarvon is provided from groundwater stored within sediments beneath the course of the Gascoyne River, and supplemented by surface water when the river is flowing. The water supply is divided into two management areas: a public water supply operated by the Water Corporation and a private wellfield. The public water supply wellfield supplies water for town use and for the horticulture industry, while the private abstraction area is used mainly for the horticulture industry, with miscellaneous licensees such as caravan park owners. The Water Corporation wellfield will be referred to as the Scheme wellfield, although it is also known as Basins B–L (Fig. 1), while the private wellfield area is known colloquially as Basin A, which will be adopted for simplicity within this text.

The Water and Rivers Commission, the government regulatory body for water in Western Australia, licences all groundwater abstraction. The government of Western Australia has regulated groundwater abstraction in the area since 1959, and there has been a moratorium on increasing allocations since 1980. The philosophy behind the controls is to provide a reliable water supply for the irrigation area during a critical drought period. Each plantation has an assessment number and a licence issued with a unit allocation with a maximum draw of 72 000 kL per annum, although some assessments have less than one unit allocation while some plantations have more than one unit. During river flow, unrestricted pumping of groundwater and surface flow is permitted. This results in reduced reliance on groundwater over some years when river flow is large. At the cessation of river flow the unit allocation is reset to some level up to a maximum of 72 000 kL per annum, but may be re-assessed from time to time during extended no flow periods. The total maximum annual allocation in 1999 was 12.8 GL. However, the actual withdrawal can exceed this figure owing to periods of unrestricted pumping. The Water Corporation is licensed to abstract up to 6.8 GL/a for the Scheme wellfield, while the private wellfield area is allocated 5.6 GL/a.


4a Total groundwater abstraction per annum

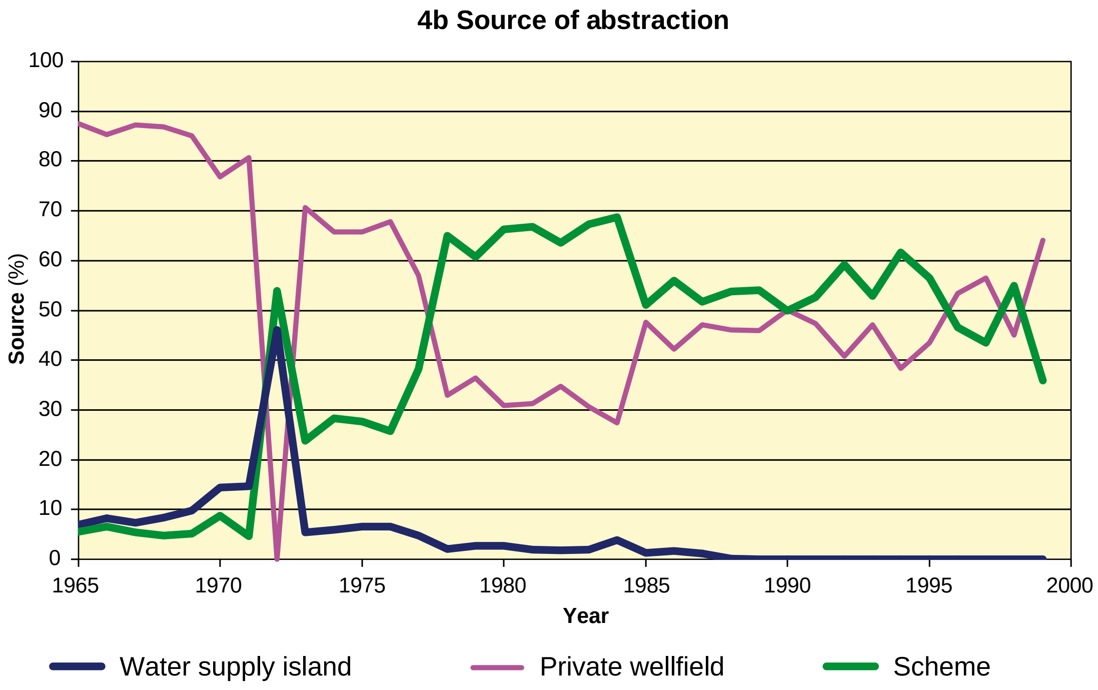

4b Source of abstraction

Figure 4 Groundwater use

Groundwater abstraction is measured by pipe flow dials on well head works, generally on a monthly basis, although the data rarely have quality assurance and so all figures are approximate. Total annual groundwater abstraction from 1961 to 1999 is presented in Figure 4a. The relative percentage abstracted from each groundwater area is represented in Figure 4b. Initially, most groundwater was abstracted from

Basin A, as the town water supply wellfield was once located at Water Supply Island, 5 km ARM. However, after a prolonged drought in 1972–73 and expansion of the Scheme wellfield, the horticultural industry began to rely more on the Scheme supply.

The town water supply demand peaked at 1.8 GL in 1988 and has stabilised at about 1.5 GL per annum. A 1% growth rate is projected until 2010 for town water supply demand (Water Corporation, 1999a). However, the principal mechanism driving demand for irrigation water from the scheme is the duration of no flow intervals. Irrigation demand is primarily met from Basin A private wells but, with increasing time between river flow, rising water salinity and reduced well yields result in an increased reliance on the Scheme water supply.

1.8 Previous investigations

1.8.1 Geology

Early geological investigations of the Carnarvon Basin were conducted in the search for petroleum resources by Clapp (1926), Condit (1935) and Condit, Raggatt and Rudd (1936). The systematic mapping of the geology was conducted by the Bureau of Mineral Resources from 1948 to 1955 and was reported by Condon (1954) and Condon et al. (1956). The geology of the Carnarvon Basin has been summarised by Playford et al. (1975), Thomas and Smith (1976), Johnstone et al. (1976) and Hocking, Moors and van de Graaff (1987). The 1:250 000 geological map sheet series of Quobba and Kennedy Range were compiled by Denman and van de Graaff (1982) and Hocking et al. (1985), respectively. Hocking (1990) summarised an updated account of the geology of the Carnarvon Basin. Most of the geological investigations concentrate on the potential for petroleum resources within the Mesozoic sediments of the Carnarvon Basin.

1.8.2 Hydrogeology

Assessment of the groundwater resources of the Gascoyne River floodplain has been ongoing since the development of the horticultural industry. Constant upgrading and replacement of wells, or installation of monitoring piezometers have resulted in drilling programs by the Public Works Department (PWD), the Water Authority of Western Australia (WAWA) and/or the Water Corporation in most years since the inception of the Scheme wellfield. However, few reports on the hydrogeology or even well completion details were documented. The major drilling programs associated with groundwater resource assessments or wellfield capacity are listed in Table 2.

The systematic reporting of the hydrogeology of the region did not begin until the late 1960s by the Geological Survey of Western Australia (GSWA) at the request of the PWD. These investigations resulted from concern raised about possible downstream losses from the controlled discharge of water from a dam at Kennedy Range. Baxter (1968) conducted a geological reconnaissance of the floodplain geology and documented the groundwater salinity of the pastoral wells in the area, while

Passmore (1968) reported on the drilling investigation of the many flood channels that diverged from the Gascoyne River.

Table 2 Major drilling programs

Program	Commenced	Bores
Gascoyne River irrigation	1961	11
Carnarvon extraction area	1964	23
Old river channel bores	1968	25
Gascoyne River cross sections	1970	51
L-series	1973	50
Production and monitoring bore drilling	1974	35
Shallow L-series	1977	27
Production and monitoring bore drilling	1977	33
Shallow observation series	1977	42
Shallow observation series	1985	13
Carnarvon older alluvium (inc. multi-port bores)	1987	52
Monitoring bores	1992	10
Exploration and production boring	1993	30

Source: PWD, GSWA, WAWA, Water Corporation, Water and Rivers Commission

Allen (1972) was the first to complete a comprehensive review of the groundwater resources of the floodplain sediments and buried Cretaceous sediments, including pumping-tests. Allen's report forms the basis for the understanding of the groundwater flow system of the floodplain. Allen (1987) later summarised the groundwater potential of the entire Carnarvon Basin sequence. In 1987/88, another detailed hydrogeological investigation was conducted by the GSWA for the WAWA to review the estimated sustainable yield of the Scheme wellfield aquifer. Three transects were drilled perpendicular to the course of the Gascoyne River and multi-port monitoring wells installed, as were other monitoring wells, and the results documented by Martin (1990a). A subsequent report (Martin, 1990b) increased the estimated fresh groundwater storage of the floodplain aquifers by threefold from those of Allen (1972).

Further drilling and replacement of abandoned wells were conducted through the 1990s by the WAWA and supervised by the GSWA (Martin, 1992; Skidmore, 1997a). Skidmore (1997b) also conducted the first comprehensive well census of the area, excluding private wells. On behalf of the Water and Rivers Commission Rockwater (1996) conducted an overall assessment of groundwater resources of the Gascoyne Region. In 2000 an exploration drilling program was conducted into the groundwater resources east of Rocky Pool, as proposed by Rockwater (2000) on behalf of the Water Corporation.

Investigations into the augmentation of the groundwater resources were conducted simultaneously with the upgrading of the Scheme wellfield capacity. Dam site proposals were re-visited at Kennedy Range, Rocky Pool and elsewhere in the inland

Carnarvon Basin after the unfavourable reports of Gibb (1969) and the Public Works Department (1969). They concluded that the dam sites were of poor basin shape, and suffered irregular runoff and high evaporation. Off-stream storage facilities were investigated by the Public Works Department (1970), as were in-stream barrages and weirs; the idea of detonating a nuclear device to create a large storage basin was even suggested (Public Works Department, 1972). Further reports on water supply augmentation consist of a BHP (1984) investigation into the Yandoo Creek scheme. Wark and Ventriss (1986) summarised all previous proposals, and Gutteridge, Haskins and Davey Pty Ltd (1993) reviewed augmentation schemes including artificial recharge options. All augmentation schemes, once thoroughly investigated, were either too expensive for the anticipated return, ineffectual or both.

1.8.3 Groundwater modelling

Groundwater modelling of the Gascoyne River floodplain was first conducted in 1975 by the PWD. The initial models were designed as aids to simulate and manage the aquifer system. The forerunner was known as GASIM and this was run on mainframe computers at the Main Roads Department and then the PWD. A PC-version, known as GASMOD was developed later (Mackie Martin, 1991), for the WAWA. Over time a number of modifications were made, however the basic modelling concept for all versions of GASMOD was the same.

GASMOD was designed to examine various model parameters and operating strategies using a simulated period of river flow data. It could also be used to predict the condition of the aquifer at some time in the future, given existing conditions, parameters and management strategy (Rogers, 1995). The conceptual model consisted of a series of natural groundwater storage basins along the river, Basins A to L, excluding Basin I. Each of the eleven basins is represented in the model by a depth versus storage/area relationship, which was modified during calibration. Groundwater abstraction scenarios, river flow simulations and evapotranspiration were applied to add or remove storage. By averaging the hydraulic heads from each basin an estimate of the storage depletion volume was given, and thus the condition of the aquifer determined.

Modified versions of GASMOD were applied in groundwater yield analyses by Marchensani (1980) and Ventriss (1980). The latter examined the scheme yield capacity based on meeting a target supply in the second year after a recharge event. Ventriss (1980) recommended an upgrading of the wellfield capacity to meet the target supply with less risk of failure.

GASMOD could be used to test abstraction scenarios, but did little to explain the effects of temporal variations in stresses on the groundwater flow system. Eventually a spreadsheet model that used a selected number of bores from each basin to estimate the average waterlevel across that basin and thus aquifer depletion, superseded the system. The Water and Rivers Commission uses this spreadsheet to supply information to the Carnarvon Water Allocation Advisory Committee (CWAAC) that recommends allocation strategies throughout the year.

In 1996 the Water and Rivers Commission instigated an assessment of:

- the situation of the Carnarvon Irrigation District,
- the economic, engineering and impacts of augmentation options,
- future management options, and
- funding and financial options for the groundwater area (SMEC Australia Pty Ltd, 1996).

The key recommendations of this report were the formation of a transitional water management body to oversee the formation of a Water Board for water supply management, and recommendations for further geological investigations to better define the Gascoyne River aquifer system. '*Thereafter, a 3-dimensional geological model for analysing groundwater flow for detailed investigations and better accuracy of sustainable yields from the flow system, and hence possible expansion, could be determined'* (SMEC Australia Pty Ltd, 1996). This final recommendation gave rise to the current groundwater modelling research.

1.8.4 Drilling and testing

Systematic drilling and testing has been conducted in both the Basin A and Scheme wellfields. Basin A also has considerable drilling and testing conducted by plantation owners in the installation and construction of private wells. All government exploratory, monitoring and production well details have been compiled by Skidmore (1997b). The Skidmore spreadsheets have been amended for errors and are included in Appendix A, however the coordinates are represented in Australian Grid Datum.

In summary there have been 209 production wells in total, although most are now abandoned and only 53 production wells are licensed (Water Corporation, 1999a), but not all are operational. However, at the time of producing this thesis drilling and replacement of abandoned production wells was being undertaken by the Water Corporation. There is a network of 351 observation wells and piezometers, many with continuous waterlevel monitoring, as well as 128 exploration holes, pastoral bores and abandoned holes (Fig.5). Some older Scheme wellfield drilling details are lacking information on screen depths and even location in some instances.

The plantation assessment areas may have numerous licensed wells. Each licence application contains some information on well construction, although not all have accurate screen details; however, as many assessment areas contain numerous licensed wells it is not always obvious which well was in use at a particular time and, hence, at what depth groundwater was being abstracted. A voluntary bore census was conducted by letter drop and some well details were updated, the results of which are given in Appendix B. The locations of abstraction points representative of each assessment are given in Figure 6.

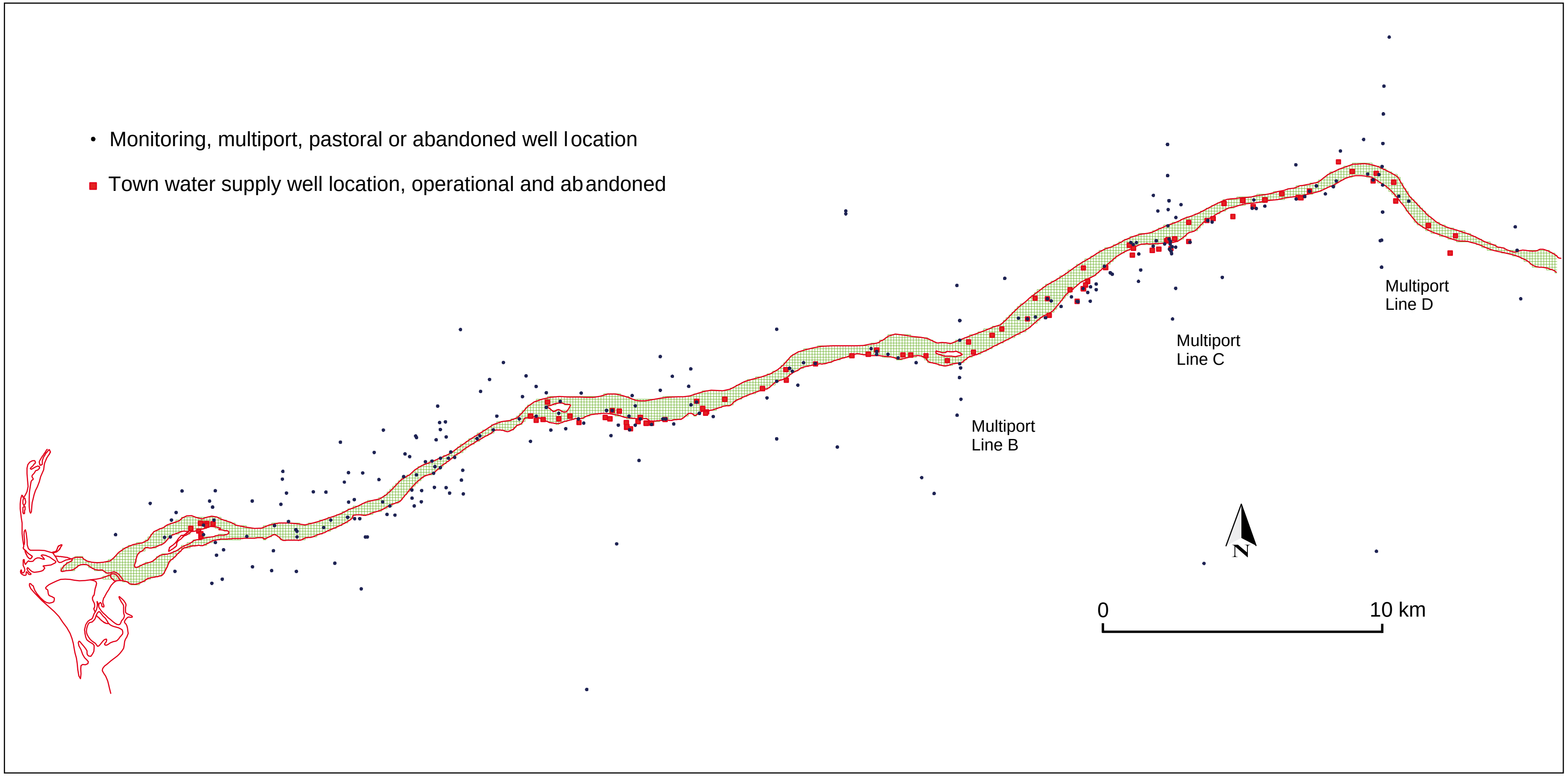


Figure 5 Basin A and Scheme well locations (excluding private wells)

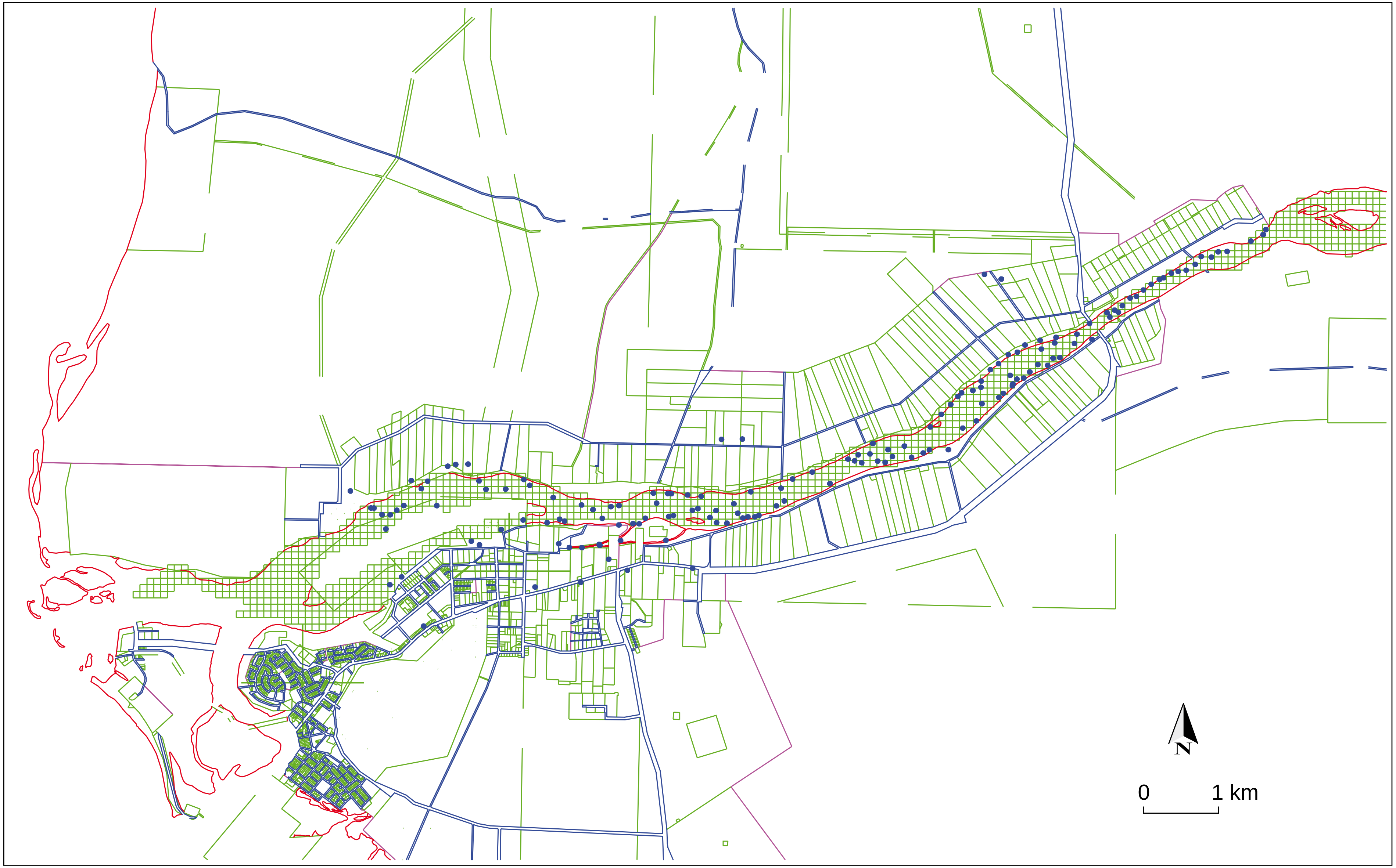


Figure 6 Basin A representative abstraction points for private wells

Most monitoring and production wells have been surveyed to Australian Map Grid (AMG) coordinates, as have licensed private wells in Basin A. However, only government wells are surveyed to Australian Height Datum (m AHD). Many monitoring wells drilled into the riverbed sand have been buried or no longer exist because of the movement of sediment within the riverbed during river flow.

Most of the Scheme wellfield drilling records after 1987 contain detailed geological logs however as most wells within the older alluvium are drilled with mud-rotary technique the geological logs represent only a rough indication of the lithology. Earlier drilling was conducted by cable tool and most geological logs are sparse or absent, excluding the drilling program of Allen (1972). Geological logs from private wells generally consist of brief descriptions of either sand or clay. The spreadsheets in Appendix A indicate whether a particular well has been geologically logged or not.

Not included in Appendix A is the 1969–72 PWD drilling survey within the dry Gascoyne River bed. An auger rig drilled the investigation holes on a 100 × 100 m grid within the riverbed sand from Nine Mile Bridge to beyond Rocky Pool. The investigation holes were drilled until the auger intersected clay and were then surveyed for elevation and location.

1.8.4.1 Pumping-tests

Pumping-test analyses have been conducted during the development of the Scheme wellfield. All details have been collated and are presented in Table 3. Vogwill (1972) conducted a pumping-test analysis on two wells screened in the riverbed sand aquifer using the method of Thies (1935). These tests were affected by boundaries to the riverbed sand and high pumping-test rates, longer duration tests and longer development time were recommended to get results representative of a greater proportion of the aquifer. Allen (1972) has detailed the results of twelve pumping-tests conducted along the Gascoyne River from 1968 to 1971. He concluded that the older alluvium is a leaky confined aquifer on the basis of results of the pumping-test analysis by the methods of Boulton (1963) and Chow (Kruseman and de Ridder, 1976). The results from both analyses have been converted to standard SI units in Table 3.

Martin (1988b) analysed the results of two constant rate pumping-tests conducted on Well 1/87 and 7/74 within the older alluvium using the analysis method of Boulton (1963). Martin notes that 67% of the 54 m saturated profile of Well 1/87 contained sand with less than 10% silt and clay. In comparison, Well 7/74 had only 2 m of sand with less than 10% silt and clay. The observation wells used for water level monitoring consisted of a series of multi-port piezometers used to measure the head at shallow, intermediate and deep depths within the aquifer.

The watertable contours at the cessation of pumping from Well 1/87 are elliptical and reflect significant horizontal anisotropy that is restricted to the finer grained upper 10–15 m of the saturated zone (Martin, 1988a). The major elliptical axis is northwest-southeast and the ratio of anisotropy is approximately 20 times that of the minor northeast-southwest axis (Martin, 1988a). The elliptical effect was not evident within intermediate or deep ports and probably reflects the orientation of a buried river channel intersected by the upper screens of the well. Test-pump wells 7/74 and 1/87 and observation wells used in the pumping-test analysis partially penetrate the aquifer, whereas the pumping-test analysis assumed the more general solution of fully penetrating wells (Martin, 1988a).

Twenty-four hour duration, pumping-tests were conducted on eight production wells drilled in the 1993/94 wellfield investigation (Skidmore, 1997a). Water levels were monitored in the pumping wells and recovery data recorded for up to 24 hours after pumping ceased. Estimates of transmissivity and hydraulic conductivity were made using the Theis method of analysis of residual drawdown for confined aquifers (Theis, 1935). As observation well data were not available for analysis, these results are not reliable (Skidmore, 1997a).

A range in hydraulic conductivity can be assumed for the older alluvium and riverbed sand. Many of the pumping-tests were conducted on wells that were to be fitted for production. In most cases these pumping-tests were conducted at sites where the thickest intervals of sand with the least clay had been intersected. As an example, of the drilling results from the 1993/94 exploration program, only eight of the twenty test holes were suitable for upgrading to production status. Hence the test results are biased towards sandy sections of the older alluvium and thus represent the upper limits of hydraulic conductivity.

1.8.4.2 Geophysical logging

Forty-three down hole geophysical wire-line logs have been run in well holes within the Scheme wellfield area by the GSWA and are reported by Skidmore (1994, 1997a). The geophysical logs consisted of a gamma ray probe which measures natural gamma radiation that originates from the potassium 40 isotope and from uranium and thorium decay series (Repsold, 1989). These isotopes are common components of clay minerals, and thus the probe allows the differentiation between sand and clay layers.

The logs have generally been run to the base of the older alluvium within either steel drill-stem casing or PVC casing. The purpose of the geophysical logging was to select suitable intervals for well screens, however they also gave an insight into the characteristics of the floodplain sediments. The natural gamma logs highlighted the thin, alternating nature of sand and clay deposition – the ‘shoe string’ sands. However, correlation between the individual thin sand beds using natural gamma logs from adjacent holes was not possible.

Table 3 Pumping-test analyses

Well ID	Aquifer	Pumping Rate (m^3/day)	Duration (hours)	Screen interval (m)	Transmissivity (m^3/day/m)	Conductivity (m^3/day/m^2)	Method of analysis
1/70	Riverbed sand	210	48	3	145	48	Theis*
4/70	Riverbed sand	600	48	3	538	176	Boulton*
5/70	Riverbed sand	295	47.2	3.6	360	100	Boulton*
Well No 18	Older alluvium	742	22.5	6.9	1430	205	Chow*
Well No 19	Older alluvium	790	29	4.5	1320	290	Chow*
Well 2/68	Older alluvium	485	114	3	74	24	Chow*
Well 3/68	Older alluvium	660	72	3	290	96	Chow*
Well 4/68	Older alluvium	560	22	2.7	330	105	Chow*
Well 6/68	Older alluvium	132	69	2.9	11	4	Chow*
IRS No 1	Older alluvium	840	72	3.6	108	30	Chow*
34/1770	Older alluvium	795	26	3.4	42	12.5	Chow*
38/4100	Toolunga Calcilutite	410	24	3	12	4	Chow*
Prod 1/93	Older alluvium	1500	24	49.8	119	2.4	Theis[‡]
Prod 2/93	Older alluvium	1500	24	49.6	43	0.9	Theis[‡]
Prod 1/94	Older alluvium	3564	24	51.7	284	5.5	Theis[‡]
Prod 15/94	Older alluvium	3564	24	43	155	3.6	Theis[‡]
Prod 18/94	Older alluvium	2724	24	57.9	830	14.3	Theis[‡]
Prod 19/94	Older alluvium	732	24	56.5	45	0.8	Theis[‡]
Prod 20/94	Older alluvium	687	24	64.8	74	1.1	Theis[‡]
Prod 21/94	Older alluvium	831	24	49.5	89	1.8	Theis[‡]
Prod 7/74	Older alluvium	381	24	4.6	4.6	1	Boulton[†]
Prod 1/87	Older alluvium	4533	24	27.5	247.5	9	Boulton[†]
Pilot Well	Riverbed sand	1584	48	3.1	6080	1960	Theis[§]
Gravel Pack Well	Riverbed sand	3576	48	4.9	3980	812	Theis[§]

Source: * Allen (1972), [†] Martin (1988), [‡] Skidmore (1997), [§] Vogwill (1972)

2 Geology

2.1 Geological setting

The proclaimed groundwater area occurs within the Gascoyne sub-basin of the Carnarvon Basin. Allen (1971) reported the stratigraphy of the Gascoyne sub-basin, and Hocking, Moors and van de Graaff (1987) have described the entire Carnarvon Basin stratigraphy in detail. The onshore Gascoyne sub-basin consists of approximately 7000 m thick sequence of Paleozoic sedimentary rocks with a veneer of Mesozoic and Cainozoic rocks (Hocking, Moors and van de Graaff, 1987). The groundwater wellfields abstract water from the surficial sediments overlying the Cainozoic and Mesozoic Upper Cretaceous sedimentary rocks. These are presented in Table 4.

Table 4 Stratigraphy of proclaimed groundwater area

Age	**Formation**	**Maximum thickness intersected** (m)	**Lithology**
Quaternary	Riverbed sand*	12	Sand, gravel, cobble, minor silt
	Older alluvium*	30–60	Clayey sand, clay, silt, sand and gravel, partly indurated
~~ unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Tertiary	Cardabia Calcarenite	5–60	Calcarenite, chalky calcisiltite
~~ unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Late Cretaceous	Toolunga Calcilutite	100–290	Calcilutite, calcisiltite

*informal names and not Formations sensu-stricto.

The Gascoyne River catchment, however, extends some 700 km inland over the eastern Carnarvon Basin comprising the Kennedy Range plateau and onto the Yilgarn Craton. The eastern Carnarvon Basin consists of Permian sediments of the Wooramel and Byro Group, consisting mainly of sandy siltstone, sandstone, claystone and shale (Hocking, Moors and van de Graaff, 1987). The Yilgarn Craton consists predominantly of granite, gneiss and migmatite, with a partially eroded duricrust. The pebbles and cobbles of the Quaternary alluvium consist of detritus from these source rocks.

The Late Cretaceous and Cainozoic rocks have a gentle regional dip to the west and consist of shallow marine and intra-tidal calcareous mudstone, siltstone and minor, thin sandstone. The eastern margin of the Scheme wellfield is underlain by the Toolunga Calcilutite, which outcrops near Rocky Pool. Weathered outcrop attributed to the Cardabia Calcarenite overlies the Toolunga Calcilutite. These sediments lie beneath a westward thickening wedge of unconsolidated to semi-consolidated, floodplain sediments that have accumulated along the major drainage, namely, the older alluvium and the riverbed sand.

2.1.1 Toolunga Calcilutite

The lithology of the Toolunga Calcilutite consists of slightly calcareous, dense clayey siltstone or silty claystone with minor thin beds of fine to very fine, moderate to well sorted sandstone up to 4.3 m thick (Allen, 1971). It is olive green, blue-black to black where unweathered, and mottled grey, pink and yellow where weathered (Allen, 1971).

Outcrop at Rocky Pool is of low relief, and consists of an asymmetric fold of the Toolunga Calcilutite which is interpreted as a drag fold along a fault by Allen (1971). The fault trends in a north-northeasterly direction and extends from Rocky Pool to the northeast, where scattered weathered outcrops occur. South and west of Rocky Pool the floodplain alluvium overlies the Toolunga Calcilutite.

2.1.2 Cardabia Calcarenite

At Rocky Pool, parts of the Toolunga Calcilutite are unconformably overlain by weathered sediments estimated to be Tertiary in age that outcrop in the area. These sediments have been intersected by drilling further west and, although weathered, they are probably the Cardabia Calcarenite (Allen, 1971). These sediments consist of yellow-brown to grey-green and mottled pink to red clayey siltstone, mudstone and white siltstone (Martin, 1990b). Skidmore (1997a) also logged lithified coarse-grained, white to yellow sand beds up to 11.5 m thick. The maximum thickness of the Cardabia Calcarenite is given by Hocking, Moors and van de Graaff (1987) as 60 m, and increases from east to west owing to the regional westerly dip of the underlying Mesozoic sediments. The Cardabia Calcarenite was intersected during the 1993/94 exploratory drilling in the east of the Scheme wellfield and ranged between 8 m and 18 m in thickness (Skidmore, 1997a).

2.1.3 Older alluvium

The floodplain sediments overlying the Toolunga Calcilutite and Cardabia Calcarenite are informally referred to as the older alluvium. Allen (1971, 1972), Johnson (1974), Martin (1988, 1990b, and 1992) and Skidmore (1994, 1997a) have described them in detail. The older alluvium ranges in thickness from approximately 20 m west of Rocky Pool to greater than 50 m near Carnarvon. The depth of the basement is presented in Figure 7.

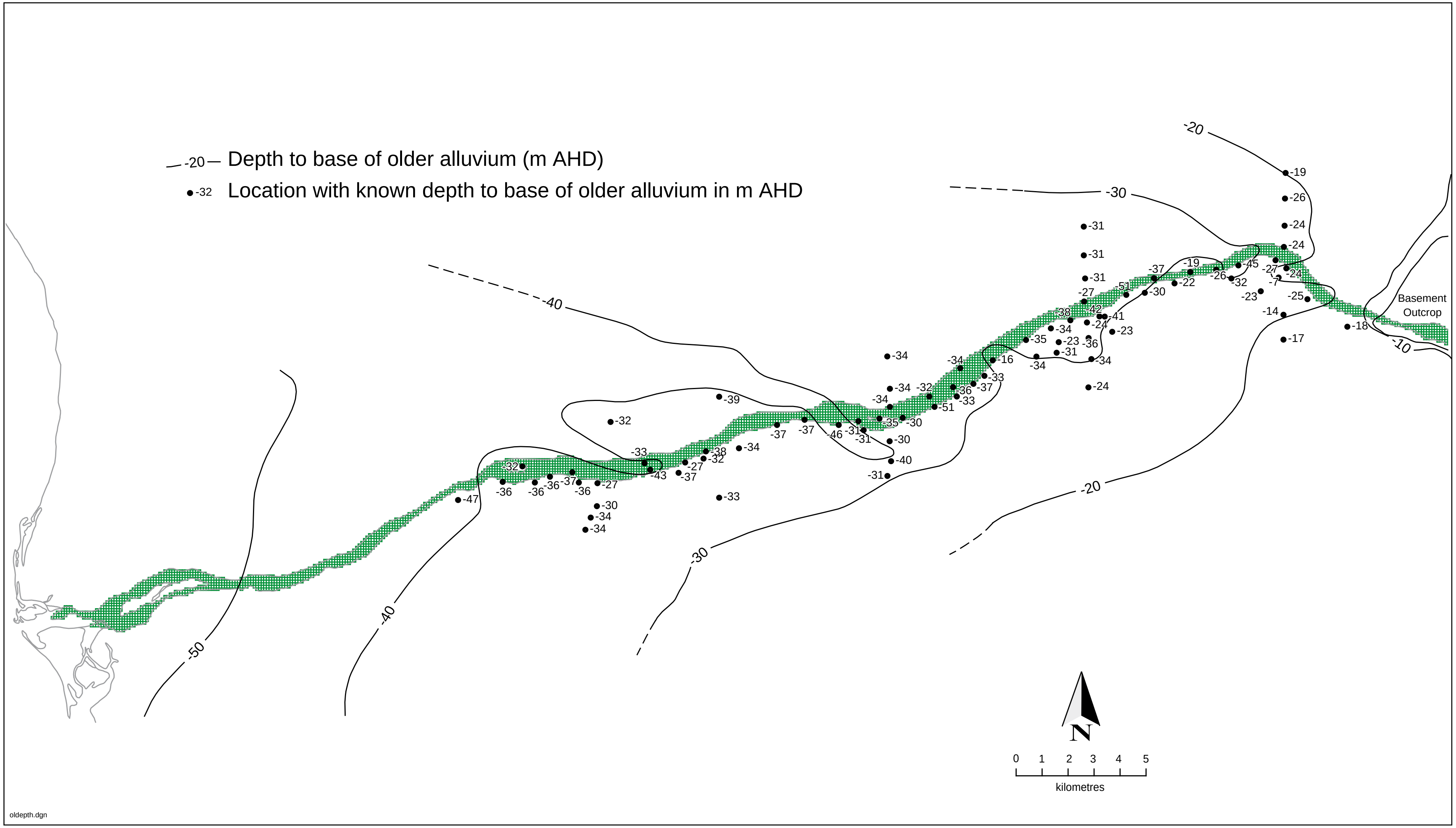


Figure 7 Depth of the basement beneath the older alluvium

The sediments consist predominantly of unconsolidated to semi-lithified, thin, alternating and irregular beds of poorly sorted sand and gravel, yellow-brown to red-brown, mottled, sandy clay, clayey silt and clay. The grain size of the sand is mostly coarse to very coarse but ranges from very fine to pebble size (Skidmore, 1997a). It is estimated that up to 30%, but generally less than 20% of the thickness of the older alluvium contains sand and gravel with less than 10% silt or clay content (Skidmore, 1997a). The sand and gravel beds are not laterally continuous, being laid down as channel lag deposits or point-bar river channel deposits.

The older alluvium profile may alternately consist of sandy clay, clayey silt and massive clay, lacking any sand or gravel beds in some locations. The massive clay generally contains some fine to coarse sand and may be strongly iron cemented and lateritic (Skidmore, 1997a). At the base of the alluvium the deposits may be marked by a mottled red and white calcareous breccia (Skidmore, 1997a). The breccia was formed by the re-working of the Tertiary palaeo surface by the juvenile Gascoyne River (Baxter, 1967; Hancock, 1969).

2.1.4 Riverbed sand

The bed load of the Gascoyne River is incised up to 5 m into the older alluvium. It has been informally named the riverbed sand when described by Allen (1971, 1972), and that name is adopted here. The riverbed sand is essentially angular to sub-angular quartz sand, with granitic and metasedimentary detritus rock, and angular secondary laterite, calcrete and silcrete (Lewis, 1990). The granitic and metasedimentary rocks are derived from the eastern Yilgarn Craton. The larger quartz gravel is predominantly vein quartz and the coarse sand fraction is generally granitic in origin (Lewis, 1990).

Table 5 Grain size distribution of the riverbed sand

Particle size (mm)		**Sample number**							
Aus IMM	**Screen**	**103922**	**103923**	**103924**	**103925**	**103926**	**103927**	**103928**	**103929**
Cobble > 64	> 60		9.1		6.9	98.7	4.1	97.4	3.2
Pebble > 4	> 20	0.4	12.9	1.4	46.6	1.1	7.4	2.5	7.8
	> 6	5.0	26.8	17.0	42.1	Trace	20.5	Trace	19.4
Granule > 2	> 2	31.4	29.1	66.4	∑4.4	∑0.2	44.8	∑0.1	32.8
Coarse > 0.5	> 0.6	61.0	19.6	14.9			21.8		26.8
Fine > 0.125	> 0.2	2.2	2.5	0.3			1.4		10.0
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Jones (1990)

Grain size in the riverbed sand varies from cobble to fine sand. Jones (1990) conducted the screening of eight sand and gravel grab samples from the riverbed sand. The eight samples ranged between 7 and 13 kilograms and were separated through non-standard size screens comprising 200 and 600 micrometres, and 2 mm, 6 mm, 20 mm and 60 mm sieves. The percentage by weight retained after separation is given in Table 5. The Australasian Institute of Mining and Metallurgy standards (Berkman and Ryall, 1987) for particle size terminology are included for reference. In all samples, 90% of the matrix was greater than coarse sand in size, thus the riverbed sand would be more aptly named the ‘riverbed gravel’.

The riverbed sand occupies the entire channel of the Gascoyne River, which varies in width from a maximum of about 1200 m to a minimum of roughly 100 m in some parts of the Kennedy Range. The average thickness of the riverbed sand is estimated at 3.5 m from contour modelling of the 1969–72 auger drilling and water well drilling logs within the area. The auger holes were drilled until clay was intersected and this is assumed to represent the base of the riverbed sand. The survey indicated a highly variable thickness of sand ranging from less than one metre to about 12 m. The results of the survey were also used to estimate the level at which surface flow stops, known as the cease to flow level.

Historically, the riverbed sand was divided into basins. It was reasoned that the riverbed sand does not form a smooth profile and isopachs of sand thickness indicated natural basins along the river with various amounts of interconnection above the older alluvium. As the watertable declined with no river flow, the older alluvium form divide between the areas of saturated sand in the riverbed. However, these basins are difficult to determine from isopachs of the riverbed sand, although the nomenclature of Basins A to L persists. Generally, it is assumed that the basin concept was a convenient means for justifying and describing the earlier modelling rationale of GASMOD (Dodson, 2000).

2.2 Depositional environment

The physical processes associated with rivers and floodplains in arid environments deposited the riverbed sand and older alluvium. The alluvial deposits have undergone various amounts of aeolian re-working which has produced the dune and playa system over parts of the Gascoyne River floodplain. The aeolian re-working began with the increasing aridity in the region during the Pliocene and there has been little change to the onshore Carnarvon Basin throughout the Holocene (Hocking, Moors and van de Graaff, 1987).

The riverbed sand deposit resembles a braided river environment owing to the considerable coarse-grained sediment material and large flow velocities associated with flooding generated from cyclonic activity. Because of the shifting position of the river channel and changing depositional velocities, the floodplain deposits of the older alluvium have characteristic textural variability from clay to gravel size particles, that results in a marked heterogeneity in the distribution of its hydraulic properties.

In studies of floodplain sediment characteristics, it has been demonstrated that the grain size composition of over-bank deposits on floodplains exhibits significant spatial variability. Sediment deposited nearer the river channel is coarser than sediment further away from the channel, and distance from the channel is an important controlling factor on grain size distribution (He and Walling, 1998). These concepts were applied in the representation of the spatial distribution of hydraulic properties of the older alluvium when modelling the floodplain characteristics. The fine-grained, low permeable matrix was represented near the model boundaries in the north and south of the model grid and with increased distance from the floodplain origin at Gascoyne Junction. The fine-grained matrix was represented by a greater percentage of lower conductivity model cells in these areas.

3 Hydrology

3.1 Stream gauging

The Gascoyne River has two permanent waterlevel gauging stations on the coastal plain where continuous river-stage levels are recorded and rating curves developed. One is at Fishy Pool, approximately 121 km ARM; the other is at Nine Mile Bridge, approximately 16 km ARM. The catchment areas for Nine Mile Bridge and Fishy Pool stations are approximately 73 400 and 70 200 km^2, respectively (Cicero, 1991). Systematic daily stage recording for Nine Mile Bridge extends back to early 1957, while records at Fishy Pool began in 1964, although discontinuous records of major flooding on the Gascoyne River have been kept since 1883.

Water levels are recorded at each gauging station and stream flow rate, or discharge, is deduced by means of a rating curve. The rating curves are developed by plotting successive measurements of discharge and stream height on a graph over a period of months or years (Chow, Maidment and Mays, 1988). The rating curve can then be used to convert records of stream height into a flow rate. However, the discharge of a stream used to calculate the rating curve is derived from measurements of velocity and depth. Scouring of the stream bed or deposition of sediment can cause the relationship of the rating curve to alter, as the stream bed depth changes, so that the same recorded gauge height produces a different discharge. Thus, rating curves on the Gascoyne River are approximate and require periodic re-evaluation. These errors must be considered when comparing stream discharge between gauging stations.

The correlation between stream discharge per month from Fishy Pool and Nine Mile Bridge gauging stations is given in Figure 8. This relationship depicts a reduction in stream discharge from Fishy Pool to Nine Mile Bridge, indicating significant loss of surface water during river flow across the width of the coastal plain. This loss of surface water flow will be referred to as a transmission loss. The transmission loss is attributed to the filling of the riverbed sand, downward seepage to the older alluvium, overflow out of the main channel, especially during large flows, and evapotranspiration. Thus the Gascoyne River, particularly across the coastal plain, is a losing stream and surface water contributes to the regional watertable, and it receives no base flow from groundwater.

A summary of total stream discharge per flow event from March 1965 until May 2000 through Nine Mile Bridge and Fishy Pool is given in Table 6. In every instance, except January 1968, total stream discharge is greatest through Fishy Pool. In January 1968 there were several peaks to the flow event, the previous flows having filled the aquifer upstream, reducing transmission loss to the watertable. Allen (1972) documented river flows where discharge at Nine Mile Bridge was comparable to Fishy Pool or greater; this was attributed to localised runoff upstream of Rocky Pool contributing to flow gains at Nine Mile Bridge. However, with the re-evaluation of the rating curves these events appear to be false.

River flow events associated with cyclones have been noted in Table 6. The Bureau of Meteorology records notable cyclones, however a notable cyclone is one that causes considerable structural damage or loss of life through strong winds or tidal surges and may not necessarily be associated with large river flows, e.g. Herbie. The three largest recorded stream discharge events occurred after the cyclones of 1960, 1961, and Cyclone Steve in 2000; however, lows associated with moisture derived from northwest Australian cloudbands, e.g. April 1980, can result in large discharge events as well. Four large flow events, resulting from cyclones, have occurred in the last 6 years, owing to Cyclones Steve, Bobby, Vance and Rachael. Generally, the commencement of river flow on the Gascoyne River has a bimodal distribution, occurring mainly in February and March, or June and July (Pearcey, 1998).

There is a poor correlation between transmission loss along the river between the two gauging stations and stream discharge, or the length of flow days, at either gauging station. The poor correlations result from variations in flood size and behaviour, antecedent drought conditions, depth to watertable, and seasonal variations in groundwater abstraction and evapotranspiration, all of which impact the stage height and duration of flow periods. As a consequence, predicting the transmission loss between gauging stations on the Gascoyne River from stage height or length of flow is problematic.

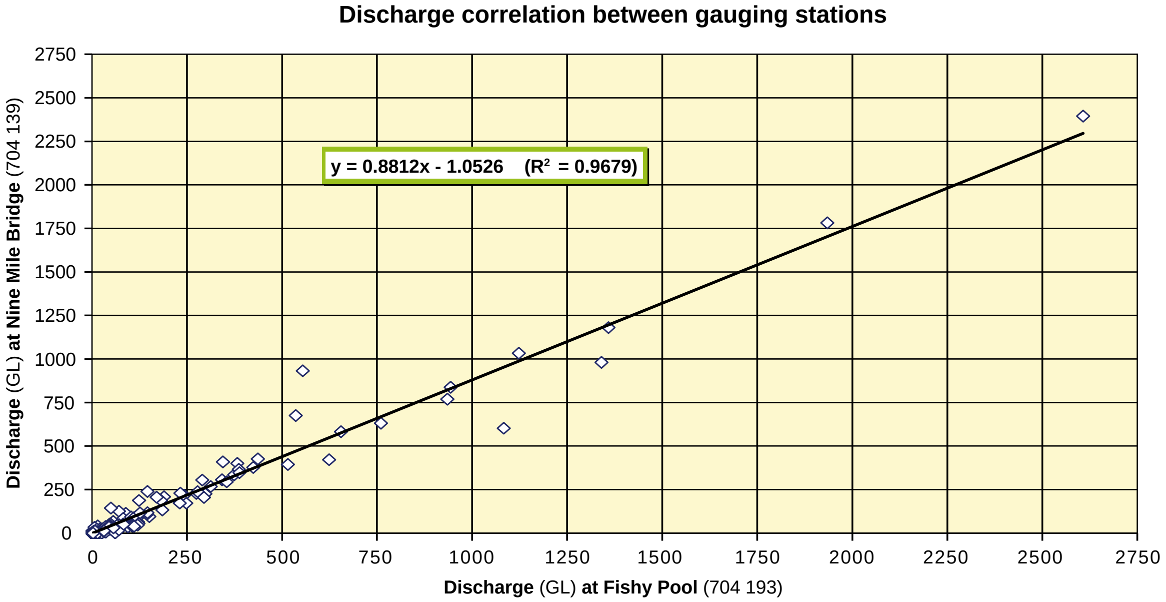


Figure 8 Monthly stream discharge relationship between Fishy Pool and Nine Mile Bridge

There is also an important distinction between transmission loss and river recharge highlighted by Lerner, Issar and Simmers (1990). Transmission loss is the component of river flow that does not arrive at the downstream end of a river, whereas river recharge is the water that enters the watertable. As such, transmission loss along the coastal plain will always be greater than the actual recharge to the watertable, given losses to evapotranspiration.

Table 6 Stream discharge at Fishy Pool and Nine Mile Bridge gauging stations

Cyclone	**Date of start**	**Total flow (GL)**		**Trans-mission**	**Total days of flow**	
Event	**to flow**	**NMB**	**FP**	**Loss** (GL)	**NMB**	**FP**
Mavis	**Mar 65**	**607.794**	**747.529**	**139.735**	**200**	**229**
	Nov 65	3.746	15.43	11.684	13	41
	Feb 66	0.023	2.094	2.071	3	23
	Apr 66	‡6.074	40.382	34.308	‡26	114
Elsie	**Jan 67**	**516.427**	**532.575**	**16.148**	**60**	**71**
	May 67	0.248	4.301	4.053	12	44
	Aug 67	0	0.027	0.027	0	9
	Jan 68	1133.735	1117.479	-16.256	214	211
	Feb 69	48.922	87.968	39.046	25	58
	May 69	145.993	206.436	60.443	62	113
	May 70	115.309	178.619	63.31	60	112
Sheila	**Jan 71**	**‡236.958**	**326.672**	**89.714**	**‡60**	**82**
	May 71	‡527.866	571.988	44.122	‡122	147
	July 72	18.607	28.965	10.358	40	40
	May 73	94.15	181.969	87.819	111	132
	Mar 74	13.151	28.999	15.848	16	26
	July 74	1600.45	1709.729	109.279	84	116
Trixie (Feb) **Beverly (Mar)**	**Feb 75**	**363.673**	**‡415.061**	**51.388**	**144**	**‡148**
	Nov 75	295.55	354.21	58.66	37	36
	Mar 76	88.317	105.134	16.817	29	37
	May 77	0	21.129	21.129	0	42
	Feb 78	293.935	344.667	50.732	79	95
	Aug 78	11.002	16.38	5.378	20	32
	Feb 79	23.665	55.826	32.161	32	41
	Jan 80	65.459	98.967	33.508	44	50
	Apr 80	2319.871	2558.532	238.661	155	188
Neil	**Mar 81**	**269.776**	**313.793**	**44.017**	**56**	**63**
	Jan 82	3.515	13.291	9.776	12	23
	May 82	56.596	91.809	35.213	37	78
	Apr 83	0	2.77	2.77	0	16
	July 83	0	0.196	0.196	0	8
	*Feb 84	1964.21	2145.049	180.839	164	213

Cyclone	**Date of start**	**Total flow (GL)**		**Trans-mission**	**Total days of flow**	
Event	**to flow**	**NMB**	**FP**	**Loss** (GL)	**NMB**	**FP**
	Sept 84	9.041	21.094	12.053	15	63
	Feb 85	49.384	108.664	59.28	23	47
	Jan 86	[‡]95.787	208.537	112.75	[‡]48	112
	June 86	641.944	703.508	61.564	76	85
	Jan 87	76.384	196.221	119.837	50	71
	June 87	45.78	104.376	58.596	38	53
	Feb 88	48.862	106.54	57.678	22	27
	Mar 88	0.174	0.454	0.28	6	3
	Apr 88	6.132	24.561	18.429	20	23
Herbie	**May 88**	**5.839**	**18.897**	**13.058**	**33**	**39**
	Aug 88	0.392	3.188	2.796	8	14
	Dec 88	0.427	10.579	10.152	7	21
	Apr 89	4.857	30.064	25.207	12	15
	Apr 89	1100.175	1543.315	443.14	117	101
	Jan 90	869.554	928.725	59.171	88	70
	Aug 90	0.651	0.775	0.124	11	5
	Feb 91	116.809	171.881	55.072	28	24
	July 91	1.073	1.913	0.84	11	5
	Mar 92	722.602	1043.644	321.042	151	158
	Feb 93	2.69	10.223	7.533	19	10
	Feb 94	434.86	526.937	92.077	42	45
Bobby	**Feb 95**	**1801.553**	**1881.73**	**80.177**	**[†]300**	**202**
	Dec 95	11.467	13.682	2.215	[†]130	23
	Apr 96	491.768	550.138	58.37	[†]151	156
Rachael	**Jan 97**	**1101.352**	**1387.956**	**286.604**	**220**	**232**
	May 98	557.858	679.4	121.542	111	117
	Dec 98	12.165	29.561	17.396	18	21
Vance	**Jan 99**	**1687.66**	**1878.532**	**190.872**	**199**	**205**
Steve	***Jan 00**	**3104.171**	**3191.501**	**87.33**	**117**	**114**

Source: Water and Rivers Commission WIN data and Bureau of Meteorology (1998);
NMB = Nine Mile Bridge; FP = Fishy Pool,
* Incomplete records, † Continuous flow at NMB for 581 days, ‡ Non continuous flow

As Fishy Pool is approximately 65 km east of the Scheme wellfield it is not ideally located for estimating transmission loss for water balance calculations. It is likely that some flows that occur at Fishy Pool, and not Nine Mile Bridge, flow downstream to at least Rocky Pool. It would be advantageous for water resource estimations if there was stream gauging at Rocky Pool; this would give a better indication of the volume of surface water entering the Scheme wellfield area.

3.2 River flow and no flow probability

A flow event is defined as any consecutive sequence of days for which there were non-zero flows. A no flow event is defined as any consecutive sequence of days for which there were zero flows. The point at which surface flow stops is called the 'cease to flow level.' This level is considered a planer surface with a gradient similar to the natural topography of the river, which is approximately 7×10^{-4} from Rocky Pool to the coast. The riverbed may contain many river pools at this point, but surface flow between the pools no longer occurs. The cease to flow gradient has been determined from the auger drilling survey of 1969–72 and is assumed to be relatively constant. The incidence of flow and no flow duration at Nine Mile Bridge is depicted in Figure 9. There is a great variation in river flow and no flow duration on the Gascoyne River.

From continuous time series flow gauging at Nine Mile Bridge and Fishy Pool, the frequency of occurrence in daily mean stage heights, starting with the highest values was compiled, and is presented in Table 7 and Table 8, respectively. The frequency of high stage heights for both stations is very similar. The probability of a given daily stage height and its return period are calculated using the Weibull formula for analyzing maximum flows where

$$\mathrm{P}(X) = \frac{\mathrm{r}}{\mathrm{N} + 1} \qquad (1)$$

where P(X) = the probability of exceedence of value X
r = the number of times X is equalled or exceeded
N = is the total number of data values

Table 7 Stage height probability at Nine Mile Bridge from 1957

Stage elevation X (m)	**Cumulative Freq.**	**Probability of X or exceedence**	**Return period of X** (years)
> 7	5	0.0003	8.037
6	9	0.0006	4.465
5	20	0.0014	2.009
4	39	0.0027	1.030
3	99	0.0067	0.406
2	232	0.0158	0.173
1	588	0.0401	0.068
0.5	1193	0.0813	0.034
0.001	3371	0.2297	0.012
< 0.001	11306	0.7703	0.004

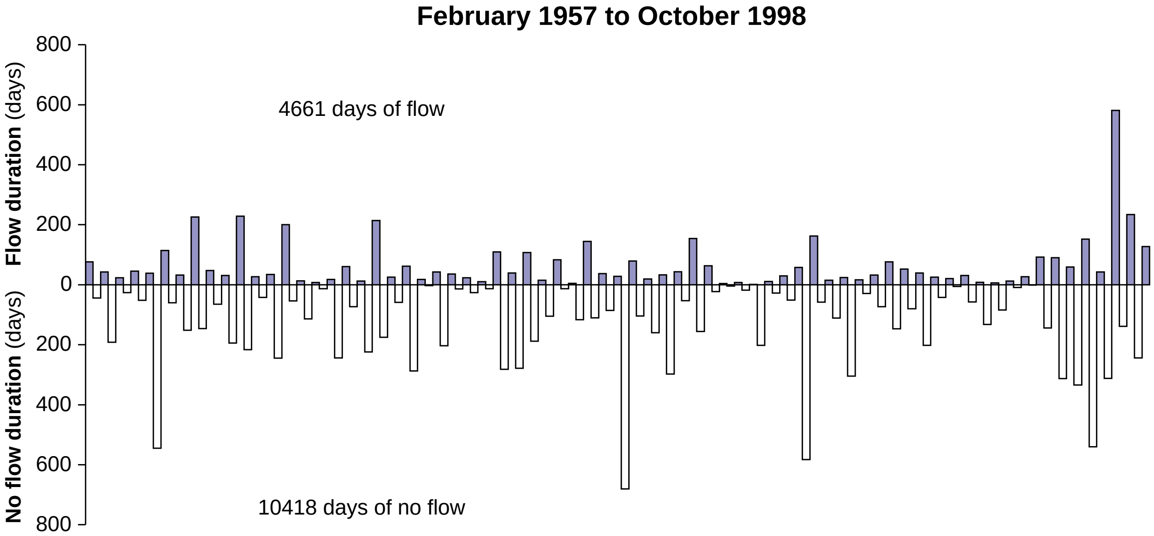


Figure 9 Flow and no flow duration at Nine Mile Bridge

Table 8 Stage height probability at Fishy Pool from 1964

Stage elevation X (m)	Cumulative Freq.	Probability of X or exceedence	Return period of X (years)
> 7	4	0.0004	7.799
6	6	0.0005	5.199
5	15	0.0013	2.080
4	31	0.0027	1.006
3	52	0.0046	0.600
2	148	0.0130	0.211
1	496	0.0435	0.063
0.5	1095	0.0961	0.028
0.001	4696	0.4121	0.007
< 0.001	11393	0.5878	0.005

The probability of large daily stage at Nine Mile Bridge or Fishy Pool (> 7 m) is low, – 0.03–0.04%, or one day in every 8 years. In general, Tables 7 and 8 indicate that peak flood stages are of short duration and are followed by low stage heights. That is, after the initial river flow peak, flow in the Gascoyne River consists of surface water derived from the slow draining of channel and bank storage.

Of great significance in estimating the sustainable yield of the groundwater resources of the floodplain aquifer is the duration of any no flow event. As evaporation is generally an order of magnitude greater than rainfall, any extended no flow period means that groundwater pumping is mining the groundwater reserves from beneath the floodplain. The series of no flow events at Nine Mile Bridge gauging station have been ranked according to length of days from the shortest time period to the longest. The longest interval of no river flow occurred for a total of 681 days, from 7 April 1976 to 17 February 1978.

The annual exceedence probability (AEP) in years for any period of no river flow is given by the following equation (Cunnane, 1978),

$$AEP = \frac{N + 0.2}{m + 0.4} \qquad (2)$$

where AEP = annual exceedence probability
m = rank of the no flow event
N = number of years of record

The rank is given by the length of duration of the no flow event; for example, the longest no flow duration has the rank of one. The cumulative frequencies from the ranking system are converted into percentages to give a flow duration curve plotted on semi-log scale in Figure 10. The curve gives the probability of consecutive months with no flow. For example, there is a 5% probability that a no flow period of 12 months will be equalled or exceeded, and only 0.9% chance of an 18 month no flow period being equalled or exceeded. Conversely, there is a 56% probability of there being no flow at Nine Mile Bridge on any particular day of the year.

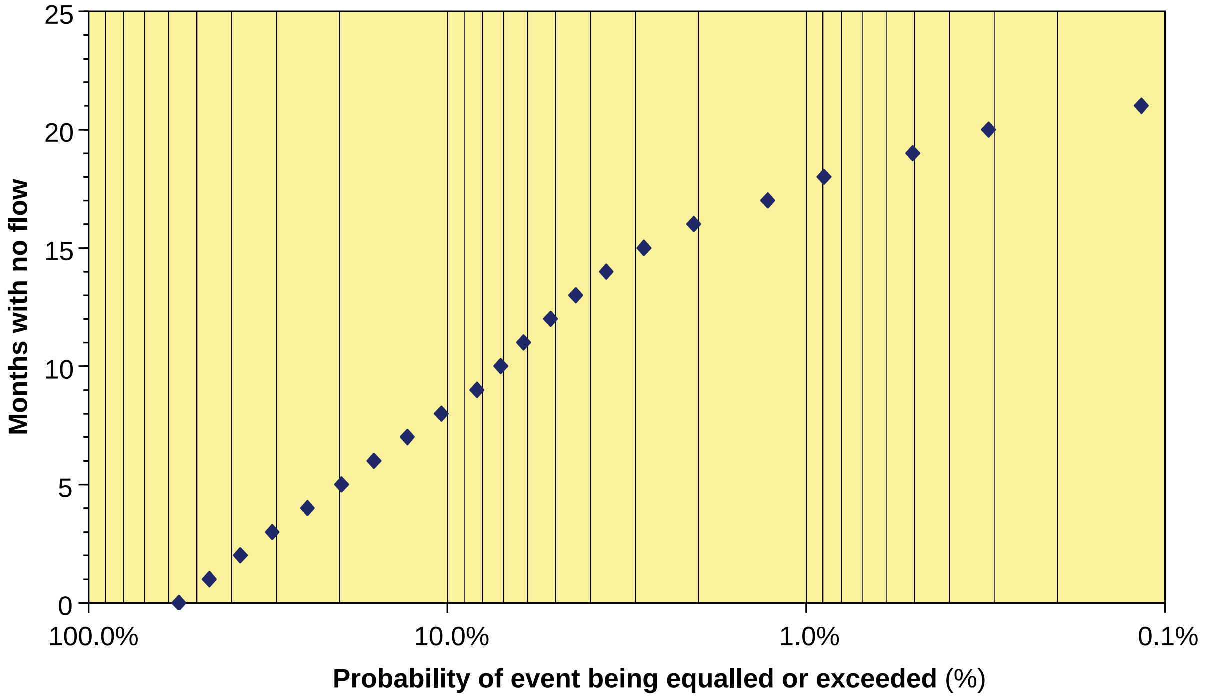


Figure 10 No flow duration curve for Nine Mile Bridge (after Pearcey, 2000)

The no flow probability is based on the 43 years of continuous recording at Nine Mile Bridge gauging station. However, there are earlier non-continuous records for the area. Although some details are inconsistent, these flow records indicate much drier conditions than the recent period of 1957 onwards. A 1914 edition of the *Northern Times* carries the heading ‘*Gascoyne nearing the sea after nearly five years’* (*Northern Times*, 1914). Historic records indicate that at the turn of the 20th century, without continuous waterlevel recording, when river flow began was recorded but not when the flow stopped, which may exaggerate the length of some of these no flow periods. However, it appears that from 1908 to 1914, there was a particularly severe drought, with only 58 mm of rainfall at Gascoyne Junction for the year 1911.

3.3 Surface water-groundwater interaction

Transmission loss from river flow is often the most important source of natural groundwater recharge in arid and semi-arid environments (Simmers et al., 1997). Lerner, Issar and Simmers (1990) classified rivers in arid and semi-arid environments according to their flow characteristics and connection with the watertable. The Gascoyne River is ephemeral in nature and is connected to, or above the watertable, but near enough for the watertable to rise in response to river flow.

Temporary stream gauging stations were used by Wark (1969) to explain the hydrology of the Gascoyne River on the coastal plain. Stream gauging stations were located at Wapet Crossing, Fishy Pool, Rocky Pool and Nine Mile Bridge. Stream flow recessions in 1967 and 68 were investigated by examining the cumulative inflow and outflow for each stream reach between the gauging stations. The cumulative inflow minus the cumulative outflow for each reach gives the amount of water stored in the reach at any given time. Wark (1969) argued that this water consists of

- water needed to fill river pools to the cease to flow level,
- water in temporary storage in river pools above the cease to flow level,
- water needed to fill the riverbed sand below the cease to flow level, and
- water in temporary storage in the riverbed sand above the cease to flow level.

The water needed to fill the river pools to the cease to flow level and water stored below the cease to flow level become permanent transmission losses. However, water in temporary storage above the cease to flow level in the riverbed sand or river pools may either be temporary or eventually become permanent losses (Wark, 1969).

Allen (1972) depicted the mass balance curve between the two gauging stations of small river flows, he argued that the flow loss, in some instances, increased with increasing time when there were several flow peaks, or spates. However, a review of stream discharge between the two gauging stations indicates this is incorrect. The greatest transmission loss occurs at the onset of flow with the filling of the riverbed sand. Stage recession in large flows is less than in small flows owing to the maintenance of flow after a large flood by emergent water released from channel storage and riverbed sand storage upstream within a reach itself (Wark, 1969).

Four stream discharge curves for large flows from Nine Mile Bridge and Fishy Pool are presented in Fig. 11, along with plots of the apparent flow loss or gain of each flood. The respective stream discharge volumes for each gauging station are corrected for the time lag between flow at the gauging stations, approximately 24 hours (Pearcey, 1998). The curves confirm the significant flow loss between the two gauging stations as surface water fills river pools and the riverbed sand to the stage height of the flow. Flow loss is followed by intervals where there is an apparent flow gain; that is, flow at Nine Mile Bridge is greater than flow at Fishy Pool. As suggested by Wark (1969), the flow gain results from the release of water temporarily stored above the falling stage height in upstream channel reaches and bank storage.

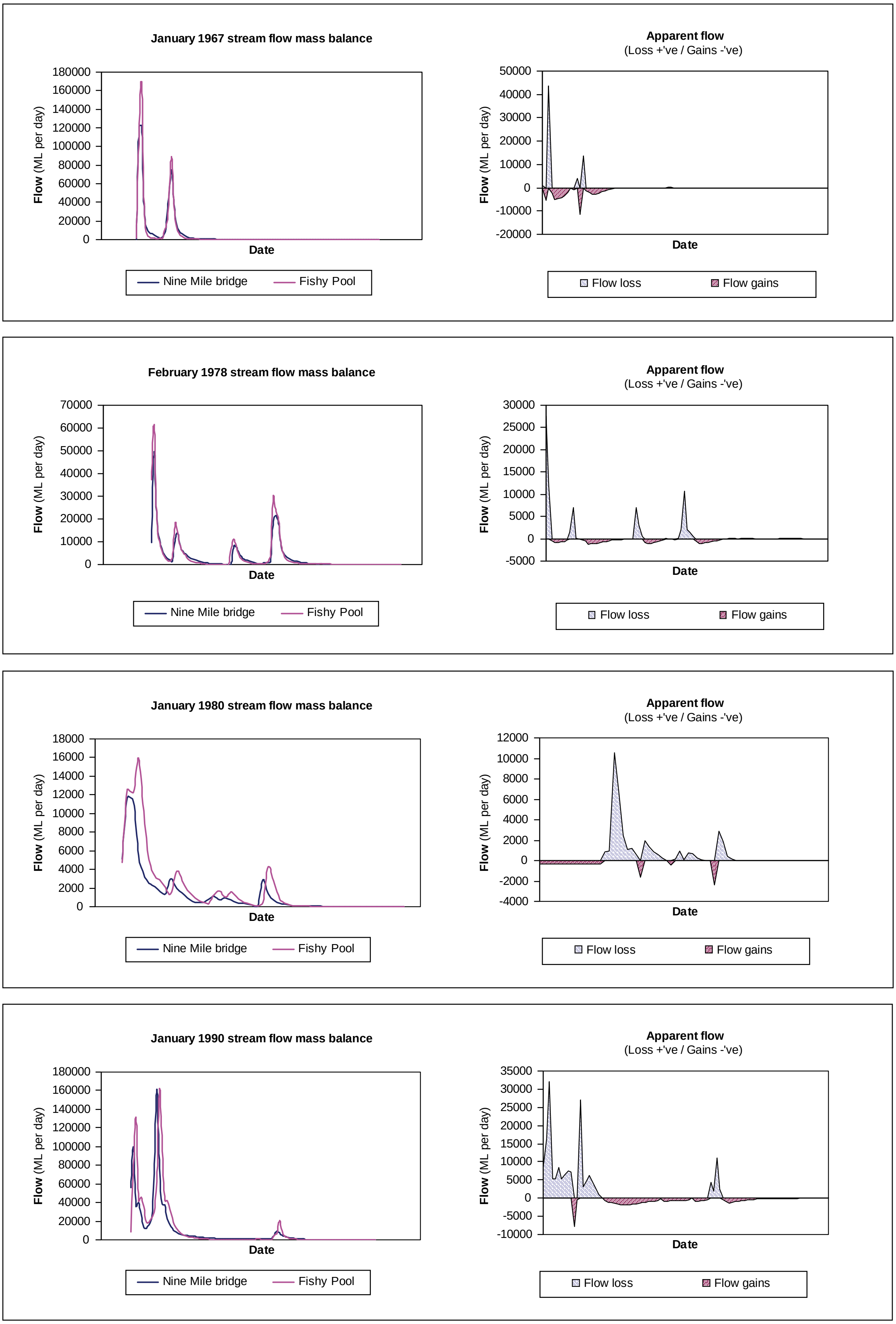
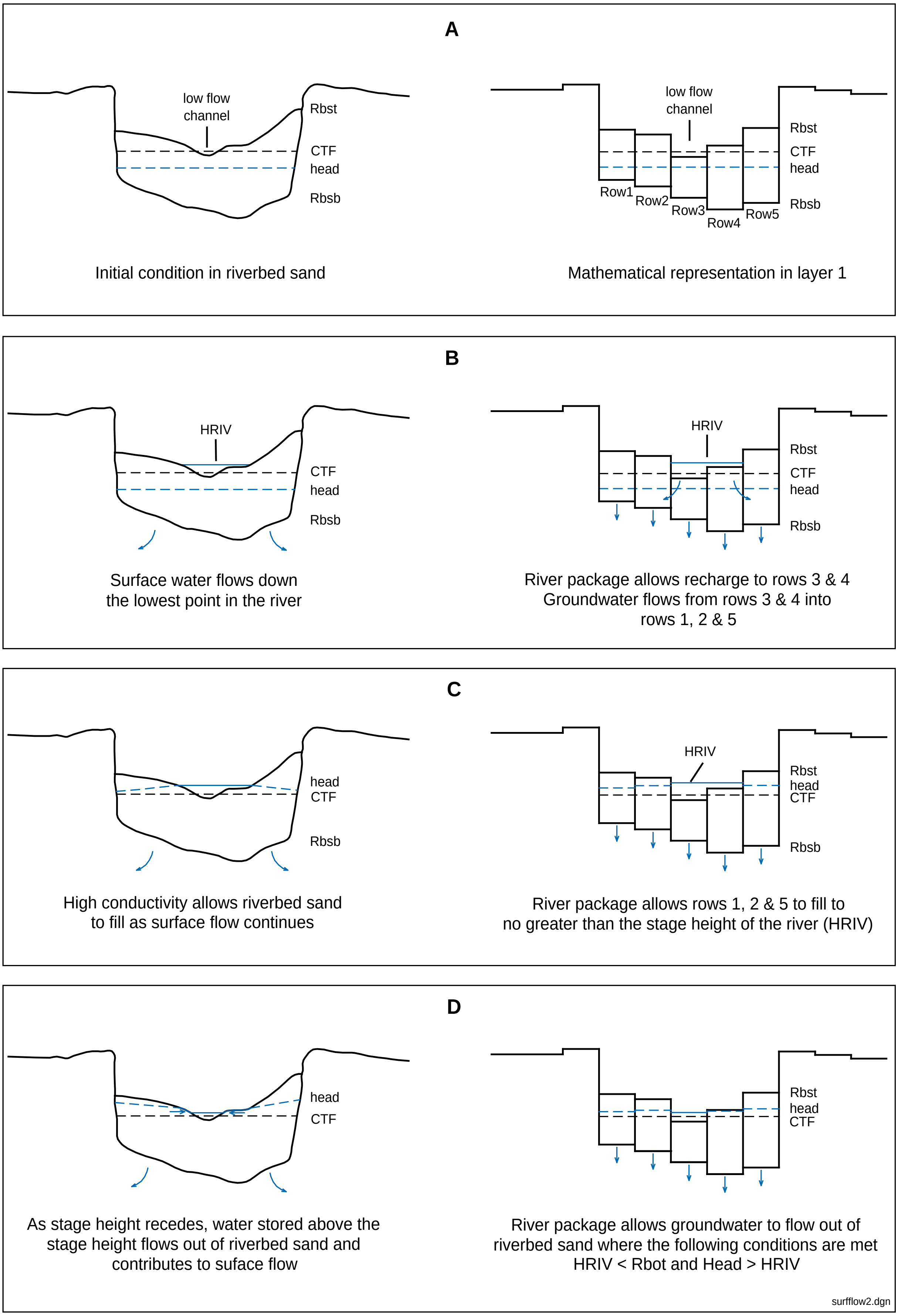


Figure 11 Daily stream discharge curves for Nine Mile Bridge and Fishy Pool



Initial condition in riverbed sand

Mathematical representation in layer 1

Surface water flows down the lowest point in the river

River package allows recharge to rows 3 & 4 Groundwater flows from rows 3 & 4 into rows 1, 2 & 5

High conductivity allows riverbed sand to fill as surface flow continues

River package allows rows 1, 2 & 5 to fill to no greater than the stage height of the river (HRIV)

As stage height recedes, water stored above the stage height flows out of riverbed sand and contributes to suface flow

River package allows groundwater to flow out of riverbed sand where the following conditions are met HRIV < Rbot and Head > HRIV

Figure 12 Conceptual model of surface water — groundwater interaction

However, from Table 6, we know that total stream discharge is greatest through Fishy Pool in most instances.

Wark's model of surface water-groundwater interaction has been conceptualised on the left hand side of Figure 12. The general condition favouring this is one in which the lateral hydraulic conductivity is substantially greater than the overall vertical hydraulic conductivity. Surface water enters the riverbed sand more rapidly than it can pass into the older alluvium, owing to the numerous clay layers within the latter. Temporarily stored water above the cease to flow level will escape laterally in the direction of least resistance, that is out of the riverbed sand and back to surface flow as the stage height begins to fall. Groundwater stored above the cease to flow level of the riverbed becomes the temporary base flow component of the ephemeral river.

3.4 Chloride in surface water

The chloride in surface water can be measured directly from chemical analysis of water samples. Surface water recharges the groundwater flow system and the chloride concentration of stream discharge has a significant impact on the salinity distribution of groundwater. In low rainfall, in high potential evaporation catchments of arid regions, chloride in the form of salt accumulates on the soil surface, particularly in areas where there is insufficient relief to drain surface water. During large rainfall events the chloride is mobilised by runoff and contributes to the concentration of chloride in streams. In the riverbed sand, chloride is concentrated within river pools and groundwater by evapotranspiration. The mixing of river pools and groundwater with surface flow results in a flushing of chloride from the sand with each large river flow.

During river flow events, twenty-three surface water sampling locations within the Gascoyne River catchment have been used to review the chloride concentration in surface water. Most sampling was conducted during the 1960s, however some sites are still sampled (Water and Rivers Commission, 1999). The sampling locations are within Kennedy Range or along the coastal plain. However, the samples are not all collected from the same flow event and are non-synoptic. As such, the representation of the mean chloride concentration of surface water at each site in Figure 13 is only indicative.

The mean chloride concentration of surface water on the coastal plain is lower than that of the Kennedy Range area. In the Kennedy Range area of shallow basement sediments, some groundwater may discharge to the river pools after surface flow passes, giving rise to the higher mean chloride concentrations. Generally, the mean chloride concentration within the Lyons River and its tributaries is lower than that within the eastern reach of the Gascoyne River. However, small tributaries within Kennedy Range that flow directly to the Gascoyne River are also of low chloride concentration (e.g. Daurie Creek). Generally, the higher chloride concentration of the upper Gascoyne River is attributed to higher evaporation and lower rainfall, in comparison to the Lyons River. The Lyons River drains mainly the Kennedy Range,

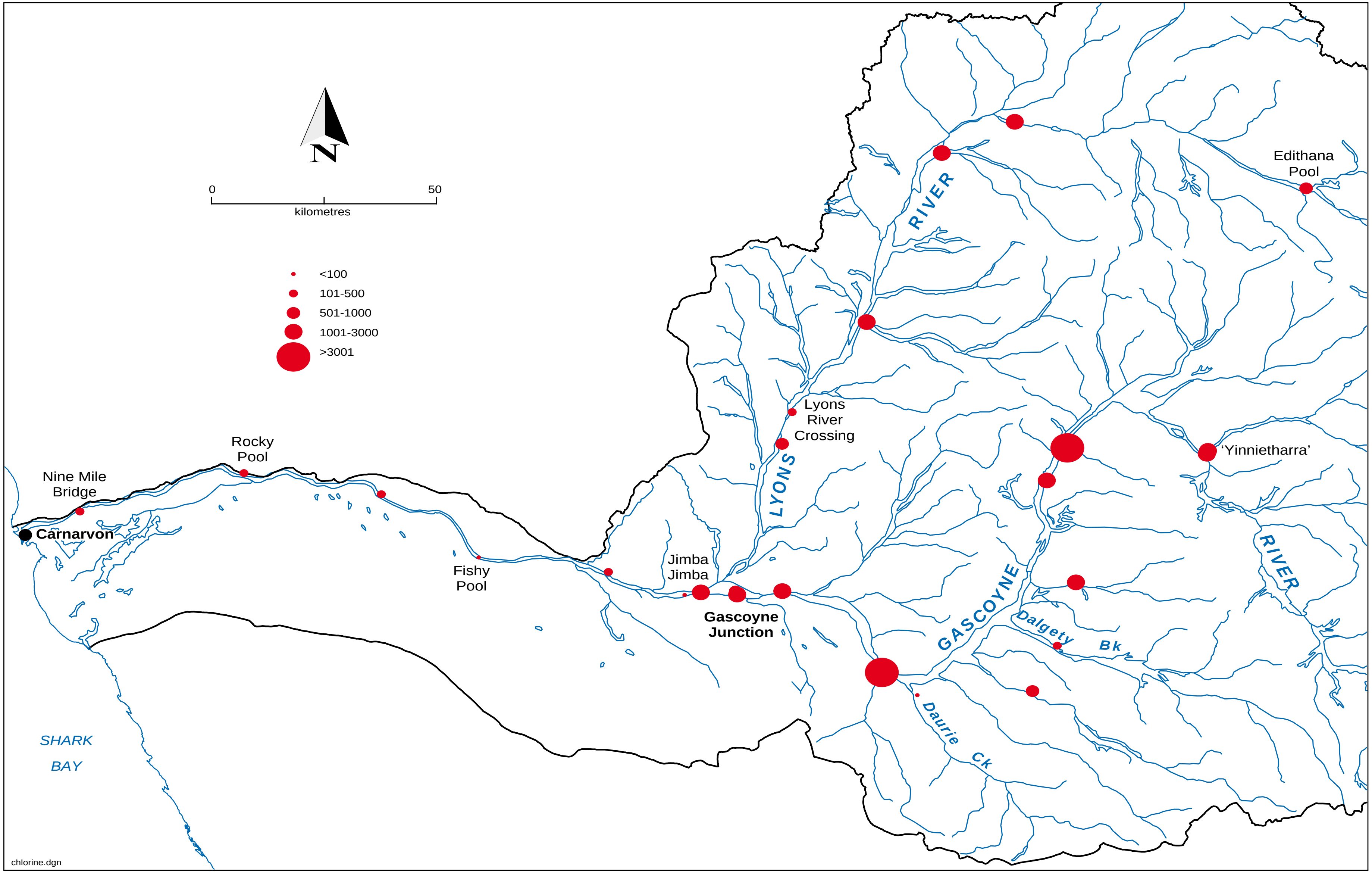
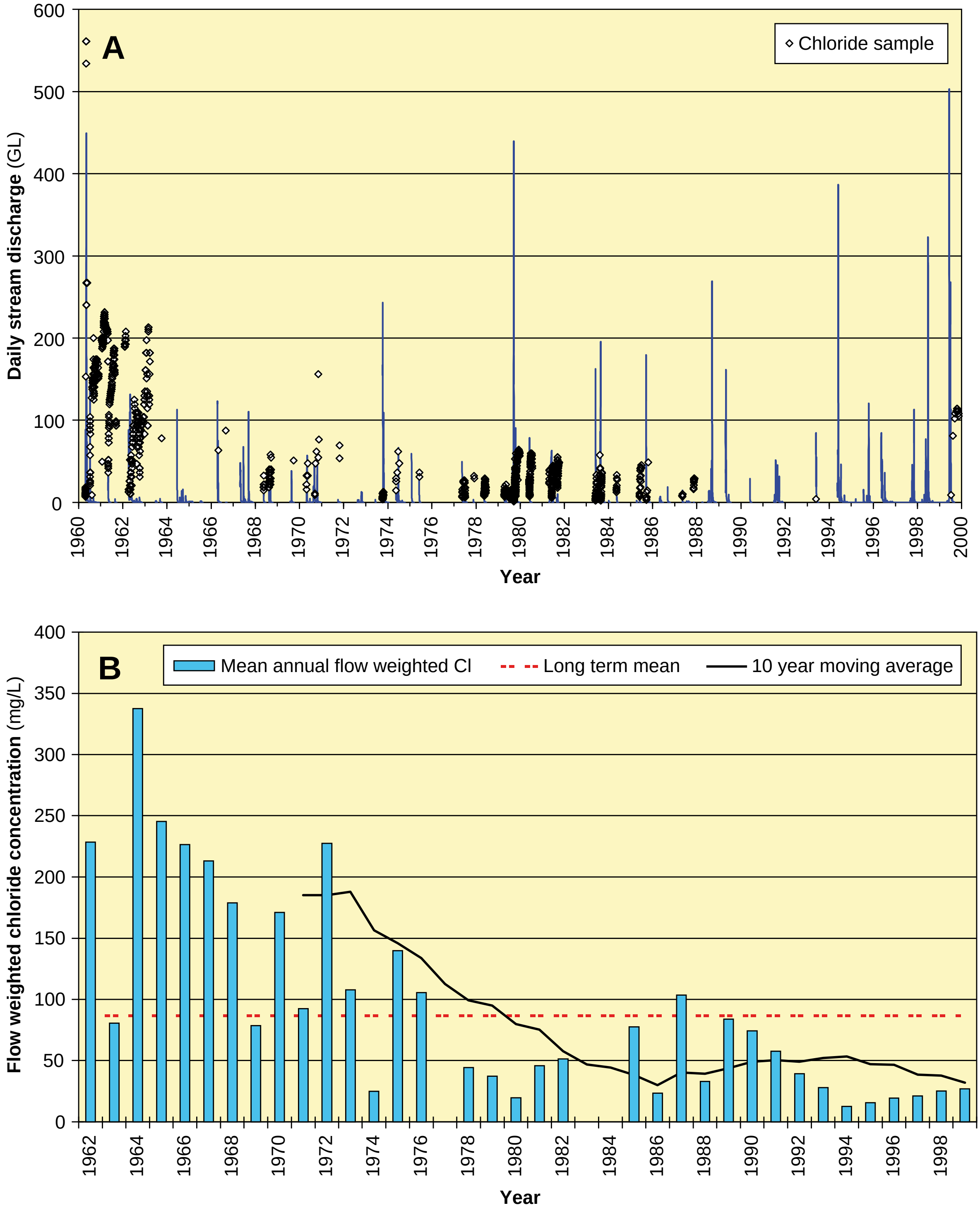


Figure 13 Mean chloride concentration of surface water in the Gascoyne River catchment

with greater relief, higher rainfall and less evaporation, resulting in lower average chloride concentration in its surface water.



