Department of Water
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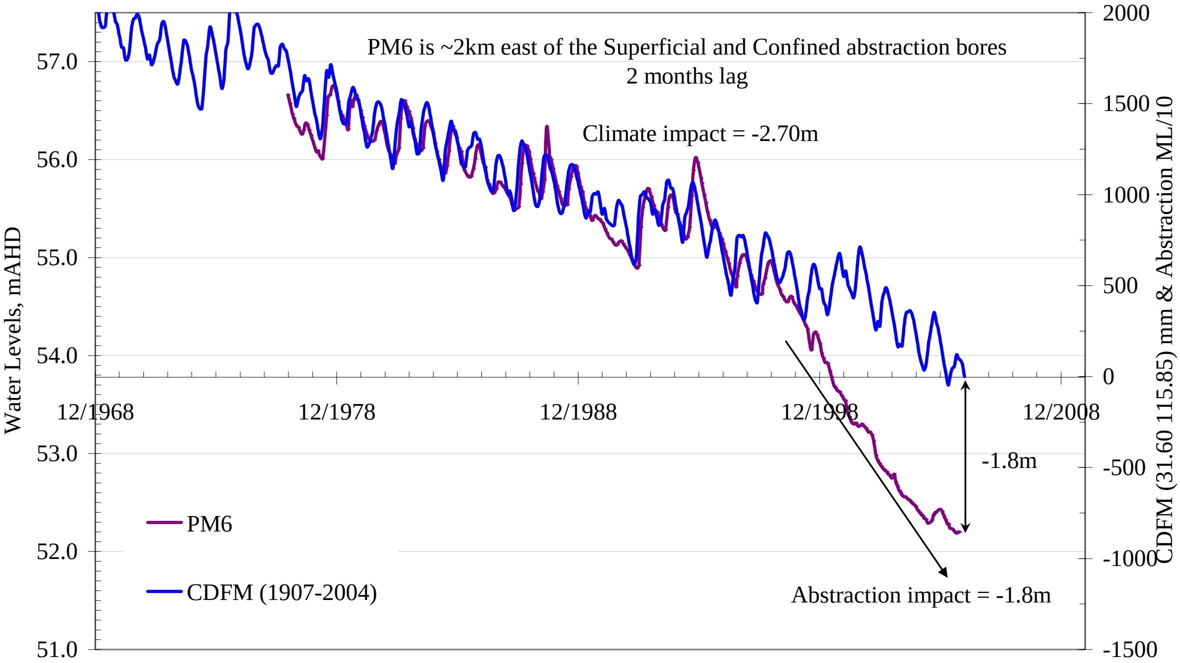
Assessment of the declining groundwater levels in the Gnangara Groundwater Mound



Cumulative effect of the abstraction on monitoring bore PM6

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Acknowledgments
This report was prepared by Dr Cahit Yesertener. The information provided in this report is summarised from an unpublished report HR 199 and updated until 2005.

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Summary

Over the last thirty-five years, the groundwater and wetlands levels on the Gnangara Groundwater Mound show steady long-term declines in most areas within the State Pine forest, the native woodlands areas and near the abstraction areas with or without seasonal variations.

The declining water levels may be attributed to climate variation, abstraction from the superficial and/or confined aquifers, and land use changes including evapotranspiration and interception loss from pine plantations. The relative contribution of these factors on the falling groundwater levels had previously been uncertain and yet to be determined.

In this study, a relationship between groundwater level data for the Gnangara region and cumulative deviation from the mean rainfall (CDFM) was established. The CDFM technique was then applied to about 110 groundwater hydrographs within the Groundwater Mound to identify land and water use impacts on groundwater levels in the region. Multiple regression analysis was then used to validate the results.

This work quantifies the relative magnitudes of the effects on groundwater levels resulting from changes in rainfall, land use and groundwater abstraction. As a result of this work it has been concluded that reduced rainfall is the major impact on reduction of the groundwater levels on the Gnangara Groundwater Area since 1969, with falls of up to four metres over the 1979 – 2005 period. The cumulative long-term impact of abstraction in the Gnangara Groundwater Area is centered on the Pinjar, Wanneroo, Gwelup, and Mirrabooka borefields with declines of maximum 2.4, 2.0, 3.0 and 1.5 m, respectively within a 6 km of the borefields. The Gnangara pine plantation has resulted in groundwater declines in the order of 3.5 m over the same period in areas where pines were particularly dense. Clearing before planting pines has a rising impact, causing a rise of 1 to 2 m in groundwater for a 3-7 year period after clearing. Bush fires cause a rising impact, resulting a rise in the groundwater levels by about 0.5 to 2.4 m for a period of 3-5 years. Thinning of pines has some impact, causing groundwater levels to rise locally for a period of 1-3 years, depending on the degree of thinning.

1 Introduction

The Gnangara Groundwater Mound is an important source of water for the metropolitan water supply and irrigated agriculture, and it also maintains wetland ecosystems.

The Gnangara Groundwater Mound is located north of Perth. The mound is bounded by Gingin Brook and Moore River in the north, Ellenbrook in the east, the Swan River in the south, and the Indian Ocean to the west as shown in Figure 1.

Wetland and groundwater levels on the Gnangara Groundwater Mound are known to have been declining for the last 35 years. Some of the hydrographs from native woodland areas, from the pine forest areas, and near the abstraction areas show steady declines in water levels with or without seasonal variations (Davidson, 1995). This suggests a significant change in rainfall recharge to the superficial aquifer over the last 35 years.

The declining water levels may be attributed to climate variation, over-abstraction from the superficial and/or confined aquifers, and evapotranspiration and interception loss from vegetation including the nearby pine plantations. However the relative contribution from these factors on the falling groundwater levels was uncertain.

The objective of the study is to determine the main underlying causes for the lowering of the water levels observed within the Gnangara Groundwater Mound. Contributing factors investigated included the changes in land use (eg. pine plantations), groundwater abstraction and climate.

The information provided in this report is summarised from Yesertener (2002). It presents and updates the results of the Stage I investigations to determine the climate, land and water use impact on groundwater decline within the Gnangara Groundwater Mound until the end of 2005. Results are obtained by comparing groundwater hydrographs with cumulative deviation from mean rainfall (CDFM). SILO rainfall data (see the Appendix A) was used to produce consistent CDFM graphs across the mound and prevent possible analysis error resulting from the calculation of the missing rainfall data. The results have been validated using statistical analysis including multi regression techniques.

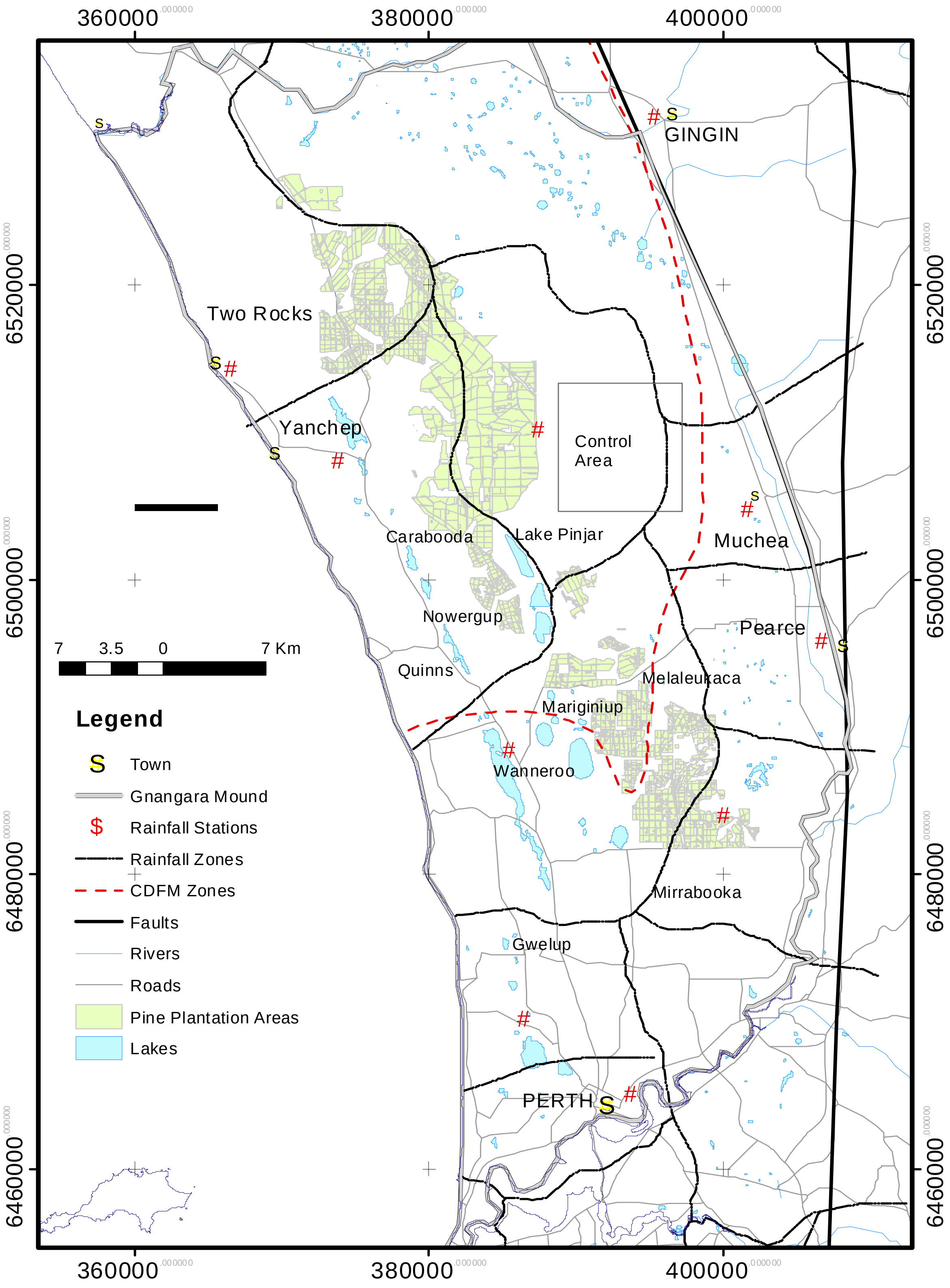

Figure 1 Gnangara Groundwater Mound

2 Methodology

Cumulative deviation from the mean rainfall (CDFM) is a simple arithmetic technique that is used for rainfall evaluation. In this method the actual rainfall over a defined period is subtracted from the long-term mean rainfall of the same period.

The deviations are plotted cumulatively in a diagram showing periods of above mean rainfall by an upward tending graph and of below mean rainfall in downward tending graph. This technique has previously been applied to groundwater studies. For example Eakin (1964) shows the relation between cumulative departure from average rainfall and the flow of a karst spring in Moapa valley in Nevada. Temperley (1980) used the CDFM technique for an extensive analysis of rainfall variation in South Africa.

Similarly, Yesertener (1986 and 1995) also used the same technique for an extensive analysis of rainfall variations in Western and Southern Turkey, which showed the close relationship between the CDFM plots of rainfall and the natural water level fluctuations of the karst springs in Turkey. Boehmer (1998) shows that the natural groundwater level fluctuations near Colesberg in the Karoo of South Africa correlate with cumulative departure graphs of rainfall, which is confirmed by groundwater model simulations. Ferdowsian and McCarron (2001) developed a software program called HARTT to estimate trends in groundwater levels. The method used by HARTT is based on the same technique as CDFM and in addition uses multiple regression analysis to separate the effect of atypical rainfall events from the underlying time trend and the lag between rainfall and its impact on groundwater level.

A relationship between groundwater level data for the Gnangara region and CDFM was established within a control area under native vegetation, which was selected due to its distance from the influence of groundwater abstraction and other land use impacts such as pine plantations and urbanisation.

Once this relationship was established, the same techniques were then applied to over a hundred other hydrographs in the Gnangara area to identify land and water use impacts on groundwater levels in the region. Multiple regression analysis was then used to validate the results.

Because the accuracy of the rainfall data is very crucial in analysis, in this study SILO rainfall data were used to produce the CDFM rainfall graphs to assess the impact on groundwater level changes rather than the usual method of using rainfall zones and representative rainfall stations of these rainfall zones. SILO data and rainfall evaluation are discussed in detail in Chapter 3.

3 Rainfall Evaluation

3.1 Data evaluation

Rainfall is the main source of recharge to groundwater systems. Therefore, accuracy of the rainfall data is crucial in estimating groundwater recharge, and in determining any impact of human induced effects on groundwater level changes. Even though the constructed network of the rainfall stations is reasonable, the number of rainfall stations that have long term complete records is not sufficient for the Gnangara Groundwater Mound. Most stations have missing rainfall data for a period of time, in some cases for more than two months or even years. Since the rainfall intensity and magnitude changes from place to place due to different topographical and meteorological conditions, it is therefore necessary to have complete records and good network coverage to use the rainfall data for any hydrological evaluation.

In the previous report (Yesertener, 2002) some essential missing data were estimated using regression analysis or other classical methods to evaluate groundwater level changes, because SILO data was not commercially available when the report was written. SILO data drill is interpolated rainfall data (Appendix A). Comparison between the SILO data and the rainfall data of the nearby station within the study area showed SILO rainfall data to be well-correlated with the observed rainfall data (Figure 2).

The classical methodology, suggested in most hydrology text books to calculate missing rainfall data using regression analysis relies on data from surrounding rainfall stations and sometimes the correlation between the rainfall data is not high enough. In such cases, there is a strong possibility to underestimate or overestimate rainfall values. A comparison of rainfall data produced by regression analysis and from SILO can show significant differences (Figure 3).

Figure 3 shows that the previous values calculated using regression analysis to fill the missing data for Lake Pinjar rainfall station have been overestimated by Yesertener (2002), when compared to the SILO data. Even though the other rainfall zones shown in Figure 1 do not generally have such problem because the monitored rainfall periods were reasonably long and have a good correlation, all analysis have been redone using the SILO rainfall data to provide increased accuracy and consistency through the study area . Moreover, SILO rainfall data has network coverage at 5km intervals, which provides more representative rainfall data near the monitoring bores. The detailed information on the theory behind the SILO data is in Appendix A.

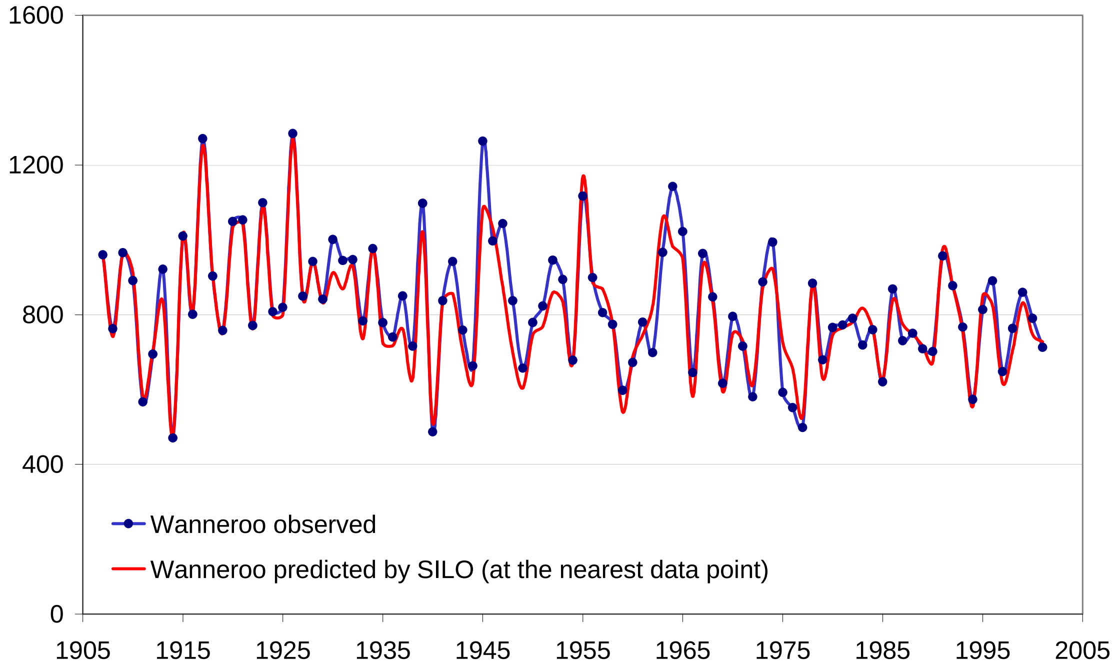

Figure 2 Comparison between Observed Rainfall and SILO Data

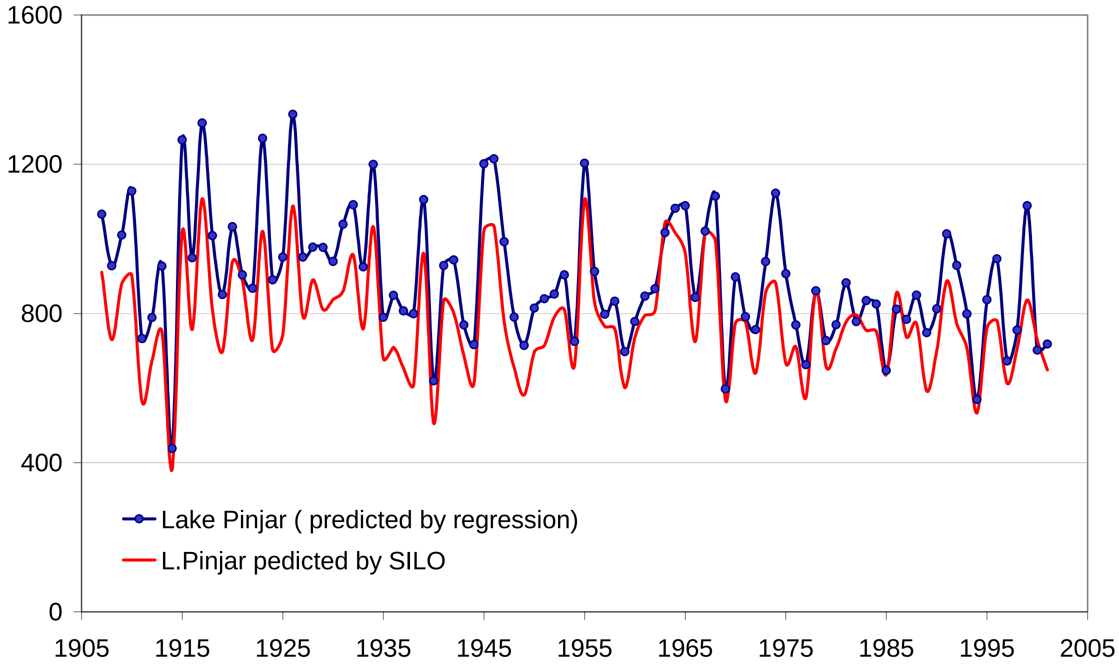

Figure 3 Comparison between regression analysis and SILO in predicting missing rainfall data when observed data is limited

3.2 Rainfall patterns

The rainfall pattern has been evaluated using the CDFM technique, which has determined a wet period between 1915 and 1968, and a dry period following 1969 (Figure 4). These periods are common in all CDFM graphs used in analysis (Yesertener, 2002). The dry period may be a natural phenomenon (reflecting the same pre-1915 condition) or it could represent an element of enhanced greenhouse effects.

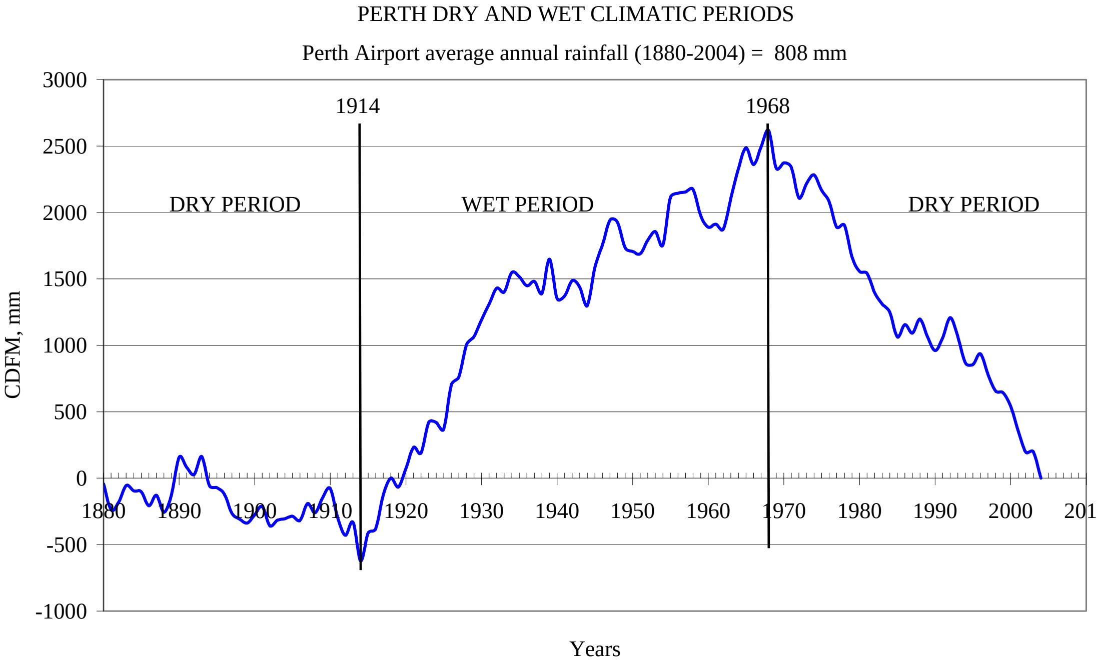

Figure 4 Perth dry and wet climatic periods shown by cumulative deviation from mean (CDFM) rainfall

The reduction in rainfall for Perth Airport meteorological station can be also seen in Figure 5 comparing the long term, wet period, and dry period annual mean rainfall values. The long term Perth Airport data is made up from Guildford PO (1877-1954). The site was 4km north of the original Airport site and recorded for 77 years and has a 10 years overlap with Airport site.

The rainfall stations and their long-term wet and dry periods mean precipitations are given in Table 1. As can be seen from Table 1, the Gnangara Groundwater Mound rainfall stations experienced a 10% to 16% reduction in annual rainfall in the 1969-2001 dry period when compared to the 1915-1968 wet period.

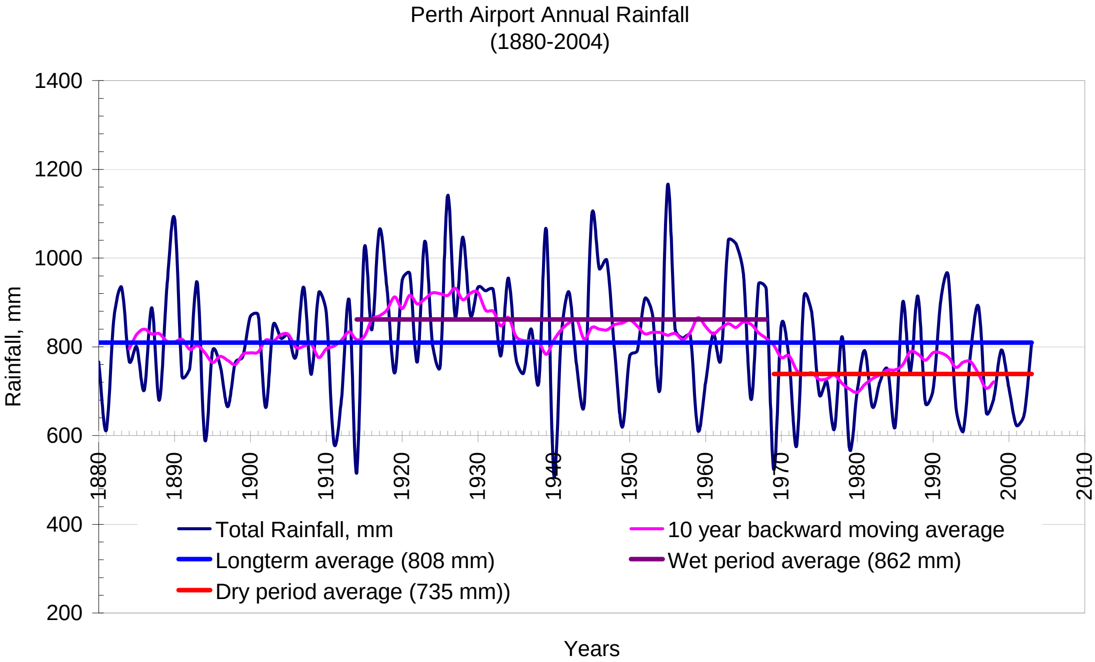

Figure 5 Perth Airport (9021) long term, wet period and dry period mean precipitation, mm

Table 1 Rainfall stations and their average annual rainfall

Rainfall Stations Name and Number	Long term average annual rainfall, mm (1907-2005)	Wet period average annual rainfall, mm (1915-1968)	Dry period average annual rainfall, mm (1969-2005)	Reduction in rainfall, %
Perth Airport (9021)	813	872	735	-15.7
Floreat Park (9056)	811	869	735	-15.4
Gingin (9018)	726	778	650	-16.5
Lake Pinjar (SILO)	777	822	721	-12.3
Muchea (9029)	762	809	698	-15.0
Pearce (9053)	724	772	656	-13.6
Two Rocks (9183)	739	776	693	-10.7
Yanchep (9045) (SILO)	768	812	718	-11.6
Wanneroo (9105)	822	882	740	-16.1
Gnangara forestry (9119)	789	833	729	-12.5

The distribution of the reduction in annual rainfall in the 1969 to 2005 dry period has been prepared using 45 SILO data points and is given in Figure 6. It shows that the crest of the Gnangara Groundwater Mound had about a 95 mm per annum reduction in rainfall. The maximum reduction of more than 100mm is in the south Gnangara Groundwater Mound and minimum reduction of about 85mm is in the Yanchep Caves area.