Graph A indicates frequency of chloride sampling during stream flow.

Graph B represents the mean annual flow weighted chloride concentration.

Figure 14 Chloride concentration and stream discharge at Nine Mile Bridge

The chloride concentration of surface water during river flow has been measured at Nine Mile Bridge stream gauging station. Figure 14A represents the frequency of sampling. From 1961 to 1988 there was consistent sampling over flow periods, after which sampling of chloride was phased out in favour of electrical conductivity. Figure 14B gives the mean annual flow weighted chloride at Nine Mile Bridge. The mean chloride concentration for Nine Mile Bridge is 194 mg/L, however the mean annual flow weighted chloride is 85 mg/L. The lack of long term continuous water quality monitoring makes it difficult to understand the water quality and quantity interactions and seasonal variations of the Gascoyne River.

There is an apparent decreasing trend in chloride concentration at Nine Mile Bridge (Fig. 14b). This is attributed to the dry period of the 1980s and early 90s, combined with greater groundwater abstraction as the reliance on groundwater supply increases over no flow intervals. Groundwater abstraction causes the watertable to decline within the riverbed sand at a greater rate than under natural conditions, thus reducing the opportunity for evaporative loss from surface pools and groundwater to the atmosphere. However, when the river does flow for extended periods, as occurred in the early 1960s and later 1990s, the chloride concentration of surface water increases.

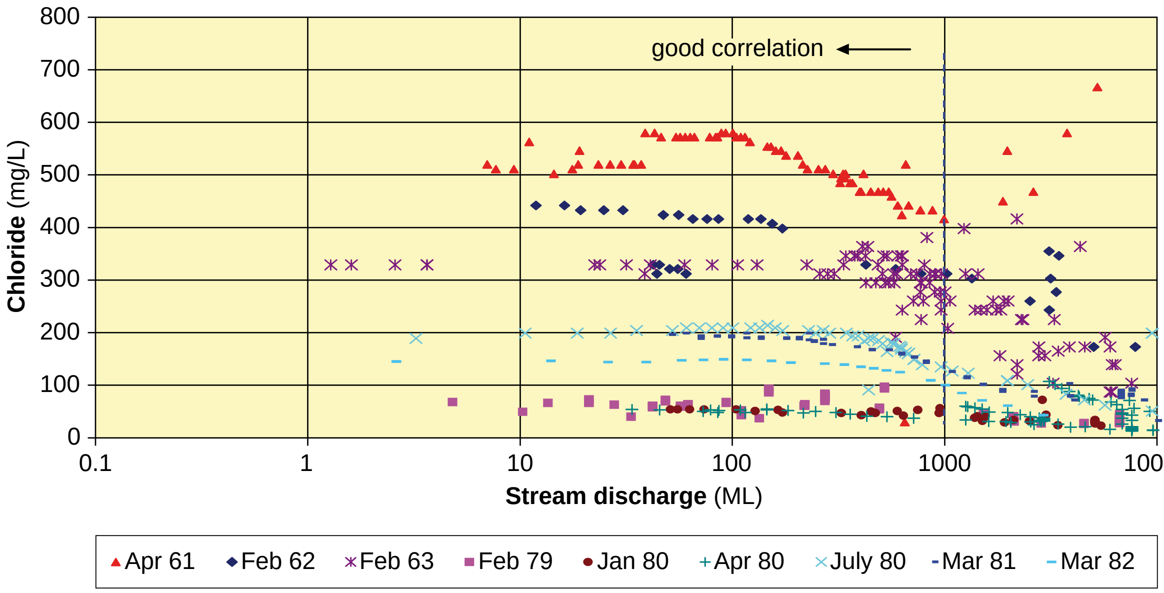


Figure 15 Chloride concentration of individual flow events

Once the main flow peak has passed, the surface water draining from the catchment increases in chloride concentration owing to evaporation and the reduced input from surface runoff. However, examining the chloride concentration at Nine Mile Bridge gauging station from individual flow events indicates that the chloride concentration of surface water eventually reaches a steady state. Stream discharge below 1 GL/day at Nine Mile Bridge develops a discrete signature for chloride concentration for each flow over its duration (Fig. 15). The chloride concentration depends on the magnitude of the river flow, where within the catchment the majority of runoff was generated, and the recent flow history; wetter periods correspond with higher salinity flows, while the first flow after a long dry period is generally low in chloride for its duration. The maximum salinity of surface flow on the coastal plain is limited by both the relatively small storage of the riverbed sand and by the downward discharge of groundwater into the older alluvium.

Overall, there is a great variation in the chloride concentration of surface water along the length of the Gascoyne River, over the duration of a flow event and between individual flow events. The variation is the result of a combination of inter-related factors, such as locality of rainfall over the catchment, the volume and intensity of rainfall, size and duration of river flow, groundwater salinity of the riverbed sand aquifer and the recent river flow history. The dynamic interaction between surface water and groundwater has a significant impact on the chloride concentration of each.

3.5 Surface water salinity

The water quality has been assessed with respect to salinity. The concentration of total dissolved salts (TDS) in water is determined by summing the individual ions that make up the total dissolved salt content. The units for TDS are milligrams per litre (mg/L). The TDS concentration in surface water can vary over several orders of magnitude depending on the environment in which the water occurs. However as the collection and analysis of the major ions of water samples is labour intensive and expensive, an indirect method for calculating TDS has been developed.

An indication of the salt content is given by the electrical conductivity (EC) of the water. The EC measures the ability of water to conduct an electric current which is carried by various ions in solution. The units for EC are siemens (S) or microsiemens (μS) and the conductance of water ranges from several tens of microsiemens for water as fresh as rainfall, to hundreds of thousands of microsiemens for brines beneath salt lakes. There is a good correlation between the TDS and the electrical conductance of water. For most water the TDS is equivalent to the EC multiplied by a factor of 0.5 to 0.8. For surface water and groundwater of the Gascoyne River catchment there is a defined relationship between the EC and TDS; the relationships are presented in Table 9. The correlation between EC and TDS of groundwater is reviewed regularly based on comprehensive sampling of major ions in groundwater.

Table 9 Electrical conductivity (EC) to TDS relationships

Surface water	**Relationship**
EC @ 25°C < 30 mS/m	(EC × 6.2) + 18
EC @ 25°C > 30 mS/m	(EC × 5.6) + 36
EC @ 25°C > 30 mS/m	(EC × 6.2) - 84
Groundwater	
EC @ 25°C < 40 mS/m	(EC × 7.53)
EC @ 25°C > 40 mS/m	(EC × 5.15) + 95.16

*Source: WRC WIN data

The salinity of flood water resulting from Cyclone Steve in March 2000 has been recorded at seven sites from Chinamans Pool, 6 km ARM, to Yinnietharra, 260 km ARM. The change in salinity at each site over time is represented in Figure 16. The average salinity of surface water on the coastal plain is lower than most sites upstream within the Kennedy Range. Furthermore, the rate of increase in salinity over time is lowest on the coastal plain and this rate decreases along the flow path of the river, for example Nine Mile Bridge versus Fishy Pool. The rate of increase in salinity is greatest in the inland catchment at Lyons River crossing and Yinnietharra. This latter phenomenon reflects the increase in potential evaporation from west to east.

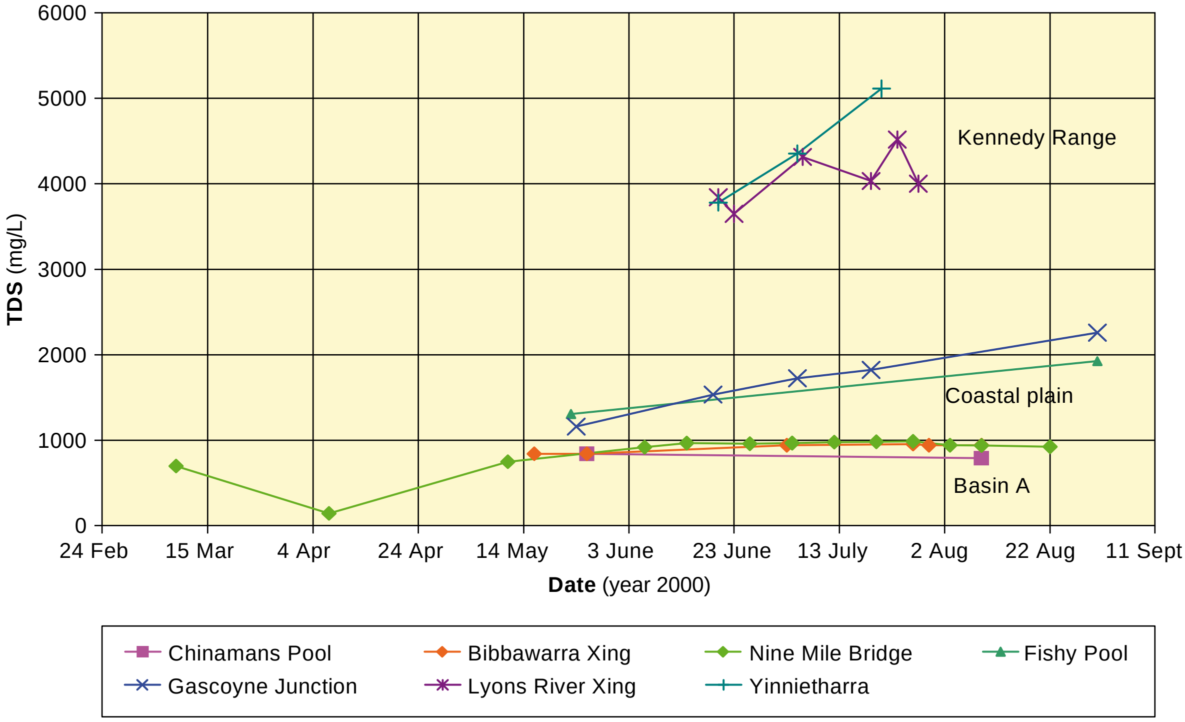


Figure 16 Change in surface water salinity over time after Cyclone Steve (March, 2000)

4 Hydrogeology

4.1 Groundwater occurrence

The groundwater in the floodplain sediments is contained within a regional, unconfined to semi-confined aquifer system. The groundwater flow system is heterogeneous and anisotropic. It is bound in the west by the saltwater interface at the Indian Ocean. In the east, the aquifer is bound by the Toolunga Calcilutite on the west side of the northeast trending fault at Rocky Pool. However, there is no surface expression of the fault to the southwest of Rocky Pool as the calcilutite is buried beneath the floodplain sediments (Allen, 1971). Thus, the aquifer is probably continuous with the alluvium east of Rocky Pool to the south of the Gascoyne River.

The floodplain sediments have been grouped into two distinct aquifers in hydraulic connection with each other, namely the riverbed sand aquifer and the older alluvium aquifer. The riverbed sand aquifer, consisting of the bed load of the Gascoyne River, is unconfined and contains fresh groundwater. It is filled by surface water from the intermittent river flows, and groundwater stored in the aquifer leaks downwards to recharge the older alluvium aquifer (Allen, 1972; Martin, 1990b).

The older alluvium aquifer is semi-confined to confined. The groundwater within the Gascoyne River mound contains tritium, indicating that it is of recent age (Martin, 1990b). The older alluvium contains old riverbed material of coarse gravel to sand in discontinuous channel beds. The confining beds consist of alluvial clay overflow material. The older alluvium contains significant volumes of groundwater in comparison to the riverbed sand aquifer. However, away from the Gascoyne River, much of the groundwater in the older alluvium is brackish to saline (1000–6000 mg/L TDS).

4.1.1 Riverbed sand aquifer

The unconfined riverbed sand aquifer is essentially single layered. It is often colloquially referred to as the ‘first water’ or ‘top water’. The matrix of the riverbed sand is predominantly coarse-grained sand, but ranges from cobble size to fine sand (Lewis, 1990). The riverbed sand has a maximum saturated thickness of about 12 m from the cease to flow level in isolated areas, and the average saturated thickness is about 3.5 m. However, after extended dry periods the sand becomes unsaturated in parts and there is no groundwater throughflow.

Recharge to the riverbed sand is by direct infiltration during river flow, and to a lesser extent by rainfall onto the surface of the riverbed. The hydrograph of monitoring well G70418364 shows the instantaneous response to river flow, and the rapid decline in watertable of a shallow well screened in the riverbed sand (Fig. 17a). Groundwater within the riverbed sand flows under the influence of gravity. The rate of groundwater flow depends on the hydraulic conductivity and the hydraulic gradient of the aquifer. The watertable within the riverbed sand is flat, with very low hydraulic gradients but high conductivity. The rate of groundwater throughflow in the riverbed sand can be estimated using the Darcy equation as expressed by Domenico and Schwartz (1990).

$$v = \frac{k \times i}{\theta} \qquad (3)$$

where v = linear velocity (m/d)
k = horizontal hydraulic conductivity (m/day)
i = hydraulic gradient (dimensionless)
θ = effective porosity (dimensionless)

The hydraulic conductivity of the riverbed sand may vary over three orders of magnitude owing to the variation in grain size of its matrix. The hydraulic conductivity estimated from pumping-tests for the riverbed sand varied between 50 and 2000 m/day (Table 3). The rate of groundwater flow from equation (3), given a hydraulic gradient of 7×10^{-4} and assuming an effective porosity of 0.3, varies between 40 and 1700 m/year.

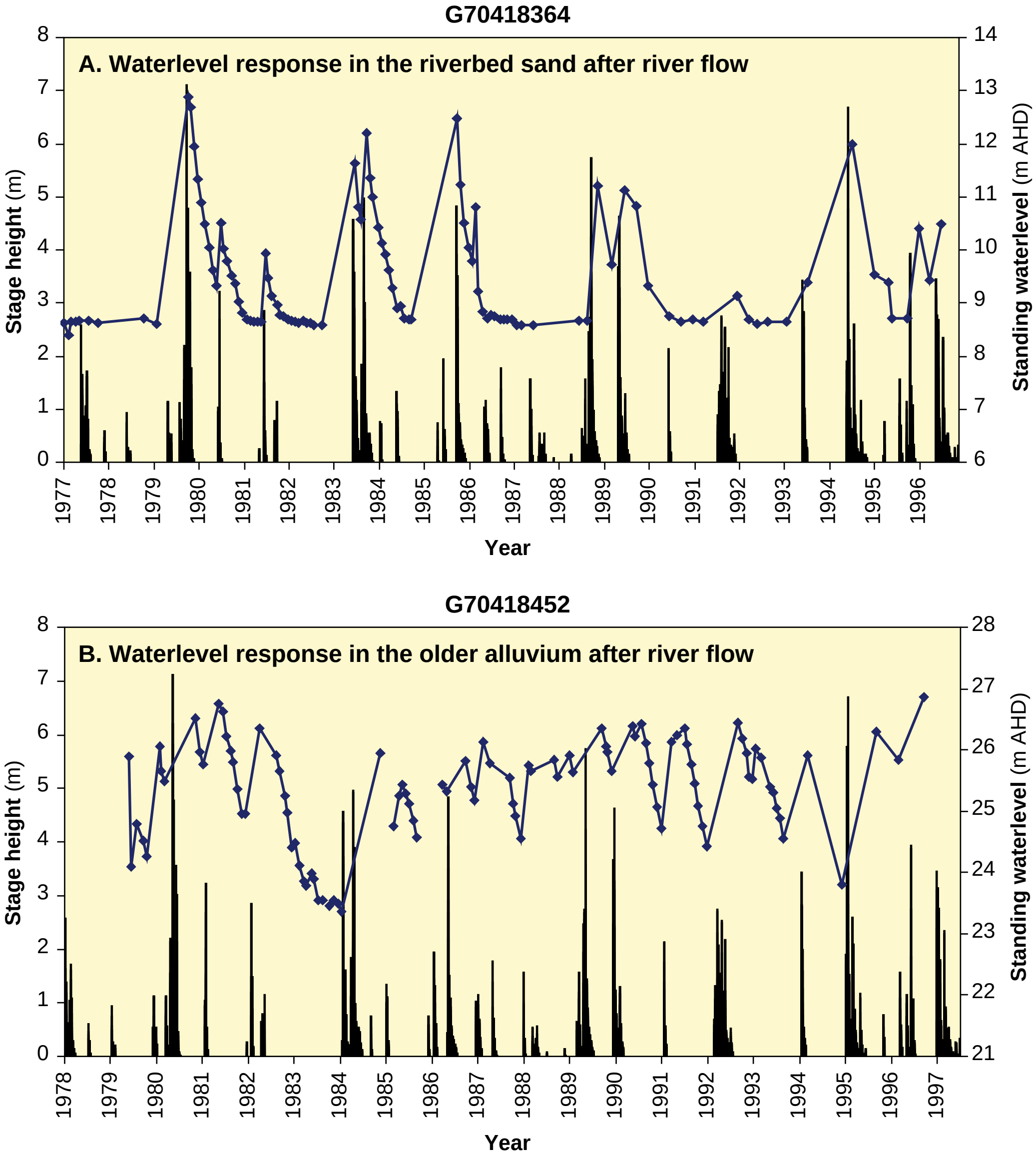


Figure 17 Waterlevel response to river flow

Groundwater discharge from the riverbed sand aquifer is by evaporation, transpiration, groundwater abstraction, vertical leakage down to the older alluvium and by groundwater throughflow.

4.1.1.1 Groundwater storage

The volume of groundwater stored in the riverbed sand aquifer is dependent on river flow, evapotranspiration, vertical infiltration and groundwater throughflow. Groundwater storage within the riverbed sand has been calculated from the cease to flow level to the top of the older alluvium, given by the depth of the first clay layer. For this research the thickness has been calculated by contouring the riverbed base using point source data from the 1969–72 auger drilling survey and water well drilling logs from government and private wells.

The specific yield of the riverbed sand was estimated to be between 0.29–0.32 by pumping-test analysis (Vogwill, 1972). Allen (1972) estimated a value of 0.30 from pumping-tests and 0.29 from analysis of hydrograph response after rainfall from Cyclone Glynnis. Groundwater storage in the riverbed sand has been calculated assuming a specific yield of 0.3. The volume of groundwater held in storage is the product of the estimated saturated volume of riverbed sand by the specific yield. The total available groundwater held within the riverbed sand at the cease to flow level is approximately 28 GL. This is greater than the estimate of 20 GL made by Allen (1972) who ultimately applied a conservative specific yield of 0.25. This volume represents the amount of water in pore spaces available to wells if the sediments were to be de-watered completely.

4.1.2 Older alluvium aquifer

The older alluvium is a semi-confined to confined, multi-layered aquifer. It is colloquially referred to as the ‘bottom water’ or ‘second water’. It contains the regional watertable for most of the coastal plain, except where ephemeral watercourses contain saturated, coarse, bed-load sand. The matrix of the older alluvium is predominantly clay, silty clay, gravel and sandy clay, clayey sand, silty sand and minor sand, gravel and laterite (Skidmore, 1997a). The older alluvium has a maximum thickness of about 65 m; its saturated thickness thins out from west to east, with an average of approximately 45 m.

The principal mechanism for groundwater recharge to the older alluvium is by downward and lateral leakage from the riverbed sand. The hydrograph of Figure 17b demonstrates the delayed response to river flow events within the older alluvium in comparison to the riverbed sand. Recharge to the older alluvium from direct infiltration of rainfall and from episodic flooding associated with large flow events that inundate the coastal plain, is also anticipated, but of much smaller magnitude in comparison to river recharge.

The groundwater mound that lies beneath the Gascoyne River dominates the watertable configuration within the older alluvium (Fig. 18). The presence of this mound is the result of surface flow in the Gascoyne River. The mound has developed because the rate of vertical infiltration during a river flow is greater than the rate of horizontal groundwater throughflow away from the mound. Steep hydraulic gradients within the older alluvium adjacent to the river course indicate the presence of low permeable sediments. The thin clay beds within the older alluvium restrict the lateral flow of water away from the mound.

During periods of no flow the groundwater mound begins to subside and the hydraulic gradient flattens as the watertable falls. Groundwater flows away from the mound to the north and south. However, with increasing distance from the river, the hydraulic gradient reduces and the flow direction gradually changes westwards towards the coast.

The change in groundwater flow direction is more pronounced south of the Gascoyne River, near Rocky Pool (Fig. 18). South of Rocky Pool, groundwater flow lines are near perpendicular to the river and the hydraulic gradient is lowest, indicating greater hydraulic conductivity in comparison to north of the river. The saturated thickness of the older alluvium is greater to the south, where the Toolunga Calcilutite plunges beneath the older alluvium. Furthermore, east of the developed groundwater area the Gascoyne River flows in a northwest direction, thus recharge from this part of the river is directed by throughflow towards the south of Rocky Pool. However, this configuration of the watertable is subjective and based on few data points south of 1 km from the river. A proposed drilling investigation by the Water Corporation may resolve the issue of throughflow south of Rocky Pool (Rockwater, 2000).

The response of the groundwater flow system to a recharge event in 1989 was described by Martin (1990b). Three transects, B, C and D, were drilled perpendicular to the Gascoyne River with multi-port or nested piezometers installed along each transect (Fig. 5). Multi-port wells contain numerous apertures within a single well that are able to measure the potentiometric head at separate depths within the aquifer profile. The groundwater isopotential pattern for each transect is given for December 1988, May 1989 and July 1989 in Figures 19, 20 and 21 (after Martin, 1990b). These periods represent conditions following a noflow period of four months, just after commencement of a major flow and after three months of flow.

The isopotential patterns indicate the hydraulic connection between the riverbed sand and older alluvium prior to the river flow event (December 1988). After the start of the river flow (May 1989) the rise of the potentiometric level within the older alluvium near the river is between 0.5–1.5 m, and varies from transect to transect and north and south along each transect (Martin, 1990b). This variability indicates the heterogeneous and anisotropic nature of the older alluvium owing to the presence of low permeable clay. Groundwater levels further from the river (> 1 km) declined between December and May.

By July 1989 the potentiometric levels in the older alluvium further than a kilometre away rose in response to river flow, the rise decreasing in magnitude with distance from the river (Martin, 1990b). However, next to the river the groundwater level response was up to 4 m in some multi-ports. The process of translatory flow best describes the mechanism for recharge to the older alluvium. Water previously stored within the aquifer is displaced downwards by successive episodes of river flow. This explains the rapid response of the watertable in the older alluvium near the river to flow events even when low permeable material occurs. However, it takes much longer for this recharge to be transferred laterally away from the river within the older alluvium.

The multi-ports also give an insight into the vertical hydraulic gradient of the older alluvium. The relationships between individual ports within selected multi-port wells are given in the hydrographs of Figures 22 and 23. Multi-port G70420001 represents a relatively homogenous, well connected vertical profile that responds equally to recharge events, although with some hysteresis. G70420001 is near the highest yielding production well within the Scheme. Multi-ports G70420004 and G70420007 are a considerable distance south of the river and display upward potentiometric heads from the deeper ports of the aquifer. In Figure 22 all three multi-port wells located close to the river indicate significant downward vertical gradients.

The older alluvium consists of clay to gravel size particles, and thus has a wide range in hydraulic conductivity. The hydraulic conductivity estimated from pumping-tests ranged from 10^{-1} to 10^{2} m/day (Table 3). The rate of groundwater flow in the older alluvium, given a hydraulic gradient of 7×10^{-4} and assuming an effective porosity of 0.1, varies between 0.2 and 250 m/year using equation (3).

Groundwater is discharged from the older alluvium mainly by abstraction, leakage downwards to the underlying basement and, to a much lesser extent, by throughflow to the Indian Ocean and evapotranspiration.

4.1.2.1 Groundwater storage

Estimates of the total groundwater storage in the older alluvium are limited by the extent of drilling exploration north and south of the river. Estimates have generally been based on the volume of groundwater, with less than 500 mg/L TDS, stored west of Rocky Pool. An arbitrary estimate of the extent of this freshwater zone is updated with each new drilling program. Estimates range from 100 GL (Allen, 1972) up to 340 GL (Martin, 1990b), using an effective porosity of 0.1. Both estimates are somewhat conservative, the extent of freshwater in the Scheme was unknown at the time of Allen, and Martin excludes any freshwater in the older alluvium within Basin A. However, there have been no drilling programs to extend the estimated 500 mg/L isohaline any further than Martin’s interpretation.

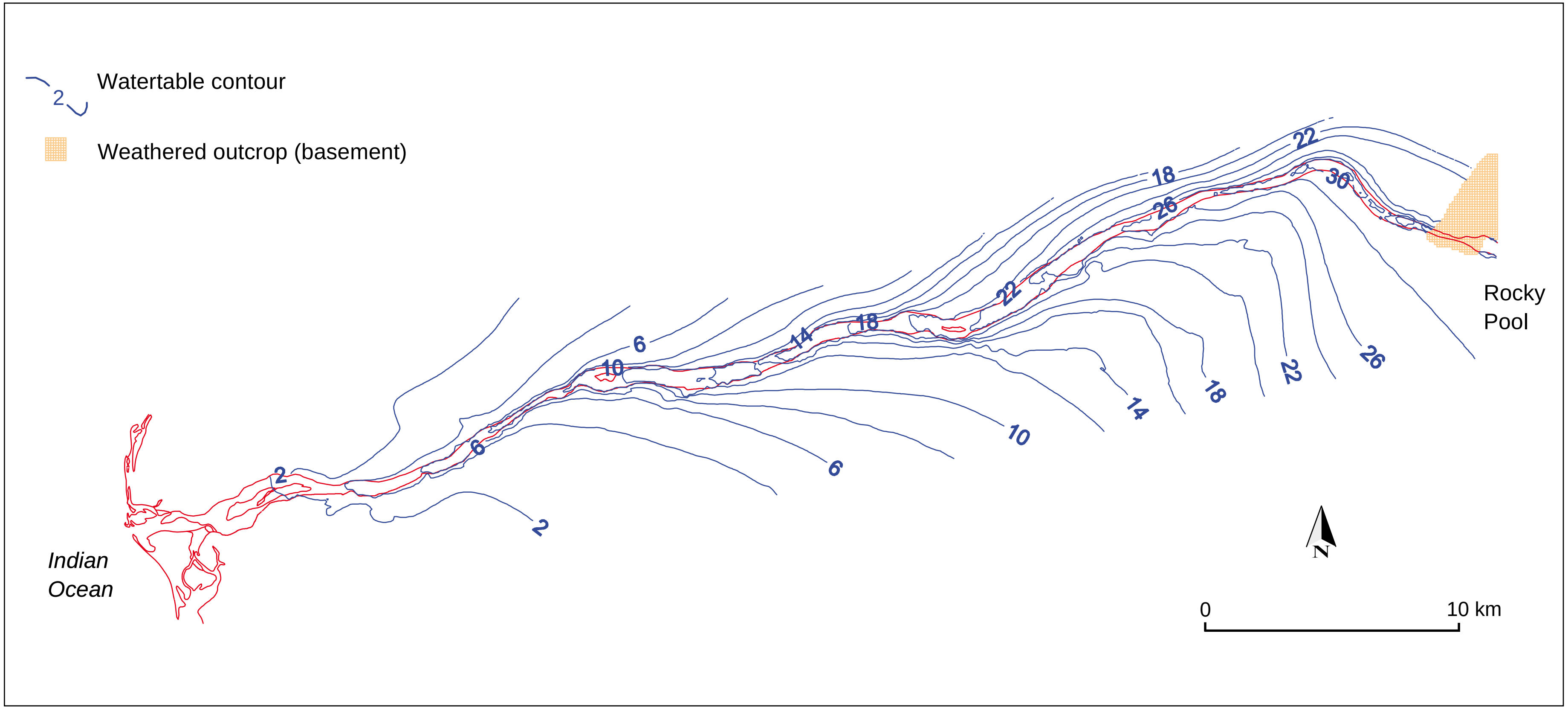


Figure 18 Computer generated watertable configuration in the older alluvium

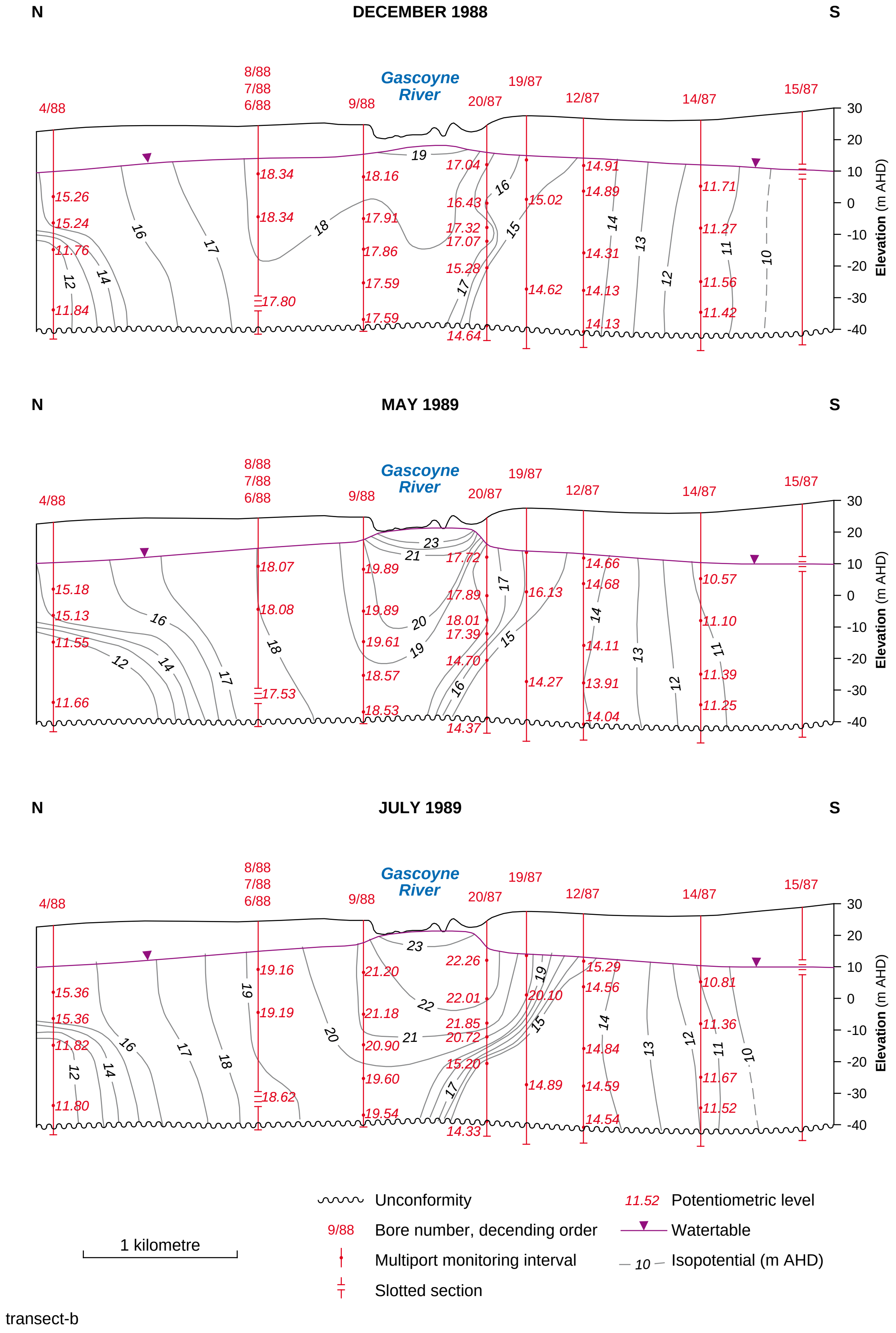


Figure 19 Isopotential of older alluvium transect B (after Martin, 1990b)

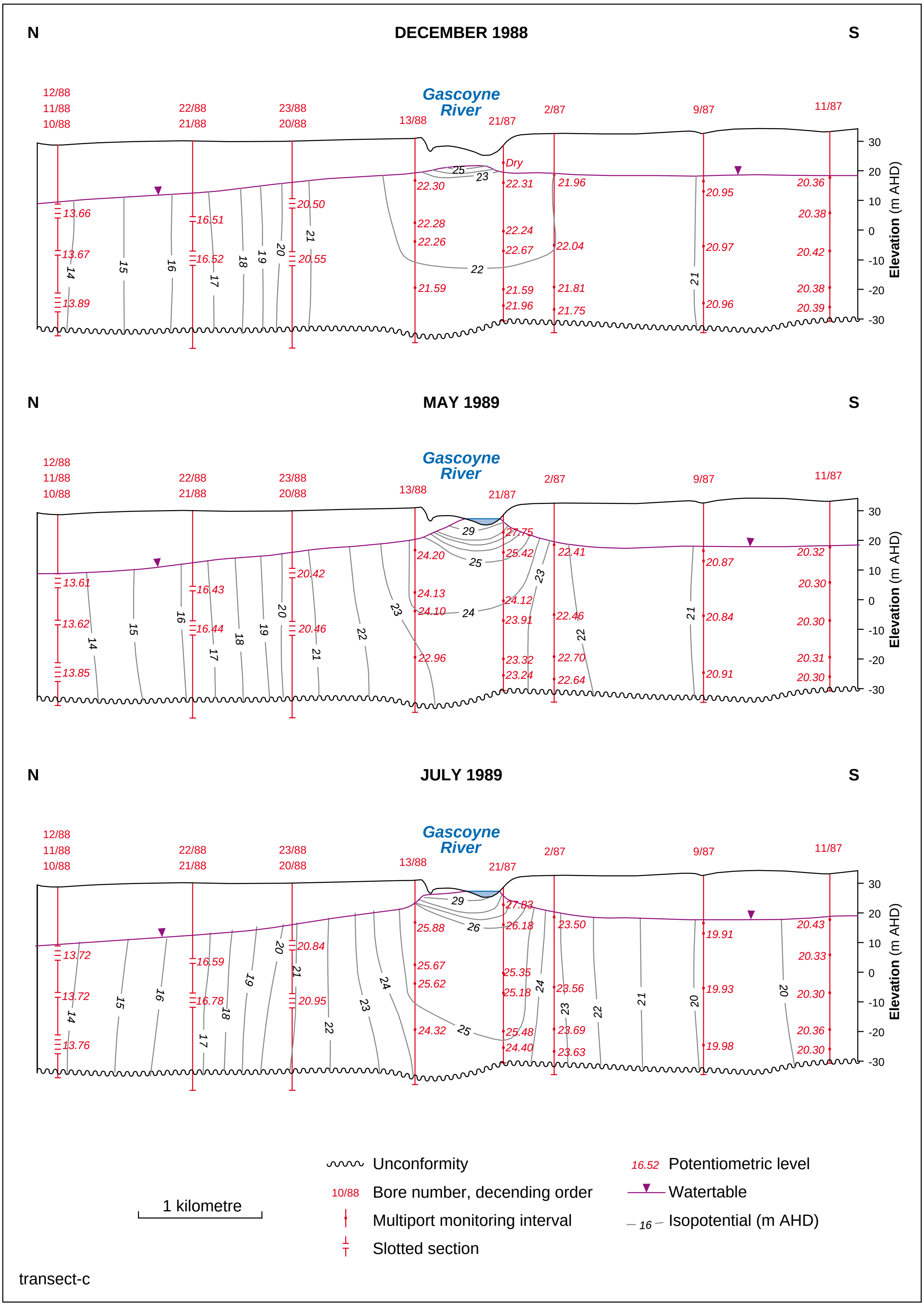


Figure 20 Isopotential of older alluvium transect C (after Martin, 1990b)

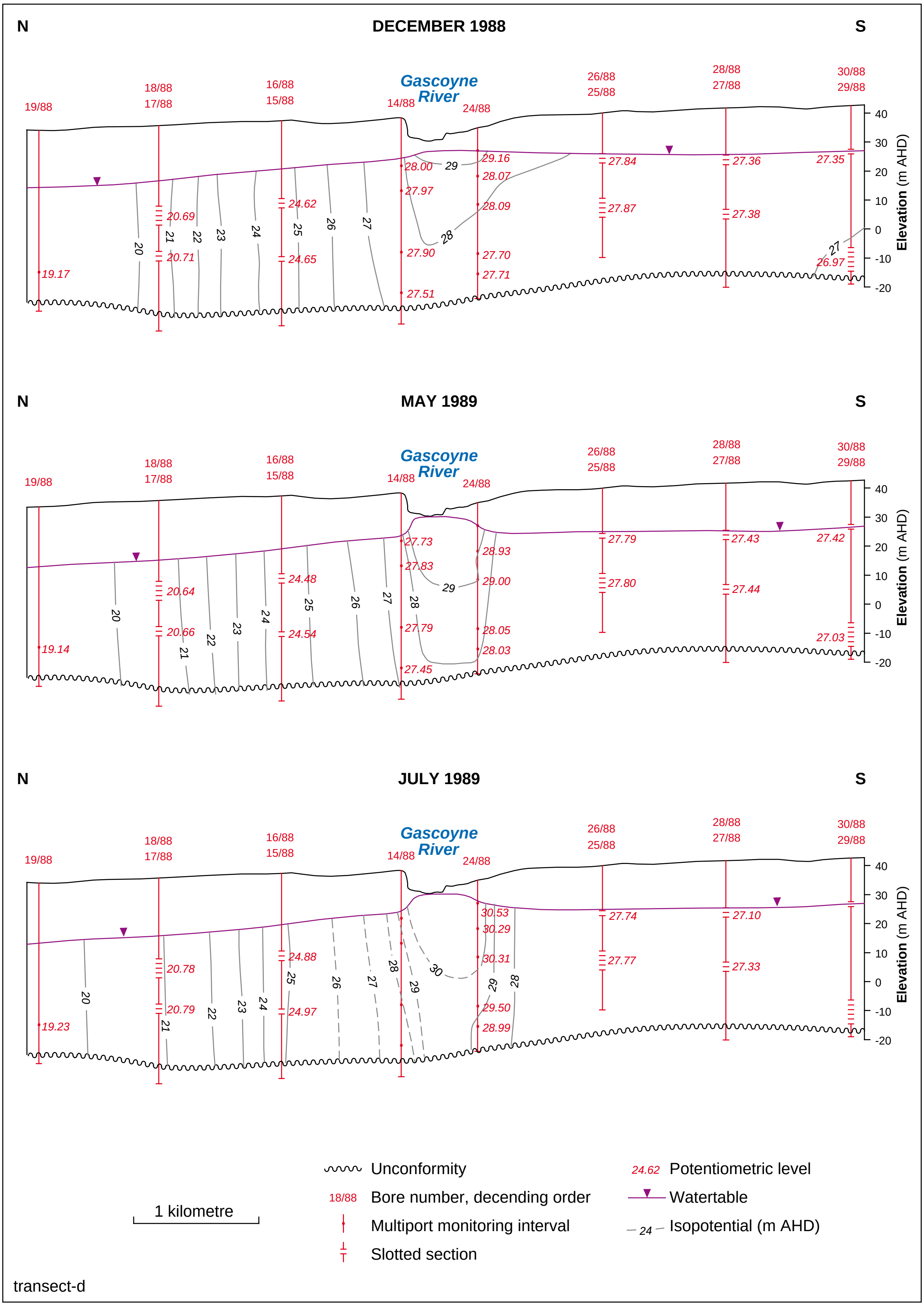


Figure 21 Isopotential of older alluvium transect D (after Martin, 1990b)

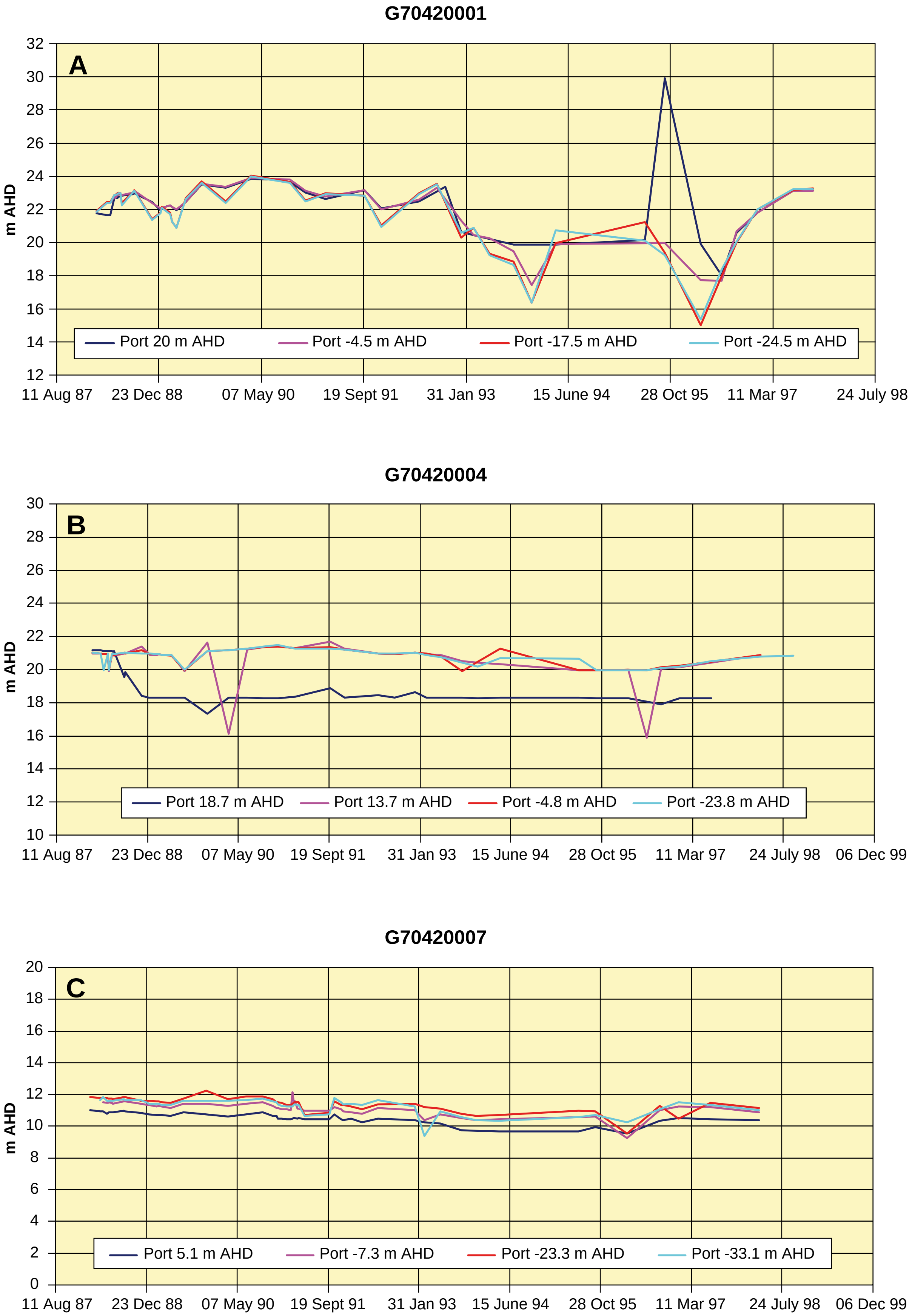


Figure 22 Multi-port monitoring well hydrographs showing A) homogenous vertical profile, B) and C) upward pressure within older alluvium.

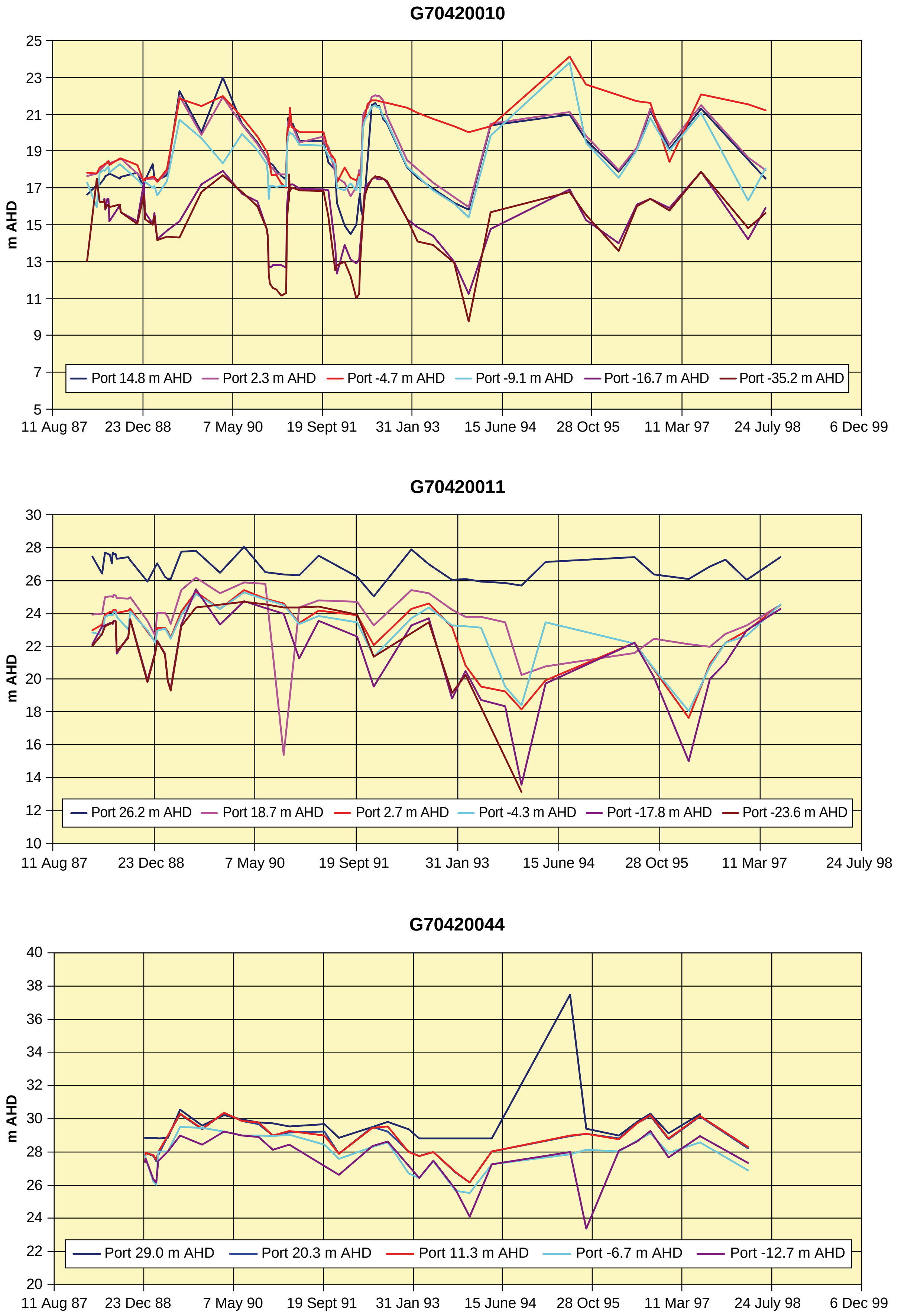


Figure 23 Multi-port monitoring well hydrographs showing downward heads

4.2 Groundwater balance

A groundwater balance equates all groundwater entering the flow system to all that which leaves the flow system. This method of analysis is essentially a book keeping procedure, estimating the balance between the inflows and outflows of water. Inputs and outputs are in water volumes per unit time. For the Gascoyne River a combination of a watertable fluctuation method during no flow intervals, and a Darcian flownet analysis coupled with a chloride mass balance for flow intervals has been applied to estimate water balance components. Fluctuations in well hydrographs and the transmission loss are used to confirm that the estimates are of the right magnitude. A complete explanation of the methods and assumptions used in the water balance is given in Dodson (2002). A brief explanation and summary of the water budget components are presented here.

4.2.1 No flow analysis

At equilibrium, the groundwater balance of the flow system for the Gascoyne River floodplain aquifer can be expressed by the following equation:

$$R_r + P + d_i = d_o + a + L_D + E \qquad (4)$$

where R_r = recharge due to river flow
P = rainfall over the area
d_i = groundwater inflow
d_o = groundwater discharge out and to the saltwater interface
a = abstraction
E = evapotranspiration
L_D = leakage downward and out

The ephemeral nature of surface flow means that the groundwater flow system has two states, a flow period and a no flow period. Thus storage within the riverbed sand is rarely at equilibrium, and this flux is an important component of the groundwater balance. Furthermore, when the river is flowing, water temporarily stored in the riverbed sand is released back to surface flow as the stage subsides. The rate at which water is released is a function of the channel morphology; that is, as the river channel thins or shallows, water will be released, and conversely where the river widens or deepens there is greater void space to store water. For the groundwater balance of the riverbed sand, the components of equation (4) can be expanded to:

$$\Delta V = (R_i + P + d_i) - (d_o + a + E + R_o + L_D) \qquad (5)$$

where ΔV = change in saturated volume of aquifer material
R_i = recharge from river flow (apparent flow loss)
P = rainfall over the area
d_i = groundwater inflow
d_o = groundwater discharge by throughflow
a = abstraction

E = evapotranspiration
R_o = aquifer loss to the river (apparent flow gains)
L_D = eakage downward to older alluvium

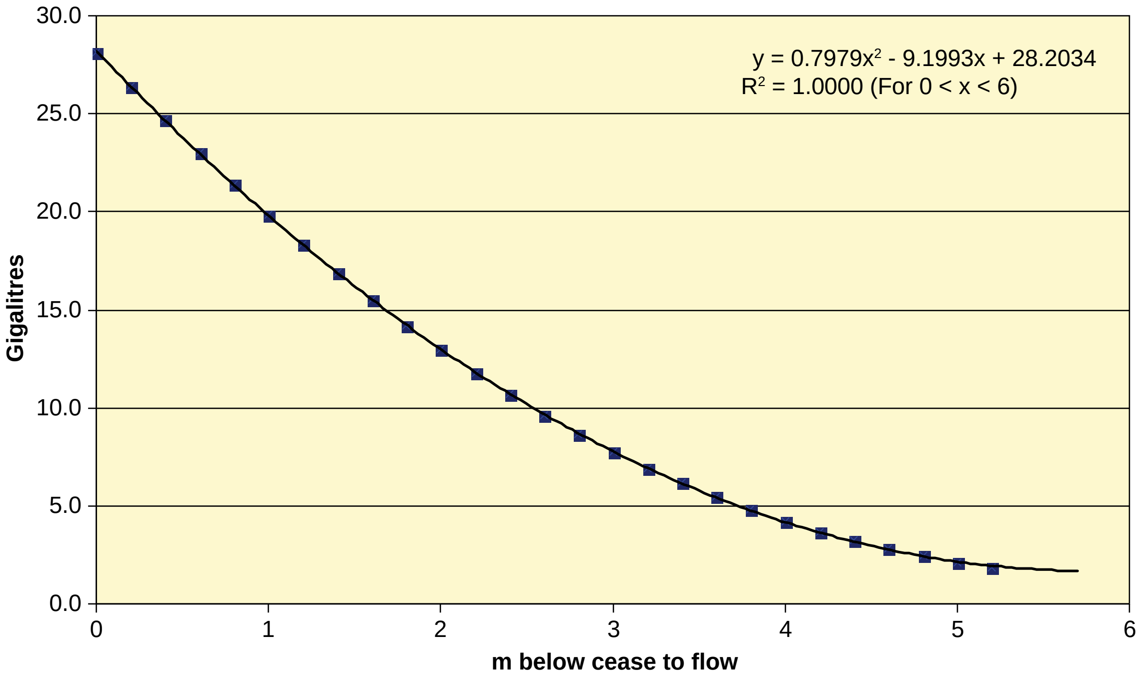
Once river flow stops, R_i and R_o are equal to zero. The other components of equation (5) were determined through indirect methods using the Darcy equation and monitoring wells screened against the riverbed sand that give the watertable recession. Eight monitoring wells screened within, or just below, the riverbed sand but not at the watertable, were used to determine a mean rate of watertable decline. Using screened intervals at the base of the riverbed sand removed the uncertainty of estimating the specific yield in the partially saturated zone of the watertable.

The watertable recession within the eight monitoring wells were collated from six selected no flow intervals. Waterlevels from the beginning of the no flow period until the start of the next flow period were used to calculate the initial and final average depth below the cease to flow level. A constant time-weighted mean rate of decline in the watertable for each no flow interval was then calculated from the average rate of decline from each monitoring well, based on the number of days that each well was measured and divided by the total number of days. The rate of decline of the watertable is exponential, as groundwater throughflow decreases as the volume of saturated sand decreases, vertical flow decreases as head potential decreases and the rate of evaporation and transpiration varies with the time of year, weather and depth to watertable. However, over the short term, use of a straight line relationship between waterlevel and time will not introduce significant error. The six no flow intervals described in Dodson (2002) and the time-weighted mean rate of decline for each interval are given in Table 10.

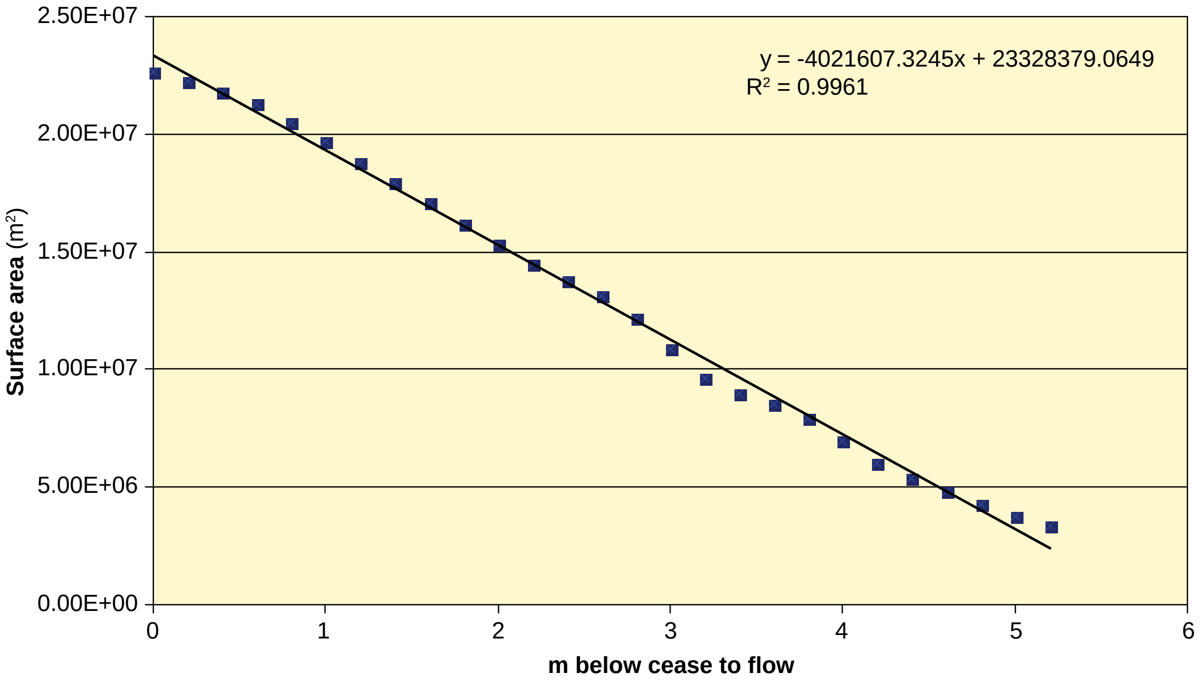
The variation in the rate of decline between locations is due to the proximity to abstraction wells, distribution in rainfall over the period, season in which flow ceased, vegetation density and variations in local hydraulic connection with the older alluvium. As many wells as possible were used to calculate the average rate of decline to negate the impact of such local effects. The longer the duration of no flow, the smaller the range in rate of decline from all wells. As a consequence the results from the 1982, 1983 and 1984 no flow intervals are more representative of a whole of aquifer rate of decline than the shorter duration intervals.

4.2.1.1 Change in riverbed sand storage

A finite difference model of the riverbed sand thickness was used to construct the saturated aquifer volume, given the depth below the cease to flow level. The finite difference model consisted of 2865 cells, each cell 100 metres square, and was constructed from the 1969–72 auger drilling survey. The volumes were calculated using the trapezoidal method from Golden Software's SURFER® for Windows software. The actual water released, or change in storage, is the product of the saturated aquifer volume and the specific yield (0.3) and the resulting relationship is given in Figure 24a.



A. Constructed saturated volume of the riverbed sand aquifer below cease to flow level



B. Constructed saturated surface area in contact with older alluvium below cease to flow level

Figure 24 Riverbed sand constructed water balance curves

The change in storage over each interval is presented in Table 10. Over the first year of a no flow interval the change in storage in the riverbed sand varied between 54 000 and 79 000 m^3/day. In the second year of a no flow period, the 1983 example, the change in storage in the riverbed sand diminished by an order of magnitude owing to the lack of recharge from river flow.

Table 10 Change in storage in riverbed sand over no flow intervals

Year	No. of wells	Mean depth below cease to flow		Days	Time-weighted mean decline (mm/day)	Water released (m^3/day)
		Initial (m)	Final (m)			
1979	7	1.7	4.4	212	13.1	55 200
1980	5	1.2	2.9	128	14.2	78 800
1981	5	1.1	3.5	245	11.0	54 200
1982	7	0.9	4.2	250	13.3	67 700
1983	7	4.4	5.3	273	3.7	4 800
1987	6	1.3	3.9	175	17.2	75 000

4.2.1.2 Leakage downwards to older alluvium

As long as the watertable in the riverbed sand remains higher than the potentiometric head in the older alluvium, groundwater will continue to leak into the older alluvium beneath the riverbed. The volume of groundwater that leaks from the riverbed sand to the older alluvium (L_D) can be expressed by the Darcy equation:

$$L_D = TiL = kbiL = kiA \qquad (6)$$

where L_D = volume of vertical groundwater throughflow (m^3/day)
T = transmissivity of aquifer (m^2/day)
i = hydraulic gradient
L = length of section (m)
k = horizontal conductivity (m/day)
b = saturated aquifer thickness (m)
A = cross section area (m^2)

The limiting conditions set by Darcy (1856) are assumed, that is:

- flow through porous media is laminar,
- the flow velocities are low, and
- the Reynolds number for turbulence is less than 1.

As the contact between the riverbed sand and the older alluvium is not a flat surface, a decline in the watertable results in a reduction of saturated surface area in contact with the older alluvium. The finite difference model of the base of the riverbed sand was used to estimate the change in saturated area per depth below the cease to flow level using Golden Software's SURFER® for Windows software. The saturated surface area and watertable depth below the cease to flow level can be approximated by the linear relationship given in Figure 24b. The saturated surface area of riverbed sand in contact with the older alluvium is calculated for each day over the no flow interval by substituting the time-weighted average rate of decline per day into the linear relationship representing saturated surface area for watertable depth below cease to flow.

The surface area is substituted into the Darcy equation using a spreadsheet and the sum of each day's vertical leakage was calculated. The rate of vertical leakage is limited by the vertical hydraulic conductivity of the older alluvium and the hydraulic gradient between the riverbed sand and older alluvium. The vertical hydraulic conductivity used for the older alluvium was 0.03 m/day from pumping-test analysis after Martin (1990b).

The hydraulic gradient between the riverbed sand and the older alluvium varies spatially and temporally. The average vertical gradient from pumping-tests was estimated at 0.09 (Martin, 1990b). However, this value gave excessive loss to vertical leakage in comparison to storage loss estimated from the constructed saturated volume analysis. Consequently, a review of the monitoring from six multi-port wells situated on the banks of the river was completed. The potentiometric levels extend from 1988 to 1998 and the potentiometric head from the top port to the base of the older alluvium was used to assess the gradient. Individual gradients were only calculated on days when both top and bottom ports were recorded.

The gradient ranged from a minimum of -0.02 (upwards gradient) to a maximum of 0.09. The sample population weighted mean vertical gradient was 0.05 and this was substituted into the Darcy equation. The results for each period are presented in Table 11. The downward leakage varied between 16 500 and 22 400 m^3/day over the first year of a no flow interval and reduced to 5400 m^3/day in the second year of a no flow event.

Table 11 Leakage from riverbed sand to older alluvium over no flow intervals

Year	**No. of wells**	**Mean depth below cease to flow** (m)	**Days**	**Time-weighted mean rate of decline** (mm/day)	**Leakage downwards** (m^3/day)
1979	7	1.7	212	13.1	16 500
1980	5	1.2	128	14.2	22 400
1981	5	1.1	245	11.0	20 500
1982	7	0.9	250	13.3	19 600
1983	7	4.4	273	3.7	5 400
1987	6	1.3	175	17.2	18 300

4.2.1.3 Groundwater flow in the riverbed sand

The groundwater throughflow in the riverbed sand depends on the watertable elevation. As the watertable declines, the throughflow volume declines. The groundwater inflow and outflow was calculated from the Darcy equation (6). The gradient is that of the cease to flow gradient 7×10^{-4} and the horizontal hydraulic conductivity assumed was 400 m/day. The length (L) for groundwater inflow was given by the width of a cross section at Rocky Pool. The length for the groundwater outflow calculation was given by the width of the river mouth below Water Supply Island. The thickness, b, is given by the saturated thickness of the riverbed sand which declines according to the time-weighted mean rate of decline. The inflow and outflow were calculated for each day from the Darcy equation using a spreadsheet and averaged to give the mean inflow and outflow for each period presented in Table 12.

The calculated inflow and outflow are several orders of magnitude less than other components of the water balance owing to the low hydraulic gradient. As the watertable drops below a certain level, storage in the riverbed sand consists of disconnected sub-surface pools and limited groundwater throughflow can occur. During the no flow intervals of 1981, 1982, 1983 and 1987 there was no groundwater outflow in the riverbed sand for a considerable part of, or all of the interval. During these intervals of no groundwater outflow, the migration of salt water upstream from the mouth of the river to the elevation of high tide would be anticipated in the riverbed sand.

Table 12 Groundwater throughflow in the riverbed sand over no flow intervals

Year	Groundwater flow in			Groundwater flow out		
	(m^3/day)	days	(% of total days)	(m^3/day)	days	(% of total days)
1979	330	212	(100%)	170	212	(100%)
1980	430	128	(100%)	160	128	(100%)
1981	260	245	(100%)	110	149	(61%)
1982	240	233	(93%)	110	139	(56%)
1983	0	0	(0%)	0	0	(0%)
1987	200	155	(89%)	50	82	(47%)

4.2.1.4 Abstraction from riverbed sand

The abstraction for each no flow interval is difficult to apportion between the riverbed sand and the older alluvium. Although recorded monthly, many wells have multiple screen intervals, and thus when a well is open to the riverbed sand and it is saturated, most water will be derived from it, as its hydraulic conductivity is generally several orders of magnitude greater than that of the older alluvium. However, only cumulative monthly totals are available for private wells for the 1980 period, thus it is not known from which wells, and hence which aquifer, the groundwater was abstracted. Using the year 2000 well construction records, the relative transmissivity of each screened interval from each well within Basin A was summed and the proportion derived from the riverbed sand, if saturated, was calculated. Within Basin A 34.4% of abstraction is derived directly from the riverbed sand. Within the Water Corporation wellfield the percentage was calculated from the production wells, excluding wells that came on line after each period. Thus a different percentage is required for each year for the Scheme wellfield.

The abstraction totals were tallied from the date of the initial measured head after flow had ceased to the date of the final head measured before flow recommenced. The abstraction from Basin A and the Scheme wellfields for each time period and the percentage of abstraction derived from the riverbed sand for each interval are presented in Table 13. Owing to the above estimates the volumes calculated are approximate, and may contain significant error over the interval of no flow.

Table 13 Groundwater abstraction over no flow intervals

Year	Abstraction total*		% derived from riverbed sand		Riverbed sand
	Basin A	Wellfield	Basin A	Wellfield	Abstraction total
1979	1 742 198	2 642 056	34.4	18.9	1 098 700
1980	1 141 630	2 320 111	34.4	18.9	831 200
1981	1 603 244	3 603 165	34.4	18.9	1 232 500
1982	2 364 451	4 321 995	34.4	17.5	1 569 700
1983	2 554 694	5 015 238	0	0	0
1987	2 846 576	3 499 335	34.4	15.7	1 528 600

*Source: Water Corporation

4.2.1.5 Rainfall recharge to riverbed sand

Rainfall recharge in semi-arid regions results from the direct infiltration of rainfall over the landscape and secondly from localised recharge where some surface flow occurs into local depressions that are not connected to draining watercourses (Simmers et al., 1997). Localised recharge is considered as significant as direct recharge within arid and semi-arid lands (Gee and Hillel, 1988). Direct recharge from precipitation is likely to be more significant for the riverbed sand, owing to its homogenous, coarse-grained matrix and relatively flat topography. Localised recharge is likely to be more significant over the older alluvium floodplain owing to the multitude of deflation clay playas and poor drainage, although direct recharge after rainfall on the floodplain alluvium of the Fortescue River was reported by Commander (1994a).

Only direct rainfall recharge will be considered for the riverbed sand in the watertable fluctuation analysis. The only documented watertable response to rainfall was conducted by Allen (1972). The rainfall from two cyclones that passed to the north of the Gascoyne region and occurred within weeks of one another was used to estimate direct recharge to the riverbed sand. The first, Cyclone Glynnis, delivered 38 mm of rainfall after 6 months of hot dry conditions with no flow in the riverbed sand and was insufficient to cause river flow or a rise in the watertable. The second, Cyclone Ingrid, delivered 40 mm of rainfall, which was insufficient to cause a river flow but did result in a rise in the watertable from a review of riverbed sand monitoring wells. Using an estimate of the area where there was a rise in the watertable, Allen (1972) calculated the percentage of annual rainfall that became recharge to the riverbed sand as 10% based on the following assumptions:

- recharge takes place after a threshold of 38 mm of rain has been received,
- rainfall occurs in one or two intense events, and
- rainfall replenishment takes place six months after a river flow in May, June and July and in areas where the watertable is 0.9 m or less below the surface (Allen, 1972).

Rainfall is recorded daily at five meteorological stations throughout the catchment, however the large spatial variability in rainfall, particularly summer rainfall, over such a large area introduces significant error to any recharge calculation. Mean rainfall from three separate meteorological stations within the lower catchment was used to calculate representative monthly rainfall totals. The three meteorological stations used were Carnarvon airport, Brickhouse Station and Gascoyne Junction.

Recharge to the watertable was applied using the 38 mm threshold detailed by Allen (1972), as it is the only reference on the amount of rainfall required to 'wet-up' the dry riverbed sand. Once the monthly total rainfall exceeded the threshold value of 38 mm the cumulative monthly rainfall in excess of this volume was calculated as recharge to the watertable. The only two no flow intervals when rainfall exceeded the threshold value were the 1981 and 1983 intervals. To determine recharge from rainfall the cumulative monthly rainfall above the threshold value was multiplied by the surface area of the riverbed sand. Using 10 or 20% of this cumulative figure as actual recharge to the watertable had little significance for the overall groundwater budget calculations, as the volume of rainfall that meets the criteria is small in comparison to the volume lost to downward leakage and evapotranspiration.

No allowance was made for localised recharge from runoff into the riverbed sand from the floodplain. Allen (1972) reported localised recharge to the riverbed sand east of Rocky Pool from observation and did not estimate localised recharge west of Rocky Pool.

Errors in estimating recharge in semi-arid and arid lands using conventional techniques will be high (Gee and Hillel, 1988). However, owing to the lack of direct measurements such as lysimetry or tracer tests of stable isotopes over the Gascoyne floodplain, few options were available for estimating recharge from rainfall over no flow intervals. Ultimately, the derived estimates of rainfall recharge had little impact on the estimated evapotranspiration loss from the watertable over no flow intervals.

4.2.1.6 Evapotranspiration from riverbed sand

Evaporation is the term used to describe the amount of water that passes into the atmosphere from open water bodies or bare soil surfaces. Evapotranspiration comprises two components:evaporation and transpiration from vegetation which is the water lost through the plant/air interface. Transpiration depends on vegetation type, density and site conditions. Along the Gascoyne River transpiration losses are dominated by the most common tree, the river red gum (*E. camaldulensis*). Site conditions that affect transpiration include climatic variables, landscape position, soil salinity, groundwater salinity and depth to the watertable (Borg and Giles, 1988).

The total leaf area of river gums was mapped using 1995 aerial photographs and was estimated at 4.3×10^6 m^2. The river gums were identified on vegetated islands in the main Gascoyne River channel and on the river banks, but do not survive on the floodplain away from a watercourse. From the distribution of river gums, it can be assumed that the groundwater stored in the riverbed sand is far more important in sustaining the river gums than local rainfall, and that the river gums will transpire far more than the annual rainfall received. However, from the tree density, it is apparent that the river gums are surviving in less than ideal conditions. Still, transpiration by the river gums is an important component of the groundwater balance along the Gascoyne River.

During no flow intervals, the components of equation (5) are solved for evapotranspiration, where a loss in storage is positive; that is, groundwater is lost from storage and gained to the flow system.

$$E = d_i + \Delta V + P - (d_o + a + L_D) \qquad (9)$$

The results, in cubic metres per day for each interval, are presented in Table 14. The evapotranspiration varies widely for each no flow period and is best correlated with the depth to groundwater during each period and, to a lesser extent, the duration of the no flow interval. The range in evapotranspiration from the riverbed sand in the first year of a no flow interval was 32 000 to 50 000 m^3/day. The lower limit occurred over winter and spring, while the upper limit coincided with summer months. These figures compare favourably with Allen (1972), who estimated evaporation losses of 23 600 m^3/day and transpiration losses of 21 000 m^3/day, using watertable recession monitored at Rocky Pool, but a specific yield of 0.25. In the second year of a no flow period, example 1983, average evapotranspiration from the riverbed sand was reduced to 1000 m^3/day. Volume lost to evapotranspiration during a no flow period is approximately 1.5 to 2 times greater than downward leakage from the riverbed sand to the older alluvium. Leakage downward and evapotranspiration are at least two orders of magnitude greater than groundwater throughflow (d_i and d_o) within the riverbed sand aquifer.

Table 14. Riverbed sand budget components for noflow intervals (m^3/day)

Year	Inflow d_I	Outflow d_o	Rainfall P	Storage ΔS	Leakage L_D	Abstraction A	Evapotranspiration E
1979	330	170	0	55 200	16 500	5 200	33 700
1980	430	160	0	78 800	22 400	6 500	49 900
1981	260	110	3 300	54 200	20 500	5 000	32 100
1982	240	110	0	67 700	19 600	6 300	41 900
1983	0	0	1 600	4 800	5 400	0	1 000
1987	200	50	0	75 000	18 300	8 700	48 100

4.2.2 River flow flownet analysis

During river flow, surface water quickly replenishes groundwater storage within the riverbed sand. The riverbed sand and older alluvium are hydraulically connected and the watertable configuration can be used in a flownet analysis. The flownet that was used in the groundwater balance analysis consists of the groundwater flow lines and watertable contours represented in Figure 25.

Classical flownets consist of flownet cells of similar dimensions with each having the same groundwater throughflow. The flownet developed for the water balance during this study consisted of graphically derived individual cells, each with a calculated groundwater throughflow, collectively forming a network of flow cells bounded by flowlines and watertable contours. The flownet cells were separated by a bounding groundwater divide drawn in the middle of the Gascoyne River and the ultimate flownet cells of each flow tube were left unbounded at a distance from the river course.

The watertable contours used for the flownet analysis were derived from non-synoptic waterlevels from all monitoring wells screened in the uppermost layer of the older alluvium, excluding production wells. A non-synoptic map was used owing to the distribution of monitoring through time; initially waterlevel data is concentrated at the western end of the wellfield and control was lacking around Rocky Pool. Groundwater levels within the riverbed sand were set at the cease to flow level to represent the aquifer when full, owing to limited monitoring data within the riverbed. The groundwater flow lines are drawn perpendicular to watertable contours to represent the direction of groundwater flow. Areas between the flow lines are referred to as flow channels, and the areas between each 2 m watertable contour and the bounding flow lines represents a flownet cell. The components for the groundwater balance are calculated for each flownet cell of Figure 25 and the results are presented in table format in Appendix C.

The amount of groundwater throughflow within each flownet cell of the older alluvium has been calculated by the two methods outlined by Davidson (1995). The first method is that of groundwater hydraulics using the Darcy equation, the second is a chloride mass balance based on the relative concentrations of chloride in river water, rainfall and groundwater.

4.2.2.1 Throughflow by groundwater hydraulics

The volume of groundwater outflow (Q_{DO}) for each flownet cell is given by the Darcy equation

$$Q_{DO} = kiA$$

where Q_{DO} = volume of groundwater passing through cell (m^3/day)

The saturated aquifer thickness for the riverbed sand was interpolated from the auger drilling survey of the riverbed sand. A mean thickness beneath the cease to flow level was calculated for each length of the riverbed sand within a flownet cell. The aquifer thickness for the older alluvium was interpolated from exploration, monitoring and production wells where Tertiary sediments were intersected by drilling. The concentration of data is skewed to the east of Nine Mile Bridge within the Scheme wellfield. Aquifer thickness for the older alluvium was calculated by subtracting the basement elevation (Fig. 7) from the watertable configuration (Fig. 18). The hydraulic gradients for each flownet cell were obtained by dividing the watertable contour

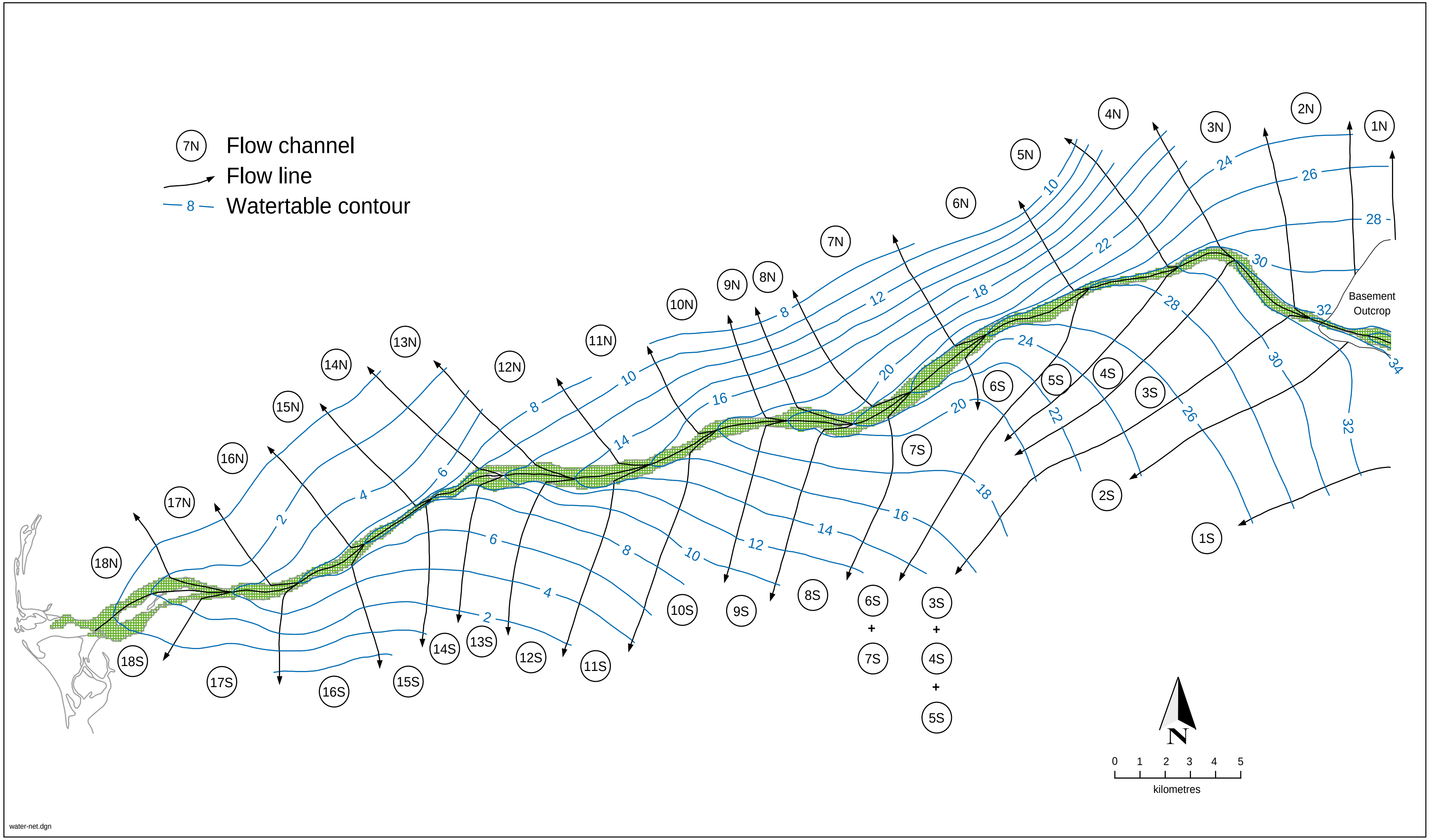


Figure 25 Watertable contours and flownet

interval by the mean difference between each contour. The section width of each flownet cell was measured directly from the flownet.