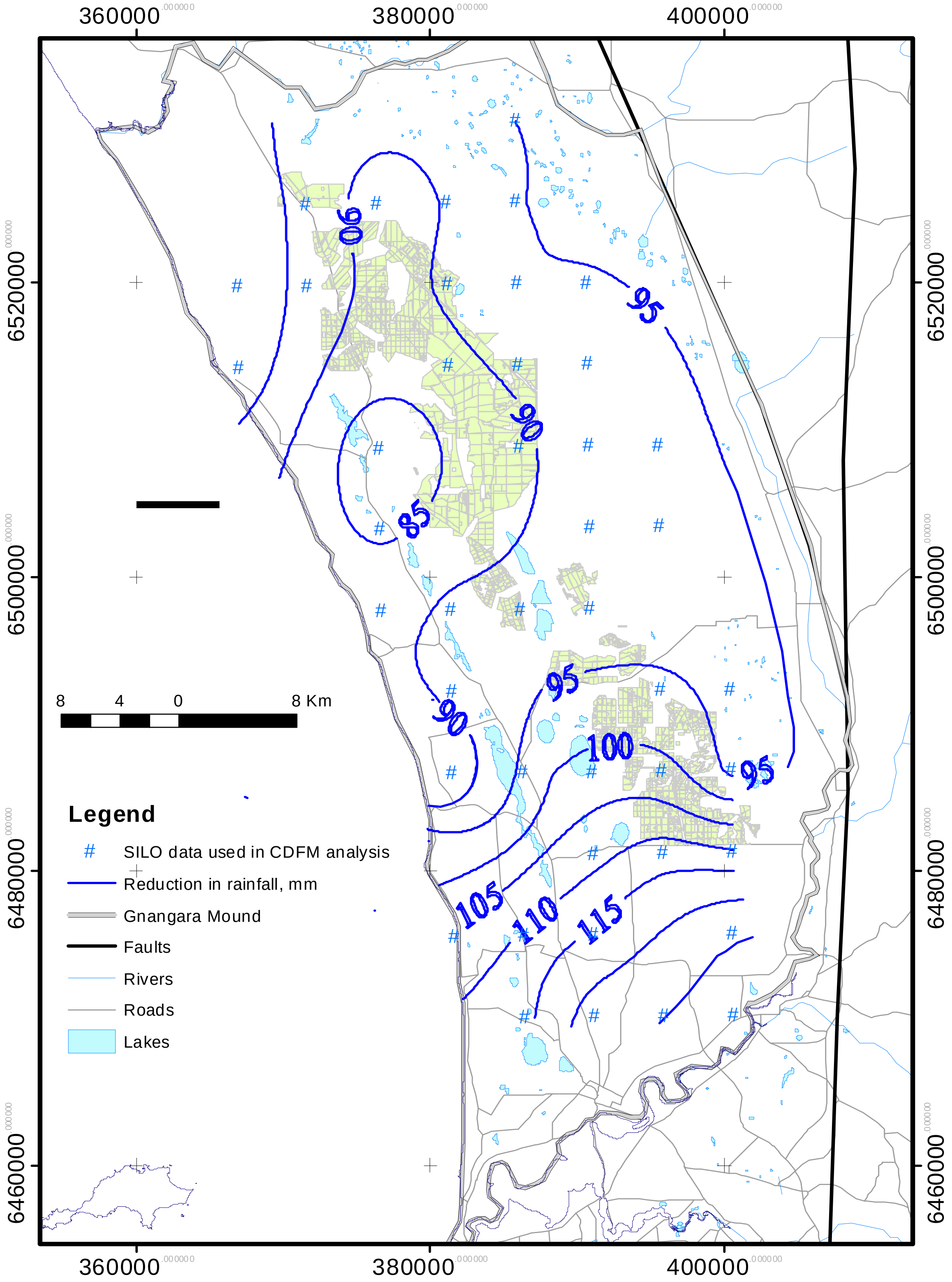

Figure 6 Distribution of the reduction in rainfall (mm) within the Gnangara Groundwater Mound

4 Groundwater Evaluation

The superficial aquifer is a complex, unconfined, multi-layered aquifer (Davidson, 1995). It is separated from the underlying shallow confined aquifer (Leederville aquifer) by a confining layer east and south of the CDFM boundary (shown in Figure 1 by the red dotted line).

Groundwater levels in the northern Pinjar area were influenced greatly by land use activities such as clearing prior to pine planting in the early 1980s. This had a significant positive effect on groundwater levels over the 1980s resulting in groundwater levels in 1988 in the Pinjar area being unnaturally high in comparison to other areas. Therefore, the year 1979 was selected as a baseline for an analysis of groundwater level changes over time, as overall, monitoring data from that year showed few anomalies or significant effects of land use impacts or abstraction on groundwater levels.

Measured groundwater level changes across the Gnangara Groundwater Mound were interpolated through a network of 242 monitoring bores over the period 1979-2005 (Appendix B) by a Kriging griding method using Surfer 8 (Figure 7). Figure 7 indicates that, over the long term, the most significant trend is a general reduction in minimum water levels over most of the Gnangara Groundwater Mound, with the largest reduction of six metres occurring at the north of Lake Pinjar, slightly west of the centre of the Mound. These areas of decline appear to be closely associated with the Pinjar and Wanneroo bore fields. The second area of groundwater decline, with falls to 2.8 metres, is in the north of the mound, an area with extensive pine plantations but no groundwater abstraction. The third area of the groundwater decline, with the falls to 3.75 metres is in Gwelup and is closely associated with the public and private abstractions. Groundwater levels in the Gwelup area have declined dramatically in the last 5 years (Figure 8).

Two zones with differing correlation of water level changes to CDFM rainfall plots can be identified in the superficial aquifer in the Gnangara Groundwater Mound. The north zone correlates with the long term CDFM rainfall (1907-2001) and south zone correlates with the short term (dry period) CDFM rainfall (1969-2005). Therefore, a separate set of CDFM graphs relative to the mean rainfall in the dry period (1969-2005) was prepared to analyse the groundwater hydrographs within the southern zone. The zones are separated by the red dotted line in Figure 1.

The boundary between the two zones coincides with the subcrop boundary of the Kardinya Shale and the Leederville aquifer; to the south the superficial aquifer rests on impermeable Kardinya Shale or lower permeability late Cretaceous formations (Davidson, 1995). This suggests that the northern zone has a larger reservoir capacity and larger discharge area than the southern part.

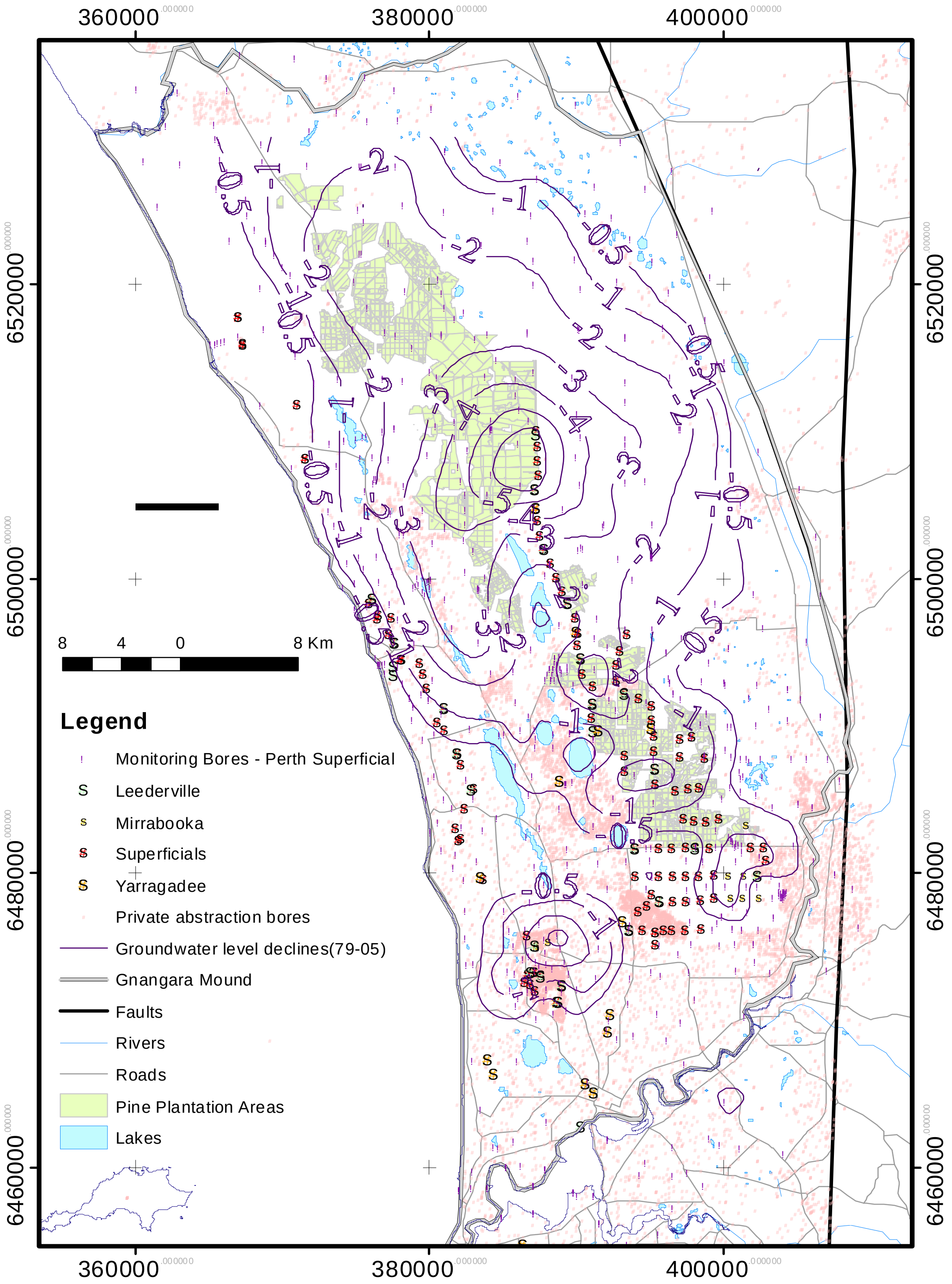

Figure 7 Groundwater level changes between 1979 and 2005 across the Gnangara Groundwater Mound

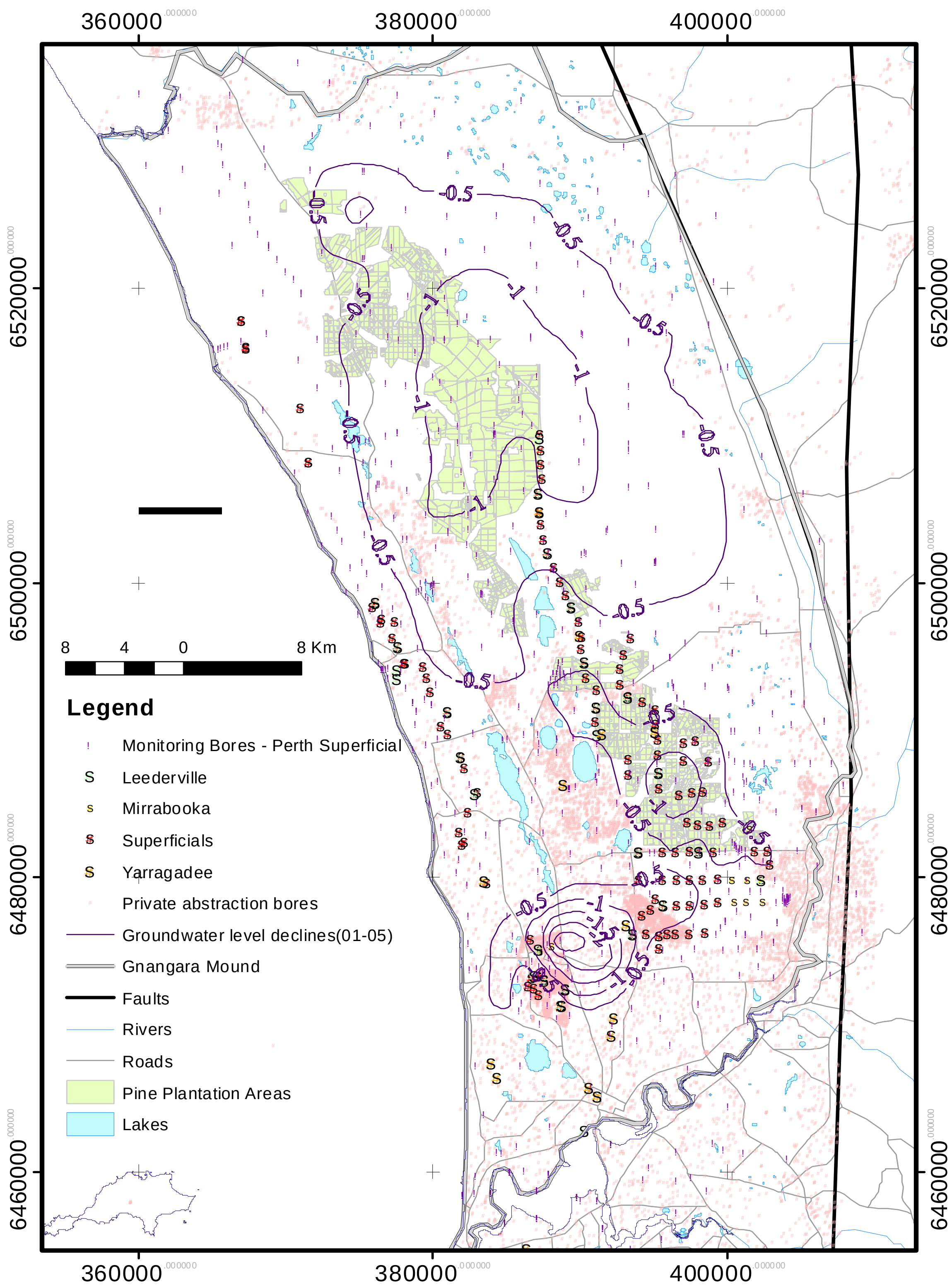

Figure 8 Groundwater level changes between 2001 and 2005 across the Gnangara Groundwater Mound

4.1 Overview of causative factors

The CDFM technique was applied to about 110 groundwater hydrographs of the superficial aquifer within the Gnangara Groundwater Mound of which about 25 are in the State Pine Forest. Rising trends seen in some hydrographs can be attributed to such factors as increased rainfall in some years, clearing, and bush fires and/or thinning of the pine trees. Of these, clearing was found to cause the most significant rise in groundwater levels due to its effect of increasing rainfall recharge. Declining trends in groundwater levels were also identified and these were attributed to abstraction from both shallow confined and unconfined aquifers, pine trees and/or decreased rainfall. Of these, reduced rainfall and groundwater abstraction (in some areas) were found to be the major causes of the declining trends.

There are three major factors, which affect groundwater levels. These are climate, land use, and groundwater abstraction. The climate factor relates to changes in rainfall. The land use factors are clearing, plantations, thinning, bush fires, market gardens, artificial maintenance of lakes and urbanisation. In the study area, pine plantations are the major land use and the effects are discussed in detail. Groundwater abstraction relates mainly to abstraction for public water supply, both from unconfined and confined aquifers.

The Gnangara hydrograph analysis results have been summarised in Appendix C and the analysed groundwater hydrographs have been given in Appendix D.

4.2 Impact of climate

The CDFM analysis shows that the major cause of groundwater level decline in the Gnangara Groundwater Mound is climate because of a dry rainfall period starting in 1969. Following 1969, total monthly rainfall is generally 15% less than the wet period average between 1914 and 1968, which caused declining groundwater levels as evidenced in Figures 9 and 10.

Groundwater level changes over the period 1979-2005 were analysed in an attempt to separate the effect of climate from the effects of abstraction and land use impacts on groundwater levels. Results for the Gnangara Groundwater Mound showed that over this period, maximum groundwater decline resulting from reduced rainfall occurred at the centre of the mound.

The Yeal Nature Reserve and the north eastern part of the Lake Pinjar area experienced the most significant declines in groundwater levels, with falls of up to four metres resulting from the reduced rainfall (Figure 11). Areas toward the coast and on the north eastern and eastern parts of the mound showed declines of 1 to 2 metres.

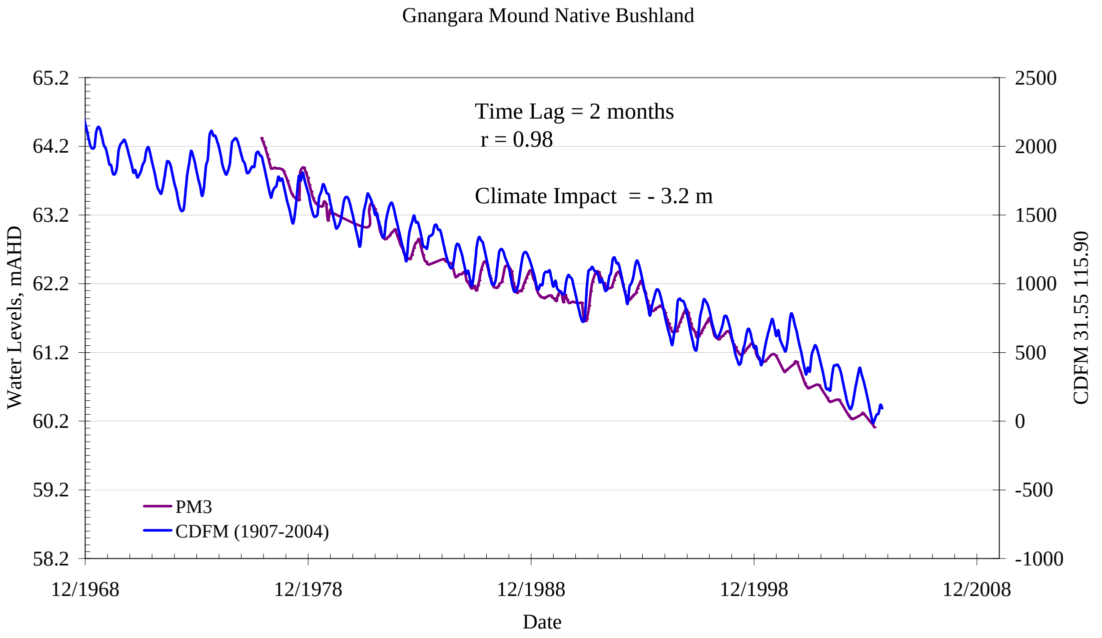

Figure 9 PM3 groundwater hydrograph evaluation using the CDFM graph of SILO rainfall data next to the bore

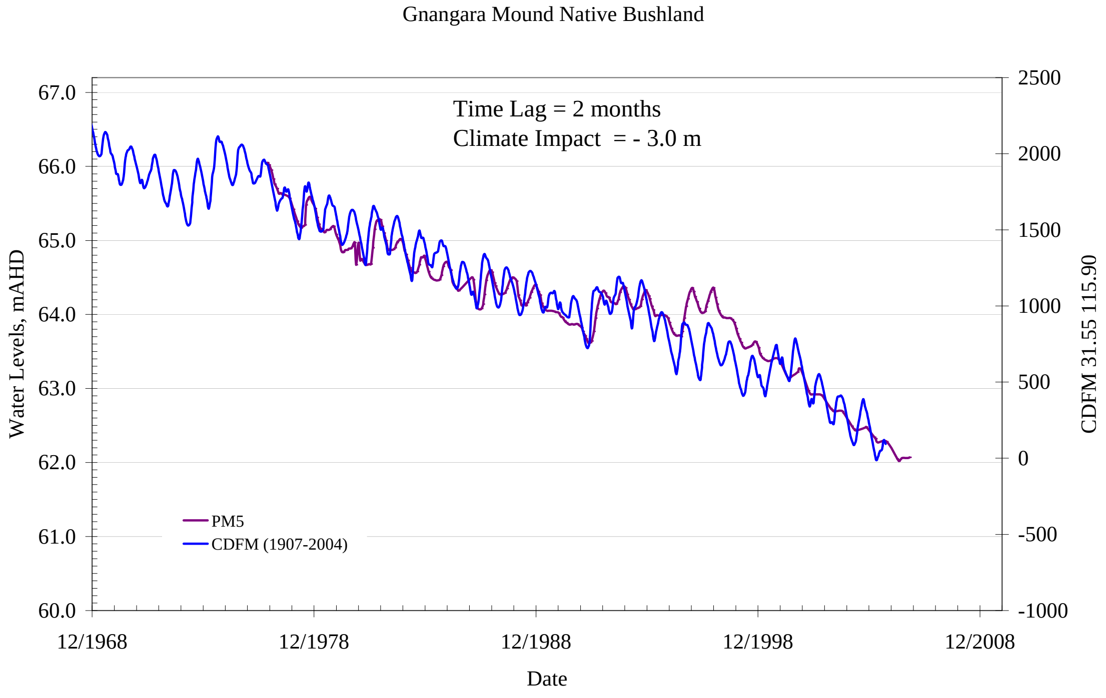

Figure 10 PM5 groundwater hydrograph evaluation using the CDFM graph of SILO rainfall data next to the bore

The impact of the reduced rainfall on the groundwater level decline decreases with proximity to the discharge zones of the mound where water levels are close to the surface. Due to the eastern edge of the mound is being controlled by the Gingin Scarp and along Ellen Brook groundwater levels are close to surface, the maximum groundwater decline resulting from reduced rainfall is shifted farther west.

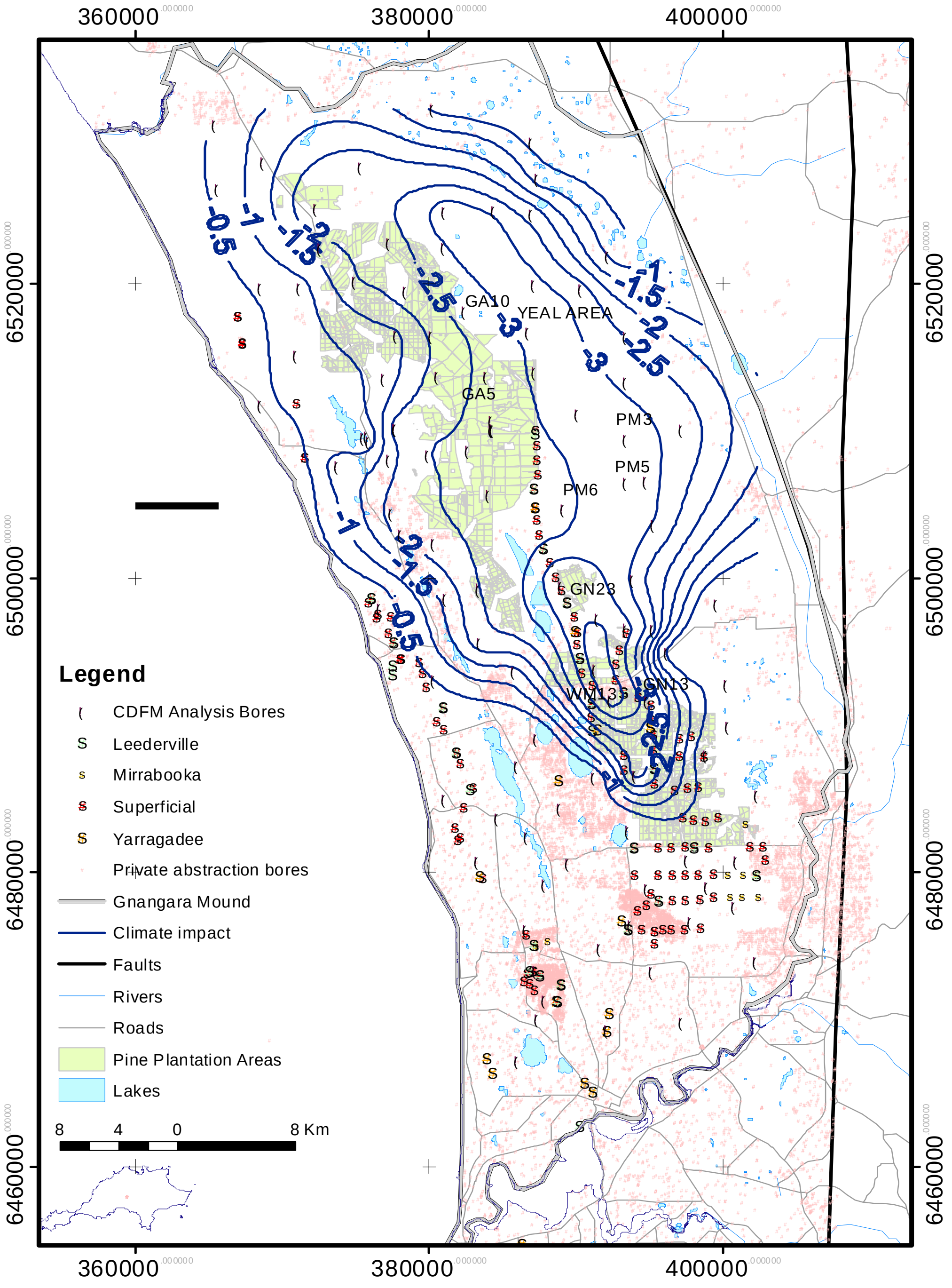

Figure 11 Predicted groundwater level decline due to reduced rainfall (1979–2005)

4.3 Impact of abstraction

The analysis of the superficial monitoring bore hydrographs shows that abstraction from the production bores in the superficial aquifer has significant impacts on the groundwater levels of the superficial aquifer within a 500 m radius of production bores, as shown by examples of groundwater response in Figure 12.

The magnitude of seasonal variation in groundwater levels at least doubled due to seasonal groundwater abstraction. The groundwater decline over ten years caused by abstraction from the superficial aquifer is about 1.75 m in bore GN13, which is only 400m away from the W60 production bore.

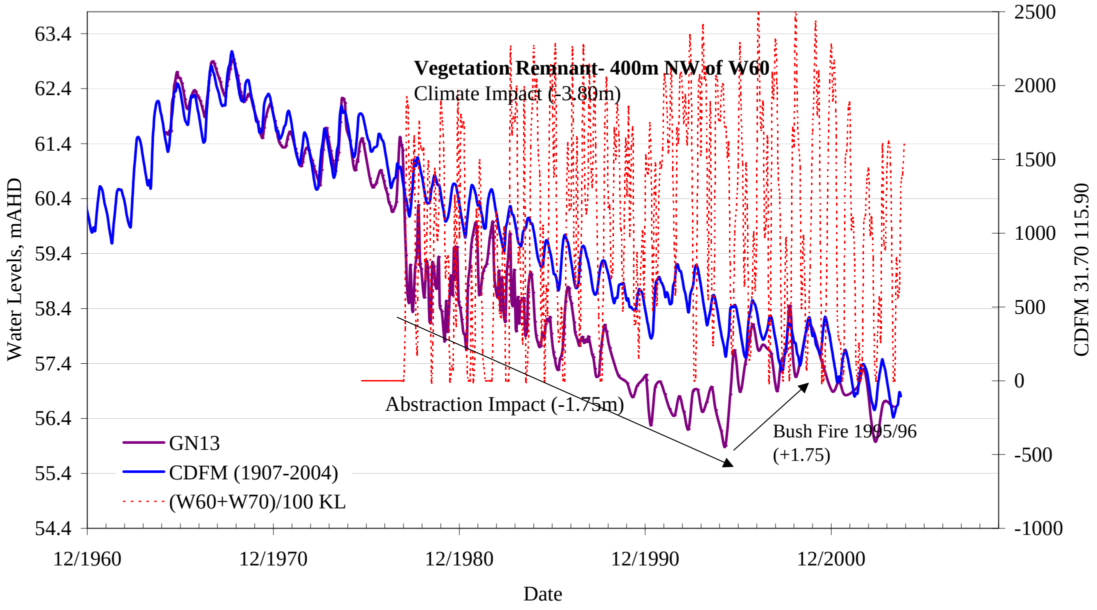

Figure 12 The impact of groundwater abstraction on groundwater levels; GN13

The analysis also shows that abstraction from the shallow confined aquifer has a significant impact on the groundwater levels of the superficial aquifer (Figure 13). The hydrograph of monitoring bore PM6 is an example showing the cumulative impact of abstraction from the confined aquifer on the superficial groundwater levels.