4.2.2.2 Throughflow by chloride mass balance

The volume of groundwater throughflow within each flownet cell (Q_{Clo}) was calculated using separate chloride mass balance equations for the riverbed sand and the older alluvium. For these two equations to represent recharge, the chloride within the groundwater flow system must be derived from two sources only, river water and rainfall. Chloride represents the most suitable environmental tracer as it is a solute for which there is no net change in amount (Kruseman, 1997). The chloride mass balance equation for the riverbed sand was adapted from the equations of Davidson (1995) and is given by:

$$Q_{Clo} = \frac{(A \times Cl_R \times k_V \times i) + (A \times P/365 \times Cl_P) + (Q_i \times Cl_I)}{Cl_O} \qquad (10)$$

where Q_{Clo} = groundwater outflow from each flownet cell (m^3/day)

A = area of riverbed sand (m^2)

Cl_R = chloride concentration in river water (mg/L)

k_V = vertical hydraulic conductivity of riverbed sand (m/day)

i = vertical gradient

P = rainfall (m/year)

Cl_P = chloride concentration in rainfall (mg/L)

Q_i = groundwater inflow to each flownet cell that is equivalent to the outflow of previous flownet cell given by the Darcy equation (m^3/day)

Cl_I = chloride concentration of inflow to flownet cell (mg/L)

Cl_O = chloride concentration in outflow from flownet cell (mg/L)

The chloride mass balance for the older alluvium is given by:

$$Q_{Clo} = \frac{(A \times P/365 \times Cl_P) + (Q_{Di} \times Cl_I)}{Cl_O} \qquad (11)$$

where Q_{Clo} = groundwater outflow from each flownet cell (m^3/day)

A = area of flownet cell (m^2)

P = rainfall (m/year)

Cl_P = chloride concentration in rainfall (mg/L)

Q_{Di} = groundwater inflow to each cell that is equivalent to groundwater outflow of previous cell given by the Darcy equation (m^3/day)

Cl_I = chloride concentration of inflow to flownet cell (mg/L)

Cl_O = chloride concentration of outflow to flownet cell (mg/L)

The analysis of the vertical groundwater flux between the riverbed sand and the older alluvium is made by comparing the flow calculated from the hydraulic method (Q_{Do}), with the flow calculated from the chloride mass balance equations (Q_{Clo}). The analysis is based on the assumption that the volumes of groundwater throughflow within each flownet cell (Q_{Do}), using the Darcy equation, are correct. The discrepancies in flow shown by the chloride mass balance (Q_{Clo}), obtained by using equations (10) and (11), indicate gains to and losses from the groundwater system. The chloride mass balance technique is applicable if the climate has remained fairly constant for many years (Davidson, 1995). The composition of oxygen-18 and deuterium in groundwater of the deeper aquifers of the Perth Basin – the southern extension of the Carnarvon Basin – is equivalent to present day rainfall, suggesting little or no palaeo climatic variability during the Holocene and Late Pliocene (Thorpe and Davidson, 1991).

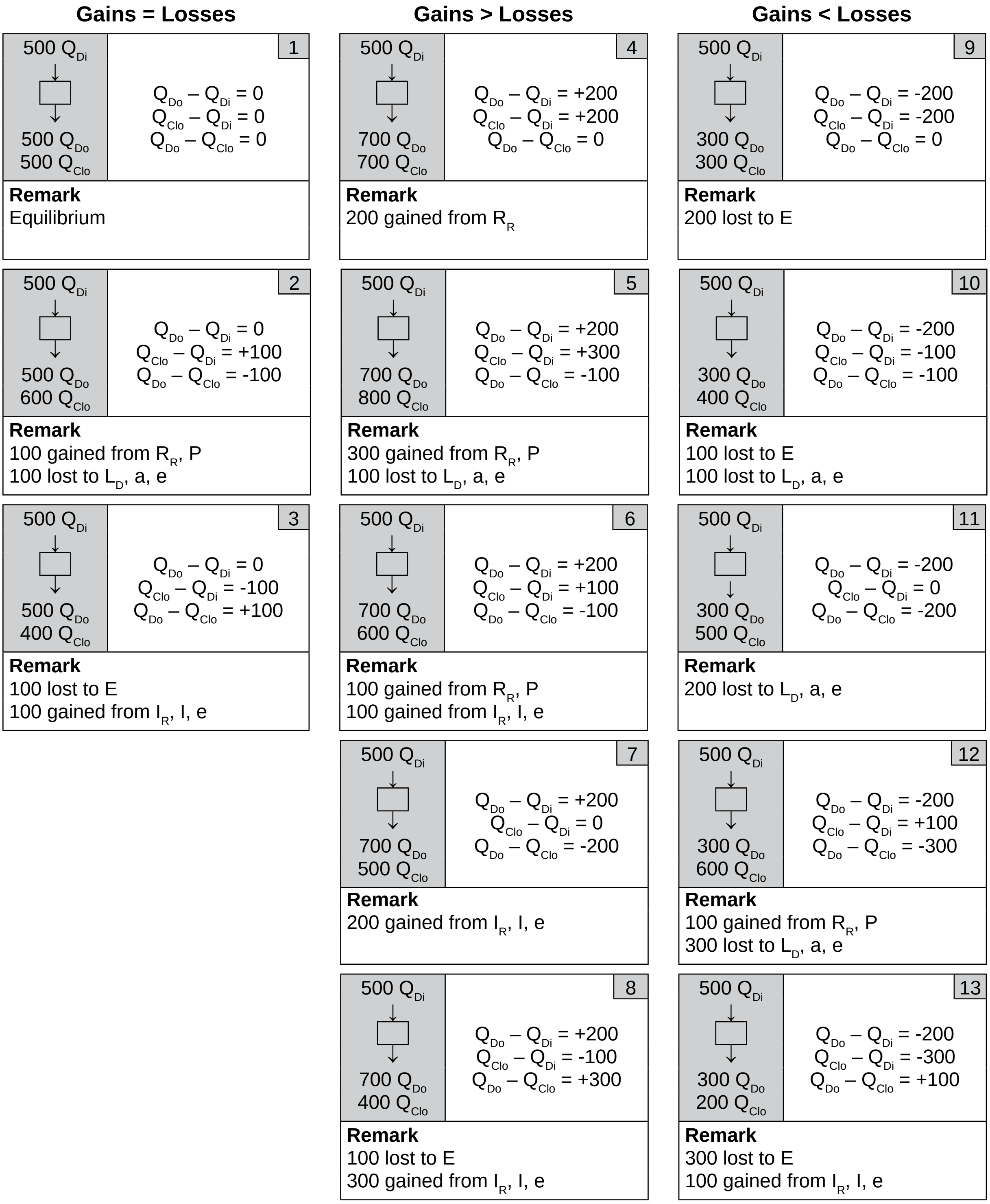
A reduction in the chloride concentration of groundwater across a flownet cell and a gain in throughflow by chloride balance ($Q_{Clo} > Q_{Di}$) suggest recharge by river flow. An increase in the chloride concentration and reduction in flow ($Q_{Clo} < Q_{Di}$) suggest that a net loss has occurred owing to evapotranspiration. When the throughflow from the chloride mass balance is greater than that from the Darcy equation ($Q_{Clo} > Q_{Do}$) groundwater has been lost from the flow system without any change to the chloride concentration. This can occur by downward leakage to an underlying aquifer or by groundwater abstraction.

With respect to Q_{Do} and Q_{Clo} flow, there are thirteen different flow combinations given by Davidson (1995). They were grouped into three main classes: gains equal to losses, gains greater than losses and gains less than losses as depicted in Figure 26. The superscript associated with each combination (Fig. 26) is given in the estimates for groundwater flow for each flownet cell in Appendix C. Equation (10) was anticipated to be sensitive to the values of Cl_P, Cl_I, Cl_O and Cl_R, and equation (11) to the values of Cl_I and Cl_O. These values, however, can be readily measured and extrapolated over the flow system. The value of each was discussed in detail in Dodson (2002).

4.2.2.3 Throughflow in the riverbed sand

The results of the flownet analysis for the riverbed sand are given in Appendix C, Table 1, and are based on the same hydraulic parameters and area as the watertable fluctuation analysis. The flownet analysis assumed that the watertable in the riverbed sand is maintained at the cease to flow level, and surface water is available to replenish losses from the riverbed sand. It was used primarily to estimate river recharge to the riverbed sand and downward leakage to the older alluvium after the riverbed sand had been filled, and the river continued to flow.

From the flownet analysis, groundwater throughflow in the riverbed sand is estimated at 8770 m^3/day (Table 1, Appendix C) when the watertable is at the cease to flow level. Groundwater outflow at the saltwater interface was given as 880 m^3/day at the cease to flow level. Evapotranspiration would be at the upper limit of potential as



Notes:

Q_{Di} = flownet groundwater inflow
Q_{Do} = flownet groundwater outflow
Q_{Clo} = groundwater outflow by chloride balance
R_R = apparent net recharge from river flow, rainfall
P = apparent net rainfall recharge to older alluvium
E = apparent loss by evapotranspiration
L_D ,a, e = losses (leakage downwards and out, abstraction, error)
I_R, I,e = gains (induced recharge/irrigation return, error)

Figure 26 Example flow combinations using aquifer hydraulics and chloride balance for the Gascoyne River (adapted from Davidson, 1995) water is readily available during river flow. The estimated maximum monthly summer evapotranspiration rate was 271 000 m^3/day. Groundwater abstraction from the riverbed sand was estimated at 6000 m^3/day.

When there is surface flow, recharge to the riverbed sand is rapid, as transmission loss is greatest within the first 24 hours of a flood wave passing, provided it is the first peak. When several flood peaks or spates occur, and the riverbed sand is already full, transmission losses are greatly reduced. When the river is flowing the riverbed sand constantly receives surface water and the recharge calculated from the flownet analysis represents the net recharge to the riverbed sand with the waterlevel at the cease to flow level; that is, river recharge less evapotranspiration and abstraction losses.

From equation (10), using an upper value of 200 mg/L for Cl_R, the mean of all chloride analyses from surface flow, the net recharge to the riverbed sand from the flownet analysis was 134 000 m^3/day; using the lower limit of 40 mg/L the net recharge is 28 400 m^3/day. Using the mean chloride concentration from peak flow analysis of 80 mg/L for Cl_R in equation (10) gives a net recharge of 54 800 m^3/day. Stage heights above the cease to flow level will give even greater recharge rates.

The groundwater loss from the riverbed sand by vertical leakage represents the groundwater inflow for the flownet analysis of the older alluvium and is controlled by the vertical conductivity and hydraulic gradient of the older alluvium. After the filling of the riverbed sand, the initial vertical leakage to the older alluvium is at a maximum, as the hydraulic gradient is at a maximum. After the initial high rate of recharge to the riverbed sand, the recharge rate reduces significantly as river flow continues. The leakage is greatest where the riverbed sand is thickest and is diminished over the duration of flow as the older alluvium begins to fill and the vertical hydraulic gradient is reduced, or the river stage height recedes. The recharge rate to the riverbed sand, less evapotranspiration and abstraction loss, is approximately equivalent to the leakage downwards to the older alluvium. That is, given an unlimited water supply from a river flow, the riverbed sand, once filled, can only recharge at the rate approximately equivalent to its losses to vertical leakage.

4.2.2.4 Throughflow in the older alluvium

The centre of the riverbed sand is assumed to represent a groundwater divide with groundwater flowing within the older alluvium to the north or south away from the mound. However, groundwater abstraction may alter the position of the groundwater divide dragging water from the north of the divide towards pumping wells in the south, shifting the groundwater divide further away from the pumping well.

South of the river

The area used for the flownet analysis south of the groundwater divide in the centre of the Gascoyne River is approximately 254 km^2. The saturated thickness of this area is not accurately known, but is mostly between 40 to 55 m and consists of clayey, sandy sediments with an estimated average hydraulic conductivity of 0.4 m/day. At the cease to flow level the leakage to the older alluvium south of the groundwater divide in the centre of the Gascoyne River is estimated at 31 970 m^3/day, or 60% of the total leakage from the riverbed sand (assuming Cl_R = 80 mg/L). With increasing time since river flow the rate of leakage to the older alluvium declines. The rate at which the older alluvium is recharged depends on the temporal variables of watertable elevation within the riverbed sand, which is influenced by ‘overfill’ above the cease to flow level during river flow, abstraction and evapotranspiration.

Recharge from precipitation to the older alluvium south of the river varied from negligible to 3.3% of annual average rainfall for individual flownet cells. This variation in recharge distribution reflects either the significance of localised recharge or error within the flownet analysis. The average daily recharge from rainfall was 1610 m^3/day, which is equivalent to 1.1% of total annual average rainfall for the floodplain south of the river.

Groundwater discharges from the older alluvium by throughflow, evapotranspiration, abstraction and vertical leakage down to the underlying Cardabia Calcarenite. Groundwater throughflow from the sum of the flownet cells was estimated at 8400 m^3/day, or 3.1 GL per annum. Groundwater abstraction from the older alluvium was estimated at 16 850 m^3/day. Vertical leakage out of the older alluvium south of the river varied from 10^{-3} to 10^{-5} m^3/day/m^2 for individual flownet cells, which equated to 11 250 m^3/day for the area, or 4.1 GL per annum. Evapotranspiration of groundwater from the older alluvium occurs adjacent to the Gascoyne River where the watertable is nearest the surface and is estimated to be 5840 m^3/day when the watertable is at the cease to flow level in the riverbed sand. This equates to less than 1 mm/day for the older alluvium over the river gum area south of the river, although individual flownet cells ranged from negligible to 5 mm/day.

North of the river

The area used for the flownet analysis north of the groundwater divide in the centre of the Gascoyne River is approximately 238 km^2. The saturated thickness and hydraulic conductivity of this area is similar to that of the area south of the river although it is not accurately known, as there is markedly less development within the Scheme wellfield north of the river. Recharge from the riverbed sand to the older alluvium north of the groundwater divide in the centre of the Gascoyne River was estimated at 20 920 m^3/day, or 40% of the total leakage from the riverbed sand.

Recharge from rainfall north of the river varied from negligible to 4% of annual average rainfall for individual flownet cells. The average daily recharge from rainfall was 1980 m^3/day, which is equivalent to 1.2% of total annual average rainfall. Groundwater throughflow by sum of the flownet cells was calculated at 14 900 m^3/day. Discharge via groundwater abstraction was 4430 m^3/day. Vertical leakage down and out north of the river varies from 1×10^{-3} to 1×10^{-5} m^3/day/m^2, or approximately 14 870 m^3/day for the area. Evapotranspiration of groundwater adjacent to the north side of the Gascoyne River is estimated to be 7280 m^3/day when the watertable is at the cease to flow level in the riverbed sand. The discrepancies between north and south of the river are attributed to the concentration of groundwater abstraction south of the river.

The groundwater budget components from the watertable fluctuation method, for riverbed sand during no flow intervals, and the flownet analysis, are used to confer with the groundwater model output to validate the model solution. The budget components are estimates and are used as indicative figures only. The river recharge from the flownet analysis is a maximum daily value at the cease to flow level, whereas the watertable fluctuation indicates how vertical leakage from the riverbed sand to the older alluvium diminishes over time with river flow.

4.3 Groundwater—ocean water interface

Groundwater within the floodplain discharges to the Indian Ocean. Because the groundwater underlying the ocean is saline, a wedge shaped interface is formed between the saline groundwater derived from the ocean and the fresh groundwater below the ground. The shape and movement of the interface depends on the hydrodynamics at the interface.

Groundwater abstraction from Water Supply Island impacted the hydrodynamics of this interface and caused the intrusion of saline groundwater. The result was the abandonment of the wellfield and several plantations on the north side of Water Supply Island. The Water and Rivers Commission monitoring network has few bores strategically located to detect the actual saltwater interface. However, the location and maximum allowable drawdown of the watertable within a well over the interface can be approximated from empirical equations.

The relationship between ocean and land derived groundwater is approximated by the Ghyben-Herzberg relationship, whereby the freshwater extends below sea level by about forty times the height of the watertable above sea level (Driscoll, 1966). The distance inland to which the saltwater interface extends can be approximated using a modified form of the Darcy equation (Todd, 1959)

$$L = \frac{\frac{1}{2}(\rho_o - \rho_f). \quad Tb}{\rho_f \quad\quad Q} \tag{12}$$

where L = distance inland of saltwater interface (m)

Q = groundwater flow to the ocean per metre of ocean front (m^3/day/m)

T = transmissivity of aquifer (m^2/day)

b = saturated thickness of the aquifer (m)

ρ_o = density of ocean water (kg/m^3)

ρ_f = density of fresh groundwater (kg/m^3)

Using estimates of transmissivity, aquifer thickness and discharge from groundwater flow through the older alluvium, and assuming the groundwater is of 500 mg/L TDS at the mouth of the Gascoyne River, equation (2) suggests that the saltwater interface extends approximately 2500 m inland within the older alluvium. If the interface is represented at the mouth of the Gascoyne River then the saltwater wedge would occur below the western third of Water Supply Island, which is approximately 500 m west of the westernmost plantation on the north side of the river.

Given that the mean sea level at Carnarvon is 0.865 m AHD and the elevation of the riverbed on the north side of Water Supply Island is 4 m AHD, the minimum depth to this interface is approximately 125 m below the watertable during river flow. However, a 3 m decline in head through groundwater abstraction over a no flow interval would see the interface rise significantly to just 5.4 m below the pumping induced waterlevel. Any greater decline in waterlevel would result in salt water intrusion into the pumping well.

These estimates are supported by monitoring well 70418301 (Fig. 43, p 175) located approximately 1 km to the northwest of Water Supply Island. The monitoring well has a TDS range between 10 000 and 16 000 mg/L and is screened between 6 and 12 m below mean sea level.

4.4 Groundwater chemistry

The chemical composition of groundwater in the Carnarvon area consists of sodium and chloride or bicarbonate water types, high in dissolved silica. The water chemistry was determined from the chemical concentrations of major ions within 40 groundwater samples. The samples were extracted from eight monitoring wells screened against discrete intervals, eight production wells screened against the partial or total aquifer thickness of the older alluvium and six multi-port wells with samples from three to five individual ports screened against discrete intervals within a single well.

The dominant cation species is sodium, while the dominant anion species are bicarbonate and chloride. In general, there is a reduction in concentration of calcium and magnesium with depth, and a corresponding increase in concentration of sodium, suggesting replacement of calcium with sodium in solution by ion exchange with clay minerals. There is a general increase in chloride with depth and lateral distance from the river.

Analysis of the monitoring and multi-port well data reveal that the chemical composition of groundwater along the direction of flow, changes from sodium bicarbonate type in recharge areas at the Gascoyne River, to sodium chloride type with increasing distance from the river. Within multi-port wells the same trend is established vertically, with the near watertable samples being sodium bicarbonate type and, with increasing depth, the dominant type is sodium chloride. Where there is an increase in bicarbonate rich water with depth from one port to another, recharge via lateral flow can be inferred as greater than flow via vertical leakage.

Water samples from scheme production wells after test-pumping, most of which were located along the river, indicated that the dominant chemical composition was sodium chloride or a mix of sodium chloride and sodium bicarbonate. Thus scheme production wells are drawing in both recharge water from the riverbed and older water from the surrounding floodplain. Groundwater flow in the older alluvium is probably reversed during production well pumping within high transmissivity sediments in connection with screen intervals.

Sampled groundwater is commonly low in phosphorus and nitrates but contains above average concentrations of fluoride and boron. The source of fluoride is the chemical weathering of Archaean greenstones and granitic pegmatite associated with the Yilgarn Craton in the upper catchment. Boron is present in the environment as borates and borosilicate minerals associated with salt deposits in saline lakes, and is commonly associated with saline hydrogeological conditions. Although boron levels are above water quality guidelines in some production wells within the scheme, it is diluted by water from the majority of other wells that have low boron concentration. However, private well operators who access only a small area of the aquifer for groundwater abstraction, may have problems with boron toxicity if the groundwater in their area is high in boron.

A simplified map of the chloride distribution within the older alluvium is presented in Figure 27, from which the salinity of groundwater can be interpreted. Small pockets of freshwater can be found in sandy intervals directly beneath and adjacent to the riverbed sand in Basin A. However, the water is generally brackish, ranging from 1000–6000 mg/L TDS. West of the Water Supply Island, the groundwater salinity increases to 10 000 mg/L, with proximity to the saltwater interface. Brackish groundwater can also be found directly beneath the riverbed sand where the older alluvium has poor hydraulic connection with the surface water owing to lenses of low permeability.

In the Scheme wellfield the extent of fresh groundwater in the older alluvium to the north and south of the river is far greater. West of Rocky Pool, groundwater with salinity less than 500 mg/L extends roughly 2 km, either side of the river, although brackish groundwater may be encountered within parts of this area. The deeper watertable in the older alluvium creates a greater vertical hydraulic gradient in comparison to Basin A. As a result, groundwater infiltrates into the older alluvium at a greater rate in the Scheme area than within Basin A, which may account for the lower salinity groundwater within the older alluvium to the east of Nine Mile Bridge.

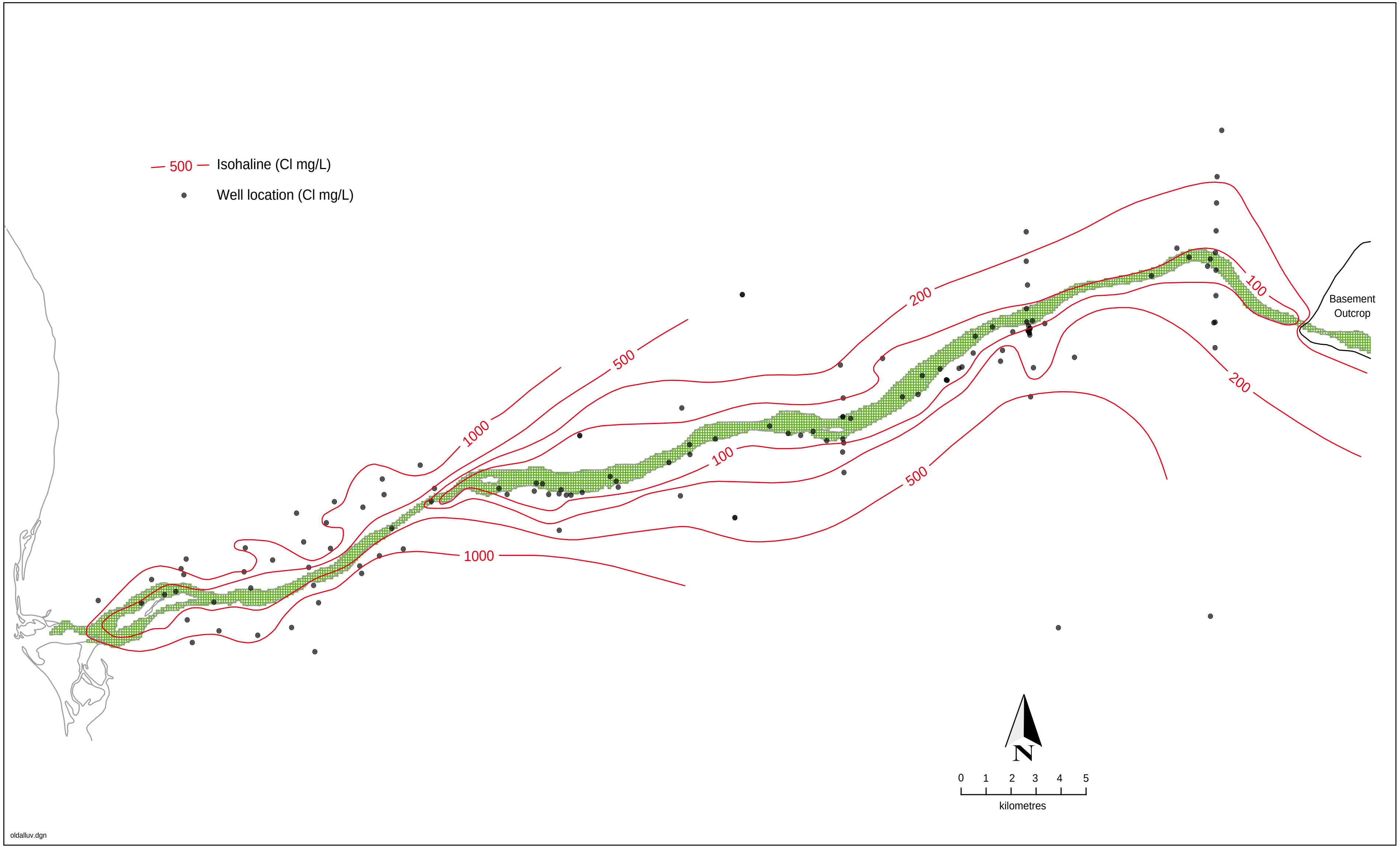


Figure 27 Chloride concentration in groundwater of the older alluvium

5 Groundwater flow model

A quasi, three-dimensional numerical model that is physically based, as much as possible, on the surface water-groundwater flow system of the Gascoyne River has been developed. The model utilises the United States Geological Survey finite-difference, block centered flow model code, MODFLOW96. The main purpose of the model was to estimate recharge to the groundwater flow system given different stage height and duration of flow along the Gascoyne River. Thus the model was designed to represent the dynamic watertable level given the temporal variations in stresses that impact the system, such as climatic variables, river flow stage and duration and abstraction volumes. Ultimately the model was used to predict the impact of increasing abstraction given historical flow events.

The conceptualisation of the Gascoyne River floodplain aquifer was performed by assembling all the available sub-surface information from water well and exploratory drilling, waterlevel monitoring and groundwater abstraction. This information was used to construct the nature of the sub-surface geology and hydro-dynamics for numerical representation. For a detailed explanation of the treatment of stresses and representation of the hydrogeological characteristics refer to Dodson (2002). A summary of the modelling results is presented here for comparison with the manual water balance calculations used to estimate flow volumes for the flow system. As such, the water budgets from the computer model, called GRFAMOD, are checks for the manual water balance and vice versa.

5.1 Computer code

The computer code selected was that of the United States Geological Survey finite-difference, modular groundwater flow model (MODFLOW96). MODFLOW96 is the industry standard for finite-difference groundwater modelling. The standard code was used with essentially no modifications, except to increase the dimension of the x array for reading in input data owing to the grid size and numerous layers of the model. The description of the code can be found in McDonald and Harbaugh (1988).

MODFLOW96 was selected

- for its ease of use with commercial pre-processing software,
- as it allows transient flow simulation,
- as it allows the simulation of temporal variations in river flow, evapotranspiration and groundwater abstraction,
- for its quasi 3-D representation of groundwater flow, and
- its wide-spread use and acceptance among groundwater scientists.

5.2 Model construction methods

5.2.1 Modelling rationale

There are two conceptual viewpoints to modelling groundwater flow, the aquifer viewpoint and the flow system viewpoint (Anderson and Woessner, 1992). The aquifer viewpoint is based on the concept of confined and unconfined aquifers, where a confined aquifer is overlain by a confining unit of lower permeability. Groundwater flow is assumed strictly horizontal in the confined aquifer and strictly vertical within the confining unit. The nature of the confining units in the older alluvium, highlighted by the review of 42 natural gamma logs, indicate that representation by the aquifer viewpoint was impractical. The thin, alternating sand and clay beds are too numerous, the sand beds being laterally discontinuous and spatially ill determined, for any attempt at an accurate representation by an aquifer viewpoint, other than the separation of the riverbed load from the floodplain older alluvium.

In the flow system view point, the identification of confining units and aquifers is secondary to the construction of the three-dimensional distribution of head, hydraulic conductivity and storage parameters everywhere within the flow system. This is the approach that has been adopted in the modelling of the Gascoyne River floodplain aquifer, referred to by the acronym GRFAMOD. GRFAMOD consists of nine layers representing a quasi three-dimensional approach. The vertical hydraulic gradient was recognised as significant, being several orders of magnitude greater than the horizontal hydraulic gradient. However, the confining beds are not explicitly discretised into individual layers but are approximated using a leakage term between the riverbed sand and the older alluvium and between arbitrary layers of the older alluvium itself.

The modelling rational needed to account for the temporal variability within stresses that impact the groundwater flow system, such as the ephemeral nature of the Gascoyne River and the variability in groundwater abstraction from the wellfields. Secondly, there are large variations in the volume of groundwater stored within the riverbed sand aquifer owing to these temporal variations, which would not be adequately represented using a steady state representation of an ephemeral river. Thus, with both time dependent stresses and large variations in storage, a transient flow model and historical stress data were required.

Owing to the large variation and unpredictable nature of ephemeral river flow, and the related demand for groundwater over no flow intervals, GRFAMOD has not been applied to predict future events, or steady state conditions. Rather GRFAMOD’s purpose was to simulate the transient historical events to predict the volume of recharge resulting from the interaction between surface water and groundwater and the temporal variations that impact this interaction. The aim was to give resources managers greater confidence and understanding of the impact of this temporal variability to allow the maximum sustainable yield of the groundwater flow system to be allocated.

The transient groundwater flow model can be used to estimate the watertable response, given the temporal variation in groundwater abstraction, monthly rainfall, potential monthly evapotranspiration and river stage height. A stress period is an interval of time where the above external stresses are applied to the simulation at a constant rate. The unit of time is days and the unit of length is metres. Although the unit of time is days, the stresses are applied in intervals of one month duration. For example, a constant abstraction rate in m^3/day for a particular well is applied for one month, an average monthly stage height is estimated for the river package for each stress, evapotranspiration is estimated from monthly pan evaporation and so on.

Output from one model (i.e. waterlevels) was used as input for the next where the model intervals followed on. The model intervals are separated into flow and no flow intervals. Each model interval has a series of stress periods that correspond to a month of the year; the number of months in a model is determined by the length of the flow and no flow intervals. In this manner the relationship between recharge volume and the effect of aquifer depletion, flow magnitude and duration could be compared using individual flow events.

A stress period may have numerous ‘time steps’ within its length. The time step length is determined on an exponential scale, so that early intervals are short in comparison to later intervals. Time steps are necessary where an external stress may create rapid change within the groundwater flow system. As an example, the change in head in the aquifer, as a result of a river flow, occurs within hours. Numerous time steps can allow the discretisation of calculations into hours at the beginning of a stress when rapid changes are occurring rather than one calculation for the length of the stress period.

The representation of infiltration due to stream flow has taken into account the following features of river flow, the riverbed and the sub-surface:

- magnitude and duration of flow passing over the aquifer,
- intervals between events,
- dimensions and slope of the riverbed,
- hydraulic conductivity of the bed and sides of the channel,
- degree of saturation before onset of flow,
- evaporation and transpiration from riverbed,
- recent alluvium volume,
- effective channel area,
- depth of watertable in the aquifer, and
- hydraulic properties of the aquifer.

5.2.2 Model grid and layers

The model area is 652 km^2, of which 28.7 km^2 represents the course of the Gascoyne River. The model grid covering this area consists of a block centred finite-difference mesh of 550 columns and 230 rows. The row and column spacing is uniform throughout the model, each cell being 100 m square. Representation at this scale was necessary to account for the differences in stage height from one river flow to the next. This grid scale over the river made it possible to represent small flows by minimising the number of river cells actually receiving surface flow.

The vertical thickness of the floodplain aquifer is arbitrarily divided into eight separate layers approximately 5 m thick or greater, plus a ninth layer representing the uppermost riverbed sand. The layers are used to represent the spatial distribution of horizontal and vertical hydraulic conductivity, and changes in head with depth. The upper layer consists of 2865 cells that map out the approximate course of the Gascoyne River captured from the 1:100 000 Carnarvon (1975) and Doorawarrah (1974) topographic map series.

As the potentiometric head decreases with distance from the river the area of active cells in each layer changes. Layer 2 directly underlies the riverbed sand and has fewer active cells than Layer 3 as the potentiometric head falls below the bottom of Layer 2 with distance from the river. Owing to the thinning of the older alluvium around Rocky Pool, the number of active cells in this region also changes with each layer. The model grid is represented in Figure 28.

5.2.3 Digital files for modelling

Representation of the basement geological structure, watertable elevation and potentiometric surface was performed using contours of equal elevation or potential. The contours of the basement geological structure and potentiometric head for the multiple layer representation of the older alluvium were manually constructed by proportional triangulation between data points. The manually constructed contours were then digitally captured and output into standard ascii text format for input into Golden Software's SURFER© v7 data interpolation software. SURFER© is a grid based graphics program that interpolates irregular spaced XYZ data into a regularly spaced grid using kriging. The riverbed sand basement was represented from computer generated data interpolation using kriging of the 100 x 100 m auger drilling survey of the river bed.

5.2.4 Boundary conditions

The boundary conditions for each layer are represented by two-dimensional integer arrays that specify the boundary condition code. The boundary conditions represent the mathematical statements specifying the dependent head at the boundaries of the model grid. In a transient simulation, boundary conditions only influence the solution when the effects of a stress reach that boundary (Anderson and Woessner, 1992).

The northern and southern hydrologic boundaries for the study area are difficult to define due to a lack of monitoring data. Waterlevels were monitored in three transects of nested and multi-port piezometers aligned north-south, either side of the Gascoyne River (Figs 19,20 and 21), between December 1989 and July 1990; during this time

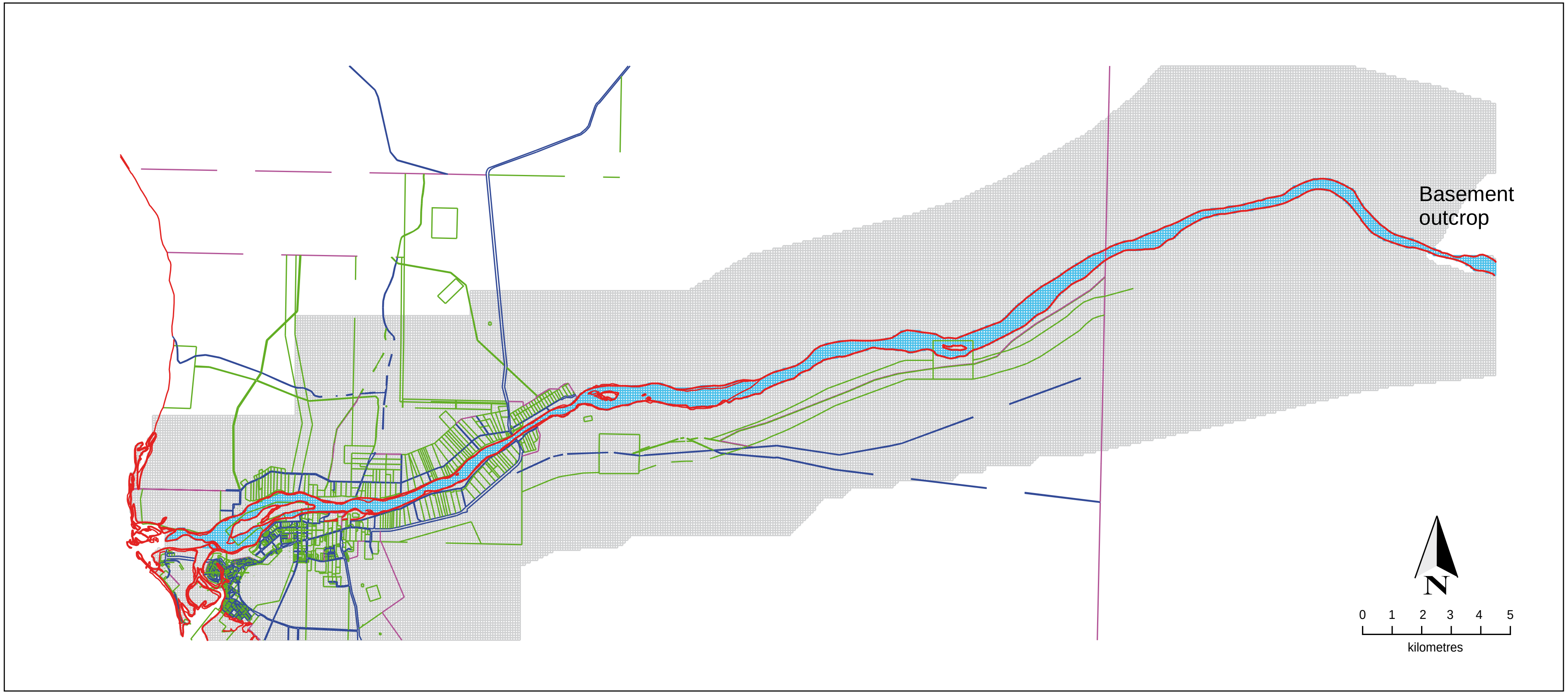


Figure 28 Finite-difference grid of model area

the river flowed from February to March (after Martin, 1990b). The response to river flow was greatest near the river but diminished with distance, and beyond 1500 m there was no discernible response to river flow within the older alluvium three months after the flow event (Martin, 1990b).

Monitoring of multi-ports 1500 m from the river over a six-year period resulted in fluctuations in watertable levels from 0.43 to 2.21 m in the south of the river, and between 1.24 and 1.47 m in the north of the river. The depths to waterlevel from the surface vary between 16 m in the south of the river, and 21 m in the north of the river. These depths are beyond the influence of evapotranspiration from the low woody scrub and spinifex, therefore the watertable fluctuations are in response to river flow or groundwater abstraction. Consequently, the model boundaries were set 4 km north and south of the river and principal area of groundwater abstraction. These boundaries are arbitrarily set far from the centre of the grid to prevent the main stresses (river flow and abstraction) from reaching them.

There are three types of mathematical conditions that approximate physical or hydrological boundaries: specified head, specified flow and head dependent flow boundaries. Where a model boundary could be aligned parallel with the watertable configuration, specified head boundary conditions are employed, i.e. the model edges are given a constant head, as the boundaries are sufficiently distant and not influenced by river flow events. Where a model boundary could be aligned perpendicular with the watertable configuration a specified flow boundary was employed. The flux is given as zero, ie, no flow, as would be anticipated by the direction of groundwater flow parallel to the boundary, but not across the boundary.

The western boundary occurs at the coast where the Indian Ocean intersects the watertable. This boundary is approximated by a specified flow boundary condition where the flux is zero (noflow boundary). This assumes upward flow at the zone of dispersion between freshwater and saltwater. When diffusion of sodium chloride is neglected and the salty groundwater seaward of the interface is assumed to be static, the freshwater-saltwater transition zone is treated as a sharp interface to form the boundary of the fresh groundwater flow system (Bear and Verruijt, 1987).

The eastern boundary at Rocky Pool consists of no flow conditions where the basement is near surface or outcrops, and head dependent flow in the south where throughflow from the older alluvium to the east is anticipated.

5.2.4.1 Re-wetting boundary condition

Model cells that fall along the course of the river are treated as a general specified head boundary. In this instance the general specified head boundary occurs where the head in the river during any flood event is given by river stage, as the stage is independent of head within the groundwater system at the onset of river flow. Upstream and downstream the head changes with time as a function of stream flow and elevation of the riverbed. Surface water heads are specified only for the duration of a river flow event by application of MODFLOW96's RIVER package (McDonald and Harbaugh, 1988).

The riverbed sand may de-water after extended periods of no flow owing to the effects of vertical leakage, groundwater abstraction and evapotranspiration. The output head array of layer 1 from a no flow simulation is used as a template to create an integer array of the new boundary conditions for the de-watered cells in the layer for the next modelling interval. Cells that have been converted to dry are specified as no flow, while still wet cells are specified as head dependent flow. The new integer array is then read as the layer 1 boundary conditions for the following model interval.

As the re-wetting option is 'on' for all cells in layer 1 during a flow interval MODFLOW96 will convert any no flow cells that meet the re-wetting criteria to head dependent flow cells. For no flow intervals the cells that are dry at the beginning of a simulation will remain dry as is anticipated when no recharge is occurring. This may negate, to some extent, recharge from rainfall on the riverbed sand during no flow events. However, as seen in the watertable fluctuation analysis over no flow intervals, the impact of rainfall is generally minimal unless sufficiently large enough to create surface flow.

5.2.5 Hydraulic parameters

5.2.5.1 Layer codes and storage properties

The layer code determines whether a model layer is confined (0), or unconfined (1), or a combination of confined/unconfined (2 and 3) a definition of each code is given in McDonald and Harbaugh (1988). The older alluvium has been represented as a multiple layered aquifer with confining clay beds represented by low vertical conductance between layers. Thus layers 3 to 9 in the older alluvium are confined beneath an upper layer. Layer 2 is confined by the uppermost clay layer within the older alluvium that is arbitrarily represented by the base of the riverbed sand.

The storage property of layers 2, 3 and 4 depend on the head of each layer and will convert to an unconfined specific yield if the waterlevel drops below the level of the confining layer. For such layers both a specific yield and storativity value must be given. For layer 1, which is unconfined, only a specific yield is given. For layers 5, 6, 7, 8 and 9 only a storativity value is given as these layers are treated as confined only. Martin (1988a and b) estimated the storage coefficient from pumping-test analysis of two production wells as 6×10^{-4} and 5×10^{-4}. The storage coefficient was reported from five pumping-tests conducted by Allen (1972) and ranged between 1.3×10^{-3} and 5×10^{-3}. The specific yield of the older alluvium could not be determined from pumping-test analysis but was represented as 0.1, assuming a sand to clay ratio of 1 to 4 and a specific yield of 0.2 for the sand and 0.08 for clay (Martin, 1990b). The values for storage properties are given as a single parameter value as opposed to a two-dimensional array and are presented in Table 17. Representation of the flow system view requires the upper limit of specific yield to be applied to represent sandy layers between the confining clay beds of low conductivity.

5.2.5.2 Hydraulic conductivity

The range in horizontal hydraulic conductivity of each layer was estimated after consideration of pumping-test analysis, natural gamma logs and the groundwater balance. The ranges in hydraulic conductivity are presented in Table 15. Hydraulic conductivity values are consistent with the aquifer pumping-test results that ranged from 1 to 300 m/day for the older alluvium, and 50 to 2000 m/day for the riverbed sand.

Table 15 Hydrogeological properties for GRFAMOD

Layer	Code	Hydraulic conductivity (m/day)	Transmissivity (m^2/day)	Vertical conductivity (m/day)	Storage co–efficient		Aquifer
					Sy	Ss	
1	1	40–400	–	0.4–4	0.30		Riverbed sand
2	3	10^{-1}–100	–	10^{-3}–1	0.25	10^{-3}	Older alluvium
3	2	10^{-2}–100	0.5–500	10^{-3}–10	0.18	10^{-3}	Older alluvium
4	2	10^{-2}–10	0.5–50	10^{-3}–10	0.18	10^{-3}	Older alluvium
5	0	10^{-2}–10	0.05–50	10^{-3}–1	–	10^{-3}	Older alluvium
6	0	10^{-2}–10	0.05–50	10^{-3}–1	–	10^{-3}	Older alluvium
7	0	10^{-2}–10	0.05–50	0–1	–	10^{-3}	Older alluvium
8	0	10^{-2}–10	0.05–50	0–1	–	10^{-3}	Older alluvium
9	0	10^{-3}–10	0.01–200	0–10	–	10^{-3}	Older alluvium

The riverbed sand was considered homogenous and isotropic; it was assigned a uniform hydraulic conductivity of 400 m/day, although the vegetated sand bars were reduced by one order of magnitude to account for silt entrapment by tree roots. The older alluvium was divided into eight separate layers. The older alluvium was considered heterogeneous and anisotropic, the thickness of which was arbitrarily set by equidistant horizontal planes at the same dip as the surface topography, excepting layer 2 which was made thicker to avoid de-watering, and layer 9 the thickness of which was impacted by the depth to basement. The hydraulic conductivity was represented by a range from 10^{-2} to 10^{2} m/day. Within any one layer of the older alluvium the hydraulic conductivity may vary by four orders of magnitude. Buried river 'channels', similar in dimension to the modern Gascoyne River, connect sand intervals of individual layers within the older alluvium. Each layer could have more than one sand 'channel' which were extrapolated from down-hole geological logs, geophysical logs and well yields. High hydraulic conductivity (10-100 m/day) were assigned to layer cells that corresponded with the screen interval of large yielding production wells.

As the lower layers (layers 3–9) of the older alluvium are confined, as realised by the potentiometric head with depth, the horizontal hydraulic conductivity is multiplied by the cell thickness to give a two-dimensional array of the layer transmissivity which is then read by MODFLOW96. The range in transmissivity for each layer is given in Table 15. Layer 9 transmissivity is much greater than upper layers owing to a greater thickness.

The vertical hydraulic conductivity for the entire profile was estimated by measuring the concentration of tritium in groundwater, and by an empirical groundwater balance technique (Martin, 1990b). These results gave a vertical hydraulic conductivity range between 0.011 and 0.03 m/day, respectively. Assuming a vertical conductivity of 10^{-2} m/day and a mean horizontal conductivity of 10^{-1} m/day, gives a horizontal to vertical anisotropy of roughly 10:1 in the older alluvium. The vertical leakance between two layers is given in MODFLOW96 by the following equation

$$Kv = \frac{1}{\left(\dfrac{d_{ijk}/2}{Kv_{ijk}} + \dfrac{d_{ijk+1}/2}{Kv_{ijk+1}} \right)} \qquad (12)$$

where Kv = vertical conductance between layers k and k+1
d_{ijk} = thickness of cell ij of layer k
d_{ijk+1} = thickness of cell ij of layer k+1
Kv_{ijk} = vertical conductivity in cell ij of layer k
Kv_{ijk+1} = vertical conductivity in cell ij of layer k+1

(ijk notation represents row i, column j and layer k of the model grid)

The actual vertical leakage depends on the vertical conductivity of each individual clay and sand layer within the older alluvium. However, in GRFAMOD not every individual clay bed could be adequately represented and thus the vertical leakance term between layers represents only a crude estimate. When many clay beds exist in a single layer the real vertical leakance becomes infinitely small. Where multi-port piezometers indicated barriers to the vertical flow of groundwater between layers in some areas, zones of non-continuous, zero vertical leakance were set between layers within these areas during the calibration process on a trial and error basis.

5.2.6 Model stresses

The three principal stresses on the groundwater flow system are river flow, evapotranspiration and groundwater abstraction. Rainfall is the fourth stress represented but is considered of minor significance in comparison to the other three. The mathematical representation of each stress is detailed below.

5.2.6.1 River flow

The Gascoyne River is an ephemeral river. Its surface flow varies significantly in magnitude and duration. As the watertable lies below the river bottom, surface flow is a source of recharge for the riverbed sand and underlying older alluvium aquifer.

However, large stage heights result in temporary storage of water above the cease to flow level of the river. As the river subsides, this water is released back to surface flow, as represented by the apparent flow gains between gauging stations (Fig. 11). This model of surface flow has been conceptualised in Figure 12. A system of rules for determining whether flow is directed into the riverbed sand aquifer, as in the initial stage of river flow, or out of the aquifer, as in the later stages of river flow, utilising the MODFLOW96 river package.

The MODFLOW96 river package utilises a head dependent boundary condition to compute the volumetric flow between the surface water feature and the aquifer (McDonald and Harbaugh, 1988). The flux is dependent on the head difference between aquifer and river stage height multiplied by a constant that represents the conductivity of the riverbed material. The equation is given by:

$$Q_{riv} = C_{riv} (H_{riv} - H_{ijk}) \qquad (13)$$

where Q_{riv} = flux (volume of water) for cell ijk (m^3/day)

C_{riv} = KLW/M (m^3/day/m)

K = vertical conductivity of riverbed material of cell ijk (m/day)

L = length of cell ijk (m)

W = width of cell ijk (m)

M = thickness of cell ijk (m)

H_{riv} = head in the river for cell ijk (s + C_{TF}) (m)

s = height of river flow (stage) (m)

C_{TF} = cease to flow level of cell ijk (m)

H_{ijk}= head in the cell ijk receiving surface flow (m)

This boundary allows representative conditions to be simulated where the aquifer potentiometric head is below the river bottom. When such a condition is established the vertical head gradient of the saturated connection must be approaching unity; any lowering of the watertable will not increase this gradient. Thus when the watertable is below the elevation of the riverbed sand aquifer, given as R_{bot}, the head in the cell can be given by the elevation of the riverbed sand, as the downward seepage of water is independent of the head in the aquifer. The relative elevations of R_{bot} and H_{ijk} become a limiting condition of flux. For a detailed explanation see McDonald and Harbaugh (1988). Hence equation (13) is represented by MODFLOW96 as the following equation set

$$Q_{riv} = C_{riv} (H_{riv} - H_{ijk}),\ H_{ijk} > R_{bot} \qquad (13a)$$

$$Q_{riv} = C_{riv} (H_{riv} - R_{bot}),\ H_{ijk} \leq R_{bot} \qquad (13b)$$

These conditions assume a low conductivity riverbed matrix that limits flow. However the Gascoyne River represents the opposite, the riverbed sand matrix having a hydraulic conductivity that may be several orders of magnitude greater than the hydraulic conductivity of the underlying older alluvium aquifer. The riverbed sand aquifer is an unconfined aquifer and is represented as such in MODFLOW96 by not having an upper limit for head. When recharge from a river flow occurs into a high hydraulic conductivity layer overlying a low hydraulic conductivity layer, the result is heads that are too high in the uppermost layer of the model. Furthermore, only a large river flow stage (> 2 m) will fill the Gascoyne River from bank to bank as the surface is irregular with elevated sand bars and some vegetated islands; hence, small stage heights will see surface flow occur over part, but not all, of the riverbed sand aquifer. The high hydraulic conductivity ensures that, with time, the riverbed sand will fill to the stage height of the river flow, but cannot exceed that level.

For MODFLOW96 to approximate these conditions this research has formulated a system of rules for selecting whether the limiting condition should be a combination of R_{bot} and H_{ijk} or H_{riv} and H_{ijk} for equations 13a and 13b. These rules ensure the riverbed sand will fill to the equivalent of the stage height of the river flow, but no greater. The relative elevations of the cease to flow level plus stage height versus the elevation of the riverbed sand determine whether a model cell will receive river flow or not. The cell with the lowest elevation in each column is assumed to receive surface flow over it. If the cell with the lowest elevation in a column has an elevation greater than the head in the river, then the stage plus the elevation give the head in the river. This assumes that the momentum of surface flow can overcome small rises in the riverbed elevation. Otherwise the head in the river will equal the cease to flow level plus the stage. In this manner, the simulation can adequately represent the saturated surface area of river flow, given a stage height.

Other cells in a column not identified as the lowest in surface elevation will receive surface flow only if their elevations are less than the head of the river. If this is true the model will calculate flow as above. However, if the elevation is above the cease to flow level plus the stage, and the cell is not the lowest cell in a column of cells, then, rather than selecting R_{bot} and H_{ijk} as the limiting condition for the equation set (13a and 13b), the value of H_{riv} and H_{ijk} is selected. Thus, equation 13a and 13b can be expanded to

$$\text{where} \quad H_{riv} \geq R_{bot} \quad Q_{riv} = C_{riv}\,(H_{riv} - H_{ijk}),\ H_{ijk} > R_{bot} \qquad (14a)$$

$$Q_{riv} = C_{riv}\,(H_{riv} - R_{bot}),\ H_{ijk} \leq R_{bot}, \qquad (14b)$$

and

$$\text{where} \quad H_{riv} < R_{bot} \quad Q_{riv} = C_{riv}\,(H_{riv} - H_{ijk}),\ H_{ijk} > H_{riv} \qquad (14c)$$

$$Q_{riv} = C_{riv}\,(H_{riv} - H_{riv}),\ H_{ijk} \leq H_{riv}, \qquad (14d)$$

This set of conditions is represented graphically in Figure 29 and ensures that no flow will be received from the river package into a cell of the riverbed sand if its elevation is too great for surface flow to occur. It also ensures that if the head of a cell in the riverbed sand reaches the elevation of the stage height plus cease to flow level (H_{riv}) as a result of groundwater flow from adjoining cells, the head in that cell cannot exceed the cease to flow plus stage height. These rules then satisfy the physical system as surface flow recedes and storage from the riverbed sand above the stage height is released back to surface flow.

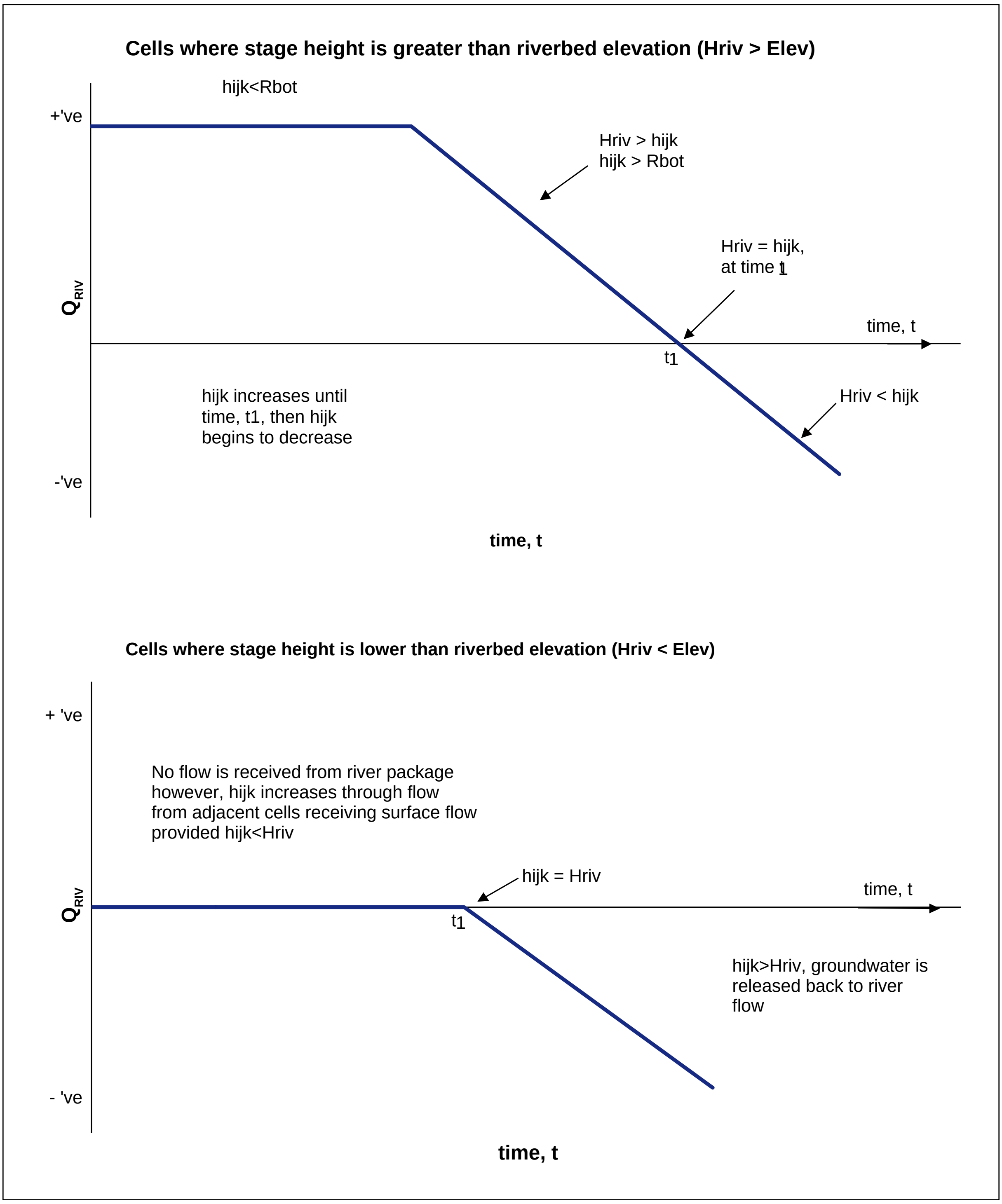


Figure 29 Graphical representation of river package limiting conditions (adapted from McDonald and Harbaugh, 1988)

5.2.6.2 Evapotranspiration

Evaporation and transpiration are simulated in MODFLOW96 by the evapotranspiration package. This package uses head dependent boundary conditions to determine the volume of water lost to evapotranspiration. A maximum evapotranspiration rate (pan evaporation multiplied by the pan coefficient) is determined for each month and applied to cells that could discharge groundwater owing to evapotranspiration. Water loss through evapotranspiration does not always proceed at the pan evaporation rate since this depends on a continuous water supply. The eventual evapotranspiration rate applied in MODFLOW96 varies linearly with the depth to the watertable according to the following equation set (McDonald and Harbaugh, 1988).

$$
\begin{aligned}
R_{evt} &= P_{ET} && \text{, when, } h \geq E_s \\
R_{evt} &= \frac{P_{ET}\left(h - (E_s - d)\right)}{d} && \text{, when, } E_x \leq h < E_s \qquad (15) \\
R_{evt} &= 0 && \text{, when, } h \leq E_x
\end{aligned}
$$

where R_{evt} = evapotranspiration rate (m^3/day)
P_{ET} = maximum rate (potential evapotranspiration) (m^3/day)
h = head in cell (m)
E_s = evaporation surface (m)
E_x = extinction depth (m)
d = $E_s - E_x$ (m)

Hence the rate of evapotranspiration is equivalent to the maximum potential rate when the watertable is at the evaporation surface. It diminishes linearly with depth until the extinction depth, at which point the rate is zero. In this study the extinction depths given were set arbitrarily, and varied on whether the cell represented an evaporation point or transpiration point.

A literature review of transpiration from *E. camaldulensis* gave estimates of water use per day per unit leaf area. Many of the studies were concentrated on plantations over a shallow saline watertable that were recharged by rainfall, and were not directly transferable to a riparian environment. The extinction depth however, should be a function of tree root depths and their ability to draw groundwater. The rooting depths of *E. camaldulensis* and *E. victrix* along Barnett Creek in the Pilbara region using the natural abundance of deuterium was estimated at 20 m (Landman, 2000). However, a numerical model of surface water – groundwater interaction in support of a mining proposal in the Pilbara region used an extinction depth of 2 m below the maximum evapotranspiration surface, which was 2 m below a steady state derived watertable (Middlemis, 2000). Given the simplified linear model of evapotranspiration rate with depth presented in MODFLOW96, and the availability of groundwater from the shallow riverbed sand, the extinction depth for transpiration used in GRFAMOD is 4 m. In modelling representation of similar ephemeral river environments in the Pilbara region of Western Australia by Middlemis (2000), the extinction depth applied for evapotranspiration was 4 m.

The volume of evaporation over the bare riverbed sand is significant given the area of the riverbed sand, in comparison to the transpiration from trees. Allen (1972) recorded measured heights of the capillary fringe above the watertable and he estimated that the watertable has to be at least 60 cm below the surface to exclude loss to evaporation. The extinction depth for evaporation cells in GRFAMOD is 0.6 m below the surface.

The maximum evapotranspiration rate for each cell is given in a two-dimensional array for each month based on the pan coefficients from Table 16 determined from the FAO-24 radiation method described by the Food and Agriculture Organisation (1984). Each array is then multiplied by the average monthly pan evaporation rate at Carnarvon. Another two-dimensional array gives the layer number that the flux volume is to be subtracted from, layer 1 for the riverbed sand and layer 2 for the older alluvium. The evaporation surface and extinction depths remain constant and are given by separate two-dimensional arrays.

Table 16 Pan evaporation and potential evapotranspiration rates (mm/day)

Month	***Pan evaporation** Ep		***Relative humidity** %	***Mean wind run** (m/sec)	**FAO-24 potential evapotranspiration** (P_{ET})	**Pan coefficient**
	Carnarvon	Brickhouse	R_h		Carnarvon	C
Jan	10.0	12.1	0.58	7.1	7.02	0.70
Feb	9.8	12.1	0.58	6.5	6.89	0.70
Mar	8.7	10.2	0.57	6.1	5.66	0.65
Apr	6.6	7.4	0.56	4.8	4.96	0.75
May	5.0	5.4	0.55	4.0	3.79	0.76
June	3.7	3.7	0.61	3.5	2.95	0.80
July	3.7	3.7	0.60	3.7	2.97	0.80
Aug	4.8	4.7	0.57	4.5	3.61	0.75
Sept	6.6	6.8	0.52	5.7	4.94	0.75
Oct	8.1	8.6	0.51	6.7	5.88	0.73
Nov	9.1	10.2	0.53	7.3	6.44	0.71
Dec	9.9	11.9	0.58	7.4	6.85	0.69

*Source: Bureau of Meteorology

5.2.6.3 Groundwater abstraction

Basin A consists of 155 assessment areas that are allocated to a licensee to abstract groundwater. An assessment area is the area in which it is permissible for the licensee to sink a well for the abstraction of groundwater. Each assessment area may have numerous licensed abstraction wells. Groundwater wells may be shallow spears, PVC cased wells, large diameter shallow wells or a combination of all (Fig. 30). Most of Basin A's wells are located within the Gascoyne River and are abstracting groundwater from the riverbed sand and the older alluvium. In the last decade, Basin A has supplied between 40 and 65% per annum of the total volume of groundwater abstraction, yet constitutes less than one-third of the total abstraction area.

Groundwater abstraction is regulated by the Commission through the issuing of licences with an allocation limit. As part of the licence agreement the Water Corporation records monthly abstraction data in kilolitres for individual production wells of the water supply network. Private well meters are also read monthly to record abstraction figures.

Each Water Corporation production well and each assessment area is given a row and column number from the model grid that approximates its location. Each scheme well and assessment area also needs a layer number, however many wells have multiple screens or screen lengths that are open to more than one layer of the model. The discharge from a multi-layer well is divided among these individual layers. The well discharge is apportioned by the transmissivity of each individual layer according to

$$\frac{Q_k}{Q_w} = \frac{T_k}{\sum T} \qquad (16)$$

where Q_k = discharge from layer k (m^3/day)

Q_w = total well discharge (m^3/day)

$\sum T$ = sum of transmissivity of each layer (m^3/day/m)

T_k = transmissivity of layer k (m^3/day/m)

In Basin A the monthly abstraction records for each assessment area do not indicate which well was operational when more than one well is licensed for an assessment. Hence the construction of each licensed well is considered when determining which layers contributed groundwater. For example, if an assessment had the three licensed wells, A, B and C, represented in Figure 30, then the transmissivity of layers 1, 2 and 3 would be considered when apportioning abstraction to the layers.

Owing to the high transmissivity of the riverbed sand, a well screened over several depths, corresponding to different layers within the model, will result in most water coming from the riverbed sand. As a consequence, after extended periods of no river flow, the riverbed sand begins to de-water and the volume of Q_k from each layer will change. So as waterlevels decline with each month of no river flow a new abstraction ratio is determined for each multi-layer well where an upper layer is de-watered.

A Microsoft© Access V7.0 database containing both the Water Corporation wellfield and the Basin A private wellfield area has been constructed for facilitating the creation of the monthly well abstraction files for input to a simulation. Simulations are then run and the output checked to ensure all recorded abstraction is accounted for. If a cell representing abstraction within a layer is found to have de-watered, new representative ratios for layer transmissivity are entered for the well input assuming zero transmissivity for the de-watered cell. Over no flow interval simulation this process may take several iterations before all abstraction is properly accounted for.

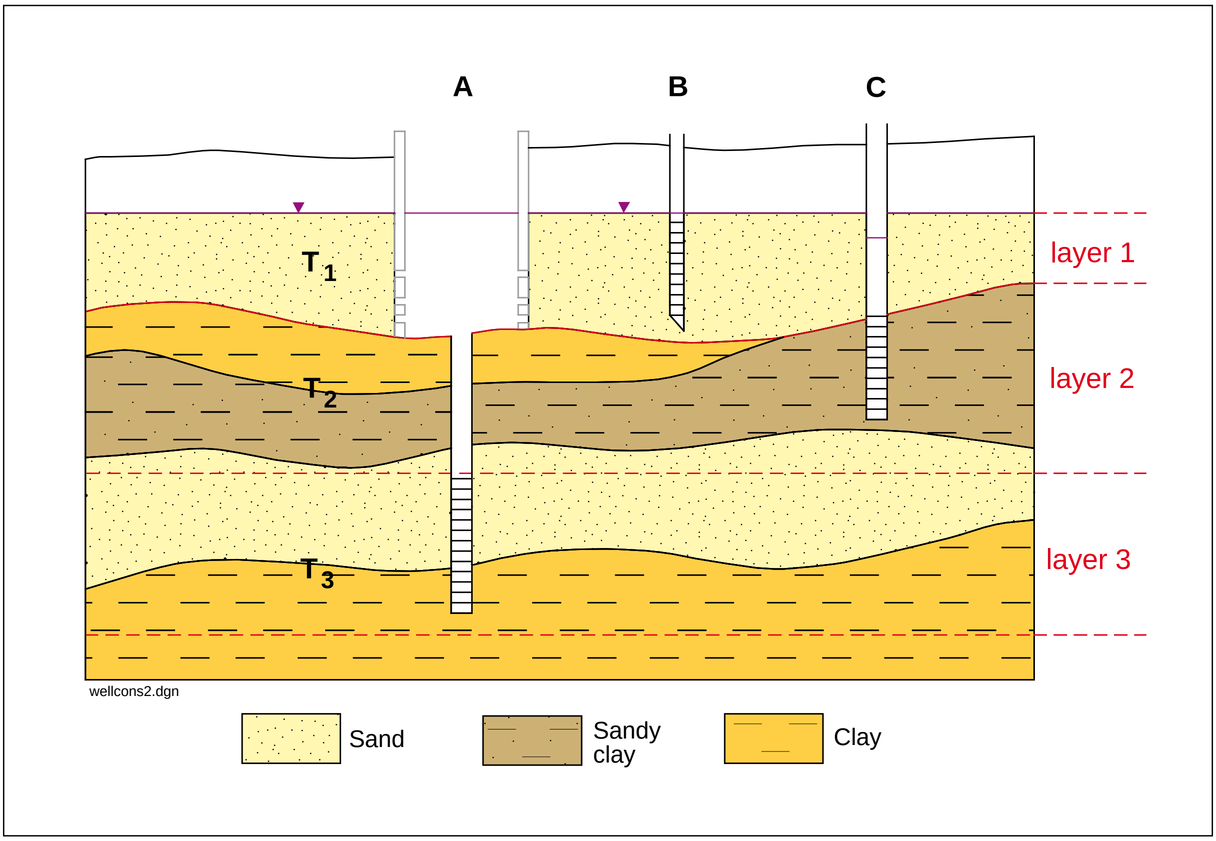


Figure 30 Abstraction wells in Basin A

5.2.6.4 Rainfall

Rainfall recharge to the older alluvium has been estimated as a percentage of the average annual rainfall by an empirical groundwater balance of the flow system using a flownet analysis. The groundwater balance compared throughflow by the Darcy equation with a chloride mass balance. The percentage of annual average rainfall that becomes recharge to the watertable beneath the older alluvium was estimated at 1.1% south of the river and 1.2% north of the river. These percentages represent broad scale estimates; however in comparison to recharge from a river flow, rainfall recharge is insignificant and the above estimates are sufficient. The actual monthly rainfall for each stress period is multiplied by the above percentages to give the recharge flux for layer 1 and layer 2, respectively. The recharge volume is calculated by MODFLOW96 by multiplying the recharge flux by the area of each cell.

The contribution from rainfall to recharge of the riverbed sand is generally masked by either evapotranspiration losses during no flow intervals or river recharge during flow intervals. The percentage of total rainfall that becomes groundwater recharge was changed from 5 to 20% during the model calibration. There was little difference to the correlation between simulated and measured heads over this range. Generally, the rainfall contribution is so small in comparison to other budget components that the difference in model predictions was also insignificant (± 0.4% of recharge over a 153 day river flow period).

5.3 Calibration

The model calibration was conducted on flow and noflow periods occurring in the early 1990s. This data was selected for calibration as these periods are representative of the current abstraction and give an indication of the sustainability of the present allocation structure. Furthermore, abstraction data for individual privately licensed assessment wells are not available pre 1991. The calibration data set ran from May 1991 to March 1992, a period of 336 days of no flow duration, followed by April to September 1992, a period of 153 days flow duration.

The calibration data consists of quarterly waterlevel measurements from deep and shallow monitoring wells. Waterlevel monitoring is a condition of the Water Corporation's well licences for the Scheme. A further series of monitoring wells, known as CIDAC wells, are used for recording waterlevels within Basin A (Skidmore, 1997a). The groundwater model was calibrated by varying the hydraulic conductivity of the older alluvium in the X direction through the range of pre-determined limits (10^{-3}–10^{2} m/day), while keeping all other parameters constant. The main criteria to satisfy calibration were that the simulations meet the monthly historical abstraction within acceptable flow budget components.

The calibration process resulted in a high fidelity model based on the representative conductivity and initial conditions of the older alluvium. Initially the horizontal hydraulic conductivity was calibrated for the no flow interval and then applied to the flow interval. As a result, the flow intervals generally have a lower correlation coefficient in comparison to the no flow intervals.

The acceptance of the calibration consisted of qualitative and quantitative measures. Qualitative measures of calibration consist of the graphical representation of model calculated heads with anticipated groundwater flow patterns, individual monitoring well hydrographs of simulated versus measured heads and scattergrams of entire simulation versus measured heads.

Quantitative measures consist of a water balance performance measure and statistical analysis of the difference between modelled and measured head levels. The latter comprised a standard correlation function, r, calculated for the two time series data given by

$$r \quad = \quad \frac{\Sigma\,(h_i - \hat{h}).\,(H_i - \hat{H})}{\sqrt{(\Sigma(h_i - \hat{h})^2)}.\ \sqrt{(\Sigma\,(H_i - \hat{H})^2)}} \qquad (17)$$

where each h_i and H_i are modeled and measured heads, and $\hat{h}$ and $\hat{H}$ are the mean of modeled and measured heads respectively (Zheng and Bennett, 1995). A value approaching unity is expected for a good calibration.

The water balance performance measure is prescribed by the difference between total inflow and total outflow, including changes in storage, divided by the average of total inflow and outflow, and is expressed as a percentage. An error of around

1% is usually deemed acceptable (Anderson and Woessner, 1992). The standard correlation function, r, and the water balance performance measure are given in Table 17, along with the flow/no flow intervals and sample population of the head measurements.

Table 17 Model intervals and calibration performance

Model No.	Date	River flow	Water balance performance measure (%)	Standard correlation function, r	Sample population
1	01.05.91–31.03.92	No	-0.14	0.9850	632
2	01.04.92–31.08.92	Yes	-0.50	0.9723	303
3	01.09.92–10.02.93	No	-0.24	0.9800	537
4	11.02.93–20.02.93	Yes	0.22	-	9
5	20.02.92–23.02.94	No	-0.23	0.9765	871
6	23.02.94–05.04.94	Yes	0.09	0.9290	30
7	05.04.94–15.02.95	No	-0.46	0.9202	129
8	16.02.95–25.08.95	Yes	-0.63	0.9637	194
9	26.08.95–13.12.95	No	-0.06	0.9756	204
10	14.12.95–20.12.95	Yes	-0.02	-	0
11	21.12.95–21.04.96	No	-0.26	0.9787	252
12	22.04.96–13.05.96	Yes	0.01	-	0
13	14.05.96–15.06.96	No	0.60	0.9579	34
14	16.06.96–31.08.96	Yes	0.05	0.9803	152
15	01.09.96–05.02.97	No	-0.45	0.9730	438
16	06.02.97–28.09.97	Yes	-0.09	0.9730	149
17	29.09.97–31.05.98	No	-0.13	-	-

The iteration residual error term is the maximum change in heads between successive iterations of the simulation. A model simulation proceeds through a number of iterations until convergence is achieved, which is when the residual error term reduces to less than the specified error criterion. If the error criterion is set too small the simulation may oscillate around some value that is higher than the specified criteria (McDonald and Harbaugh, 1988). The error criterion for every simulation was set to 0.1 m owing to poor convergence at low error criterion values.

The poor convergence is caused by the combination of de-watering of model cells by evapotranspiration and abstraction during no flow simulations, and the re-wetting of dry cells during river flow simulations within the first model layer representing the shallow watertable of the thin riverbed sand aquifer. The re-wetting of dry cells results in oscillations in the waterlevel of cells directly beneath the re-wet cell during iterations to solve the equations of flow. This impacts model convergence if the iteration residual error criterion for convergence is set too low. As a consequence, during river flow simulations when re-wetting of dry cells occurred the acceleration parameter of the model solver package was used to dampen the oscillation effect during convergence, thus solving the equations of flow within the range of iterations specified. However this can have a detrimental impact on model error.

5.3.1 Sensitivity analysis

A sensitivity analysis was conducted by changing model parameters and comparing the model outcomes. The purpose of the sensitivity analysis was to improve calibration, but also to quantify the error within model predictions. The sensitivity analysis was conducted on the calibration data set prior to any verification simulations. When investigating hydraulic conductivity the sensitivity analysis was performed by varying anisotropic ratios rather than on individual cell conductivity, as the calibration process involved perturbing individual cells through an acceptable range of conductivity to meet historical abstraction criteria. Two calibration performance measures were adopted; the first was the standard correlation function between simulated and measured heads given in Table 17.

The second was that the model abstraction must reconcile with historical abstraction, as many wells in Basin A are screened against the riverbed sand. If a parameter variation results in the drying of a cell containing an abstraction well, the historical abstraction is not met, then the parameter value has failed the second calibration performance measure. The characteristic model prediction response used for gauging the model sensitivity to a particular parameter consisted of the mean drawdown rate within the riverbed sand for a no flow period, and the average daily river recharge for flow periods. The latter characteristic was selected for analysing the uncertainty of model predictions.

The model proved to be most sensitive to the specific yield of the riverbed sand, as this is the temporary storage basin for recharge water to the older alluvium. For a range in specific yield of 0.25 to 0.35 an error of ±6% within recharge for a 153 day flow event occurred. The sensitivity of the specific yield highlights the lack of monitoring within the riverbed sand, although numerous pumping tests have given a specific yield of the riverbed sand of 0.30 and this assumption was used within the modelling. Ultimately, the biggest influence on model prediction outcome is the variation in the temporal stresses applied, namely river flow duration and groundwater abstraction, which are adequately represented within the transient discretisation used.

5.3.2 Verification

After completing calibration of the physical parameter set against the no flow and flow interval the model was verified against subsequent years. The head output from one interval was used as input to the next and the physical parameter sets were kept constant. This ensured the physical parameter set was verified against different stress scenarios that were deliberately excluded from consideration during calibration. Fifteen verification simulations, were completed and their calibration performance has been detailed in Table 17.

The calibration performance was also assessed using graphical representation of scattergrams of measured versus calculated heads and from individual well hydrographs of measured and calculated heads versus time. Scattergrams of measured versus calculated heads should show a random distribution about the line y = x (a perfect fit). The scattergrams of nine representative models are presented in Figure 31.

Scattergrams have also been created for individual layers within the model from every simulation in Figure 32. Generally, the watertable is well represented (layer 2), but excludes the riverbed sand where monitoring in the last decade was scarce and a scattergram is not warranted. Scattergrams of layers 4 and 5 indicate poor correlation in the western end of the wellfield where calculated heads are generally greater than measured. The scattergrams from layers 6, 7, 8 and 9 reveal very little deep monitoring within the western end of the model where the older alluvium generally contains brackish water. The poor correlation in layers 4 and 5 in the western part of the model could be improved by increasing the hydraulic vertical gradients, if deeper monitoring wells indicated downward heads.

5.3.3 Hydrographs

Selections of hydrographs of individual monitoring wells are given in Appendix D. The hydrographs are presented by their SWRIS number in ascending order from layer 1 to layer 9. If a hydrograph has no data points before the first vertical grid within the graph then it was not included within the calibration process (as no monitoring for that individual bore existed). Generally, the calculated hydrographs under predict the peaks and troughs in the measured data set, but do follow the trends of measured waterlevels, e.g. G70418358, G70418436. This is a consequence of using average monthly abstraction from production wells and using an average monthly stage height. The impact of production well abstraction is illustrated in G70418446, G70418448, G70418460, and G70418461 for example.

The calculated heads of many hydrographs closely follow the pattern and amplitude of the measured heads, but differ in absolute magnitude as a consequence of poor initial head modelling or an unknown boundary condition, e.g. G70418402, G70418425. Layer 1 is generally under represented in monitoring which is a significant issue for the calibration of GRFAMOD. However, layer 2, which represents the watertable within the older alluvium, is well represented by monitoring wells and generally has the best fitting hydrographs, e.g. G70418424 and G70418426.

Multi-port monitoring well locations and hydrographs are also presented in Appendix E. In general, a good correlation was achieved with those multi-ports where the aquifer was relatively homogenous, e.g. G70420001. However, in multi-ports where there were significant vertical gradients GRFAMOD allowed too much vertical connection, and thus some layers correlated well whereas other layers did not, e.g. G70420010 layers 8 and 9.

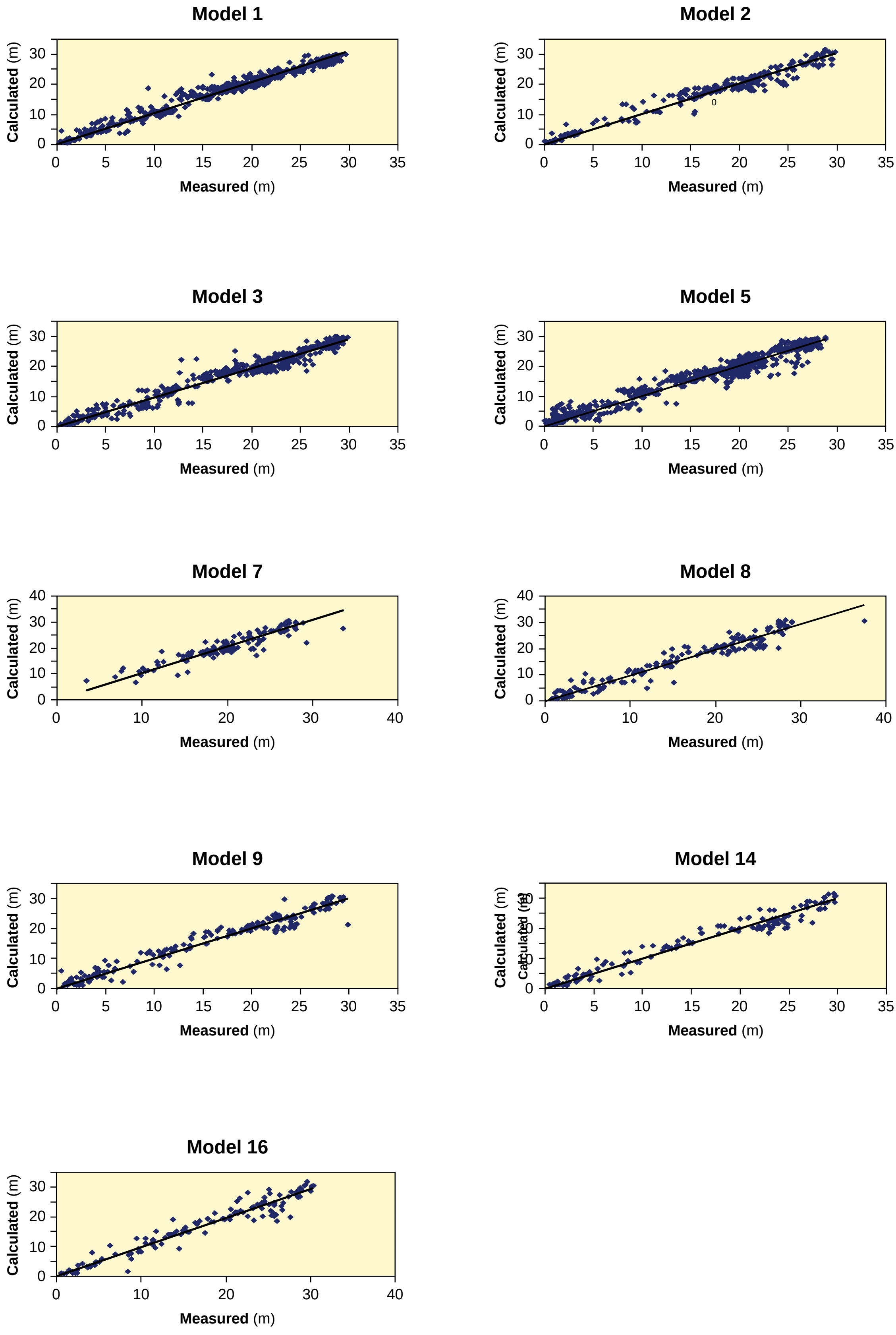


Figure 31 Model interval scattergrams

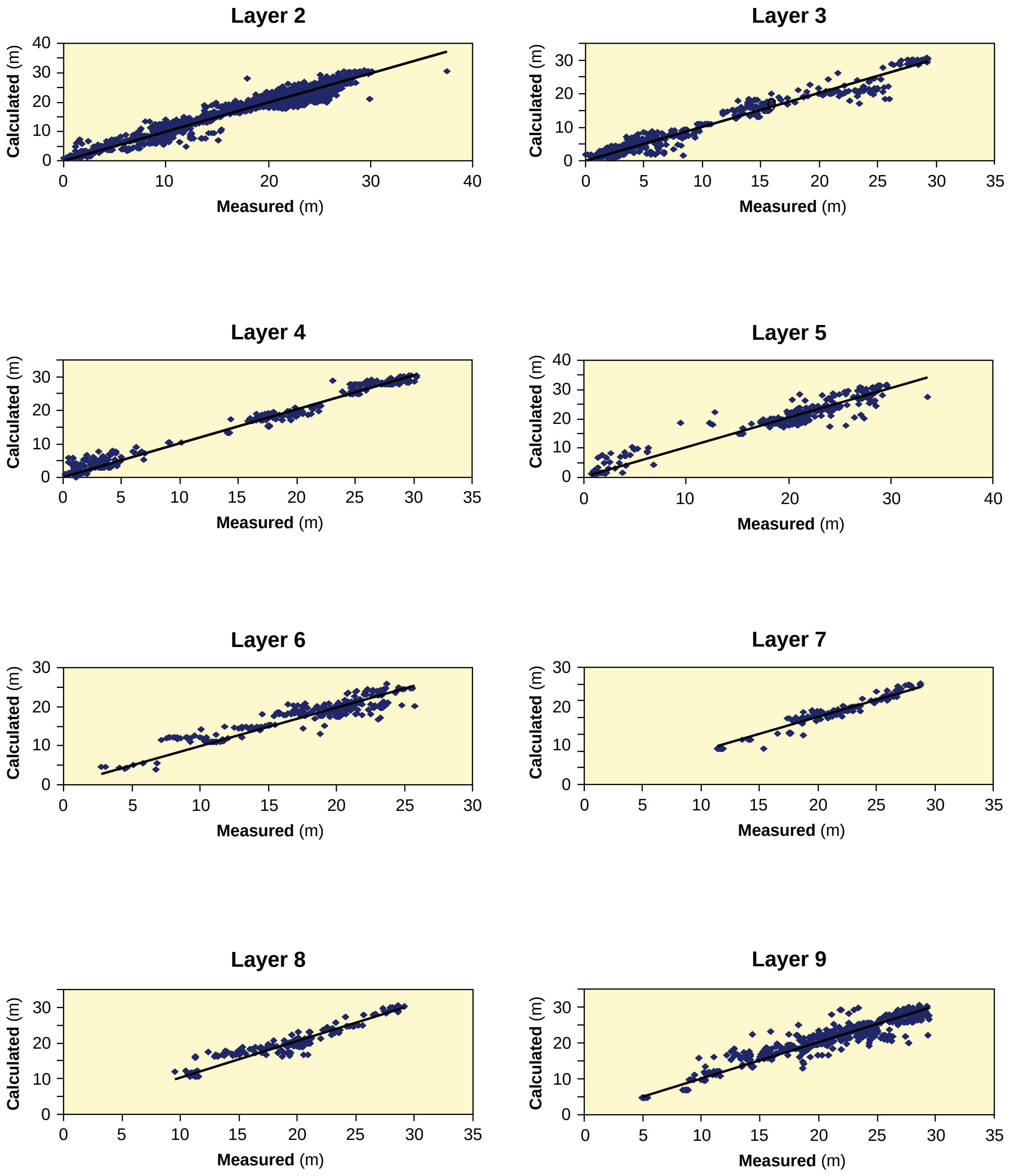


Figure 32 Model layer scattergrams

5.3.4 Water balance components

The manual water balances comprised a watertable fluctuation analysis to estimate riverbed sand flow components over no flow intervals; and a flownet analysis to estimate the entire flow system components during a flow period assuming the riverbed sand is saturated to the cease to flow level. The manual balances often comprised averaged or estimated temporal stress components but still provided indicative volumes for comparison with modelling output and are used to evaluate the model acceptability. The most important components are evapotranspiration loss, river recharge and the corresponding storage change, abstraction being a pre-set component based on historical pumping rates.