The groundwater level trend changed significantly, and the seasonal variation on the groundwater level disappeared almost within a month after the start of confined aquifer abstraction in March 1997 from bores P105 and P97. In this example it is not possible to separate the effects of pumping from P105 in the Leederville aquifer and pumping from P97 in the underlying Yarragadee aquifer, as abstraction from both commenced at the same time. However, the fact that the Leederville aquifer subcrops below the superficial aquifer, and the Yarragadee aquifer is confined below the South Perth Shale suggests that it is the effect of the Leederville abstraction that is apparent on the superficial aquifer.

The cumulative impact of abstraction on groundwater levels in the vicinity of PM6 has been calculated as about 1.8 m, approximately 44% of the total decline between 1979 and 2005. However, abstraction from the superficial aquifer had started in 1992 followed by confined aquifer abstraction in 1997. The cumulative impact of abstraction from both superficial and the Leederville aquifers over the period of abstraction from 1992 to 2005 is around 61% of the groundwater level decline in the vicinity of PM6 (Figure 13).

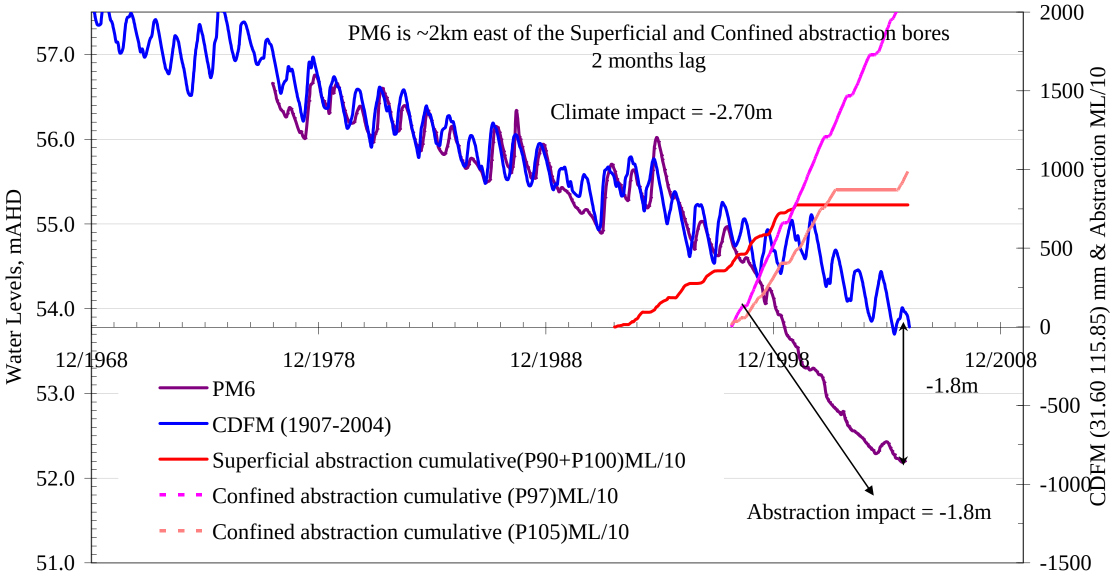

Figure 13 Cumulative effect of the abstraction on PM6

The cumulative impact of abstraction extends up to 6 km from the abstraction area (Figure 17). Abstraction impacts over the 1979-2005 period in the Gnangara Groundwater Mound were centred on the Pinjar Borefield, with declines of between 0.5 m and 2.4 m within a 5 km radius of the borefield. This impact is coincident with the increase in the abstraction from the Pinjar borefield in 1997. Declines due to abstraction in the area south west of Melaleuca Park were centred on W60 and W70 superficial abstraction bores, with declines of between 0.5 m and 2.0 m within a 3 to 4 km radius of the bores. Another area impacted due to abstraction is Mirrabooka Borefield, with declines of between 0.5 m and 1.5m.

The decline in the area south west is centred on the Gwelup Borefield, with declines of between 0.5 m and 3 m, apparently resulting from both public and private abstraction (Figure 17).

Declines in the areas west and north-west of the mound such as Joondalup, Jandabup, Mariginiup, Nowergup, Quinns, Carabooda, tended to be more localised and in the order 0.5 m to 3.4 m, apparently resulting from major private abstraction.

4.4 Impact of pine plantations

The analysis of the hydrographs selected from the pine plantation area shows that the impact on the groundwater levels from pine plantations limited to high, and is dependent on the pine plantation density. In some areas the hydrograph behaviour before and after planting is very similar, indicating that the pine trees have limited impact on reducing the recharge to the superficial aquifer (Figure 14), and show similar effects to the native vegetation. As seen from Figure 14, groundwater levels responded positively to the clearing of the land and rose by about 1.45m. This observed groundwater level stayed parallel to CDFM rainfall till 2001, even though pines were maturing in these years. From year 2001 onwards, there was an additional reduction in rainfall, which shows clearly as a change in trend in Figure 14. Following this additional reduction in rainfall, pines and or dense native vegetation close to GA10 also impacted the groundwater levels causing declines of 0.5m.

Dense pine plantation areas have moderate to high impacts on declining groundwater levels. As seen from Figure 15, calculated groundwater level decline resulting from pine trees in the vicinity of GA5 bore, which is remote from abstraction, is around 3.3 m. The groundwater level decline due to reduced rainfall in the same area is 2.35 m over the same period.

Clearing before planting, and bush fires have resulted in additional recharge and a rising groundwater level in the following 3 to 7 years and 3 to 5 years, respectively depending on the surface area covered (Figure 14 and 15).

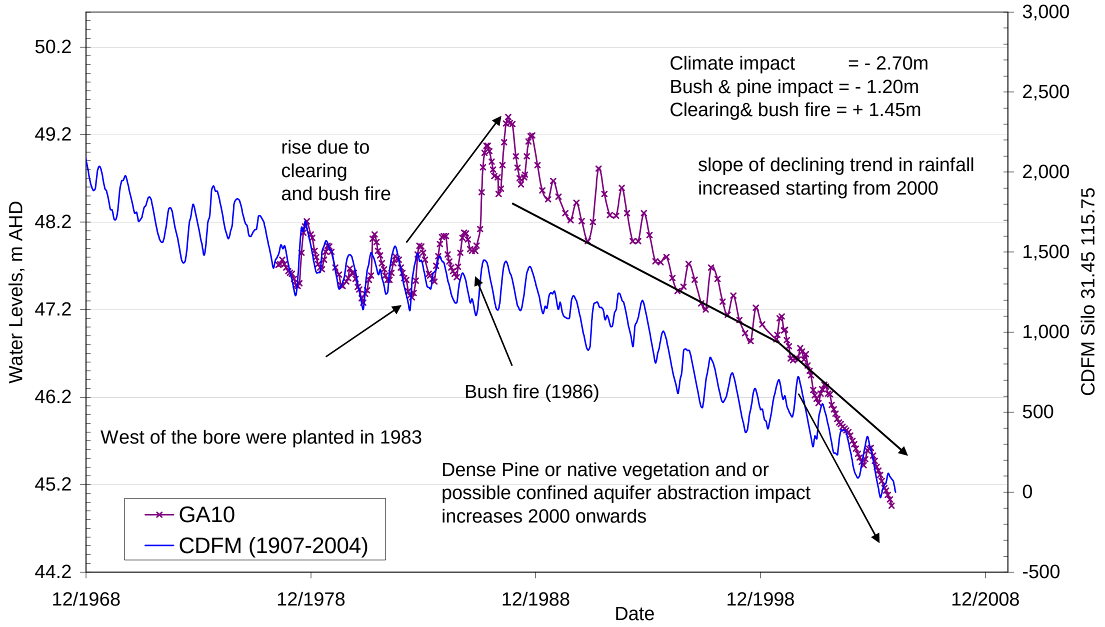

Figure 14 Comparison of the groundwater fluctuations before and after pine planting

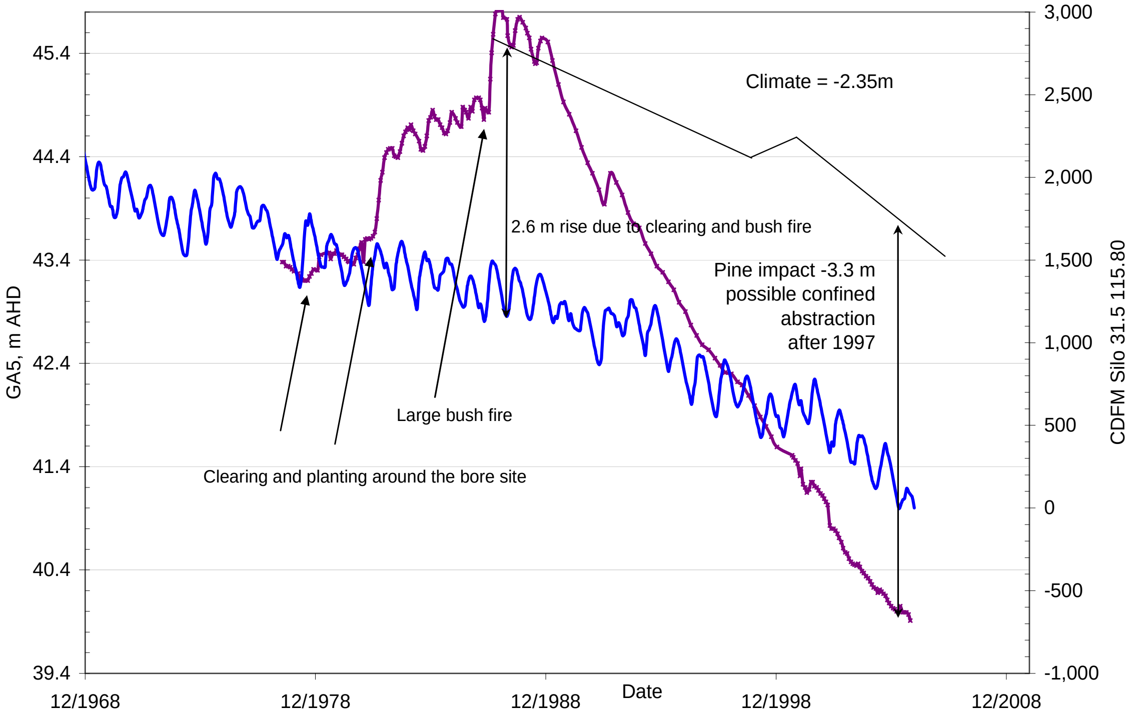

Figure 15 Groundwater level rise resulting from clearing and bush fire, followed by decline resulting from reduced rainfall and dense pine trees

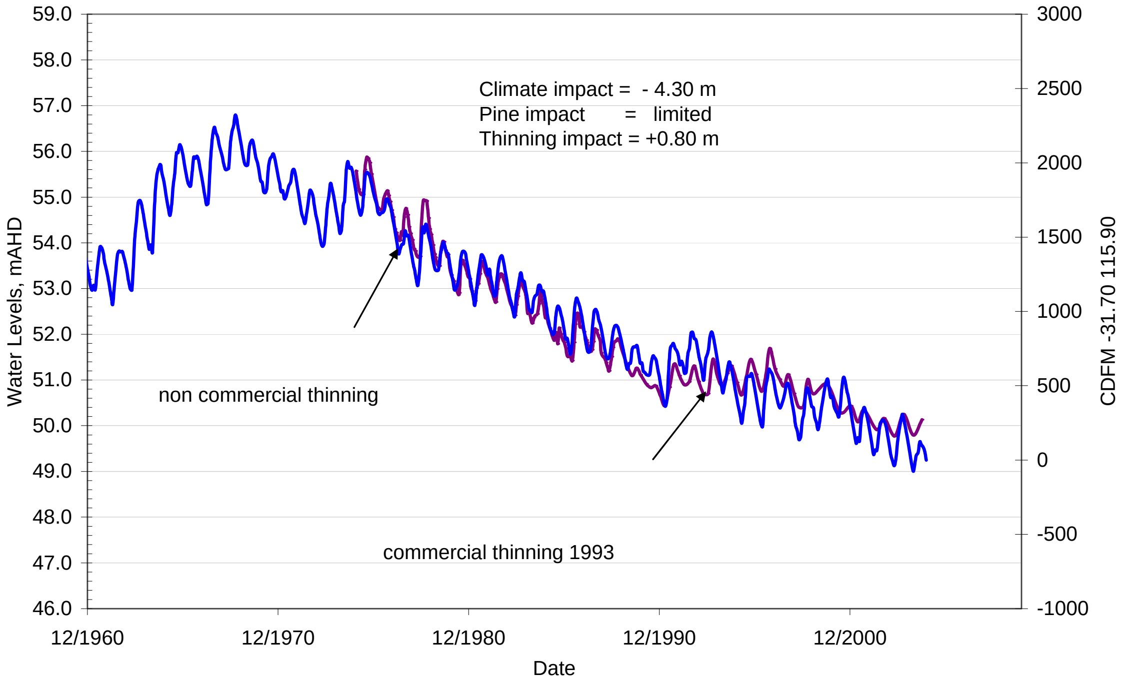

Figure 16 Impact of thinning on groundwater levels in the vicinity of monitoring bore WM13

The positive impacts on groundwater levels caused by clearing are over 2 m in some areas. Similarly groundwater level rise caused by bush fires is up to 2.4 m around GN13 and GN20. Thinning within plantation areas also has a short term rising impact. Groundwater levels in WM13 rose 0.9 m in the 1 to 3 years following thinning, as seen in Figure 16. Impacts vary depending on the degree of thinning.

Groundwater declines due to evapo-transpiration and interception losses resulting from pine trees of about 3.5 m over the 1979-2005 period were apparent in some areas north and east of Yanchep where pines were particularly dense (Figure 17).

This does not include the positive effect on groundwater levels due to clearing/bush fires/thinning that may have occurred prior to and during the plantation operations. Clearing and bush fires have significant positive effects on groundwater levels and often override the negative effects on groundwater levels of abstraction and evapotranspiration from the pine trees.

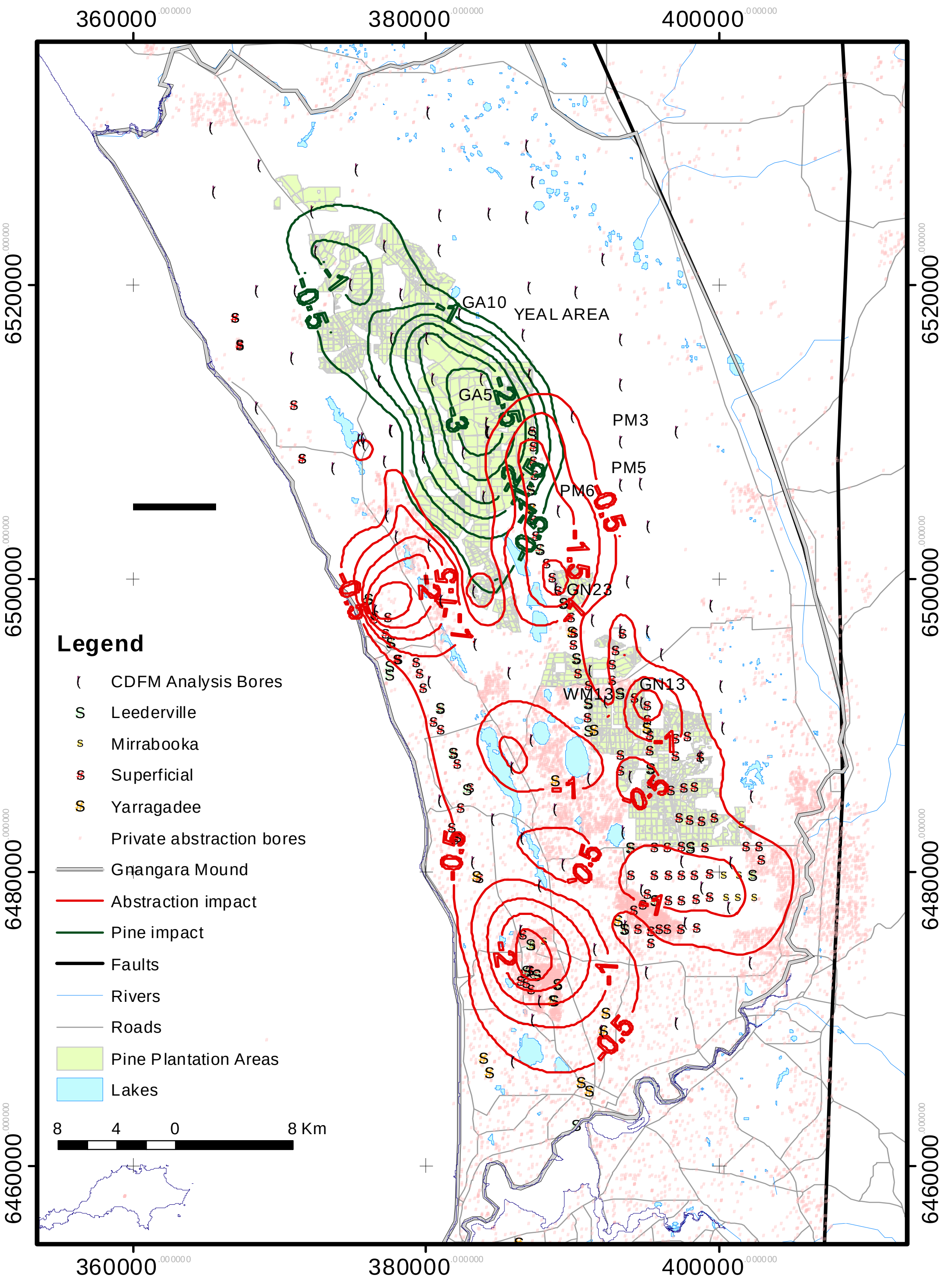

Figure 17 Predicted impact of abstraction and pine trees in the Gnangara Groundwater Mound

5 Validation Study

The groundwater level data for the region were related to the cumulative deviation from the mean rainfall (CDFM) within a pilot area selected distant from the overriding influence of and land and groundwater use. The CDFM curve and groundwater hydrograph were matched by eye fitting to enable identification of land and water uses impact on groundwater levels. To minimise the error resulting from eye fitting, multiple regression analysis was used to validate the results.

The simplest regression equation to explain trends in groundwater levels and differentiate between atypical rainfall events and time trends is:

$$Y = k_o + k_1 * CDFM_{t-L} + k_2 * t \qquad (1)$$

In Equation (1) Y is the depth to groundwater below the ground level, t is the months since observations commenced, L is the length of time lag in months between rainfall and its impact on groundwater, and k_o, k_1 and k_2 are the parameters to be estimated by regression analysis. Parameter k_o is the initial depth to groundwater in the observation period, k_1 represents the impact of above or below mean rainfall on the groundwater level, and k_2 is the trend rate of the groundwater rise or decline over the time period.

The technique is appropriate for cases where there is no major change in land and water use during the period of analysis. If such a land and water use change occurs, there are two main types of shifts that affect the pattern of groundwater levels: (i) there may be a sudden change, which shifts all groundwater levels, or (ii) there may be a change in the underlying rate of groundwater rise or decline. To include these possible impacts into the model, a dummy variable D_t is introduced, which takes a zero value in periods of no land and water use change, otherwise it takes the value 1 when the land and water use changes, and a variable S_t , which is the cumulative sum of D_t up to time. The equation then is:

$$Y = k_o + k_1 * CDFM_{t-L} + k_2 * t + k_3 * D_t + k_4 * S_t \qquad (2)$$

In Equation (2) the fourth term represents a shift in the groundwater level during time periods when the change in land use is in place (with the parameter k_3 representing the extent of the shift). The fifth term represents a change in the time trend of water level caused by the land and water use (with k_4 representing the change of slope). Depending on the nature of the land and water use changes either or both of these terms may be included in the equation for statistical estimation.

The multiple regression analysis is applied to several groundwater hydrographs, which appear to show different land and water use changes. Figure 18 shows the result of the multiple regression analysis applied to the PM6 monitoring bore data, which indicates abstraction impact during the period of analysis. The cumulative impact of abstraction on groundwater decline in the vicinity of PM6 has been calculated as about 64.5% between 1/1992 and 9/2005. PM6 is generally representative of groundwater level declines occurring due to abstraction in the Pinjar area.

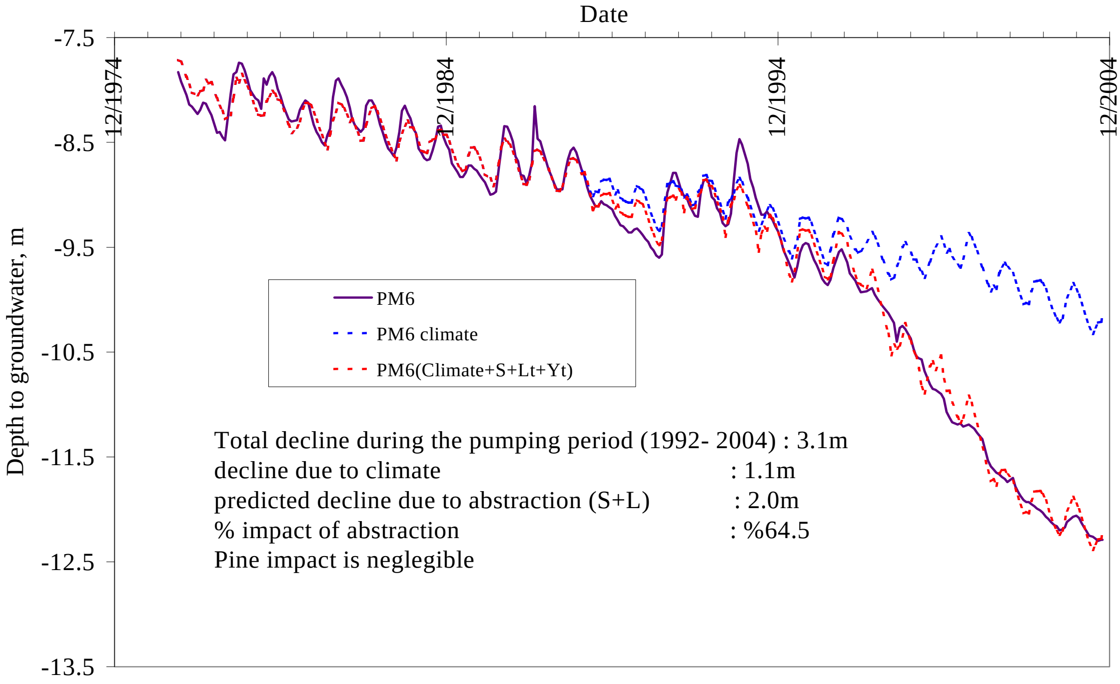

Figure 18 Quantitative determinations of the effects of abstraction on groundwater levels at PM6 using multiple regression analysis.

Another example showing the result of multiple regression analysis applied to GA10 monitoring data is given in Figure 19. The cumulative impact of reduced rainfall, clearing before planting and bush fire have been calculated to be about 2.75 m, 0.7 m and 1.0 m respectively, during the same period of 1979 to 2005. The impact calculated using the model coincides with the results from the hydrograph analysis previously presented.

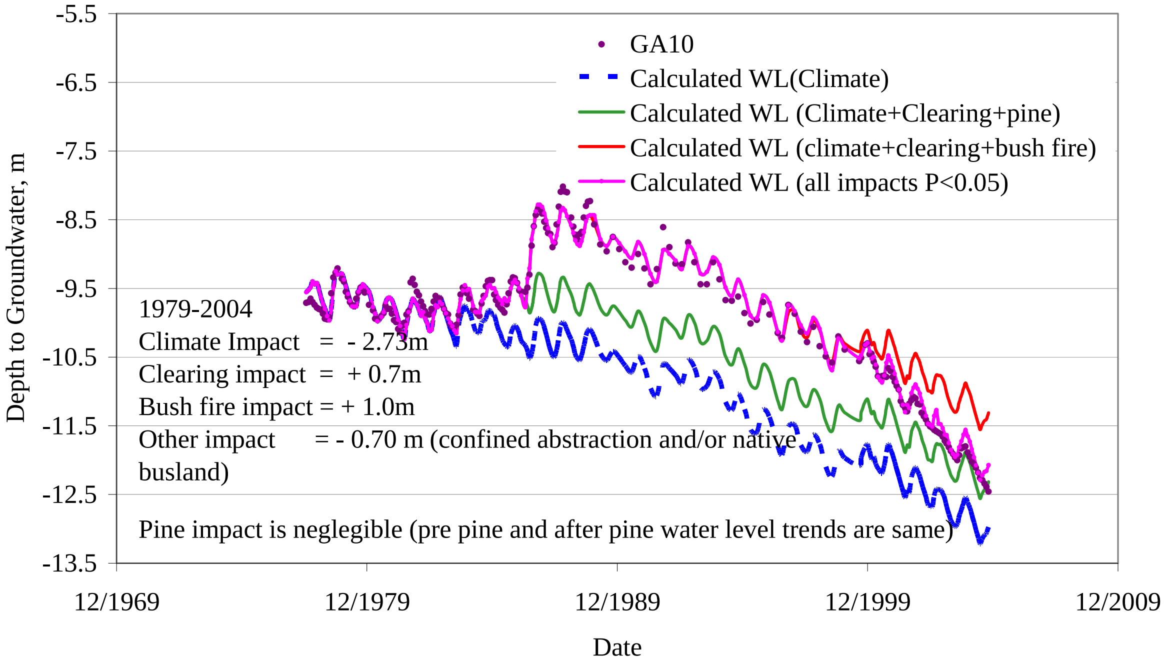

Figure 19 Quantitative determination of the effects of climate, clearing and bush fire on groundwater levels at GA10.

6 Discussion

The availability and accuracy of the rainfall data are crucial in this technique. The long-term rainfall records within the area of interest are not sufficient; therefore SILO data drill, which is derived from actual recorded data provided by the Bureau of Meteorology and computed by splining and Kriging techniques, has been used to increase the accuracy of results from the CDFM technique.

Groundwater levels in the northern Pinjar area were influenced significantly by land use activities such as clearing prior to pine planting in the early 1980s. This had a notable rising effect up to 2 m on groundwater levels over the 1980s, and groundwater levels in 1988 in that area were unnaturally high in comparison to other areas. Difference plots created as part of environmental compliance reporting for Gnangara, using 1988 as the baseline, tend to show large declines in this area. Therefore, any year before 1980, preferably 1979 would be more appropriate to use as a baseline year if an ‘average’ groundwater condition is required for benchmarking purposes as, overall, monitoring data from that year showed few anomalies or significant effects of land use impacts or abstraction on groundwater levels.

The results from applying the CDFM technique are consistent across about 200 hydrographs evaluated by Yesertener (2002) and 110 bores evaluated in this report.

7 Conclusions

This study quantifies the relative magnitude of the effects on groundwater levels resulting from changes in rainfall, land use and groundwater abstraction. It can be concluded that:

- Reduced rainfall is the major impact on reduction of the groundwater levels on the Gnangara Groundwater Mound since 1969 as much as 4 m.
- Abstraction impacts over the 1979-2005 period in the Gnangara Groundwater Mound were centred on the Pinjar, Wanneroo, Gwelup, and Mirrabooka Borefields with declines of maximum 2.4, 2.0, 3.0 and 1.5 m, respectively, within 6 km of the borefields.
- The Gnangara pine plantation has resulted in groundwater level declines in the order of 3.5 m over the 1979-2005 period in some areas north and east of Yanchep where pines were particularly dense.

The following land use changes have contributed to short term and localized groundwater level rise:

- Clearing before planting pines has caused a rise of 1 to 2 m rise in groundwater for a 3-7 year period after clearing.
- Bush fires have caused groundwater levels to rise about 0.5 to 2.4 m for a period of 2-4 years until vegetation reestablishes.
- Thinning of pines causes groundwater levels to rise locally about 0.2-0.9 m for a period of 1-3 years, depending on the degree of thinning.

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Appendix A – The SILO data drill

The data drill is a facility for extracting data from an archive of interpolated rainfall and climate surfaces maintained by the Queensland Department of Natural Resources and Mines. These surfaces were constructed by spatially interpolating observational data collected by the Australian Bureau of Meteorology. The Bureau maintains an archive of observational rainfall and climate records which dates back to the mid-late 1800's. Unfortunately, much of the available data recorded before 1957 are not in digital format. For this reason, a different interpolation algorithm produces the climate surfaces prior to 1957, but the rainfall surfaces commence in 1890.

The number and location of data points used to construct the interpolated surfaces varies in time. The number of stations reporting monthly rainfall data are shown in Figure 20, and the number reporting climate data are presented in Figure 21. As stations commence or cease reporting data, the location of available data points varies and a single figure indicating station locations is not appropriate. However the spatial distribution of stations is indicative of the location of stations used to construct the interpolated climate surfaces.

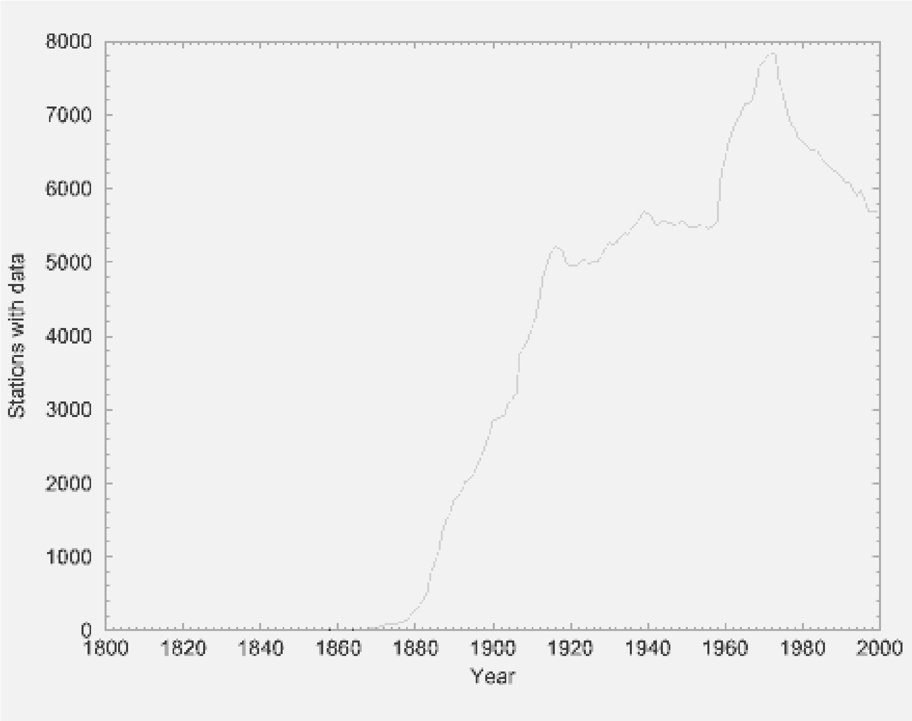

Figure 20. Number of stations reporting rainfall data, as at April 2000.

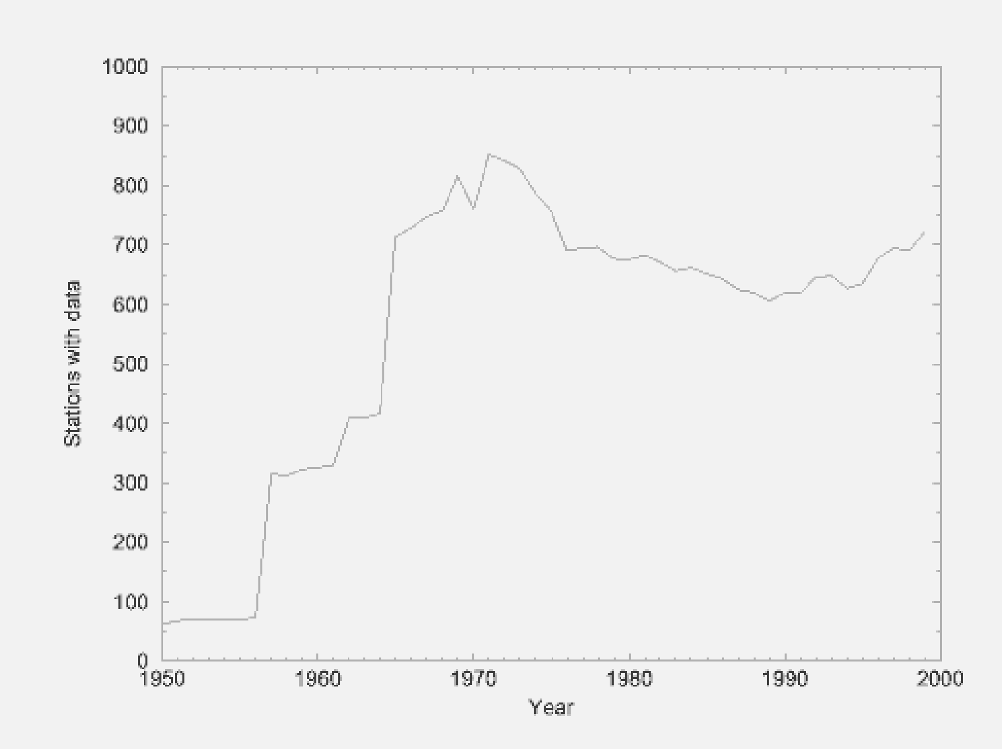

Figure 21. Number of stations reporting climate data, as at April 2000.

1. Interpolation Procedure

The interpolated surfaces were computed on a regular 0.05 degree grid extending from 10^o S to 44^o S, and 112^o E to 154^o E. All surfaces are available on a daily timestep, however monthly rainfall and long term mean surfaces for both rainfall and climate elements are available upon request. In the following sections, we provide details regarding the interpolation of the rainfall and climate variables.

1.1 Climate variables

All climate variables (except mean sea level pressure) were interpolated using a trivariate thin plate smoothing spline (Wahba and Wendelberger, 1990) with latitude, longitude and elevation as independent variables. Elevation was expressed in kilometres to minimise the validated root mean square interpolation error (Hutchinson, 1995). Latitude and longitude were in units of degrees. All surfaces were fitted by minimising the Generalised Cross Validation (GCV) error with the constraint of first order smoothness imposed.

The only exception to the above is mean sea level pressure (MSLP). The conversion from station pressure to MSLP explicitly removes the elevation component and can thus be omitted from the interpolation. Consequently MSLP was interpolated using a bivariate spline with latitude and longitude as independent variables.

A two pass interpolation algorithm was used to detect and remove erroneous data. In the first pass, the observational data were interpolated and the residual associated with each data point was computed. If any given residual exceeded a fixed threshold, the corresponding datum was flagged as a possible outlier. The maximum number of data points that could be rejected was capped at 5%. Those data points which were not flagged as outliers were reinterpolated in a second pass, to produce the final surface. The thresholds used for outlier detection are shown in Table 2.

Table 2. Threshold values used for identifying outliers.

Vapour Pressure	3.0 hPa
Pressure	3.5 hPa
Maximum Temperature	1.4 C
Minimum Temperature	1.6 C
% E.T. Radiation	16.0 %
Evaporation	2.7 mm
Relative Humidity	10 %
Vapour Pressure Deficit	1.5 hPa

1.2 Rainfall

Daily rainfall is intrinsically difficult to interpolate due its high variability, short range spatial correlation and the variety of mechanisms that can result in precipitation. However as the accumulation period increases, one can obtain improved interpolation accuracy as the day-to-day variability is overcome by topographic effects which influence long term rainfall patterns. This fact has led to the widespread use of normalisation techniques which attempt to remove the topographic component of rainfall (by subtracting the mean rainfall) and reducing the data variance (by standardising). The normalised variable can then be regarded as an anomaly, representing departures from the mean rainfall pattern due to broad scale synoptic features which can be reliably interpolated.

The distribution of rainfall is positively skewed for time steps ranging from hourly to monthly. If the observational data are raised to an appropriate power, one can obtain a distribution function that is approximately normal. Maximum likelihood has been used to determine those parameters (power, mean and variance) which define a truncated normal distribution for which it is most likely that the observational data could have arisen.

A truncated distribution is used as small rainfall mounds are unreliably reported, and the computed distribution must be positive semi-definite with respect to rainfall. The truncation level is currently set to 0.7mm.

A maximum likelihood algorithm was used to compute the power, mean and variance required to normalise monthly rainfall data at each station. These parameters were only computed for those stations having at least 40 years of monthly rainfall data. The resulting values were then interpolated using a trivariate smoothing spline. Monthly rainfall data were interpolated as follows. Firstly, the observational data were transformed to a variable which is approximately normal by raising each data value to the power appropriate for the given location. The transformed variable was then normalised using the mean and variance appropriate to that datum's location. The resulting anomaly was interpolated using Ordinary Kriging with zero nuggets and a variable range. The nugget was set to zero to enforce exact interpolation, and under these conditions the sill can be set arbitrarily. The range was computed locally and set to (1.5 times) the average distance to the neighbouring data points. Those data points which were within a 75 km radius of the target location were included in the interpolation, but this radius may have been increased to ensure at least 25 data points were utilised. After the transformed variable was interpolated, the normalisation and transformation were reversed to yield interpolated monthly rainfall.

Interpolated daily rainfall surfaces were derived from monthly surfaces by partitioning the interpolated monthly rainfall on to individual days. At each grid cell, the distribution of rainfall throughout the month was computed by interpolating the daily rainfall data directly. The monthly rainfall at each grid cell was then partitioned on to individual days according to the computed daily distribution of rainfall. The main advantage of this technique, as compared to interpolating the daily data directly, is (1) the magnitude (as opposed to the day-to-day distribution) of the interpolated estimates have been computed using monthly data, which are of higher quality than daily data, and (2) accumulated daily rainfall values could be utilised as they could be incorporated into the monthly total. If daily data were being interpolated directly, the accumated values could not have been used. (Naturally these values could not be used in the daily interpolations used to determine the daily distribution. However the interpolated daily values were only used for partitioning the interpolated monthly value, and were not used for computing the actual magnitude of the daily rainfall.)

With the exception of those days in the current month, all daily rainfall surfaces have been derived from monthly data using the algorithm described above. Daily rainfall surfaces for days within the current month are generated by Kriging the available daily data. These surfaces are continually reinterpolated throughout the month as the near real-time datasets are updated with additional and error-checked data. At the end of the month, or typically a few days thereafter, the accumulated monthly rainfall becomes available. The monthly rainfall is then spatially interpolated and used to derive daily rainfall surfaces which supersede those surfaces computed using the daily data.

1.3 Error Analysis

A comprehensive analysis of the accuracy of the interpolated surfaces has been undertaken on a temporal and spatial basis. These results, and a detailed discussion of the psychrometric equations used for computing climate variables such as vapour pressure, mean sea level pressure, relative humidity etc. are described in Jeffrey *et al.*, 2001.

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Appendix B – Gnangara monitoring bores

No	Bore Name	Datum mAHD	Easting	Northing	WL_{min} (79/80) mAHD	WL_{min} (2001) mAHD	WL_{min} (2005) mAHD	WL Changes (m) (1979-2001)	WL Changes (m) (1979-2005)	WL Changes (m) (2001-2005)
1	1072	7.790	395530	6455180	5.598	5.400	5.590	-0.20	-0.01	0.190
2	1081	9.846	393500	6454640	6.903	6.756	7.176	-0.15	0.27	0.420
3	125	24.463	393840	6468775	20.853	20.713	20.953	-0.14	0.10	0.240
4	142	3.112	384321	6461154		0.172	0.122	0.17	0.12	-0.050
5	144B	13.549	398870	6461790	10.930	11.859	11.292	0.93	0.36	-0.567
6	149	13.757	397560	6459440	10.137	9.827	9.857	-0.31	-0.28	0.030
7	1606	7.460	396480	6457090	4.920	4.460	4.670	-0.46	-0.25	0.210
8	2069	24.951	397000	6469650	21.714	20.651	21.270	-1.06	-0.44	0.619
9	2288	18.267	399960	6464270	13.807	12.317	12.457	-1.49	-1.35	0.140
10	2436	10.590	398550	6458540	8.260	8.180	8.350	-0.08	0.09	0.170
11	2729	13.947	396465	6459185	8.079	7.877	8.017	-0.20	-0.06	0.140
12	3020	12.155	396430	6461170	8.915	8.725	8.555	-0.19	-0.36	-0.170
13	459	29.581	387733	6479000	26.131	26.381	26.130	0.25	0.00	-0.251
14	637	26.540	393560	6470943	22.665	23.310	23.500	0.65	0.84	0.190
15	643	22.931	392170	6469770	20.381	20.221	20.281	-0.16	-0.10	0.060
16	649	30.550	395035	6473098	27.610	27.640	27.850	0.03	0.24	0.210
17	675B	17.791	401076	6461104	15.751	15.441	15.531	-0.31	-0.22	0.090
18	678	8.410	397200	6466800	6.700	6.820	6.870	0.12	0.17	0.050
19	7593	7.177	385017	6477134	3.570	3.167	2.677	-0.40	-0.89	-0.490
20	7597	3.193	382409	6475373	1.263	1.313	1.153	0.05	-0.11	-0.160
21	793	4.140	382462	6473511	0.763	1.020	0.880	0.26	0.12	-0.140
22	7970	24.972	395420	6470230	22.712	23.142	23.332	0.43	0.62	0.190
23	821	25.660	398000	6471200	22.500	22.210	22.670	-0.29	0.17	0.460
24	8279	4.358	386165	6459898	0.668	0.758	0.898	0.09	0.23	0.140

No	**Bore Name**	**Datum mAHD**	**Easting**	**Northing**	**WL_{min} (79/80) mAHD**	**WL_{min} (2001) mAHD**	**WL_{min} (2005) mAHD**	**WL Changes (m) (1979-2001)**	**WL Changes (m) (1979-2005)**	**WL Changes (m) (2001-2005)**
25	8281	21.374	385796	6487089	18.274	17.664	17.774	-0.61	-0.50	0.110
26	8282	4.359	385640	6428000	1.259	1.129	1.129	-0.13	-0.13	0.000
27	8283	7.723	388050	6452050	5.470	6.153	6.413	0.68	0.94	0.260
28	8284	28.595	393780	6446490	25.902	25.345	25.045	-0.56	-0.86	-0.300
29	8285	27.016	399505	6448325	23.266	24.576	23.716	1.31	0.45	-0.860
30	8525	13.250	385970	6471330	4.150	3.860	3.863	-0.29	-0.29	0.003
31	BCM	50.252	375470	6524022	34.130	31.902	31.262	-2.23	-2.87	-0.640
32	BD2(TR2)	25.850	368700	6516760	1.100	1.110	0.990	0.01	-0.11	-0.120
33	GA1	30.490	370868	6514980	1.670	1.650	1.470	-0.02	-0.20	-0.180
34	GA10	57.421	382335	6517936	47.470	46.131	44.661	-1.34	-2.81	-1.470
35	GA11	30.635	368456	6519560	1.077	1.105	0.965	0.03	-0.11	-0.140
36	GA12	15.172	371138	6519531	5.580	4.912	4.632	-0.67	-0.95	-0.280
37	GA13	58.652	374840	6519990	28.550	26.152	25.762	-2.40	-2.79	-0.390
38	GA14	70.976	378325	6519339	38.190	36.236	35.356	-1.95	-2.83	-0.880
39	GA15	54.149	380550	6520142	44.980	43.359	42.369	-1.62	-2.61	-0.990
40	GA16	52.560	366325	6522785	1.700	1.780	1.520	0.08	-0.18	-0.260
41	GA17	47.696	372420	6522243	22.260	20.106	19.656	-2.15	-2.60	-0.450
42	GA18	57.058	377150	6522612	36.350	34.178	33.568	-2.17	-2.78	-0.610
43	GA2	47.191	373765	6513394	6.261	5.791	5.381	-0.47	-0.88	-0.410
44	GA21	43.785	372250	6524970	27.220	25.765	25.285	-1.46	-1.94	-0.480
45	GA22	55.369	375055	6524900	34.840	32.969	32.189	-1.87	-2.65	-0.780
46	GA23	50.512	378145	6525192	42.640	40.932	40.412	-1.71	-2.23	-0.520
47	GA24	44.409	365444	6526298	1.290	1.289	1.099	0.00	-0.19	-0.190
48	GA25	25.863	363000	6527960	1.060	1.083	0.893	0.02	-0.17	-0.190
49	GA26	49.424	371668	6527925	26.490	25.524	25.084	-0.97	-1.41	-0.440
50	GA27	26.208	362850	6532853	2.108	2.148	1.768	0.04	-0.34	-0.380
51	GA28	32.170	360543	6528187	0.050	0.130	0.060	0.08	0.01	-0.070
52	GA29	35.645	365358	6530660	2.560	2.515	2.065	-0.05	-0.50	-0.450
53	GA3	58.260	376753	6513433	24.144	22.990	22.090	-1.15	-2.05	-0.900

No	**Bore Name**	**Datum mAHD**	**Easting**	**Northing**	**WL_{min} (79/80) mAHD**	**WL_{min} (2001) mAHD**	**WL_{min} (2005) mAHD**	**WL Changes (m) (1979-2001)**	**WL Changes (m) (1979-2005)**	**WL Changes (m) (2001-2005)**
54	GA30	34.566	361490	6525109	0.300	0.406	0.456	0.11	0.16	0.050
55	GA31	38.721	368648	6528129	9.970	9.161	8.988	-0.81	-0.98	-0.173
56	GA33	16.330	368450	6511595	0.740	0.720	0.620	-0.02	-0.12	-0.100
57	GA5	60.150	383703	6513588	43.300	40.610	39.540	-2.69	-3.76	-1.070
58	GA6	67.990	387001	6513834	54.640	52.090	50.990	-2.55	-3.65	-1.100
59	GA7	37.654	372102	6516435	5.850	5.304	4.884	-0.55	-0.97	-0.420
60	GA8	54.650	377675	6516311	30.830	29.030	28.080	-1.80	-2.75	-0.950
61	GA9	61.420	383945	6516420	50.850	49.270	48.220	-1.58	-2.63	-1.050
62	GB1	39.220	370880	6535145	24.340	23.970	23.150	-0.37	-1.19	-0.820
63	GB10	63.200	389910	6532041	58.580	59.460	61.020	0.88	2.44	1.560
64	GB11	28.969	371824	6530223	27.050	26.259	25.939	-0.79	-1.11	-0.320
65	GB12	40.860	375730	6530930	35.840	35.040	34.980	-0.80	-0.86	-0.060
66	GB13	46.420	377824	6531000	39.640	38.720	38.260	-0.92	-1.38	-0.460
67	GB15	46.890	377618	6527807	41.640	39.730	39.230	-1.91	-2.41	-0.500
68	GB16	60.600	384806	6528202	56.550	56.800	56.800	0.25	0.25	0.000
69	GB19	65.230	387279	6527007	60.370	60.000	59.730	-0.37	-0.64	-0.270
70	GB2	62.364	366240	6532975	9.320	9.434	8.474	0.11	-0.85	-0.960
71	GB20	62.683	380958	6524730	56.973	56.053	55.363	-0.92	-1.61	-0.690
72	GB21	66.650	384300	6524780	61.480	60.650	59.820	-0.83	-1.66	-0.830
73	GB22	65.170	386883	6524549	59.150	58.390	57.620	-0.76	-1.53	-0.770
74	GB23	68.204	383510	6522490	60.150	59.184	58.304	-0.97	-1.85	-0.880
75	GB3	47.071	373055	6533806	26.230	25.831	25.051	-0.40	-1.18	-0.780
76	GB4	42.550	375600	6533900	32.650	32.270	31.940	-0.38	-0.71	-0.330
77	GB5	47.410	377585	6533025	37.710	37.170	36.600	-0.54	-1.11	-0.570
78	GB7	35.130	373690	6531461	30.580	30.060	29.760	-0.52	-0.82	-0.300
79	GB8	50.730	380153	6531724	46.010	45.830	45.480	-0.18	-0.53	-0.350
80	GB9	58.140	385972	6532618	56.770	56.420	56.700	-0.35	-0.07	0.280
81	GC10	69.270	395120	6521380	67.360	66.730	66.910	-0.63	-0.45	0.180
82	GC11	69.334	387020	6519772	59.550	58.164	57.254	-1.39	-2.30	-0.910

No	Bore Name	Datum mAHD	Easting	Northing	WL_{min} (79/80) mAHD	WL_{min} (2001) mAHD	WL_{min} (2005) mAHD	WL Changes (m) (1979-2001)	WL Changes (m) (1979-2005)	WL Changes (m) (2001-2005)
83	GC12	73.470	390230	6519508	65.440	64.840	64.100	-0.60	-1.34	-0.740
84	GC13	71.408	392691	6520005	67.130	66.948	66.508	-0.18	-0.62	-0.440
85	GC14	67.765	396220	6519280	65.630	65.435	65.365	-0.20	-0.27	-0.070
86	GC15	72.992	399010	6520295	70.880	71.242	71.272	0.36	0.39	0.030
87	GC16	83.733	390060	6516740	62.850	61.643	60.730	-1.21	-2.12	-0.913
88	GC17	67.847	395790	6516805	65.630	65.117	64.537	-0.51	-1.09	-0.580
89	GC18	63.932	398718	6517358	61.860	61.722	61.652	-0.14	-0.21	-0.070
90	GC19	73.550	389668	6513454	58.950	57.060	55.940	-1.89	-3.01	-1.120
91	GC2	76.121	394642	6526292	72.690	72.901	72.921	0.21	0.23	0.020
92	GC20	76.787	393262	6513158	63.140	61.167	60.687	-1.97	-2.45	-0.480
93	GC21	69.361	396318	6513583	63.810	62.331	61.841	-1.48	-1.97	-0.490
94	GC22	60.470	399473	6514330	58.650	58.680	58.610	0.03	-0.04	-0.070
95	GC3	83.111	396524	6527518	78.850	77.041	75.951	-1.81	-2.90	-1.090
96	GC4	65.497	391535	6524665	62.930	62.617	62.687	-0.31	-0.24	0.070
97	GC6	72.653	396830	6523224	71.110	71.373	71.403	0.26	0.29	0.030
98	GC7	94.938	399218	6524789	92.380	92.708	92.668	0.33	0.29	-0.040
99	GC8	72.340	389843	6521505	64.920	64.450	63.820	-0.47	-1.10	-0.630
100	GC9	69.150	392088	6521706	65.860	65.670	65.204	-0.19	-0.66	-0.466
101	GD10	42.390	395140	6479586	37.730	38.110	37.095	0.38	-0.63	-1.015
102	GD11	45.630	394692	6481519	41.080	41.110	41.310	0.03	0.23	0.200
103	GD13	19.424	407880	6486078	11.720	12.024	11.624	0.30	-0.10	-0.400
104	GD14	25.180	407020	6487589	22.340	23.210	23.660	0.87	1.32	0.450
105	GD16	32.298	405175	6491625	30.250	30.348	30.178	0.10	-0.07	-0.170
106	GD17	32.431	405600	6495530	29.660	29.431	29.643	-0.23	-0.02	0.212
107	GD19	40.030	406550	6498660	38.120	37.870	37.220	-0.25	-0.90	-0.650
108	GD2	21.119	386567	6482263	20.060	19.969	20.349	-0.09	0.29	0.380
109	GD20	61.790	405125	6505870	55.660	57.600	56.830	1.94	1.17	-0.770
110	GD21	49.940	402310	6508420	47.720	48.240	48.200	0.52	0.48	-0.040
111	GD22	60.488	400040	6514535	58.550	58.708	58.588	0.16	0.04	-0.120