5.3.4.1 Evapotranspiration

The watertable fluctuation balance applied only to the riverbed sand, and thus is not directly comparable to the model volumetric budgets that represent the entire flow system. However, the main purpose of the watertable fluctuation balance was to estimate anticipated evapotranspiration losses using watertable recession in the riverbed sand over no flow intervals. Furthermore, combining the analyses of the flownet and the saturated fluctuation balance indicated that most evapotranspiration losses are derived from the riverbed sand. The anticipated loss to evapotranspiration from the older alluvium from the flownet analysis during river flow was roughly 5 – 12% of total evapotranspiration loss. Over a no flow interval, when waterlevels are even lower, the loss from the older alluvium would be an even smaller percentage.

The evapotranspiration component from each no flow simulation is listed in Table 18 for comparison with the watertable fluctuation balance (Table 14). The simulation models generally have a comparable evapotranspiration loss in the first year of a no flow event. For example, the 1980 no flow interval of 128 days from October to February comprised an estimated mean loss of 49 900 m^3/day to evapotranspiration, with an abstraction of 6500 m^3/day. The M11 interval of 123 days duration over a similar season from December to April comprised an estimated loss of 43 200 m^3/day to evapotranspiration with a mean abstraction rate of 8000 m^3/day. Generally, the mean evapotranspiration rate in cubic metres per day reduces with increasing length of no flow and with increasing abstraction.

Table 18 Evapotranspiration for no flow simulations

Simulation model	**Days**	**Estimated mean abstraction from RBS** (m^3/day)	**Estimated mean evapotranspiration from RBS** (m^3/day)
M1 – May 91 – March 92	336	4600	16 500
M3 – September 92 – February 93	163	9400	42 500
M5 – February 93 – February 94	368	4300	18 700
M7 – April 94 – February 95	316	5300	26 900
M9 – August 95 – December 95	110	9600	55 900
M11 – Dec 95 – April 96	123	8000	43 200
M13 – May/June 1996	33	5200	32 800
M15 – September 96 – February 97	158	7200	37 900
M17 – September 97 – May 98	245	6100	30 000

5.3.4.2 River recharge

The flownet analysis of the river flow events was used to estimate the net river recharge volume from the riverbed sand to the older alluvium. The flownet analysis was not used to estimate the volume of recharge required to fill the riverbed sand at the onset of river flow, that is calculated by GRFAMOD, and thus is not directly comparable to the model volumetric budgets which represent the entire flow system. However, the main purpose of the flownet analysis was to estimate recharge rates to the older alluvium given the riverbed sand is fully saturated. The net mean monthly recharge rate in cubic metres per day, the total recharge in gigalitres and flow event characteristics for the eight simulated flow events are given in Table 19.

The recharge rates and total volumes given by the eight flow intervals simulated conform well with anticipated recharge rates from the flownet analysis. The flownet analysis estimated mean net daily recharge rates to the older alluvium of between 28 000 and 134 000 m^3/day after the riverbed sand had been filled. From the modelling output, after the initial filling of the riverbed sand at the onset of flow, that is excluding the first month of a flow interval, the recharge rates from subsequent months of the four largest recharge events were in the order of 10 000–100 000 m^3/day. However, the mean daily recharge rates for the entire flow, as reported in Table 19, are much higher as the model includes the filling of the riverbed sand.

The largest recharge event had the highest peak daily stage, Cyclone Bobby. However, the greatest net daily recharge rates occurred during the shortest flow events owing to the filling of the riverbed sand aquifer, e.g. December 1995 and February 1993. As the flow duration increases and the riverbed sand is filled, the mean daily recharge rate decreases as the aquifer waterlevels recover. The length of the preceding no flow interval also influenced the rate of recharge. The 77 day flow interval of June 1996, although nearly twice the duration of the 41 day flow of February 1994, had a mean daily recharge rate an order of magnitude lower and delivered only a third of the recharge volume of the latter. The smallest recharge event was associated with a flow at Fishy Pool that ceased somewhere before Nine Mile Bridge.

5.3.5 Model assumptions and limitations

There are numerous simplifying assumptions made in completing GRFAMOD that limit the accuracy of the model output. The major assumptions occur in the interpolation of spatial hydrogeological parameters and temporal representation of monthly groundwater pumping and mean river stage heights. There are also the assumptions inherent in the equations that represent groundwater flow and interactions with the applied dynamic stresses (e.g. evapotranspiration, river recharge, etc.).

Owing to data limitations, the representation of river flow assumes that the elevation of the riverbed sand, the gradient of the river and the cease to flow level remain constant. The elevation of the riverbed sand is most likely to change during each major flow as the sediment is redistributed within the riverbed. However, the main purpose of estimating the elevation is to approximate the flow width given stage height, thus an approximate cell elevation for the riverbed sand is sufficient. The gradient of the river and the cease to flow level are presumed to be constant for the time intervals involved.

The study area has two stream gauging stations, although one lies to the east of the model area. The distance between the two gauging stations along the course of the Gascoyne River was estimated at 111 km. The stage height, s, is calculated from the average monthly stage height recorded at Nine Mile Bridge and Fishy Pool gauging stations. A linear relationship is used to determine a gradient. The gradient for each month is added to columns east of the Nine Mile Bridge stage for flows decreasing in stage height from east to west and subtracted west of the station. For flows that increase in stage from east to west the gradient is subtracted from columns east of Nine Mile Bridge gauging station and added to each column west of the bridge. The stage height for each column is added to the individual cell cease to flow level to determine whether a river cell will receive surface flow over it or not.

Finally, this technique requires large-scale representation of the ephemeral river so differences in the surface area of individual flows were adequately represented. It required every cell within the river to be active for a river flow simulation, which increases model construction and processing time. It also required the re-wetting of dry cells which impacted model convergence and increased the error within the volumetric budget of the water balance performance criteria (Table 17).

Table 19 River recharge volume and mean recharge rates from numerical simulations

Flow start and finish date at Fishy Pool	**Flow days at FP**	**Peak daily stage height at NMB** (m)	**Peak monthly stage height for model** (m)	**Net mean daily recharge rate** (m^3/day)	**Recharge total for flow interval** (GL)	**Comment**
11 February – 20 February 1993	10	0.7*	0.26*	364 400	0.4	*Peak stage for Fishy Pool, 163 days after last flow at Fishy Pool, flow never received at Nine Mile Bridge
14 December – 20 December 1995	7	0.8	0.31	664 400	0.7	First flow at Nine Mile for 136 days
16 June – 31 August 1996	77	1.1	0.75	68 740	5.6	3 days after flow ceased at Fishy Pool
22 April – 13 May 1996	22	1.6	0.77	311 500	6.9	First flow at Nine Mile for 265 days
24 February – 5 April 1994	41	3.4	2.6	405 000	16.6	First flow at Nine Mile for 546 days
1 April – 31 August 1992	153	2.7	1.4	184 200	28.2	First flow at Nine Mile for 336 days
6 February – 29 September 1997	235	3.6	2.2	111 700	32.3	First flow at Nine Mile for 158 days
16 February – 25 August 1995	191	6.7	2.2	171 200	32.7	Cyclone Bobby, first flow at Nine Mile for 316 days

NMB = Nine Mile Bridge; FP = Fishy Pool

6 Groundwater resources

The potential groundwater resources of the Gascoyne River floodplain aquifer can be considered relative to the four major components of the water balance: recharge, throughflow, discharge and storage. However, estimates of recharge from the numerical simulation of river flow vary significantly from year to year and flow event to flow event (Table 19). Furthermore, altering one of these components will affect the others. For example, groundwater abstraction (discharge) causes local lowering of the waterlevels around the well, increasing the hydraulic gradients towards the abstraction point. The change in hydraulic gradient, regardless of the depth of abstraction, will propagate to the watertable, inducing greater recharge and reducing evaporative loss where the watertable is shallow.

The sustainable groundwater abstraction potential may best be assessed by quantifying the additional groundwater recharge induced by reducing stream loss to the ocean when the river is flowing. The best way to achieve this is by lowering waterlevels before a recharge event occurs, thus increasing available storage. However, lowering of the watertable will impact the volume of groundwater available for dependent environments. Depending on the environmental constraints for conservation of the riparian ecology that stabilises river banks, significant gains could be achieved by lowering the watertable through groundwater abstraction.

6.1 Groundwater recharge

The sustainable yield of an aquifer is usually based on the long term average annual recharge. As recharge varies widely owing to the variations in flow and no flow intervals on the Gascoyne River, it is difficult to quantify. There were eight separate flow events between May 1991 and May 1998, and the results of modelling these flow periods were presented in Table 19. Big floods deliver more water and thus result in greater recharge, e.g. Cyclone Bobby, but flows of similar duration or stage height can result in different rates and volumes of recharge. In general, the greatest recharge event is associated with high river stage, long flow duration and extended antecedent no flow condition. The early period of a river flow results in the greatest rate of recharge, which corresponds with the rapid filling of the riverbed sand. After the riverbed sand has filled to the stage height of surface flow, groundwater recharge depends on the hydraulic properties of the older alluvium, and the rate of infiltration diminishes appreciably. Flow events that occur within relatively short duration of a previous flow result in minimal recharge owing to the riverbed sand being relatively full.

The mean of total river recharge from the eight flow simulations was 15.5 GL/a; however, this is biased by the influence of extreme events, such as Cyclone Bobby. A more sophisticated approach has been developed for this research and applied to calculate the expected river recharge from the simulated output. The simulated period consisted of 84 months in total, of which 30 months had some flow. The recharge rate for the first month of flow from each river simulation, regardless of whether flow was for the whole month or not, was ranked and a cumulative distribution function (cdf) constructed. The process was repeated for the second month, and third month, and so on. The intervals were broken down on a monthly basis as early flow recharge rates are significantly greater than late flow recharge rates, except if subsequent larger spates occur. The classes, X, for recharge rates were grouped into a logarithmic distribution in cubic metres per day given as

- $X < 10^3$
- $10^3 \le X < 10^4$
- $10^4 \le X < 10^5$
- $10^5 \le X < 10^6$
- $X \ge 10^6$

The probability of the recharge rate for each class for each month of an annual flow year, as derived from the monthly cdfs, is presented in Table 20. The recharge rate is given by the mid-point of the logarithmic class interval, listed in Table 20. The expected recharge rate is then given by the product of the recharge rate, the probability of the recharge rate and the flow length:

$$E(R) = P(r).R \times t \qquad (18)$$

where $E(R)$ = expected monthly recharge (m^3)
$P(r)$ = probability of recharge rate
R = recharge rate (m^3/day)
t = 30.4375 (average month in days)

Table 20 Monthly recharge intervals and cumulative distributions

Interval m^3/day	**Recharge rate, R** ($x10^3$)	**Monthly cumulative distributions** (month of flow)								
		1	2	3	4	5	6	7	8	9–12*
$< 10^3$	0.5		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10^3–10^4	5		0.75	0.63	0.38	0.38	0.25	0.25	0.13	0.00
10^4–10^5	50	1.00	0.75	0.50	0.38	0.38	0.25	0.25	0.00	0.00
10^5–10^6	500	0.88	0.63	0.38	0.00	0.00	0.00	0.00	0.00	0.00
$> 10^6$	5000	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*The longest flow period was 8 months, thus for months 9,10,11 and 12 there is a 100% probability that the recharge rate will be les than 10^3 m^3/day.

Although based on a limited number of river flow simulations the expected monthly recharge rates can be used to give the probability of a flow event meeting annual abstraction. The total number of combinations of expected monthly recharge rates for a 12 month flow period using the log normal range is the product of the number of intervals for which a probability is assigned for each month, that is 7776. By using a spreadsheet to sum all possible combinations of expected recharge the percentage of flow events expected to exceed annual abstraction can be estimated.

Over May 1991 to May 1998 the annual groundwater abstraction averaged 9.4 GL. Thus the probability that the flow system would receive 9.4 GL in a flow event is given by:

$$P(X > 9.4) = \frac{\text{no. of times } \Sigma\, E(r) > 9.4 \text{ GL}}{\text{Total no. of combinations}} \qquad (19)$$

The probability of equalling or exceeding 9.4 GL recharge in a flow event for the May 1991 to May 1998 period was 76.5%. The recharge probability function constructed from the above probabilities gives a broad range in expected recharge. There is an 80% probability that recharge from a flow event during the simulation period was between 3.4 and 28.5 GL, with an expected volume (50th percentile) of 17 GL. The maximum expected recharge from a flow event was given as 36.2 GL.

However, this method assumes a river flow event, if the recharge probability function is annualised by including the probability of flow, then the results are different. The probability of a length of no flow was calculated from river gauging recorded at Nine Mile Bridge and was given in Figure 10. If the probability of no flow is given by P(no flow)= P(X), then the probability of flow, P(F), is given by P(F) = 1 - P(X). The probability of flow can then be included in equation (18) where:

$$E_a(r) = E(r).P(F) \qquad (20)$$

and $E_a(r)$ = expected recharge in an annual year

$P(F)$ = probability of flow

From the annualised recharge probability distribution that includes the probability of flow, there is an 80% probability that recharge in an annual year of between 0.8–10.5 GL, with an expected volume of 6.8 GL. Furthermore, there is only a 17.5% probability that recharge in an annual year would exceed average annual abstraction for the 1991 to 1998 interval. However, including the probability of flow predicts a maximum annual recharge of just 13.2 GL. Since four out of the eight flow intervals simulated had a total recharge in excess of 16 GL (Table 19), these probabilities are conservative. The annual and river flow recharge probability distributions are given in a frequency diagram (Fig. 33). The plotting position for the recharge probability function was smoothed using the plotting position formula of Cunnane (1978) that is generally applied to flood frequency analysis.

The interval of time and number of flow events simulated limit these results. However, the cdf of the mean monthly recharge rate and the derived estimate of total recharge represent a statistical method for assessing the probability of groundwater recharge from ephemeral river flow. The cdfs require updating as more simulation periods are represented. These statistics are representative of an average annual abstraction volume of 9.4 GL; a change in this abstraction volume would change the probability of recharge for any given flow event.

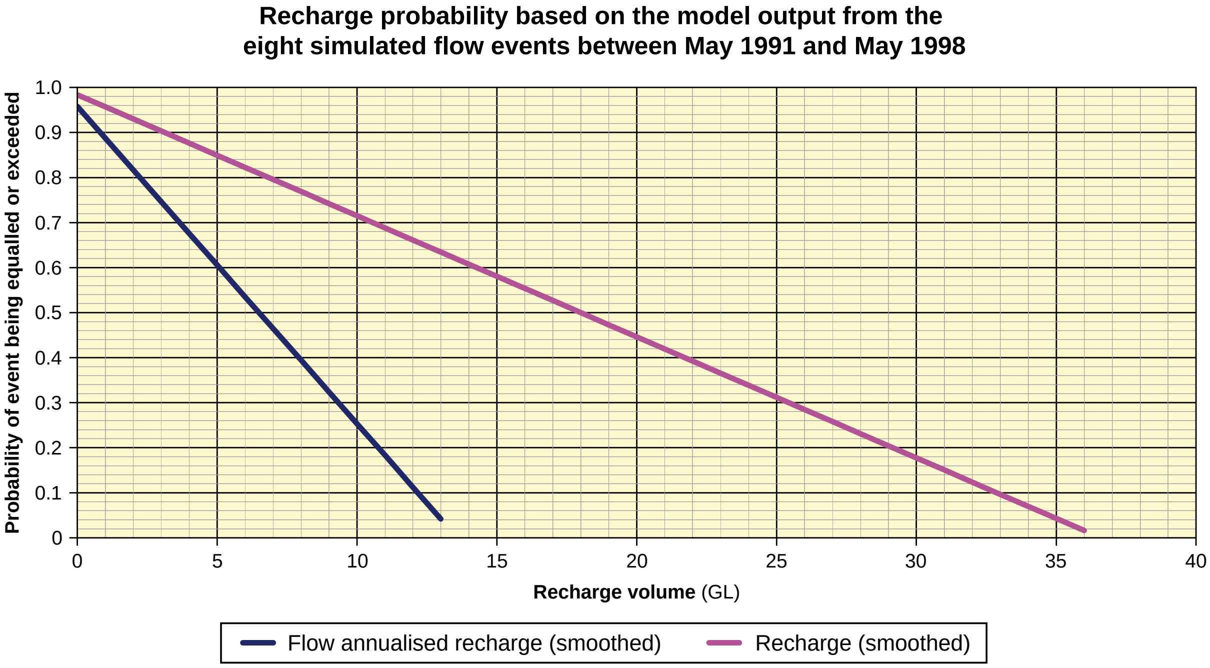


Figure 33 Groundwater recharge frequency diagram

The modelling has highlighted both the spatial and temporal factors that govern recharge to the groundwater flow system beneath the Gascoyne River under groundwater abstraction. Many of the temporal factors are inter-related and are listed in order of importance to recharge quantity:

- stream flow volume and duration,
- antecedent no flow duration and depth to watertable, and
- groundwater abstraction and depth to watertable.

The spatial variables, in order of importance, consist of the:

- specific yield of the river bed load,
- effective channel area of the river course,
- permeability of the recent alluvium and floodplain sediments, and
- presence of impeding layers or clay barriers to the downward percolation of recharge water.

All of these conditions concur with those referred to by Issar and Passchier (1990) in their summary of riverbed basin recharge. However, the monthly cumulative distribution functions (Table 20) highlight the decline in recharge rate as flow duration increases. Beyond the 3rd month of flow, rarely does recharge occur at a significant rate owing to the presence of low permeability clay layers within the older alluvium. This would indicate that the flow duration is of less importance than actual storage depletion, given by the depth to watertable and controlled by the duration of no flow intervals, and to some extent, groundwater abstraction. In Table 19, there are two intervals of shorter flow duration than the June 1996 event, yet both delivered more recharge as a result of greater storage depletion at the time river flow started.

Groundwater recharge estimates in arid environments will nearly always be subject to considerable uncertainty and large error (Foster, 1987). Through continued monitoring and modelling of the natural system a greater degree of certainty could be assigned to the recharge predictions given the hydrologic characteristics of flow. The challenge is to adopt a water resource management approach that considers the variability of the natural system to ensure that the allocation of water is for the benefit of the community, while ensuring protection of the resource.

6.2 Groundwater throughflow

Groundwater throughflow is down hydraulic gradient towards discharge boundaries at the ocean. Groundwater throughflow from the flownet analysis over an area of approximately 650 km^2 was 8.5 GL/a. However, the flownet analysis covered some areas where brackish groundwater occurs, and thus, this volume is not truly representative of the freshwater resources in throughflow.

The vertical hydraulic gradient is several orders of magnitude greater than the horizontal, and discharge via leakage to the underlying Cardabia Calcarenite is likely. The rate of vertical throughflow via downward leakage to the underlying Cardabia Calcarenite was estimated at 5×10^{-5} m^3/day/m^2 from the flownet analysis. The area of groundwater with salinity less than 1000 mg/L is 185 km^2 (Martin, 1990b). Applying this area, the discharge via downward leakage to the Cardabia Calcarenite is 9250 m^3/day, or approximately 3.4 GL per annum.

Discharge from the riverbed sand was estimated at 880 m^3/day when the riverbed was full to the cease to flow level, but can reduce to negligible over no flow periods. These estimates are an indication of magnitude only. Discharge over the saltwater interface from the older alluvium, and throughflow to the north and south of the river, are essential to prevent the inland migration of saline water, or the lateral migration of brackish groundwater towards the wellfield, respectively.

6.3 Groundwater storage

Beneath the Gascoyne River groundwater storage in the older alluvium is assumed to be in steady state. The total groundwater in storage in the older alluvium with a salinity less than 500 mg/L TDS was estimated by Martin (1990b) as 340 GL, and under 1000 mg/L as 875 GL. These volumes represent 36 and 93 times the current annual average abstraction for total water supply, respectively.

The groundwater flow system of the riverbed sand is in a constant state of flux. During a no flow period groundwater storage is depleted by evapotranspiration, throughflow and groundwater abstraction, which effectively mines groundwater storage. However, during flow events recharge from surface water flow exceeds losses to evapotranspiration, throughflow and abstraction, and thus groundwater storage is replenished. At the cease to flow level the riverbed sand is estimated to contain a further 28 GL of groundwater of less than 1000 mg/L, approximately three times the current annual average abstraction.

6.4 River flow

The volume of surface water that is available to recharge the groundwater flow system is detailed in Table 6. The impact of inducing more recharge will reduce stream flow discharge, the source of the additional recharge water. A comparison of the simulated recharge volume from the eight flow intervals and the stream discharge from gauging at Fishy Pool has been conducted. During large river flows where total river discharge through Fishy Pool exceeds 100 GL, the percentage of surface flow that becomes recharge ranged between 0.1 and 3.3% of river discharge. For river flows where total stream discharge was between 10–100 GL the percentage that becomes groundwater recharge ranged between 6.1 and 37.2% of stream discharge. The percentage of volume lost to groundwater recharge increases with a reduction in stream discharge. Similarly, recharge to the wellfield as a percentage of transmission loss varied between 8 and 42% for large rivers (> 100 GL discharge) and 50 to near 100% for smaller river discharge volumes.

From the eight flow events simulated it is proposed that the state of depletion within the riverbed sand has a significant impact on the extent of small river flows only. During large floods, groundwater recharge represents a small percentage of total stream discharge. From Table 6, the largest flood recorded through Fishy Pool not to reach Nine Mile Bridge was 21 GL in May 1977. This flood occurred after a 398 day no flow interval at Fishy Pool and the riverbed sand aquifer was probably extensively depleted. Hence, increasing storage depletion within the riverbed sand by groundwater abstraction may impact flows with a discharge magnitude of 22 GL or less through Fishy Pool when there has been a preceding extended no flow interval of 12 months or greater. Under these circumstances, flow days at Nine Mile Bridge may be reduced. Flows of less than 22 GL magnitude at Fishy Pool represent 30% of total flows recorded at Fishy Pool since 1965, and all but four of these reached Nine Mile Bridge.

6.5 Abstraction potential

The increase in recharge induced from groundwater pumping on the Gascoyne River was first investigated by Martin (1993). A pumping trial was conducted in Basin F of the Scheme wellfield by increasing the pumping rate from 1 to 2 GL from three of the higher yielding bores in the area over a 4 month period. This was followed by a cessation in pumping over 5 months during a flow interval after which waterlevels recovered to a 'full' aquifer status. Based on the increased drawdown after 4 months and the complete recovery in waterlevels after river flow, Martin (1993) concluded that increasing the pumping rate by 1 GL had doubled recharge from river flow.

The transient groundwater flow model can be used to test abstraction potential by increasing groundwater abstraction and observing the response in the recharge discharge balance over time. The aquifer yield will depend on the manner in which abstraction is transmitted through the aquifer and on the change in rates of groundwater discharge and recharge induced by abstraction. This research employed historical river flow events and simulated the impact of increasing groundwater abstraction for comparison with historical abstraction. By taking the approach of what if abstraction were greater, the numerical model was used to estimate the impacts of such. A safe yield for the groundwater flow system that ensures a maximum supply without increasing the risk to water quality or the dependent groundwater ecosystems was then tested. This also avoids the uncertainty in predicting future stage heights and flow duration along the Gascoyne River for model input, as this would introduce uncertainty owing to the variability in flow events.

Predictive simulations were compared with the base case of historical abstraction and the impact on the flow system analysed. The different abstraction scenarios consisted of increasing historical abstraction from the Scheme by 2 and 4 GL per annum. The extra groundwater abstracted was removed from the older alluvium using the existing infrastructure (including some abandoned production wells) and pumping rates were generally in the order of 600 m^3/day. Abstraction was not increased within Basin A. A no abstraction simulation to estimate the impact of the current abstraction scenario in comparison to natural conditions was also simulated.

The impact of increased abstraction on the main groundwater balance components of evapotranspiration, river recharge and storage is given in Figure 34A, B and C. Figure 34A consists of a column graph of the monthly evapotranspiration loss from each simulation over a four year period. With no abstraction the loss to evapotranspiration is significantly greater over no flow periods. Groundwater abstraction reduces evapotranspiration during no flow intervals, but makes negligible difference during a flow interval, as water is readily available. The impact of historical annual groundwater abstraction has resulted in an approximate 30% reduction in evapotranspiration, most of this reduction occurring within no flow intervals. However, increasing annual abstraction by 2 and 4 GL per annum reduced evaporative loss by approximately 1.5% and 3% from the current annual abstraction simulation, respectively.

The monthly river recharge rate is shown in Figure 34B for two flow events from each simulation scenario. River recharge under no abstraction conditions was only 63% in comparison to estimated recharge under historical abstraction. In comparison, increasing groundwater abstraction by 2 and 4 GL per annum on historical abstraction resulted in an increase in river recharge of approximately 3.9% and 6.3%, respectively. At some greater rate of abstraction the watertable will reach a depth where it no longer influences seepage into the older alluvium and the maximum recharge rate will be attained. If abstraction was to continue beyond this point it would be impossible for a recharge event to replace the volume of water removed. The only source of water for abstraction would come from the continued depletion of groundwater storage, which would manifest itself in decreasing potentiometric heads throughout the aquifer.

The change in storage for each abstraction scenario relative to no abstraction is shown in Figure 34C. The change in storage for the no abstraction case is expressed relative to the estimated groundwater storage of 368 GL. Under no abstraction conditions the change in storage was minimal, with the no flow intervals being balanced by later river flow; that is the groundwater flow system was in equilibrium over the seven year simulation period. Including historical groundwater abstraction to the simulation resulted in groundwater storage depletion, however the rate of depletion begins to decline over time as a new equilibrium is established between river recharge, abstraction and evapotranspiration. Steady state equilibrium is approached at similar time intervals for each abstraction scenario, but at different depletion levels owing to the difference in groundwater abstracted. The new steady state is reached after approximately 1400 days, nearly 4 years, corresponding roughly with the recurrence of cyclones over the region. Groundwater storage depletion calculated after the first eight model intervals was 8.9, 10.7 and 12.4% relative to the no abstraction simulation for the historical abstraction, extra 2 GL and extra 4 GL per annum simulations, respectively.

The volume of storage depletion from the extra 2 GL and 4 GL per annum abstraction was converted to a watertable decline within the older alluvium in comparison to current historical abstraction. The estimated decline in the older alluvium watertable would be 3.0 and 4.4 m after 1400 days for the extra 2 and 4 GL per annum abstraction, respectively, when the following conditions are satisfied.

- Extra abstraction is sourced from the older alluvium only.
- Extra abstraction is derived from the area beneath the riverbed sand only.
- The impact of extra abstraction is evenly distributed within this area.
- The older alluvium is unconfined with a specific yield of 0.1.

The area of the older alluvium containing groundwater with less than 1000 mg/L TDS is 185 km^2 (after Martin, 1990b). The decline in watertable if abstraction was evenly distributed through this area after 1400 days and the remaining conditions above were met, would be approximately 0.47 and 0.69 m after 2 and 4 GL per annum extra abstraction, respectively. However, in reality groundwater abstraction will have greater impact at the point of pumping and minimal effect away from a pumping well.

The different abstraction scenarios simulated made no allowance for a change in the surface water stage between each model. Under no abstraction conditions it can

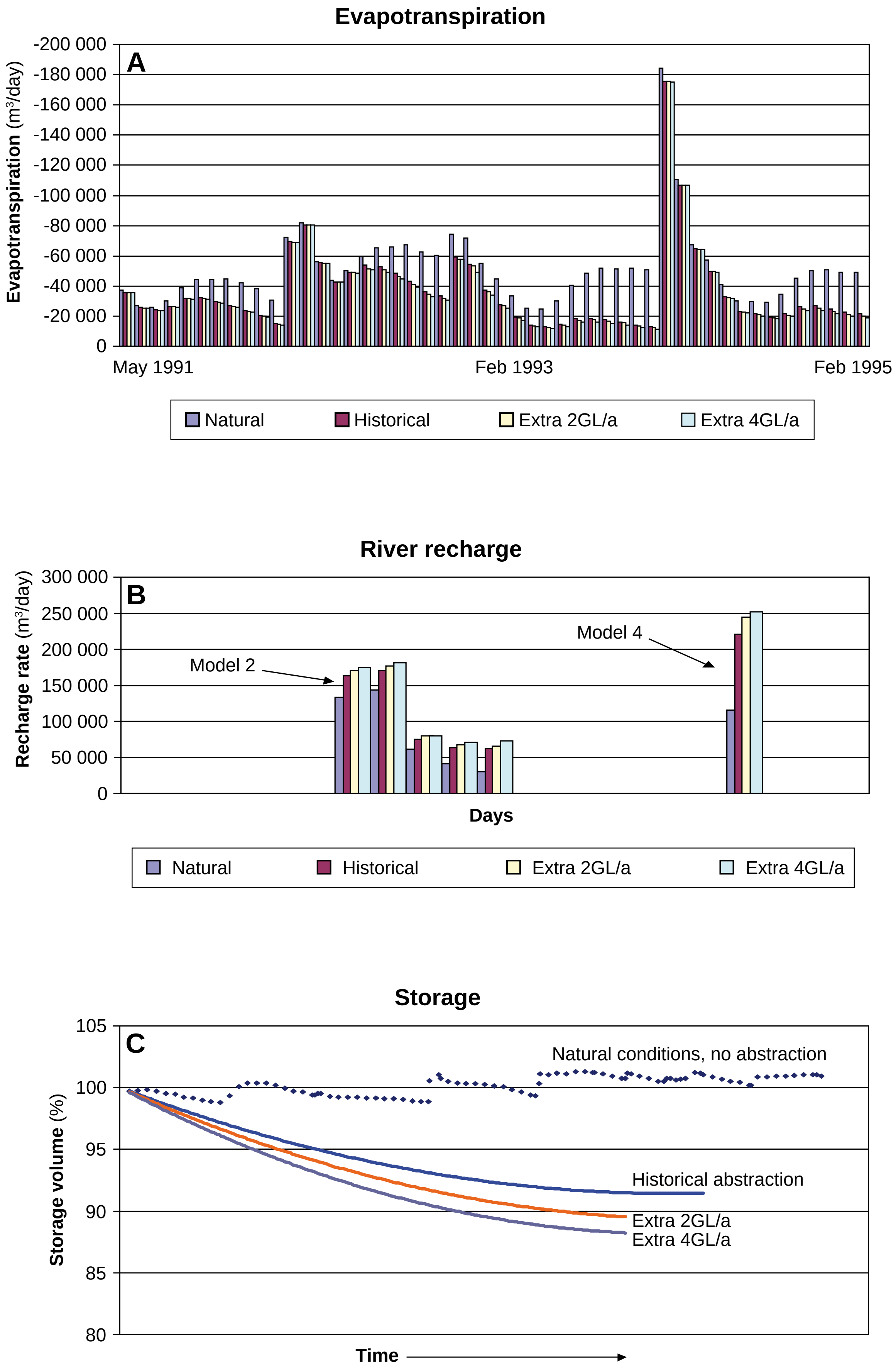


Figure 34 Effects of increased abstraction on the major flow system components

be assumed that the riverbed sand would not be as depleted and thus river stages would be higher than those represented. Similarly, under greater abstraction, small river flows may not have continued for the same length of time as represented. Finally, the evapotranspiration component consists of both evaporation and transpiration and the impact on the groundwater dependent environment is not directly transferable or known.

7 Implications for groundwater management

Groundwater management should balance the socioeconomic and environmental values of a water resource before allocating groundwater for abstraction. The Water and Rivers Commission views the determination of the safe yield of a groundwater flow system as paramount for the sustainable development and preservation of environmental values dependent on the resource. The key benefits are that groundwater abstraction and the environmental values of the system are sustained in perpetuity.

The groundwater yield is best viewed in the context of the full three-dimensional system that constitutes the groundwater flow. Todd (1959) described the concept of a safe yield of a groundwater flow system as the amount of water that can be withdrawn without producing an undesired result. The 'undesired results' that are anticipated by overdraw of groundwater along the Gascoyne River are the deterioration in water quality, the depletion of groundwater reserves and any adverse impact on the riparian environment that stabilises the river banks. The concept of sustainable yield for a groundwater aquifer is the level of extraction measured over a specified planning timeframe that should not be exceeded to protect the higher value social, environmental and economic uses associated with the aquifer.

7.1 Effects of abstraction

The effects of groundwater abstraction on the waterlevels will depend on the abstraction rate of individual wells and on the number, location and spacing of the wells. Abstraction causes waterlevel drawdown that diminishes with increasing distance from the well, resulting in a cone of depression around the well. The radius of the cone of depression depends mainly on the aquifer type. For unconfined aquifers the radius is generally small in extent and, in low permeability sediments such as the older alluvium, the radius will be small but drawdown steep. Conversely, in the high permeability riverbed sands the radius will be large and the drawdown shallow (Kruseman and de Ridder, 1994).

The effects of groundwater abstraction on potentiometric heads are monitored quarterly, and sometimes monthly, within the monitoring network around both wellfields. However, after large floods access to monitoring wells is not possible and there is a reduction in monitoring during major recharge events. The monitoring data were quality assured by ensuring no potentiometric heads were below the bottom screen interval of the monitoring wells. At some locations there are two wells, one deep and one shallow, that record the potentiometric head at different levels in the aquifer. In some instances the pair of wells at the one location have been confused and suspect data were omitted from the monitoring data used for history matching and potentiometric head analyses.

The monitoring well networks of both Basin A and the Scheme wellfields were reviewed using a qualitative assessment of water level trends. Quantitative analysis, such as linear regression fitting of heads, is heavily influenced by the initial head in each record and gave very poor correlation for linear trend fitting. Cumulative fluctuation from mean or moving averages of head were investigated, but also gave a poor correlation and the results were similar to those of the simple linear regression analysis. Most monitoring wells are located near the river and display a large fluctuation between flow and no flow intervals. Many monitoring wells are also located close to production wells, and thus heads are affected during pumping.

The simple linear trend in the potentiometric head of the monitoring network will indicate whether the current groundwater abstraction along the Gascoyne River flow system is having an adverse impact on groundwater reserves. If the majority of monitoring wells exhibit a qualitative lowering trend of the potentiometric surface, then a reduction in storage is the most likely result of groundwater abstraction. However, if the groundwater head indicates only the expected fluctuation between flow and no flow events, it can be assumed that the groundwater flow system has been able to maintain abstraction demand.

7.1.1 Basin A groundwater storage

Within Basin A there are 72 monitoring wells that have greater than 10 years of continuous monthly or quarterly potentiometric head records for evaluating trends. There are 16 monitoring wells that have potentiometric head measurements dating back to the early 1960s; however, most monitoring ceased within these wells in the mid-1970s when they were replaced by the L series wells, completed in 1974, or the shallow observation wells, completed in 1977. Monitoring wells need constant maintenance and replacement, particularly those within the riverbed, owing to wells being lost underneath shifting sand, or because of silting up, fouling or obstruction of screens. On the floodplain, monitoring wells also require replacement owing to loss from silting up, obstruction of screens or, more regularly, from damage by machinery. Of the later series of replacement monitoring wells there are 57 that have been monitored until 1995, at which point monitoring was reduced after the split of the Water Authority of Western Australia. Potentiometric head monitoring has continued to the present in 30 wells around Basin A.

A selection of hydrographs and their locations are displayed in Figures 35 and 36; the wells are identified by the last three digits of their individual WIN data reference number (e.g. 70418310). The wells represented are all screened within the older alluvium. There is little monitoring within the riverbed sand itself as floods destroy or bury wells under sediment. Wells near the western end of the wellfield, 301 and 323, display little variation in head owing to their proximity to the hydraulic boundary of the saltwater interface. Wells near, or in the river, show the greatest fluctuation, such as 304 and 400. Hydrographs from wells in the eastern end of Basin A (336, 338 and 394) show the greatest lowering in potentiometric head and are highlighted in bold in

Figure 37. However, the large river flows associated with Cyclones Vance 1999, and Steve 2000, have aided waterlevel recovery to some extent.

Of the 72 monitoring wells, 24 have trends that indicate some head decline within Basin A, using linear regression, two indicate increasing head, and 46 have no significant trend. Most of the 24 wells with declining head are clustered within an area west of Nine Mile Bridge down to Bibbawarra Crossing both north and south of the river. The maximum decline in head since the mid-1970s is approximately 150 mm/a, which represents a maximum drawdown of 3 m within the older alluvium to the east of Basin A. Generally, the decline in head in the east of Basin A is 75 mm/a, an order of drawdown of 1.5 m. To the west of Bibbawarra Crossing potentiometric heads are generally constant, although some hydrographs indicate a decline of roughly 0.5 m since the 1970s. However, these estimates of decline are based on linear trend analyses which gave very poor correlation, and hence are indicative only.

7.1.2 Basin A groundwater quality

The systematic monitoring of groundwater salinity within Water and Rivers Commission Basin A monitoring wells commenced in March 1974. The chloride concentration in groundwater was measured from seven wells around Water Supply Island. In 1975 the monitoring program was expanded to include more wells; however, EC was measured by laboratory analysis rather than chloride concentration. The analysis of chloride concentration was eventually phased out in preference to measuring EC. The laboratory analysis of EC was conducted regularly in 46 wells until March 1984. Prior to this, the measurement of EC in situ was tested, and began to replace the more expensive, labour intensive collection of samples for laboratory analysis of EC. The monitoring of EC in situ was conducted initially in 1980, and started again in the late 1980s until the present. The monitoring of EC in situ is now conducted in 22 Basin A wells on a quarterly basis. Overall, there were a total of 72 monitoring wells within Basin A and 10 ex-production wells located on Water Supply Island with some EC or chloride concentration measured. Only 46 of these have been monitored consistently, owing to changes in sampling routine or loss or damage to monitoring wells.

The salinity distribution within the older alluvium is complex. Small pockets of freshwater can be found in sandy intervals directly beneath and adjacent to the riverbed sand in Basin A. However, the salinity is generally brackish, ranging from 1000–6000 mg/L TDS. West of Water Supply Island the groundwater salinity increases to 10 000 mg/L with proximity to the saltwater interface. Brackish groundwater can also be found directly beneath the riverbed sand where the older alluvium has poor hydraulic connection with the surface water owing to clay lenses of low permeability.

The change in the monitoring of a natural environment that is subjected to periods of flooding and prolonged drought makes it difficult to identify trends from the Water and Rivers Commission data set. The chloride concentration analysis is generally over too short a time frame to indicate any meaningful trends and has been ignored. Of the 46 wells monitored regularly for laboratory EC, 17 have trends that indicate increasing salinity within the groundwater wells, of which seven have been monitored in the last decade. Of the remaining 29 wells, five indicate decreasing trends in salinity, while the rest exhibit spikes or sinuous trends that correspond with the droughts of 1976–78 and 1983–84 and subsequent recovery during river flow years. The location of the 46 monitoring wells, including the recently monitored group of 22 and the 17 wells with increasing salinity trends, are given in Figure 37.

From the distribution of EC trends, and those wells in equilibrium, it can be concluded that:

- any significant changes in groundwater EC occur west of Nine Mile Bridge,
- increases in groundwater EC are localised in extent, and
- increases in EC do not correlate with head decline within Basin A.

The second point indicates that the recommendations of Skidmore (1997b) to increase the number of monitored wells or even the frequency of monitoring will not necessarily clarify the overall trend in EC. Generally, it can be assumed that groundwater abstraction has had some adverse impact around Water Supply Island. This area has since recovered with decommissioning, but otherwise the majority of the groundwater wells (64%) are exhibiting a natural fluctuation in salinity as a result of river flow and drought periods, despite the impact of abstraction on groundwater storage. Severe droughts show as high spikes with a hysteresis that varies with distance and connection to river recharge that may persist over several years. Eventually the EC decreases after sufficient river recharge events in the majority of monitoring wells.

7.1.2.1 Monitoring of assessment wells

The monitoring of EC within private wells is a condition of licensing within Basin A groundwater area. Assessment wells within Basin A sub-area 002 and 003 are monitored on a quarterly basis; in sub-area 001 wells are monitored on a monthly basis owing to the general higher salinity groundwater of that area. There are 139 assessments with EC measurements that extend from the mid-1980s until the present. Many assessment areas have more than one well and some of the EC measurements have been conducted on different wells on different occasions. From other assessment areas, samples represent the EC of water from a combination of wells and, at times, different combinations of wells depending on which licensed well was being used for a water supply.

As a consequence, the records of EC from private wells are unreliable as indicators for EC trends. Most assessments have a scatter of EC measurements over some range that equate to 100 ~ 2600 mg/L TDS. The principal trends in EC were:

- oscillating, with a period of 3 to 4 years,
- increasing,
- decreasing,
- spreading (increasing maximums or decreasing minimums, or both), and
- scattered or equilibrium.

Some wells had peaks in groundwater EC during no flow intervals that increased over time, but after a recharge event returned to an EC similar to before the no flow event. In some cases an assessment area with high EC groundwater would have new wells drilled and attain a lower EC water supply. In other instances, the water quality of the new well would deteriorate quickly to the condition of the previous well. Most EC maximums were associated with drought periods, the 1993/94 interval being the most conspicuous. The intervals of flow and no flow, groundwater abstraction, evapotranspiration and the EC of infiltrating surface water influence the large variation in EC from private wells. For the growers to have a better indication of the trend in EC in their assessment area they should sample one well consistently. However, for compliance with licence regulations, the supply well should be monitored for EC also.

7.1.3 Groundwater storage in the Scheme wellfield

Within the Scheme wellfield there are 102 monitoring wells that have quality assured potentiometric head data for this research. However, 28 of these have short term records from 1988 to 1994, although monitoring recommenced in 1998; otherwise most monitoring has been continuous since 1976. A selection of 42 hydrographs are shown along with their locations in Figures 38, 39 and 40. Again the hydrographs are represented by the last three digits of their individual WIN database reference number, except for WIN numbers over 70420000, which are represented by the last five digits. Hydrographs within the river or nearby have a range in head up to 6 m, e.g. 344, 418 and 364. Hydrographs near production wells show a range in head up to 14 m, e.g. 446, 458 and 462. The monitoring wells that are distant from the river, the 20000 series, generally show minimal variation in head.

The large variation in potentiometric head in most monitoring wells make it difficult to ascertain definitive head trends. A qualitative assessment of hydrographs would indicate that there is a large fluctuation about a mean with no discernible decrease within any well. Again, linear regression analysis gave very poor correlation in all wells. After 1995 there has been numerous river flows, some representing the larger flows ever recorded, and many wells indicate an increase in head from this time on, e.g. 422, 423, 386, 442 and 458. This is symptomatic, not only of an increase in river recharge, but also a reduction in abstraction as the horticulturalists have access to surface water and are less reliant on the Scheme wellfield. Some monitoring wells indicate a continual increase in head since the beginning of monitoring, e.g. 450 and 455.

Around the largest yielding production well, namely P1/87, monitoring wells indicate a decrease in head within a 100 m radius. However, as waterlevels in the monitoring wells were declining in the area before the well began producing in 1992 as consequence of the low flow period between 1990 and 1995, the actual drawdown as a result of pumping is open to conjecture. At a distance of 190 m from the production well a monitoring well has waterlevels that have completely recovered, whereas within a 100 m radius of the production well the waterlevels as at 1998, had failed to recover beyond the low waterlevels recorded in 1993. Beyond this radius, groundwater abstraction within the Scheme wellfield has had minimal impact on groundwater storage within the older alluvium aquifer.

7.1.4 Groundwater quality in the Scheme wellfield

The groundwater well licence for the Scheme wellfield comprises a water resource management operation strategy that requires the Water Corporation to comply to a groundwater monitoring plan. The monitoring requires quarterly conductivity and temperature measurements and annual major ion analysis of groundwater from production wells (Water Corporation, 1999b). The analysis of chloride from the production wells has been used to assess the impact of groundwater abstraction from the Scheme wellfield on groundwater quality. Although there are 73 production wells within the scheme, only 35 are operational and rarely more than 20 are used during a calendar year. Generally, the Water Corporation only conduct the major ion analysis from operational wells.

Production wells with greater than 20 chloride measurements are presented in Figure 41. The chloride concentration has decreased in most instances, the exception being some of the shallow screened production wells, e.g. G70418641 and G70418642, where the chloride concentration is low and is related more to surface water quality and river flow incidence. Abstraction over no flow periods from the older alluvium effectively mines groundwater and chloride from storage; river recharge with a lower chloride concentration then replaces the lost storage. Production wells with deep screens and mixed depth screens show the greatest decrease in chloride concentration over time, e.g. G70418721, G70418741 and G70418762.

The analysis of major ions in groundwater from abstraction wells in the Scheme wellfield indicates no adverse impact on the groundwater quality within the Scheme wellfield owing to groundwater abstraction.

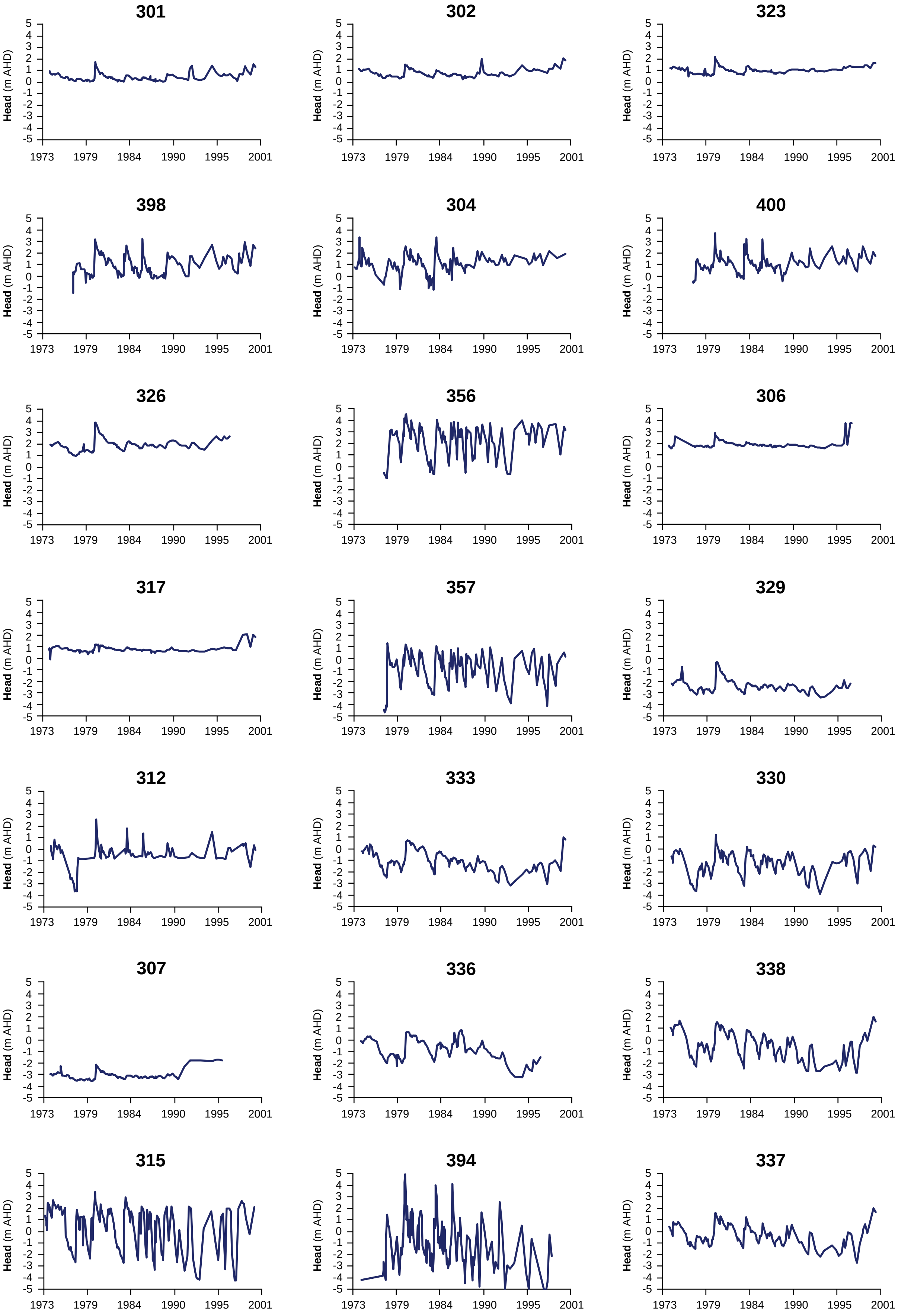


Figure 35 Selected well hydrographs from within Basin A

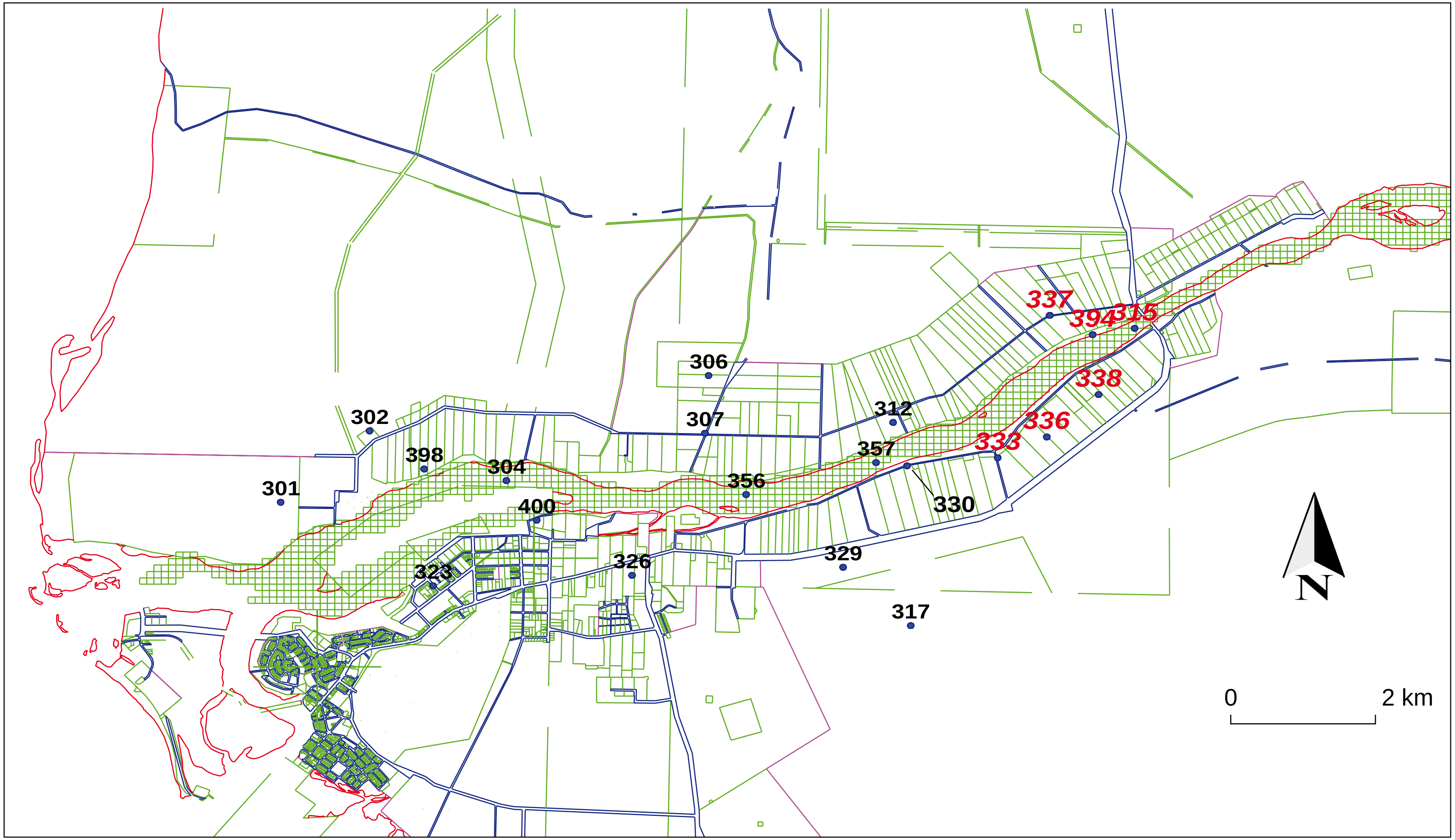


Figure 36 Basin A monitoring well locations for hydrographs

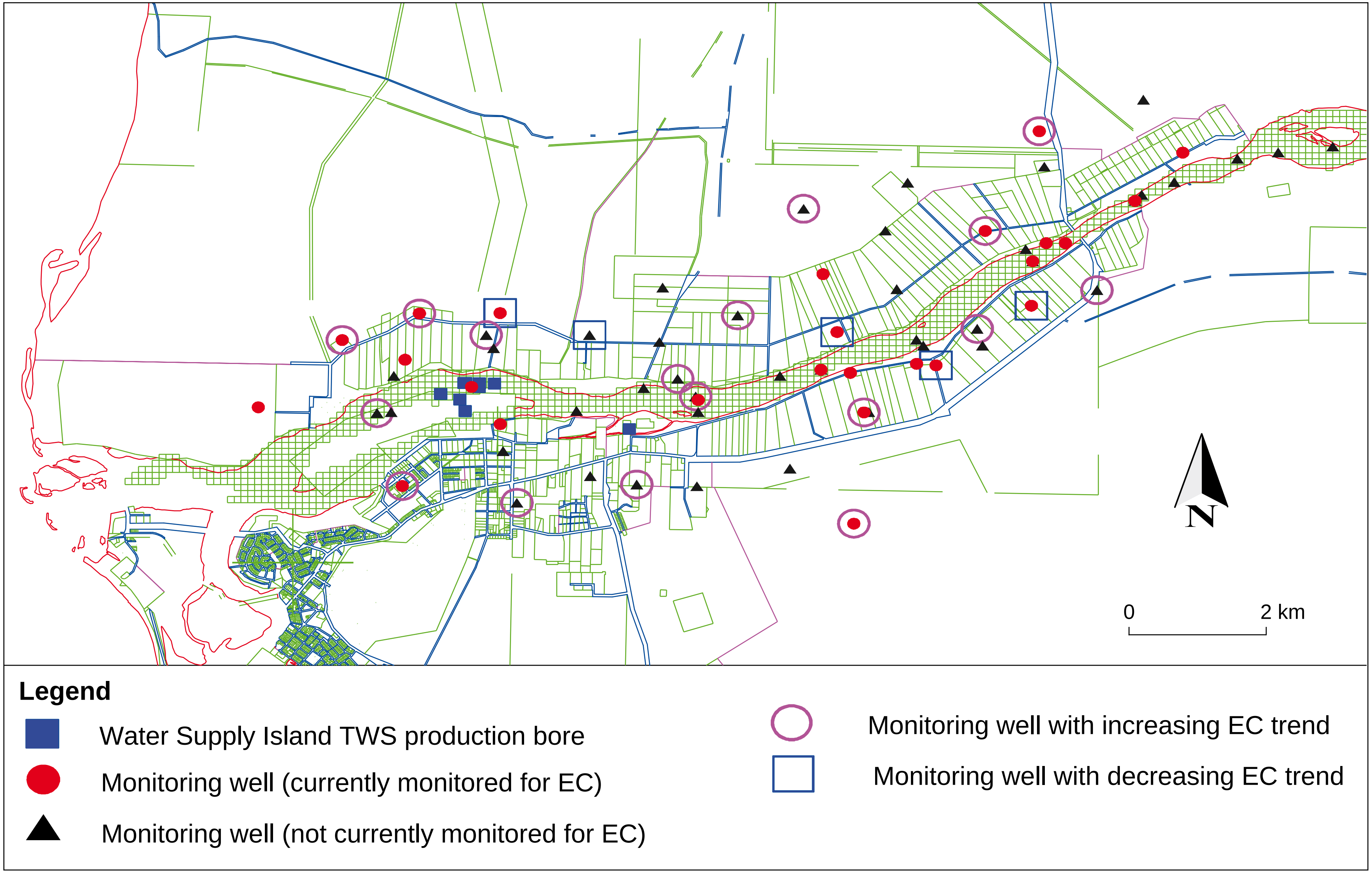


Figure 37 Basin A electrical conductivity monitoring

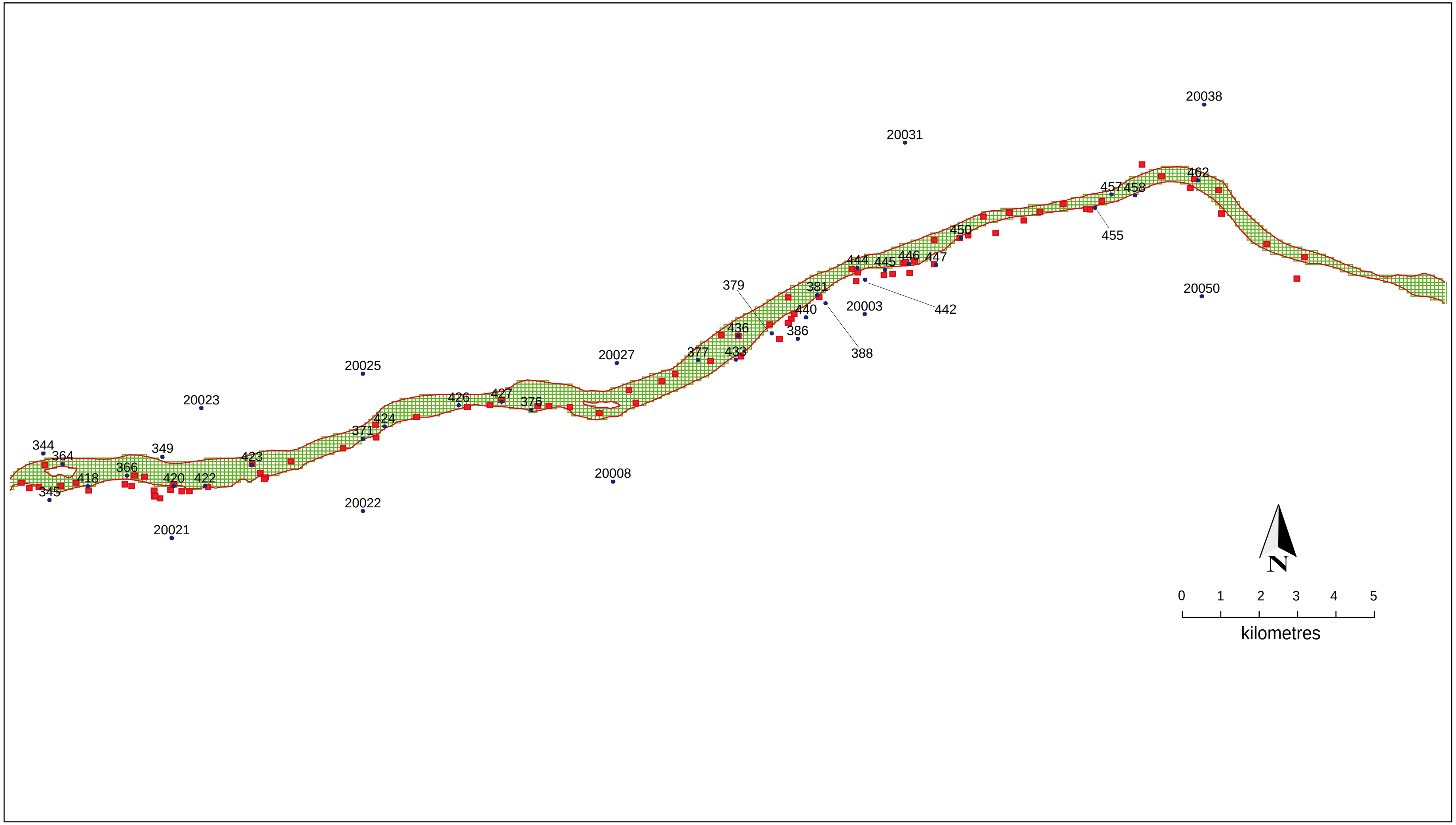


Figure 38 Scheme production and monitoring well locations for hydrographs

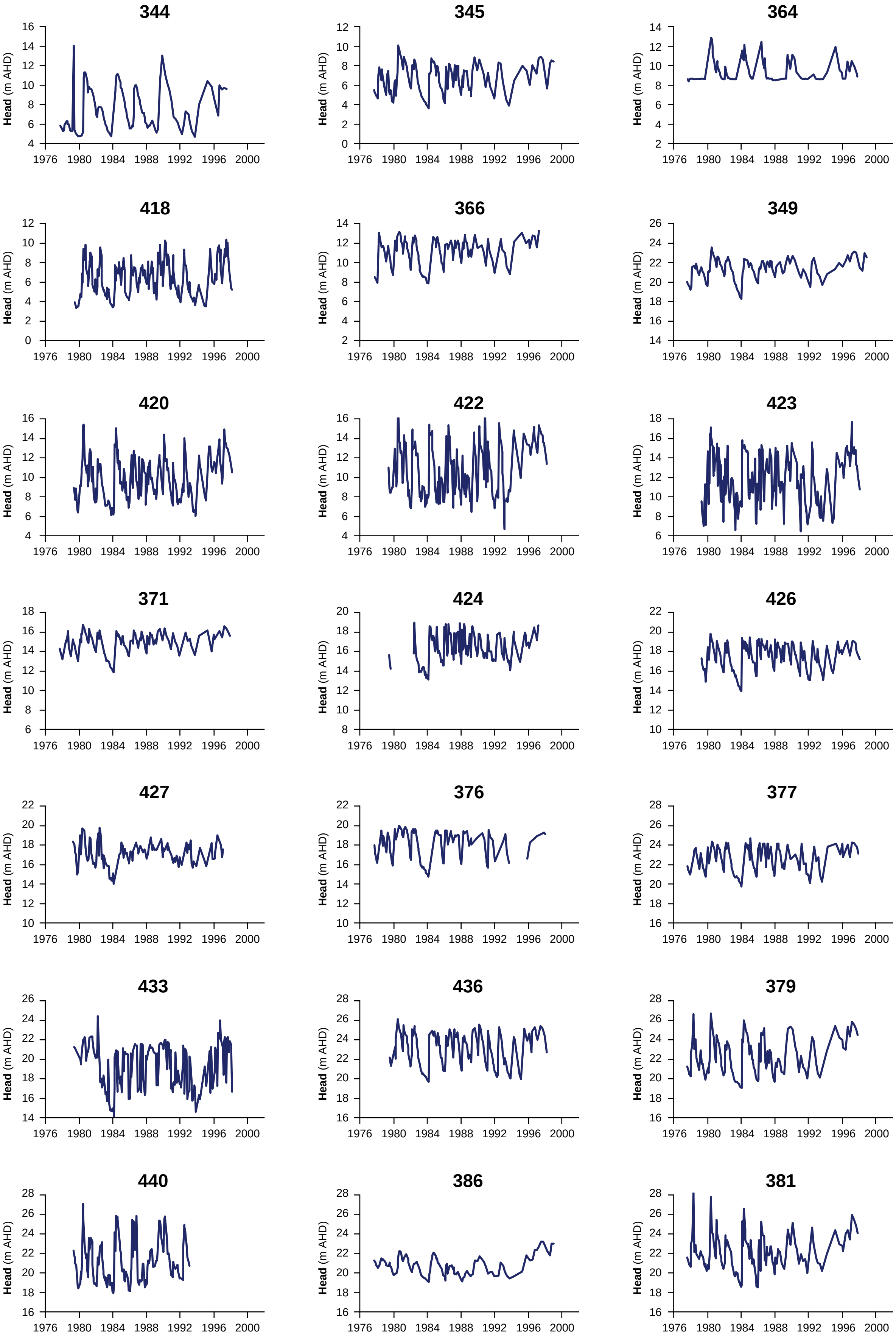


Figure 39 Scheme monitoring well hydrographs

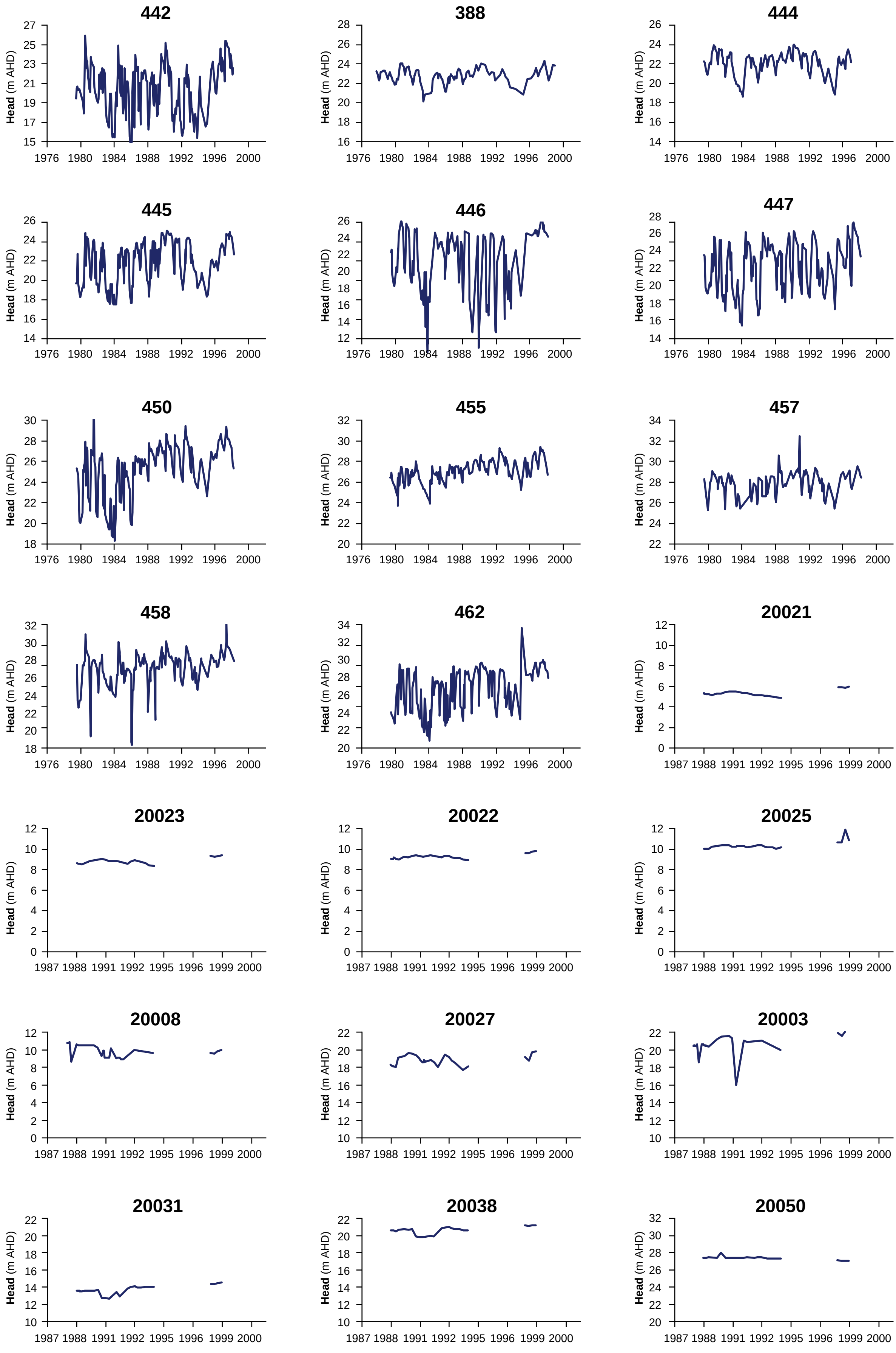


Figure 40 Scheme monitoring well hydrographs

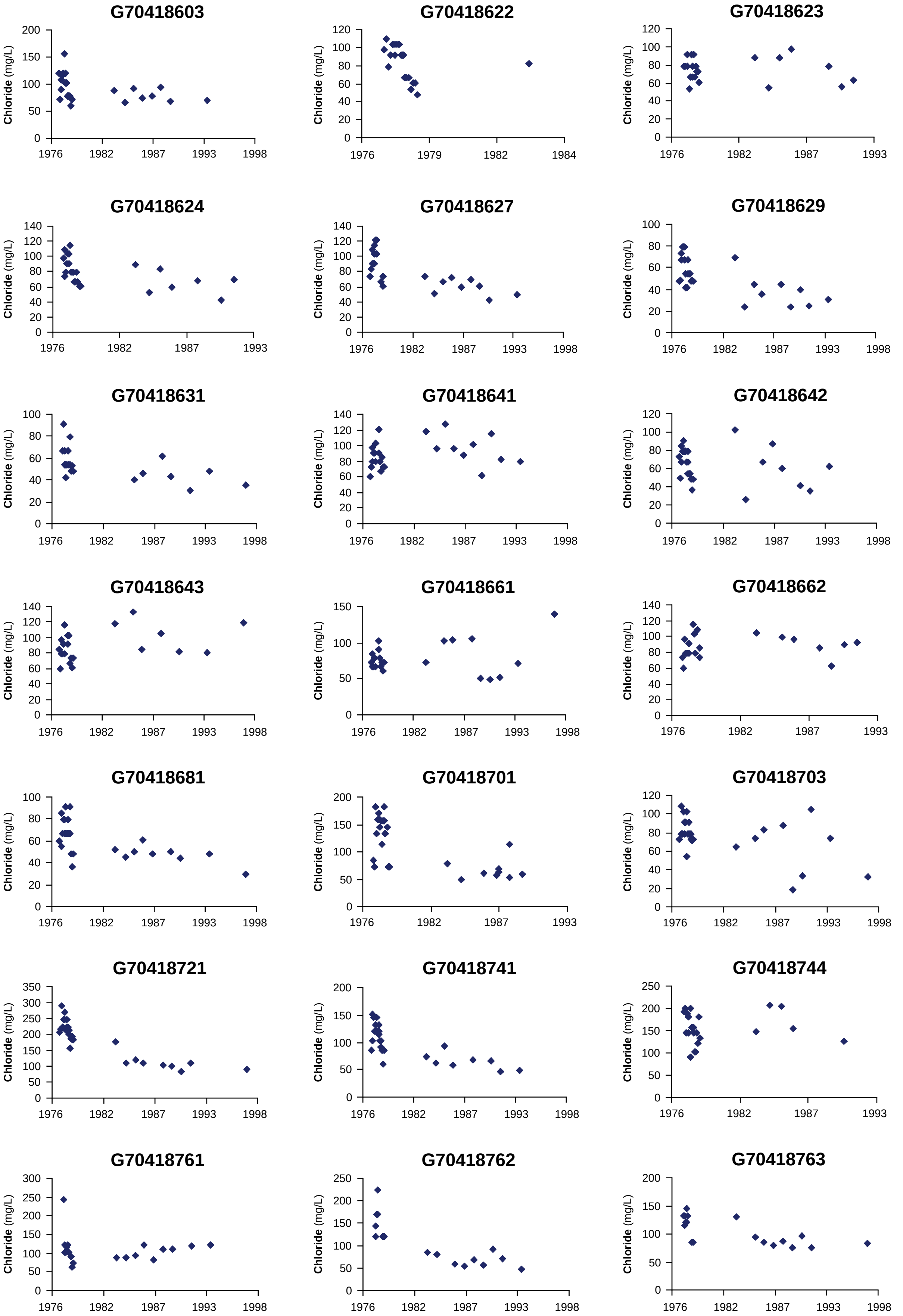


Figure 41 Chloride concentration of groundwater from production wells

7.2 Groundwater allocation

In the Carnarvon Groundwater Area, encompassing both Basin A and the Scheme wellfield, all abstraction wells are required to be licensed. Ownership of the groundwater is vested in the Crown and the allocation is subject to State legislation, the basis of which is constituted in the *Rights in Water and Irrigation Act 1914*. Groundwater management in Carnarvon has been through various Water Advisory Committees consisting of government representatives and the horticultural community. The record of rules, known as the 'Rules of the River', have been established over a long period of time and the earliest record of resolutions dates back to 1959 (Crinion, 1998). An attempt has been made to document those policies that are currently accepted as the basis for resolving management issues, from known minutes and records in a draft document by Crinion (1998). A summary from this draft document is given below.

A groundwater licence to take and use groundwater is generally issued with a unit allocation. The annual allocation for the Carnarvon Groundwater Area is set for the new fiscal year beginning July 1 and in the past was determined by the Carnarvon Water Allocation Advisory Committee (CWAAC). Each individual allocation is determined on the basis of the annual allocation for each fiscal year and the number of units of allocation held by an assessment. The maximum allocation for one unit of allocation in Carnarvon is equivalent to 72 000 kL per annum. The CWAAC determine a target annual draw from the groundwater reserves and deduct the town water supply (TWS) requirements. A percentage of allocation to be used is determined by CWAAC and this percentage is used to divide the target annual draw less the TWS. This volume has fixed allocations subtracted from it and is divided between the total number of units allocated within Carnarvon. This gives the annual allocation to each individual unit for the fiscal year.

There is some discrepancy in the recorded number of unit allocations within Carnarvon. The Carnarvon irrigation water allocation monthly district summary gives 192 assessments with 169.66 units, Crinion (1998) reported 166.79 units and although this document was only a draft. The Carnarvon Water Source plan (Water Corporation, 1999a) states 185 allocation units and 176 assessments. Finally, the Water and Rivers Commission database indicates 171 assessments with licensed wells, although not all are irrigators; however there are no records indicating the individual units of allocation for each assessment.

Given 169.66 units of allocation issued and a maximum annual allocation of 72 000 kL per unit, plus a fixed allocation of 0.47 GL, the maximum allocated groundwater draw is 12.67 GL per annum. A fixed allocation is an allocation made to non-plantation users and is held constant until three years after no flow when it is then set to zero. The units of allocation maybe drawn from either the Scheme wellfield or from licensed private wells within Basin A; the maximum monthly draw is set at 13.888% of the annual allocation. After all this consideration, there is unrestricted pumping whenever surface water is flowing over Bibbawarra Crossing.

For the set annual allocation for each fiscal year the cost of water from the Scheme wellfield is 24.5 cents per kilolitre, after which there is an incremental cost increase per kilolitre drawn governed by the total consumption. The maximum charge is $3.59 per kilolitre in excess of 11 000 kL for the month. There is no financial penalty for groundwater abstraction within Basin A. However, to extract groundwater from Basin A an assessment must have a prolongation. In October 1990 general conditions were established for prolongations such that '*properties fronting a river, water course or vacant land shall receive consideration for granting licenses to construct and use wells within the area contained within the projection of the side boundaries at the frontage up to the centre line of the river'* (Crinion, 1998). Numerous provisions and special cases including access to the river without frontage were also considered. The last condition of access to groundwater within Basin A is that the water quality from the licensed well must be less than 1000 mg/L TDS.

From an economic viewpoint, it is more attractive to extract groundwater from within Basin A rather than the Scheme wellfield. However, not all irrigation licensees have access to the river via prolongations, and some areas have very limited supplies owing to a thin cover of riverbed sand within their prolongation or brackish groundwater within the older alluvium beneath the riverbed sand. Furthermore, with increased time since river flow, groundwater salinity within the riverbed sand and older alluvium begins to increase within Basin A. Eventually, declining waterlevels result in diminished yields from groundwater wells and/or if salinity increases above the licence limit, an irrigator must rely on the Scheme wellfield for their water supply until the next river flow.

The Water Corporation has a Community Service Obligation (CSO) to supply each irrigator 5000 kL per month for 20 months of a no flow period. However, the current Water Corporation licence of 6.8 GL/a is not sufficient for the Corporation to take this volume to meet its CSO. The Water Corporation is currently undertaking a rationalisation and upgrading of the Scheme wellfield infrastructure to ensure it can meet peak demand during a 2 year no flow scenario and has requested an increase in its licence allocation as a consequence of its obligations.

The water industry is currently in a state of major reform driven by national and local interests that recognise the environmental and economic forces impacting on a limited resource. There are considerable pressures facing water resource management in Carnarvon owing to the current water supply situation. The horticultural industry is facing increased competition for its markets from intrastate and interstate competitors. The maximum unit allocation of 72 000 kL per annum, with a maximum monthly draw of 13.888% (10 000 kL), has remained under a State moratorium for many years.

The average quantity of water used by each irrigator over the last ten years has been 48 200 kL/a (Water Corporation, 1999a). Only 10–12 irrigators actually used above the annual maximum allocation of 72 000 kL/a between 1994/95 and 1997/98 (Water Corporation, 1999a). However, it is estimated that 50% of irrigation land in Carnarvon is fallow, and that there is a genuine demand for increased water allocation to allow growth within the industry. There is also a need for security of supplies to enable planning which maximises the returns for the horticulturalists.

7.3 Groundwater availability

The response of river recharge and evapotranspiration to increased groundwater abstraction was simulated with the aid of GRFAMOD. Figure 34 shows that when groundwater pumping increases with time, although not excessively, adjustments to the overall water balance of the flow system occur in response to the increased abstraction. Any increase in abstraction will be balanced by an immediate change in storage over no flow intervals, which manifests in the form of a watertable decline and consequently a reduction in evapotranspiration loss. Subsequently, when river flow begins to recharge the aquifer, the lower watertable in the older alluvium results in greater induced leakage from the riverbed sand to the older alluvium as a new balance is established in the groundwater flow system of the older alluvium (Fig. 34c).

If groundwater pumping were to increase indefinitely, an unstable situation may arise where the declining watertable reaches a depth at which the maximum rate of leakage from the riverbed sand no longer results in recovery of the watertable in the older alluvium. Increases in groundwater pumping beyond this point would result in a continually declining watertable. The analyses of monitoring well hydrographs indicate that this point has not been reached as waterlevels are recovering after each river flow, the possible exceptions, being a slow decline within eastern parts of Basin A of the order of 3 m over 20 years (Figs. 35 and 36).

However, increasing groundwater abstraction is tempered by the ephemeral nature of the Gascoyne River and the limits imposed for the conservation of the groundwater dependent environment. Ventriss (1980) argued that a target supply should be defined as *'the supply level to be met during the second year after a significant recharge event*'. This assures an acceptable frequency of failure if one considers that the probability of a 22 month no flow interval from Nine Mile Bridge flow records is 0.1% (Fig. 10) with an annual recurrence interval of 43 years (Pearcey, 2000). During the first year after a flow event, a percentage in excess of the target supply could be provided, with progressive restrictions after the target year if the river fails to flow. The limiting factor in determining the target supply is the impact of temporarily lowering the watertable over no flow intervals on

- the groundwater dependent environment, and
- the groundwater salinity.

7.3.1 Groundwater dependent environment

The source of water used by the river gums has not been investigated on the Gascoyne River, however from research by Hookey, Loh and Bartle (1987), Thorburn

(1993), Marshall et al. (1997) and Landman (2000), it is likely that groundwater forms a major source of water for the river gums. Hatton and Evans (1998) list streamside eucalypt vegetation along inland rivers and streams in the arid zone as '*ecosystems certainly and entirely dependent on groundwater.'* Marshall (2001) estimated that the upper and lower environmental water requirements for the river gums along the Gascoyne River were between 4.25 and 1.6 GL/a respectively, of which groundwater is a major source. This was done by extrapolation of water use by river gums measured from experimental and natural conditions at other sites within Western Australia.

However, alternate sources of water for the river gums over the older alluvium include soil moisture, rainfall and flood inundation. The assumption of Hatton and Evans (1998) that the inland dry river ecosystems are entirely dependent on groundwater may overstate the case given that the trees occur in association with surface drainage. Furthermore, Hatton and Evans (1998) argue that where surface water, either permanent or ephemeral, is in recharge mode and develops a local groundwater mound, it is presumed that the ecosystems are not locally dependent on the groundwater. The argument primarily refers to lakes, but is applicable also to ephemeral rivers, and along the Gascoyne River, the riverbed sand is undoubtedly in recharge mode and a groundwater mound has developed that is dependent on river flow.

Ultimately, the plants and animals of Australian arid zone rivers are very opportunistic, owing to the large variability in flood frequency (Puckridge et al., 1998). Marshall (2001) noted, from a brief comparison of sets of aerial photos from Carnarvon to Rocky Pool covering 1976 to 1990, that little change in the extent of the riverine forest could be observed. Thus the current and past abstraction may have had some impact on the riparian environment at some time, but overall the ecosystem is adapted to the flow variability, and thus the watertable variability of the groundwater flow system.

GRFAMOD is a poor indicator for estimating the water requirements for the dependent environment as it coupled evaporation with transpiration demand; however, the latter is insignificant in comparison to the former. The estimated area of bare riverbed sand with a shallow watertable was 28.7 km^2 where potential evaporation was applied, as opposed to the area of river gums of 4.3 km^2 where transpiration was applied. The focus of the modelling was to estimate groundwater flow and recharge, and the estimate of evapotranspiration from the modelling output is indicative only. The groundwater model will produce estimates of depth to the watertable, but not whether these depths are causing stress or endangering the viability of the riparian environment.

Evapotranspiration demand has been determined by indirect methods and no direct measurements of water use at Carnarvon are available. It is recommended that the source and amount of water used by the river gums be investigated along the Gascoyne River to improve the understanding of the groundwater dependence of river gums and their environmental water requirements. Importantly, the depth to which the riverine environment can extract groundwater is of interest, as shallow rooted juvenile trees must rely on the surface water of the Gascoyne River as the watertable on the banks of the older alluvium is generally 10 m below the surface or greater.

7.3.2 Groundwater salinity

The interaction between surface water and groundwater, and the impact of evapotranspiration and groundwater pumping influence groundwater salinity. Monitoring of EC within Basin A and the chloride concentration within production wells from the Scheme indicates an increase in salinity over no flow intervals. The increase in salinity within the riverbed sand is a direct result of evaporation. Groundwater pumping from the older alluvium over no flow intervals mines groundwater storage from the aquifer. The longer the no flow interval the greater the impact of pumping, drawing in water towards the pumping well from farther away where higher salinity groundwater may occur. After a river flow, fresh groundwater replaces storage lost during the no flow interval and the net result has been a reduction in the chloride concentration, particularly within the Scheme wellfield and especially from wells with the deepest screened intervals (Fig. 41).

The same impact could be expected within Basin A from groundwater pumping. However, within Basin A, the extent of fresh groundwater is less, resulting in brackish groundwater being encountered earlier during a no flow interval than in the Scheme wellfield. Groundwater abstraction from Basin A is also concentrated in the upper portion of the older alluvium aquifer, owing to the brackish water quality occurring at depth. The licence conditions of Basin A prevent the abstraction of groundwater above 1000 mg/L TDS. As a consequence, the impact of groundwater abstraction on Basin A salinity is less apparent. Some production and monitoring wells have a declining salinity trend, while in other areas with poor connection to recharge water, salinity has an increasing trend. Ultimately, the lowering of the watertable at a greater rate by groundwater abstraction would eventually result in a reduction in salinity, owing to the reduction in evaporation from the shallow watertable.

7.3.3 Groundwater allocation limit

The allocation limit is the maximum level of groundwater allocation, as authorised by the Water and Rivers Commission, that can be utilised over a specified time interval, which allows acceptable levels of pumping stress but protects the dependent social, economic and environmental values of the groundwater flow system. Water resource managers have always taken a precautionary approach to setting allocation limits of water for consumptive use to avoid unacceptable risk to both the communities relying on the aquifer system and the groundwater dependent environment. The present groundwater allocation limit is 12.4 GL, of which 5.6 GL is allocated from Basin A and 6.8 GL is allocated from the Scheme.

After the implementation of the COAG water reform the allocation limit must consider the water requirements of the dependent ecosystem, known as the environmental water requirements (EWRs). The volume of water that will be provided to the environment after consideration of the social and economic impacts of such a requirement for the environment is known as the environmental water provision (EWP). Generally, the allocation limit is defined on an annual basis and derived from consideration of annual recharge over the area where the groundwater flow system receives recharge and a percentage of this recharge is allocated for the environment. Compliance is effected by identifying a series of monitoring wells or network with specified maximum depths to the watertable to ensure the EWPs are not being breached by the consumptive use of groundwater. However the flow variability creates large fluctuations in the waterlevels and the setting of such EWP 'trigger' depths is fraught with difficulty.

The flow variability of the Gascoyne River, and thus the variability in recharge events, leads to the extension of the specified time interval for which an allocation limit should be considered. For example, in comparing the analysis of modelling output on an annual basis versus the consideration of flow events, the former suggested an expected annual recharge of 6.8 GL while the latter indicated an expected recharge of 17 GL from a flow event. The extension of the specified time interval for allocation was first introduced in the area by the target supply concept. Ventriss (1980) recommended meeting a target supply in the second year after a recharge event as a management option for allocation.

Furthermore, the determination of a safe yield is hindered by the variability of abstraction. Increased groundwater abstraction lowers the watertable and increases the vertical hydraulic gradient within the aquifer. A lower watertable also allows for greater recharge, as there is a greater capacity to receive surface water. In a groundwater flow system where, in general, there is an abundance of surface water lost to the ocean during river flow, the greater the groundwater abstraction the greater the anticipated recharge from a flow event, owing to the increased vertical hydraulic gradient and the increased storage capacity of a lower watertable at the onset of river flow. However, if EWPs are applied using a maximum depth to watertable for the conservation of the groundwater dependent environment, this is in direct conflict with a management principle that would allow maximum utilisation of the resource.

The solution is an adaptive management approach. It is recommended that the allocation limit be increased in stages and the management of allocation adapted after evaluation of the aquifer response to recharge events, and the response of the dependent environment to the stress applied by the increased allocation. This represents the only method for ensuring the maximum sustainable allocation is reached.

The argument for increased allocation from the Scheme is supported by the hydrographs from the Scheme wellfield that indicate the present allocation is within the limits of the sustainable yield (Figs. 39, 40 and Appendix D). Furthermore, numerical simulations of increased abstraction indicate that the Scheme resource is being underutilised. To test this hypothesis, a simulation consisting of 18 GL per annum abstraction was conducted over a two year no flow interval and compared to a no abstraction scenario with the same no flow interval. Average monthly rainfall and evapotranspiration rates from Carnarvon were applied over the two year period, with the year running from May to April.

Historical abstraction records were used to generate abstraction from Basin A while Scheme well yields were invented using Water Corporation installed capacity yields as a guide (Coleman, 1993). The current well infrastructure within the Scheme was unable to sustain the increased abstraction and a total of 28 ‘new wells’ were invented to meet demand. These new wells were assumed to be screened over the entire older alluvium aquifer and to be relatively low yielding (~500 m^3/day). Shallow screened wells within the Scheme were excluded from pumping.

Twenty-three Basin A assessment wells failed over the two year no flow scenario. A well was deemed to fail if the corresponding model cell went dry during the simulation. Abstraction from these wells was replaced by increasing yields from the Scheme wells to maintain an 18 GL/a average. Over the two year period approximately 30% of abstraction was drawn from Basin A and 70% from the Scheme. However the model does not consider solute transport and these figures are probably misleading; many more Basin A wells may be de-licensed over this period owing to increases in salinity above 1000 mg/L.

At the end of the two years no flow with 18 GL/a abstraction groundwater storage in the riverbed sand had fallen to 4.9 GL, assuming a specific yield of 0.3, and that the storage at the beginning of the simulation was at the cease to flow level (28 GL). This compared to an estimated 17 GL of storage after two years of no flow with no abstraction. The storage depletion from the no abstraction scenario changed little in the second year of no flow, from 18.8 GL down to 17 GL. This indicates that the watertable was below the depth for evaporation to occur (> 0.6 m) and that transpiration from the river gums is a relatively minor component, less than 1.8 GL/a in the second year of a no flow interval.

The depletion volume gives the change in groundwater storage in the older alluvium. As no flow conditions extend, a greater percentage of groundwater is lost from the older alluvium as the riverbed sand begins to dry. With no abstraction, the depletion volume of the older alluvium is minimal, as groundwater outflow is minimal. However, with 18 GL/a abstraction, the older alluvium storage was depleted by 23.5 GL over the two years. Most of the groundwater loss in the no abstraction case takes place within the riverbed sand via evapotranspiration. With the abstraction scenario the riverbed sand is depleted at a greater rate and evapotranspiration losses are reduced by 40%, from 18.3 down to 10.7 GL. Most of this reduction is anticipated to come from reducing the evaporation loss. Given that the current annual average abstraction of 9.8 GL was estimated to reduce evapotranspiration loss by 30%, the extra abstraction caused a reduction in existing evapotranspiration volume loss of approximately 10%.

The impacts of increasing groundwater abstraction are:

- to increase the rate and volume of storage depletion in the riverbed sand,
- to reduce groundwater lost to evapotranspiration, and
- to increase the rate and volume of storage depletion in the older alluvium.

Abstraction at 18 GL/a represents an increase on the maximum historical abstraction rate for any one year by roughly 40%. In general 18 GL/a represents an 80% increase in yield from the aquifers compared with the average per annum abstraction over the last five years. Under a two year no flow scenario Basin A would be severely impacted by low waterlevels. However, an equivalent quantity to the loss of supply from Basin A can be met by increasing yield from the Scheme. Storage depletion in the riverbed sand will be replaced by the next river flow, however depletion of the older alluvium aquifer takes longer to achieve. The recovery in waterlevels in the older alluvium will depend on abstraction volume, river flow stage height and duration.

Increasing groundwater abstraction reduces the volume of water lost to evapotranspiration by lowering the watertable at a greater rate. This reduces the amount of water available for evapotranspiration; it is not known what impact the reduction would have on the riparian environment. The extra depletion within the riverbed sand was extrapolated to a depth below the cease to flow level using the constructed saturated volume graph of Figure 24A. Averaged over the entire area of the riverbed sand the difference in watertable below the cease to flow level was 2.4 m, from 1.3 down to 3.7 m below the cease to flow level, or an extra 6 mm/day in watertable decline for the 18 GL/a abstraction. However, most of this decline would come in the beginning of the no flow period.

The estimated decline in the watertable within the older alluvium is given assuming that the groundwater storage depletion in the older alluvium was within the 1000 mg/L TDS area of 185 km^2. The total decline in head between the two simulations is 1.27 m; averaged over the entire two year interval this equates to little more than 2 mm a day. However, groundwater pumping would be concentrated around the production well heads where watertable declines would be in tens of metres, reducing with radial distance from the abstraction point. Where production wells were absent the impact would be negligible. If groundwater abstraction was concentrated beneath the area of the riverbed sand only, the rate of decline in head would be of the order of 11 mm/day averaged over a two year period, which represents an 8 m decline in head from a full aquifer level. The variation in the watertable level near the river, but away from pumping wells, as a result of historical abstraction is approximately 6 m.

Groundwater resources could be allocated as a percentage of the total fresh groundwater storage within the system for no flow intervals. Groundwater storage would be released where the watertable or potentiometric surface is permanently reduced. However, this abstraction must be concentrated within the Scheme wellfield.

Furthermore, the increased abstraction would see a greater depletion rate within the riverbed sand that could manifest itself in poor well yields and higher salinity in Basin A occurring earlier than previously experienced during an extended no flow event. However, in the long term salinity would probably decrease in response to the reduced evapotranspiration from a lower watertable.

Production well locations would also need careful planning to avoid mutual interference between wells and to limit the extent of drawdown in areas where the riparian environment would be most susceptible to large changes in the watertable. However, given that the aim is a lowering of the watertable or potentiometric surface to increase the space available for inducing recharge when a river flow occurs, a graduated increase in abstraction will be necessary to ensure no long term damage befalls the groundwater dependent environment.

Foster (1987) argued that the key to managing the inherent uncertainty in ephemeral rivers in arid environments is a flexible approach to increasing groundwater abstraction. The numerical modelling has indicated that increasing groundwater abstraction from the Scheme wellfield will yield greater water resources by altering components of the groundwater balance. However, the impact on the riparian environment is less certain. Allocation planning for environmental water requirements has generally resulted in the setting of maximum depths to watertable as criteria for protection of dependent ecosystems. However, in an environment where flow alternates with no flow events, great fluctuations in the depth to watertable occur. Innovative criteria, such as limiting the total pumping rate from individual bores, limiting the number of wells screened within the riverbed sand and concentrating abstraction at pre-determined distances from the river or river gum forest, provided freshwater occurs, are management options that need consideration.

Ultimately, the groundwater resources depend on river flow for replenishment; however, this research has shown that, with a greater appreciation of the variability within dynamic hydrologic systems, greater resources are available at no greater risk to the groundwater reserves. The challenge left it is to define the extent of groundwater dependence of the riparian environment to ensure that the environmental values of the Gascoyne River are sustained in perpetuity.

7.3.4 Recommendations for groundwater resource management

The aim of any groundwater management strategy in Carnarvon should be to maximise water resource availability for customer use while maintaining the integrity of the water resources and the dependent environment. There is no substitute for properly designed long term monitoring of the flow system, even considering the advent of high fidelity numerical modelling. Monitoring should be accompanied by quality assurance measures to ensure the data is of the utmost integrity. The regulator and utility require better operating systems to ensure the timely and electronic transfer of monitoring data from well head production figures to groundwater quality and potentiometric head monitoring. This will negate delays in decision making by regulators and ensure timely attention to undesirable effects that increased groundwater abstraction may cause.

The groundwater management strategy should limit the volume of groundwater abstraction in Basin A to the current level owing to the decline in head within the eastern margin of the basin and the incidence of localised increases in salinity. However, management options that allow optimisation of the use of groundwater in areas of Basin A that are sustainable should be considered. Water trading could be used as mechanism for shifting abstraction within Basin A to areas where it is sustainable and away from areas where groundwater salinity deteriorates rapidly after the cessation of river flow.

It is important that the Water and Rivers Commission gains an unambiguous understanding of the current allocation structure in Carnarvon. In conjunction with the Water Corporation, the Water and Rivers Commission must have up to date accounts of the total units of allocation and number of assessments with irrigation licences in the Carnarvon Groundwater Area. The Water and Rivers Commission needs to gain an appreciation of the shortfall between allocation and demand, if any, for assessing the level of allocation increase required to satisfy demand.

The quantity of groundwater available for allocation from the Gascoyne River floodplain aquifer is limited by the environmental requirements for the preservation of the groundwater dependent ecosystems in the area. This dependence however, is generally poorly understood, and although transpiration is an important component of the groundwater flow system of the riverbed sand, the ecosystems, dependence on groundwater from the older alluvium is not clear owing to the variation in the depth to water within the older alluvium. The source of water used by the river gums and the depth to which groundwater is accessed during the life cycle of the river gums should be investigated along the Gascoyne River.

The Water and Rivers Commission should give consideration to increasing allocation from the Scheme wellfield provided there is a need for greater water resources in the area. The Scheme wellfield area is capable of supplying 18 GL/a over two years of no flow. However, the impact of increasing abstraction should be reviewed to ensure no undesirable impacts are associated with the increased draw. Furthermore, the horticultural community, and in particular Basin A users, must be informed that increasing the abstraction from the Scheme wellfield will result in an increased reliance on the Scheme for water supply over no flow intervals, and that this reliance may occur earlier within a no flow interval than previously experienced. The increased reliance will be a manifestation of the increased rate of drawdown within the riverbed sand aquifer, the volume of storage removed being replaced by the next river flow. As a new equilibrium in the groundwater flow system is established under the increased abstraction scenario the net result will be lower salinity river flows and lower salinity groundwater within the riverbed sand.

The Water and Rivers Commission may need to consider incentives for converting water supply reliance to the Scheme wellfield to ensure not only the continued growth of the horticultural industry, but also the preservation of the groundwater dependent environment of Basin A. Limiting the development of the groundwater resources available within the Scheme wellfield, owing to concern about Basin A groundwater users, is in contrast to recommendations from the task force report on the Council of Australian Governments (COAG) water reforms. Basin A constitutes an inefficient wellfield, owing to the higher salinity groundwater in proximity to the riverbed and with depth in the older alluvium in comparison to the wealth of resources available from the ‘shoe-string sands’ of the Scheme wellfield.

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Appendix A Scheme wellfield data sheets

WIN reference number	Well name	Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
						Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL From	m BGL To	m AHD** From	m AHD** To	D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
	Gascoyne River bore cross sections																																
70418001	GRBXS -6MILE	1970.1971	E		Destroyed	49	774200	7248100			Cable tool or auger			5.142		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418002	GRBXS -6MILE-	1970.1971	E		Destroyed	49	774200	7248400			Cable tool or auger			6.559		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418003	GRBXS -6MILE	1970.1971	E		Destroyed	49	774200	7248600			Cable tool or auger			8.199		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418004	GRBXS -10MIL	1970.1971	E		Destroyed	49	779800	7251200			Cable tool or auger			8.586		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418005	GRBXS -10MIL	1970.1971	E		Destroyed	49	779800	7251200			Cable tool or auger			7.806		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418006	GRBXS -14MIL	1970.1971	E		Destroyed	49	785700	7252500			Cable tool or auger			14.539		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418007	GRBXS -14MIL	1970.1971	E		Destroyed	49	785800	7252800			Cable tool or auger			14.868		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418008	GRBXS -14MIL	1970.1971	E		Destroyed	49	785900	7253100			Cable tool or auger			15.017		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418009	GRBXS -18MIL	1970.1971	E		Destroyed	49	792000	7254100			Cable tool or auger			18.891		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418010	GRBXS -18MILE	1970.1971	E		Destroyed	49	791900	7254300			Cable tool or auger			17.075		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418011	GRBXS -18MIL	1970.1971	E		Destroyed	49	791800	7254500			Cable tool or auger			19.541		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418012	GRBXS -22MIL	1970.1971	E		Destroyed	49	798300	7254600			Cable tool or auger			23.341		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418013	GRBXS -22MIL	1970.1971	E		Destroyed	49	798300	7254900			Cable tool or auger			26.204		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418014	GRBXS -22MIL	1970.1971	E		Destroyed	49	798200	7255200			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418015	GRBXS -23MIL	1970.1971	E		Destroyed	49	799600	7256000			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418016	GRBXS -24MIL	1970.1971	E		Destroyed	49	801300	7256600			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418017	GRBXS -24MIL	1970.1971	E		Destroyed	49	801200	7256700			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418018	GRBXS -24MIL	1970.1971	E		Destroyed	49	800900	7257000			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418019	GRBXS -25 MI	1970.1971	E		Destroyed	49	802500	7257700			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418020	GRBXS -25MIL	1970.1971	E		Destroyed	49	802400	7257800			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418021	GRBXS -25MIL	1970.1971	E		Destroyed	49	802300	7257900			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418022	GRBXS -26MIL	1970.1971	E		Destroyed	50	196900	7258500			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418023	GRBXS -26MIL	1970.1971	E		Destroyed	50	196900	7258600			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418024	GRBXS -26MIL	1970.1971	E		Destroyed	50	196900	7258600			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418025	GRBXS -28MIL	1970.1971	E		Destroyed	50	199800	7260000			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2

WIN reference number	Well name	Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
						Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																					From	To	From	To									
70418026	GRBXS -29MIL	1970.1971	E		Destroyed	50	201600	7260500			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418027	GRBXS - 30MI	1970.1971	E		Destroyed	50	203100	7260800			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418028	GRBXS -30MIL	1970.1971	E		Destroyed	50	203100	7260900			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418029	GRBXS -30MIL	1970.1971	E		Destroyed	50	203100	7261000			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418030	GRBXS -33MIL	1970.1971	E		Destroyed	50	207000	7260100			Cable tool or auger			33.857		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418031	GRBXS -34MIL	1970.1971	E		Destroyed	50	208500	7259400			Cable tool or auger			35.866		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418032	GRBXS -34MIL	1970.1971	E		Destroyed	50	208500	7259500			Cable tool or auger			36.152		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418033	GRBXS -34MIL	1970.1971	E		Destroyed	50	208600	7259600			Cable tool or auger			34.43		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418034	GRBXS - 36MI	1970.1971	E		Destroyed	50	211200	7258600			Cable tool or auger			38.313		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418035	GRBXS -36MILE	1970.1971	E		Destroyed	50	211200	7258700			Cable tool or auger			37.106		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418036	GRBXS -36MIL	1970.1971	E		Destroyed	50	211300	7258900			Cable tool or auger			38.255		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418037	GRBXS -36MILE	1970.1971	E		Destroyed	50	212000	7258500			Cable tool or auger			38.133		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418038	GRBXS -36MILE	1970.1971	E		Destroyed	50	212000	7258600			Cable tool or auger			38.109		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418039	GRBXS -36MILE	1970.1971	E		Destroyed	50	212100	7258800			Cable tool or auger			38.362		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418040	GRBXS -37MILE	1970.1971	E		Destroyed	50	213200	7257800			Cable tool or auger			0.322		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418041	GRBXS -37MILE	1970.1971	E		Destroyed	50	213200	7257800			Cable tool or auger			40.288		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418042	GRBXS -37MIL	1970.1971	E		Destroyed	50	213300	7258000			Cable tool or auger			40.971		1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418043	GRBXS -37MIL	1970.1971	E		Destroyed	50	213300	7258200			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418045	GRBXS -39MIL	1970.1971	E		Destroyed	50	217000	7259000			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418046	GRBXS - 3.MI	1970.1971	E		Destroyed	50	216900	7259300			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418047	GRBXS -39MIL	1970.1971	E		Destroyed	50	216800	7259500			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418048	GRBXS -41MILE	1970.1971	E		Destroyed	50	218700	7259900			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418049	GRBXS - 41MI	1970.1971	E		Destroyed	50	218600	7260100			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418050	GRBXS -44MILE	1970.1971	E		Destroyed	50	223600	7258400			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418051	GRBXS -44MIL	1970.1971	E		Destroyed	50	223600	7258600			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
70418052	GRBXS - 44MIL	1970.1971	E		Destroyed	50	223600	7258800			Cable tool or auger					1" or 3"	PVC			Slotted PVC										Yes			1 & 2
	Old River channel bores																																
	ORCC 1	11-12.1968	O		Operational						Auger					25 *	Plastic			Slotted Plastic	24.69	25.67								Yes		Bores unused.Survey data RL to which S.L. Approx. 16 km south of river.	1, 3 & 4

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL From	m BGL To	m AHD** From	m AHD** To	D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
70418101	ORCC	2	11-12.1968	O		Operational	50	210723	7259022			Auger					25 *	Plastic			Slotted Plastic										Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418102	ORCC	3	11-12.1968	O		Operational	50	210621	7259851			Auger			42.559		25 *	Plastic			Slotted Plastic										Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418103	ORCC	4	11-12.1968	O		Operational	50	210928	7257302			Auger			45.656		25 *	Plastic			Slotted Plastic										Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418104	ORCC	5	11-12.1968	O		Operational	50	205104	7262722			Auger			42.202		25 *	Plastic			Slotted Plastic	16.16	17.68								Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418105	ORCC	6	11-12.1968	O		Operational	50	204298	7262274			Auger			41.706	0.608	25 *	Plastic			Slotted Plastic	14.48	15.55	26.62	25.55						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418106	ORCC	7	11-12.1968	O		Operational	50	202735	7261717			Auger			40.605	0.544	25 *	Plastic			Slotted Plastic	15.09	16.16	24.97	23.90						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418107	ORCC	8	11-12.1968	O		Operational	50	198273	7259926			Auger			36.384	0.591	25 *	Plastic			Slotted Plastic	16.16	17.23	19.63	18.56						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418108	ORCC	9	11-12.1968	O		Operational	50	198560	7259655			Auger			33.473	0.516	25 *	Plastic			Slotted Plastic	11.74	12.81	21.22	20.15						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418109	ORCC	10	11-12.1968	O		Operational	50	198719	7260121			Auger					25 *	Plastic			Slotted Plastic	13.26	14.33	22.59	21.52						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418110	ORCC	11	11-12.1968	O		Operational	50	197909	7259857			Auger			35.265	0.539	25 *	Plastic			Slotted Plastic	16.31	17.38	18.42	17.35						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418111	ORCC	12	11-12.1968	O		Operational	50	197728	7260407			Auger			34.567	0.543	25 *	Plastic			Slotted Plastic	16.01	17.07	18.01	16.95						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418112	ORCC	13	11-12.1968	O		Operational	49	796401	7250309			Auger			29.486	0.584	25 *	Plastic			Slotted Plastic	16.61	17.68	12.3	11.22						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418113	ORCC	14	11-12.1968	O		Operational	49	796838	7249746			Auger			30.178	0.483	25 *	Plastic			Slotted Plastic	21.19	22.56	8.51	7.14						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418114	ORCC	15	11-12.1968	O		Operational	49	785359	7251805			Auger					25 *	Plastic			Slotted Plastic	12.35	13.42	6.19	5.12						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418115	ORCC	16	11-12.1968	O		Operational	49	784497	7242769			Auger					25 *	Plastic			Slotted Plastic	9.91	10.98	7.68	6.79						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418116	ORCC	17	11-12.1968	O		Operational	49	782696	7253554			Auger					25 *	Plastic			Slotted Plastic	12.35	13.41	5.15	4.09						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418117	ORCC	18	11-12.1968	O		Operational	49	782339	7253930			Auger					25 *	Plastic			Slotted Plastic										Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418118	ORCC	19	11-12.1968	O		Operational	49	781533	7254409			Auger					25 *	Plastic			Slotted Plastic										Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418119	ORCC	20	11-12.1968	O		Operational	49	781043	7253803			Auger					25 *	Plastic			Slotted Plastic	14.79	15.85	.52	-.54						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418120	ORCC	21	11-12.1968	O		Operational	49	780011	7255579			Auger					25 *	Plastic			Slotted Plastic	11.74	12.81	.18	-.89						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418121	ORCC	22	11-12.1968	O		Operational	49	787539	7253915			Auger					25 *	Plastic			Slotted Plastic	11.13	12.2	9.88	8.81						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418122	ORCC	23	11-12.1968	O		Operational	49	788191	7254179			Auger					25 *	Plastic			Slotted Plastic	11.74	12.81	.211	-.86						Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418123	ORCC	24	11-12.1968	O		Operational	49	778205	7251058			Auger					25 *	Plastic			Slotted Plastic	13.57	14.63								Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
70418124	ORCC	25	11-12.1968	O		Operational	49	779293	7250667			Auger					25 *	Plastic			Slotted Plastic	10.82	11.89								Yes		Bores unused.Survey data RL to which S.L.	1, 3 & 4
	Carnarvon Extraction Area bores																																	
70418201	CEA	A69	These bores were drilled between 1964 and 1970	O		Operational	49	773824	7249760						12.359																			1
70418202	CEA	A169		O		Operational	49	775229	7249794						10.756																			1
70418203	CEA	21		O		Operational	49	775883	7250150						12.954																			1
70418204	CEA	22		O		Operational	49	776037	7249439						14.91																			1
70418205	CEA	23		O		Operational	49	776536	7250476																									1
70418206	CEA	26		O		Operational	49	778039	7251154						14.74																			1

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL From	m BGL To	m AHD** From	m AHD** To	D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
70418207	CEA	28	These bores were drilled between 1964 and 1970	O		Operational	49	779145	7251655					15.636																				1
70418208	CEA	33		O		Operational	49	779293	7252022																									1
70418209	CEA	112		O		Operational	49	782211	7253194					5.142																				1
70418210	CEA	+4AA		O	Yes	Operational	49	786224	7252865					19.375																				1
70418211	CEA	3JJ		O	Yes	Operational	49	786220	7252180		C			19.699																				1
70418212	CEA	11TT		O	Yes	Operational	49	786020	7252015		C			22.018																				1
70418213	CEA	29		O		Operational	49	778445	7250407					15.319																				1
70418214	CEA	30		O		Operational	49	778630	7249849					15.078																				1
70418215	CEA	31		O		Operational	49	777245	7249446					14.35																				1
70418216	CEA	32		O		Operational	49	776250	7248850					14.099																				1
70418217	CEA	14		O		Operational	49	785560	7247952					11.491																				1
70418218	CEA	A28		O		Operational	49	775148	7248533					13.002																				1
70418219	CEA	A151		O		Operational	49	773361	7247707					11.424																				1
70418220	CEA	RACE COURSE		O		Operational	49	771175	7246549					7.004																				1
70418221	CEA	B60		O		Operational	49	771592	7247742					9.333																				1
70418222	CEA	116		O		Operational	49	771250	7248800																									1
70418223	CEA	110		O		Operational																													1
	L-Series bores with no known screen depths																																	
70418301	CLS	L1-	23.09.74	O	Yes	Operational	49	767754	7248279		A	Auger	>152	16.24~	4.3	0.9	50*	PVC	16.24~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418302	CLS	L4-		O	Yes	Operational	49	768984	7249394		A	Auger			6.27																				1 & 4
70418303	CLS	L7-	27.02.73	O	Yes	Operational	49	771297	7249841		A	Auger	>127	21.66	6.06	0.81	76.2	PVC	21.66	-16.41	Slotted PVC													1 & 4
70418304	CLS	L8-	26.02.73	O	Yes	Operational	49	770879	7248618		A	Auger	>127	17.97	7.74	0.69	76.2	PVC	17.97	-10.92	Slotted PVC													1 & 4
70418305	CLS	L11-	20.09.74	O	Yes	Operational	49	772610	7249477		A	Auger	>152				50*	PVC			Slotted PVC												May not be cased. Poorly documented drillers report.	1 & 4
70418306	CLS	L14-	27.09.74	O	Yes	Operational	49	773680	7250260	DL14.INF	A	Auger	>152	20.86~	7.5		50*	PVC	20.86~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418307	CLS	L15-	19.09.74	O	Yes	Operational	49	773630	7249360	DLF15.INF	A	Auger	>152	12.8	8.74		50*	PVC	12.8		Slotted PVC												Poorly documented drillers report.	1 & 4
70418308	CLS	L16A	31-Sep-74	O	No	Operational	49	773900	7248750		A	Auger	>152	>30		0.8	50*	PVC	>30		Slotted PVC												Poorly documented drillers report. Trouble during construction. Cannot be located on ground.	4
70418309	CLS	L20-	10.10.74	O	No	Destroyed	49	774780	7249803		A	Auger	>152	14.30~	10.49	0.8	50*	PVC	14.30~		Slotted PVC												Poorly documented drillers report. Replacement for L16	1 & 4
70418310	CLS	L22-	03.03.73	O	Yes	Operational	49	775743	7251570		A	Auger	>127	18.86	8.52	0.22	76.2	PVC	18.86	-10.56	Slotted PVC													1 & 4
70418311	CLS	L23-	04.10.74	O	Yes	Operational	49	776030	7250486		A	Auger	>152	16.3~	11.82	0.8	50*	PVC	16.3~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418312	CLS	L24-	14.10.74	O	Yes	Operational	49	776236	7249527		A	Auger	>152	13.23~	11.5	0.8	50*	PVC	13.23~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418313	CLS	L30-	16.10.74	O	No	Operational	49	777269	7252001		A	Auger	>152	13.16~	12.21	0.8	50*	PVC	13.16~		Slotted PVC												Poorly documented drillers report. Bore unable to be located on ground.	1 & 4
70418314	CLS	L36-	06.03.73	O	Yes	Operational	49	779197	7252855		A	Auger	>127	16.73	12.96	0.63	50*	PVC	16.73	-4.4	Slotted PVC													1 & 4

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL From	To	m AHD** From	To	D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
70418315	CLS	L38-	07.03.73	O	Yes	Operational	49	779581	7251000		A	Auger	>127	16.15	14.941		76.2	PVC	16.15		Slotted PVC													1 & 4
70418316	CLS	L39-	12.03.73	O	Yes	Operational	49	780043	7250220		A	Auger	>127	20.79	13.63	0.43	76.2	PVC	20.79	-7.59	Slotted PVC													1 & 4
70418317	CLS	L43-		O	Yes	Operational	49	776481	7246351		A	Auger	>152	12.96~	6.09	0.8	50*	PVC	12.96~														Poorly documented drillers report.	1 & 4
70418318	CLS	L44-	17.09.74	O	Yes	Operational	49	771093	7249476		A	Auger	>152	13.34~	7.53	0.9	50*	PVC	13.34~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418320	CLS	L46-	10.09.74	O	Yes	Operational	49	770116	7249834		A	Auger	>127		6.79	0.85	50*	PVC			Slotted PVC												Poorly documented drillers report.	1 & 4
70418321	CLS	L10-	14.03.73	O	Yes	Operational	49	771544	7246696		A	Auger	>127	16.73	5.58	0.69	76.2	PVC	16.73		Slotted PVC													1 & 4
70418322	CLS	L5-	26.09.74	O	Yes	Operational	49	769494	7248183		A	Auger	>152	19.34~	6.13	0.8	50*	PVC	19.34~		Slotted PVC												Poorly documented drillers report. Two L5's shown at same site.	1 & 4
70418323	CLS	L6-		O	Yes	Operational	49	769864	7246975		A				5.55																			1 & 4
70418325	CLS	L12-	26.11.74	O	No	Operational	49	772416	7248218		A	Auger	>152	23.50~	9.06	0.8	50*	PVC	23.50~		Slotted PVC												Poorly documented drillers report. Bore unable to be located on ground.	1 & 4
70418326	CLS	L13-	25.11.74	O	Yes	Operational	49	772620	7247136		A	Auger	>152	14.68~	8.15	0.8	50*	PVC	14.68~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418327	CLS	L17-	21.11.74	O	Yes	Abandoned	49	774163	7248460		A	Auger	>152	9.10~	9.79			PVC			None												Bore cased but no piezometer fitted.	1 & 4
70418328	CLS	L19-	23.11.74	O	Yes	Operational	49	774180	7246970	DL19.INF	A	Auger	>152	13.16~	8.98	0.8	50*	PVC	13.16~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418329	CLS	L21-	20.11.74	O	Yes	Operational	49	775544	7247263		A	Auger	>152	14.78~	9.81	0.8	50*	PVC	14.78~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418330	CLS	L25-	18.11.74	O	Yes	Operational	49	776430	7248850	DL25.INF	A	Auger	>152	13.26~	11.51	0.8	50*	PVC	13.26~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418331	CLS	L27-	19.11.74	O	Yes	Operational	49	776630	7248195		A	Auger	>152	22.38~	11.38	0.8	50*	PVC	22.38~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418332	CLS	L28-	19.10.74	O	Yes	Operational	49	777110	7250240	DL28.INF	A	Auger	>152	17.7~	11.89	0.8	50*	PVC	17.7~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418333	CLS	L29-		O	Yes	Operational	49	777685	7248975		A				11.51																			1 & 4
70418334	CLS	L31	18.10.74	O	Yes	Operational	49	776944	7251207		A	Auger	>152	13.2	13.04	0.8	50*	PVC	13.2	-0.96	Slotted PVC													1 & 4
70418335	CLS	L32-	12.11.74	O	Yes	Operational	49	778288	7249579		A	Auger	>152	14.68~	12.44	0.8	50*	PVC	14.68~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418336	CLS	L33-	14.11.74	O	Yes	Operational	49	778366	7249300		A	Auger	>152	16.30~	11.92	0.8	50*	PVC	16.30~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418337	CLS	L34-	23.10.74	O	Yes	Operational	49	778417	7251793		A	Auger	>152	14.68~	13.42	0.8	50*	PVC	14.68~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418338	CLS	L35-	31.10.74	O	Yes	Operational	49	779082	7249963		A	Auger	>152	19.34~	13.36	0.42	50*	PVC	19.34~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418339	CLS	L37-	24.10.74	O	No	Destroyed	49	779269	7252268		A	Auger	>152	20.16~	14.67	0.8	50*	PVC	20.16~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418340	CLS	L40-	28.10.74	O	Yes	Operational	49	780725	7253378		A	Auger	>152	16.2	15.54	0.8	50*	PVC	16.2	-1.46	Slotted PVC												Poorly documented drillers report.	1 & 4
70418341	CLS	L41-	24.10.74	O	Yes	Operational	49	781300	7252500	DL41.INF	A	Auger	>152	17.82~	16.89	0.8	50*	PVC	17.82~		Slotted PVC												Poorly documented drillers report.	1 & 4
70418342	CLS	L42-	30.10.74	O	Yes	Operational	49	781175	7252014		A	Auger	>152	20.1	16.59	0.8	50*	PVC	20.1	-4.31	Slotted PVC												Poorly documented drillers report.	1 & 4
70418343	CLS	L47-	05.02.75	O	Yes	Operational	49	769905	7249068		A		>127	14.7	6.69	0.8	76.2	PVC	14.7	-8.01	Slotted PVC													1 & 4
70418347	CLS	L 26	13.03.73	O	Yes	Operational	49	776700	7248200		A	Auger	>127	17.57	11.37	0.76	76.2	PVC	17.57	-6.96	Slotted PVC													1 & 4

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
70418348	CLS	L 51	22.07.77	O	Yes	Operational	49	784390	7252250	DL51.INF	B	Auger	>76	19.49	18.129	0.51	50*	PVC	19.49	-1.87	Slotted PVC													1 & 4
70418350	CLS	L 53	25.07.77	O	Yes	Operational	49	785620	7252180	DL53.INF	C	Auger	>76	15.62	17.78	0.4	50*	PVC	15.62	1.76	Slotted PVC													1 & 4
70418390	CLS	L 62	04.08.77	O	Yes	Operational	50	199852	7259550	FB 205-31	J	Auger	>76	17.82	37.714	0.5	50*	PVC	17.82	19.394	Slotted PVC													1 & 4
70418472	CLS	L45A	12.09.74	O		Operational	49	771200	7249260		A	Auger	>152	14.56~		0.9	50*	PVC	14.56~		Slotted PVC												Poorly documented drillers report.	4
	Shallow L Series wells																																	
	CLS	L14 REDRILL		O		Operational	49	773700	7250530		A	Auger	>102	21.19		0.43	50*	PVC	21.19		Slotted PVC	15.19	21.19											4
	CLS	L8A	23.09.77	O		Operational	49	770880	7248280		A	Auger	>102	14.6		0.36	50*	PVC	14.6		Slotted PVC	8.46	14.6											4
70418344	CLS	L48	22.08.77	O	Yes	Operational	49	783060	7253330	DL48.INF	B	Auger	>102	14.3	19.16	0.5	50*	PVC	14.3	4.36	Slotted PVC	8.3	14.3	10.36	4.36									1 & 4
70418345	CLS	L49	15.07.77	O	Yes	Operational	49	783219	7252002	DL49.INF, FB222-16	B	Auger	>76	16.79	17.818	0.5	50*	PVC	16.79	0.528	Slotted PVC	10.79	16.79	6.53	0.53									1 & 4
70418346	CLS	L 50	19.08.77	O	Yes	Operational	49	784300	7253320	DL50.INF	B	Auger	>102	15.7	18.665	0.5	50*	PVC	15.7	2.46	Slotted PVC	9.7	15.7	8.46	2.46									1 & 4
70418349	CLS	L 52	16.08.77	O	Yes	Operational	49	786110	7253230	DL52.INF	C	Auger	>102	11.85	30.244	0.5	50*	PVC	11.85	17.89	Slotted PVC	5.85	11.85	23.89	17.89								Survey data suspect, 10 m higher than surrounding landscape	1 & 4
70418351	CLS	L 54	15.08.77	O	Yes	Operational	49	787110	7253420	DL54.INF, FB 222-17	C	Auger	>102	13.53	20.392	0.5	50*	PVC	13.53	6.36	Slotted PVC	7.53	13.53	12.36	6.36									1 & 4
70418352	CLS	L 55	08.07.77	O	Yes	Operational	49	787590	7252220	DL55.INF	C	Auger	>76	15.65	21.145		50*	PVC			Slotted PVC	6	15.65										Poorly documented drillers report.	1 & 4
70418353	CLS	L 56	12.08.77	O	Yes	Operational	49	788120	7253560	DL56.INF	C	Auger	>102	16.57	29.958	0.5	50*	PVC	16.57	12.88	Slotted PVC	10.57	16.57	18.88	12.88								Survey data suspect, 10 m higher than surrounding landscape	1 & 4
70418354	CLS	L 57	12.07.77	O	Yes	Operational	49	788990	7252480	DL57.INF	C	Auger	>76	16.37	21.895	0.5	50*	PVC	16.37	5.03	Slotted PVC	11	16.37	10.39	5.03									1 & 4
70418355	CLS	L 63	27.09.77	O	Yes	Operational	49	769700	7248200		A	Auger	102	14.79	6.748	0.58	50*	PVC	14.79	-8.622	Slotted PVC	8.79	14.79	-2.62	-8.62									1 & 4
70418386	CLS	L 58	01.08.77	O	Yes	Operational	49	802390	7256590	DL58.INF	G	Auger	>76	12.53	30.854	0.5	50*	PVC	12.53	17.82	Slotted PVC	6.53	12.53	23.82	17.82									1 & 4
70418387	CLS	L 59	28.07.77	O	Yes	Operational	49	803170	7257550	DL59.INF, FB 222-24	G	Auger	>76	18.84	33.021	0.4	50*	PVC	18.84	13.781	Slotted PVC	12.84	18.84	19.78	13.78									1 & 4
70418388	CLS	L 60	03.08.77	O	Yes	Operational	50	197300	7258300	LB 225-23	H	Auger	>76	13.32	34.525	0.5	50*	PVC	13.32	20.705	Slotted PVC	7.32	13.32	26.72	20.72									1 & 4
70418389	CLS	L 61	04.08.77	O	Yes	Operational	50	198600	7258600		H	Auger	>76	13.42	35.287	0.5	50*	PVC	13.42	21.867	Slotted PVC	7.42	13.42	27.36	21.36									1 & 4
70418391	CLS	L 64	24.08.77	O	Yes	Operational	49	782100	7252400		A	Auger	>102	13.43	9.128	0.5	50*	PVC	13.43	-4.802	Slotted PVC	7.43	13.43	1.198	-4.80								Bore unable to be located on ground.	1 & 4
70418392	CLS	L 65	29.08.77	O	No	Operational	49	780700	7251800		A	Auger	>102	19.96	7.082	0.35	50*	PVC	19.96	-13.228	Slotted PVC	13.96	19.96	-7.22	-13.22									1 & 4
70418393	CLS	L 66	02.09.77	O	Yes	Operational	49	779300	7251000		A	Auger	>102	25.76	15.073	0.54	50*	PVC	25.76	-11.227	Slotted PVC	21.76	25.76	-5.22	-11.22									1 & 4
70418394	CLS	L 67	07.09.77	O	Yes	Operational	49	779000	7250900		A	Auger	>102	19.73	13.658	0.5	50*	PVC	19.73	-6.572	Slotted PVC	13.73	19.73	-.572	-6.572									1 & 4
70418395	CLS	L 68	10.09.77	O	Yes	Operational	49	775400	7248800		A	Auger	>102	11.45	5.97	0.58	50*	PVC	11.45	-6.06	Slotted PVC	5.452	11.45	-.062	-6.062								Bore unable to be located on ground.	1 & 4
70418396	CLS	L 69	18.09.77	O	Yes	Operational	49	773400	7248600		A	Auger	>102	7.74		0.6	50*	PVC	7.74		Slotted PVC	1.74	7.74											1 & 4
70418398	CLS	L 70	29.09.77	O	Yes	Operational	49	769740	7248800		A	Auger	>102	9	6.387	0.5	50*	PVC	9	-3.113	Slotted PVC	3	9	2.887	-3.113									1 & 4
70418399	CLS	L 71	17.09.77	O	Yes	Operational	49	773300	7247000		A	Auger	>102	11.88	3.098	0.47	50*	PVC	11.88	0.748	Slotted PVC	5.88	11.88	-3.252	-9.252									1 & 4

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
70418400	CLS	L 72	23.09.77	O	Yes	Operational	49	771300	7248000		A	Auger	>102	11.1	6.878	0.5	50*	PVC	11.1	-4.722	Slotted PVC	5.1	11.1	1.278	-4.722									1 & 4
70418401	CLS	L 73	12.09.77	O	Yes	Operational	49	774200	7248200		A	Auger	>102	10	10.227	1.63	50*	PVC	10	-1.403	Slotted PVC	4	10	4.597	-1.403									1 & 4
70418402	CLS	L 74	14.09.77	O	Yes	Operational	49	777500	7249300		A	Auger	>102	18.43	7.032	0.42	50*	PVC	18.43	-11.818	Slotted PVC	12.43	18.43	-5.818	-11.818									1 & 4
70418408	CLS	L 75	18.10.78	O	Yes	Operational	50	201400	7260100		K	Auger	>102	19.62		0.66	50	PVC	19.62		Slotted PVC	13.62	19.62											1 & 4
70418409	CLS	L 76	16.10.78	O	Yes	Operational	50	202800	7260500	LB 218-2	K	Auger	>102	23.33	42.252	0.66	63	PVC	23.33		Slotted PVC	17.33	23.33											1 & 4
	OBS Series bores with no known screen depths																																	
		OB 19/78								LB 225-14					16.421																			
70418358	GR	OB 3/77		O	Yes	Operational	49	777400	7249400	LB 225-32	A				19.794																		Construction data not on file. Replaced by 1/85.	1 & 4
70418378	GR	OB 20/77	10.06.77	O	Yes	Operational	49	800439	7256029	FB 205-34	F	Auger	>76	10.82	25.475		50*	PVC	10.82		Slotted PVC												Need height agl to calculate screen depths.	1 & 4
70418397	GR	OB 26/77	16.06.77	O	Yes	Abandoned Site	50	199600	7260000		J	Auger	>76		34.257			None			None													1 & 4
70418464	GR	OB 5/77		O	Yes	Operational	49	780600	7251700		A				9.757																			1 & 4
70418465	GR	OB 5/77 B		O	Yes	Operational	49	780600	7251700		A																							1 & 4
70418466	GR	OB 2/77 B		O	Yes	Operational	49	776000	7248900		A																							1 & 4
	Shallow OBS series bores																																	
		OB 6A/77	17.05.77	O	Yes	Operational	49	783060	7252810		B	Auger	>102	3.17		0.58	50*	PVC	3.17		Slotted PVC	2.17	3.17											4
	GR	OB 26A/77	25.06.77	O		Operational	29	886329	7259778	FB 205-32	J	Auger	>76	13.04+			50*	PVC	13.04+		Slotted PVC	6	13.04											4
70418356	GR	OB 1/77	12.05.77	O	Yes	Operational	49	774200	7248400		A	Auger	>102	7.9	10.452	0.46	50	PVC	7.9	2.092	Slotted PVC	6	7.9	3.99	2.09									1 & 4
70418357	GR	OB 2A/77	28.06.77	O	Yes	Operational	49	776000	7248900		A	Auger	>76	8.39	7.025	0.61	50*	PVC	8.39	-1.98	Slotted PVC	6	8.39	.41	-1.98								Is this a redrill of OB 2/77 ?	1 & 4
70418359	GR	OB 3A/77	28.06.77	O	Yes	Operational	49	777400	7249000	LB 218-13	A	Auger	>76	9.17	7.25	0.5	50*	PVC	9.17	-2.41	Slotted PVC	6	9.67	1.26	-2.41								Is this a redrill of OB 3/77 ?	1 & 4
70418360	GR	OB 4/77	15.05.77	O	Yes	Operational	49	779100	7250700		A	Auger	>102	7.15	9.697	0.46	50*	PVC	7.15	2.09	Slotted PVC	6	7.15	3.24	2.09									1 & 4
70418361	GR	OB 4A/77	29.06.77	O	Yes	Operational	49	779100	7250700		A	Auger	>76	21.78	9.697	0.5	50*	PVC	21.78	-12.58	Slotted PVC	6	21.78	3.2	-12.58									1 & 4
70418362	GR	OB 5A/77	30.06.77	O	Yes	Operational	49	780600	7251700		A	Auger	>76	13.17	100	0.44	50*	PVC	13.17		Slotted PVC	6	13.13										Elevation TOC from SWRISS appears to be incorrect.	1 & 4
70418363	GR	OB 6/77	17.05.77	O	Yes	Operational	49	783057	7252813	LB 399-24, FB 177-28	B	Auger	>102	3.75	20.8	0.58	50*	PVC	3.75	7.41	Slotted PVC	2.75	3.75	17.47	16.47									1 & 4
70418364	GR	OB 7/77	17.05.77	O	Yes	Operational	49	783556	7253024	FB 177-28	B	Auger	>102	5.44	14.028	0.52	50*	PVC	5.44	8.07	Slotted PVC	3.44	5.44	10.07	8.07									1 & 4
70418365	GR	OB 8A/77		O	Yes	Operational	49	785200	7252700		C	Auger	>76	10.27	13.889	0.42	50*	PVC	10.27	3.2	Slotted PVC	6	10.27	7.47	3.2								Is this a redrill of OB 8/77 ?	1 & 4
70418366	GR	OB 8/77	18.05.77	O	Yes	Operational	49	785200	7252700		C	Auger	>102	6.13	13.889	0.48	50*	PVC	6.13	7.28	Slotted PVC	4	6.13	9.41	7.28									1 & 4
70418367	GR	OB 9/77	19.05.77	O	Yes	Operational	49	786000	7252500	LB 218-11	C	Auger	>102	4.45	15.965	0.43	50*	PVC	4.45	11.2	Slotted PVC	3.45	4.45	12.2	11.2								Replaced by 3/85	1 & 4
70418368	GR	OB 10/77	21.05.77	O	Yes	Abandoned	49	787300	7252400	LB 218-10	C	Auger	>76	13.55	17.617	0.5	50*	PVC	13.55	3.7	Slotted PVC	6	13.55	11.25	3.7								Replaced by 4/85	1 & 4
70418369	GR	OB 11/77	26.05.77	O	Yes	Abandoned	49	788200	7252900	LB 218-9	C	Auger	>76	11.9	17.218	0.48	50*	PVC	11.9	4.35	Slotted PVC	6	11.9	10.25	4.35								Replaced by 5/85	1 & 4
70418370	GR	OB 12/77	25.05.77	O	Yes	Abandoned	49	788500	7252600		C	Auger	>76	11.8	16.895	0.63	50*	PVC	11.8	4.46	Slotted PVC	6	11.8	10.26	4.46								Replaced by 6/85	1 & 4

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL From	m BGL To	m AHD** From	m AHD** To	D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
70418371	GR	OB 13/77	07.06.77	O	Yes	Abandoned	49	791246	7253741	FB 222-18	D	Auger	>76	9.9	17.842	0.43	50*	PVC	9.9	7.51	Slotted PVC	6	9.9	11.41	7.51								Replaced by 8/85	1 & 4
70418372	GR	OB 14/77	27.05.77	O	Yes	Abandoned	49	791700	7254200	LB 218-7	D	Auger	>76	7.62	18.219	0.5	50*	PVC	7.62	10.09	Slotted PVC	6	7.62	11.71	10.09								Replaced by 7/85	1 & 4
70418373	GR	OB 15/77	30.05.77	O	Yes	Operational	49	792200	7254400	LB 218-7	D	Auger	>76	7.62	18.865	0.4	50*	PVC	7.62	9.97	Slotted PVC	6	7.62	11.59	9.97									1 & 4
70418374	GR	OB 16/77	31.05.77	O	Yes	Operational	49	794600	7254900		E	Auger	>76	8.75	19.711		50*	PVC	8.75		Slotted PVC	6	8.75											1 & 4
70418375	GR	OB 17/77	02.06.77	O	Yes	Operational	49	794800	7254700		E	Auger	>76	9.86	20.974	0.46	50*	PVC	9.86	10.65	Slotted PVC	6	9.86	14.51	10.65									1 & 4
70418376	GR	OB 18/77	03.06.77	O	Yes	Operational	49	795560	7254572	FB 205-35	E	Auger	>76	9	20.296		50*	PVC	9		Slotted PVC	6	9											1 & 4
70418377	GR	OB 19/77	08.06.77	O	Yes	Operational	49	799834	7255985	LB 399-9, FB 205-34	F	Auger	>76	7.31	25.59	0.54	50*	PVC	7.31	17.71	Slotted PVC	6	7.31	19.02	17.71									1 & 4
70418379	GR	OB 21/77		O	Yes	Operational	49	801720	7256745	FB 177-7, LB 225-27	G	Auger	>76	15.99		0.6	50*	PVC	15.99	14.49	Slotted PVC	10	15.99	20.45	14.49									1 & 4
70418380	GR	OB 22/77		O	Yes	Operational	49	802600	7257000		G	Auger	>76	17.5	32.63	0.6	50*	PVC	17.5	14.53	Slotted PVC	11.5	17.5	20.53	14.53									1 & 4
70418381	GR	OB 23/77		O	Yes	Operational	49	802887	7257834	FB 181-12	G	Auger	>76	14.78	29.548	0.5	50*	PVC	14.78	14.27	Slotted PVC	8.78	14.78	20.78	14.78									1 & 4
70418382	GR	OB 24/77		O	Yes	Operational	50	197200	7258700	LB 225-23	H	Auger	>76	6.44	28.39	0.46	50*	PVC	6.44	21.49	Slotted PVC	5	6.44	22.93	21.49									1 & 4
70418383	GR	OB 25/77	14.06.77	O	Yes	Abandoned	50	197900	7258800		H	Auger	>76	5.29	29.922	0.5	50*	PVC	5.29	24.132	Slotted PVC	4	5.29	25.42	24.13								Replaced by 9/85	1 & 4
		OB 25/77A					50	197900	7258800	LB 218-6					27.643																			
70418385	GR	OB 25B/77	23.06.77	O	Yes	Operational	50	198200	7258700		H		>76	10.52+	32.036		50*	PVC	10.52+														Also known as OB25 (1/2) /77. Screen depths reported as 6 mbgl to 4.52 mbgl	1 & 4
70418410	GR	OB 27/78	14.10.78	O	Yes	Operational	50	201254	7260104	FB 205-29	J	Auger	>102	10.53		0.74	50	PVC	10.53		Slotted PVC	5.16	10.53										Shown as OBS 23/78 on plan.	1 & 4
70418411	GR	OB 28/78	12.10.78	O	Yes	Operational	50	203828	7260729	FB 205-27	J	Auger	>102	14.28	31.27	1	50	PVC	14.28	15.99	Slotted PVC	6.66	14.28	23.61	15.99								Elev. TOC and grid data not off SWRISS	1 & 4
70418412	GR	OB 29/78	10.10.78	O	Yes	Operational	50	204197	7261205	FB 205-26	K	Auger	>102	15	34.93	1.14	50	PVC	15	18.79	Slotted PVC	9.7	15	24.09	18.79								Elev. TOC and grid data not off SWRISS	1 & 4
70418413	GR	OB 30/78	06.10.78	O	Yes	Operational	50	205300	7261500		K	Auger	>102	3.54	35.14	1.07	50	PVC	3.54	24.53	Slotted PVC	4.93	9.54	29.14	24.53								Elev. TOC and grid data not off SWRISS. Called 30/77 on bore plan.	1 & 4
70418414	GR	OB 31/78	13.11.78	O	Yes	Abandoned	50	206800	7260600	LB 218-2	L	Auger	>102	10.05	32.426	0.6	50*	PVC	10.05		Slotted PVC	5.15	10.05										Replaced by 11/85.	1 & 4
70418415	GR	OB 32/78	14.11.78	O	Yes	Operational	50	206440	7260757	FB 205-25	K	Auger	>102	15.56		1.1	50*	PVC	15.56		Slotted PVC	11.56	15.56											1 & 4
70418463	GR	OB 2/77		O	Yes	Operational	49	776000	7248900		A	Auger	>102	4.87	6.855	0.46	50	PVC	4.87		Slotted PVC	3.87	4.87											4
	Production bore piezometers with no known screen depths																																	
70418416	GR	P5		O	No	Not Operational	49	782700	7252500		A				12.278																			1 & 4
70418417	GR	P7		O	No	Not Operational	49	783500	7252600		A				13.935																			1 & 4
70418419	GR	P3C		O	Yes	Operational	49	785400	7252700		C				15.062																			1 & 4
70418420	GR	P19		O	Yes	Operational	49	786400	7252400		C				16.44																			1 & 4
	Shallow production bore piezometers																																	
70418418	GR	P2/76	06.11.77	O	Yes	Abandoned	49	784200	7252400	LB 218-12	B	Auger	>102	19.34	18.651	0.66	63*	PVC	19.34	-1.349	Slotted PVC	15.94	19.34	2.203	-1.197								Replaced by 2/85	1 & 4
70418421	GR	P2/71	07.11.78	O	Yes	Operational	49	786800	7252200		C	Auger	>102	15.7	19.73	0.69	63*	PVC	15.7	3.34	Slotted PVC	9.85	15.7	9.19	3.34									1 & 4

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
70418422	GR	P2/73	08.11.78	O	Yes	Operational	49	787200	7252400		C	Auger	>102	12.33	17.903	0.9	63*	PVC	12.33	4.673	Slotted PVC	6.33	12.33	10.67	4.673									1 & 4
70418424	GR	P GP1	08.11.78	O	Yes	Operational	49	791800	7254100	LB 218-7	D	Auger	>102	10.87	18.435	0.96	63*	PVC	10.87	6.605	Slotted PVC	7.87	10.87	11.01	8.007								Also known as PGP1/78.	1 & 4
70418425	GR	P3/73	16.11.78	O	Yes	Operational	49	792620	7254370	LB 225-31	D	Auger	>102	10.11	13.867	0.76	63*	PVC	10.11	2.997	Slotted PVC	5.11	10.11	11.55	6.545									1 & 4
70418426	GR	P3/77	16.10.78	O	Yes	Abandoned	49	793700	7259700		E	Auger	>102	10.04	19.948	0.83	63*	PVC	10.04	9.078	Slotted PVC	4.04	10.04	15.08	9.078								Lost since 1980	1 & 4
70418427	GR	PGP2	15.11.78	O	Yes	Operational	49	794800	7254800		E	Auger	>102	11.15	20.38	0.79	63*	PVC	11.15	8.44	Slotted PVC	5.88	11.15	13.71	8.44									1 & 4
70418428	GR	P6/77	15.11.78	O	Yes	Operational	49	795200	7254700		E	Auger	>102	9.25	20.764	1	63*	PVC	9.25	10.514	Slotted PVC	5.25	9.25	14.514	10.514									1 & 4
70418430	GR	P9/77A	03.05.79	O	Yes	Operational	49	796200	7254400		E	Mud Rotary*		5	23.899	0.95	50	PVC	5	17.949	Slotted PVC	2	5	20.82	17.82								Assumes slots occur at base of bore. Also known as 9/77/79.	1 & 4
70418432	GR	P10/77A	22.06.79	O	Yes	Operational	49	800153	7255961	LB 399-8, FB 205-34	F	Mud Rotary*	NQ	9	28.21	0.6	50	PVC	9	18.61	Slotted PVC	6	9	21.32	18.32								Assumes slots occur at base of bore. Also known as 10.77.79.1.	1 & 4
70418434	GR	P14/74A	18.05.79	O	Yes	Operational	49	800800	7256000		F	Mud Rotary*		11	31.056	0.6	60*	PVC	11	19.456	Slotted PVC	5	11	25.46	19.46								Assumes slots occur at base of bore. Also known as 14/74/79-1.	1 & 4
70418438	GR	P8/74	11.11.78	O	Yes	Operational	49	802300	7256900		G	Auger	>102	16.63	32.899	0.6	63*	PVC	16.63	15.669	Slotted PVC	12.33	16.33	19.67	15.67									1 & 4
70418439	GR	P13/74	10.11.78	O	Yes	Operational	49	802400	7257100		G	Auger	>102	12.24	32.91	0.52	63*	PVC	12.24	20.15	Slotted PVC	7.24	12.24	25.15	20.15									1 & 4
70418440	GR	P10/74	09.11.78	O	Yes	Operational	49	802600	7257200	LB 225-26	G	Auger	>102	16.78	31.843	0.63	63*	PVC	16.78	14.433	Slotted PVC	13.78	16.78	17.85	14.85									1 & 4
70418442	GR	P9/74	03.11.78	O	Yes	Operational	49	803100	7257600		G	Auger	>102	16.38	32.302	0.66	63*	PVC	16.38	15.262	Slotted PVC	10.38	16.38	21.24	15.24								Also known as 9/74/78.	1 & 4
70418443	GR	P12/77A	25.05.79	O	Yes	Operational	50	197000	7258700		H	Mud Rotary		8	27.698	0.85	50*	PVC	8	18.848	Slotted PVC	5	8	21.85	18.85								Assumes slots occur at base of bore. Also known as 12/77/79-1.	1 & 4
70418445	GR	P22/74	26.10.78	O	Yes	Operational	50	197800	7258600		H	Auger	>102	18.22	36.329	0.66	63	PVC	18.22	17.449	Slotted PVC	12.22	18.22	23.45	17.449								Scrn. depths may be in error by approx. +/- 1 m. Also known as 22/74/78	1 & 4
70418448	GR	P12/74	26.06.78	O	Yes	Operational	50	199100	7258800		J	Auger	>102	20.62	35.429	0.59	63	PVC	20.62	14.22	Slotted PVC	18.12	20.62	16.72	14.22								Also known as 12/74/78	1 & 4
70418449	GR	P8/77A	19.06.79	O	Yes	Operational	50	199700	7259600		J	Mud Rotary	>76	14	33.745	0.6	50*	PVC	14	19.145	Slotted PVC	8	14	25.15	19.15								Also known as 8.77.79.1.	1 & 4
70418451	GR	P13/77A	31.07.79	O	Yes	Operational	50	203262	7260798	FB 205-27	J	Mud Rotary	>76	9	29.587	0.76	50	PVC	9	19.827	Slotted PVC	6	9	22.83	19.83								Assumes slots occur at base of bore. Also known as 13.77.79.1.	1 & 4
70418453	GR	P16/74	23.10.78	O	Yes	Operational	50	201700	7260200		J	Auger	>102	20	39.497	0.69	63	PVC	20	18.807	Slotted PVC	16	20	22.81	18.81								Scrn. depths may be in error by approx. +/- 1 m. Also known as 16/74/78	1 & 4
70418454	GR	P17/74A	21.10.79	O	Yes	Operational	50	203100	7260600		J	Auger	>102	16.81	41.364	0.61	63*	PVC	16.81	23.94	Slotted PVC	12.48	16.28	28.27	24.42								Also known as 17/74/78	1 & 4
70418456	GR	P16/77A	15.06.79	O	Yes	Operational	50	203500	7261000	LB 218-2	K	Mud Rotary	>76	20	30.219	0.6	50	PVC	20	9.619	Slotted PVC	14	20	16.90	10.90								Assumes slots occur at base of bore. Also known as 16.77.79.1.	1 & 4
	Deep production bore piezometers																																	
		P21.77.79	25.05.79	O	Yes	Operational	49	805190	7258800		H	Mud Rotary		56		0.6	50 *	PVC	56		Slotted PVC	50	56										Coordinates from Prod 21/77	4
70418423	GR	P5/76	07.05.79	O	Yes	Operational	49	788400	7253000		C	Mud Rotary*	-	30	17.612	0.79	50	PVC	30	-13.178	Slotted PVC	24	30	-7.178	-13.178								Assumes slots occur at base of bore. Also known as 5/76/79.	1 & 4

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
70418429	GR	P9/77	16.05.79	O	Yes	Operational	49	796200	7254400	LB 399-21	E	Mud Rotary*		53	21.05	0.79	50	PVC	53	-32.74	Slotted PVC	47	53	-23.891	-29.891								Assumes slots occur at base of bore. Also known as 9/77-79	1 & 4
70418431	GR	P10/77	22.06.79	O	Yes	Operational	49	800154	7255962	FB 205-34	F	Mud Rotary*	NQ	39	27.968	0.6	50	PVC	39	-11.632	Slotted PVC	33	39	17.632	-11.632								Assumes slots occur at base of bore. Also known as 10.77.79.	1 & 4
70418433	GR	P14/74	17.05.79	O	Yes	Operational	49	800800	7256000	LB 225-17	F	Mud Rotary*		38.76	31.283	0.6	60*	PVC	38.76	-8.077	Slotted PVC	32.76	38.76	-2.29	-8.29								Assumes slots occur at base of bore. Also known as 14/74/79.	1 & 4
70418435	GR	P11/77A	21.06.79	O	Yes	Operational	49	800864	7256676	FB 177-5	F	Mud Rotary*	NQ	26	27.126	0.6	50	PVC	26	0.526	Slotted PVC	20	26	6.53	0.53								Also known as 11.77.79.1.	1 & 4
70418436	GR	P11/77	20.06.79	O	Yes	Operational	49	800865	7256675	FB 177-5, LB 225-19	F	Mud Rotary*	NQ	58.53	26.808	0.6	50	PVC	58.53	-32.322	Slotted PVC	52.53	58.53	26.019	-32.019								Assumes slots occur at base of bore. Also known as 11/77.2 and 11.77.79	1 & 4
70418437	GR	P7/74	18.05.78	O	Yes	Operational	49	801000	7256600	LB 225-20	G	Mud Rotary*		59	33.071	0.6	60	PVC	59	-26.529	Slotted PVC	53	59	-20.485	-26.485								Assumes slots occur at base of bore. Also known as 7/74/79, AMG coordinates appear to be incorrect.	1 & 4
70418441	GR	P9/74A	21.05.79	O	Yes	Operational	49	803100	7257600			Mud Rotary*		39	32.531	0.55	60	PVC	39	-7.019	Slotted PVC	33	39	-1.019	-7.019								Also known as 9/74/79.	1 & 4
70418444	GR	P12/77	22.05.79	O	Yes	Operational	50	197090	7258630	FB 177-14	H	Mud Rotary		60	27.623	0.81	50*	PVC	60	-33.187	Slotted PVC	54	60	-27.187	-33.187								Assumes slots occur at base of bore. Also known as 12/77/79.	1 & 4
70418446	GR	P21/77	25.05.79	O	Yes	Operational	50	198400	7258800		H	Mud Rotary		56	29.104	0.6	50*	PVC	56	-27.496		50	56	-21.496	-27.496								Assumes slots occur at base of bore.	1 & 4
70418447	GR	P12/74A	26.05.79	O	Yes	Operational	50	199100	7258800		J	Mud Rotary		65.72	35.478	0.66	50*	PVC	65.72	-30.9	Slotted PVC	59.72	65.72	-24.9	-30.9								Also known as 12/74/79	1 & 4
70418450	GR	P8/77	18.06.78	O	Yes	Operational	50	199700	7259600		J	Mud Rotary	>76	55	33.77	0.6	50*	PVC	55	-21.83	Slotted PVC	49	55	-15.83	-21.83								Also known as 8.77.79.	1 & 4
70418452	GR	P13/77	30.05.79	O	Yes	Operational	50	201300	7260400		J	Mud Rotary	>76	36.3	29.689	0.73	50	PVC	36.3	-7.341	Slotted PVC	30.3	36.3	1.341	-7.34								Assumes slots occur at base of bore. Also known as 13/77/79.	1 & 4
70418455	GR	P17/74	04.06.79	O	Yes	Operational	50	203100	7260600		J	Mud Rotary	>76	59.62	41.349	0.6	65	PVC	59.62	-18.87	Slotted PVC	53.62	59.62	-12.87	-18.87								Also known as 17/74/79	1 & 4
70418457	GR	P16/77	16.06.79	O	Yes	Operational	50	203500	7261000		K	Mud Rotary	>76	50	31.589	0.6	50*	PVC	50	-19.011	Slotted PVC	44	50	-13.011	-19.011								Assumes slots occur at base of bore. Also known as 16.77.79.	1 & 4
70418458	GR	P18/74A	14.06.79	O	Yes	Operational	50	204100	7261000		K	Mud Rotary	>76	30.5	40.128	0.6	65	PVC	30.5	9.028	Slotted PVC	24.5	30.5	15.028	9.028								Assumes slots occur at base of bore. Also known as 18/74/79-1.	1 & 4
70418459	GR	P18/74	13.06.79	O	Yes	Operational	50	204100	7261000		K	Mud Rotary	PQ	80.16	40.149	0.6	65	PVC	80.16	-40.611	Slotted PVC	74.16	80.16	-34.611	-40.611								Assumes slots occur at base of bore. Also known as 18/74/79.	1 & 4
70418460	GR	P19/74A	08.06.79	O	Yes	Operational	50	205500	7261300		K	Mud Rotary	PQ	35	40.606	0.6	65	PVC	35	5.006	Slotted PVC	31	35	11.006	5.006								Assumes slots occur at base of bore. Also known as 19.74.79.1.	1 & 4
70418461	GR	P19/74	05.06.79	O	Yes	Operational	50	205500	7261300		K	Mud Rotary		69	40.474	0.6	65	PVC	69	-29.126	Slotted PVC	63	69	-23.126	-29.126								Assumes slots occur at base of bore. Also known as 19/74/79.	1 & 4
70418462	GR	PIRS	09.06.79	O	Yes	Operational	50	205700	7261500	LB 218-2	K	Mud Rotary	PQ	25	34.155	0.6	50	PVC	25	8.426	Slotted PVC	21	25	12.42	8.42								Also known as IRS/79	1 & 4
	Shallow 1985 series observation bores																																	
	GR	1/85	02.10.85	O		Operational					F	R.C. Twin Tube.		5.13		0.7	53	PVC	5.13		Slotted PVC	3	5.13										Replaced OBS 3/77. Shown to repl. 1/84 on plan. No survey data.	5
	GR	10/85	29.09.85	O		Operational		203500	7261000		K	R.C. Twin Tube.		3.54		0.5	53	PVC	3.54		Slotted PVC	2	3.54										Redrill OBS P16/77A. Coords from P16/77A. No other survey data.	5

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL From	m BGL To	m AHD** From	m AHD** To	D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
	GR	11/85	29.09.85	O		Operational		206800	7260600		L	R.C. Twin Tube.		5.48		0.5	53	PVC	5.48		Slotted PVC	4.18	5.48										Redrill OBS 31/78. Coords from OB31/78. No other survey data.	5
	GR	2/85	01.10.85	O		Operational		784200	7252400	LB 206-5, LB 225-19	B	R.C. Twin Tube.		18.92	25.461	0.7	53	PVC	18.92		Slotted PVC	8	18.92										Redrill P2/76. Coords from P2/76. No other survey data.	5
	GR	3/85	01.10.85	O		Operational		786000	7252500		C	R.C. Twin Tube.		3.84		0.7	53	PVC	3.84		Slotted PVC	2	3.84										Redrill OB 9/77. Coords from OB9/77. No other survey data.	5
	GR	4/85	01.10.85	O		Operational		787300	7252400	LB 206-1	C	R.C. Twin Tube.		10.3	33.828	0.7	53	PVC	10.3		Slotted PVC	4	10.3										Redrill OBS 10/77. Coords from OB10/77. No other survey data.	5
	GR	5/85	30.09.85	O		Operational	50	200570	7259913	FB 205-30																								
	GR	5/85	30.09.85	O		Operational		788200	7252900	LB206-3	C	R.C. Twin Tube.		5.16	37.807	0.7	53	PVC	5.16		Slotted PVC	3	5.16										Redrill OBS 11/77. Coords from OB11/77. No other survey data.	5
	GR	6/85	30.09.85	O		Operational		788500	7252600	LB 206-8	C	R.C. Twin Tube.		12.08	29.911	0.7	53	PVC	12.08		Slotted PVC	3.7	12.08										Redrill OBS 12/77. Coords from OB12/77. No other survey data.	5
	GR	7/85	30.09.85	O		Operational		791700	7254200		D	R.C. Twin Tube.		7.06		0.7	53	PVC	7.06		Slotted PVC	3	7.06										Redrill OBS 14/77. Coords from OB 14/77. No other survey data.	5
	GR	8/85	29.09.85	O		Operational	49	802135	7257040	FB 222-2	D	R.C. Twin Tube.		5.16		0.7	53	PVC	5.16		Slotted PVC	3.6	5.16										Redrill OBS 13/77. Coords from OB 13/77. No other survey data.	5
	GR	9/85	29.09.85	O		Operational		197900	7258800		H	R.C. Twin Tube.		5.26		0.7	53	PVC	5.26		Slotted PVC	3	5.26										Redrill OBS 25/77. Coords from OB 25/77. No other survey data.	5
	Multiport bores 1987																																	
70420001	COAM	2/87	20.06.87	O	Yes	Operational	50	198464	7258362	FB 222-8	H	R.C. Twin Tube.		68.58	36.366	0.968	79.1	PVC	65	-29.602	Ports	15.4	15.4	19.998	19.998						Yes		Black Port.	1, 5
										LB 225-8												39.9	39.9	-39.9	-39.9								Red Port	& 6
																						52.9	52.9	-52.9	-52.9								Yellow Port	
																						59.9	59.9	-24.5	-24.5								Green Port	
70420004	COAM	9/87	13.07.87	O	Yes	Operational	50	198665	7257138	FB 222-8	H	R.C. Twin Tube.		68.45	33.88	0.68	79.1	PVC	63.5	-30.3	Ports	14.5	14.5	18.7	18.7						Yes		Black Port.	1, 5
										LB 225-8												19.5	19.5	13.7	13.7								Red Port	& 6
																						38	38	-4.8	-4.8								Yellow Port	
																						57	57	-23.8	-23.8								Green Port	
70420005	COAM	11/87	15.07.87	O	Yes	Operational	50	198600	7256040	FB 222-8	H	R.C. Twin Tube.		65	34.662	0.692	79.1	PVC	63.05	-29.08	Ports	14.8	14.8	19.17	19.17						Yes		Black Port.	1, 5
																						27	27	6.97	6.97								Red Port	& 6
																						40	40	-6.03	-6.03								Yellow Port	
																						52	52	-18.03	-18.03								Green Port	
																						59	59	-25.03	-25.03								Blue Port	
70420006	COAM	12/87	07.06.87	O	Yes	Operational	49	797739	7253871	FB 222-9	F	R.C. Twin Tube.		71.55	29.321	0.835	79.1	PVC	71.55	-43.064	Ports	15	15	13.41	13.41						Yes		Black Port.	1, 5
										LB 225-3												23	23	5.41	5.41								Red Port	& 6
																						42	42	-13.59	-13.59								Yellow Port	
																						53.5	53.5	-25.09	-25.09								Green Port	
																						68.8	68.8	-40.39	-40.39								Blue Port	
70420007	COAM	14/87	03.06.87	O	Yes	Operational	49	797793	7253101	FB 222-9	F	R.C. Twin Tube.		71.56	27.351	0.635	79.1	PVC	70	-43.284	Ports	21.65	21.65	5	5						Yes		Black Port.	1, 5
										LB 225-3												34	34	-7.35	-7.35								Red Port	& 6

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						Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m³/d)	Comments	Max. rec. rate (Gee) (m³/d)					
																					From	To	From	To									
																					50	50	-23.35	-23.35								Yellow Port	
																					59.8	59.8	-33.15	-33.15								Green Port	
70420009	COAM 19/87	03.06.87	O	Yes	Operational	49	797784	7254216	FB 222-9	F	R.C. Twin Tube.		71.53	30.198	0.973	79.1	PVC	60	-30.775	Ports	14.8	14.8	14.3	14.3						Yes		Black Port.	1, 5
									LB 225-2												25.5	25.5	3.64	3.64								Red Port	& 6
																					53	53	-23.86	-23.86								Yellow Port	
70420010	COAM 20/87	13.06.87	O	Yes	Operational	49	797747	7254363	LB 399-15	F	R.C. Twin Tube.		68	28.34	0.569	79.1	PVC	66	-38.229	Ports	13	13	14.79	14.79						Yes		Black Port.	1, 5
									FB 222-9												25.5	25.5	2.29	2.29								Red Port	& 6
									LB 218-2					27.789							32.5	32.5	-4.71	-4.71								Yellow Port	
																					36.8	36.8	-9.01	-9.01								Green Port	
																					44.5	44.5	-16.71	-16.71								Blue Port	
																					63	63	-35.21	-35.21								White Port	
70420011	COAM 21/87	18.06.87	O	Yes	Operational	50	198399	7258701	FB 222-13	H	R.C. Twin Tube.		61.28	33.031	0.851	79.1	PVC	58	-25.82	Ports	6	6	26.18	26.18								Black Port.	1, 5
																					13.5	13.5	18.68	18.68								Red Port	& 6
																					29.5	29.5	2.68	2.68								Yellow Port	
																					36.5	36.5	-4.32	-4.32								Green Port	
																					50	50	-17.82	-17.82								Blue Port	
																					55.8	55.8	-23.62	-23.62								White Port	
70420024	COAM 4/88	04.10.88	O	Yes	Operational	49	797650	7257150	LB 225-37	F	R.C. Twin Tube.		65	28.912	0.792	79	PVC	65	-36.88	Ports	20	20	8.12	8.12						Yes		Black Port.	1, 5
						50	190920	7256910	D488.INF												28	28	.12	.12								Red Port	& 6
																					37	37	-8.88	-8.88								Yellow Port	
																					55	55	-26.88	-26.88								Green Port	
70420029	COAM 9/88	29.09.88	O	Yes	Operational	49	797750	7255200	LB 225-36	F	R.C. Twin Tube.		65	29.574	1.154	79	PVC	65	-36.58	Ports	16.8	16.8	11.62	11.62						Yes		Black Port.	1, 5
						50	191090	7254980	D988.INF												29.8	29.8	-1.38	-1.38								Red Port	& 6
																					39.3	39.3	-10.88	-10.88								Yellow Port	
																					49.8	49.8	-21.38	-21.38								Green Port	
																					60.8	60.8	-32.38	-32.38								Blue Port	
70420033	COAM 13/88	05.10.88	O	Yes	Operational	50	198290	7259350	D1388.INF	H	R.C. Twin Tube.		71	35.26	0.82	79	PVC	57.3	-22.86	Ports	15.4	15.4	19.04	19.04						Yes		No colours given for ports. Assume – Black	1, 5
									LB 225-41												29.5	29.5	4.94	4.94								Red	& 6
																					35	35	-.56	-.56								Yellow	
																					52	52	-17.56	-17.56								Green	
70420034	COAM 14/88	17.10.88	O	Yes	Operational	50	205800	7261790	D1488.INF	K	R.C. Twin Tube.		71	42.774	1.104	79	PVC	65.9	-24.23	Ports	17	17	24.67	24.67						Yes		No colours given for ports. Assume – Black	1, 5
																					25.5	25.5	16.17	16.17								Red	& 6
																					47	47	-5.33	-5.33								Yellow	
																					60	60	-18.33	-18.33								Green	
70420044	COAM 24/88	14.10.88	O	Yes	Operational	50	205850	7261130	D2488.INF	K	R.C. Twin Tube.		57	38.44	1.1	79	PVC	57	-19.66	Ports	8.3	8.3	29.04	29.04						Yes		No colours given for ports. Assume – Black.	1, 5
									LB 225-34												17	17	20.34	20.34								Red	& 6
																					26	26	11.34	11.34								Height AGL in doubt. Yellow	