No	Bore Name	Datum mAHD	Easting	Northing	WL$_{min}$ (79/80) mAHD	WL$_{min}$ (2001) mAHD	WL$_{min}$ (2005) mAHD	WL Changes (m) (1979-2001)	WL Changes (m) (1979-2005)	WL Changes (m) (2001-2005)
112	GD4	30.992	382893	6467000	1.460	1.642	1.322	0.18	-0.14	-0.320
113	GD5	10.982	385942	6467014	5.800	6.522	6.372	0.72	0.57	-0.150
114	GD6	15.169	390720	6465580	11.970	12.689	12.770	0.72	0.80	0.081
115	GD7	22.043	391984	6469088	19.140	19.123	19.230	-0.02	0.09	0.107
116	GD8	8.581	401362	6470016	2.780	2.961	2.821	0.18	0.04	-0.140
117	GE1	15.301	383405	6463761	1.130	1.151	0.981	0.02	-0.15	-0.170
118	GE2	10.527	382867	6459546	-0.122	0.057	0.117	0.18	0.24	0.060
119	GE3	20.434	385682	6461550	1.120	1.214	1.144	0.09	0.02	-0.070
120	GE4	12.539	387874	6462874	2.890	3.509	2.786	0.62	-0.10	-0.723
121	GG3 (O)	78.140	396986	6510016	65.850	64.050	63.250	-1.80	-2.60	-0.800
122	GM1	9.758	385466	6475861	4.868	4.628	3.690	-0.24	-1.18	-0.938
123	GM11	18.577	387789	6474380	13.957	13.647	12.220	-0.31	-1.74	-1.427
124	GM12	31.871	388891	6474650	21.091	20.231	18.210	-0.86	-2.88	-2.021
125	GM13	10.200	386286	6472471	6.760	5.250	5.640	-1.51	-1.12	0.390
126	GM14	20.063	387144	6473187	9.973	8.943	8.503	-1.03	-1.47	-0.440
127	GM15	23.610	388325	6473353	15.620	15.240	14.050	-0.38	-1.57	-1.190
128	GM16	32.231	389222	6473699	19.921	19.741	17.869	-0.18	-2.05	-1.872
129	GM17	16.879	385396	6471802	4.709	4.419	3.759	-0.29	-0.95	-0.660
130	GM2	21.609	386467	6475935	8.499	7.389	6.288	-1.11	-2.21	-1.101
131	GM20	18.314	388826	6472330	15.854	16.234	15.279	0.38	-0.58	-0.955
132	GM22	13.073	385821	6470754	6.353	5.623	5.433	-0.73	-0.92	-0.190
133	GM23	13.745	387739	6471128	9.995	8.135	9.575	-1.86	-0.42	1.440
134	GM24	21.885	388939	6471741	15.995	16.065	15.501	0.07	-0.49	-0.564
135	GM25	44.919	389991	6471946	19.279	19.139	18.190	-0.14	-1.09	-0.949
136	GM26	18.653	387308	6469851	9.283	9.003	9.013	-0.28	-0.27	0.010
137	GM27	16.698	388358	6470269	11.962	11.568	11.390	-0.39	-0.57	-0.178
138	GM28	33.320	389237	6470514	15.740	15.340	15.230	-0.40	-0.51	-0.110
139	GM3	36.460	387415	6476320	12.388	11.540	10.180	-0.85	-2.21	-1.360
140	GM4	14.336	385672	6474846	5.016	4.646	3.856	-0.37	-1.16	-0.790

No	Bore Name	Datum mAHD	Easting	Northing	WL$_{min}$ (79/80) mAHD	WL$_{min}$ (2001) mAHD	WL$_{min}$ (2005) mAHD	WL Changes (m) (1979-2001)	WL Changes (m) (1979-2005)	WL Changes (m) (2001-2005)
141	GM6	31.125	387706	6475266	13.522	12.625	11.165	-0.90	-2.36	-1.460
142	GM7	36.140	388658	6475577	23.341	22.790	19.590	-0.55	-3.75	-3.200
143	GM8	11.226	385278	6473127	4.676	3.586	2.876	-1.09	-1.80	-0.710
144	GM9	12.409	386284	6473900	7.439	6.949	6.749	-0.49	-0.69	-0.200
145	GN3 W	45.610	398105	6481560	40.513	40.470	40.303	-0.04	-0.21	-0.167
146	JB10C	52.610	391098	6488928	46.050	46.940	46.472	0.89	0.42	-0.468
147	JB12A	50.410	391015	6486688	45.220	44.380	44.312	-0.84	-0.91	-0.068
148	JB4	63.280	389706	6486009	42.580	41.900	42.100	-0.68	-0.48	0.200
149	JB5	49.944	391132	6486310	45.760	44.404	44.294	-1.36	-1.47	-0.110
150	M290	34.390	403187	6479643	29.109	28.640	28.609	-0.47	-0.50	-0.031
151	M80C	21.540	401206	6475974	18.860	18.600	18.650	-0.26	-0.21	0.050
152	MM10	47.783	395565	6482635	43.780	44.293	43.463	0.51	-0.32	-0.830
153	MM12	47.660	399449	6482712	43.407	43.240	42.617	-0.17	-0.79	-0.623
154	MM15	48.950	391415	6480483	38.748	39.120	38.980	0.37	0.23	-0.140
155	MM16	44.460	393375	6480637	39.163	38.820	38.770	-0.34	-0.39	-0.050
156	MM17	43.040	394915	6480692	39.741	39.540	39.441	-0.20	-0.30	-0.099
157	MM18	43.510	397441	6480676	39.320	39.160	38.940	-0.16	-0.38	-0.220
158	MM19	44.570	399465	6481565	40.731	40.610	39.741	-0.12	-0.99	-0.869
159	MM25	37.540	397559	6478641	34.120	34.700	33.870	0.58	-0.25	-0.830
160	MM26	39.278	399348	6479609	35.668	34.938	34.878	-0.73	-0.79	-0.060
161	MM27	36.799	401286	6479626	34.589	33.729	33.749	-0.86	-0.84	0.020
162	MM28	74.010	391514	6476563	30.730	31.480	29.880	0.75	-0.85	-1.600
163	MM33	25.761	399534	6476380	22.071	21.861	21.901	-0.21	-0.17	0.040
164	MM34	68.436	391555	6474682	26.996	27.826	25.300	0.83	-1.70	-2.526
165	MM36	37.188	395669	6474162	29.270	29.988	30.428	0.72	1.16	0.440
166	MM38	22.020	399668	6474940	19.850	19.390	19.350	-0.46	-0.50	-0.040
167	MM40	74.280	391276	6472646	23.220	23.380	22.100	0.16	-1.12	-1.280
168	MM43	28.470	397624	6473128	25.850	25.680	25.640	-0.17	-0.21	-0.040
169	MM45	13.450	402055	6473741	11.070	10.170	10.210	-0.90	-0.86	0.040

No	Bore Name	Datum mAHD	Easting	Northing	WL_{min} (79/80) mAHD	WL_{min} (2001) mAHD	WL_{min} (2005) mAHD	WL Changes (m) (1979-2001)	WL Changes (m) (1979-2005)	WL Changes (m) (2001-2005)
170	MM46	16.600	400747	6474948	13.330	13.400	13.360	0.07	0.03	-0.040
171	MM47	16.815	402013	6474961	15.120	14.805	14.865	-0.31	-0.25	0.060
172	MM48	21.590	403123	6475451	17.042	16.220	16.192	-0.82	-0.85	-0.028
173	MM49B	28.530	400673	6477569	26.090	24.980	25.020	-1.11	-1.07	0.040
174	MM52	24.270	403284	6478146	22.718	22.370	22.868	-0.35	0.15	0.498
175	MM53	37.060	398804	6478901	34.120	33.340	33.240	-0.78	-0.88	-0.100
176	MM54B	44.013	400107	6478854	33.590	32.343	32.233	-1.25	-1.36	-0.110
177	MM55B	32.310	401493	6478876	30.200	29.550	29.420	-0.65	-0.78	-0.130
178	MM56B	31.161	402286	6478878	28.961	28.881	29.201	-0.08	0.24	0.320
179	MM58	42.960	398579	6480590	38.670	38.460	38.150	-0.21	-0.52	-0.310
180	MM59B	41.496	400807	6480655	37.106	36.196	35.876	-0.91	-1.23	-0.320
181	MM60	39.230	402398	6480889	36.890	36.140	35.550	-0.75	-1.34	-0.590
182	MM9	56.600	393380	6482725	42.370	42.040	41.880	-0.33	-0.49	-0.160
183	MP2D	26.620	399820	6476870	22.720	22.150	22.190	-0.57	-0.53	0.040
184	MP3C	18.670	400597	6475994	16.550	16.530	16.570	-0.02	0.02	0.040
185	MS10	43.495	387207	6488973	41.065	40.485	40.285	-0.58	-0.78	-0.200
186	MS14	51.124	388398	6488361	42.734	42.504	41.684	-0.23	-1.05	-0.820
187	MS7	43.835	386708	6489554	40.995	40.395	40.185	-0.60	-0.81	-0.210
188	MS9	60.000	386143	6489514	38.158	36.420	36.460	-1.74	-1.70	0.040
189	MT1S	45.254	388392	6489267	42.564	42.094	41.764	-0.47	-0.80	-0.330
190	PB2	52.410	401108	6486220	48.361	48.200	48.090	-0.16	-0.27	-0.110
191	PCM21	49.134	385441	6503736	42.630	40.164	39.534	-2.47	-3.10	-0.630
192	PM1	76.700	389999	6511009	58.420	55.780	54.760	-2.64	-3.66	-1.020
193	PM11	76.120	392830	6501159	66.740	65.130	64.340	-1.61	-2.40	-0.790
194	PM12	58.799	390406	6499451	56.320	53.819	53.189	-2.50	-3.13	-0.630
195	PM13	74.580	393740	6499750	68.920	67.940	67.270	-0.98	-1.65	-0.670
196	PM15	63.760	382546	6508549	36.960	33.250	32.070	-3.71	-4.89	-1.180
197	PM16	69.990	386010	6509017	48.790	43.270	42.530	-5.52	-6.26	-0.740
198	PM17	58.930	384160	6506869	39.630	34.690	33.680	-4.94	-5.95	-1.010

No	Bore Name	Datum mAHD	Easting	Northing	WL_{min} (79/80) mAHD	WL_{min} (2001) mAHD	WL_{min} (2005) mAHD	WL Changes (m) (1979-2001)	WL Changes (m) (1979-2005)	WL Changes (m) (2001-2005)
199	PM18	65.190	386150	6506157	48.930	43.590	42.740	-5.34	-6.19	-0.850
200	PM19	57.990	383894	6505497	39.980	35.680	34.690	-4.30	-5.29	-0.990
201	PM2	75.690	393249	6511810	62.790	60.720	60.080	-2.07	-2.71	-0.640
202	PM23	48.020	387831	6500014	45.700	44.660	44.220	-1.04	-1.48	-0.440
203	PM24	43.980	387053	6497705	42.050	41.440	41.390	-0.61	-0.66	-0.050
204	PM25	47.190	388795	6496683	43.990	42.940	42.890	-1.05	-1.10	-0.050
205	PM26	44.500	380374	6510185	30.180	27.990	26.950	-2.19	-3.23	-1.040
206	PM27	40.920	377181	6507951	16.570	15.150	14.370	-1.42	-2.20	-0.780
207	PM28	84.510	379831	6508236	24.350	22.120	21.130	-2.23	-3.22	-0.990
208	PM29	49.300	379389	6504587	19.240	16.550	15.550	-2.69	-3.69	-1.000
209	PM3	70.720	393260	6509295	63.120	60.680	59.840	-2.44	-3.28	-0.840
210	PM32	59.930	382422	6500254	27.090	24.240	23.390	-2.85	-3.70	-0.850
211	PM33	51.740	381032	6498436	21.960	19.230	18.460	-2.73	-3.50	-0.770
212	PM34	37.510	381499	6496453	21.230	18.870	17.940	-2.36	-3.29	-0.930
213	PM35	51.220	383965	6497726	31.090	28.870	28.000	-2.22	-3.09	-0.870
214	PM36	60.770	383387	6495469	28.950	26.390	25.440	-2.56	-3.51	-0.950
215	PM4	68.200	390270	6506202	59.960	57.350	56.300	-2.61	-3.66	-1.050
216	PM5	74.130	393254	6506317	64.670	62.890	62.020	-1.78	-2.65	-0.870
217	PM6	64.490	389056	6504556	56.190	52.750	51.920	-3.44	-4.27	-0.830
218	PM7	70.210	391841	6503520	63.600	61.300	60.350	-2.30	-3.25	-0.950
219	PM8	80.710	395086	6503501	69.710	68.130	67.400	-1.58	-2.31	-0.730
220	PM9	64.620	390100	6501788	58.770	57.040	56.380	-1.73	-2.39	-0.660
221	WM1	61.155	391720	6497310	57.605	55.705	55.235	-1.90	-2.37	-0.470
222	WM11	65.643	385830	6491469	37.433	36.133	35.993	-1.30	-1.44	-0.140
223	WM13	57.742	392277	6491575	52.862	50.082	49.732	-2.78	-3.13	-0.350
224	WM16	27.248	385058	6489240	18.528	17.748	18.028	-0.78	-0.50	0.280
225	WM18	54.819	387217	6488330	38.375	37.629	37.649	-0.75	-0.73	0.020
226	WM2	72.675	395120	6496323	68.198	67.495	67.215	-0.70	-0.98	-0.280
227	WM22	65.521	386921	6486412	37.421	36.591	36.591	-0.83	-0.83	0.000
228	WM23	52.721	391240	6486968	46.071	45.211	45.071	-0.86	-1.00	-0.140

No	Bore Name	Datum mAHD	Easting	Northing	WL_{min} (79/80) mAHD	WL_{min} (2001) mAHD	WL_{min} (2005) mAHD	WL Changes (m) (1979-2001)	WL Changes (m) (1979-2005)	WL Changes (m) (2001-2005)
229	WM24	54.320	393900	6486435	49.280	47.840	46.970	-1.44	-2.31	-0.870
230	WM28	80.990	388762	6484185	39.206	38.630	38.901	-0.58	-0.30	0.271
231	WM29	63.120	390784	6483010	41.470	40.860	40.830	-0.61	-0.64	-0.030
232	WM3	61.660	392040	6495180	57.401	54.340	54.840	-3.06	-2.56	0.500
233	WM31	50.737	389773	6492604	47.897	46.147	45.417	-1.75	-2.48	-0.730
234	WM32	62.094	397740	6489120	57.244	56.414	55.634	-0.83	-1.61	-0.780
235	WM33	61.132	396455	6486390	52.802	52.572	51.032	-0.23	-1.77	-1.540
236	WM4	64.248	385677	6493509	37.218	35.848	35.308	-1.37	-1.91	-0.540
237	WM5	57.236	391180	6493647	52.146	48.876	48.166	-3.27	-3.98	-0.710
238	WM6	65.931	393576	6493045	59.638	58.301	58.321	-1.34	-1.32	0.020
239	WM7	73.771	396238	6493032	66.474	66.341	65.941	-0.13	-0.53	-0.400
240	WM8	71.097	398552	6492874	65.618	65.517	65.267	-0.10	-0.35	-0.250
241	WM9	47.556	387828	6492941	42.475	41.506	41.016	-0.97	-1.46	-0.490
242	YCM	63.077	380036	6516345	37.280	35.907	34.907	-1.37	-2.37	-1.000

Appendix C – Gnangara Hydrograph Analysis

Name	Easting	Northing	Datum mAHD	Climate (m)	Abstraction (m)	Pine (m)	Clearing (m)	Thinning (m)	Fires (m)	Urbanisation (m)	Native Bush (m)	Comments
2069	397139	6469799	24.95		0	0	0	0	0	0	0	Discharge Zone, correlation is not satisfactory
459	387870	6479158	29.58									Water levels are influenced by drains
649	395174	6473247	30.55									Water levels are controlled by drainage system
8281	385935	6487238	21.37	0.5	-1.6	0	0	0	0	0	0	Impact is higher, but levels artificially maintained
CG4-90	377478	6504388	13.03	-2.2	0	0	0	0	0	0	0	
Crystal Cave	375844	6509266	13.32	-0.7	-0.55	0	0	0	0	0	0	
GA1	371007	6515129	30.49	-0.75	0	0	0	0	0.3	0	0	
GA10	382473	6518086	57.42	-2.7	0	-0.5	0.7	0	0.75	0	-0.7	
GA11	368595	6519709	30.64	-0.6	0	0	0	0	0.25	0	0	
GA12	371277	6519680	15.17	-0.8	0	0	0	0	0	0	0	Climate
GA13	374979	6520139	58.65	-2	0	-1.25			0	0	0	Pine has minor impact after 1987
GA14	378464	6519488	70.98	-2.3	0	-0.5			0	0	0	Pine has minor impact after 1993
GA17	372559	6522392	47.70	-1.7	0	-1.1			0	0	0	Pine has minor impact after 1989
GA18	377289	6522761	57.06	-2.1	0	-0.8			0	0	0	Pine has minor impact after 1985

Name	Easting	Northing	Datum mAHD	Climate (m)	Abstraction (m)	Pine (m)	Clearing (m)	Thinning (m)	Fires (m)	Urbanisation (m)	Native Bush (m)	Comments
GA21	372389	6525119	43.79	-2.65	0	-0.5	1.1	0	0	0	0	
GA24	365583	6526447	44.41	-0.55	0	0	0	0	0.25	0	0	
GA29	365497	6530809	35.65	-0.7	0	0	0	0	0.5	0	0	
GA3	376888	6513573	58.26	-1.2	0	-1.1	0	0	0.2	0	0	Pine or native vegetation impact
GA31	368787	6528278	38.80	-1.25	0	0	0	0	0.3	0	0	
GA33	368586	6511729	16.33	-0.45	-0.1	0	0	0	0	0.25	0	
GA4	380572	6513670	45.36	-2.2	0	-2.8	1.7	0	0.8	0	0	
GA5	383844	6513732	60.15	-2.35	0	-3.3	1.95	0	0.65	0	0	
GA6	387140	6513983	67.99	-3.1	0	-0.8	0	0	0	0	-0.8	-0.80 is either pine or native vegetation?
GA8	377814	6516460	54.65	-1.4	0	-1.4			0.5	0	0	
GB19	387414	6527158	65.23	-0.65	0	0	0	0	0	0	0	Climate
GB20	381097	6524879	62.68	-3.3	0	0	0	0	1.5	0	0	
GB21	384439	6524929	66.65	-2.95	0	0	0	0	0.9	0	0	
GB22	387022	6524698	65.17	-2.4	0	0	0	0	0.9	0	0	
GB8	380313	6531873	50.73	-0.4	0	0	0	0	0	0	0	
GC9	392240	6521849	69.15	-0.7	0	0	0	0	0	0	0	Climate
GC11	387159	6519921	69.33	-3.1	0	0	0	0	0.5	0	0	
GC12	390369	6519657	73.47	-2.8	0	0	0	0	1.3	0	0	
GC20	393410	6513302	76.79	-2.9	0	0	0	0	0	0	0	
GD2	386714	6482424	21.12	0.4	-0.45	0	0	0	0	0	0	Climate and abstraction
GD5	386081	6467163	10.98									Water Levels influenced by Herdsman Lake
GD7	392123	6469237	22.04									Next to Compensating Basin

Name	Easting	Northing	Datum mAHD	Climate (m)	Abstraction (m)	Pine (m)	Clearing (m)	Thinning (m)	Fires (m)	Urbanisation (m)	Native Bush (m)	Comments
GE7	381078	6484937	41.17	0.75	-0.5	0	0	0	0	0	0	Climate and abstraction
GG2 (I)	384342	6510064	72.74	-2.7	0	-3.5	1.8	0	0.75	0	0	
GG3 (I)	397140	6510109	77.17	-2.85	0	0	0	0	1.3	0	0	
GG4 (I)	386784	6516670	75.52	-3.1	0	0	0	0	0.45	0	0	
GG5 (I)	393408	6516372	78.50	-2.5	0	0	0	0	0.5	0	0	
GG9 (O)	387002	6529620	65.25									No sufficient data
GM14	387283	6473336	20.06	0.4	-3	0	0	0	0	0	0	Climate and abstraction
GM2	386606	6476084	21.72	0.2	-2.6	0	0	0	0	0	0	Climate and abstraction
GM23	387878	6471277	13.75	0.5	-1.6	0	0	0	0	0	0	Climate and abstraction
GM26	387447	6470000	18.65	0.4	-1.1	0	0	0	0	0	0	Climate and abstraction
GN13	394830	6491603	66.99	-3.3	-2.1	0	0	0	1.75	0	0	
GN17	398899	6487939	61.64	0.1	-1	0	0	0	0	0	0	
GN20	393389	6496549	68.33	-3.8	-0.9	0	1.7	0	2.35	0	0	
GN23	389030	6499466	57.25	-3.6	-2.4	0	1.1	0.9	0	0	0	
GN30 (I)	394782	6506532	79.20	-3	0	0	0	0	0	0	0	
GN5	394864	6478898	42.36	-0.2	-1.6	0	0	0	0	0	0	
JB5	391272	6486453	49.94	0.1	-1.3	0	0	0	0	0	0	Artificial maintenance of Jandabup Lake
JP12	376713	6497920	22.16	0.15	-3.4	0	0	0	0	0	0	Climate and abstraction
JP16B	383421	6499255	42.05	-2.5	0	-0.5	0	0	0	0	0	
JP19	378159	6502989	22.88	-2.2	-1.3	0	0	0	0	0	0	Climate and abstraction
JP3D	380402	6493063	20.46	-0.5	-0.5	0	0	0	0	0.2	0	Climate and abstraction
L220C	400362	6489909	56.41	0.2	0	0	0	0	0	0	0	

Name	Easting	Northing	Datum mAHD	Climate (m)	Abstraction (m)	Pine (m)	Clearing (m)	Thinning (m)	Fires (m)	Urbanisation (m)	Native Bush (m)	Comments
L50C	402276	6485230	52.52	0	0	0	0	0	0	1.3		Data period is not long enough
MM14	389482	6480567	54.28	0.4	0	0	0	0	0	0	0	Climate
MM18	397578	6480820	43.51	-0.1	-1	0	0	0	0	0	0	Levels are stabilised
MM31	397809	6476605	32.31	0.05	-0.9	0	0	0	0	0	0	
MM34	391694	6474831	68.44	-0.15	-1.3	0	0	0	0	0	0	
MM45	402194	6473890	13.45									Discharge Zone, correlation is not satisfactory
MM49B	400817	6477709	28.53	-0.15	-1.1	0	0	0	0	0	0	
MM53	398946	6479044	37.06	-0.1	-1	0	0	0	0	0	0	
MM59B	400957	6480757	41.50	-0.1	-1	0	0	0	0	0	0	
MM68	393705	6476381	43.28	0.1	0	0	0	0	0	1.15		
MM9	393565	6482805	56.60	0.35	-0.8	0	0	0	0	0	0	
MS10	387344	6489116	43.50	0.35	-1.4	0	0	0	0	0	0	
NR11C	400182	6492787	59.21	-0.3	0	0	0	0	0	0	0	
NR2C	399619	6498229	70.68	0.3	0	0	0	0	0	0	-1.2	Close to the discharge zone
NR3C	396211	6494917	73.64	0.2	0	0	0	0	0	0	-0.8	
PE1A	384308	6510082	72.76	-2.7	0	-3.5	1.8	0	0.75	0	0	
PE1C	384311	6510077	72.72	-2.7	0	-3.5	1.8	0	0.75	0	0	
PE2A	384301	6510092	72.64	-2.7	0	-3.5	1.8	0	0.75	0	0	
PE2B	384304	6510720	72.74	-2.7	0	-3.5	1.8	0	0.75	0	0	
PM1	390136	6511158	76.70	-3.2	-0.5	0	0	0	0	0	-0.5	
PM13	393879	6499899	74.58	-2.7	0	0	0	0	1.3	0	-0.45	
PM15	382699	6508698	63.76	-2.5	0	-3	1.85	0	0.55	0	0	
PM19	384020	6505647	57.99	-2.5	0	-2.3	0.7	0	0	0	0	
PM27	377314	6508095	40.92	-1.8	-0.3	0	0	0	0	0	0	
PM28	379968	6508382	84.51	-2.5	0	-1.6	1.2	0	0	0	0	
PM3	393392	6509440	70.72	-3.2	0	0	0	0	0	0	0	

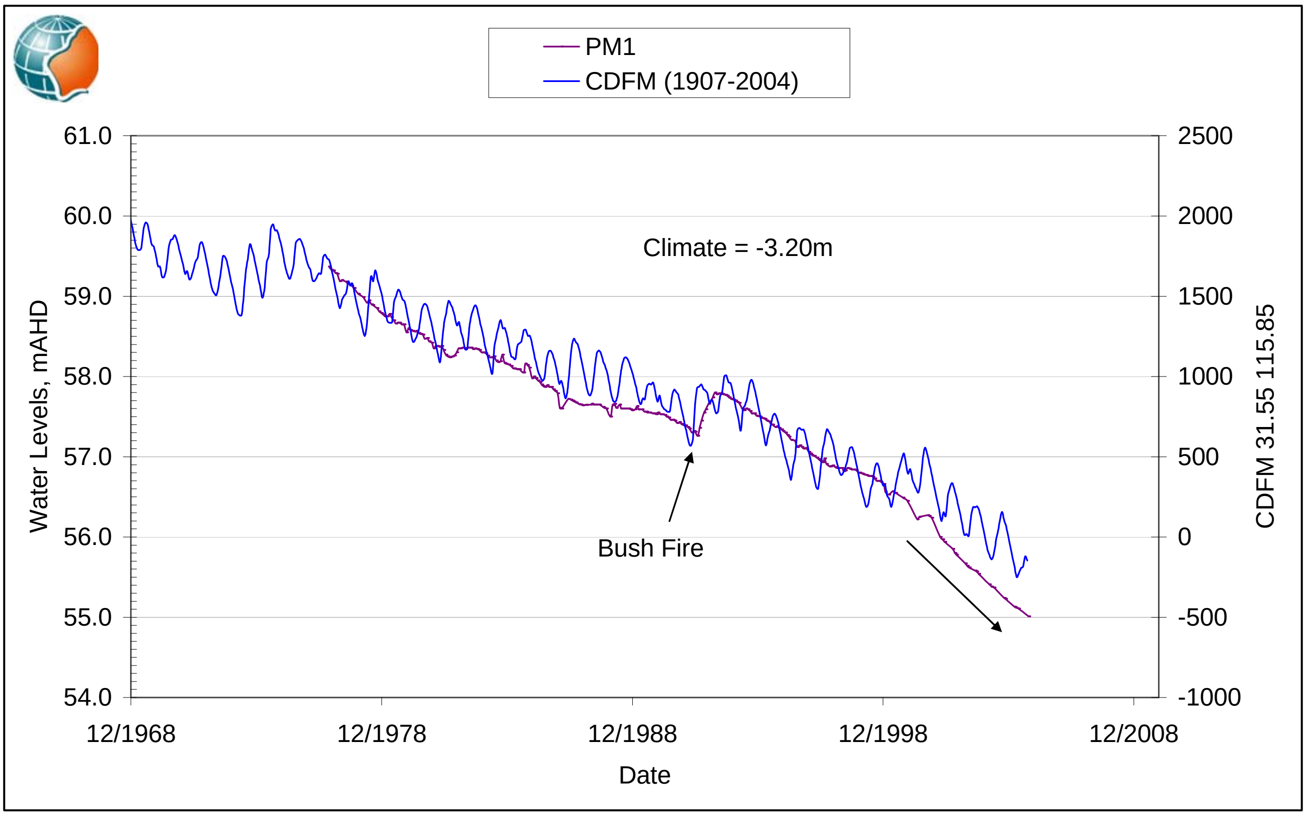
Name	Easting	Northing	Datum mAHD	Climate (m)	Abstraction (m)	Pine (m)	Clearing (m)	Thinning (m)	Fires (m)	Urbanisation (m)	Native Bush (m)	Comments
PM31	380399	6502357	53.61	-2.3	-1.95	0	0	0	0	0	0	
PM33	381171	6498585	51.74	-1.65	-1.7	0	0	0	0	0	0	
PM36	383526	6495618	60.77	-2.35	-1	0	0	0	0	0	0	
PM5	393390	6506467	74.13	-3.1	0	0	0	0	0.5	0	0	
PM6	389194	6504700	64.49	-2.7	-1.8	0	0	0	0	0	0	
PM8	395224	6503644	80.71	-3.05	0	0	0	0	1.4	0	-0.5	
WF12	383335	6480752	32.68	0.4	-0.7	0	0	0	0	0	0	
WH100	384683	6483681	34.69	0.18	-0.75	0	0	0	0	1.2	0	
WM1	391479	6497246	61.16	-3.25	0	0	0	0	1.05	0	0	
WM13	392416	6491724	57.74	-4.3	0	-0.2	0	0.8	0	0	0	
WM2	395282	6496476	72.68	-2.6	0	0	0	0	1.5	0	0	
WM24	394039	6486584	54.32	-2.8	0	0	0	0	0	0	0	
WM28	388914	6484322	81.07	0.15	-0.8	0	0	0	0	0	0	
WM4	385816	6493658	64.25	-1.3	-0.65	0	0	0	0	0	0	
WM5	391319	6493796	57.24	-4.2	0	0	0	0	0	0	0	
YB11	373799	6507649	12.27	-1.3	0	0	0	0	0.85	0	0	
YCM	380175	6516494	63.08	-2.1	-0.2	-2.85	1.75	0	1	0	0	
YN1	377693	6510183	73.68	-2.25	0	0	0	0	0	0	0	
YN3	375804	6509679	33.68	-0.6	-0.4	0	0	0	0	0	0	
YN4	375558	6509599	12.50	-0.6	-0.3	0	0	0	0	0	0	
YY2 (O)	377689	6510174	73.57	-2.25	0	0	0	0	0	0	0	
YY7 (I)	380966	6522451	58.46	-2.95	0	0	0	0	0.95	0	0	
YY9 (I)	375436	6527990	52.19	-2.3	0	0	0	0	0.45	0	0	