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						Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL From	m BGL To	m AHD** From	m AHD** To	D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																					44	44	-6.66	-6.66								Green	
																					50	50	-12.66	-12.66								Blue	
	Carnarvon recharge investigation bores																																
70418900	CRI 1/97 (10.6M)	12.08.97	O	no	Operational	49	777992	7250346		A	Hollow stem auger		14.4	14.118	0.945	50	PVC	14.4	-1.227	Port in PVC coupling	10.6	10.6	2.573	2.573						yes	yes	black tube, sampling tube	11
70418901	CRI 1/97 (8.8M)		O	no	Operational	49	777992	7250346		A	Hollow stem auger		14.4	14.093	0.92	50	PVC	14.4		Port in PVC coupling	8.8	8.8	4.373	4.373						yes	yes	clear tube	11
70418902	CRI 2/97 (18.3M)	13.08.97	O	no	Operational	49	778764	7250875		A	Hollow stem auger		19.5	15.212	0.83	50	PVC	19.5	-5.118	Port in PVC coupling	18.3	18.3	-3.918	-3.918						yes	yes	black tube, sampling tube	11
70418903	CRI 2/97 (11.5M)		O	no	Operational	49	778764	7250875		A	Hollow stem auger		19.5	15.252	0.87	50	PVC	19.5		Port in PVC coupling	11.5	11.5	2.882	2.882						yes	yes	red tube	11
70418904	CRI 2/97 (7.8M)		O	no	Operational	49	778764	7250875		A	Hollow stem auger		19.5	15.272	0.89	50	PVC	19.5		Port in PVC coupling	7.8	7.8	6.582	6.582						yes	yes	clear tube	11
70418905	CRI 3/97 (18.4M)	13.08.97	O	no	Operational	49	778448	7251733		A	Hollow stem auger		20.1	13.374	1.15	50	PVC	20.1	-7.876	Port in PVC coupling	18.4	18.4	-6.176	-6.176						yes	yes	black tube, green sampling tube	11
70418906	CRI 3/97 (14.4M)		O	no	Operational	49	778448	7251733		A	Hollow stem auger		20.1	13.374	1.15	50	PVC	20.1		Port in PVC coupling	14.4	14.4	-2.176	-2.176						yes	yes	red tube	11
70418907	CRI 3/97 (11.4M)		O	no	Operational	49	778448	7251733		A	Hollow stem auger		20.1	13.344	1.12	50	PVC	20.1		Port in PVC coupling	11.4	11.4	0.824	0.824						yes	yes	yellow tube	11
70418908	CRI 3/97 (8.4M)		O	no	Operational	49	778448	7251733		A	Hollow stem auger		20.1	13.344	1.12	50	PVC	20.1		Port in PVC coupling	8.4	8.4	3.824	3.824						yes	yes	clear tube	11
70418909	CRI 4/97 (13.6M)	14.08.97	O	no	Operational	49	779676	7251223		A	Hollow stem auger		14.2	16.151	1	50	PVC	14.2	0.951	Port in PVC coupling	13.6	13.6	1.551	1.551						yes	yes	black tube, sampling tube	11
70418910	CRI 4/97 (9.8M)		O	no	Operational	49	779676	7251223		A	Hollow stem auger		14.2	16.146	0.995	50	PVC	14.2		Port in PVC coupling	9.8	9.8	5.351	5.351						yes	yes	clear tube	11
70418911	CRI 5/97 (14.6M)	15.08.97	O	no	Operational	49	779553	7251758		A	Hollow stem auger		19.2	15.537	1.4	50	PVC	19.2	-5.063	Port in PVC coupling	14.6	14.6	-0.463	-0.463						yes	yes	black tube, sampling tube	11
70418912	CRI 5/97 (12.6M)		O	no	Operational	49	779553	7251758		A	Hollow stem auger		19.2	15.512	1.375	50	PVC	19.2		Port in PVC coupling	12.6	12.6	1.537	1.537						yes	yes	red tube	11
70418913	CRI 5/97 (10.6M)		O	no	Operational	49	779553	7251758		A	Hollow stem auger		19.2	15.467	1.33	50	PVC	19.2		Port in PVC coupling	10.6	10.6	3.537	3.537						yes	yes	yellow tube	11
70418914	CRI 5/97 (8.1M)		O	no	Operational	49	779553	7251758		A	Hollow stem auger		19.2	15.457	1.32	50	PVC	19.2		Port in PVC coupling	8.1	8.1	6.037	6.037						yes	yes	clear tube	11
70418915	CRI 6/97 (12.2M)	15.08.97	O	no	Operational	49	779477	7252296		A	Hollow stem auger		13.4	14.318	0.78	50	PVC	13.4	0.138	Port in PVC coupling	12.2	12.2	1.338	1.338						yes	yes	black tube, sampling tube	11
70418916	CRI 6/97 (10.2M)		O	no	Operational	49	779477	7252296		A	Hollow stem auger		13.4	14.318	0.78	50	PVC	13.4		Port in PVC coupling	10.2	10.2	3.338	3.338						yes	yes	clear tube	11
70418917	CRI 7/97 (15.9M)	16.08.97	O	no	Operational	49	779828	7251030		A	Hollow stem auger		18	14.903	1.02	50	PVC	18	-4.117	Port in PVC coupling	15.9	15.9	-2.017	-2.017						yes	yes	black tube, sampling tube	11

WIN reference number	Well name	Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
						Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Diameter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																					From	To	From	To									
70418918	CRI 7/97 (13.9M)		O	no	Operational	49	779828	7251030		A	Hollow stem auger		18	14.858	0.975	50	PVC	18		Port in PVC coupling	13.9	13.9	-0.017	-0.017						yes	yes	red tube	11
70418919	CRI 7/97 (11.9M)		O	no	Operational	49	779828	7251030		A	Hollow stem auger		18	14.863	0.98	50	PVC	18		Port in PVC coupling	11.9	11.9	1.983	1.983						yes	yes	yellow tube	11
70418920	CRI 7/97 (8.9M)		O	no	Operational	49	779828	7251030		A	Hollow stem auger		18	14.843	0.96	50	PVC	18		Port in PVC coupling	8.9	8.9	4.983	4.983						yes	yes	clear tube	11
70418921	CRI 8/97 (13.6M)	16.0897	O	no	Operational	49	780089	7250572		A	Hollow stem auger		15.6	14.558	0.89	50	PVC	15.6	-1.932	Port in PVC coupling	13.6	13.6	0.068	0.068						yes	yes	black tube, sampling tube	11
70418922	CRI 8/97 (10.6M)		O	no	Operational	49	780089	7250572		A	Hollow stem auger		15.6	14.568	0.9	50	PVC	15.6		Port in PVC coupling	10.6	10.6	3.068	3.068						yes	yes	clear tube	11
70418923	CRI 9/97 (14.6m)	17.08.97	O	no	Disconnected	49	780108	7249731		A	Hollow stem auger		15.4	13.201	1.29	50	PVC	15.4	-3.489	Port in PVC coupling	14.6	14.6	-2.689	-2.689						yes	yes	black tube, sampling tube	11
70418924	CRI 9/97 (11.6m)		O	no	Operational	49	780108	7249731		A	Hollow stem auger		15.4	13.171	1.26	50	PVC	15.4		Port in PVC coupling	11.6	11.6	0.311	0.311						yes	yes	red tube	11
70418925	CRI 9/97 (8.9M)		O	no	Operational	49	780108	7249731		A	Hollow stem auger		15.4	13.141	1.23	50	PVC	15.4		Port in PVC coupling	8.9	8.9	3.011	3.011						yes	yes	clear tube	11
70418926	CRI 10/97 (11.5M)	18.08.97	O	no	Operational	49	779058	7250467		A	Hollow stem auger		12.5	15.367	1.09	50	PVC	12.5	1.777	Port in PVC coupling	11.5	11.5	2.777	2.777						yes	yes	black tube, sampling tube	11
70418927	CRI 11/97 (19.2M)	18.08.97	O	no	Operational	49	779499	7249953		A	Hollow stem auger		20.6	14.678	1.24	50	PVC	20.6	-7.162	Port in PVC coupling	19.2	19.2	-5.762	-5.762						yes	yes	black tube, sampling tube	11
70418928	CRI 11/97 (16.7M)		O	no	Operational	49	779499	7249953		A	Hollow stem auger		20.6	14.678	1.24	50	PVC	20.6		Port in PVC coupling	16.7	16.7	-3.262	-3.262						yes	yes	red tube	11
70418929	CRI 11/97 (13.7M)	18.08.97	O	no	Operational	49	779499	7249953		A	Hollow stem auger		20.6	14.658	1.22	50	PVC	20.6		Port in PVC coupling	13.7	13.7	-0.262	-0.262						yes	yes	yellow tube	11
70418930	CRI 11/97 (11.2M)		O	no	Operational	49	779499	7249953		A	Hollow stem auger		20.6	14.638	1.2	50	PVC	20.6		Port in PVC coupling	11.2	11.2	2.238	2.238						yes	yes	clear tube	11
70418931	CRI 12/97 (19.05M)	19.08.97	O	no	Operational	49	779622	7249760		A	Hollow stem auger		20.6	13.433	0.89	50	PVC	20.6	-8.057	Port in PVC coupling	19.05	19.05	-6.507	-6.507						yes	yes	black tube, green sampling tube	11
70418932	CRI 12/97 (14.05M)		O	no	Operational	49	779622	7249760		A	Hollow stem auger		20.6	13.423	0.88	50	PVC	20.6		Port in PVC coupling	14.05	14.05	-1.507	-1.507						yes	yes	red tube	11
70418933	CRI 12/97 (10.05M)		O	no	Operational	49	779622	7249760		A	Hollow stem auger		20.6	13.433	0.89	50	PVC	20.6		Port in PVC coupling	10.05	10.05	2.493	2.493						yes	yes	clear tube	11
70418934	CRI 13/97 (19.55M)	20.08.97	O	no	Operational	49	778282	7249870		A	Hollow stem auger		20.6	14.625	0.92	50	PVC	20.6	-6.895	Port in PVC coupling	19.55	19.55	-5.845	-5.845						yes	yes	black tube, sampling tube	11
70418935	CRI 13/97 (17.55M)		O	no	Operational	49	778282	7249870		A	Hollow stem auger		20.6	14.595	0.89	50	PVC	20.6		Port in PVC coupling	17.55	17.55	-3.845	-3.845						yes	yes	red tube	11
70418936	CRI 13/97 (15.55M)		O	no	Operational	49	778282	7249870		A	Hollow stem auger		20.6	14.615	0.91	50	PVC	20.6		Port in PVC coupling	15.55	15.55	-1.845	-1.845						yes	yes	yellow tube	11
70418937	CRI 13/97 (13.55M)		O	no	Operational	49	778282	7249870		A	Hollow stem auger		20.6	14.595	0.89	50	PVC	20.6		Port in PVC coupling	13.55	13.55	0.155	0.155						yes	yes	clear tube	11

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m³/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m³/d)	Comments	Max. rec. rate (Gee) (m³/d)					
																						From	To	From	To									
70418938	CRI	14/97	21.08.97	O	no	Operational	49	778618	7249452		A	Hollow stem auger		14.9	12.259	0.71	50	PVC	14.9	-3.351	Port in PVC coupling	12.5	13.5	-0.95	-1.95						yes	yes	slotted PVC	11
	Shallow 1987 and 1988 observation bores																																	
70420002	COA	4/87	15.05.87	O	Yes	Operational	50	197392	7257735	FB 222-8	H	R.C. Twin Tube.		68.58	34.905	0.49	43	PVC	68.58	-34.165	Slotted PVC	12	18	22.415	16.415						Yes	N.P.		1, 5 & 6
70420003	COA	5/87	16.05.87	O	Yes	Operational	50	197331	7257324	FB 222-8	H	R.C. Twin Tube.		68.6	34.084	0.42	43	PVC	68.6	-34.936	Slotted PVC	12	18	21.664	15.664						Yes	N.P.		1, 5 & 6
70420008	COA	15/87	28.05.87	O	Yes	Operational	49	797656	7252530	FB 222-9	F	R.C. Twin Tube.		71.55	28.043	0.632	43	PVC	71.55	-44.139	Slotted PVC	20	26	7.42	1.42						Yes	Yes		1, 5 & 6
70420012	COA	22/87	21.06.87	O	Yes	Operational	50	198444	7258445	FB 222-8, LB 225-6	H	R.C. Twin Tube.		20	36.229	0.584	43	PVC	20.4	15.245	Slotted PVC	14	20	21.78	15.78						Yes			1, 5 & 6
70420017	COA	27/87	17.07.87	O	Yes	Operational	50	198388	7258523	FB 222-12, LB 225-21	H	R.C. Twin Tube.		20	36.418	0.562	43	PVC	15.65	20.206	Slotted PVC	13	15.65	22.94	20.29						Yes	Yes		1, 5 & 6
70420020	COA	30/87	21.07.87	O	Yes	Operational	50	198468	7258610	FB 222-12, LB 225-21	H	R.C. Twin Tube.		18.31	36.753	0.501	43	PVC	18.31	17.942	Slotted PVC	16.31	18.31	20	18						Yes			1, 5 & 6
70420028	COA	8/88	29.09.88	O	Yes	Operational	49	797750	7255900	LB 255-36	F	R.C. Twin Tube.		17	28.966	0.596	43	PVC	15.9	12.47	Slotted PVC	13.5	16.5	14.87	11.87						Yes		Screen depths taken from Martin, 1990.	1, 5 & 6
70420032	COA	12/88	01.10.88	O	Yes	Operational	50	198150	7262240	D101112. INF	H	R.C. Twin Tube.		26	34.613	0.803	43	PVC	26	7.81	Slotted PVC	20	26	13.81	7.81						Yes			1, 5 & 6
70420043	COA	23/88	12.10.88	O	Yes	Operational	50	198290	7260240	D202388. INF	H	R.C. Twin Tube.		26	34.883	0.804	43	PVC	26	8.079	Slotted PVC	20	24	14.08	10.08						Yes			1, 5 & 6
70420046	COA	26/88	19.10.88	O	Yes	Operational	50	205890	7260170	D252688. INF, LB 225-47	L	R.C. Twin Tube.		17	42.184	0.594	43	PVC	17	24.59	Slotted PVC	14	16	27.59	25.59						Yes			1, 5 & 6
70420048	COA	28/88	20.10.88	O	Yes	Operational	50	205850	7259150	LB 225-48	L	R.C. Twin Tube.		20	43.044	0.47	43	PVC	20	22.574	Slotted PVC	15	18	27.57	24.57						Yes		Sreen depths taken from drillers completion diagram.	1, 5 & 6
70420050	COA	30/88	20.10.88	O	Yes	Operational	50	205940	7258210	D293088. INF, LB 225-48	L	R.C. Twin Tube.		20	43.074	0.444	43	PVC	20	22.63	Slotted PVC	14	17	28.63	25.63						Yes			1, 5 & 6
70420063	COA	33/87	22.07.87	O		Operational	49	801952	7256573	FB 222-10, LB 225-20	G	R.C. Twin Tube.		20.53	32.682	0.48	43	PVC	20.53	11.672	Slotted PVC	15	19	17.26	13.26						Yes	Yes		1, 5 & 6
	Deep 1987 and 1988 observation bores																																	
70420013	COA	23/87	22.06.87	O	Yes	Operational	50	198444	7258446	FB 222-8, LB 225-6	H	R.C. Twin Tube.		68.95	36.245	0.504	43	PVC	68.95	-33.209	Slotted PVC	57	61	-21.22	-25.22						Yes	Yes		1, 5 & 6
70420014	COA	24/87	22.06.87	O	Yes	Operational	50	198444	7258447	FB 222-8, LB 225-6	H	R.C. Twin Tube.		43	36.284	0.559	43	PVC	43.4	-7.675	Slotted PVC	38.9	42.9	-3.12	-7.12						Yes			1, 5 & 6
70420015	COA	25/87	16.07.87	O	Yes	Operational	50	198388	7258521	FB 222-12, LB 225-21	H	R.C. Twin Tube.		62.58	36.387	0.507	43	PVC	62.58	-26.7	Slotted PVC	53	61	-17.06	-25.06						Yes			1, 5 & 6
70420016	COA	26/87	17.07.87	O	Yes	Operational	50	198388	7258522	FB 222-12, LB 225-21	H	R.C. Twin Tube.		43.38	36.365	0.525	43	PVC	43.4	-7.56	Slotted PVC	36.4	43.4	-.46	-7.46						Yes			1, 5 & 6
70420018	COA	28/87	20.07.87	O	Yes	Operational	50	198466	7258611	FB 222-12, LB 225-21	H	R.C. Twin Tube.		59.58	36.738	0.474	43	PVC	59.58	-23.316	Slotted PVC	49	57	-12.69	-20.69						Yes	Yes		1, 5 & 6
70420019	COA	29/87	20.07.87	O	Yes	Operational	50	198467	7258610	FB 222-12, LB 225-21	H	R.C. Twin Tube.		41.58	36.735	0.475	43	PVC	41.58	-5.32	Slotted PVC	38	41.58	-1.69	-5.27						Yes			1, 5 & 6
70420021	COA	1/88	21.09.88	O	Yes	Operational	49	786353	7250920	FB 222-16, LB 225-51	C	R.C. Twin Tube.		56	18.466	0.536	43	PVC	56	-38.07	Slotted PVC	43	46	-25.07	-28.07						Yes		Screen depths taken from Martin, 1990. 2 bores shown on plan.	1, 5 & 6
70420022	COA	2/88	22.09.88	O	Yes	Operational	49	791246	7251690	FB 222-18, LB 225-49	D	R.C. Twin Tube.		60	22.333	0.543	43	PVC	60	-38.21	Slotted PVC	52	55	-30.21	-33.21						Yes	Yes		1, 5 & 6
70420023	COA	3/88	23.09.88	O	Yes	Operational	49	787109	7254618	FB 222-17, LB 225-43	C	R.C. Twin Tube.		53	19.531	0.801	43	PVC	53	-34.27	Slotted PVC	41	51	-22.27	-32.27						Yes	Yes	Screen depths taken from Martin, 1990.	1, 5 & 6
70420025	COA	5/88	25.09.88	O	Yes	Operational	49	791246	7255593	FB 222-18, LB 225-42	D	R.C. Twin Tube.		56	23.055	0.485	43	PVC	56	-33.43	Slotted PVC	45	51	-22.43	-28.43						Yes	Yes		1, 5 & 6
70420026	COA	6/88	27.09.88	O	Yes	Operational	49	797750	7255900	LB 225-36	F	R.C. Twin Tube.		65	28.979	0.609	43	PVC	65	-36.63	Slotted PVC	53	58	-24.63	-29.63						Yes	Yes		1, 5 & 6

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
70420027	COA	7/88	29.09.88	O	Yes	Operational	49	797750	7255900	LB 225-36	F	R.C. Twin Tube.		32	29.011	0.641	43	PVC	32	-3.63	Slotted PVC	27	29	1.37	-.63									1, 5 & 6
70420030	COA	10/88	30.09.88	O	Yes	Operational	50	198150	7262240	D101112. INF	H	R.C. Twin Tube.		66.2	34.559	0.799	43	PVC	66.2	-32.44	Slotted PVC	52.2	58.2	-18.44	-24.44						Yes	N.P.	Screen depths taken from Martin, 1990.	1, 5 & 6
70420031	COA	11/88	01.10.88	O	Yes	Operational	50	198150	7262240	D101112. INF	H	R.C. Twin Tube.		41	34.615	0.795	43	PVC	41	-7.18	Slotted PVC	38	40	-4.18	-6.18						Yes			1, 5 & 6
70420032	COA	12/88	01.10.88	O	Yes	Operational	50	198150	7262240	D101112. INF	H	R.C. Twin Tube.		26	34.613	0.803	43	PVC	26	7.81	Slotted PVC	20	26	13.81	7.81						Yes			1, 5 & 6
70420035	COA	15/88	06.10.88	O	Yes	Operational	50	205790	7262610	D151688. INF, LB 225-46	K	R.C. Twin Tube.		71	41.77	0.8	43	PVC	71	-30.03	Slotted PVC	46	49	-5.03	-8.03						Yes	N.P.		1, 5 & 6
70420036	COA	16/88	06.10.88	O	Yes	Operational	50	205790	7262610	D151688. INF	K	R.C. Twin Tube.		29	41.68	0.8	43	PVC	29	11.88	Slotted PVC	26	29	14.88	11.88						Yes		Sreen depths taken from drillers completion diagram.	1, 5 & 6
70420037	COA	17/88	07.10.88	O	Yes	Operational	50	205760	7263660	D171888. INF, LB 225-44	K	R.C. Twin Tube.		71	40.922	0.802	43	PVC	71	-30.88		44	47	-3.88	-6.88						Yes	N.P.		1, 5 & 6
70420038	COA	18/88	08.10.88	O	Yes	Operational	50	205760	7263660	D171888. INF, LB 225-44	K	R.C. Twin Tube.		35	40.934	0.804	43	PVC	35	5.13	Slotted PVC	28	35	12.13	5.13						Yes			1, 5 & 6
70420039	COA	19/88	09.10.88	O	Yes	Operational	50	205740	7264650	D1988. INF, LB 225-45	K	R.C. Twin Tube.		62	40.069	0.799	43	PVC	62	-22.73	Slotted PVC	44	45	-4.73	-5.73						Yes	Yes		1, 5 & 6
70420040	COA	20/88	10.10.88	O	Yes	Operational	50	198290	7260240	D202388. INF	H	R.C. Twin Tube.		72	34.869	0.799	43	PVC	72	-37.93	Slotted PVC	40	44	-5.93	-9.93						Yes	Yes		1, 5 & 6
70420041	COA	21/88	11.10.88	O	Yes	Operational	50	198200	7261130	D212288. INF, LB 225-38	H	R.C. Twin Tube.		71	34.585	0.805	43	PVC	71	-37.22	Slotted PVC	38	44	-4.22	-10.22						Yes	Yes		1, 5 & 6
70420042	COA	22/88	12.10.88	O	Yes	Operational	50	198200	7261130	D212288. INF	H	R.C. Twin Tube.		28	34.58	0.8	43	PVC	28	5.78	Slotted PVC	26	28	7.78	5.78						Yes		Screen depths taken from Martin, 1990.	1, 5 & 6
70420043	COA	23/88	12.10.88	O	Yes	Operational	50	198290	7260240	D202388. INF	H	R.C. Twin Tube.		26	34.883	0.804	43	PVC	26	8.079	Slotted PVC	20	24	14.08	10.08						Yes			1, 5 & 6
70420045	COA	25/88	19.10.88	O	Yes	Operational	50	205890	7260170	D252688. INF, LB 225-47	L	R.C. Twin Tube.		50	42.194	0.604	43	PVC	50	-8.41	Slotted PVC	30	36	11.59	5.59						Yes	N.P.		1, 5 & 6
70420047	COA	27/88	19.10.88	O	Yes	Operational	50	205900	7259170	D272888. INF, LB 225-48	L	R.C. Twin Tube.		62	42.963	0.393	43	PVC	62	-19.43	Slotted PVC	35	39	7.57	3.57						Yes	Yes		1, 5 & 6
70420049	COA	29/88	20.10.88	O	Yes	Operational	50	205940	7258210	D293088. INF, LB 225-48	L	R.C. Twin Tube.		62	43.203	0.573	43	PVC	62	-19.37	Slotted PVC	50	58	-7.37	-15.37						Yes	Yes		1, 5 & 6
70420061	COA	31/87	21.07.87	O		Operational	49	801922	7256585	FB 222-10, LB 225-20	G	R.C. Twin Tube.		68.53	33.121	0.625	43	PVC	68.53	-36.034	Slotted PVC	56	58	-23.55	-25.55						Yes			1, 5 & 6
70420062	COA	32/87	22.07.87	O		Operational	49	801952	7256574	FB 222-10, LB 225-20	G	R.C. Twin Tube.		68.53	32.651	0.44	43	PVC	68.53	-36.319	Slotted PVC	57	60	-24.74	-27.74						Yes	Yes		1, 5 & 6
70420064	COA	34/87	23.07.87	O		Operational	49	801952	7256572	FB 222-10, LB 225-20	G	R.C. Twin Tube.		35.1	32.68	0.478	43	PVC	35.1	-2.898	Slotted PVC	32	35.1	.26	-2.84						Yes	Yes		1, 5 & 6
	1992 Series monitoring bores																																	
70418851		1/92	16.02.92	O		Operational	49	782500	7251600	LB 399 31	A	R.C. Twin Tube.	121		18.06	0.88	53	PVC	32.6	-15.43	Slotted PVC	26.6	32.6	-9.43	-15.43						Yes	Yes		6 & 5
70418852		2/92	17.02.92	O		Operational	49	783750	7252050	LB 399-27	A	R.C. Twin Tube.	121		18.92	1.02	53	PVC	50.6	-32.7	Slotted PVC	44.6	50.6	-26.7	-32.7						Yes	Yes		6 & 5
70418853		3/92	18.02.92	O		Operational	49	792000	7253600	LB 399-10	D	R.C. Twin Tube.	121		23.7	1	53	PVC	62.6		Slotted PVC	44.3	50.3								Yes	Yes		6 & 5
70418854		4/92	22.02.92	O		Operational	49	801350	7256400	LB 399-5	G	R.C. Twin Tube.	121		31.97	1.04	53	PVC	68.6	-37.67	Slotted PVC	59.6	63.6	-28.67	-32.67						Yes	Yes		6 & 5
70418858		8/92	02.03.92	O		Operational	49	790900	7253150	LB 399-12	D	R.C. Twin Tube.	121	65.7	23.9		53	PVC			Slotted PVC	41	47								Yes	Yes	Gamma logged to 49.5 m.	6 & 5

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL From	m BGL To	m AHD** From	m AHD** To	D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
	Miscellaneous pastoral bores with no known screen depths																																	
70420051	COA	Mill Bore North		Pa		Operational	49	799350	7257400																									1
70420052	COA	North Rocky Well		Pa		Operational	50	205850	7266400																									1
70420053	COA	Mill D South 8.		Pa		Operational																												1
70420054	COA	Mill C South 3 K.		Pa		Operational																												1
70420055	COA	East Cockburn		Pa		Operational	49	793400	7251400																									1
70420056	COA	Square Tank Artesian		Pa		Operational																												1
70420057	COA	Four Corner Well		Pa		Operational	50	206200	7248100																									1
70420058	COA	Square Tank Shallow		Pa		Operational	50	200100	7247400																									1
70420059	COA	Moyamber		Pa		Operational	50	200300	7257600																									1
70420060	COA	Nemmanwarra well		Pa		Operational	49	793700	7259800																									1
		Boundary well		Pa		Operational	49	821361	7252105																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		Canterbury		Pa		Operational	49	793800	7267500																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		Cockburn Shed		Pa		Operational	49	786579	7251476																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		Coomero		Pa		Operational	49	781655	7254505																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		East Moolooloo		Pa		Operational	49	798150	7246200																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		Red tank		Pa		Operational	49	788250	7261450																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		South Rocky		Pa		Operational	49	817968	7248006																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		Tee tree		Pa		Operational	49	795600	7238950																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		Tripod		Pa		Operational	49	812899	7252839																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		Turners		Pa		Operational	49	802950	7240700																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	
		West Cockburn		Pa		Operational	49	783500	7244700																								Pastoral well, AMG's from GPS survey in 1997 by Dodson	

WIN reference number	Well name	Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
						Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																					From	To	From	To									
	Uncased exploration bores																																
	1/76	31.03.76	E		Abandoned	49	781300	7251600			Mud Rotary		82.3				None			None												Uncased exploration hole.	5
	10/87	20.05.87	E		Abandoned	50	198640	7256612	FB 222-8	H	R.C. Twin Tube.		68.55				None			None										Yes		Uncased exploration hole. Elevated salinity toward base.	5 & 6
	13/87	23.05.87	E		Abandoned	49	797790	7253100			R.C. Twin Tube.		26.5				None			None												Uncased exploration hole. May have rods stuck in hole.	5 & 6
	15/77	21.09.77	E		Abandoned	49	803918	7258611		H	Mud Rotary		75				None			None												Uncased exploration hole.	5
	16/87	05.06.87	E		Abandoned	49	786588	7251362	FB 222-7, FB 222-16		R.C. Twin Tube.		62.55				None			None										Yes		Uncased exploration hole. Potential production bore site.	5 & 6
	17/77	29.09.77	E		Abandoned	49	783750	7252900		A	Mud Rotary		53				None			None												Uncased exploration hole.	5
	17/87		E		Abandoned	49	786150	7250450		E							None			None												Uncased exploration hole.	5
	17/87	07.06.87	E		Abandoned	49	786154	7250530	FB 222-7		R.C. Twin Tube.		53				None			None										Yes		Uncased exploration hole. Elevated salinities at depth.	5 & 6
	18/77	01.10.77	E		Abandoned	49	784800	7252500			Mud Rotary		56				None			None												Uncaswed exploration hole.	5
	2/70		E		Abandoned	49	788500	753000		C							None			None												Uncased exploration hole. Tested for 9.7 to 12.7 but screens removed.	
	2/74	05.07.74	E		Abandoned	49	793450	7254500		D	Cable Tool		59.7				None			None										Yes		Uncased exploration hole.	7
	2/79	26.10.79	E		Abandoned	50	205650	7260600		L	Mud Rotary		100				None			None												Uncased exploration hole.	5
	23/74	14.12.74	E		Abandoned	49	795800	7254500		E	Mud Rotary		70.1				None			None										Yes		Uncased exploration hole. Shown as monitoring bore on plan.	5
	3/74	28.08.74	E		Abandoned	49	790650	7253200		D	Cable Tool		70.4				None			None										Yes		Uncased exploration hole.	7
	3/81		E		Abandoned	49	791900	7254000		D							None			None												Uncased exploration hole.	
	3/85	05.05.85	E		Abandoned	50	202400	7260550		J	R.C. Twin Tube.		55.75				None			None												Uncased exploration hole. Driller did not supply log. Shown as abandoned production bore on plan.	5
	3/87	14.05.87	E		Abandoned	50	198523	7257947	FB 222-8, LB 225-3	H	R.C. Twin Tube.		71.56	27.863			None			None										Yes		Uncased ? exploration hole. Good potential production bore site.	5 & 6
	4/74	19.09.74	E		Abandoned	49	789700	7252650		C	Cable Tool		65.9				None			None						12.96	Screens removed.			Yes		Uncased exploration hole.	7
	4/81		E		Abandoned	49	792600	7254300		D							None			None												Uncased exploration hole.	
	4/84	1984	E		Abandoned	49	801300	7257000		G			66				None			None												Uncased exploration hole.	5
	5/74	10.10.74	E		Abandoned	49	796750	7254300		F	Cable Tool		76				None			None												Uncased exploration hole.	5 & 7
	5/79	08.11.79	E		Abandoned	49	787900	7253000		C	Mud Rotary		65				None			None												Uncased exploration hole.	5
	5/82	12.12.82	E		Abandoned	49	789950	7253050		D	Mud Rotary		48.3				None			None												Uncased exploration hole.	5
	6/74	12.10.74	E		Abandoned	49	799450	7255200		F	Cable Tool		79.8				None			None										Yes		Uncased exploration hole.	7

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
		6/79	09.11.79	E		Abandoned	50	198900	7258800		H	Mud Rotary		85				None			None												Uncased exploration hole.	5
		6/87	16.05.87	E		Abandoned	50	196569	7257142	FB 222-8	G	R.C. Twin Tube.		68.55				None			None										Yes		Uncased exploration hole. Elevated salinity at depth.	5 & 6
		7/77	17.07.77	E		Abandoned	49	798950	7254800		F	Mud Rotary		70.3				None			None												Uncased ex[loration hole.	5
		7/87	17.05.87	E		Abandoned	50	199414	7258222	FB 222-8	J	R.C. Twin Tube.		68.55				None			None										Yes		Uncased exploration hole. Good potential production bore site.	5 & 6
		8/84		E		Abandoned	49	793050	7254550		D							None			None												Uncased exploration hole.	
		8/87	18.05.87	E		Abandoned	50	199405	7258666	FB 222-8	J	R.C. Twin Tube.		68.5				None			None										Yes		Uncased exploration hole. Potential production bore site.	5 & 6
	CLS	L16-	30.09.74	O	Yes	Abandoned Site	49	773900	7248750		A	Auger	>152		10.64																		Abandoned before cased.	1 & 4
70418319	CLS	L45-	11.09.74	O	Yes	Abandoned	49	771201	7249258		A	Auger	>152		6.67		50*	None			None												May not be cased. Poorly documented drillers report.	1 & 4
70418324	CLS	L9-	02.12.74	O	Yes	Abandoned	49	771340	7247550	DL9.INF	A	Auger	>152	23.90~	7.85	0.8	50*	None	23.90~		None												Poorly documented drillers report. – Could not fit piezometer.	1 & 4
70418397	GR	OB 26/77	16.06.77	O	Yes	Abandoned	50	199600	7260000		J	Auger	>76		34.257			None			None													1 & 4
70418780	CI	5/93	18.12.93	E		Abandoned	50	208517	7259442	D194A.INF	M	R.C. Twin Tube.	121	48				None			None										Yes		Uncased exploration hole. Prod bore 1/94 completed at this site. Hole abandoned before reaching desired depth due to collapse and was redrilled as G70418782.6 (7/93) approx. 8m north.	
70418782.6	CI	7/93	19.12.93	E		Abandoned	50	208517	7259442	D194A.INF	M	R.C. Twin Tube.	121	63				None			None										Yes	Yes	Uncased exploration hole. Prod bore G70418787.5 (1/94) completed at this site.	4,5 & 6
70418784.X	CI	9/93	21.12.93	E		Abandoned	50	207480	7259610	D993.INF	L	R.C. Twin Tube.	121	69				None			None										Yes	Yes	Uncased exploration hole.	4,5 & 6
70418796.6	CI	10/94	12.01.94	E		Abandoned	50	207534	7259764	D1594.INF	L	R.C. Twin Tube.	121	65				None			None										Yes		Hole abandoned before reaching desired depth due to collapse & was redrilled as G70418798.x (12/94) approx. 6 m north.	4,5 & 6
70418800.4	CI	14/94	15.01.94	E		Abandoned	50	206700	7259995	D1494.INF	L	R.C. Twin Tube.	121	75				None			None										Yes	Yes	Uncased exploration hole.	4,5 & 6
70418802.8	CI	16/94	16.01.94	E		Abandoned	50	200585	7259785	D1694.INF		R.C. Twin Tube.	121	75				None			None										Yes	Yes	Uncased exploration hole. Prod bore G70418807.5 (21/94) completed at this site.	4,5 & 6
70418803.X	CI	17/94	16.01.94	E		Abandoned	50	203855	7260485	D1794.INF		R.C. Twin Tube.	121	78				None			None										Yes	Yes	Uncased exploration hole.	4,5 & 6
	Shallow production bores																																	
	CWS	1/67	04.11.67	P		Operational						Cable Tool	324	20.72		0.38	203		17.23		Brz. & S. Steel	13.44	17.23			3.48	982	25 Hrs.						9
		1/70		P		Abandoned	49	788750	7252650		C			12.8		0.61	203		11.58		Wire Wound	8.54	11.58			4.65	257	48 Hrs.					Shown as monit. bore on plan. GSWA bore card 1648 IID - 48	10
	GRI	17	04.10.67	P		Abandoned	49	786610	7252250	LB 225-14	C	Cable Tool		17.07	18.932	0.43	203		16.81		Brz. & S. Steel	12.6	16.4			3.43	1331	8 Hrs.					Replaced by 7/82. Grid data as for 7/82.	1, 5 &8

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
	CWS	3/67	29.11.67	P		Operational						Cable Tool		20.42		0.37	203		15.47		Brz. & S. Steel	12.9	15.47			2.43	349	8 Hrs.						9
	CWS	4/67	15.12.67	P		Operational						Cable Tool		23.48		0.53	203		17.92		Brz. & S. Steel	14.45	17.92			4.39	775	12 Hrs.						9
	GRI	5	16.10.61	P		Operational	49	782700	7252350		B	Cable Tool		18.29		0.152	203		6.55		Brz. & S. Steel	6.24	10.06			4.57	916	8 Hrs.					Shown as abandoned on bore location diagram.	5 & 8
		5/70		P		Abandoned	49	785150	7252450		C			18.29		0.61	203		11.28		Wire Wound	7.62	11.28			4.37	358	47 Hrs.					Shown as monit. bore on plan. GSWA bore card 1648 - IID - 50.	10
	GRI	6	09.10.61	P		Operational	49	782500	7252500		B	Cable Tool		18.29		0.152	203		7.93		Brz. & S. Steel	7.6	11.48			4.88	1091	32 Hrs.					Shown as abandoned on bore location diagram.	5 & 8
	CWS	6/68		P		Operational					A	Cable Tool	305	25								19.2	22.3				162							8
	GRI	7	19.10.61	P		Operational	49	783500	7252400		B	Cable Tool		18.29		0.152	203		13		Brz. & S. Steel	12.55	16.39			8.23	1091	56 Hrs.					Shown as abandoned on bore location diagram.	5 & 8
	CWS	Budgie Bore No. 3	17.12.66	P		Abandoned						Cable Tool	324	18.29		0.25	203		15.34		Brz. & S. Steel	11.53	15.34			3.66	1047	2 Hrs.						9
		PROD 1/79	31.10.79	P		Operational NIU	40	799250	7255600	LB 399-8	F	Mud Rotary		100	24.94	1.32	203		36.43	-12.81	S. Steel	7.5	1.1	16.12	22.52	3.2	1434	8 Hrs.	1800				Bore not on bore plan. NIU due to uneconomical yield.	5
		Prod 1/82	23.05.82	P	Yes	Operational						Mud Rotary		19.5		0.3		PVC	17.9		S. Steel	14.9	17.9			1.5	144	8 Hrs.					Not shown on bore plan. Cvn. East Primary School Bore.	5
		PROD 4/79	19.11.79	P		Operational NIU	49	798902	7255378	LB 399-17, FB 205-34	F	Mud Rotary		100	25.15	0.4	203		18	6.75	S. Steel	9	15	15.75	9.75	3.5	609	8 Hrs.	300					5
		PROD 6/84	27.07.84	P		Operational NIU	49	783100	7253000	FB 177-38	B	Mud Rotary		57.24		0.3	206	Steel	17.27		S. Steel	12.5	15.5			9.4	496	8 Hrs.	335				Shown as Monit. bore on plan. NIU due to uneconomical yield.	5
		PROD 7/84	04.11.84	P		Operational NIU	49	789401	7253100	FB 177-37	C	Mud Rotary		54		0.4	206	Steel	21.34		S. Steel	16.81	18.87										Shown as Monit. bore on bore plan. NIU due to uneconomical yield.	5
	CWS	Production Bore `A'	03.08.66	P		Operational						Cable Tool		17.68		0.305	203		17.68			12.65	17.68			3.73	458	24 Hrs.						9
	CWS	Production Bore `C'	22.08.66	P		Operational						Cable Tool	324	48.46		0.305	203		15.75		Brz. & S. Steel	11.95	15.75			5.4	393	8 Hrs.						9
70418601	GR	PROD N0.8	26.10.61	P	Yes	Operational NIU	49	783900	7252500	LB 225-13	B			15.24	13.47	0.23	203		7.32	4.68	Brz. & S. Steel	6.8	10.7	5.2	1.3	2.13	1091	18 Hrs.					Elev. TOC not off SWRISS. Site not worth a redrill, uneconomical yield.	1, 5 & 8
70418602	GR	PROD NO.10	30.11.60	P		Abandoned	49	782950	7252375		B			18.29			203				Brz. & S. Steel	6.83	9.45			1.83	1091	32 Hrs.						1, 5 & 8
70418603	GR	PROD 2/76	04.04.76	P	Yes	Operational	49	784225	7252275		B	Mud Rotary		70	18.97	0.46	203		22.2	-4.19	S. Steel	16.1	19.1	1.91	-1.09	4.5	1626	8 Hrs.		1872		Yes	Elev. TOC. not off SWRISS. Gamma log to 50.6 m.	1 & 5
70418621	GR	PROD NO.3C		P	Yes	Operational	49	785400	7252700		C				14.82									11.72	8.72					1272			Elev. TOC. not off SWRISS	1
70418623	GR	PROD NO.18		P	Yes	Operational	49	786320	7252300	LB 225-14	C				18.947									8.02	4.92					1224			Elev. TOC. not off SWRISS	1, 5 & 8
70418624	GR	PROD N0.19		P	Yes	Operational	49	786400	7252450	LB 225-14	C				16.421									6.08	2.98					720			Elev. TOC. not off SWRISS	1, 5 & 8

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
70418625	GR	PROD 4/70		P	Yes	Operational	49	785320	7252400		C			11.89	19.19	0.61	203		11.96		Wire Wound	8.91	11.96	9.67	6.67	5.26	742	48 Hrs.		576			Elev. TOC. not off SWRISS. Pumped sand during test. Construction details from borecard 1646 - IID - 49.	10
70418626	GR	PROD 1/71		P		Abandoned	49	785910	7252100		C				20									10.2	9.2								Elev. data not from SWRISS. Replaced by 7/85.	1
70418627	GR	PROD 2/71		P	Yes	Operational	49	786800	7252250	LB 225-29	C				19.75									8.11	5.01					720			Elev. TOC. not off SWRISS	1
70418628	GR	PROD 1/73		P	Yes	Operational NIU	49	788721	7252601	FB 177-25	C				21.56									8.26	5.26								Elev. TOC. not off SWRISS. Showed as abandoned on plan. NIU due to uneconomical yield.	1
70418629	GR	PROD 2/73		P	Yes	Operational	49	787281	7252381	FB 222-17, LB 218-10, LB 225-15	C				18.047									9.27	5.57					1080			Elev. TOC. not off SWRISS	1
70418641	GR	PROD GP1		P	Yes	Operational	49	791575	7254150	LB 218-7, LB 225-30	D				18.08, 18.717									14.08	9.78					4320			Elev. TOC. not off SWRISS	1 & 5
70418642	GR	PROD 7/70		P	Yes	Operational	49	791590	7253780		D				22.62									10.72	7.72					576			Elev. TOC. not off SWRISS	1 & 5
70418643	GR	PROD 3/73		P	Yes	Operational	49	792624	7254362	FB 177-21, LB 225-31	D				14.276									9.81	6.71					1152			Elev. TOC. not off SWRISS	1 & 5
70418661	GR	PROD GP2		P	Yes	Operational	49	794800	7254850		E				20.81									16.21	8.91					1728			Elev. TOC. not off SWRISS	1 & 5
70418702	GR	PROD 8/74	17.10.74	P		Abandoned	49	802149	7257033	FB 177-7, LB 225-26	G	Mud Rotary		16	32.599	0.54	203		15.52	17.34	S. Steel	11.52	15.52	21.34	17.34	2.18?	2793	7 Hrs.					Elev. TOC. not off SWRISS. Replaced by 8/85	1, 5 & 7
70418704	GR	PROD 10/74	29.10.74	P	Yes	Operational	49	802297	7257294	FB 177-7, LB 225-26	G	Cable Tool		16.7	31.993	0.07	203		16.63	16.2	S. Steel	13.23	16.63	19.6	16.2	3.45	2793	8 Hrs		1200	Yes		Elev. TOC. not off SWRISS	1, 5 & 7
70418705	GR	PROD 13/74	09.11.74	P	Yes	Operational	49	802220	7257164	FB 177-7, LB 225-26	G	Cable Tool		16.34	32.928	0.63	203		16.34	16.76		12.4	16.34	20.7	16.76	2.18	3328	7.5 Hrs.		2304				1, 5 & 7
70418708	GR	PROD 8/85		P	Yes	Operational	49	802135	7257040	LB 225-26	G				32.457							8.7	17.2							1728			Replaces 8/74. Elev. TOC. not off SWRISS	1 & 5
70418710	GR	PROD 3/84	24.09.84	P	Yes	Operational	49	801668	7257002	FB 177-34, LB 182-8, LB 225-27	G	Mud Rotary		78.7	27.881	0.3	206	Steel	17.56	10.08	S. Steel	6.3	12.56	21.34	15.08	4.61	1872	8 Hrs.		1658			Elev. TOC. not off SWRISS	1 & 5
70418725	GR	PROD 24/74	10.06.75	P	Yes	Operational	50	198000	7258500		H	Mud Rotary		24.4	29.01	0.41	203		20.16		S. Steel	9.34	10.91	19.26	17.69	9.95	546	8 Hrs.			Yes			1, 5 & 7
																						15.81	18.92	12.79	9.68									
70418761	GR	PROD 1RS		P	Yes	Operational	50	205603	7261539	FB 205-25, LB 218-2	K				33.962									24.37	21.93					768				1 & 5
70419038	CTWS	BORE D	05.09.66	P		Abandoned	49	770427	7248503		A	Cable Tool	324	17.68	19.824	0.28	203		17.68		Brz. & S. Steel	13.88	17.68			5.87	840	24 Hrs.						1 & 9
	Mixed depth and deep production bores																																	
		14/77	02.09.77	P		Abandoned	49	803918	7258611		H	Mud Rotary		75					63.6		S. Steel	54.48	60.6										Casing broke off above screen and was pulled from hole.	5
	CWS	6/68		P		Operational					A	Cable Tool	305	25								19.2	22.3				162							8
		PROD 1/79	31.10.79	P		Operational NIU	40	799250	7255600	LB 399-8	F	Mud Rotary		100	24.94	1.32	203		36.43	-12.81	S. Steel	7.5	1.1	16.12	22.52	3.2	1434	8 Hrs.	1800				Bore not on bore plan. NIU due to uneconomical yield.	5
																						27.31	33.43	-3.69	-9.81									
		PROD 1/84	17.09.84	P		Abandoned	49	797351	7254747	FB 177-35	F	Mud Rotary		68.15	26.32	0.3	206	Steel	62.83		S. Steel	29.6	31.1			32.25	622	8 Hrs.					Replaced by 1/85. Shown as monitoring bore on plan.	5

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
															TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
							Zone	Easting	Northing													From	To	From	To									
		PROD 1/85	03.04.85	P		Operational NIU				LB 206-6												46	49	-20.09	-23.09								Replaces prod. bore 1/84. NIU due to uneconomical yield.	
							49	797353	7254745	FB 205-3	F	Mud Rotary	310	68.15	26.214	0.3	206	Steel	50.55	-24.64	S. Steel	29	32	-3.09	-6.09				1700				Shown as Monit. bore on plan. Elev. TOC & grid data not off SWRISS.	5
		PROD 11/74	16.12.74	P		Operational	49	795953	7254545	LB 399-21	E				27	0.48	203		81.58		S. Steel	22.27	25.37			36.24	829	8 Hrs.			Yes		Is this bore collapsed? Shown as monitoring bore on plan.	5 & 7
		PROD 2/85	24.04.85	P		Operational NIU																33.4	37.6	-8.24	-12.44								Elev. TOC & grid data not off SWRISS.	
							49	800429	7256695	FB 205-34	G	Mud Rotary		69.6	25.46	0.3	203	Steel	37.9	-12.74	S. Steel	7.7	10.7	17.46	14.46				1000				Shown as abandoned on plan. NIU due to uneconomical yield.	5
	GR	PROD 20/74	24.04.75	P		Operational NIU																30.31	31.88											
							50	206337	7260585	FB 205-25	L	Mud Rotary		88.4		0.4	203		84.37			17.68	24.44								Yes		Replaced by 20/94	5 & 7
																						77.53	80.65											
																						69.63	72.72											
	GR	PROD 21/74	08.05.75	P		Operational NIU																66.94	70.44											
							50	207350	7259750		L	Mud Rotary		74.4		0.35	203		73.59			36.36	39.8										NIU due to construction of bore 15/94 < 200 m away.	5 & 7
																						44.94	46.87											
	GR	PROD 4/76	12.04.75	P		Operational	49		7252300		A	Mud Rotary		64		0.6	203		51			33.8	51			42.96	513	8 Hrs.				Yes	Not shown on bore plan. No SWRISS Number. Casing is slotted. Gamma log to 46.15m. Shown as monit bore on plan.	5
																						36.8	39.8	-3.27	-6.27								Elev. TOC. & grid data not off SWRISS.	
		PROD 4/85	10.05.85	P		Operational	50	206236	7261248	FB 205-25	K	Mud Rotary		43.6	33.83	0.3	206	Steel	41	-7.47	S. Steel	16	22.3	17.53	11.23	4	1241	8 Hrs.	2000				Bore redeveloped and air lifted at 1000 m^3/day in Nov., 1993.	5
		PROD 5/85	21.05.85	P		Operational NIU	50	200569	7259913		J	Mud Rotary		69.3	37.81	0.3	206	Steel	27.6	9.91	S. Steel	23.4	26.4	14.11	11.11	11	370	8 Hrs.					NIU due to uneconomical yield. Elev. TOC & grid data not off SWRISS. Shown as abandoned on plan.	5
		PROD 6/85	26.05.85	P		Operational	50	202282	7260666		J	Mud Rotary		60.1	29.91	0.3	206	Steel	50.2	-20.59	S. Steel	6.5	9.5	23.11	20.11	8.4	1105	8 Hrs.	2000				Bore redeveloped and air lifted at 1000 m^3/day in Nov., 1993.	5
																						46	49	-16.39	-19.39								Elev. TOC. and grid data not off SWRISS.	
70418468.0	C	PROD 2/93	30.10.93	P		Operational												S. Steel				37.48	52.78											
							50	198266	7258815	D293.INF	H	Mud Rotary		60			273	& FG	56.41		S. Steel	19.58	31.48			34.75	1523	24 Hrs.			Yes	Yes	Bore was constructed in reamed 121 mm diam. twin tube hole.	4, 5 & 6
70418630	GR	PROD 3/76	08.04.76	P	Yes	Abandoned	49	785900	7252275		C	Mud Rotary		73.2	17.47	0.6	203		47.05	-29.58		8.62	44	8.85	-26.53	19.2	731	8 Hrs.				Yes	Elev. TOC. not off SWRISS. Screens = Slotted Casing.	1 & 5
70418631	GR	PROD 5/76	30.04.76	P	Yes	Operational	49	788404	7253024	FB 177-25	C	Mud Rotary		65.5	17.93	0.6	203		31.86	-14.53	S. Steel	8.87	15.04	8.46	2.29	8.3	1613	8 Hrs.		960		Yes	Elev. TOC. not off SWRISS. Pumping sand needs redrill (Coleman).	1 & 5
																						25.72	28.82	-8.39	-11.49								Gamma log to 29.8 m.	

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
70418632	GR	PROD 19/77	01.10.77	P	Yes	Operational	49	785650	7252675		C	Mud Rotary			15.08	0.3	203		39.55	-24.77	S. Steel	18.94	22	-4.16	-7.22	20.25	393	8 Hrs.		432			Elev. TOC. not off SWRISS	1 & 5
															18.59							30.88	37	-16.1	-22.22									
70418633	GR	PROD 6/82	12.06.82	P	Yes	Operational									19.15							20.05	26.15	-1.76	-7.86								no construction details have been found. Elev. TOC not off SWRISS.	
							49	786050	7252050		C	Mud Rotary		47.7	19.31	0.3	219	Steel	27.15	-8.86	S. Steel	9.11	12.16	9.18	6.13	9.25	1102	8 Hrs.		648			Replaces 3/70 which is not shown on bore plan and for which	1 & 5
70418634	GR	PROD 7/82	07.12.82	P	Yes	Operational	49	786610	7252250	LB 225-14	C	Mud Rotary			19.314	1.15	204	Steel	27.07	8.91	S. Steel	11.83	14.88	7.02	3.97	4.75	1436	8 Hrs.		864			Replaces 17 which is not shown on bore plan. Elev. TOC not off SWRISS.	1 & 5
																						21.42	24.47	-2.57	-5.62								Also same bore recorded as 70418622 in WIN	
70418635	GR	2/81	15.07.81	P	Yes	Operational NIU	49	788619	7252772	FB 177-25	C	Mud Rotary			19.145	0.3	219	Steel	33.05	-14.2	S. Steel	10.5	12.06	8.35	6.79	15.5	779	8 Hrs.		720			Elev. TOC. not off SWRISS	1 & 5
										LB 225-16												28	31.05	-9.15	-12.2									
70418636	GR	PROD 7/85	16.09.85	P	Yes	Operational NIU	49	785930	7252120	LB 225-28	C	Mud Rotary		45.8	18.568	0.3	205	Steel	28		S. Steel	9	12			10	391	8 Hrs.					Replaces Prod 1/71. NIU due to uneconomical yield.	1 & 5
																						21	24										Replaces prod. 1/71.	
70418644	GR	PROD 20/77	25.10.77	P	Yes	Operational	49	790740	7253480		D	Mud Rotary		62	17.03	0.37	203		47	-30.34	S.Steel	16.87	20	-.21	-3.34	26.5	490	8 Hrs.		648			Elev. TOC. not off SWRISS	1 & 5
																						27.94	31	-11.28	-14.34									
																						39.88	46	-23.22	-29.34									
70418663	GR	PROD 6/77		P	Yes	Operational	49	795731	7254681	LB 399-24	E			58.16	20.77	0.92	203		57.16	-37.31		8.84	10.41	11.01	9.44	19.5	700	8 Hrs. Uncertain		1176			Elev. TOC. not off SWRISS	1 & 5
										FB 205-35												26.44	28	-6.59	-8.15			pump test						
										LB 225-17					20.568							50.14	54.76	-30.29	-34.91			figures.						
70418664	GR	PROD 9/77	12.08.77	P	Yes	Operational	49	796010	7254677	LB 399 21	E	Mud Rotary		61	21.13	0.89	203		55.7	-35.47		3	4.55	17.23	15.68	27.25	1047	8 Hrs.		864			Elev. TOC. not off SWRISS	1 & 5
																						47.88	52.7	-27.65	-32.47									
										FB 177-3												23	27.62	-2.77	-7.39								Pumps fine material at start up.	
																						40	43.05	-19.77	-22.82									
70418665	CI	4/82	19.12.82	P		Operational	49	794500	7254700		E	Mud Rotary		60.3		0.3	203	Steel	32.3		S. Steel	5.34	8.34			17.5	301	8 Hrs.					Shown as unsuccessful or backfilled site on plan.	1 & 5
																						30.75	32.3											
70418666	GR	PROD 2/84	24.09.84	P	Yes	Operational	49	796549	7254649	FB 177-31	E	Mud Rotary		67.29	23.14	1.07	206	Steel	55	-32.01	S. Steel	17.3	20.3	5.69	2.69	4.2	2041	8 Hrs.		3480			Elev. TOC. not off SWRISS	1 & 5
										LB 182-5												28.4	31.4	-5.41	-8.41								Bore not straight.	
																						50.7	53.7	-27.71	-30.71									
70418681	GR	PROD 14/74	20.11.74	P	Yes	Operational	49	800931	7256090	LB 399-7	F	Mud Rotary		76.8	31.68	0.98	203		38.76	-8.06	S. Steel	8.84	10.41	21.86	20.29	19.05	2793	8 Hrs.		840	Yes		Elev. TOC not off SWRISS	1, 5 & 7
										FB 205-33												25.55	31.75	5.15	-1.05									
										LB 225-17												35.66	38.76	-4.96	-8.06									
70418682	GR	PROD 10/77	26.08.77	P	Yes	Operational				FB 205-34												27.94	31	-.1	-3.16									
																						36.44	38	-8.6	-10.16									
							49	800155	7255962	LB 399-8	F	Mud Rotary		64	28.24	0.4	203		41	-13.42		6.44	8.44	21.4	19.4	23.5	720	8 Hrs.		600			Elev. TOC. not off SWRISS	1 & 5
70418683	GR	PROD 3/79	12.11.79	P	Yes	Operational	49	797306	7254472	LB 399-16, FB 177-12	F	Mud Rotary		72	24.78	0.82	203		52.75	-28.78	S. Steel	45.25	49.75	-21.28	-25.78	14.5	2190	8 Hrs.	2000	1440			Elev TOC not off SWRISS.	1 & 5

WIN reference number	Well name	Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
						Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																					From	To	From	To									
70418684	GR PROD 3/82	22.12.82	P	Yes	Operational	49	798239	7254778	LB 399-14	F	Mud Rotary		62	23.65	1.57	203	Steel	45	-22.91	S. Steel	20.37	23.42	1.71	-1.34	5.25	1436	8 Hrs.		1200			Elev. TOC. not off SWRISS	1 & 5
70418685	GR PROD 10/84	07.11.84	P	Yes	Operational NIU				LB 182-7												25.1	28.1	-.85	-3.85								NIU because yield uneconononical shortly after river flow ceases.	
						49	798064	7255138	FB 177-36	F	Mud Rotary		56.84	24.501	0.3	206	Steel	29.6	-5.35	S Steel	6.15	10.65	18.1	13.6	8	1892	8 Hrs.	2500	1440			Elev TOC not off SWRISS.	1 & 5
70418701	GR PROD 7/74	14.10.74	P	Yes	Operational NIU	49	801923	7256584	FB 177-10, LB 225-20	G	Mud Rotary		68.6	33.2	0.46	203				S. Steel	53.89	58.51	-21.15	-25.77	39.92	775	8 Hrs.			Yes		Elev. TOC. not off SWRISS. NIU due to low yield.	1, 5 & 7
70418703	GR PROD 9/74	17.10.74	P	Yes	Operational																27.83	30.93	4.62	1.52									
																					35.5	38.61	-3.05	-6.16									
						49	802935	7257786	FB 181-12	G	Mud Rotary		79.9	32.93	0.48	203		38.61	-6.16	S. Steel	10.43	15.1	22.02	17.35	19.6	2793	8 Hrs.		1944	Yes		Elev. TOC. not off SWRISS	1, 5 & 7
70418706	GR PROD 11/77	17.08.77	P	Yes	Operational NIU	49	800864	7256676	FB 177-5	G	Mud Rotary		102.5	26.765	0.3	203		61.5	-35.035	S. Steel	21.38	26	5.085	.465	38.75	1145	8 Hrs.	800				Elev. TOC. not off SWRISS, NIU due to connection cost.	1 & 5
70418707	GR PROD 1/82	20.05.82	P	Yes	Operational																29.01	36.3	-1.83	-9.12								Elev. TOC. not off SWRISS	
						49	802144	7257771	FB 177-9	G	Mud Rotary			27.48	0.3	219	Steel	36.3	-9.12	S. Steel	17.21	23.31	9.97	3.87	4.25	1613	8 Hrs.		1560			Not shown on bore plan.	1 & 5
70418709	GR PROD 11/84	08.11.84	P	Yes	Operational				LB 182-3												17.88	24	8.9	2.78									
						49	803882	7258234	FB 177-32	G	Mud Rotary		61.5	27.03	0.3	206	Steel	25.74	1.34	S. Steel	9.44	11	17.34	15.78	7.8	1206	8 Hrs.		1392			Elev. TOC. not off SWRISS.	1 & 5
70418721	GR PROD 22/74	14.12.74	P	Yes	Operational	50	197775	7258450		H	Mud Rotary		77.7	36.53	0.48	203	Steel	61.23			12.8	58.52	23.25	22.47	18.25	2673	8 Hrs.		1440	Yes		Screen = slotted casing. Elev. TOC. not off SWRISS.	1, 5 & 7
70418722	GR PROD 12/77	21.09.77	P	Yes	Operational	49	803918	7258611	FB 177-14												25.64	28.7	1.51	-1.55								Bores 14/77 and 15/77 also on this site.	
																					50.8	51.8	-23.65	-24.65								Bottom screen is now cemented off.	
						50	196950	7258600	LB 225-23	H	Mud Rotary		75	27.918	0.3	203		61.95	-34.8	S. Steel	4.94	8	23.25	22.47	7.75	2793	8 Hrs.		1440			Elev. TOC. not off SWRISS	1 & 5
																					55.33	59.95	-28.18	-32.8									
70418723	GR PROD 21/77	04.11.77	P	Yes	Operational	50	198320	7258850	LB 225-22	H	Mud Rotary		61	28.951	0.3	203		55.35	-26.25	S. Steel	46.17	55.35	-17.07	-26.25	36	731	8 Hrs.		624			Elev. TOC. not off SWRISS	1 & 5
70418724	GR PROD 7/79	14.11.79	P	Yes	Abandoned	50	198550	7258900	LB 225-22	H	Mud Rotary		65	28.254	0.5			41.5	-13.74	S. Steel	4.5	7.5	23.26	20.26	19.8	1864	Pumping		864			Casing damaged. Can not be equipped.	1 & 5
						49	804933	7258675	FB 177-19												28.5	31.5	-.74	-3.74			period						
																					35.5	38.5	-7.74	-10.74			unknown.						
70418726	GR PROD 1/87	29.07.87	P		Operational	50	198434	7258543	LB 399-38, FB 222-12	H	Mud Rotary		68	36.72	0.33	261	Steel	64.35	-28.31	S. Steel	34.82	62.32	1.22	-26.28	18.05	4535	36 Hrs.	5000	4320	Yes	Yes	Elev. TOC. not off SWRISS.	1 & 5
70418727	GR PROD 10/92	23.03.92	P		Operational	50	199411	7258226	FB 222-31, LB 254-18	J	Mud Rotary	375		35.684	0.4	256	ABS	56.6	-21.87	S. Steel	29.6	38.6	5.13	-3.87	17.23	1000	24 Hrs.		960	Yes		Re-developed using cable tool in 1993.	1 & 6
70418741	GR PROD 12/74	06.12.74	P	Yes	Operational																49.6	52.7	-14.24	-17.34									
																					58.49	60.06	-23.13	-24.7									
						49	805898	7258897	FB 177-17												26.51	29.61	8.85	5.75									
						50	199050	7258820		J	Mud Rotary		77.1	35.82	0.46	203		75.53	-40.17	S. Steel	18.86	20.44	16.5	14.92	25.73	2191	8 Hrs.		1440	Yes		Elev. TOC. not off SWRISS	1, 5 & 7
																					67.72	75.53	-32.36	-40.17									
70418742	GR PROD 15/74	06.12.74	P	Yes	Operational NIU																73.04	74.62			61.16	545	8 Hrs.						

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Diameter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
																						36.16	39.26											
																						24.93	28.03											
							50	199884	7259676	FB 205-31	J	Mud Rotary		88.4		0.13	203		74.62		S. Steel	13.78	15.36			61.16	545	8 Hrs.			Yes		NIU due uneconomical yield.	1, 5 & 7
70418743	GR	PROD 16/74	11.12.74	P	Yes	Operational	50	201289	7260165	FB 205-29	J	Mud Rotary		79.9	39.815	0.38	203		61.03		S. Steel	16.56	19.66			40.23	666	8 Hrs.		1008	Yes		Elev. TOC. not off SWRISS. Pumps sand upon start up. Hole in casing.	1, 5 & 7
										LB 225-25												35.4	41.6											
																						57.93	61.03											
70418744	GR	PROD 17/74	03.06.75	P	Yes	Abandoned																59.38	60.96											
										LB 225-24					41.685							51.71	56.38										Replaced by 1/93.	
							50	202970	7260550	FB 205	J	Mud Rotary		73.2		0.48	203		64.81			13.66	16.76			40.21	2191	8 Hrs.			Yes		Casing collapsed.	1, 5 & 7
70418745	GR	PROD 8/77	01.08.77	P	Yes	Abandoned				& FB 177-16												50.04	54.76	-16.58	-21.3								Abandoned due to invasion of bore by tree roots.	
							49	806506	7259420	FB 181-8												26.44	28	7.02	5.46								Bore shown as abandoned on bore plan.	
							50	199670	7259600		J	Mud Rotary		63	33.86	0.4	203		57.76	-24.3	S. Steel	8.88	13.5	24.58	19.96	19.5	786	8 Hrs.	407				Elev. TOC. not off SWRISS.	1 & 5
70418746	GR	PROD 13/77	02.09.77	P	Yes	Operational																33.94	37	-4.7	-7.76									
																						20.94	24	8.3	5.24									
							50	200910	7260365	FB 205-29	J	Mud Rotary		102.3	29.74	0.5	203		40	-10.76	S. Steel	4.95	8	24.29	21.24	8	2673	8 Hrs.		1440			Elev. TOC. not off SWRISS	1 & 5
70418747	GR	PROD 22/77	01.11.77	P	Yes	Abandoned				LB 182-2												32.88	39	-9.36	-9.54								Elev. TOC. not off SWRISS	
							50	201690	7260420	FB 205-29	J	Mud Rotary		103	30.027	0.3	203		49	-19.54	S. Steel	5.94	15.24	23.52	14.22	37.5	1560	8 Hrs.					Replaced by 12/84.	1 & 5
																						43.94	47	-14.48	-17.54								Abandoned due to damage suffered during flood.	
70418749	CI	2/82	09.12.82	P		Operational NIU	50	200247	7260229	FB 205-29	J	Mud Rotary		65.5		0.3	206	Steel	39.3		S. Steel	12.14	15.18			15.6	378	8 Hrs.					Shown on bore plan as backfilled or unsuccessful site.	1 & 5
																						36.26	39.3										Never equipped due to uneconomical yield.	
70418750	GR	PROD 12/84		P	Yes	Operational NIU	50	201692	7260417	LB 399-19	J				24.06							44.7	46.2										NIU due to uneconomical yield. Drilled to replace 22/77.	1 & 5
70418751	GR	PROD 5/84	22.10.84	P		Operational NIU	50	199020	7259505	FB 177-33	J	Mud Rotary		66	29.036	0.3	206	Steel	29.47	-0.38	S. Steel	4.94	8	23.85	20.79	15.75	1011	8 Hrs					Shown as abandoned on bore plan. Elev. TOC. not off SWRISS	1 & 5
										LB 182-2												24.94	28	3.85	.79								Max. recommended pump rate 1100 m^3/day	
70418762	GR	PROD 18/74	12.12.74	P	Yes	Operational	50	204242	7261888	FB 205-26	K	Mud Rotary		85.3	36.365	0.35	203		82.67		S. Steel	28.32	29.9	7.70	6.12	63.16	513	8 Hrs.		648	Yes		Elev. TOC. not from SWRISS.	1, 5 & 7
										LB 225-21												33.55	35.15	2.47	0.87									
																						40.56	42.14	-4.55	-6.13									
																						53.44	56.54	-17.43	-20.53									
																						73.78	79.48	-37.77	-43.47									
70418763	GR	PROD 19/74	17.11.75	P	Yes	Operational																67.06	68.66	-26.45	-28.05									

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL From	m BGL To	m AHD** From	m AHD** To	D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						45.34	48.44	4.73	-7.83									
							50	205504	7261262	FB 205-25	K	Mud Rotary		86	41.01	0.4	203		72.69	-32.08		27.66	33.86	12.95	6.75	18.41	2138	8 Hrs.		1992			Elev. TOC. not from SWRISS.	1, 5 & 7
70418764	GR	PROD 16/77	07.10.77	P	Yes	Abandoned				LB 218-2					30.316							42.88	49	14.44	11.38								Elev. TOC. not off SWRISS	
							50	203260	7260801	FB 205-27	K	Mud Rotary		102.5		0.3	203		50	-18.62	S. Steel	16.94	20	-11.5	-17.62	32.75	786	8 Hrs.					Replaced by 8/82.	1 & 5
70418765	GR	PROD 8/82	22.12.82	P		Operational NIU	50	203263	7260797	FB 205-27	K	Mud Rotary		57.35	30.668	0.5	203	Steel	37.8	-7.62	S. Steel	34.2	37.3	-4.02	-7.12	20	254	8 Hrs.	150	864			Replaces 16/77. Elev. TOC. not off SWRISS.	1 & 5
										LB 225-24												16.5	19.5	13.68	10.68								Regarded as not being worth equipping.	
70418766	GR	PROD 13/84		P	Yes	Operational	50	204750	7261571		K				32.42									-4.58	-7.58								Elev. data not from SWRISS	1
																								25.22	22.22									
70418786.4	C	PROD 19/94	01.02.94	P		Operational NIU												S. Steel			& S. Steel	45	75										(Exploration hole 11/93) used for this bore. Gamma log only to 47 mbgl.	
							50	205930	7260967		L	Mud Rotary		81			224	PVC &	79		Slotted PVC	27	45					24 Hrs.			Yes	Yes	Slotted PVC shallow and S. Steel screens deep. Logs from G70418786.3	4, 5 & 6
70418787.5	C	PROD 1/94	13.01.94	P		Operational	50	208517	7259442	D194A.INF	M	Mud Rotary		65			224	PVC &	65		Slotted PVC	11.7	29.7			14	3564	8 Hrs.			Yes	Yes		4, 5 & 6
																		S. Steel			& S. Steel	30.7	60.7										(Exploration hole 7/93) used for this bore.	
70418801.6	C	PROD 15/94	20.01.94	P		Operational	50	207534	7259764	D1594.INF	L	Mud Rotary		67.5			224	PVC &	64.82		Slotted PVC	17.6	29.6			29.38	3564	24 Hrs.			Yes	Yes	Slotted PVC shallow and S. Steel screens deep. Logs from G70418782.6	4, 5 & 6
																		S. Steel			& S. Steel	30.42	60.42										(Exploration hole 12/94) used for this bore.	
70418804.1	C	PROD 18/94	26.01.94	P		Operational												S. Steel			& S. Steel	35.5	65.5										(Exploration hole 11/94) used for this bore.	
							50	208350	7258819		M	Mud Rotary		72			224	PVC &	69.5		Slotted PVC	21.7	33.7			24.75	3564	24 Hrs.			Yes	Yes	Slotted PVC shallow and S. Steel screens deep. Logs from G70418797.8	4, 5 & 6
70418806.5	C	PROD 20/94	08.02.94	P		Operational NIU	50	206339	7260581		L	Mud Rotary		90			224	PVC &	88		Slotted PVC	30	54					24 Hrs.			Yes	Yes	Slotted PVC shallow and S. Steel screens deep. Logs from G70418781.4	4, 5 & 6
																		S. Steel			& S. Steel	54	84										(Exploration hole 6/93) used for this bore.	
70418807.5	C	PROD 21/94	14.02.94	P		Operational NIU	50	200585	7259780			Mud Rotary		73			224	PVC &	70.7		Slotted PVC	19	37					24 Hrs.			Yes	Yes	Slotted PVC shallow and S. Steel screens deep. Logs from G70418802.8	4, 5 & 6
																		S. Steel			& S. Steel	37	67										(Exploration hole 16/94) used for this bore.	
70418859		PROD 9/92	13.03.92	P		Operational	50	197100	7258500	LB 399-2	H	Mud Ratary			35.42	0.3	280	ABS	68.7		S. Steel	32	68								Yes	Yes	Re-developed using cable tool in 1993 and commissioned. No survey data.	6
	Production bores with no known screen details																																	
		GP3		P		Operational NIU	49	799945	7255759	FB 205-34	F																						NIU due to uneconomical yield.	5
70418662	GR	PROD 3/77		P	Yes	Operational	49	793920	7254650		E				20.09															1152			Elev. TOC. not off SWRISS	1 & 5

WIN reference number	Well name		Completion date	Use	Well monitored	Well status	AMG grid coordinates (AGD)			Surveyors ref	Basin	Drilling method	Drill dia. (mm)	Drill depth (mBGL)	Casing details				Base depth (mBGL)	Base depth (mAHD)	Screen details					Pumping test information				Installed capacity (m^3/d)	Geological logs	Geophysical logs	Comment and anecdotal data	Data source
							Zone	Easting	Northing						TOC elev (mAHD)	TOC height (mAGL)	Dia-meter (mm)	Type			Type	m BGL		m AHD**		D/down (m)	Rate (m^3/d)	Comments	Max. rec. rate (Gee) (m^3/d)					
																						From	To	From	To									
70418748	GR	PROD 8/79		P	Yes	Operational	50	200907	7260364	FB 205-29	J				29.75																		Standby bore for 13/77. Used intermitantly.	1 & 5
70419031	CTWS	Warrens		P		Operational	49	770787	728308		A				26.494																			
70419032	CTWS	BORE 9A		P		Abandoned	49	770787	7248219		A																							1
70419033	CTWS	BORE 10A		P		Abandoned	49	771217	7248673		A																							1
70419034	CTWS	BORE H		P		Abandoned	49	770993	7248677		A																							1
70419035	CTWS	BORE IVY		P		Abandoned	49	770768	7248682		A																							1
70419036	CTWS	BORE BA		P		Abandoned	49	770796	7248681		A																							1
70419037	CTWS	BORE J		P		Abandoned	49	770706	7248406		A																							1
70419039	CTWS	BORE HA		P		Abandoned	49	770991	7248616		A																							1
70419040	CTWS	Pump Well		P		Abandoned	49	770787	7248219		A																							1
70419080	CBA	Callagiddy		P		Operational	50	202170	7221820																									1
70419081	CBA	Boola-thanna		P		Operational	49	772520	7293450																									1
	Production bores with no known construction or location details																																	
		10		P		Abandoned																											Shown on Plates 1 & 2 in Allen's (1972) report.	2
		10/85		P							K																						May have replaced 16/77. Same site as 8/82.	
	GRI	19(D9)	.08.1968	P		Operational						Cable Tool		15.85		0.12	203									2.67	976	29 Hrs.					3 m of screen but depths unknown.	5 & 8
		3/70		P							C																						Replaced by 6/82	
	CWS	7/67 or 3/68		P		Operational								21.6																			Two bore numbers given in file.	8
	CWS	8/67 or 4/68		P		Operational								21.3																			Two bore numbers given in file.	8
		9		P		Abandoned																											Shown on Plates 1 & 2 in Allen's (1972) report.	2
		B-1		P		Abandoned																											Shown on Plates 1 & 2 in Allen's (1972) report.	2
		B-2		P		Abandoned																											Shown on Plates 1 & 2 in Allen's (1972) report.	2
		I		P		Abandoned																											Shown on Plates 1 & 2 in Allen's (1972) report.	2
		PROD 4/85	10.05.85	P		Operational																											Shown as abandoned on plan.	
		PROD 6/85	26.05.85	P		Operational																											Shown as abandoned on plan. No survey data.	
		T.W.		P		Abandoned																											Shown on Plates 1 & 2 in Allen's (1972) report.	2
70418750	GR	PROD 12/84		P	Yes	Operational NIU				LB206-2					29.117																		Air lift developed @ 500 m^3/day, November, 1993.	
70418764	GR	PROD 16/77	07.10.77	P	Yes	Abandoned				LB 225-24					30.644																			

Legend:

GRBXS	Gascoyne River bed cross sections
ORCC	Old River channels Carnarvon
CEA	Carnarvon Extraction Area
CLS	Carnarvon L Series wells
CRI	Carnarvon recharge investigation
GR	Gascoyne River
CTWS	Carnarvon Town Water Supply
COA	Carnarvon Older alluvium
CBA	Carnarvon Basin Artesian
GRI	Gascoyne River Irrigation
CWS	Carnarvon Water Suply

O	Monitoring well
E	Exploration bore
P	Production well
U	Unknown
Pa	Pastoral well
NIU	Not in use
OB	Observation bore
P 2/76	Production piezometer
Brz	Bronze screen
ABS	Thermo-plastic screen
FG	Fibreglass screen
m BGL	meters below ground level
m AHD	meters Australian Height datum

Data source:

1	SWRISS now converted to WIN data base
2	GSWA Record No. 1972/9 (Allen, 1972)
3	GSWA Record No. 1968/11 (Passmore, 1968)
4	Water Authority Drilling and Testing Branch file
5	Water Authority Groundwater and Environment Branch file
6	GSWA Hydrogeology Section reports
7	GSWA file 316/1975
8	GSWA file 39/1955
9	GSWA file 319/1967
10	GSWA bore cards
11	Water and Rivers Commission Hydrogeology reports

** Note:

Depths in AHD should be regarded as approximate since often bore headworks are altered and/or ground level may change due to shifting sediment in river flows.

In addition to bores on spreadsheet, details of other bores from the Carnarvon area are contained in data source 4. Drilling and Testing Branch files. These bores were drilled under the rpoject name Gascoyne River Investigation and have bore numbers of the following format – D 72/74, 20/1, 20/2 and 23/7 for example. They were drilled using auger technique and location details are available. The file also contains numerous exploration auger holes under the project name Probe Holes. The bores have the following format – SS 1/77, SS 7/77 etc. They are shallow holes and left uncased, no location details available.

Between 1954 and 1955, 32 cable tool holes were drilled to a depth of 61 m, west of 10 mile bridge. No construction details are available for these holes, however, drillers logs are contained in data source 8, and locations are shown in Allen (1972) report plates 1 & 2.

Drillers logs for two holes drilled in 1955 to depths of 22 and 34 m exist in data source 9, however no construction details are available and their location details are inconclusive. A large number of auger holes were drilled around Rocky Pool to investigate a possible dam site and are contained in data source 3.

Installed capacity obtained from Coleman, R., 1993, Determination of Carnarvon wellfield abstraction capacity. Groundwater and Environment Branch, Water Authority of Western Australia.

The details of the 1969–72 auger drilling survey of the riverbed are contained on microfiche at the Water Corporation's reprographics centre in Leederville. Digital capture of this data was conducted as part of the numerical modelling study and is held by the Water and Rivers Commission Hydrology and Water Resources Branch.

Appendix B Private wellfield details

Assessment number	**File number**	**Number of licensed wells**	**No. of licensed wells on file**	**Well I.D****	**No. with known screen intervals**	**Elevation** m AHD	**Representative screen intervals***			
							m BGL		m AHD	
							from	to	from	to
1	C329	2	1	A	2	12.2	11.0	13.5	1.2	-1.3
2	C248	1	2	AC	1	9.4	10.7	13.7	-1.3	-4.3
3	C396	1	2	DC	-	9.5				
4	C229	2	2	CG	-	8.4				
5	C237	2	4	ABEG	1	8.1	0.0	19.5	8.1	-11.4
6	C285	3	2	BC	-	7.9				
6.01	C397	4	4	ABCD	-	9.1				
7	C398	3	3	ABC	-	10.8				
8	C253	2	2	EI	1	11.0	9.5	14.5	1.5	-3.5
9	C238	2	2	AC	2	11.4	12.1	21.3	-0.7	-9.9
9.01	C292	2	5	BCDEF	2	12.4	8.0	14.0	4.4	-1.6
10	C320	2	4	BCGF	-	11.0	30.0	35.0	-19.0	-24.0
11	C335	2	2	EF	1	10.5	15.0	19.6	-4.5	-9.1
12	C308	2	3	DEF	1	12.0	12.5	16.5	-0.5	-4.5
12.01	C315	1	2	DA	1	10.4	8.0	14.0	2.4	-3.6
13	C347	4?	4	BDEF	1	10.4	5.5	10.0	4.9	0.4
14	C260	3	4	ABGD	2	11.7	9.1	13.7	2.6	-2.0
15	C239	4	4	CEFG	4	8.7	4.5	6.0	4.2	2.7
16	C234	1	2	CF	2	7.6	5.8	17.0	1.8	-9.4
17	C280	-	2	DC	2	8.2	1.0	12.0	7.2	-3.8
18	C750	1	3	ACL	1	7.5	6.5	7.0	1.0	0.5
20	C274	2	2	DH	1	7.0	5.5	5.5	1.5	1.5
21	C319	2	2	BD	1	8.8	4.5	4.5	4.3	4.3
22	C236	1	2	BG	1	8.7	11.2	12.2	-2.5	-3.5
22	C236	1			1	8.7	23.4	24.4	-14.7	-15.7
23	C228	2	2	CF	1	7.0	5.0	15.0	2.0	-8.0
24	C230	3	3	CWX	-	7.3	4.7	7.5	2.6	-0.2
26	C322	1	3	DEF	1	7.6	16.0	22.0	-8.4	-14.4
27	C389	11	13	DEFGHIJKLMNPQ	12	10.0	4.8	9.9	5.2	0.1
29	C328	2	2	AB	-	6.2				
30	C390	3	3	ABC	-	6.2				
31	C263	1	1	A	1	5.5	5.5	5.5	0.0	0.0
32	C311	3	3	BCE	-	5.3	0.0	9.0	5.3	-3.7
33	C278	5	4	BCDE	-	5.3				
34	C312	2	2	CE	-	5.8	0.0	7.3	5.8	-1.5

Assessment number	File number	Number of licensed wells	No. of licensed wells on file	Well I.D**	No. with known screen intervals	Elevation m AHD	Representative screen intervals*			
							m BGL		m AHD	
							from	to	from	to
35	C302	6?	4	BEHI	1	5.1	3.4	9.7	1.7	-4.6
36	C395	3	5	EFHIJ	-	8.0				
37	C392	3	1	G	1	6.5	0.0	14.3	6.5	-7.8
38	C284	4	2	EF	2	5.4	0.0	15.0	5.4	-9.6
39	C279	4	4	BCFG	4	9.4	2.0	10.0	7.4	-0.6
40	C342	1	1	D	-	4.8				
41	C261	-	1	B	-	4.9				
42	C246	1	1	B	-	8.1	3.0	6.0	5.1	2.1
43	C265	2	1	C	1	4.9	5.5	11.6	-0.6	-6.7
43.01	C362	1	1	A	1	8.6	11.3	13.1	-2.7	-4.5
44	C346	1	1	C	1	7.0	8.5	11.5	-1.5	-4.5
45	C399	1	3	BCD	-	7.0				
46	C247	1	1	B*	1	5.8	13.7	15.7	-7.9	-9.9
47	C376	1	2	DF	1	7.1	4.5	8.2	2.6	-1.1
48	C400	5	4	DCFG	1	7.1	10.4	12.2	-3.3	-5.1
53	C326	4	5	BCDEF	2	2.4	4.0	6.6	-1.6	-4.2
54	C324	2	1	A	1	4.2		4.8		-0.6
55	C325	2	1	A	1	7.6	4.0	12.5	3.6	-4.9
56	C359	1	3	BDE	-	4.0				
57	C297	6	5	DHIK	4	4.7	8.5	17.0	-3.8	-12.3
57	C297	6	5	G	1	4.7	0.0	4.0	4.7	0.7
60	C393	4	4	CDEF	1	2.2	0.0	2.0	2.2	0.2
66	C339	1	1	A	-	4.7				
71	C267	2	3	ACD	1	5.8	13.0	17.7	-7.2	-11.9
74	C299	1	2	BE	1	7.3	10.0	16.0	-2.7	-8.7
75	C380	2	2	BC	-	11.3	7.5	10.8	3.8	0.5
76	C298	1	4	ACJK	2	10.9	9.5	25.3	1.4	-14.4
77	C269	3?	4	FGHI	1	9.9	14.0	26.0	-4.1	-16.1
77.01	C250	-	2	AH	-	14.2	15.8	19.5	-1.6	-5.3
78	C255	3	3	ABD	1	15.9	14.0	20.0	1.9	-4.1
79	C235	2	3	BCD	1	10.2	7.0	7.0	3.2	3.2
80	C275	2?	4	EFGH	4	13.3	12.1	28.0	1.1	-14.7
81	C332	1	1	G	1	13.5	6.4	23.5	7.1	-10.0
81.01	C333	1	1	A	1	14.4	15.2	23.8	-0.9	-9.4
82	C289	1	1	C	-	12.2				
82.01	C288	1	1	B	-	12.6				
83	C276	1	1	D	-	12.5	0.0	12.2	12.5	0.3
84	C356	1	5	CDEGH	1	10.0	15.5	27.5	-5.5	-17.5
85	C412	1	3	DEF	1	10.8	18.0	24.0	-7.2	-13.2

Assessment number	**File number**	**Number of licensed wells**	**No. of licensed wells on file**	**Well I.D****	**No. with known screen intervals**	**Elevation** m AHD	**Representative screen intervals***			
							m BGL		m AHD	
							from	to	from	to
85.01	C373	1	1	G	1	12.7	6.0	9.0	6.7	3.7
85.01	C373	1			1	12.7	15.0	24.0	-2.3	-11.3
85.02	C290	2	2	BC	2	10.6	15.0	33.5	-4.4	-22.9
86	C330	3	3	BCE	2	7.9	6.0	12.0	1.9	-4.1
87	C413	3	3	ABD	1	7.9	6.0	12.0	1.9	-4.1
88	C277	3	3	BEF	2	10.2	9.2	31.6	1.1	-21.4
89	C273	4	5	AFLMN	-	8.8				
90	C340	2	2	AC	-	7.9				
91	C387	2	2	BC	-	7.1		7.9		-0.8
92	C251	2	2	AD	1	11.5	16.0	28.0	-4.5	-16.5
93	C371	2	2	BC	2	7.9	3.0	6.0	4.9	1.9
94	C352	3	2	AB	2	7.6	6.1	30.5	1.5	-22.9
95	C256	2	2	AB	1	7.1	8.0	12.0	-0.9	-4.9
96	C266	3	3	BCF	-	9.8				
97	C406	1	1	CD?	1	6.5	8.0	25.0	-1.5	-18.5
98	C336	2	3	A	1	7.8	4.5	5.5	3.3	2.3
98	C336	2		BC	2	7.8	6.0	14.0	1.8	-6.2
99	C300	4	4	BDFG	1	5.3	0.0	8.0	5.3	-2.7
100	C286	2	2	DE	-	7.7	0.0	9.8	7.7	-2.1
101	C264	2	2	AB	2	7.3	0.0	5.5	7.3	1.8
102	C307	1	1	D	-	6.5				
103	C309	1	2	BD	-	6.8	1.0	9.8	5.8	-2.9
104	C232	1	1	C	-	7.2				
105			1	D						
106	C365	1	1	B	-	5.2				
107	C411	3	3	ABC	3	5.9	0.0	7.0	5.9	-1.1
108	C262	1	1	E	1	4.9	0.0	6.0	4.9	-1.1
109	C374	3	3	ABC	-	6.2				
110	C294	1	1	EFGH	1	4.4	3.0	7.0	1.4	-2.6
112	C354	3	3	ABC	-	4.9				
113	C337	-	3	ACD	1	4.9	6.0	12.0	-1.1	-7.1
114	C361	-	4	FGHJ	-	5.7				
114.01	C301		2	AB			5.5	17.5		
115	C348	2	4	ADGH	2	6.1	7.8	15.3	-1.7	-9.2
116	C241	3	5	DFGIJ	1	4.2	10.7	12.2	-6.4	-8.0
117	C349	2	3	ADV	1	3.4	6.0	12.0	-2.6	-8.6
118	C257	1?	4	KLMS	2	3.9	6.0	12.1	-2.1	-8.2
119	C386	2	4	DLMN	2	6.3	0.0	13.0	6.3	-6.7
120	C293	2	2	BF	2	6.5	6.0	15.0	0.5	-8.5

Assessment number	File number	Number of licensed wells	No. of licensed wells on file	Well I.D**	No. with known screen intervals	Elevation m AHD	Representative screen intervals*			
							m BGL		m AHD	
							from	to	from	to
121	C321	2	4	ABHI	2	4.0	2.0	8.5	2.0	-4.5
122	C350	7	7	AEFHIJK	1	4.2	10.0	12.0	-5.8	-7.8
123	C281	3	2	EG	2	4.2	12.0	14.0	-7.8	-9.8
123	C281	3	2	B not licensed	1	4.2	18.0	20.0	-13.8	-15.8
124	C367	1?	4	ACD (E not used)	3	5.5	4.0	7.0	1.5	-1.5
125	C377	3?	5	ABCEF	1	4.9	0.0	12.0	4.9	-7.1
126	C242	2	2	CD	1	3.8	7.0	13.0	-3.2	-9.2
128	C403	3	7	ABCD EFG	2	4.0	8.0	13.0	-4.0	-9.0
129	C240	5	5	CDFG	3	4.1	7.0	14.4	-2.9	-10.3
129	C240	5	5	E	1	4.1	4.5	4.5	-0.4	-0.4
130	C283	5	3	EGH	2	3.4	0.0	11.0	3.4	-7.6
131	C314	1?	2	CD	-	3.4				
136	C404	3	4	EFGI	1	8.9	10.0	30.0	-1.1	-21.1
147	C366	1	1	G	1	6.2	4.6	7.9	1.6	-1.7
147	C366	1			1	6.2	9.4	14.9	-3.2	-8.7
148	C327	1	1	B	1	12.5	6.0	10.0	6.5	2.5
150	C408	3	5	BCEFG	2?	12.4	8.0	15.0	4.4	-2.6
152	C363	1	1	A	-	5.9				
154	C391	1	1	H	-	4.0				
155	C351	2	2	AB	2	2.7	0.0	3.0	2.7	-0.3
158	C381	1	1	A	1	9.5	0.0	4.2	9.5	5.4
160	C296	1	1	C	1	17.3	5.8	8.8	11.5	8.5
161	C231	1	1	A	1	11.1	12.7	15.5	-1.6	-4.3
161.01	C316	1	1	A	-	8.4	11.0	13.7	-2.6	-5.3
161.01	C316	1	1	A	-	8.4	21.9	23.8	-13.6	-15.4
162	C271	2	2	DE	2	12.0	0.0	6.0	12.0	6.0
162	C271	2			2	12.0	12.0	14.0	-0.0	-2.0
163	C303	4	4	ABCE	2	9.1	3.0	4.6	6.1	4.5
163	C303	4			2	9.1	13.0	22.0	-3.9	-12.9
164	C368	1	1	B	-	9.0				
165	C317	1	2	AE	1	9.3	15.0	24.3	-5.7	-15.0
166	C353	3	3	ABC	1	9.1	0.0	3.6	9.1	5.5
167	C259	1	1	B	-	6.2				
172	C401	1	3	ACF	1	12.9	33.0	39.0	-20.1	-26.1
173	C407	1	1	B	-	12.2				
190.01	C334	1	1	B	1	8.9	6.1	18.2	2.8	-9.3
197.01	C410		1	A		7.1				

Assessment number	File number	Number of licensed wells	No. of licensed wells on file	Well I.D**	No. with known screen intervals	Elevation m AHD	Representative screen intervals*			
							m BGL		m AHD	
							from	to	from	to
202	C345	1	1	A	-	8.1				
203.01	C258	1	1	A	-	10.8				
208	C383	2	2	AC	1	9.8	14.3	16.8	-4.5	-7.0
215	C370	1	2	AB	1	10.2	4.6	20.7	5.6	-10.5
216	C355	3	1	A	1	9.2	4.3	18.3	4.9	-9.1
217	C252	2	2	AC	2	9.4	0.0	6.7	9.4	2.7
217	C252	2			2	9.4	8.7	11.7	0.7	-2.3
217	C252	2		C?	2	9.4	4.0	17.0	5.4	-7.6
218	C318	1	3	DGF	2	11.2	12.0	24.0	-0.8	-12.8
219	C244	1	1	D	1	11.3	5.5	17.5	5.8	-6.2
290	C379	1	1	A	-	5.3				
302	C304	1	2	AB	-	4.5				
303	C375	1	1	C	1	2.2	0.0	2.5	2.2	-0.3
307	C295	5	8	ABCD EFGH	1	11.9	21.0	28.0	-9.1	-16.1
308	C272	3	2	EH	2	10.2	6.0	15.0	4.2	-4.8
308	C272	3			2	10.2	18.0	33.0	-7.8	-22.8
309	C268	3	7	CDEFGHI	3	12.6	10.0	27.0	2.6	-14.4
310	C358	4	3	ABD	3	10.5	5.0	44.0	5.5	-33.5
311	C282	1	1	C	1	9.0	3.0	17.0	6.0	-8.0
312	C306	1	1	B	1	9.3	12.1	18.2	-2.9	-8.9
313	C291	1	1	A	1	4.9	14.8	17.9	-9.9	-13.0

* Representative screen intervals as not all well records are complete. These screen intervals were used to determine which layer groundwater abstraction would be accounted from within GRFAMOD numerical simulations.

** Each new well drilled within an assessment is given a letter to represent its details. The well intervals represent the collective screen intervals of all licensed wells within an assessment as it is not always known which well has been utilised over time.

Assessments were the screen interval is unknown were assigned to Layers 1 and 2 within GRFAMOD.

Appendix C Estimates of groundwater flow beneath the Gascoyne River from flownet analysis adapted from Davidson (1995)

Riverbed sand – estimate of groundwater flow (rounded to nearest 10 m^3/day)

Riverbed sand flow cell (see fig. 28)	**Legend**							**LD per unit area of flow cell**
	Q_{DO}	Q_{Clo}	G_n	L_n	Rn	a	L_D	(m^3/day/m^2)
Rocky Pool	590							
1(12)	380	1 530	0	210	940	0	1 150	0.0021
2(12)	70	1 190	0	370	810	60	1 120	0.0024
3(12)	230	2 580	0	50	2 520	210	2 360	0.0015
4(12)	170	1 490	0	60	1 410	140	1 320	0.0014
5(12)	220	1 820	0	70	1 650	130	1 600	0.0015
6(12)	260	4 640	0	120	4 410	150	4 380	0.0022
7(2)	310	8 360	0	100	8 100	150	8 060	0.0030
8(5)	530	6 110	180	0	5 810	50	5 580	0.0029
9(12)	520	4 130	0	270	3 600	260	3 610	0.0020
10(5)	750	2 790	40	0	2 270	190	2 040	0.0016
11(12)	370	3 780	0	520	3 030	140	3 410	0.0020
12(5)	1 280	4 960	760	0	4 590	140	3 680	0.0019
13(12)	760	5 240	0	620	3 960	110	4 470	0.0022
14(12)	220	2 520	0	910	1 750	360	2 300	0.0019
15(12)	340	1 580	0	2 260	1 360	2 380	1 240	0.0016
16(12)	390	2 230	0	550	1 900	600	1 850	0.0015
17(12)	510	2 450	0	700	2 060	820	1 940	0.0016
18(5)	880	5 100	20	0	4 590	350	4 220	0.0009
Total flow	8 770	62 500						
Balance			-1 000	+6810	+54 760	-6 240	-54 330	0

Superscript (e.g. (12)) denotes flow combination shown in Figure 29

Notes:

Q_{Do} = groundwater flow by aquifer hydraulics from flownet
Q_{Clo} = groundwater flow by chloride (Cl) balance
G_N = net gain to groundwater flow
L_N = net loss from groundwater flow
R_N = apparent net recharge from river flow, rainfall
P = apparent net rainfall recharge to older alluvium
E = apparent loss by evapotranspiration
L_D ,a, e = losses (leakage downwards and out, abstraction, error)
I_R, e = gains (induced recharge/irrigation return, error)
$P_{\%}$ = apparent rainfall recharge as percentage of average annual rainfall
$L_{D\%}$ = downward flux to underlying sediments m/day (L_D / Area of flownet cell)
(I_R) = gains per area of flownet cell in m/day (I_R / Area of flownet cell)

Southern flow cells – estimates of groundwater flow in the older alluvium (rounded to nearest 10 m^3/day)

	1S Flow in specific channel (m^3/day)				Total	
Legend	$1^{(12)}$	$2^{(12)}$	$3^{(12)}$	$4^{(12)}$	m^3/day	Balance
Q_{Do}	110	90	80	70	360	
Q_{Clo}	630	230	190	180	1230	
L_N	550	20	10	10	590	+ 590
P	-	120	100	100	320	+ 320
E	30	-	-	-	30	- 30
L_D	520	140	110	110	880	- 880
$P_{\%}$ $L_{D\%}$	- 10^{-4}	2.6 10^{-5}	2.3 10^{-5}	2.1 10^{-5}		0

	2S Flow in specific channel (m^3/day)				Total	
Legend	$1^{(12)}$	$2^{(12)}$	$3^{(12)}$	$4^{(2)}$	m^3/day	Balance
Q_{Do}	60	40	20	20	140	
Q_{Clo}	190	110	80	80	460	
L_N	500	20	10	-	530	+ 530
P	-	60	50	50	160	+ 160
A	370	-	-	-	370	- 370
L_D	130	80	60	50	320	- 320
$P_{\%}$ $L_{D\%}$	- 10^{-5}	2.2 10^{-5}	1.8 10^{-5}	1.9 10^{-5}		0

	3S Flow in specific channel (m^3/day)						Total	
	$1^{(12)}$	$2^{(12)}$	$3^{(5)}$	$4^{(2)}$	$5^{(12)}$	$6^{(2)}$	m^3/day	Balance
Q_{Do}	110	50	30	20	20	20	240	
Q_{Clo}	260	140	110	60	40	30	640	
L_N	1570	50	-	-	10	-	1630	+ 1630
G_N	-	-	10	-	-	-	10	- 10
P	-	30	60	40	20	10	160	+ 160
A	1330	-	-	-	-	-	1330	- 1330
L_D	150	90	40	40	30	10	360	- 360
$P_{\%}$ $L_{D\%}$	- 10^{-4}	1.2 10^{-5}	1.8 10^{-5}	1.5 10^{-5}	1.2 10^{-5}	1.1 10^{-5}		0

	4S Flow in specific channel (m^3/day)						Total	
	$1^{(10)}$	$2^{(12)}$	$3^{(2)}$	$4^{(2)}$	$5^{(2)}$	$6^{(2)}$	m^3/day	Balance
Q_{Do}	70	50	30	20	20	20	210	
Q_{Clo}	60	270	90	60	40	30	550	
L_N	920	200	-	-	-	-	1120	+ 1120
P	-	30	40	40	20	10	140	+ 140
A	920	-	-	-	-	-	920	- 920
E	10	-	-	-	-	-	10	- 10
L_D	-	220	40	40	20	10	330	- 330
$P_{\%}$ $L_{D\%}$	- -	1.9 10^{-4}	1.9 10^{-5}	2.2 10^{-5}	1.3 10^{-5}	1.0 10^{-5}		0

	5S Flow in specific channel (m^3/day)				Total	
Legend	$1^{(10)}$	$2^{(12)}$	$3^{(2)}$	$4^{(12)}$	m^3/day	Balance
Q_{Do}	50	30	30	20	140	
Q_{Clo}	110	70	40	40	260	
L_N	1020	20	-	10	1050	+ 1050
P	-	30	20	10	60	+ 60
A	850	-	-	-	850	- 850
E	110	-	-	-	110	- 110
L_D	60	50	20	20	150	- 150
$P_{\%}$ $L_{D\%}$	- 10^{-5}	1.7 10^{-5}	1.6 10^{-5}	1.2 10^{-5}		0

	6S Flow in specific channel (m^3/day)				Total	
Legend	$1^{(10)}$	$2^{(10)}$	$3^{(12)}$	$4^{(12)}$	m^3/day	Balance
Q_{Do}	240	170	120	30	560	
Q_{Clo}	700	40	200	150	1090	
L_N	1510	2110	50	90	3760	+ 3760
P	-	30	30	30	90	+ 90
I_R	-	130	-	-	130	+ 130
A	970	2270	-	-	3240	- 3240
E	80	-	-	-	80	- 80
L_D	460	-	80	120	660	- 660
$P_{\%}$ $L_{D\%}$ ($I_{R\%}$)	- 10^{-4}	3.0 - (10^{-4})	1.3 10^{-5}	2.0 10^{-5}		0

	7S Flow in specific channel (m^3/day)		Total	
Legend	$1^{(10)}$	$2^{(10)}$	m^3/day	Balance
Q_{Do}	570	220	790	
Q_{Clo}	2500	270	2770	
L_N	3460	350	3810	+ 3810
A	930	-	930	- 930
E	590	290	880	- 880
L_D	1940	60	2000	- 2000
$P_{\%}$ $L_{D\%}$	- 10^{-3}	- 10^{-5}		0

	8S Flow in specific channel (m^3/day)					Total	
Legend	$1^{(10)}$	$2^{(10)}$	$3^{(11)}$	$4^{(2)}$	$5^{(12)}$	m^3/day	Balance
Q_{Do}	440	100	90	90	90	810	
Q_{Clo}	1950	220	100	100	100	2470	
L_N	2350	330	10	-	10	2700	+ 2700
P	-	-	-	10	10	20	+ 20
E	840	220	-	-	-	1060	- 1060
L_D	1510	120	10	10	10	1660	- 1660
$P_{\%}$ $L_{D\%}$	- 10^{-3}	- 10^{-5}	- -	0.4 10^{-5}	0.4 10^{-5}		0

9S Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(11)}$	$3^{(2)}$	$4^{(12)}$	$5^{(2)}$	Total m^3/day	Balance
Q_{Do}	90	80	70	70	60	370	
Q_{Clo}	150	80	90	90	90	500	
L_N	1720	10	-	10	-	1740	+ 1740
P	-	-	10	20	20	50	+ 50
A	1640	-	-	-	-	1640	- 1640
E	10	-	-	-	-	10	- 10
L_D	70	10	20	20	20	140	- 140
$P_{\%}$ $L_{D\%}$	- 10^{-5}	- -	1.0 10^{-5}	1.1 10^{-5}	1.1 10^{-5}		0

10S Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(11)}$	$3^{(11)}$	$4^{(12)}$	$5^{(2)}$	Total m^3/day	Balance
Q_{Do}	50	120	100	70	70	410	
Q_{Clo}	110	130	110	120	90	560	
L_N	1310	-	20	20	-	1350	+ 1350
P	-	20	-	10	20	60	+ 50
A	1190	-	-	-	-	1190	- 1190
E	70	-	-	-	-	70	- 70
L_D	50	20	10	40	20	140	- 140
$P_{\%}$ $L_{D\%}$	- 10^{-4}	1.3 10^{-5}	- 10^{-5}	0.8 10^{-5}	0.9 10^{-5}		0

11S Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(10)}$	$3^{(11)}$	$4^{(11)}$	$5^{(12)}$	$6^{(2)}$	Total m^3/day	Balance
Q_{Do}	260	150	100	70	60	60	700	
Q_{Clo}	820	230	150	110	90	80	1480	
L_N	1440	120	50	30	10	-	1650	+ 1650
P	-	-	-	-	30	20	50	+ 50
A	160	-	-	-	-	-	160	- 160
E	730	30	-	-	-	-	760	- 760
L_D	550	90	50	40	30	20	780	- 780
$P_{\%}$ $L_{D\%}$	- 10^{-4}	- 10^{-5}	- 10^{-5}	- 10^{-5}	1.1 10^{-5}	0.9 10^{-5}		0

12S Flow in specific channel (m^3/day)

Legend	$1^{(6)}$	$2^{(10)}$	$3^{(12)}$	$4^{(12)}$	$5^{(12)}$	Total m^3/day	Balance
Q_{Do}	350	140	80	70	50	690	
Q_{Clo}	160	240	190	110	90	790	
L_N	2410	210	60	10	20	2710	+ 2710
P	20	-	50	30	20	120	+ 120
I_R	190	-	-	-	-	190	+ 190
A	2620	-	-	-	-	2620	- 2620
E	-	110	-	-	-	110	- 110
L_D	-	100	110	40	40	290	- 290
$P_{\%}$ $L_{D\%}$ ($I_{R\%}$)	1.2 - (10^{-4})	- 10^{-5}	2.0 10^{-5}	1.1 10^{-5}	0.9 10^{-5}		0

	13S Flow in specific channel (m^3/day)					Total	
Legend	$1^{(10)}$	$2^{(10)}$	$3^{(10)}$	$4^{(12)}$	$5^{(12)}$	m^3/day	Balance
Q_{Do}	410	130	60	50	40	690	
Q_{Clo}	1330	360	120	90	80	1980	
L_N	1820	280	70	10	10	2190	+ 2190
P	-	-	-	30	30	60	+ 60
A	730	-	-	-	-	730	- 730
E	180	50	10	-	-	240	- 240
L_D	910	230	70	40	30	1280	- 1280
$P_{\%}$ $L_{D\%}$	- 10^{-3}	- 10^{-4}	- 10^{-5}	1.6 10^{-5}	1.4 10^{-5}		0

	14S Flow in specific channel (m3/day)				Total	
Legend	$1^{(10)}$	$2^{(10)}$	$3^{(12)}$	$4^{(2)}$	m^3/day	Balance
Q_{Do}	290	50	40	30	410	
Q_{Clo}	630	200	70	50	950	
L_N	860	240	10	-	1110	+ 1110
P	-	-	20	20	40	+ 40
E	520	90	-	-	610	- 610
L_D	340	150	30	20	540	- 540
$P_{\%}$ $L_{D\%}$	- 10^{-3}	- 10^{-4}	1.4 10^{-5}	1.4 10^{-5}		0

	15S Flow in specific channel (m^3/day)				Total	
Legend	$1^{(13)}$	$2^{(12)}$	$3^{(12)}$	$4^{(12)}$	m^3/day	Balance
Q_{Do}	240	100	70	60	470	
Q_{Clo}	30	270	130	80	510	
L_N	70	140	30	10	250	+ 250
P	-	30	30	10	70	+ 70
A	200	-	-	-	200	- 200
I_R	210	-	-	-	2640	+ 210
E	80	-	-	-	80	- 80
L_D	-	170	60	20	250	- 250
$P_{\%}$ $L_{D\%}$ (I_R)	- - (10^{-4})	1.1 10^{-4}	1.5 10^{-5}	0.6 10^{-6}		0

	16S Flow in specific channel (m^3/day)				Total	
Legend	$1^{(8)}$	$2^{(6)}$	$3^{(12)}$	$4^{(12)}$	m^3/day	Balance
Q_{Do}	140	120	100	90	450	
Q_{Clo}	210	50	150	70	480	
L_N	790	10	20	20	840	+ 840
P	-	70	30	-	100	+ 100
A	490	150	-	-	640	- 640
I_R	-	70	-	-	70	+ 70
E	230	-	-	-	230	- 230
L_D	70	-	50	20	140	- 140
$P_{\%}$ $L_{D\%}$ (I_R)	- 10^{-5}	3.3 - (10^{-5})	1.5 10^{-5}	0.2 10^{-5}		0

	17S Flow in specific channel (m^3/day)			Total	
Legend	$1^{(8)}$	$2^{(8)}$	$3^{(12)}$	m^3/day	Balance
Q_{Do}	100	190	70	360	
Q_{Clo}	70	90	170	330	
L_N	810	560	110	1480	+ 1480
P	-	40	-	40	+ 40
A	810	690	20	1520	- 1520
I_R	20	100	-	120	+ 120
E	20	-	-	20	- 20
L_D	-	-	100	100	- 100
$P_{\%}$ $L_{D\%}$ (I_R)	- - (10^{-5})	2.4 - (10^{-5})	0.1 10^{-5}		0

	18S Flow in specific channel (m^3/day)			Total	
Legend	$1^{(13)}$	$2^{(13)}$	$3^{(11)}$	m^3/day	Balance
Q_{Do}	50	20	30	100	
Q_{Clo}	580	1310	160	5320	
L_N	2240	2320	750	1400	+ 1400
A	290	220	-	510	- 660
I_R	390	110	-	500	+ 500
E	90	540	-	630	- 630
L_D	-	-	610	610	- 610
$P_{\%}$ $L_{D\%}$ (I_R)	- - (10^{-3})	- - (10^{-5})	- 10^{-4}		0

	3S+4S+5S Flow in specific channel (m^3/day)		Total	
Legend	$1^{(12)}$	$2^{(12)}$	m^3/day	Balance
Q_{Do}	30	20	50	
Q_{Clo}	100	60	160	
L_N	20	10	30	+ 30
P	40	30	70	+ 70
L_D	60	40	100	- 100
$P_{\%}$ $L_{D\%}$	1.2 10^{-5}	1.1 10^{-5}		0

	6S+7S Flow in specific channel (m^3/day)		Total	
Legend	$1^{(12)}$	$2^{(12)}$	m^3/day	Balance
Q_{Do}	40	30	70	
Q_{Clo}	270	70	340	
L_N	200	10	210	+ 210
P	30	30	60	+ 60
L_D	230	40	270	- 270
$P_{\%}$ $L_{D\%}$	0.5 10^{-5}	0.9 10^{-5}		0

Northern flow cells – estimates of groundwater flow in the older alluvium (rounded to nearest 10 m^3/day)

1N Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(2)}$	$3^{(5)}$	$4^{(2)}$	Total m^3/day	Balance
Q_{Do}	-	-	20	20	40	
Q_{Clo}	50	10	30	50	140	
L_N	570	-	-	-	570	+ 570
G_N	-	-	20	-	20	- 20
P	-	10	30	30	70	+ 70
E	520	-	-	-	520	- 520
L_D	50	10	10	30	100	- 100
$P_{\%}$ $L_{D\%}$	- 10^{-4}	0.6 10^{-5}	1.7 10^{-5}	1.6 10^{-5}		0

2N Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(12)}$	$3^{(12)}$	$4^{(2)}$	$5^{(2)}$	Total m^3/day	Balance
Q_{Do}	150	50	40	40	50	330	
Q_{Clo}	550	220	140	120	100	1130	
L_N	410	100	10	-	-	520	+ 520
P	-	70	90	80	50	290	+ 290
E	10	-	-	-	-	10	- 10
L_D	400	170	100	80	50	800	- 800
$P_{\%}$ $L_{D\%}$	- 10^{-4}	3.1 10^{-5}	3.0 10^{-5}	2.5 10^{-5}	1.8 10^{-5}		0

3N Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(10)}$	$3^{(12)}$	$4^{(2)}$	Total m^3/day	Balance
Q_{Do}	140	90	70	70	430	
Q_{Clo}	540	130	150	120	940	
L_N	640	50	20	-	710	+ 710
P	-	-	60	50	110	+ 110
E	250	10	-	-	260	- 260
L_D	400	30	80	50	560	- 560
$P_{\%}$ $L_{D\%}$	- 10^{-4}	- 10^{-5}	2.0 10^{-5}	1.7 10^{-5}		0

4N Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(12)}$	$3^{(12)}$	$4^{(12)}$	$5^{(2)}$	$6^{(5)}$	Total m^3/day	Balance
Q_{Do}	290	110	100	100	100	110	810	
Q_{Clo}	320	310	140	120	110	120	1120	
L_N	40	180	10	10	-	-	240	+ 240
G_N	-	-	-	-	-	10	10	- 10
P	-	20	30	20	20	10	100	+ 100
E	10	-	-	-	-	-	10	- 10
L_D	30	200	40	30	10	10	320	- 320
$P_{\%}$ $L_{D\%}$	- 10^{-4}	1.7 10^{-4}	2.0 10^{-5}	1.4 10^{-5}	1.4 10^{-5}	1.5 10^{-5}		0

	5N Flow in specific channel (m³/day)										Total	
Legend	$1^{(10)}$	$2^{(12)}$	$3^{(12)}$	$4^{(12)}$	$5^{(5)}$	$6^{(5)}$	$7^{(5)}$	$8^{(2)}$	$9^{(2)}$	$10^{(2)}$	m³/day	Balance
Q_{Do}	480	270	220	190	210	230	240	240	250	240	2570	
Q_{Clo}	500	490	300	230	220	230	250	250	250	260	2990	
L_N	50	210	60	20	-	-	-	-	-	-	340	+ 340
G_N	-	-	-	-	20	20	10	-	-	-	50	- 50
P	-	10	30	20	30	20	20	20	10	10	170	+ 170
E	30	-	-	-	-	-	-	-	-	-	30	- 30
L_D	20	220	90	40	10	10	10	10	-	20	430	- 430
$P_{\%}$ $L_{D\%}$	- 10^{-5}	0.7 10^{-4}	1.9 10^{-5}	1.5 10^{-5}	2.2 10^{-5}	1.9 -	1.6 10^{-5}	1.4 10^{-5}	0.9 -	1.7 10^{-5}		0

	6N Flow in specific channel (m³/day)									Total	
Legend	$1^{(8)}$	$2^{(10)}$	$3^{(12)}$	$4^{(12)}$	$5^{(2)}$	$6^{(2)}$	$7^{(12)}$	$8^{(12)}$	$9^{(12)}$	m³/day	Balance
Q_{Do}	600	530	410	350	350	350	340	330	320	3580	
Q_{Clo}	250	620	560	430	370	370	370	370	360	3700	
L_N	-	70	120	60	-	-	10	10	10	280	+ 280
G_N	20	-	-	-	-	-	-	-	-	20	- 20
P	-	20	30	20	20	20	20	30	30	200	+ 200
I_R	350	-	-	-	-	-	-	-	-	350	+ 350
E	330	60	-	-	-	-	-	-	-	330	- 330
L_D	-	80	90	70	30	20	20	20	20	410	- 410
$P_{\%}$ $L_{D\%}$ (I_R)	- - (10^{-4})	1.6 10^{-5}	2.1 10^{-4}	1.3 10^{-5}	1.5 10^{-5}	1.3 10^{-5}	1.2 10^{-5}	1.9 10^{-5}	1.8 10^{-5}		0

7N Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(12)}$	$3^{(12)}$	$4^{(2)}$	$5^{(2)}$	$6^{(2)}$	$7^{(5)}$	Total m^3/day	Balance
Q_{Do}	270	230	210	210	210	210	220	2030	
Q_{Clo}	2810	290	280	270	250	250	250	4390	
L_N	3760	30	20	-	-	-	-	3810	+ 3810
G_N	-	-	-	-	-	-	10	10	- 10
P	-	30	40	60	30	40	40	240	+ 240
E	1220	-	-	-	-	-	-	1220	- 1220
L_D	2540	60	70	50	30	40	30	2820	- 2820
$P_{\%}$ $L_{D\%}$	- 10^{-3}	1.4 10^{-5}	2.1 10^{-5}	2.7 10^{-5}	1.9 10^{-5}	2.2 10^{-5}	2.1 10^{-5}		0

8N Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(10)}$	$3^{(12)}$	$4^{(5)}$	$5^{(2)}$	$6^{(5)}$	$7^{(2)}$	$8^{(11)}$	Total m^3/day	Balance
Q_{Do}	130	120	70	80	90	90	90	80	750	
Q_{Clo}	930	640	140	100	100	100	100	90	2190	
L_N	2660	580	40	-	-	-	-	10	3290	+ 3290
G_N	-	-	-	10	-	10	-	-	20	- 20
P	-	-	20	20	10	20	10	-	80	+ 80
A	340	-	-	-	-	-	-	-	340	- 340
E	1520	60	-	-	-	-	-	-	1580	- 1580
L_D	790	520	60	20	10	10	10	10	1430	- 1430
$P_{\%}$ $L_{D\%}$	- 10^{-3}	- 10^{-4}	2.5 10^{-5}	2.9 10^{-5}	2.1 10^{-5}	2.3 10^{-5}	1.4 10^{-5}	0.7 10^{-5}		0

9N Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(12)}$	$3^{(5)}$	$4^{(12)}$	$5^{(2)}$	$6^{(2)}$	$7^{(12)}$	$8^{(2)}$	Total m^3/day	Balance
Q_{Do}	60	60	70	60	60	60	50	50	480	
Q_{Clo}	1640	80	70	80	70	70	70	60	2140	
L_N	1740	-	-	10	-	-	10	-	1760	+ 1760
G_N	-	-	10	-	-	-	-	-	10	- 10
P	-	20	10	20	10	10	10	10	90	+ 90
E	170	-	-	-	-	-	-	-	170	- 170
L_D	1580	20	10	20	10	10	10	10	1670	- 1670
$P_{\%}$ $L_{D\%}$	- 10^{-3}	2.2 10^{-5}	2.7 10^{-5}	3.1 10^{-5}	2.6 10^{-5}	1.8 10^{-5}	1.5 10^{-5}	1.6 10^{-5}		0

10N Flow in specific channel (m^3/day)

Legend	$1^{(10)}$	$2^{(9)}$	$3^{(2)}$	$4^{(2)}$	$5^{(2)}$	$6^{(5)}$	$7^{(2)}$	$8^{(2)}$	Total m^3/day	Balance
Q_{Do}	160	120	140	140	140	150	150	150	1160	
Q_{Clo}	520	170	170	190	170	170	170	180	1740	
L_N	520	130	-	-	-	-	-	-	650	+ 650
G_N	-	-	20	-	-	-	10	-	30	- 30
P	-	-	50	40	30	30	30	20	200	+ 200
E	160	70	-	-	-	-	-	-	230	- 230
L_D	360	50	20	40	30	30	20	30	590	- 590
$P_{\%}$ $L_{D\%}$	- 10^{-3}	- 10^{-5}	2.9 10^{-5}	2.5 10^{-5}	1.8 10^{-6}	1.9 10^{-5}	1.9 10^{-5}	1.8 10^{-5}		0

	11N Flow in specific channel (m^3/day)				Total	
Legend	$1^{(10)}$	$2^{(10)}$	$3^{(5)}$	$4^{(5)}$	m^3/day	Balance
Q_{Do}	80	80	90	100	350	
Q_{Clo}	940	360	130	130	1560	
L_N	1630	750	-	-	2380	+ 2380
G_N	-	-	10	10	20	- 20
P	-	-	50	30	80	+ 80
A	710	-	-	-	710	- 710
E	50	480	-	-	530	- 530
L_D	860	280	40	20	1200	- 1200
$P_{\%}$ $L_{D\%}$	- 10^{-3}	- 10^{-4}	1.8 10^{-5}	1.5 10^{-5}		0

	12N Flow in specific channel (m^3/day)				Total	
Legend	$1^{(10)}$	$2^{(10)}$	$3^{(5)}$	$4^{(4)}$	m^3/day	Balance
Q_{Do}	50	50	80	110	290	
Q_{Clo}	630	210	90	110	1040	
L_N	880	400	-	-	1280	+ 1280
G_N	-	-	30	30	60	- 60
P	-	-	40	30	70	+ 70
E	290	240	-	-	530	- 530
L_D	590	160	10	-	760	- 760
$P_{\%}$ $L_{D\%}$	- 10^{-4}	- 10^{-4}	2.2 -	2.0 -		0

	13N Flow in specific channel (m^3/day)					Total	
Legend	$1^{(10)}$	$2^{(3)}$	$3^{(2)}$	$4^{(12)}$	$5^{(12)}$	m^3/day	Balance
Q_{Do}	80	90	90	70	50	380	
Q_{Clo}	2020	50	100	110	110	2390	
L_N	2160	-	-	20	30	2210	+ 2210
P	-	-	10	20	30	60	+ 60
I_R	-	40	-	-	-	40	+ 40
E	210	40	-	-	-	250	- 250
L_D	1950	-	10	40	60	2060	- 2060
$R_{N\%}$ $L_{D\%}$ (I_R)	- 10^{-3}	- - (10^{-5})	1.7 10^{-5}	2.2 10^{-5}	1.9 10^{-5}		0

	14N Flow in specific channel (m^3/day)					Total	
Legend	$1^{(13)}$	$2^{(10)}$	$3^{(11)}$	$4^{(12)}$	$5^{(12)}$	m^3/day	Balance
Q_{Do}	420	210	90	50	30	800	
Q_{Clo}	90	270	210	120	70	760	
L_N	730	210	130	30	30	1130	+ 1130
P	-	-	-	30	20	50	+ 50
A	690	-	-	-	-	690	- 690
I_R	330	-	-	-	-	330	+ 330
E	370	150	-	-	-	520	- 520
L_D	-	60	120	60	60	300	- 300
$P_{\%}$ $L_{D\%}$ (I_R)	- - (10^{-3})	- 10^{-4}	- 10^{-5}	1.1 10^{-5}	0.8 10^{-5}		0

	15N Flow in specific channel (m^3/day)				Total	
Legend	$1^{(8)}$	$2^{(12)}$	$3^{(12)}$	$4^{(12)}$	m^3/day	Balance
Q_{Do}	360	130	60	40	590	
Q_{Clo}	120	340	150	80	690	
L_N	570	230	70	20	890	+ 890
P	-	-	20	20	40	+ 40
A	600	-	-	-	600	- 600
I_R	240	-	-	-	240	+ 240
E	210	20	-	-	230	- 230
L_D	-	210	90	40	340	- 340
$R_{N\%}$ $L_{D\%}$ (I_R)	- - (10^{-3})	- 10^{-5}	0.8 10^{-5}	0.9 10^{-5}		0

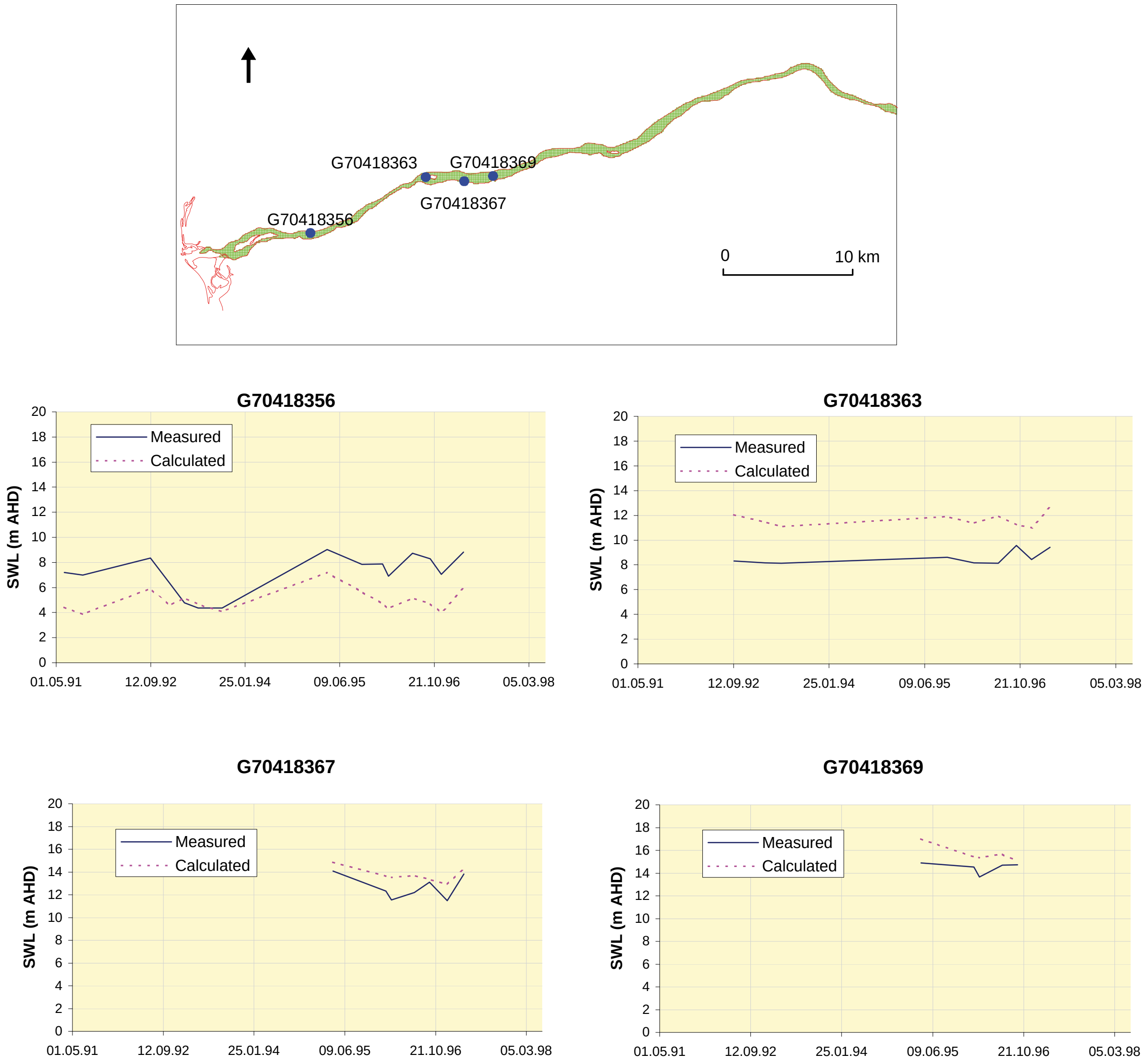
	16N Flow in specific channel (m^3/day)				Total	
Legend	$1^{(13)}$	$2^{(13)}$	$3^{(9)}$	$4^{(12)}$	m^3/day	Balance
Q_{Do}	200	130	100	40	470	
Q_{Clo}	160	100	100	130	490	
L_N	720	380	30	60	1190	+1190
P	-	-	-	30	30	+ 30
A	650	-	-	-	650	- 650
I_R	40	30	-	-	70	+ 70
E	110	410	30	-	550	- 550
L_D	-	-	-	90	90	- 90
$P_{\%}$ $L_{D\%}$ (I_R)	- - (10^{-4})	- - (10^{-5})	- -	0.8 10^{-5}		0

	17N Flow in specific channel (m^3/day)			Total	
Legend	$1^{(13)}$	$2^{(12)}$	$3^{(12)}$	m^3/day	Balance
Q_{Do}	60	120	40	220	
Q_{Clo}	10	70	20	100	
L_N	200	70	80	350	+ 350
P	-	70	30	100	+ 100
A	240	260	-	500	- 500
I_R	50	120	-	170	+ 170
E	10	-	-	10	- 10
L_D	-	-	110	110	- 110
$P_{\%}$ $L_{D\%}$ (I_R)	- - (10^{-3})	4.4 - (10^{-5})	0.7 10^{-5}		0

	18N Flow in specific channel (m^3/day)			Total	
Legend	$1^{(10)}$	$2^{(10)}$	$3^{(12)}$	m^3/day	Balance
Q_{Do}	30	70	40	140	
Q_{Clo}	1540	990	40	2570	
L_N	2080	2060	30	4170	+ 4170
A	370	570	-	940	- 940
E	190	570	30	790	- 790
L_D	1520	920	-	2440	- 2440
$P_{\%}$ $L_{D\%}$	- 10^{-3}	- 10^{-4}	- -		0

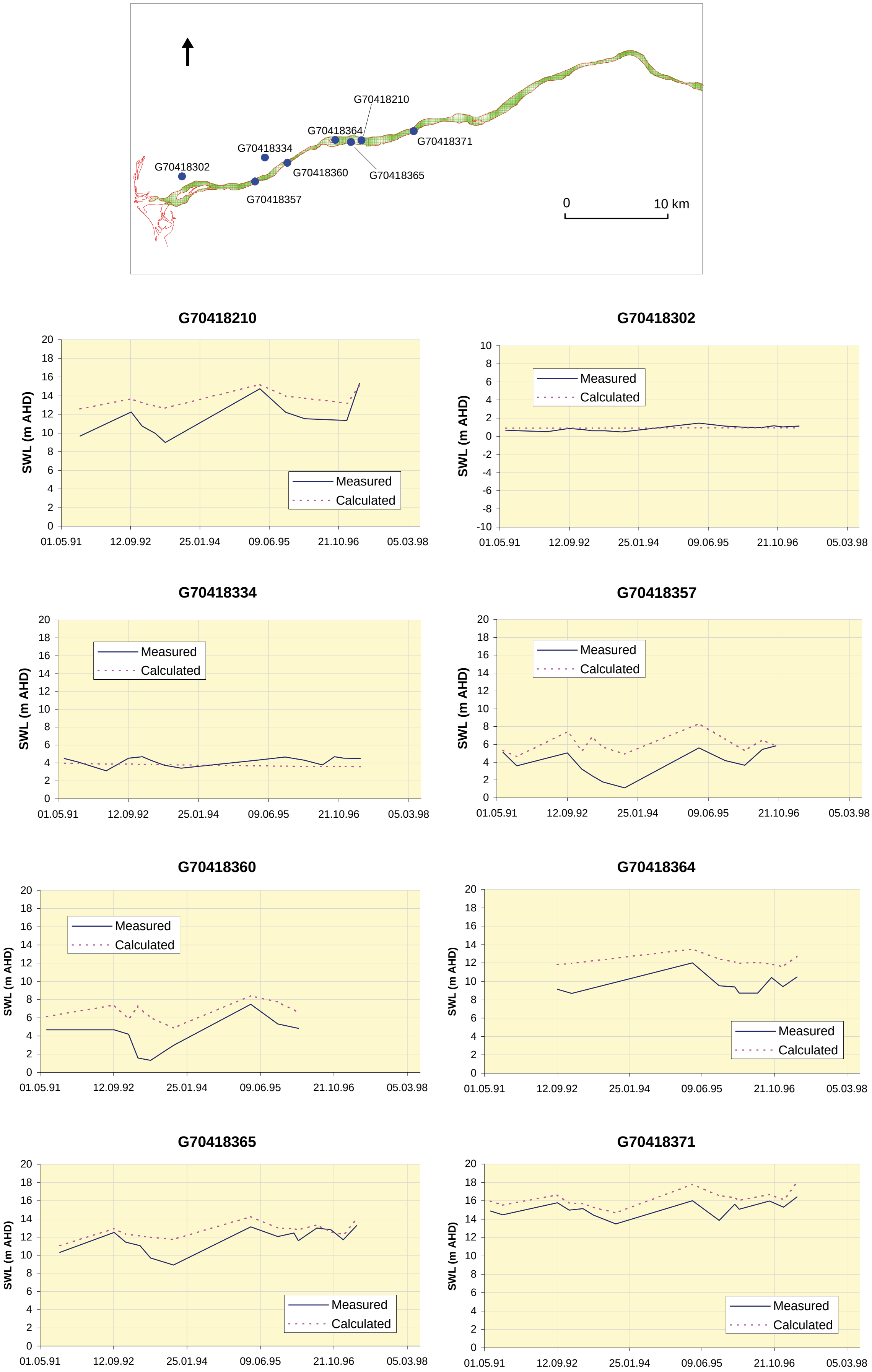
Superscript (e.g. $^{(12)}$) denotes flow combination shown in Figure 29 (after Davidson, 1995)

Appendix D Hydrographs

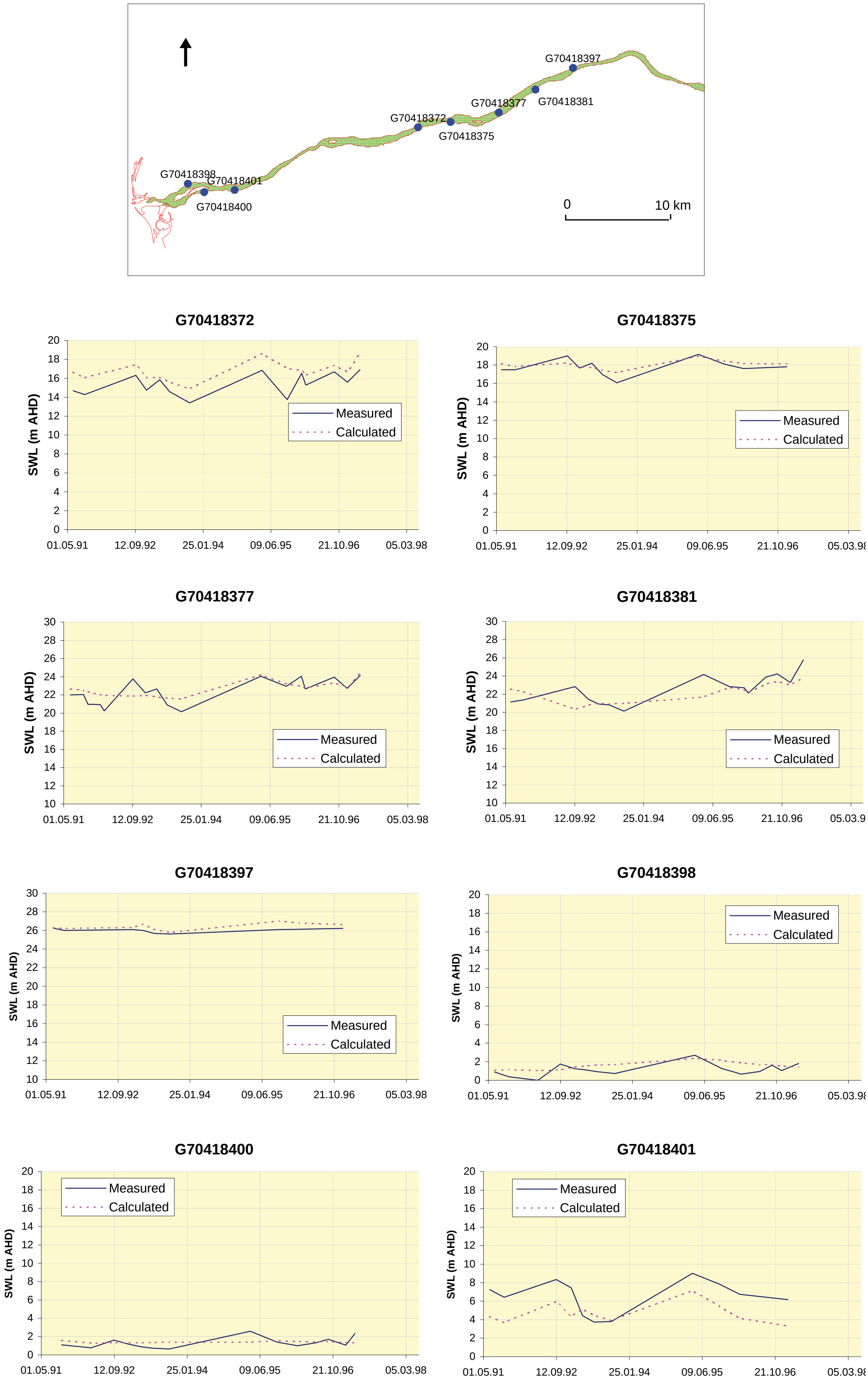


Note: Hydrographs with waterlevels to the right of the first vertical grid line (Sept '92) were not involved in the calibration process

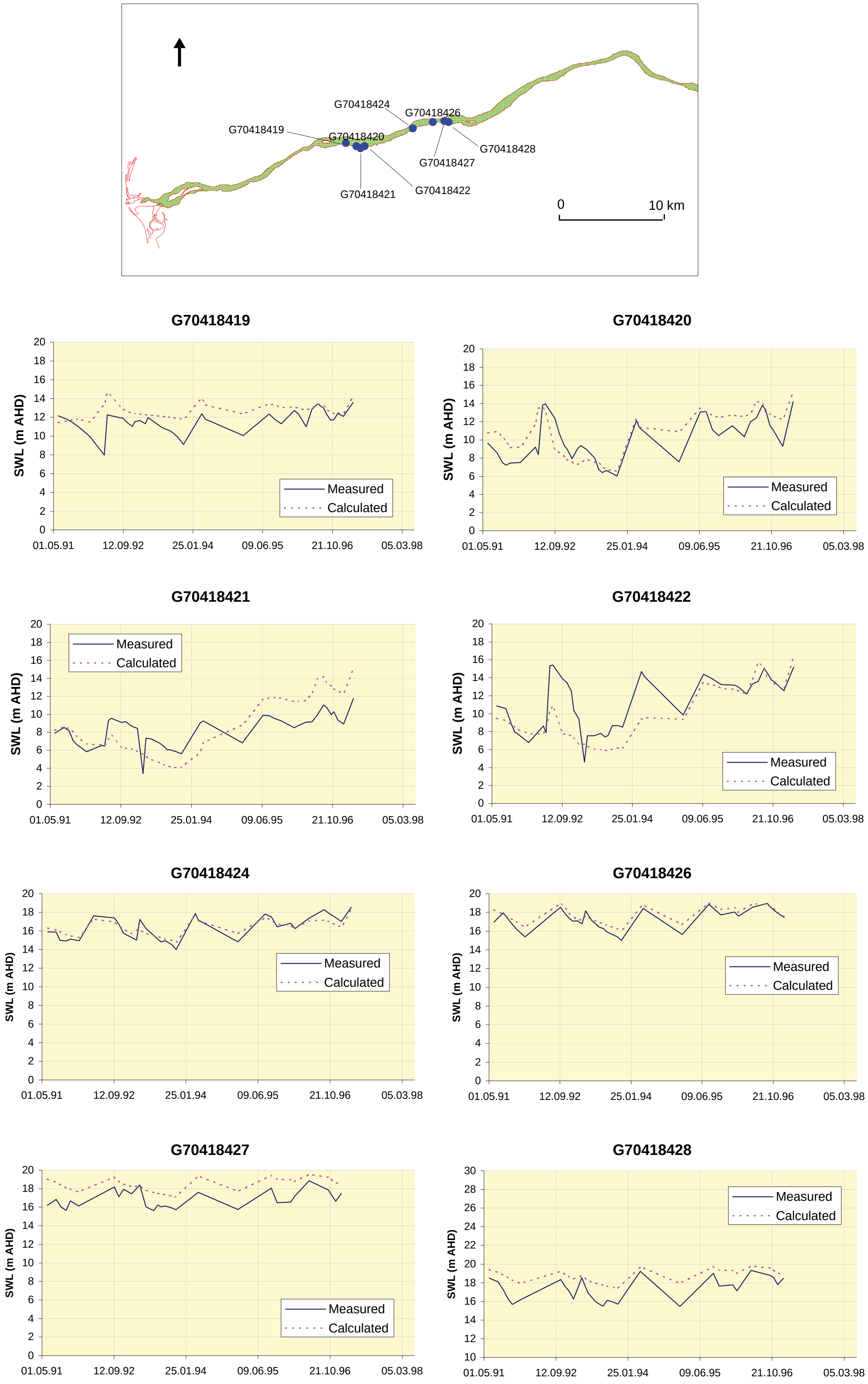
Appendix D1 Hydrographs and locations of layer 1 monitoring wells



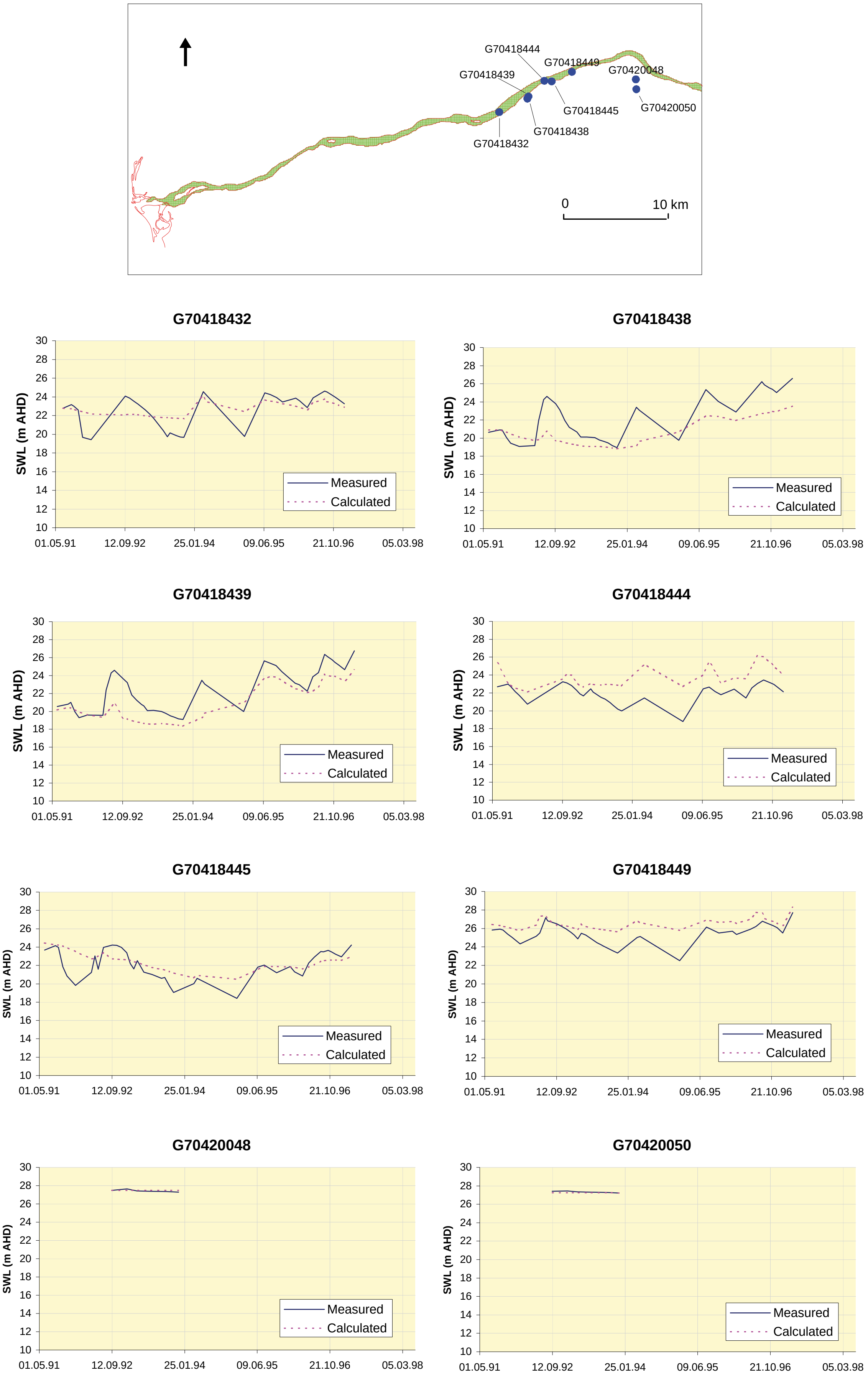
Appendix D2 Hydrographs and locations of layer 2 monitoring wells



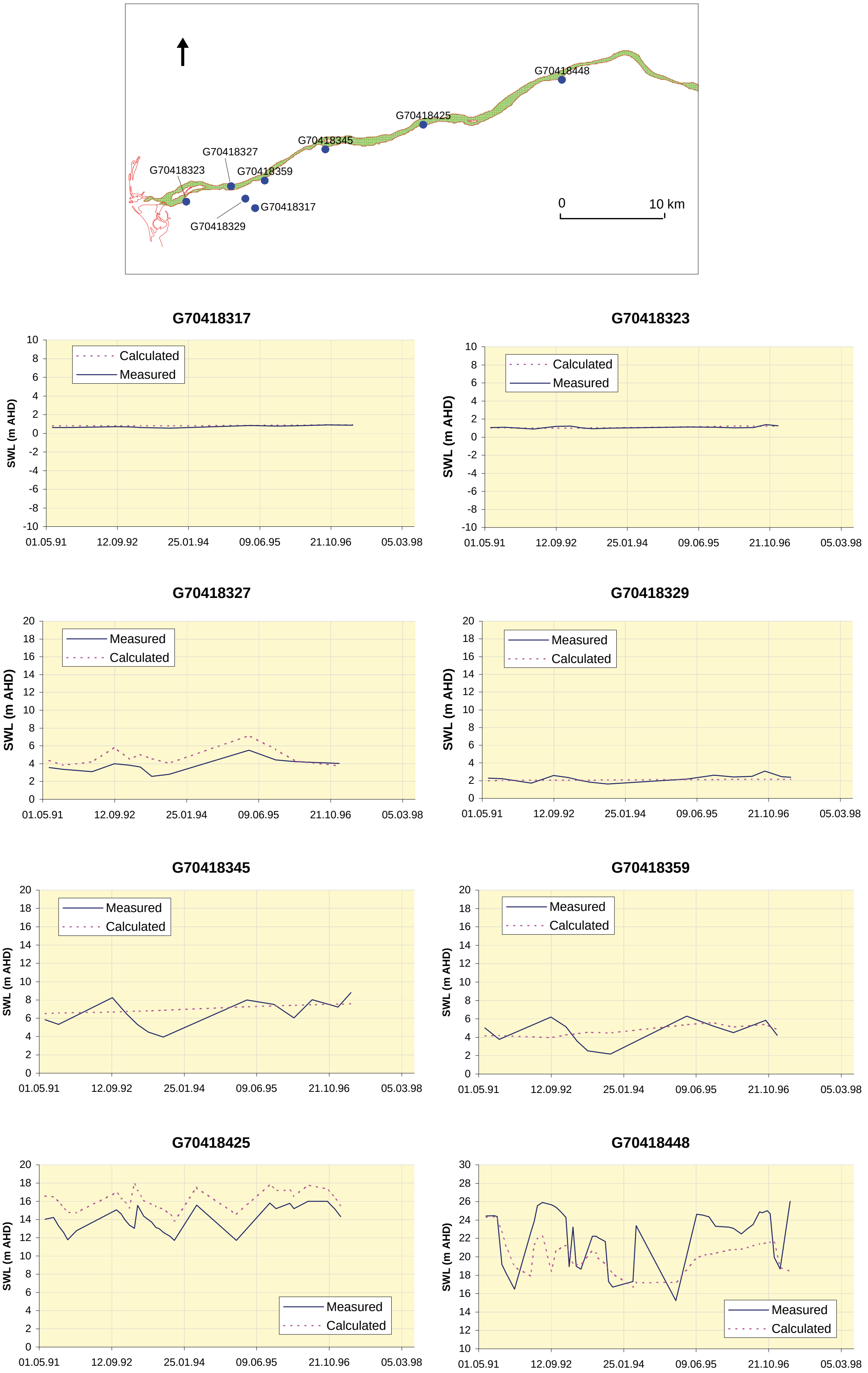
Appendix D3 Hydrographs and locations of layer 2 monitoring wells



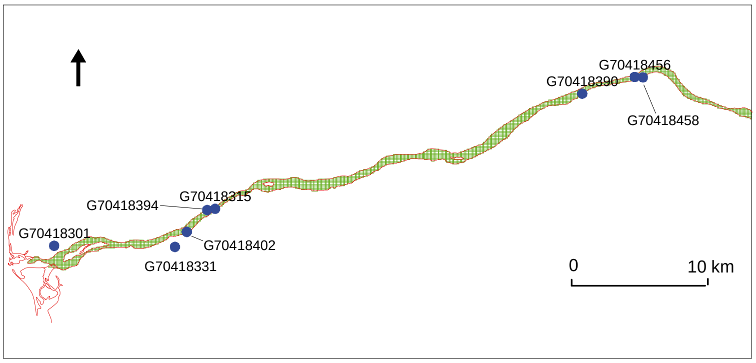
Appendix D4 Hydrographs and locations of layer 2 monitoring wells



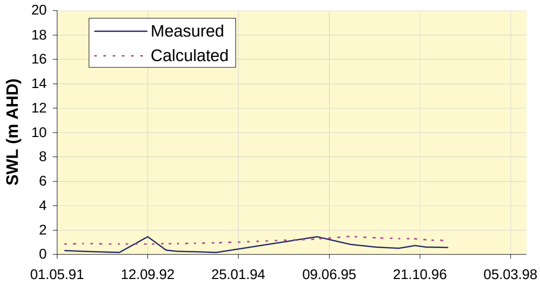
Appendix D5 Hydrographs and locations of layer 2 monitoring wells



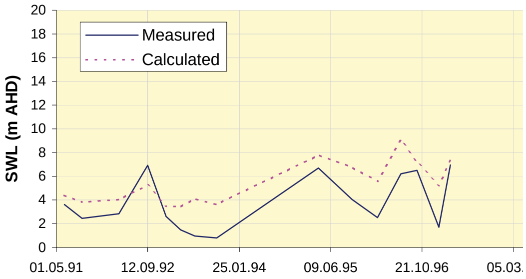
Appendix D6 Hydrographs and location of layer 3 monitoring wells



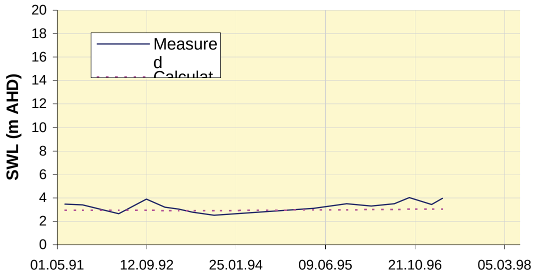
G70418301



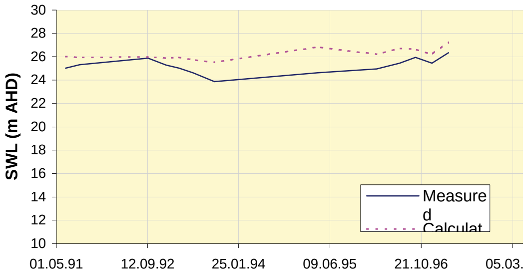
G70418315



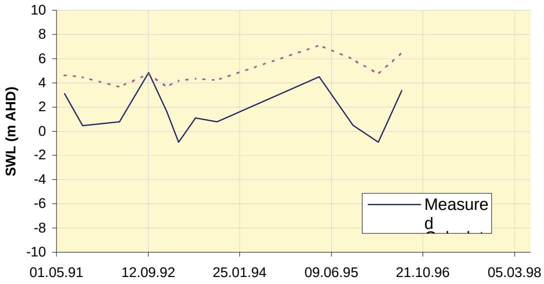
G70418331



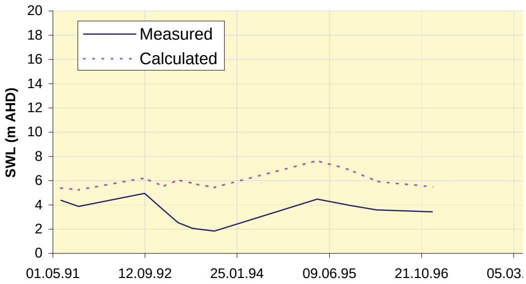
G70418390



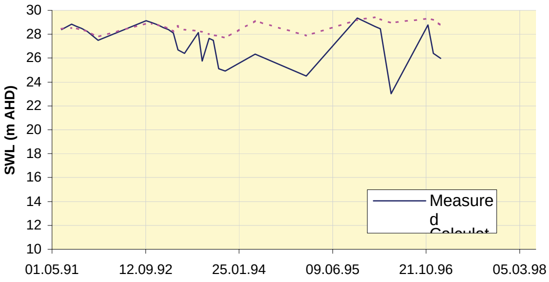
G70418394



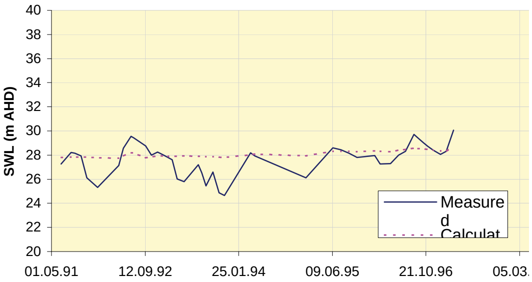
G70418402



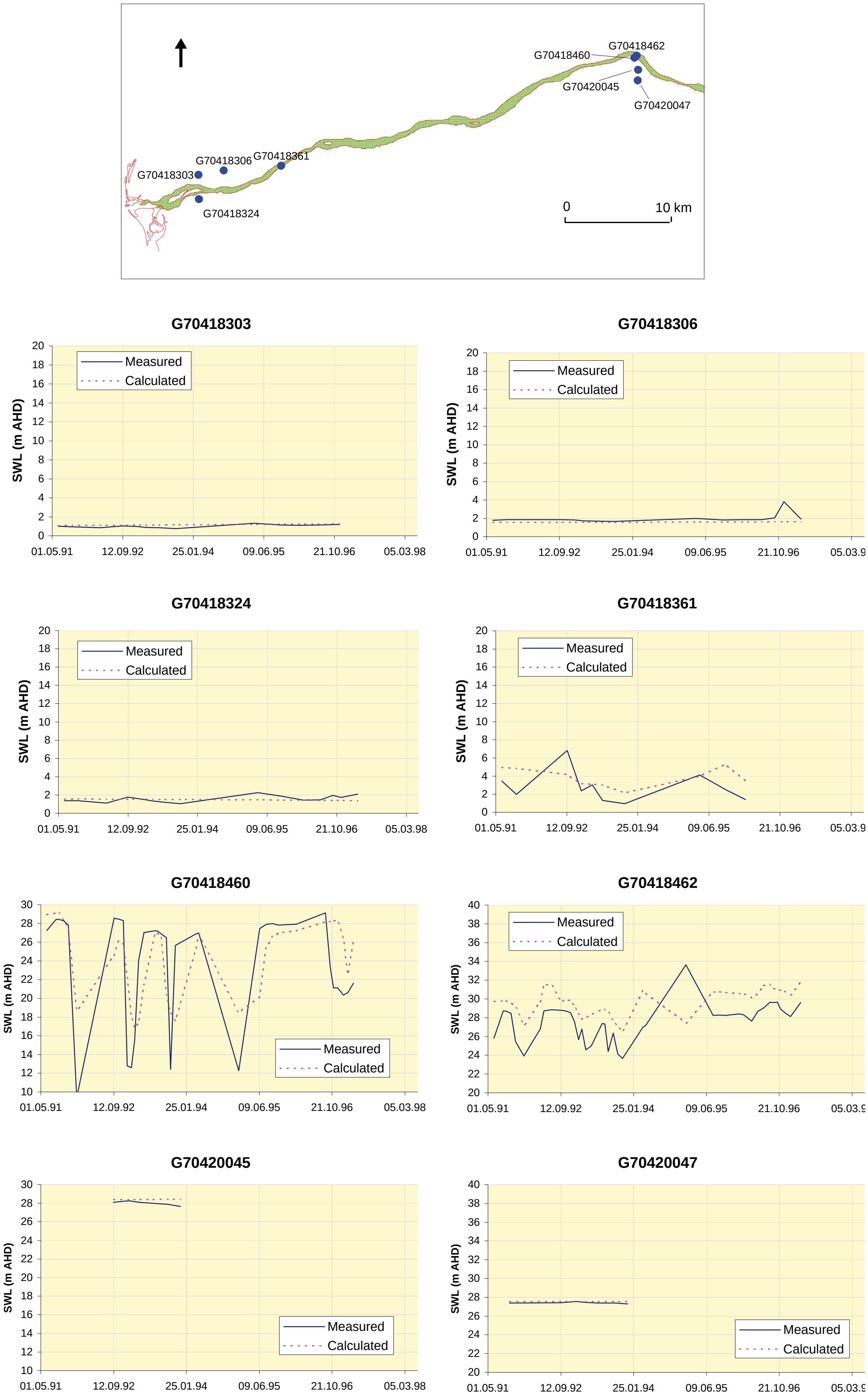
G70418456



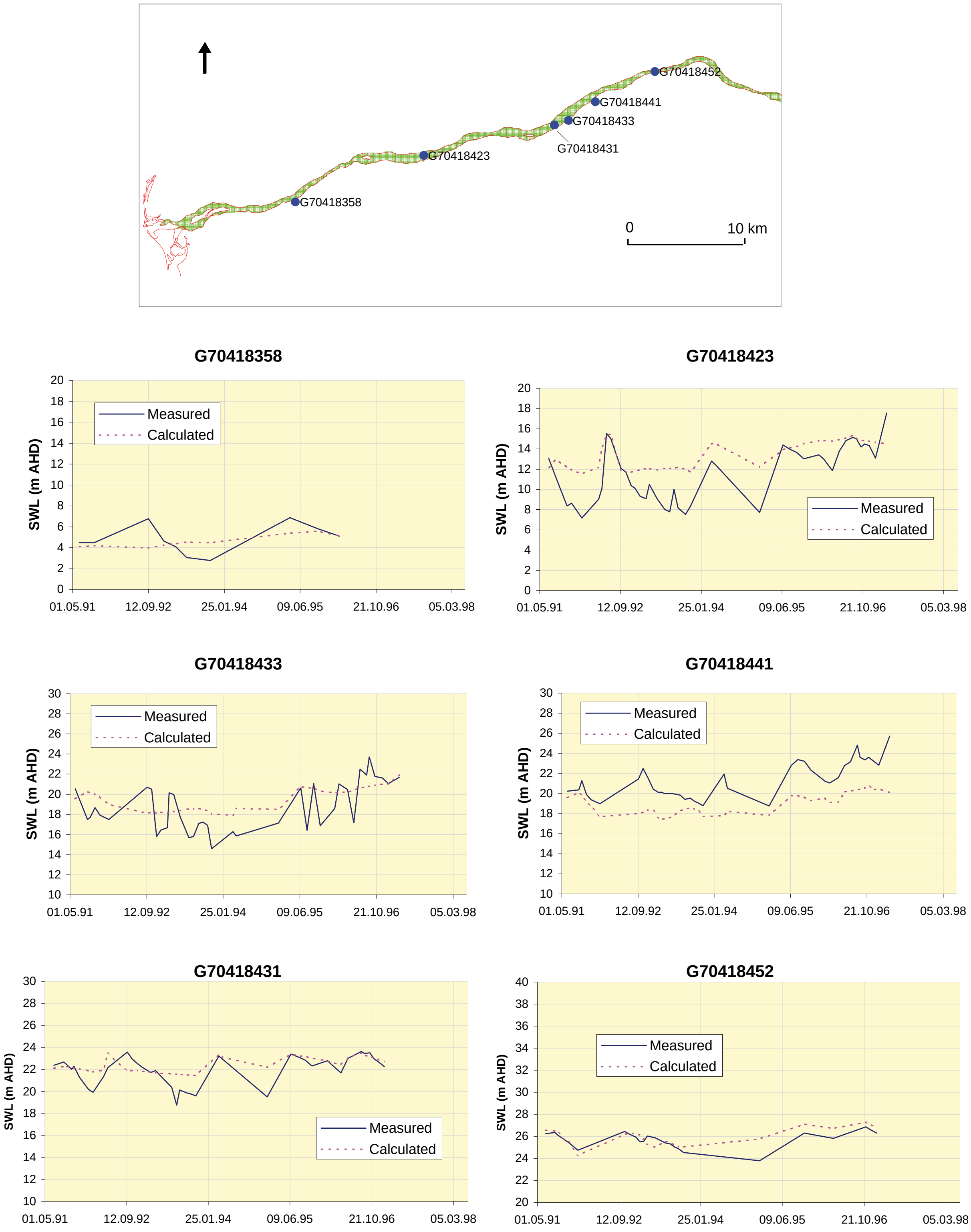
G70418458



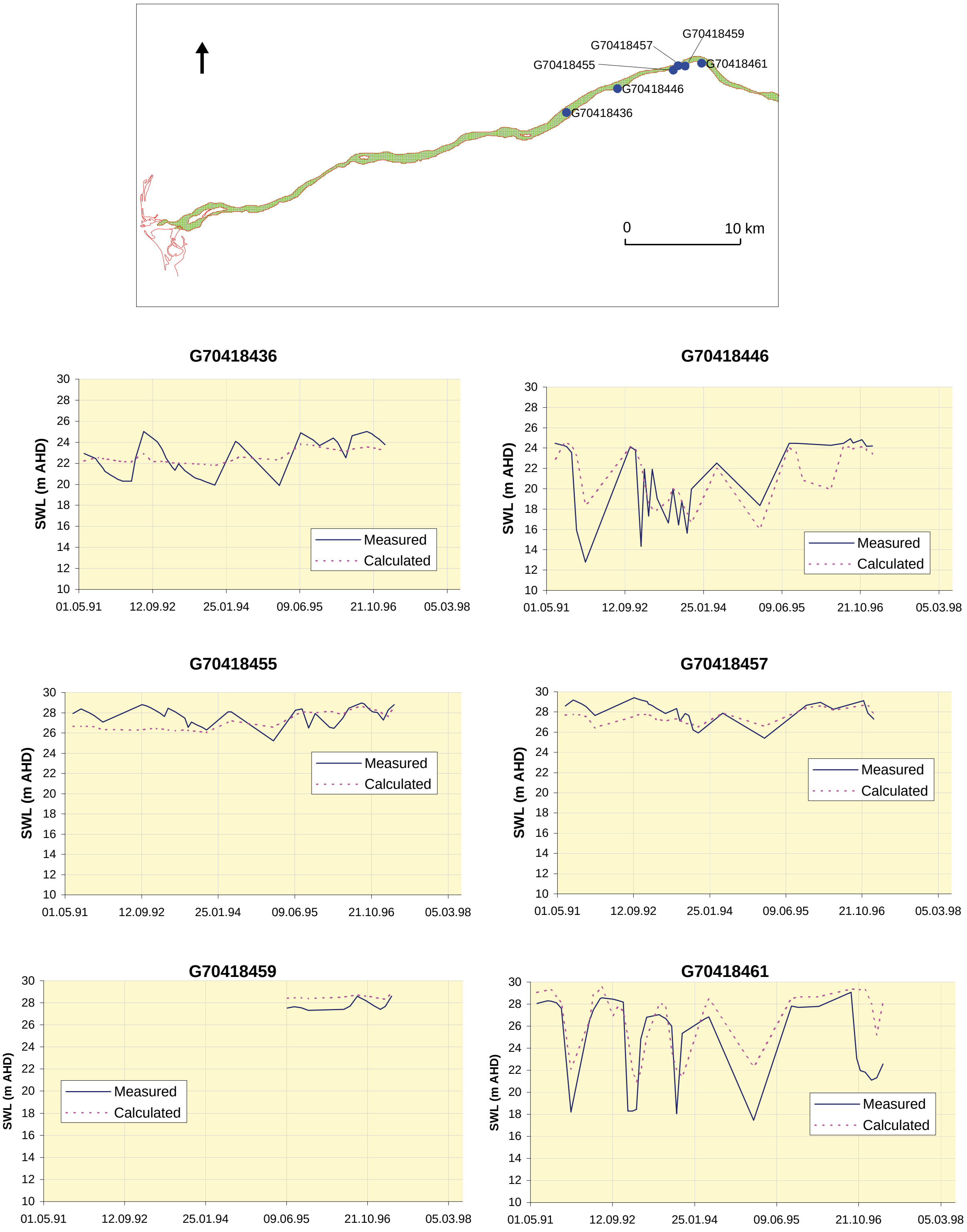
Appendix D7 Hydrographs and locations of layer 4 monitoring wells