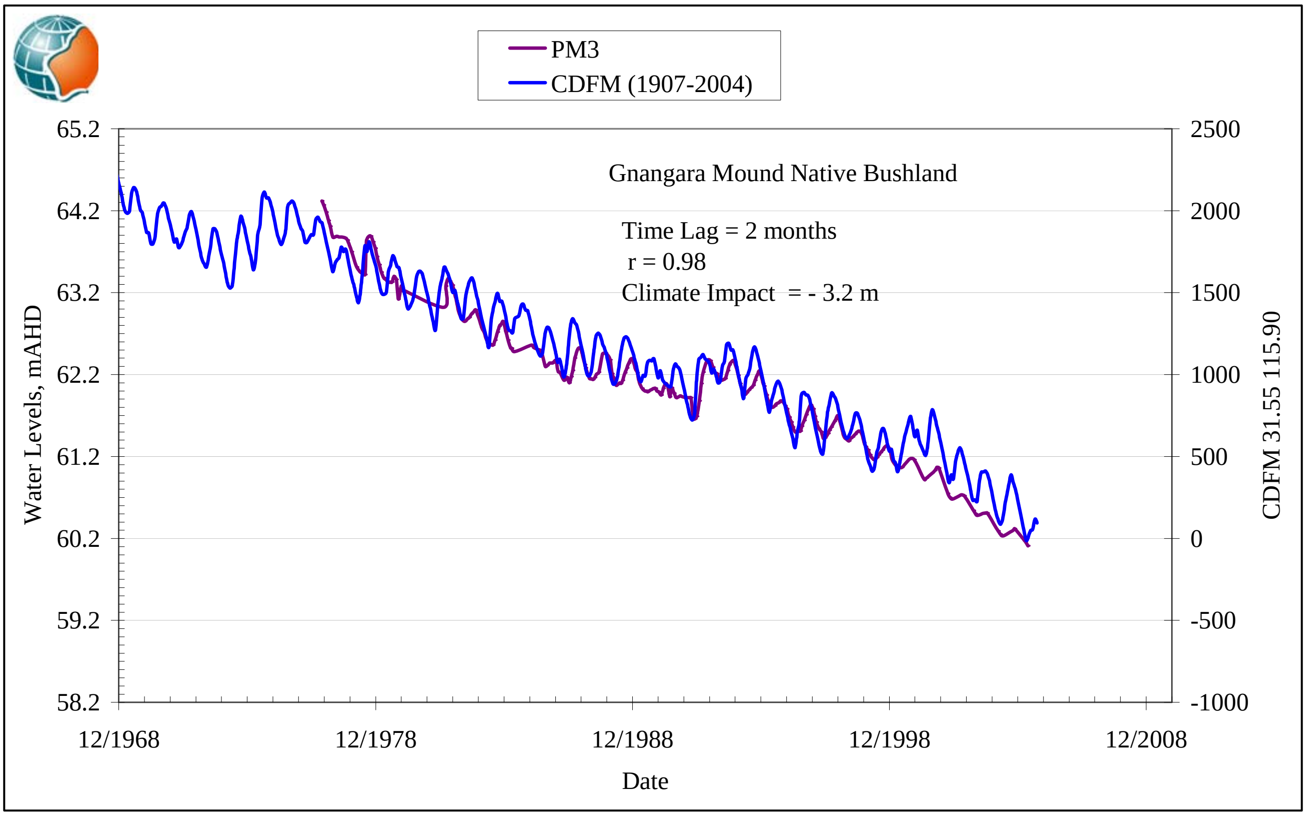
Appendix D – Gnangara groundwater hydrographs

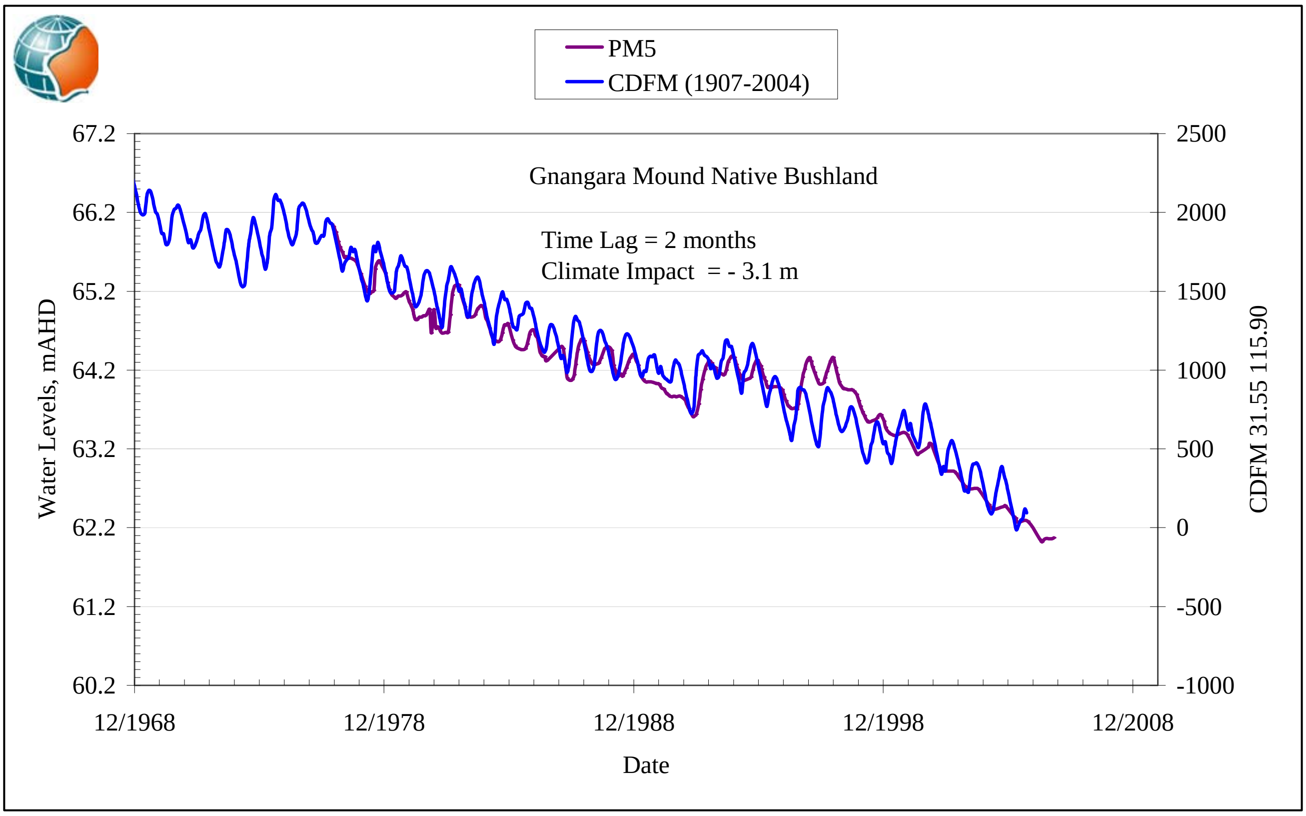
1. Lake Pinjar Rainfall Zone
2. Gingin Rainfall Zone
3. Muchea and Pearce Rainfall Zones
4. Wanneroo Rainfall Zone
5. Yanchep Rainfall Zone
6. Two Rocks Rainfall Zone
7. Gnangara Forestry Rainfall Zone

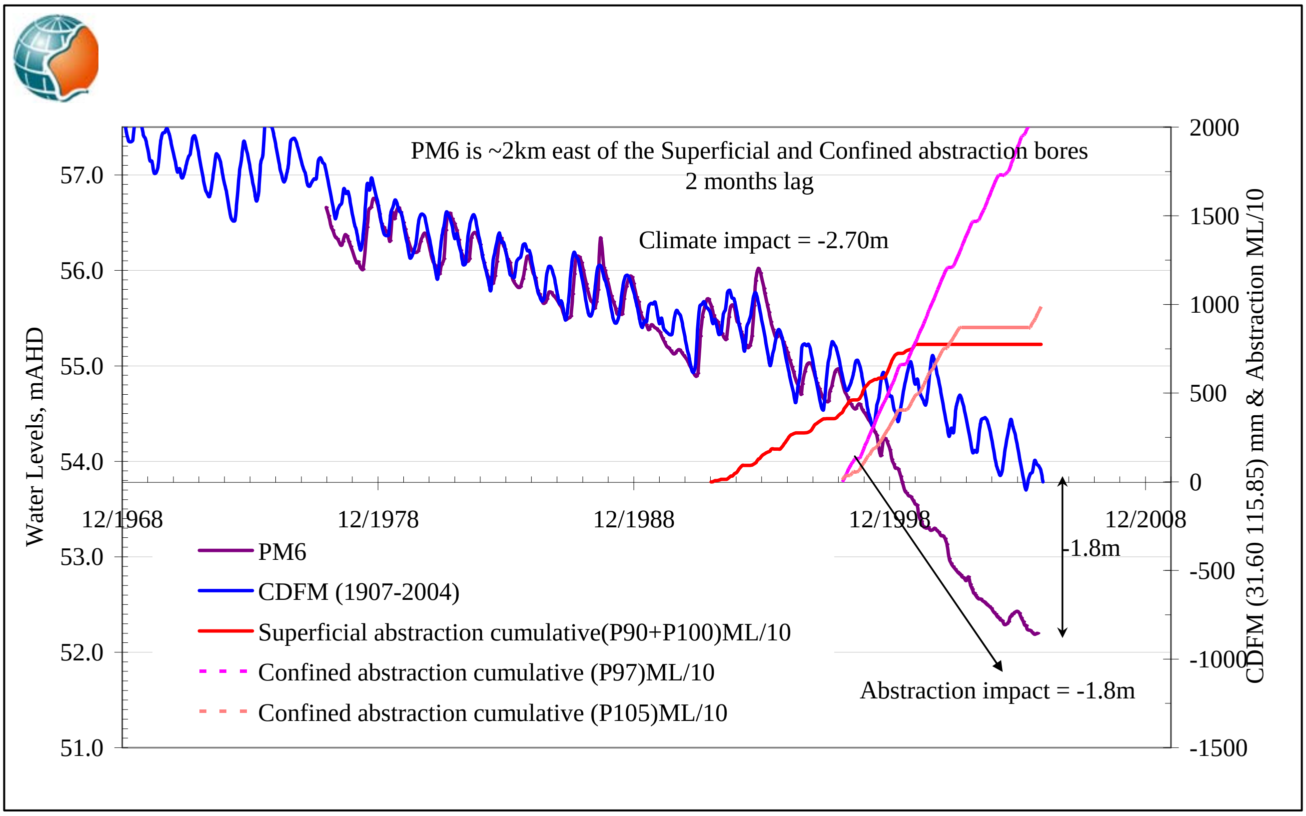
1. Lake Pinjar Rainfall Zone

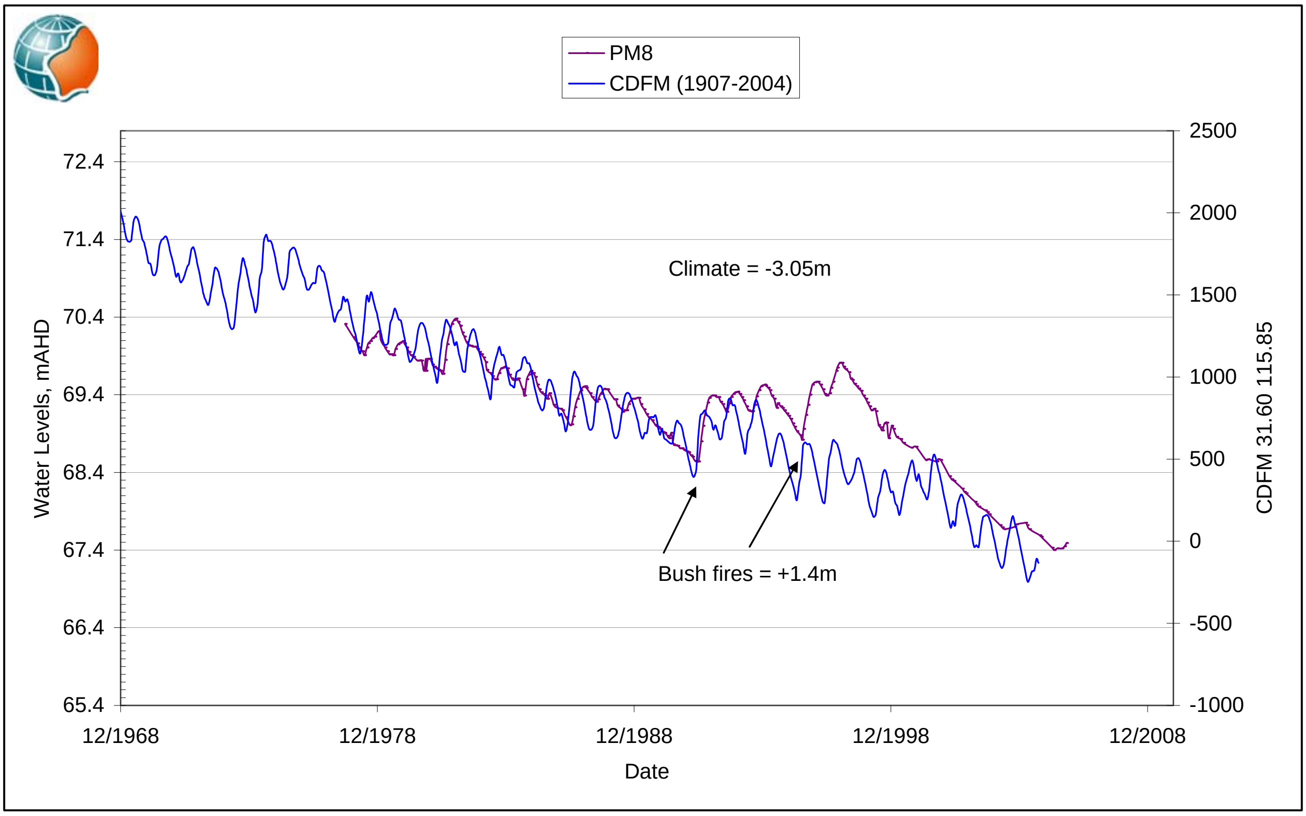
(PM1, PM3, PM5, PM6, PM8, PM15, PM19, GG2, PE1, PE2, GC11, GG5, GC20, GN30, GG4, GA5, GA6, GA10)

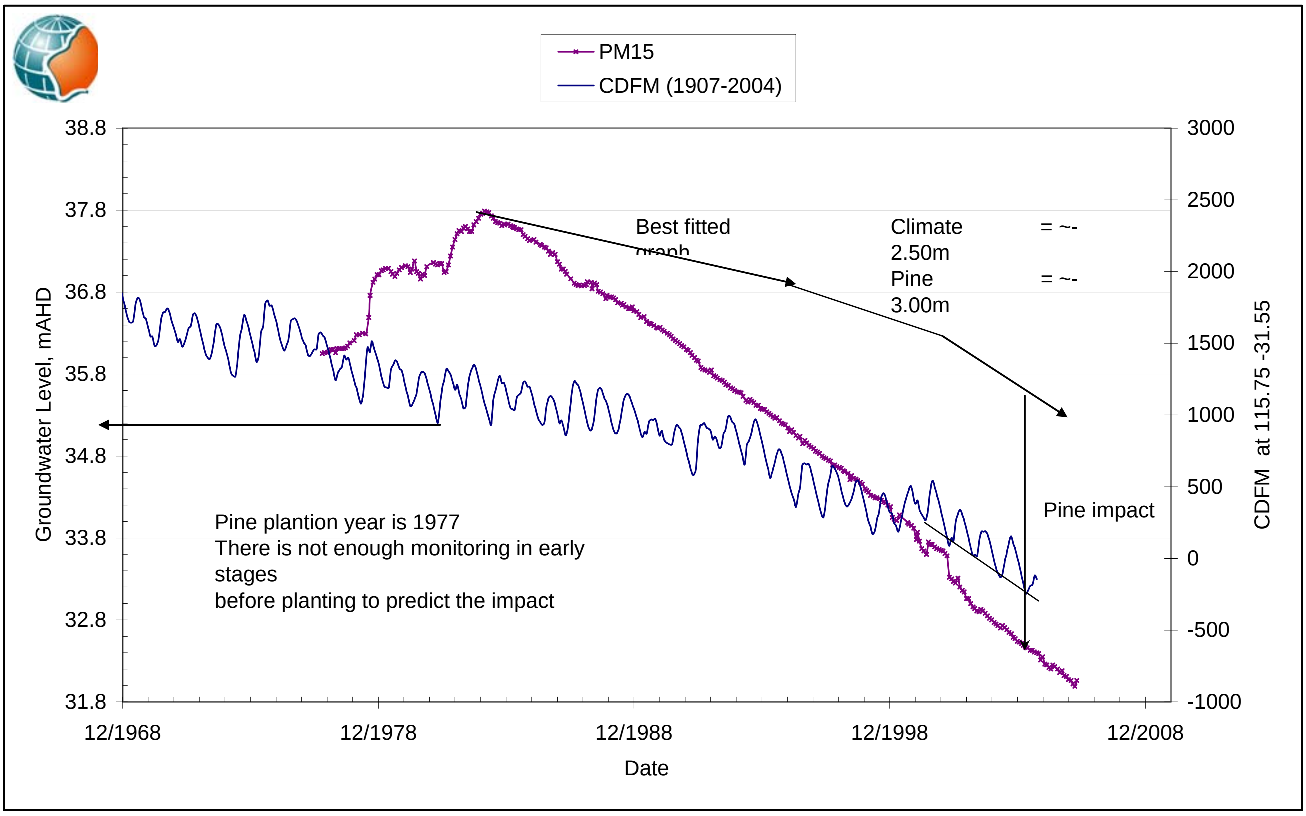

PM1
CDFM (1907-2004)
Climate = -3.20m
Bush Fire
Water Levels, mAHD
61.0
60.0
59.0
58.0
57.0
56.0
55.0
54.0
CDFM 31.55 115.85
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

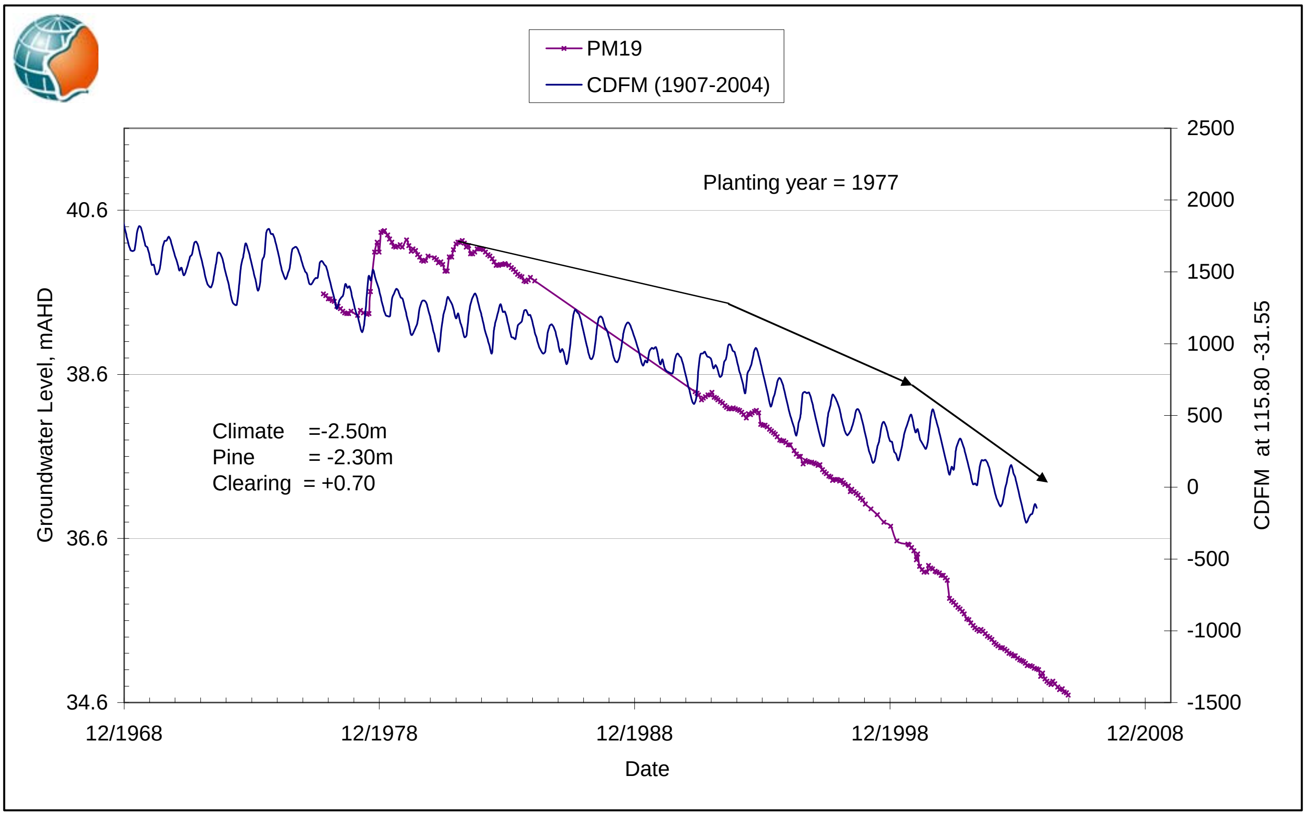

PM3
CDFM (1907-2004)
Gnangara Mound Native Bushland
Time Lag = 2 months
r = 0.98
Climate Impact = - 3.2 m
Water Levels, mAHD
65.2
64.2
63.2
62.2
61.2
60.2
59.2
58.2
CDFM 31.55 115.90
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

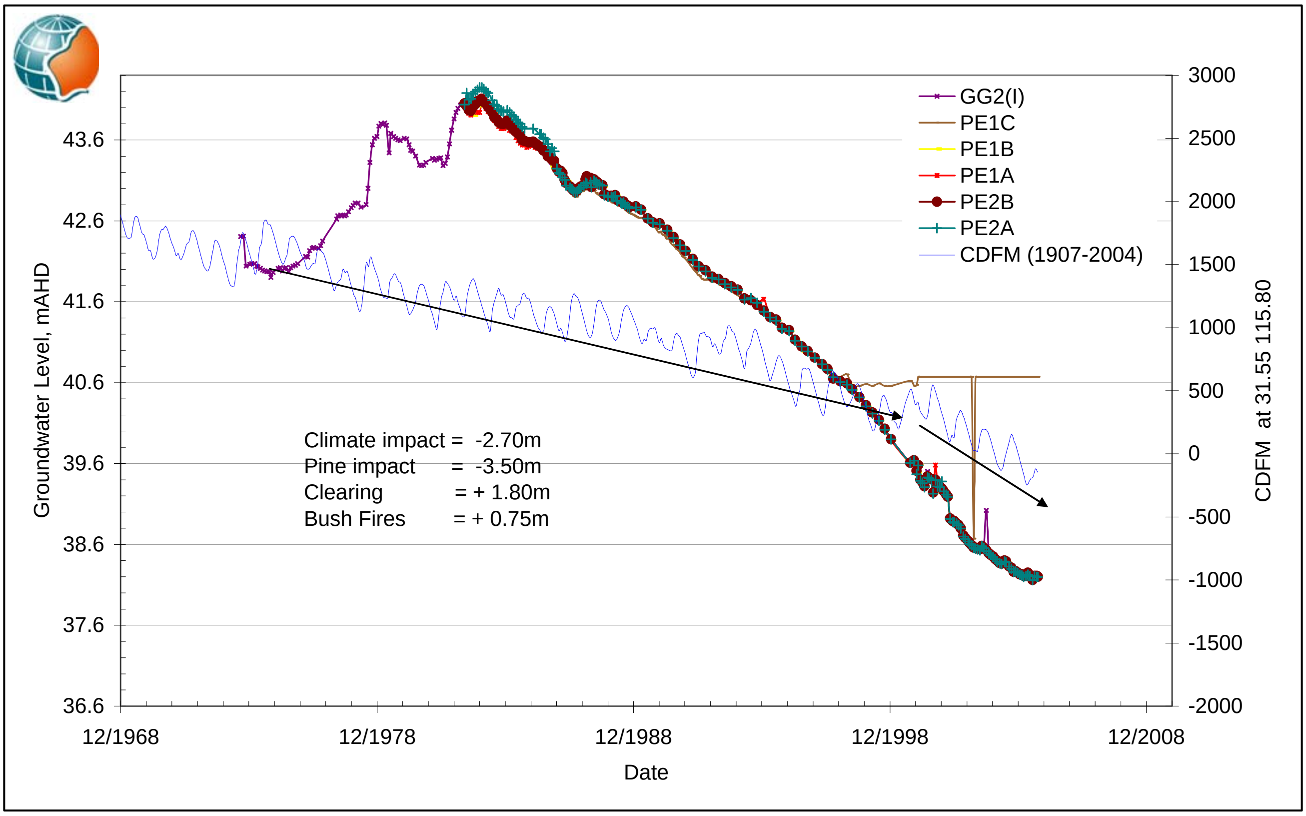

PM5
CDFM (1907-2004)
Gnangara Mound Native Bushland
Time Lag = 2 months
Climate Impact = - 3.1 m
Water Levels, mAHD
67.2
66.2
65.2
64.2
63.2
62.2
61.2
60.2
CDFM 31.55 115.90
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