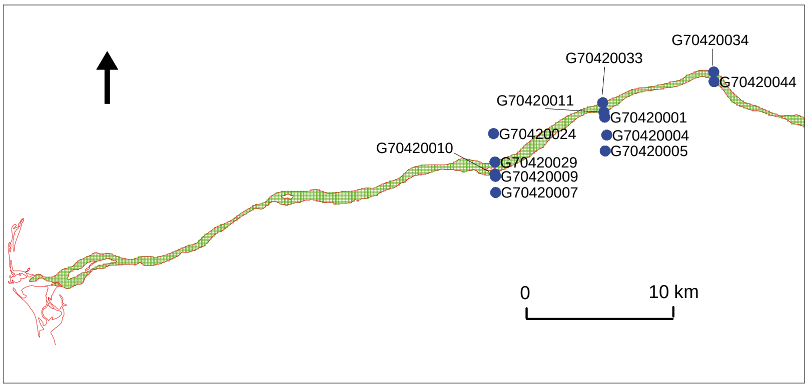
Appendix D8 Hydrographs and location of layer 5 monitoring wells



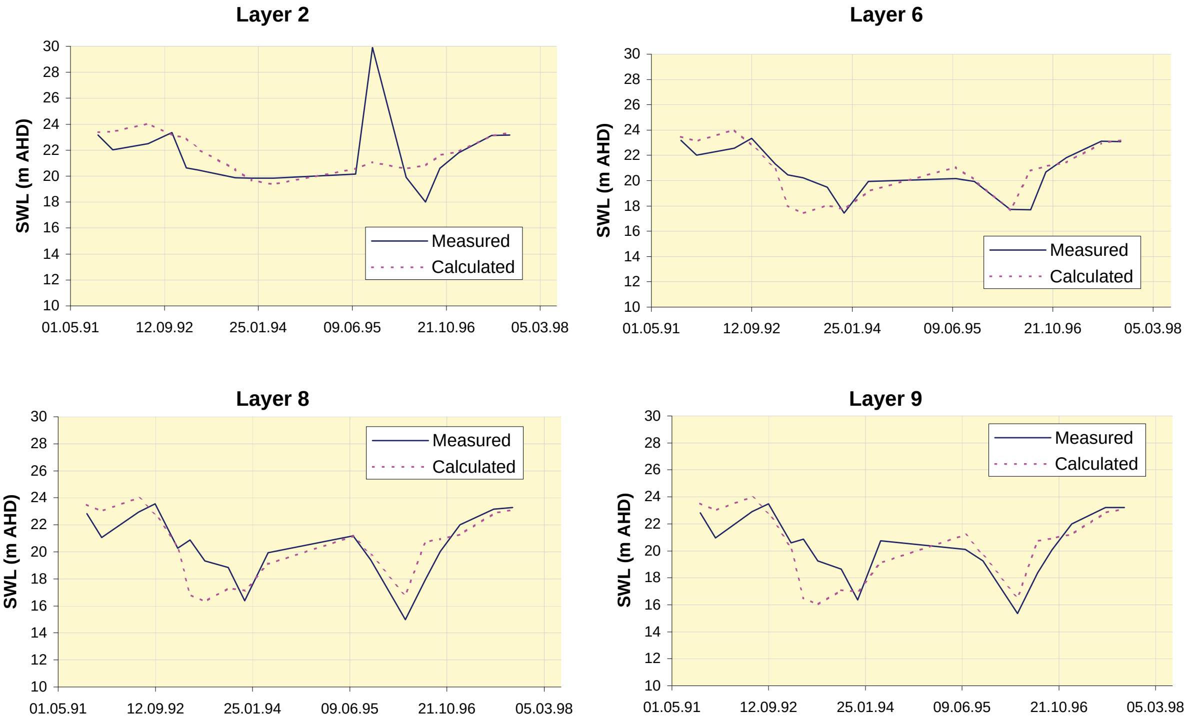
Appendix D9 Hydrographs and locations of layer 6 and 7 monitoring wells



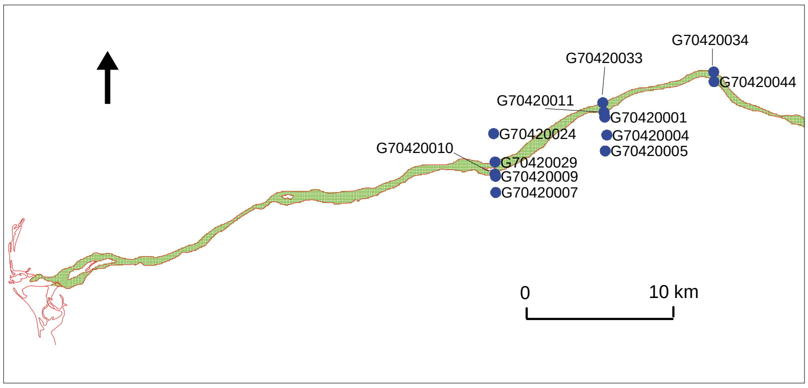
Appendix D10 Hydrographs and location of layer 9 monitoring wells



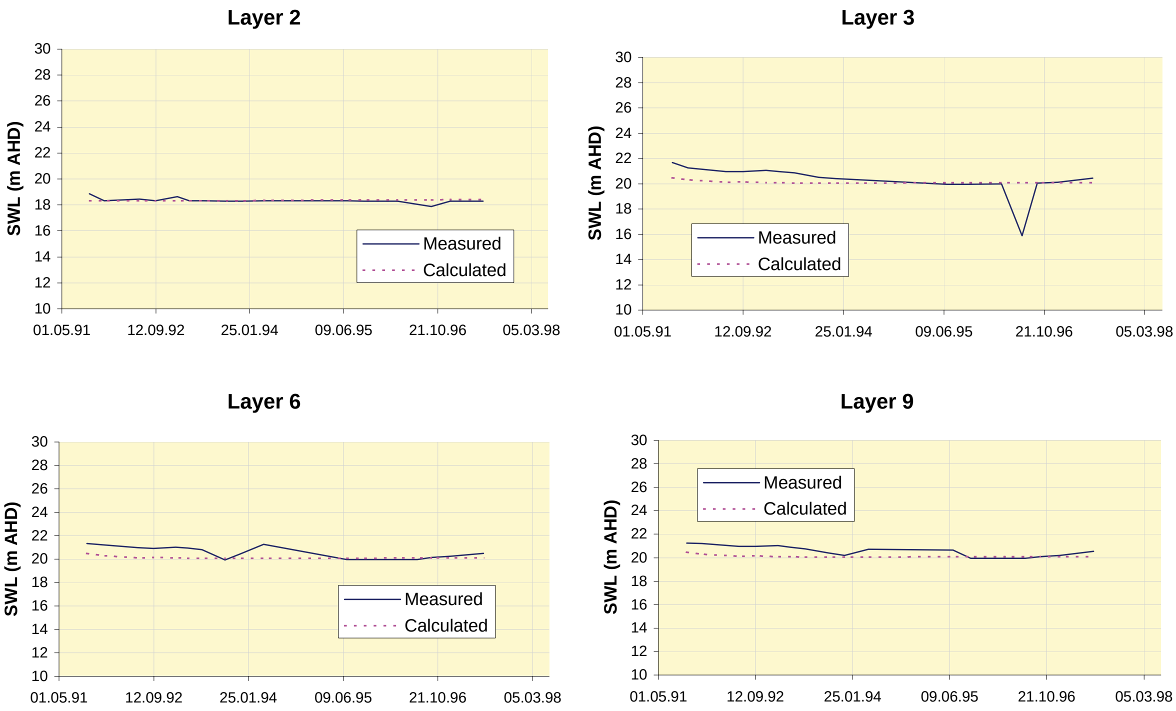
G70420001



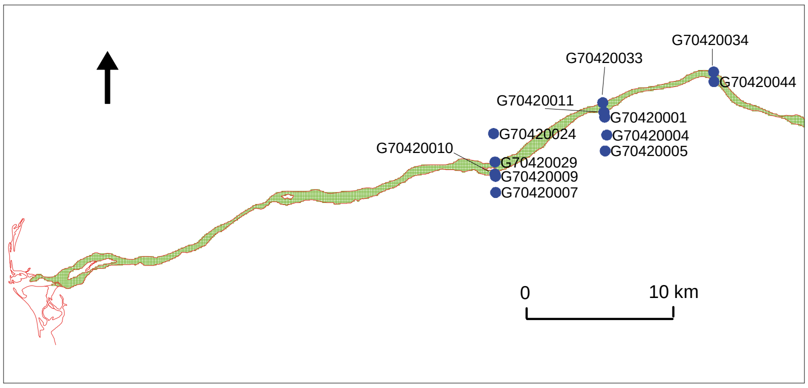
Appendix D11 Hydrographs of multiport monitoring wells



G70420004



Appendix D12 Hydrographs of multiport monitoring wells



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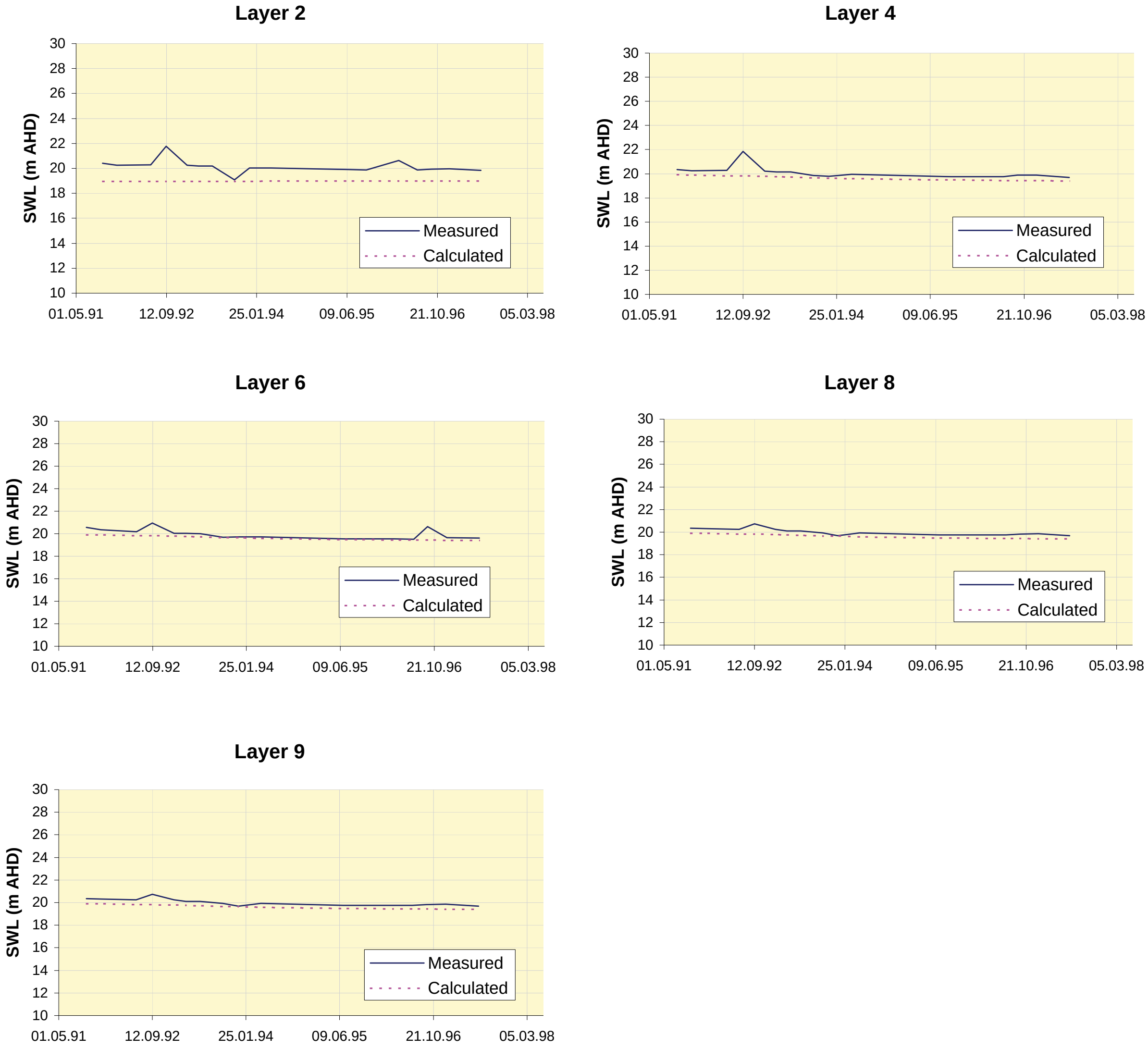
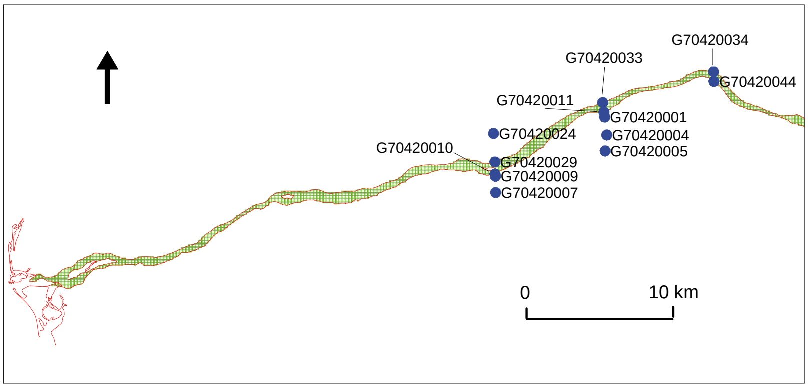
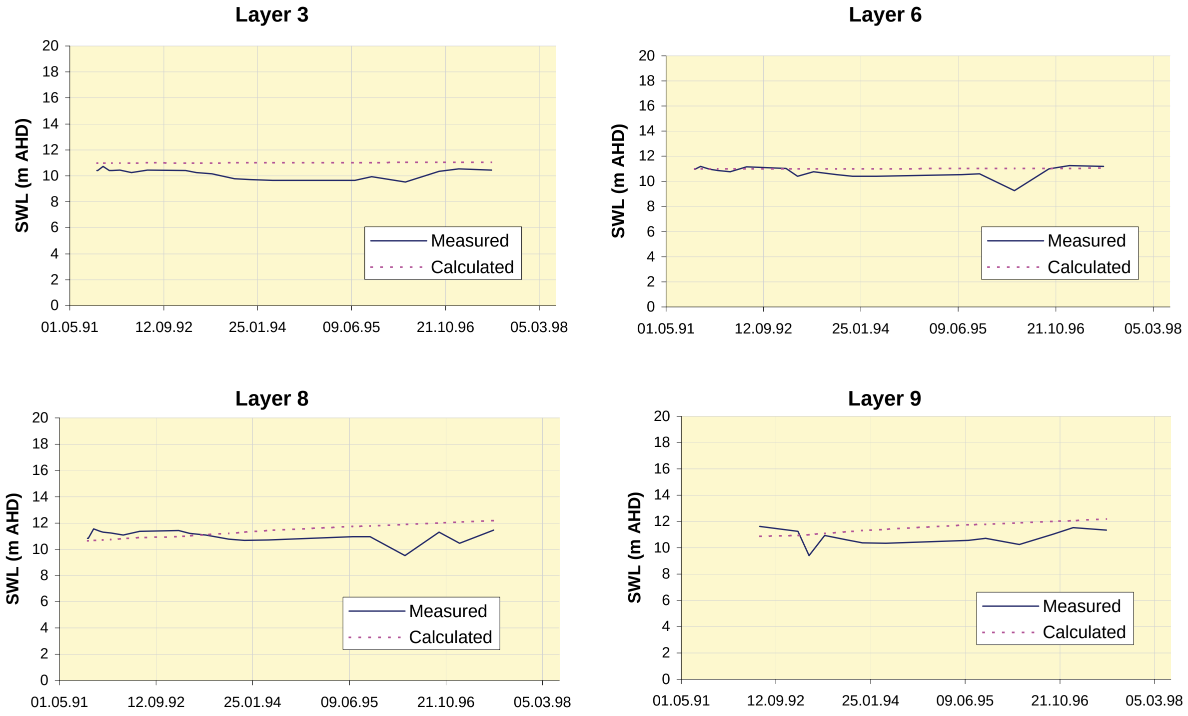


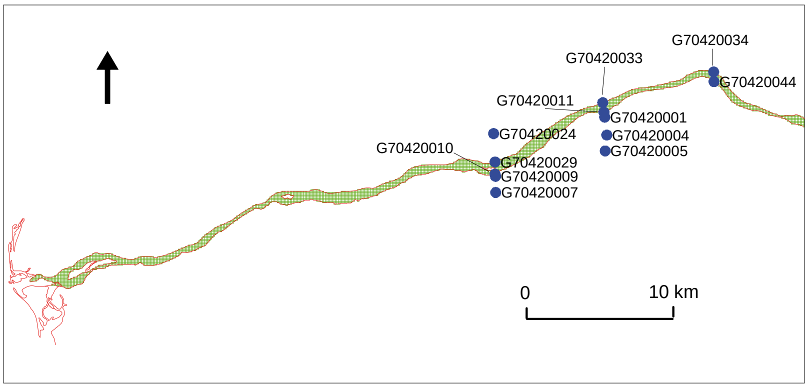
Appendix D13 Hydrographs of multiport monitoring wells



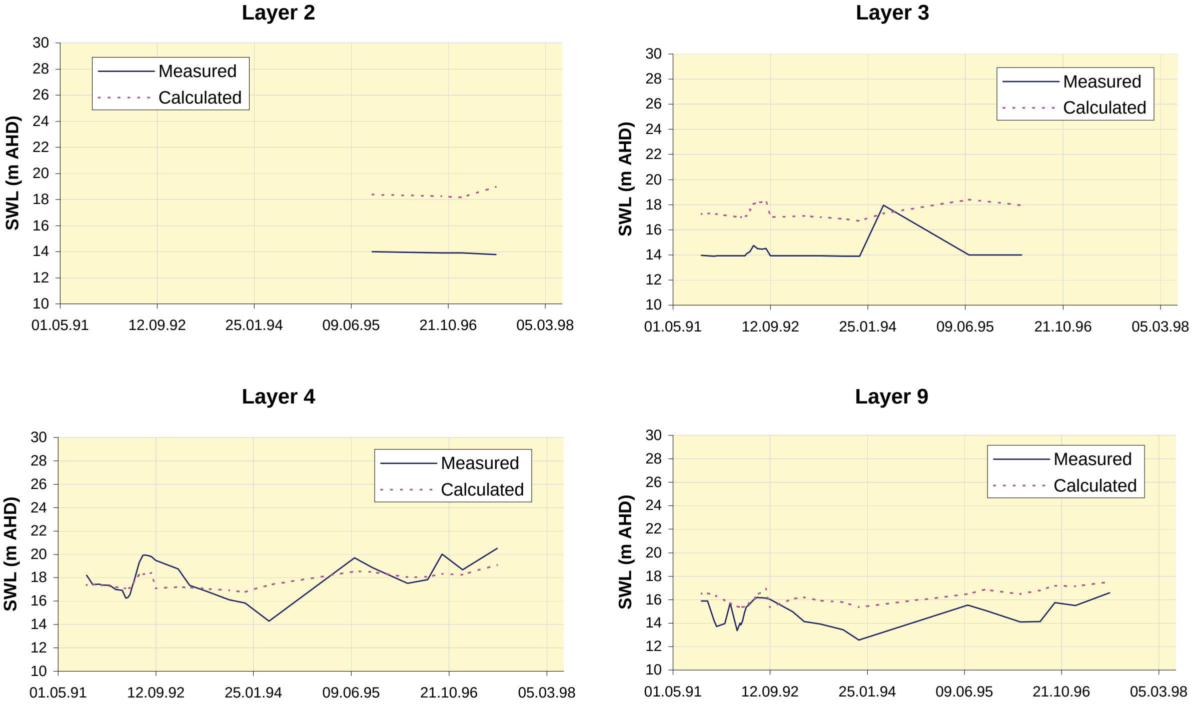
G70420007



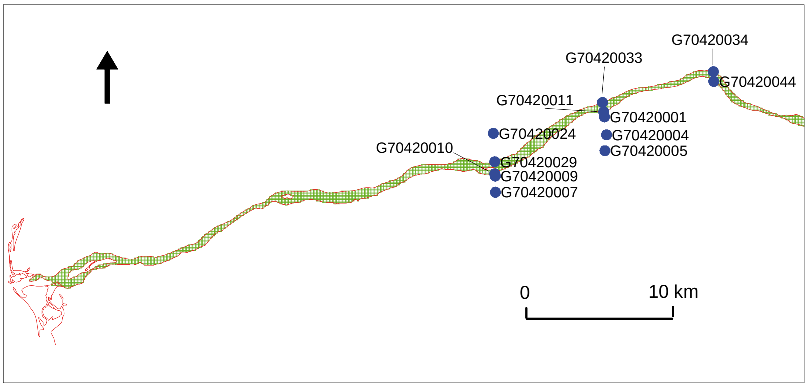
Appendix D14 Hydrographs of multiport monitoring wells



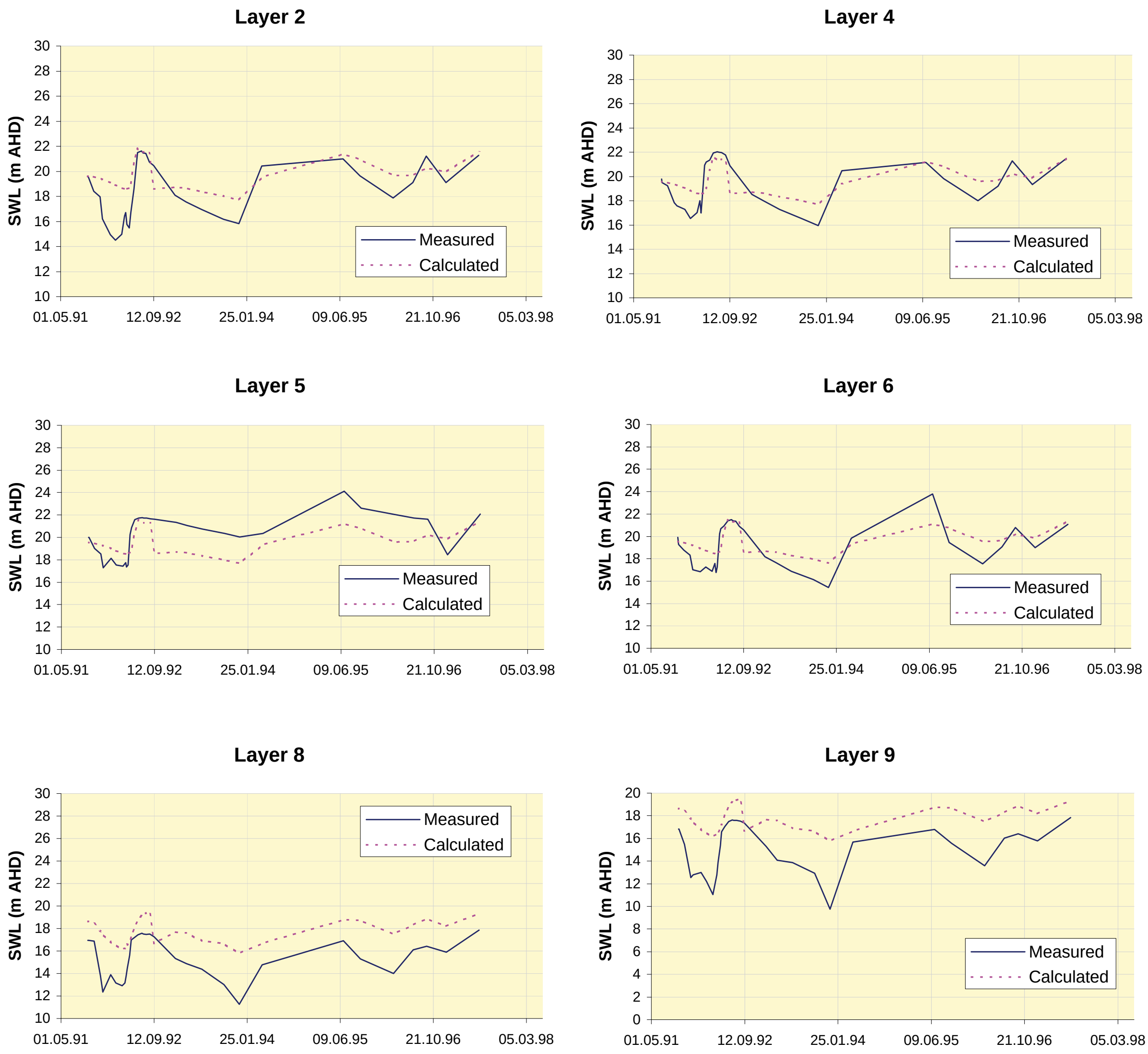
G70420009



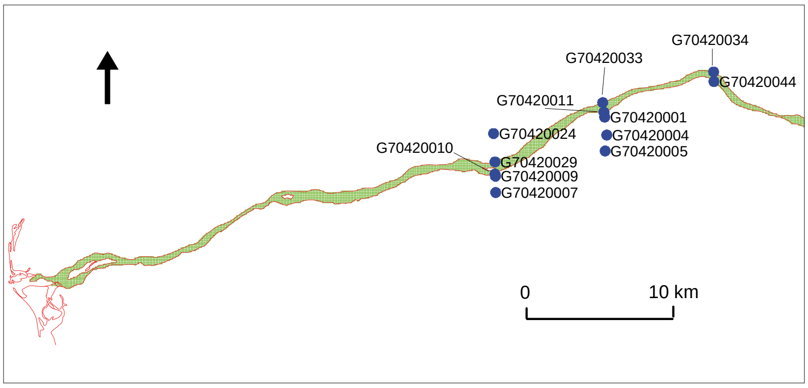
Appendix D15 Hydrographs of multiport monitoring wells



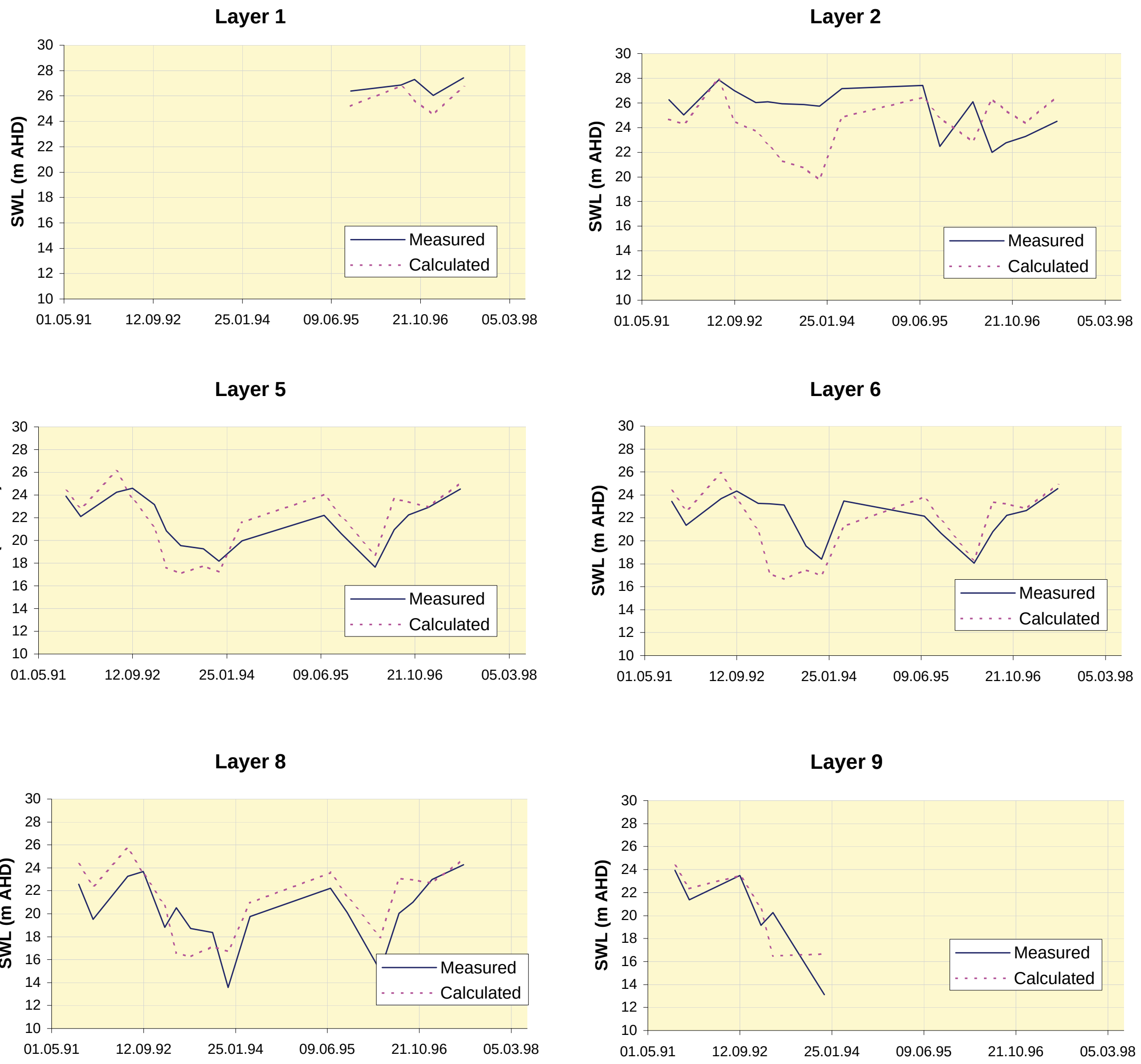
G70420010



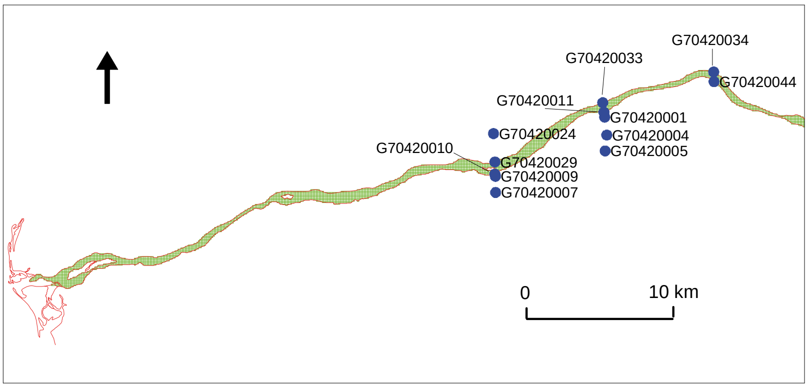
Appendix D16 Hydrographs of multiport monitoring wells



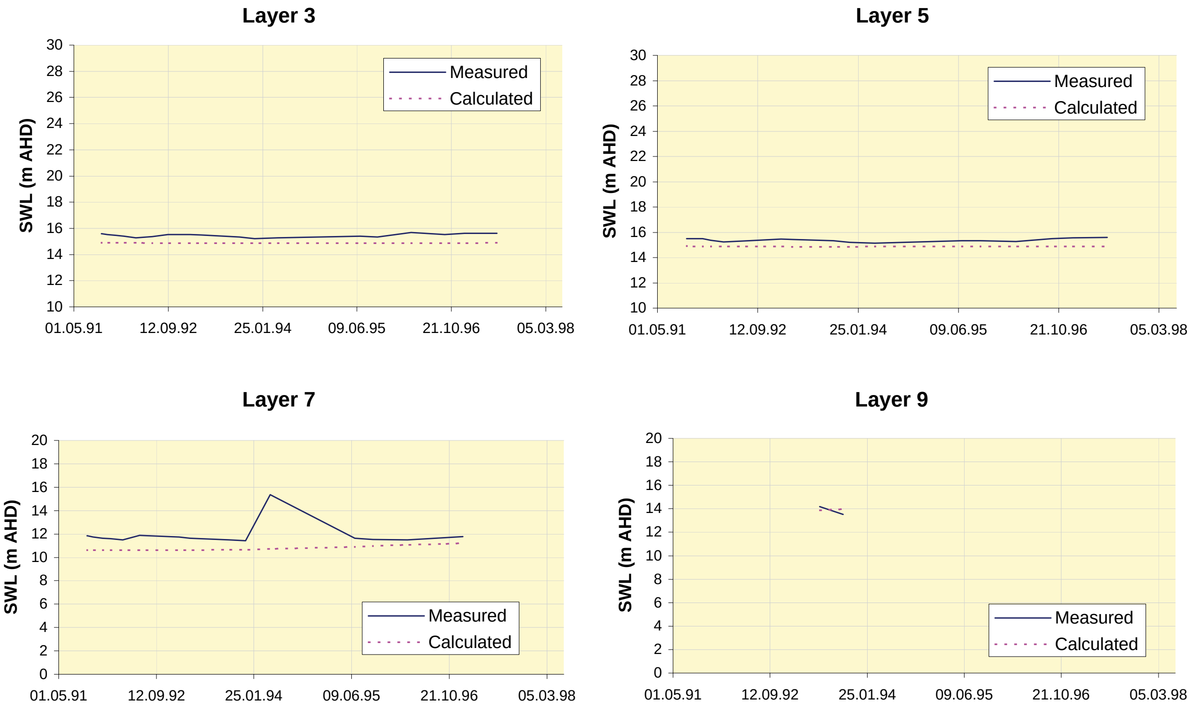
G70420011



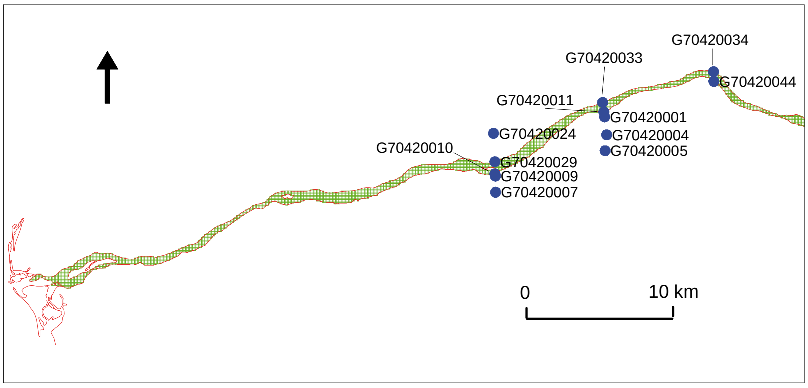
Appendix D17 Hydrographs of multiport monitoring wells



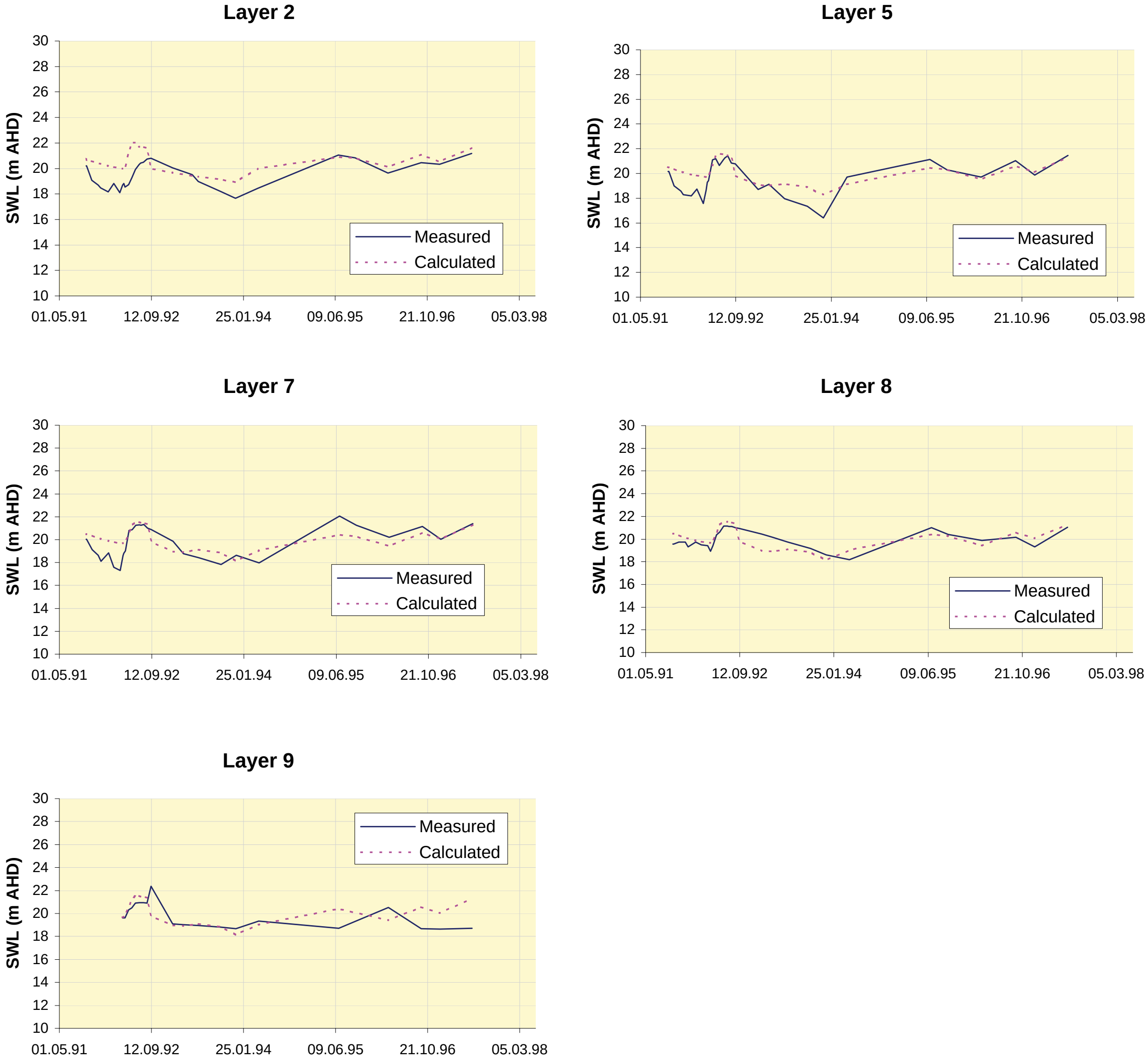
G70420024



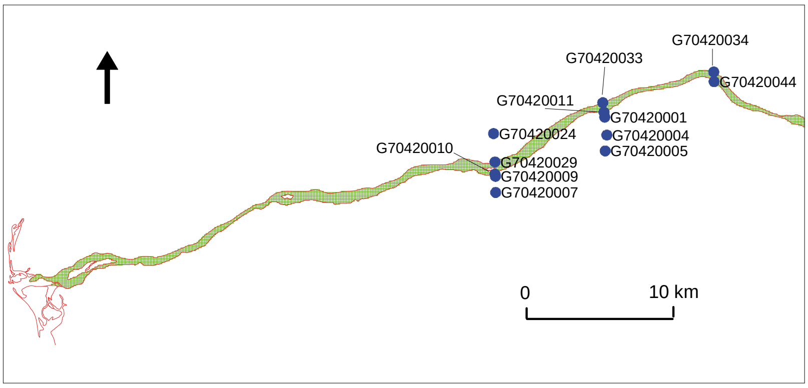
Appendix D18 Hydrographs of multiport monitoring wells



G70420029

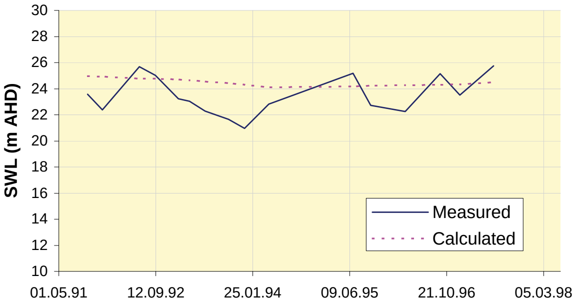


Appendix D19 Hydrographs of multiport monitoring wells

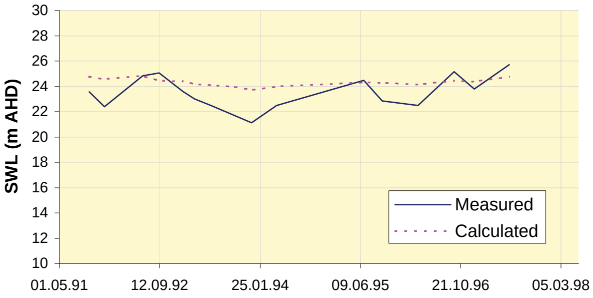


G70420033

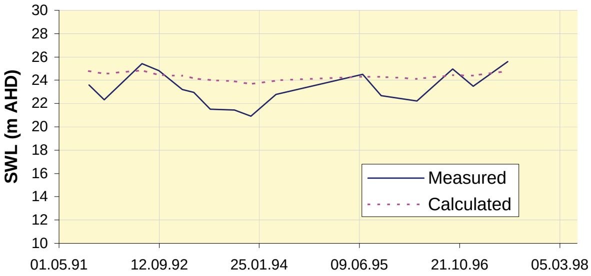
Layer 2



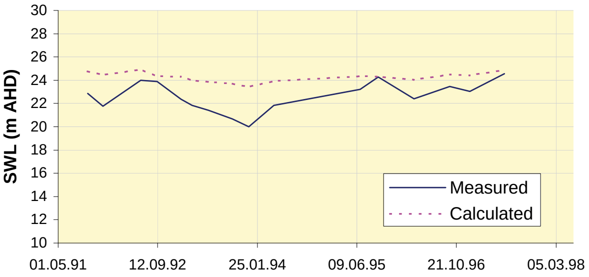
Layer 5



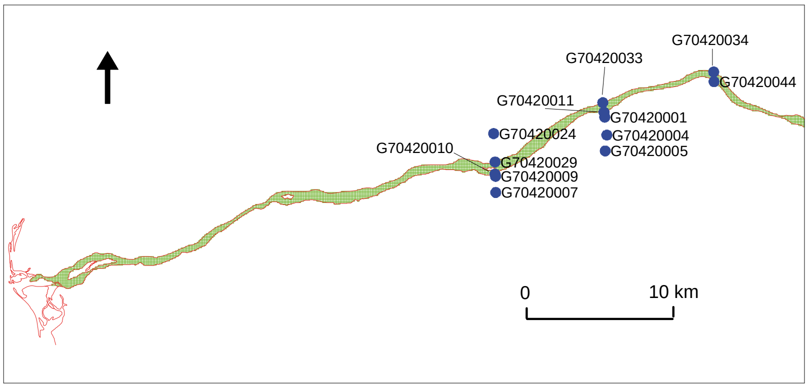
Layer 6



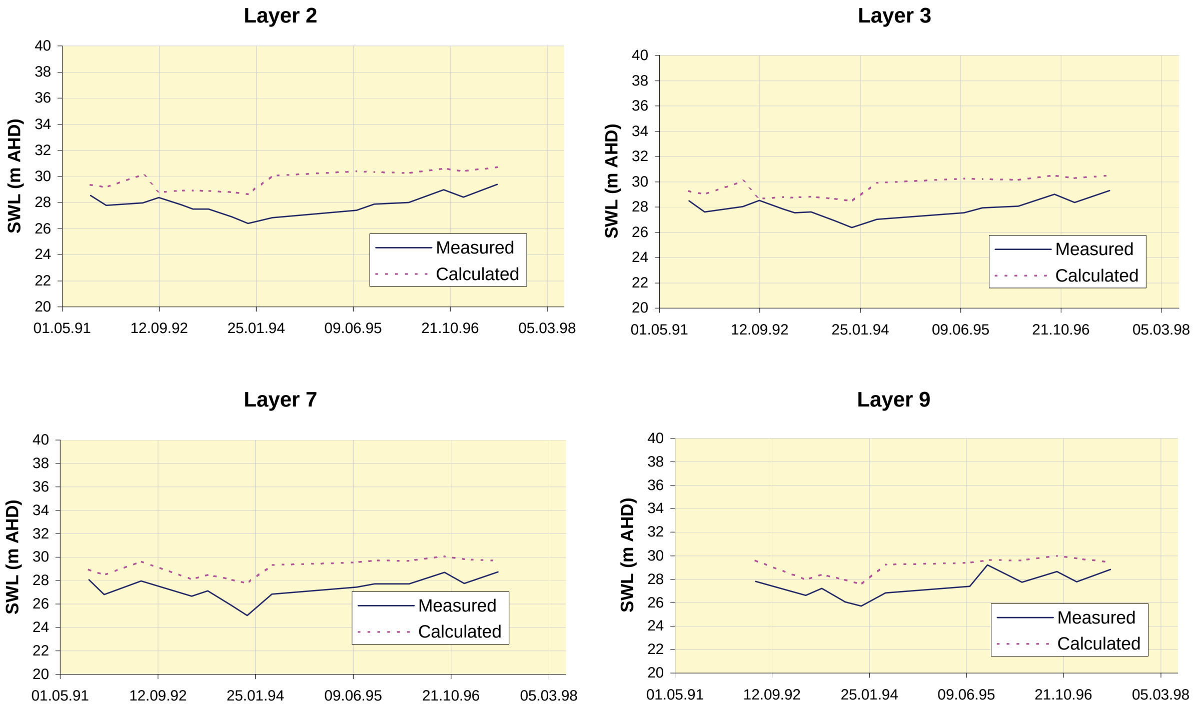
Layer 9



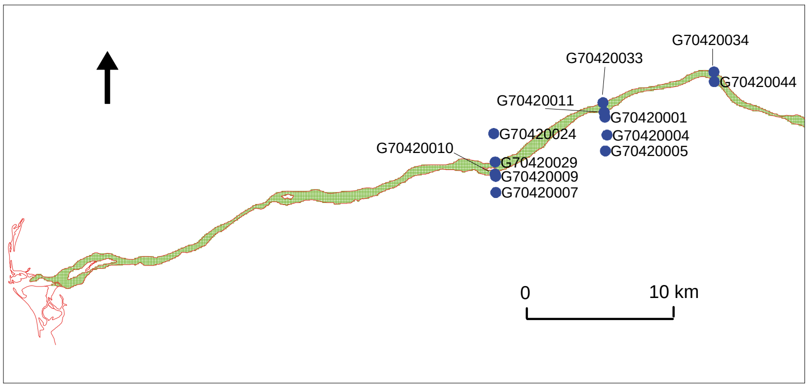
Appendix D20 Hydrographs of multiport monitoring wells



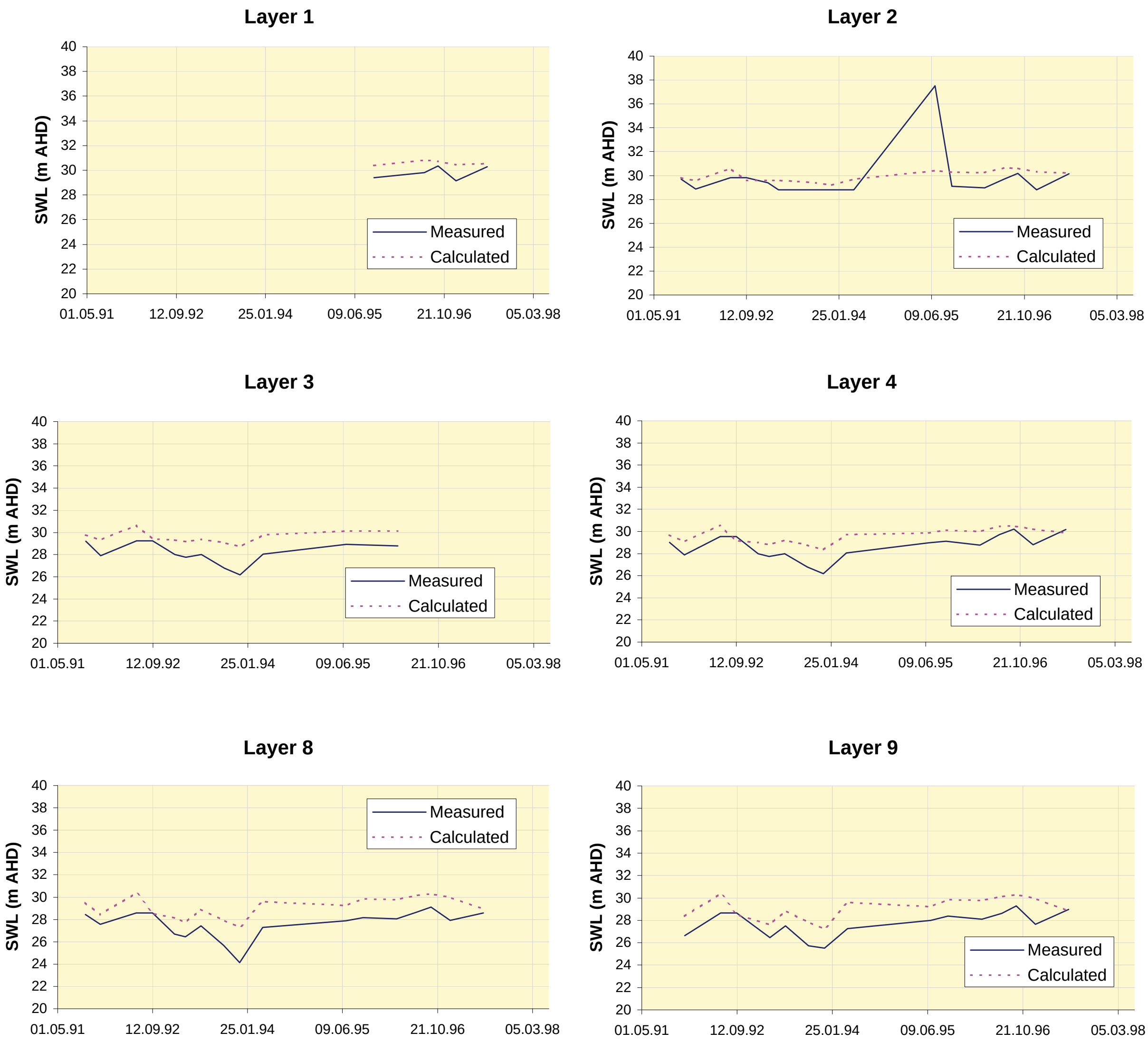
G70420034



Appendix D21 Hydrographs of multiport monitoring wells



G70420044



Appendix D22 Hydrographs of multiport monitoring wells

Appendix E Model input files

The following file list details the files and directory structure contained on the Gascoyne CD. A complete set of information and files are included to allow the running of any model on the Gascoyne River using GRFAMOD. However a copy of MODFLOW96 is not included. To run a selected model the directory structure should be maintained ‘as is’, with the exception of the initial head arrays for the selected model which require copying from the \\gascoyne\ihd directory to the \\gascoyne\data directory. This will then honour the directions as listed in the MODFLOW96 input files.

The table details the file and array name, formats, which MODFLOW96 package calls the file/array and a brief explanation of its purpose and the layer that the file/array corresponds to. Some files/arrays are included as they are used in the construction of other files/arrays that are called by GRFAMOD. Also included are the output waterlevels for each layer from each model simulation in SURFER grid format for viewing with Golden Software SURFER v7.0.

The table is organised into four sections.

- Arrays called by the GRFAMOD MODFLOW96 input files
- Examples of GRFAMOD MODFLOW96 input files for each model
- Examples of output grid files
- Files and databases used in the construction of arrays called by GRFAMOD

Some output files are used as templates for input files, or represent the input for the next simulation and so are included as arrays called by GRFAMOD MODFLOW96. Not all files on the CD are listed owing to the number involved, but examples of the naming format are given as an explanation. Examples of the contents of each GRFAMOD MODFLOW96 input package file are included at the end of the table.

Input arrays and file list for running GRFAMOD

File name	Location	File type	Format	Package	Layer	Explanation
Arrays called by GRFAMOD MODFLOW96 input files.						
Ibnd1.inf	:\\gascoyne\binary	Integer array	20I5	Basic	1	Boundary array, sets general, no flow & constant head cells for the first model simulation.
Ibnd2.inf	:\\gascoyne\binary	Integer array	20I5	Basic	2	As above
Ibnd3.inf	:\\gascoyne\binary	Integer array	20I5	Basic	3	Boundary array, sets general, no flow & constant head
Ibnd4.inf	:\\gascoyne\binary	Integer array	20I5	Basic	4	Boundary array, sets general, no flow & constant head
Ibnd5.inf	:\\gascoyne\binary	Integer array	20I5	Basic	5	Boundary array, sets general, no flow & constant head
Ibnd6.inf	:\\gascoyne\binary	Integer array	20I5	Basic	6	Boundary array, sets general, no flow & constant head
Ibnd7.inf	:\\gascoyne\binary	Integer array	20I5	Basic	7	Boundary array, sets general, no flow & constant head
Ibnd8.inf	:\\gascoyne\binary	Integer array	20I5	Basic	8	Boundary array, sets general, no flow & constant head
Ibnd9.inf	:\\gascoyne\binary	Integer array	20I5	Basic	9	Boundary array, sets general, no flow & constant head
M1l1p11.inf	:\\gascoyne\binary	Integer array	20I5	Basic	1	Input boundary array for model2 from model1 output
M1l2p11.inf	:\\gascoyne\binary	Integer array	20I5	Basic	1	Input boundary array for model2 from model1 output
M2l1p5.inf	:\\gascoyne\binary	Integer array	20I5	Basic	1	Input boundary array for model3 from model2 output
M2l2p5.inf	:\\gascoyne\binary	Integer array	20I5	Basic	2	Input boundary array for model3 from model2 output

etc… the output head array is used as a template for the input binary array for layers 1 and 2 for each subsequent model owing to cells converting to dry during no flow simulations and then re-wetting during a river simulation. The binary file name is given by the model number, (e.g. M2) the layer number (e.g. l2) and the number of stress periods of the previous model run (e.g. p5).

File name	Location	File type	Format	Package	Layer	Explanation
M1l1ih.ref	:\\gascoyne\data	Real array	7F14.7	Basic	1	Initial head input array for model1, which is equivalent to the cease to flow level
M1l2ihd.ref	:\\gascoyne\data	Real array	7F14.7	Basic	2	Initial head input array for model1
M1l3ihd.ref	:\\gascoyne\data	Real array	7F14.7	Basic	3	Initial head input array for model1
M1l4ihd.ref	:\\gascoyne\data	Real array	7F14.7	Basic	4	Initial head input array for model1
M1l5ihd.ref	:\\gascoyne\data	Real array	7F14.7	Basic	5	Initial head input array for model1
M1l6ihd.ref	:\\gascoyne\data	Real array	7F14.7	Basic	6	Initial head input array for model1

File name	Location	File type	Format	Package	Layer	Explanation
M1l7ihd.ref	:\\gascoyne\data	Real array	7F14.7	Basic	7	Initial head input array for model1
M1l8ihd.ref	:\\gascoyne\data	Real array	7F14.7	Basic	8	Initial head input array for model1
M1l9ihd.ref	:\\gascoyne\data	Real array	7F14.7	Basic	9	Initial head input array for model1
M1l1p11.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	1	Initial head input array for model2
M1l2p11.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	2	Initial head input array for model2
M1l3p11.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	3	Initial head input array for model2
M1l4p11.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	4	Initial head input array for model2
M1l5p11.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	5	Initial head input array for model2
M1l6p11.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	6	Initial head input array for model2
M1l7p11.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	7	Initial head input array for model2
M1l8p11.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	8	Initial head input array for model2
M1l9p11.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	9	Initial head input array for model2
M2l1p5.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	1	Initial head input array for model3
M2l2p5.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	2	Initial head input array for model3
M2l3p5.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	3	Initial head input array for model3
M2l4p5.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	4	Initial head input array for model3
M2l5p5.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	5	Initial head input array for model3
M2l6p5.hed	:\\gascoyne\ihd	Binary array	Binary	Basic	6	Initial head input array for model3

etc… an initial head array is read for every new model and consists of the output from the previous model run, except for the first simulation which was constructed using hand drawn contours, digitised and captured into SURFER grid files. The file name is given by the previous model number (e.g. M1) the layer number (e.g. l4) and the number of stress periods in the previous model simulation (e.g. p11).

Riv100.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	1	Horizontal hydraulic conductivity array
L2hy26.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	2	Horizontal hydraulic conductivity array
L3trn.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	3	Transmissivity array
L4trn.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	4	Transmissivity array
L5trn.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	5	Transmissivity array
L6trn.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	6	Transmissivity array

File name	Location	File type	Format	Package	Layer	Explanation
L7trn.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	7	Transmissivity array
L8trn.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	8	Transmissivity array
L9trn.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	9	Transmissivity array
Rbsbamg.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	1	Elevation of bottom of riverbed sand
Confin2.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	2	Confining elevation
Confin3.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	3	Confining elevation
Confin4.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	4	Confining elevation
Vconl1.ref	:\\gascoyne\data	Real array	7F14.7	Bcf		Vertical conductance between layers 1 & 2
Vconl2.ref	:\\gascoyne\data	Real array	7F14.7	Bcf		Vertical conductance between layers 2 & 3
Vconl3.ref	:\\gascoyne\data	Real array	7F14.7	Bcf		Vertical conductance between layers 3 & 4
Vconl4.ref	:\\gascoyne\data	Real array	7F14.7	Bcf		Vertical conductance between layers 4 & 5
Vconl5.ref	:\\gascoyne\data	Real array	7F14.7	Bcf		Vertical conductance between layers 5 & 6
Vconl6.ref	:\\gascoyne\data	Real array	7F14.7	Bcf		Vertical conductance between layers 6 & 7
Vconl7.ref	:\\gascoyne\data	Real array	7F14.7	Bcf		Vertical conductance between layers 7 & 8
Vconl8.ref	:\\gascoyne\data	Real array	7F14.7	Bcf		Vertical conductance between layers 8 & 9
Lay1wetn.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	1	Re-wetting array for no flow periods (10% saturated thickness)
Lay1wetf.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	1	Re-wetting array for flow periods (10% saturated thickness)
Lay2thk.ref	:\\gascoyne\data	Real array	7F14.7	Bcf	2	Re-wetting array (90% saturated thickness)
Evpsf2.inf	:\\gascoyne\data\evap	Integer array	20I5	Evt		Surface at which maximum evapotranspiration occurs
Extdepth.ref	:\\gascoyne\data\evap	Real array	7F14.7	Evt		Maximum depth to which evapotranspiration impacts
Evaplay.inf	:\\gascoyne\data\evap	Integer array	20I5	Evt		Sets layers to which evapotranspiration is applied
Evtjan.ref	:\\gascoyne\data\evap	Real array	7F14.7	Evt	1 & 2	January and February pan evaporation coefficient (must be multiplied by monthly pan evaporation rate)
Evtmar.ref	:\\gascoyne\data\evap	Real array	7F14.7	Evt	1 & 2	March pan evaporation coefficient (must be multiplied by monthly pan evaporation rate)
Evtapr.ref	:\\gascoyne\data\evap	Real array	7F14.7	Evt	1 & 2	April, August and September pan evaporation coefficient (must be multiplied by monthly pan evaporation rate)
Evtmay.ref	:\\gascoyne\data\evap	Real array	7F14.7	Evt	1 & 2	May pan evaporation coefficient (must be multiplied by monthly pan evaporation rate)

File name	Location	File type	Format	Package	Layer	Explanation
Evtjun.ref	:\\gascoyne\data\evap	Real array	7F14.7	Evt	1 & 2	June and July pan evaporation coefficient (must be multiplied by monthly pan evaporation rate)
Evtoct.ref	:\\gascoyne\data\evap	Real array	7F14.7	Evt	1 & 2	October pan evaporation coefficient (must be multiplied by monthly pan evaporation rate)
Evtnov.ref	:\\gascoyne\data\evap	Real array	7F14.7	Evt	1 & 2	November pan evaporation coefficient (must be multiplied by monthly pan evaporation rate)
Evtdec.ref	:\\gascoyne\data\evap	Real array	7F14.7	Evt	1 & 2	December pan evaporation coefficient (must be multiplied by monthly pan evaporation rate)
Rainin.inf	:\\gascoyne\data\rain	Integer array	20I5	Rch		Sets layers to which rainfall recharge is applied
Raindist.ref	:\\gascoyne\data\rain	Real array	7F14.7	Rch		Percentage rainfall recharge array (must be multiplied by monthly rainfall)

File name	Location	File type	Format	Package	Explanation
Examples of GRFAMOD MODFLOW96 input files for each model					
grfamod9.nam	:\\gascoyne\M01	Input file	Text file	MODFLOW96	List of, and location, of packages to be called by MODFLOW96
grfamod9.bas	:\\gascoyne\M01	Input file	Text file	MODFLOW96	List of arrays and parameters required by the MODFLOW96 Basic package
grfamod9.bcf	:\\gascoyne\M01	Input file	Text file	MODFLOW96	List of arrays and parameters required by the MODFLOW96 Block centred flow package
grfamod9.wel	:\\gascoyne\M01	Input file	Text file	MODFLOW96	List of abstraction wells operational over stress period and abstraction rates in cubic metres per day
grfamod9.evt	:\\gascoyne\M01	Input file	Text file	MODFLOW96	List of arrays of monthly pan evaporation coefficients and dam evaporation coefficient required by the MODFLOW96 Evapotranspiration package
grfamod9.rch	:\\gascoyne\M01	Input file	Text file	MODFLOW96	List of arrays and monthly rainfall required by the MODFLOW96 Recharge package
grfamod9.sip	:\\gascoyne\M01	Input file	Text file	MODFLOW96	List of parameters required by the MODFLOW96 Strongly Implicit Procedure package for solving groundwater flow matrices.

File name	Location	File type	Format	Package	Explanation
grfamod9.oc	:\\gascoyne\M01	Input file	Text file	MODFLOW96	List of parameters required by the MODFLOW96 Output package to control the desired output. Presently the output is set for water budgets after each monthly stress and head in each layer at the model simulation end only.
grfamod9.riv	:\\gascoyne\M02	Input file	Text file	MODFLOW96	List of riverbed cells and stage, conductance and limiting conditions for surface water flow
…etc. up to directory \\gascoyne\M17		Same input files are required for each model interval, however the river package is only required for every even numbered model, as odd numbered simulations are no flow events. Each input file also calls different input arrays representing layer 1 and 2 boundary conditions and initial head for each layer, as well as abstraction rates, rainfall and evaporation records.			

File name	Location	File type	Format	Package	Layer	Explanation
Examples of output grid files						
M1l1p11.grd	:\\gascoyne\M01	Output file	SURFER grid file	Not read	1	End of model 1 head array
M1l2p11.grd	:\\gascoyne\M01	Output file	SURFER grid file	Not read	2	End of model 1 head array
…etc. and all layers in between						
M1l9p11.grd	:\\gascoyne\M01	Output file	SURFER grid file	Not read	9	End of model 1 head array
M2l1p5.grd	:\\gascoyne\M02	Output file	SURFER grid file	Not read	1	End of model 2 head array
…….etc and all layers in between						
M2l9p5.grd	:\\gascoyne\M02	Output file	SURFER grid file	Not read	9	End of model 2 head array
M3l1p6.grd	:\\gascoyne\M03	Output file	SURFER grid file	Not read	1	End of model 3 head array
…etc. up to layer 9						

File name	Location	File type	Format	Package	Layer	Explanation
M4l1p1.grd	:\\gascoyne\M04	Output file	SURFER grid file	Not read	1	End of model 4 head array
…etc. up to layer 9						
M5l1p13.grd	:\\gascoyne\M05	Output file	SURFER grid file	Not read	1	End of model 5 head array
…etc. up to directory \\gascoyne\M17						
Files and databases used in the construction of arrays called by GRFAMOD						
Lay1thk.ref	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	1	Thickness grid for calculating transmissivity and vertical hydraulic conductance term
Lay2thk.ref	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	2	Thickness grid for calculating transmissivity and vertical hydraulic conductance term
Lay3thk.ref	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	3	Thickness grid for calculating transmissivity and vertical hydraulic conductance term
Lay4thk.ref	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	4	Thickness grid for calculating transmissivity and vertical hydraulic conductance term
Lay5thk.ref	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	5	Thickness grid for calculating transmissivity and vertical hydraulic conductance term
Lay6thk.ref	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	6	Thickness grid for calculating transmissivity and vertical hydraulic conductance term
Lay7thk.ref	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	7	Thickness grid for calculating transmissivity and vertical hydraulic conductance term
Lay8thk.ref	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	8	Thickness grid for calculating transmissivity and vertical hydraulic conductance term
Lay9thk.ref	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	9	Thickness grid for calculating transmissivity and vertical hydraulic conductance term
L3hyk.grd	:\\gascoyne\surfgrid	SURFER grid	GS Binary	Not read	3	Horizontal hydraulic conductivity grid
L4hyk.grd	:\\gascoyne\surfgrid	SURFER grid	GS Binary	Not read	4	Horizontal hydraulic conductivity grid
L5hyk.grd	:\\gascoyne\surfgrid	SURFER grid	GS Binary	Not read	5	Horizontal hydraulic conductivity grid

File name	Location	File type	Format	Package	Layer	Explanation
L6hyk.grd	:\\gascoyne\surfgrid	SURFER grid	GS Binary	Not read	6	Horizontal hydraulic conductivity grid
L7hyk.grd	:\\gascoyne\surfgrid	SURFER grid	GS Binary	Not read	7	Horizontal hydraulic conductivity grid
L8hyk.grd	:\\gascoyne\surfgrid	SURFER grid	GS Binary	Not read	8	Horizontal hydraulic conductivity grid
L9hyk.grd	:\\gascoyne\surfgrid	SURFER grid	GS Binary	Not read	9	Horizontal hydraulic conductivity grid
Confin5.grd	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	5	Confining elevation
Confin6.grd	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	6	Confining elevation
Confin7.grd	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	7	Confining elevation
Confin8.grd	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	8	Confining elevation
Basement.grd	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	9	Base of older alluvium
Elevmahd.grd	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	1	Modelled surface elevation
Ctflow.grd	:\\gascoyne\geology	SURFER grid	GS Binary	Not read	1	Model of the cease to flow elevation within the riverbed
Wells.mdb	:\\gascoyne	Access database		Not read	All	Database for constructing wel input files for each model, contains monthly abstraction rates in cubic metres per day for all bores and links these rates to cells within GRFAMOD
Riverpak.mdb	:\\gascoyne	Access database		Not read	1	Database for constructing riv input files for each flow simulation.
Alltime.xls	:\\gascoyne	Excel spreadsheet		Not read	All	List of all calculated and measured heads, residuals and squared residuals plus hydrographs and scattergrams. Using the auto-filter in each column a particular well hydrograph or model run scattergram can be viewed within the respective worksheet

GRFAMOD.*nam* input file example

```
LIST         6 c:\mfi2.3\bin\grfamod.lst
BAS          5 c:\mfi2.3\bin\grfamod.bas
BCF         11 c:\mfi2.3\bin\grfamod.bcf
WEL         12 c:\mfi2.3\bin\grfamod.wel
EVT         15 c:\mfi2.3\bin\grfamod.evt
RCH         18 c:\mfi2.3\bin\grfamod.rch
SIP         19 c:\mfi2.3\bin\grfamod.sip
OC          22 c:\mfi2.3\bin\grfamod.oc
DATA(BINARY)     76 c:\pest\welcbc.out
DATA(BINARY)     89 c:\pest\grfamod.hed
```

GRFAMOD.*bas* input file example

```
Gascoyne River floodplain aquifer groundwater model May 91 - Mar 92
  9    230    550    11     4 NLAY,NROW,NCOL,NPER,ITMUNI
FREE
     0     0 IAPART,ISTRT
OPEN/CLOSE c:\gascoyne\binary\ibnd1.inf     1 ‘(20I5)’  -1 IBOUND layer 1
OPEN/CLOSE c:\gascoyne\binary\ibnd2.inf     1 ‘(20I5)’  -1 IBOUND layer 2
OPEN/CLOSE c:\gascoyne\binary\ibnd3.inf     1 ‘(20I5)’  -1 IBOUND layer 3
OPEN/CLOSE c:\gascoyne\binary\ibnd4.inf     1 ‘(20I5)’  -1 IBOUND layer 4
OPEN/CLOSE c:\gascoyne\binary\ibnd5.inf     1 ‘(20I5)’  -1 IBOUND layer 5
OPEN/CLOSE c:\gascoyne\binary\ibnd6.inf     1 ‘(20I5)’  -1 IBOUND layer 6
OPEN/CLOSE c:\gascoyne\binary\ibnd7.inf     1 ‘(20I5)’  -1 IBOUND layer 7
OPEN/CLOSE c:\gascoyne\binary\ibnd8.inf     1 ‘(20I5)’  -1 IBOUND layer 8
OPEN/CLOSE c:\gascoyne\binary\ibnd9.inf     1 ‘(20I5)’  -1 IBOUND layer 9
  999.99 HNOFLO
OPEN/CLOSE c:\gascoyne\data\m1l1ih.ref 1.000E+00 ‘(7F14.7)’ -1 SHEAD layer 1
OPEN/CLOSE c:\gascoyne\data\m1l2ihd.ref 1.000E+00 ‘(7F14.7)’ -1 SHEAD layer 2
OPEN/CLOSE c:\gascoyne\data\m1l3ihd.ref 1.000E+00 ‘(7F14.7)’ -1 SHEAD layer 3
OPEN/CLOSE c:\gascoyne\data\m1l4ihd.ref 1.000E+00 ‘(7F14.7)’ -1 SHEAD layer 4
OPEN/CLOSE c:\gascoyne\data\m1l5ihd.ref 1.000E+00 ‘(7F14.7)’ -1 SHEAD layer 5
OPEN/CLOSE c:\gascoyne\data\m1l6ihd.ref 1.000E+00 ‘(7F14.7)’ -1 SHEAD layer 6
OPEN/CLOSE c:\gascoyne\data\m1l7ihd.ref 1.000E+00 ‘(7F14.7)’ -1 SHEAD layer 7
OPEN/CLOSE c:\gascoyne\data\m1l8ihd.ref 1.000E+00 ‘(7F14.7)’ -1 SHEAD layer 8
OPEN/CLOSE c:\gascoyne\data\m1l9ihd.ref 1.000E+00 ‘(7F14.7)’ -1 SHEAD layer 9
 3.100E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
 3.000E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
 3.100E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
 3.100E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
 3.000E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
 3.100E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
 3.000E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
 3.100E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
 3.100E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
```

```
 2.900E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
 3.100E+01     1 1.000E+00 PERLEN,NSTP,TSMULT
```

GRFAMOD.*bcf* input file example

```
0     0  999.99     1 1.00E-01     1     1 ISS,IBCFCB,HDRY,IWDFLG,WETFCT,IWETIT
,IHDWET
 1 3 2 2 0 0 0 0 0
CONSTANT  1.000E+00 TRPY
CONSTANT  1.000E+02 DELR
CONSTANT  1.000E+02 DELC
CONSTANT  3.000E-01 SF1 layer 1
OPEN/CLOSE c:\gascoyne\data\riv100.ref 1.000E+00 '(7F14.7)'  -1 HY layer 1
OPEN/CLOSE c:\gascoyne\data\rbsbamg.ref 1.000E+00 '(7F14.7)'  -1 BOT layer 1
OPEN/CLOSE c:\gascoyne\data\vconl1.ref 1.000E+00 '(7F14.7)' -1 VCONT layer 1
OPEN/CLOSE c:\gascoyne\data\lay1wetn.ref 1.000E-01 '(7F14.7)' -1 WETDRY layer 1
CONSTANT  5.000E-04 SF1 layer 2
OPEN/CLOSE c:\gascoyne\data\l2hy26.ref 1.000E+00 '(7F14.7)'  -1 HY layer 2
OPEN/CLOSE c:\gascoyne\data\confin3.ref 1.000E+00 '(7F14.7)'  -1 BOT layer 2
OPEN/CLOSE c:\gascoyne\data\vconl2.ref 1.000E+00 '(7F14.7)' -1 VCONT layer 2
CONSTANT  2.000E-01 SF2 layer 2
OPEN/CLOSE c:\gascoyne\data\confin2.ref 1.000E+00 '(7F14.7)'  -1 TOP layer 2
OPEN/CLOSE c:\gascoyne\data\lay2wet.ref 9.000E-01 '(7F14.7)' -1 WETDRY layer 2
CONSTANT  5.000E-04 SF1 layer 3
OPEN/CLOSE c:\gascoyne\data\l3trn.ref 1.000E+00 '(7F14.7)'  -1 TRAN layer 3
OPEN/CLOSE c:\gascoyne\data\vconl3.ref 1.000E+00 '(7F14.7)' -1 VCONT layer 3
CONSTANT  1.800E-01 SF2 layer 3
OPEN/CLOSE c:\gascoyne\data\confin3.ref 1.000E+00 '(7F14.7)'  -1 TOP layer 3
CONSTANT  5.000E-04 SF1 layer 4
OPEN/CLOSE c:\gascoyne\data\l4trn.ref 1.000E+00 '(7F14.7)'  -1 TRAN layer 4
OPEN/CLOSE c:\gascoyne\data\vconl4.ref 1.000E+00 '(7F14.7)' -1 VCONT layer 4
CONSTANT  1.800E-01 SF2 layer 4
OPEN/CLOSE c:\gascoyne\data\confin4.ref 1.000E+00 '(7F14.7)' -1 TOP layer 4
CONSTANT  5.000E-04 SF1 layer 5
OPEN/CLOSE c:\gascoyne\data\l5trn.ref 1.000E+00 '(7F14.7)'  -1 TRAN layer 5
OPEN/CLOSE c:\gascoyne\data\vconl5.ref 1.000E+00 '(7F14.7)' -1 VCONT layer 5
CONSTANT  5.000E-05 SF1 layer 6
OPEN/CLOSE c:\gascoyne\data\l6trn.ref 1.000E+00 '(7F14.7)'  -1 TRAN layer 6
OPEN/CLOSE c:\gascoyne\data\vconl6.ref 1.000E+00 '(7F14.7)' -1 VCONT layer 6
CONSTANT  5.000E-05 SF1 layer 7
OPEN/CLOSE c:\gascoyne\data\l7trn.ref 1.000E+00 '(7F14.7)'  -1 TRAN layer 7
OPEN/CLOSE c:\gascoyne\data\vconl7.ref 1.000E+00 '(7F14.7)' -1 VCONT layer 7
CONSTANT  1.000E-05 SF1 layer 8
OPEN/CLOSE c:\gascoyne\data\l8trn.ref 1.000E+00 '(7F14.7)'  -1 TRAN layer 8
OPEN/CLOSE c:\gascoyne\data\vconl8.ref 1.000E+00 '(7F14.7)' -1 VCONT layer 8
CONSTANT  1.000E-05 SF1 layer 9
OPEN/CLOSE c:\gascoyne\data\l9trn.ref 1.000E+00 '(7F14.7)'  -1 TRAN layer 9
```

GRFAMOD.*evt* input file example

```
2     0 NEVTOP IEVTCB
     0     0     0     0 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evpsf2.ref 1.000E+00 ‘(7F14.7)’  -1 SURF
OPEN/CLOSE c:\gascoyne\data\evap\evtmay.ref 5.000E-03 ‘(7F14.7)’  -1 EVTR
OPEN/CLOSE c:\gascoyne\data\evap\extdepth.ref 1.000E+00 ‘(7F14.7)’  -1 EXDP
OPEN/CLOSE c:\gascoyne\data\evap\evaplay.inf   1 ‘(20I5)’  -1 IEVT
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtjun.ref 3.700E-03 ‘(7F14.7)’  -1 EVTR
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtjun.ref 3.700E-03 ‘(7F14.7)’  -1 EVTR
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtapr.ref 4.800E-03 ‘(7F14.7)’  -1 EVTR
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtapr.ref 6.600E-03 ‘(7F14.7)’  -1 EVTR
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtoct.ref 8.100E-03 ‘(7F14.7)’  -1 EVTR
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtnov.ref 9.100E-03 ‘(7F14.7)’  -1 EVTR
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtdec.ref 9.900E-03 ‘(7F14.7)’  -1 EVTR
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtjan.ref 1.000E-02 ‘(7F14.7)’  -1 EVTR
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtjan.ref 9.800E-03 ‘(7F14.7)’  -1 EVTR
    -1     0    -1    -1 INSURF INEVTR INEXDP INIEVT
OPEN/CLOSE c:\gascoyne\data\evap\evtmar.ref 8.700E-03 ‘(7F14.7)’  -1 EVTR
```

GRFAMOD.*rch* input file example

```
2     0 NRCHOP IRCHCB
     0     0 INRECH INIRCH
CONSTANT  0.000E+00 RECH
OPEN/CLOSE c:\gascoyne\data\rain\rainin.inf     1 ‘(20I5)’  -1 IRCH
     0    -1 INRECH INIRCH
OPEN/CLOSE c:\gascoyne\data\rain\raindist.ref 2.880E-03 ‘(7F14.7)’  -1 RECH
     0    -1 INRECH INIRCH
OPEN/CLOSE c:\gascoyne\data\rain\raindist.ref 2.410E-03 ‘(7F14.7)’  -1 RECH
     0    -1 INRECH INIRCH
OPEN/CLOSE c:\gascoyne\data\rain\raindist.ref 2.000E-05 ‘(7F14.7)’  -1 RECH
     0    -1 INRECH INIRCH
CONSTANT  0.000E+00 RECH
     0    -1 INRECH INIRCH
CONSTANT  0.000E+00 RECH
     0    -1 INRECH INIRCH
CONSTANT  0.000E+00 RECH
```

```
     0    -1 INRECH INIRCH
CONSTANT  0.000E+00 RECH
     0    -1 INRECH INIRCH
CONSTANT  0.000E+00 RECH
     0    -1 INRECH INIRCH
CONSTANT  0.000E+00 RECH
     0    -1 INRECH INIRCH
CONSTANT  0.000E+00 RECH
```

GRFAMOD.*sip* input file example

```
30     5 MXITER NPARM
2.00E-01 1.50E-01    0 3.54E-07     1 ACCL HCLOSE IPCALC WSEED IPRSIP
```

GRFAMOD.*wel* input file example

```
380    76   MXWELL IWELCB
    372      ITMP -- Stress Period  1
     2    48    477 -1.589E+0
     7    48    477 -2.830E-2
     8    48    477 -2.830E-2
     2    49    486 -6.203E+1
     5    52    485 -3.309E-1
     8    52    485 -8.271E-2
     9    52    485 -2.639E-1
     1    59    439 -3.221E-2
     4    59    439 -3.226E-5
     7    59    439 -1.935E-5
     9    73    412 -2.265E+2
```

…etc…

```
380      ITMP -- Stress Period  2
     5    45    473 -1.304E-2
     6    45    473 -5.216E-2
     8    45    473 -5.216E-2
     9    45    473 -2.827E-1
     2    48    477 -4.538E+0
     7    48    477 -8.084E-2
     8    48    477 -8.084E-2
     2    49    486 -2.832E+2
     5    52    485 -4.249E+0
```

…etc…

‘

‘

```
311      ITMP -- Stress Period 11
     5    45    473 -4.477E+0
```

```
     6    45    473 -1.791E+1
     8    45    473 -1.791E+1
     9    45    473 -9.705E+1
     7    48    477 -5.820E+2
     8    48    477 -5.820E+2
```

GRFAMOD.*riv* input file example

```
2865,-1       MXRIVR IRIVCB
2865       ITMP -- Stress Period  1
1,190,19,0.881280119,58181.00576,0.108305
1,189,20,0.994164305,51875.40068,0.221189007
1,190,20,0.878118301,41918.77323,0.439420998
1,188,21,0.929788473,56167.278,0.156812996
1,189,21,0.908887478,39070.86468,0.534758985
1,190,21,0.892891476,34195.54096,0.706529975
1,188,22,1.18666065,43501.41179,0.413684994
1,189,22,0.907753649,33223.67311,0.757661998
1,190,22,0.897977653,28778.10471,0.897977653
1,187,23,0.912975836,28291.72798,0.912975836
1,188,23,1.451653811,35292.81499,0.678677976
```

…etc…

```
2865       ITMP -- Stress Period  2
1,190,19,0.881280119,58181.00576,0.108305
1,189,20,0.994164305,51875.40068,0.221189007
1,190,20,0.878118301,41918.77323,0.439420998
1,188,21,0.929788473,56167.278,0.156812996
1,189,21,0.908887478,39070.86468,0.534758985
1,190,21,0.892891476,34195.54096,0.706529975
1,188,22,1.18666065,43501.41179,0.413684994
1,189,22,0.907753649,33223.67311,0.757661998
1,190,22,0.897977653,28778.10471,0.897977653
1,187,23,0.912975836,28291.72798,0.912975836
1,188,23,1.451653811,35292.81499,0.678677976
```

…etc…

Numbers on each row represent layer, row, column, stage, conductivity, limiting condition. Every river cell must be on for every river flow simulation for the limiting conditions of equations 2(a, b, c & d).

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