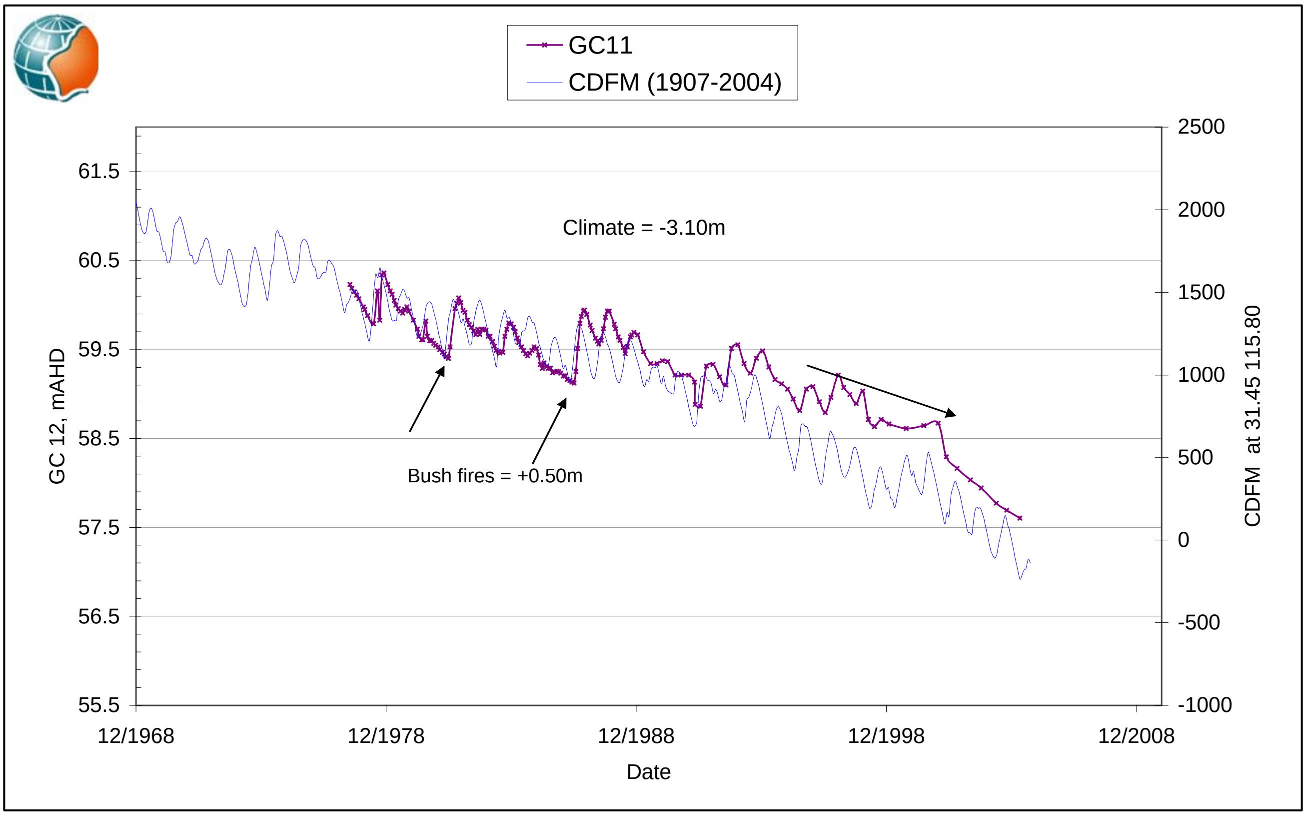

PM6 is ~2km east of the Superficial and Confined abstraction bores
2 months lag
Climate impact = -2.70m
Water Levels, mAHD
57.0
56.0
55.0
54.0
53.0
52.0
51.0
CDFM (31.60 115.85) mm & Abstraction ML/10
2000
1500
1000
500
0
-500
-1000
-1500
12/1968
12/1978
12/1988
12/1998
12/2008
-1.8m
PM6
CDFM (1907-2004)
Superficial abstraction cumulative(P90+P100)ML/10
Confined abstraction cumulative (P97)ML/10
Confined abstraction cumulative (P105)ML/10
Abstraction impact = -1.8m

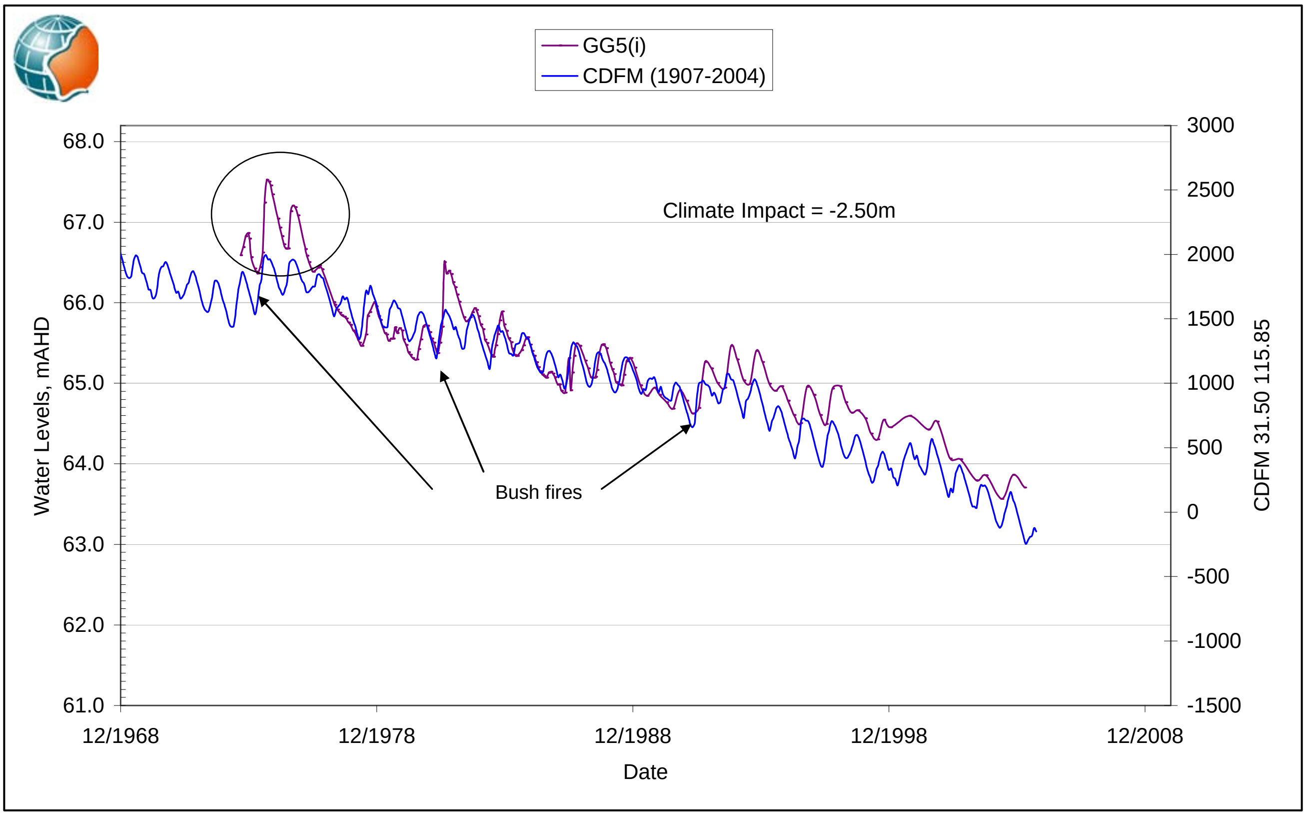

PM8
CDFM (1907-2004)
Water Levels, mAHD
72.4
71.4
70.4
69.4
68.4
67.4
66.4
65.4
CDFM 31.60 115.85
2500
2000
1500
1000
500
0
-500
-1000
Climate = -3.05m
Bush fires = +1.4m
12/1968
12/1978
12/1988
12/1998
12/2008
Date

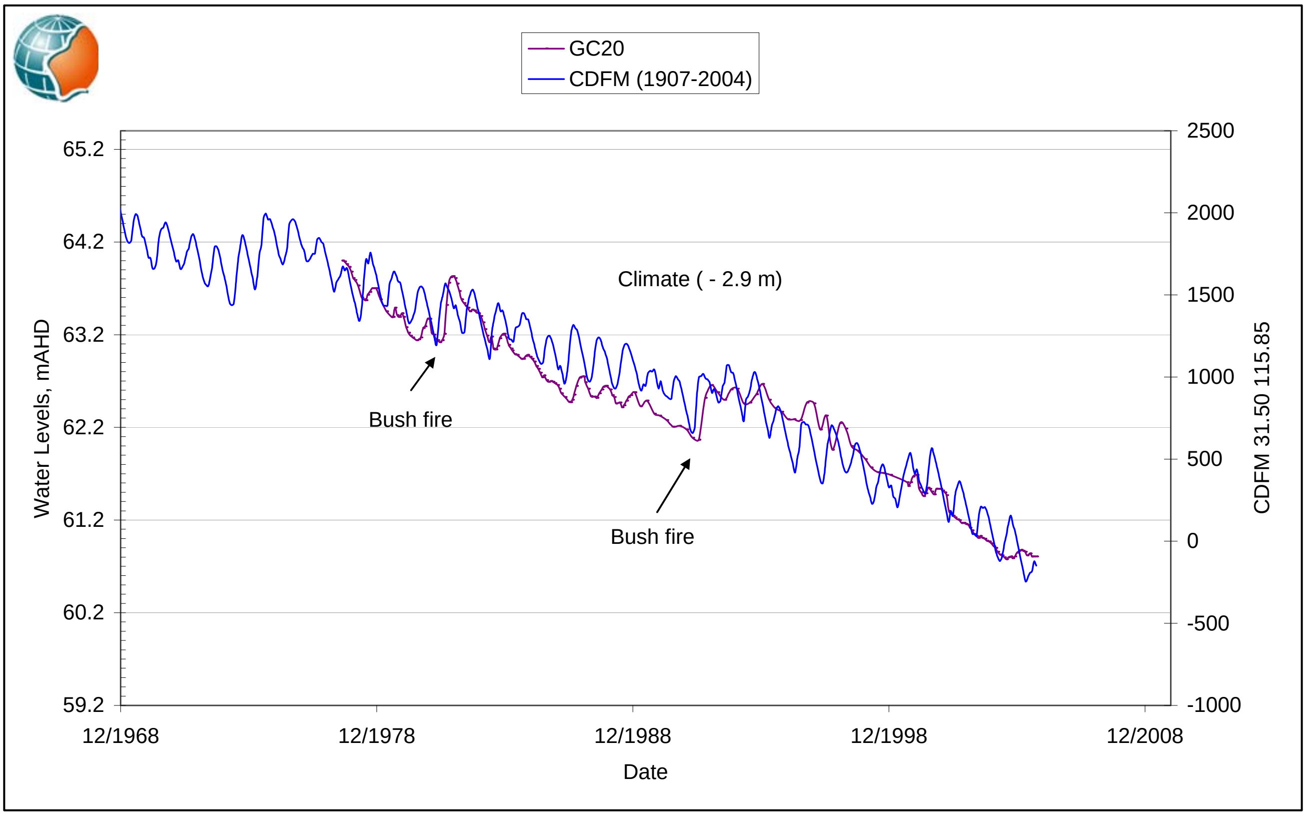

PM15
CDFM (1907-2004)
Groundwater Level, mAHD
38.8
37.8
36.8
35.8
34.8
33.8
32.8
31.8
CDFM at 115.75 -31.55
3000
2500
2000
1500
1000
500
0
-500
-1000
Best fitted
Climate = ~-2.50m
Pine = ~-3.00m
Pine impact
Pine plantion year is 1977
There is not enough monitoring in early stages
before planting to predict the impact
12/1968
12/1978
12/1988
12/1998
12/2008
Date

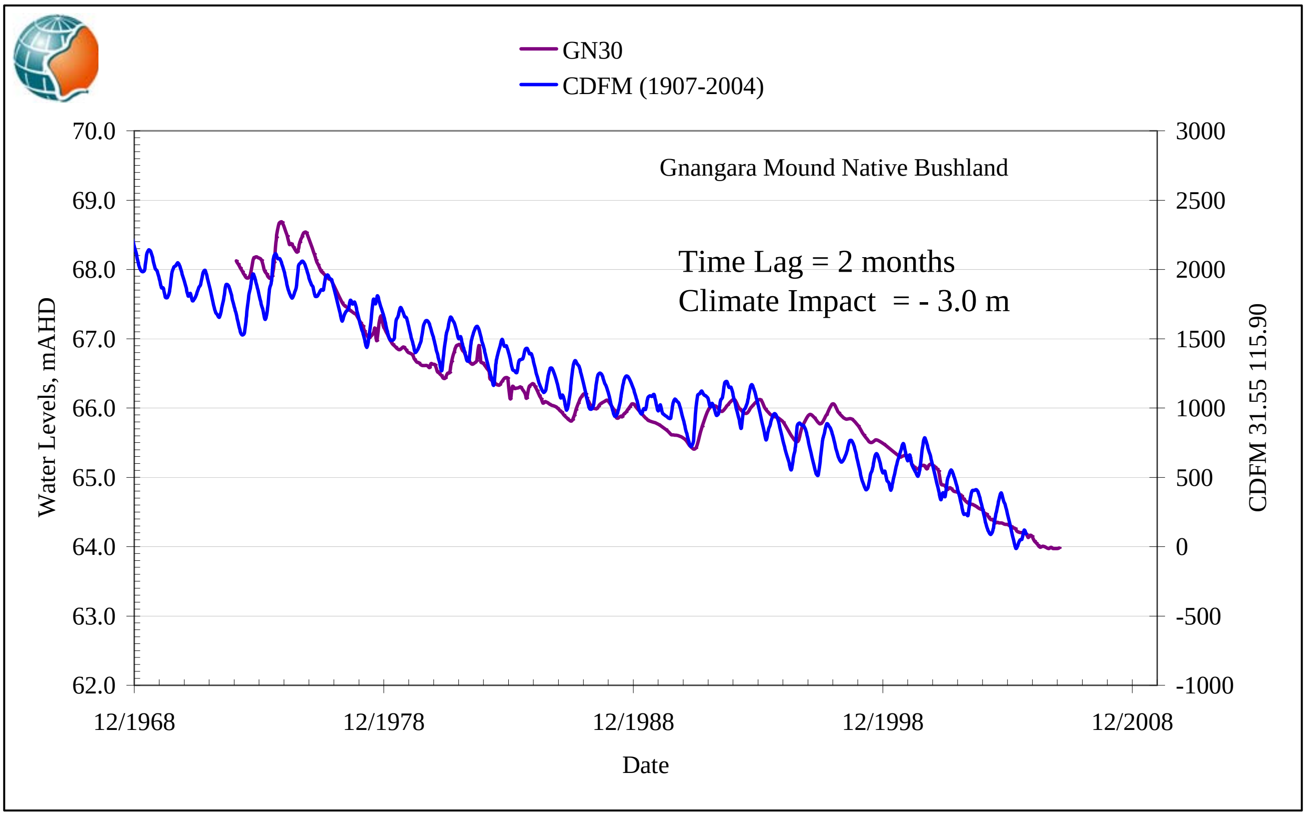

PM19
CDFM (1907-2004)
Planting year = 1977
Climate =-2.50m
Pine = -2.30m
Clearing = +0.70
Groundwater Level, mAHD
40.6
38.6
36.6
34.6
CDFM at 115.80 -31.55
2500
2000
1500
1000
500
0
-500
-1000
-1500
12/1968
12/1978
12/1988
12/1998
12/2008
Date

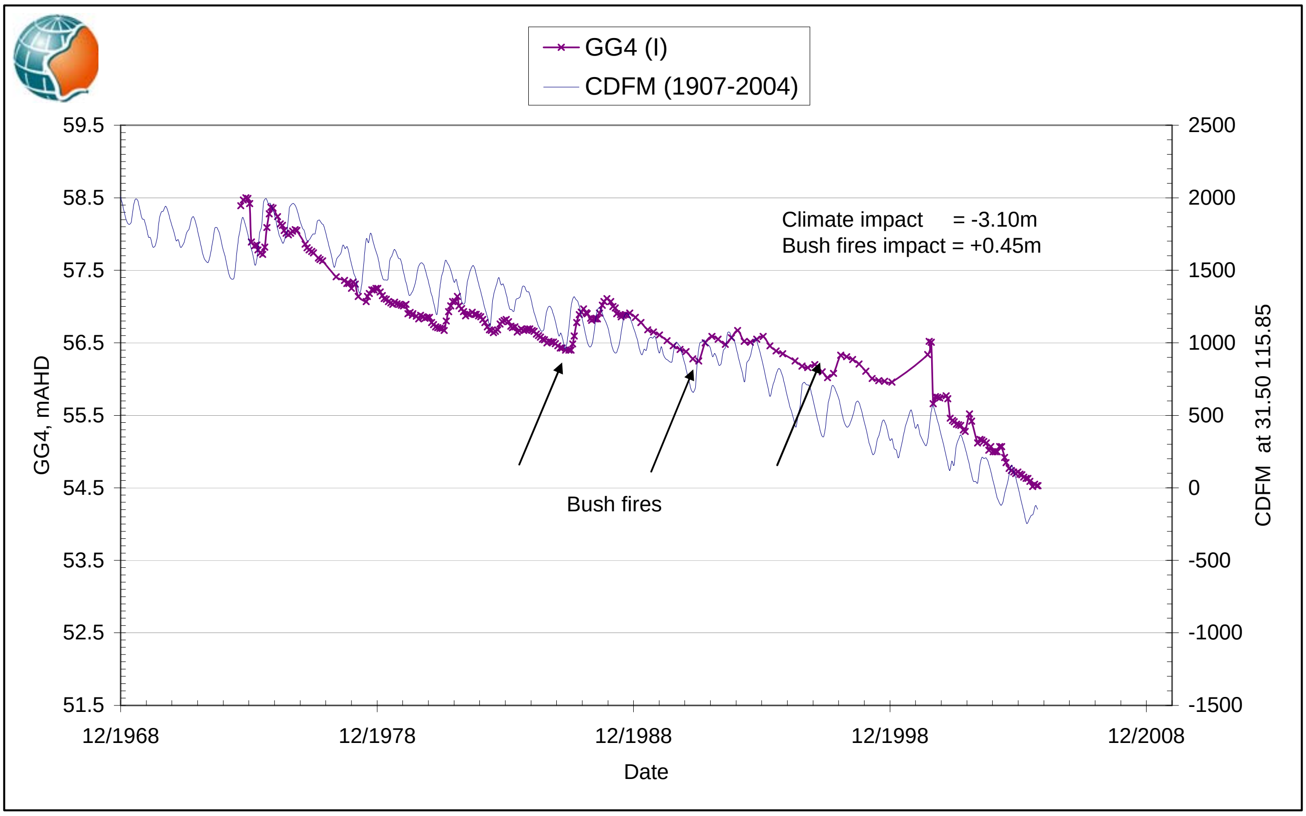

GG2(I)
PE1C
PE1B
PE1A
PE2B
PE2A
CDFM (1907-2004)
Climate impact = -2.70m
Pine impact = -3.50m
Clearing = + 1.80m
Bush Fires = + 0.75m
Groundwater Level, mAHD
43.6
42.6
41.6
40.6
39.6
38.6
37.6
36.6
CDFM at 31.55 115.80
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

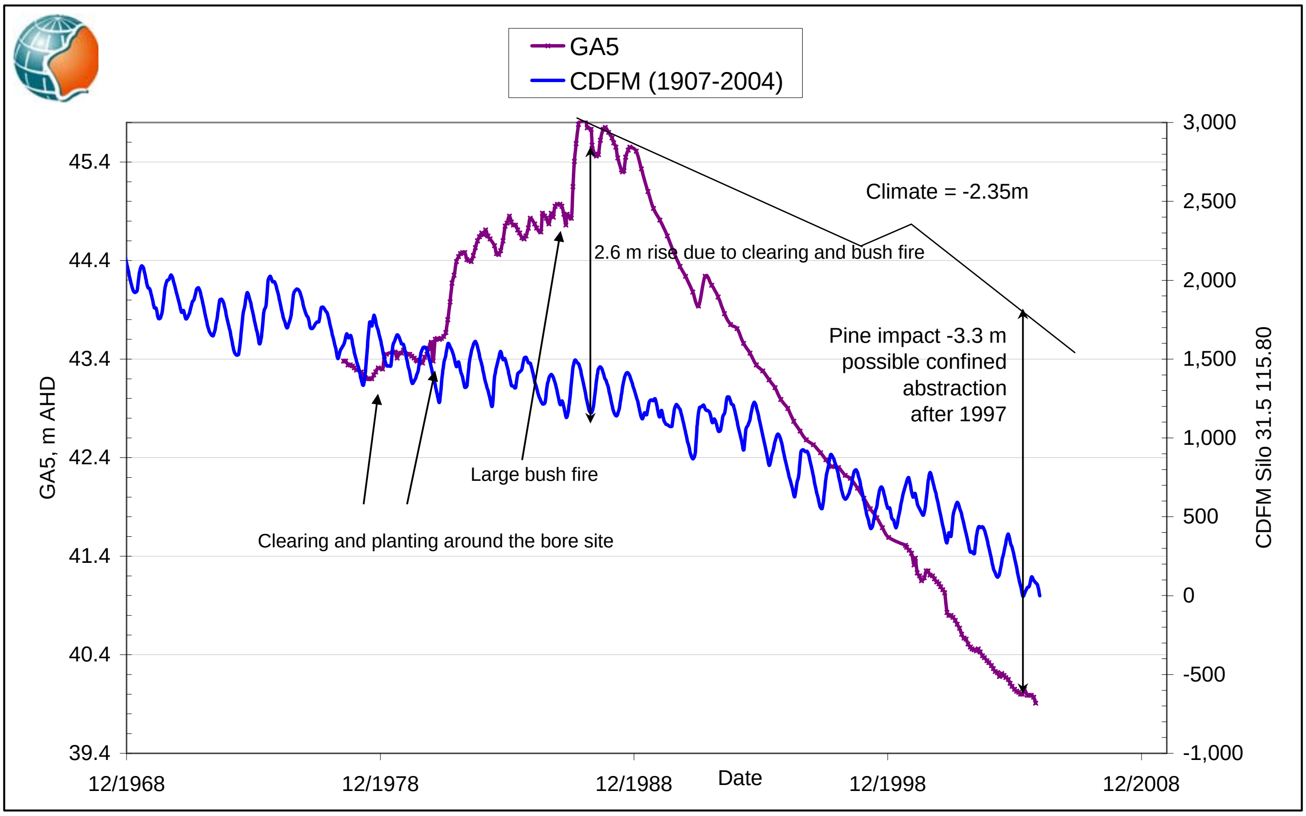

GC11
CDFM (1907-2004)
Climate = -3.10m
Bush fires = +0.50m
GC 12, mAHD
61.5
60.5
59.5
58.5
57.5
56.5
55.5
CDFM at 31.45 115.80
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

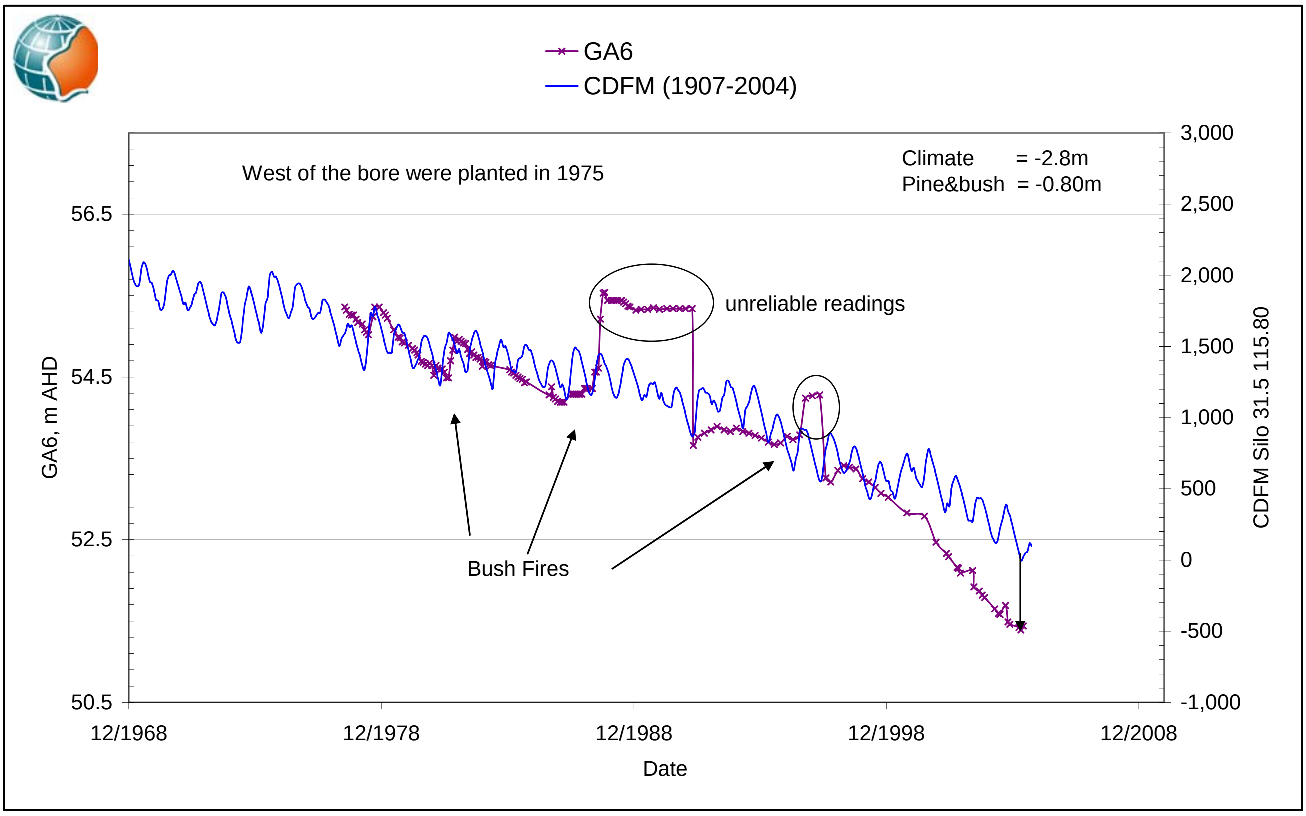

GG5(i)
CDFM (1907-2004)
Climate Impact = -2.50m
Bush fires
Water Levels, mAHD
68.0
67.0
66.0
65.0
64.0
63.0
62.0
61.0
CDFM 31.50 115.85
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
12/1968
12/1978
12/1988
12/1998
12/2008
Date

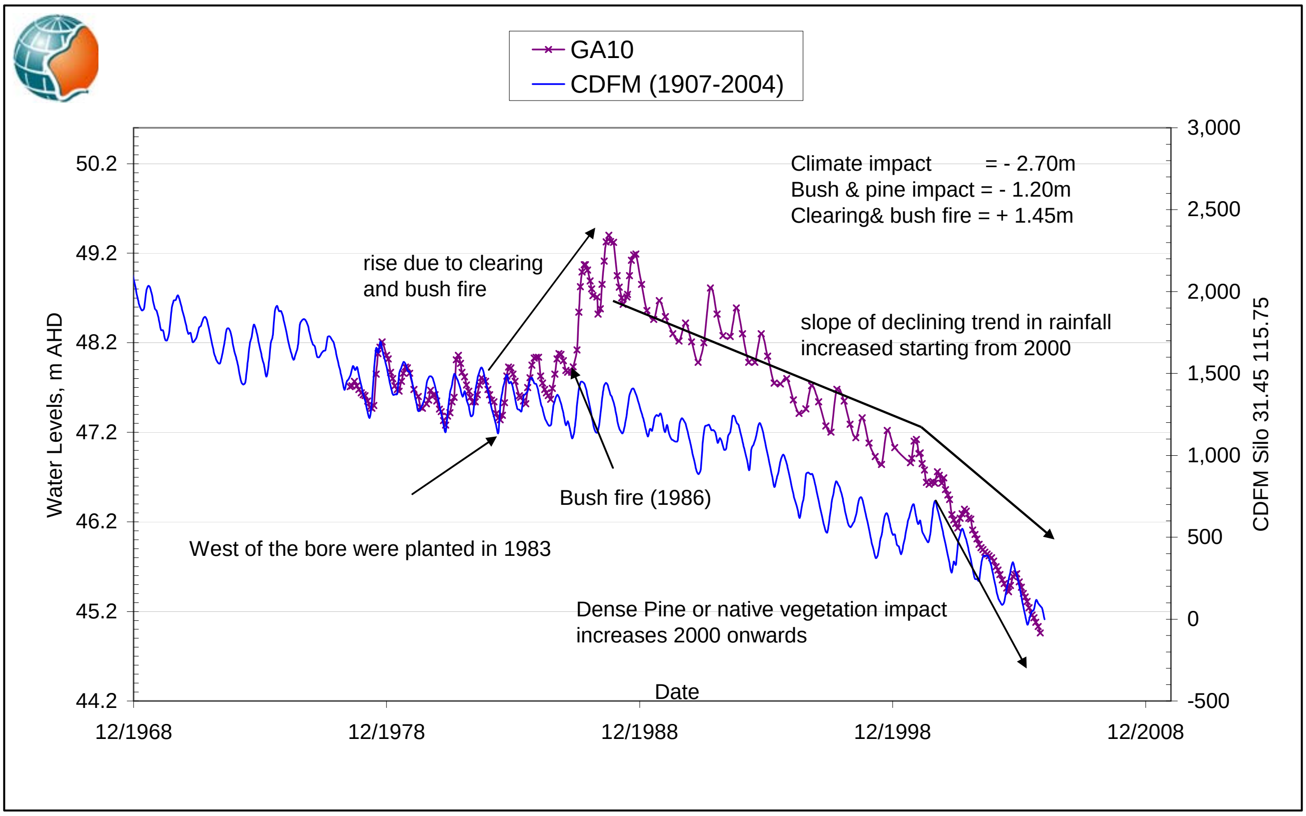

GC20
CDFM (1907-2004)
Water Levels, mAHD
65.2
64.2
63.2
62.2
61.2
60.2
59.2
CDFM 31.50 115.85
2500
2000
1500
1000
500
0
-500
-1000
Climate (- 2.9 m)
Bush fire
Bush fire
12/1968
12/1978
12/1988
12/1998
12/2008
Date


GN30
CDFM (1907-2004)
Gnangara Mound Native Bushland
Time Lag = 2 months
Climate Impact = - 3.0 m
Water Levels, mAHD
70.0
69.0
68.0
67.0
66.0
65.0
64.0
63.0
62.0
CDFM 31.55 115.90
3000
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date


GG4 (I)
CDFM (1907-2004)
Climate impact = -3.10m
Bush fires impact = +0.45m
Bush fires
GG4, mAHD
59.5
58.5
57.5
56.5
55.5
54.5
53.5
52.5
51.5
CDFM at 31.50 115.85
2500
2000
1500
1000
500
0
-500
-1000
-1500
12/1968
12/1978
12/1988
12/1998
12/2008
Date

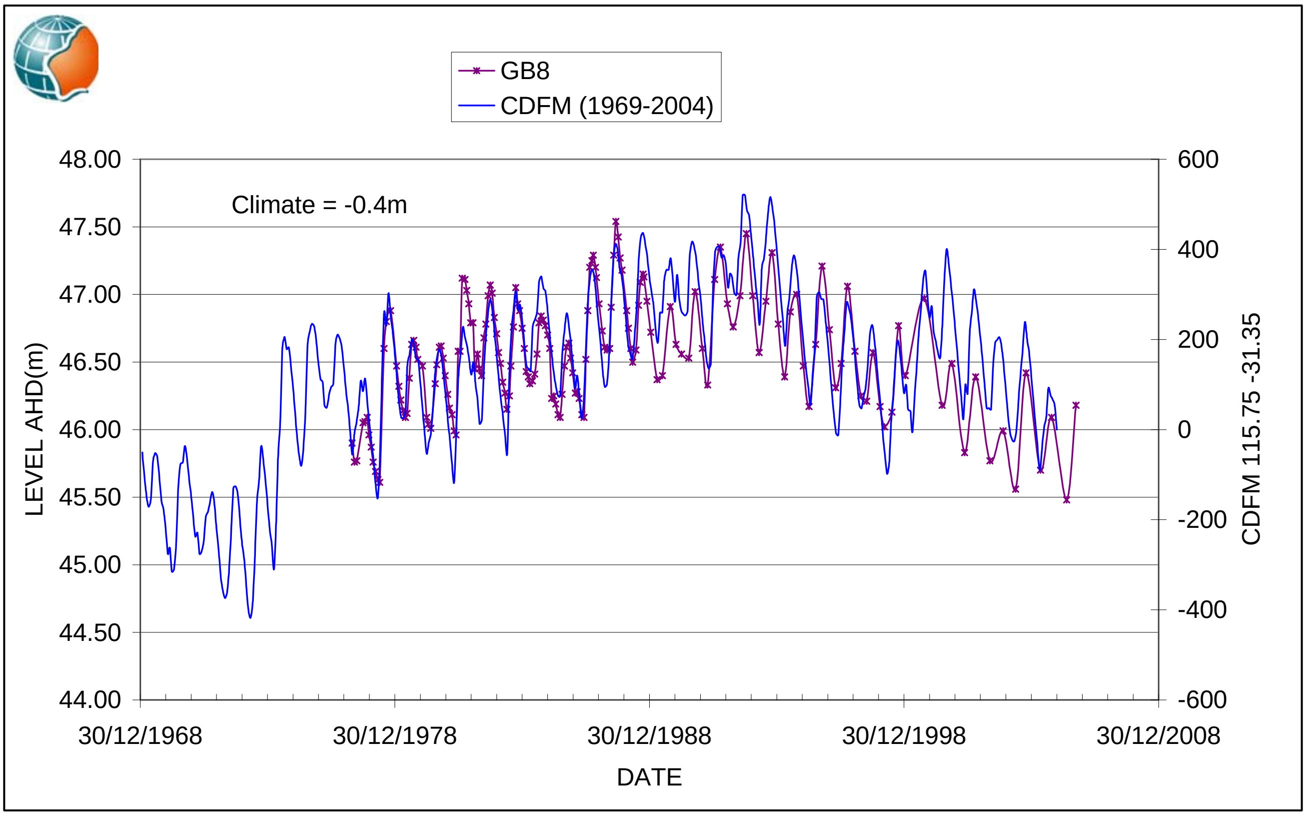

GA5
CDFM (1907-2004)
Climate = -2.35m
2.6 m rise due to clearing and bush fire
Pine impact -3.3 m
possible confined
abstraction
after 1997
Large bush fire
Clearing and planting around the bore site
GA5, m AHD
45.4
44.4
43.4
42.4
41.4
40.4
39.4
CDFM Silo 31.5 115.80
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

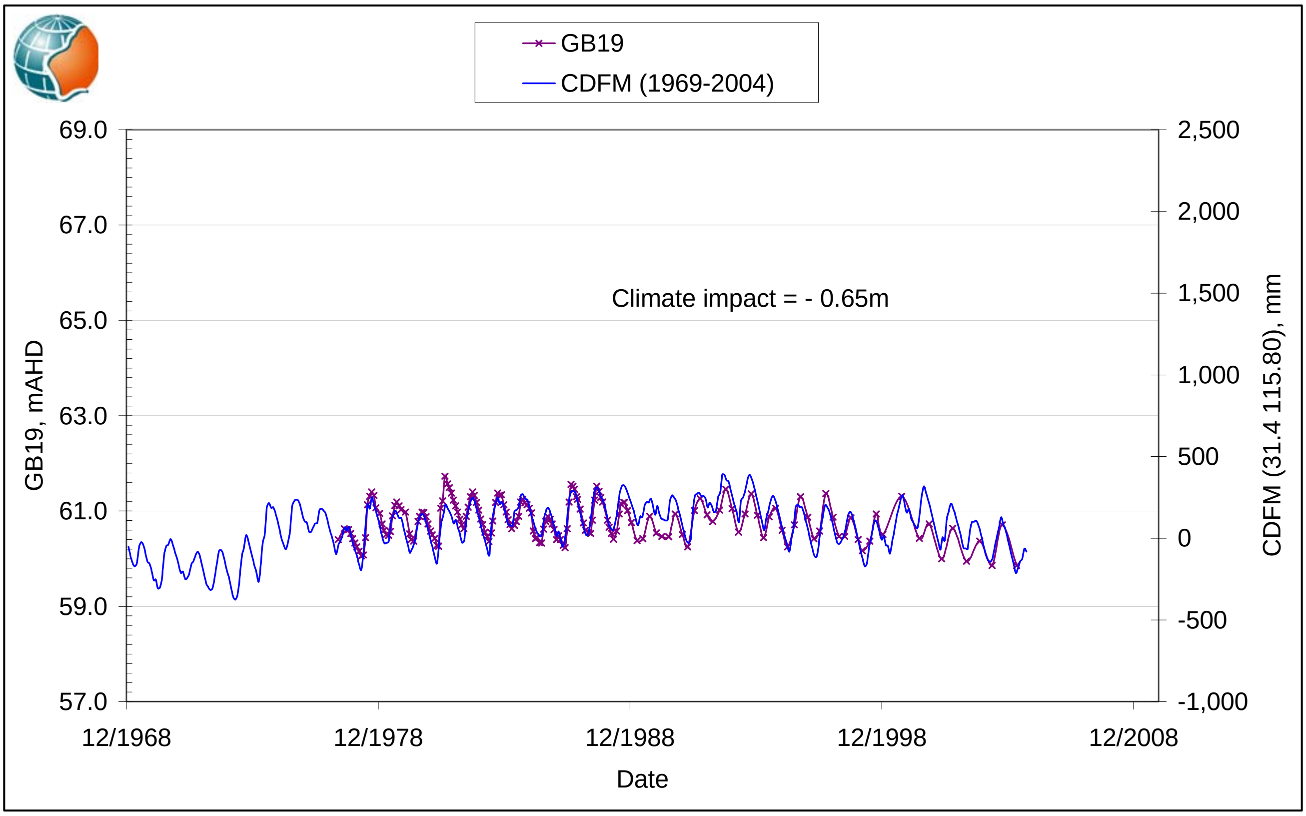

GA6
CDFM (1907-2004)
West of the bore were planted in 1975
Climate = -2.8m
Pine&bush = -0.80m
unreliable readings
Bush Fires
GA6, m AHD
56.5
54.5
52.5
50.5
CDFM Silo 31.5 115.80
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

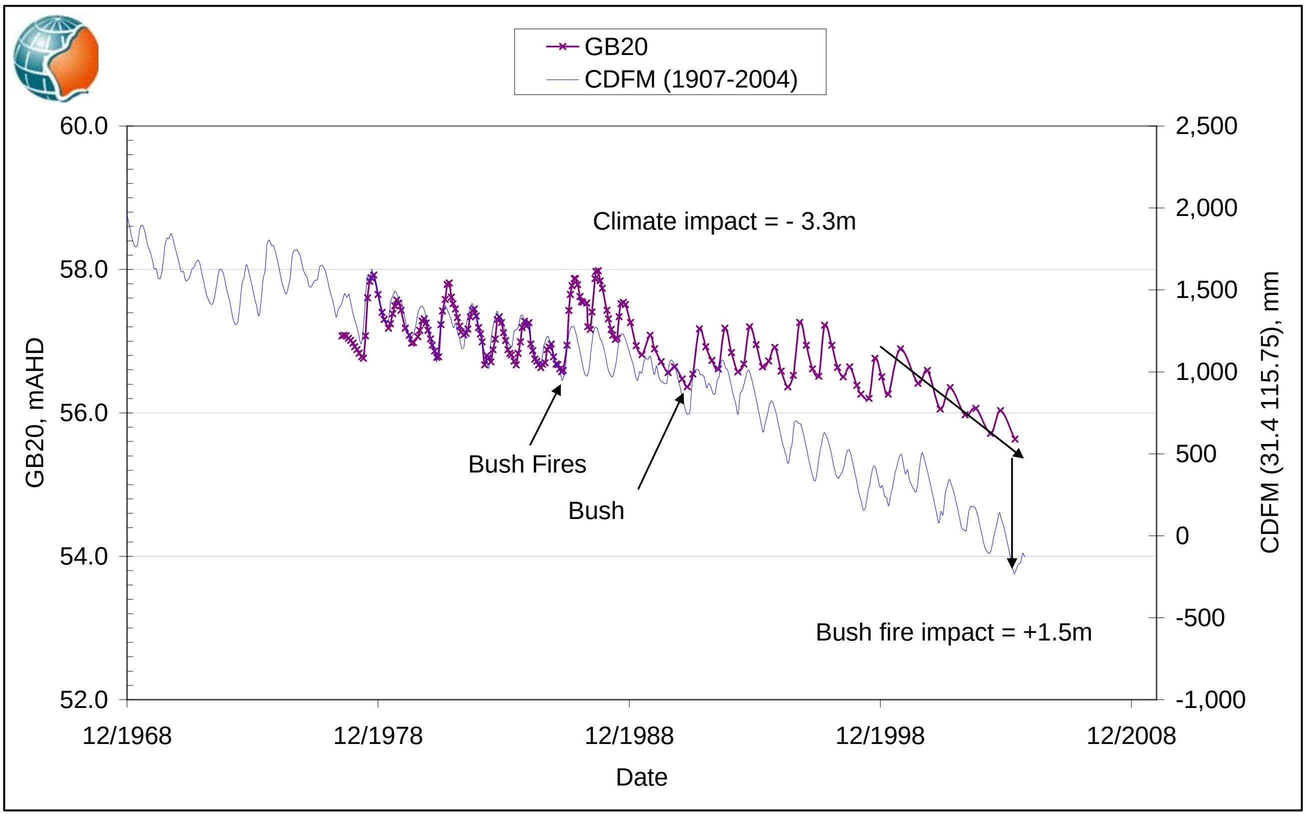

GA10
CDFM (1907-2004)
Climate impact = - 2.70m
Bush & pine impact = - 1.20m
Clearing& bush fire = + 1.45m
rise due to clearing and bush fire
slope of declining trend in rainfall increased starting from 2000
Bush fire (1986)
West of the bore were planted in 1983
Dense Pine or native vegetation impact increases 2000 onwards
Water Levels, m AHD
50.2
49.2
48.2
47.2
46.2
45.2
44.2
CDFM Silo 31.45 115.75
3,000
2,500
2,000
1,500
1,000
500
0
-500
Date
12/1968
12/1978
12/1988
12/1998
12/2008

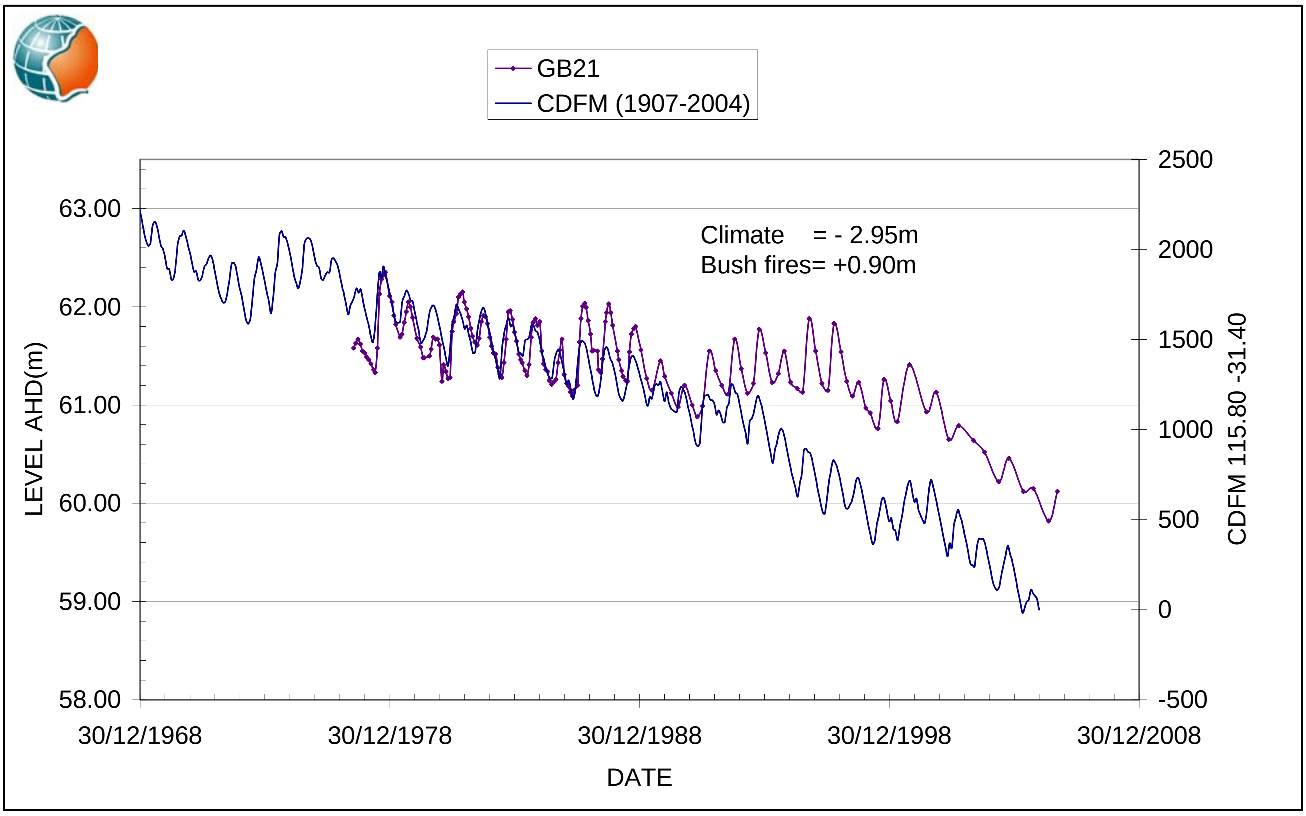
2. Gingin Rainfall Zone

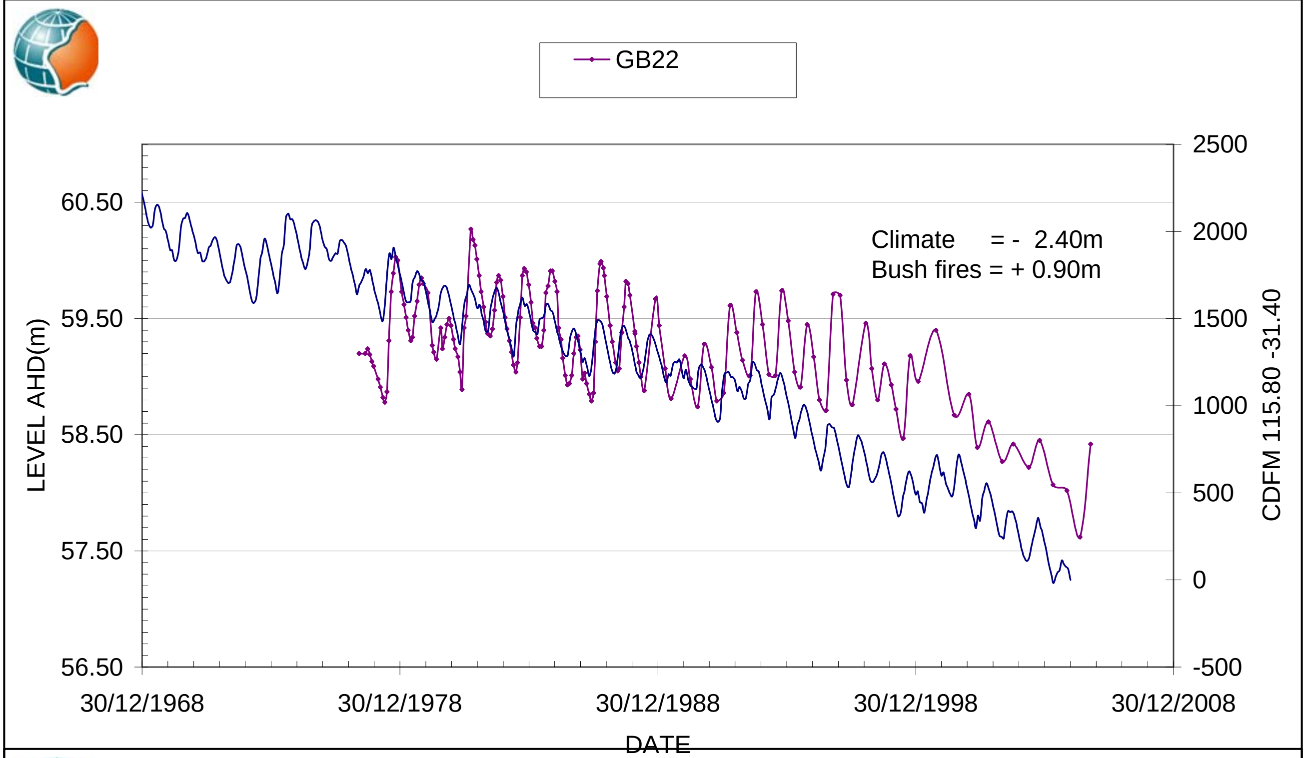
(GB8, GB19, GB20, GB21, GB22, GC9, GC12, GG9, YY7, YY9, GA21, GA31)

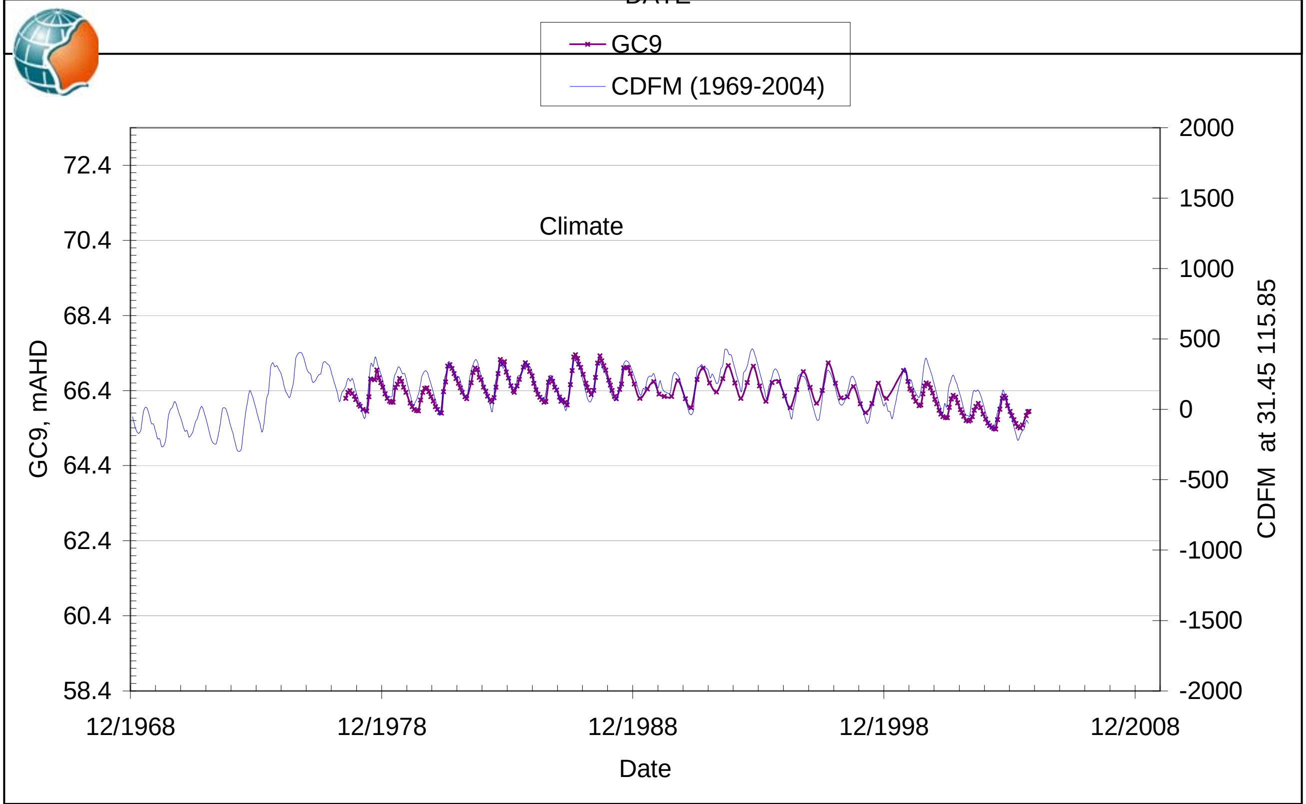

GB8
CDFM (1969-2004)
Climate = -0.4m
LEVEL AHD(m)
48.00
47.50
47.00
46.50
46.00
45.50
45.00
44.50
44.00
600
400
200
0
-200
-400
-600
CDFM 115.75 -31.35
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
DATE

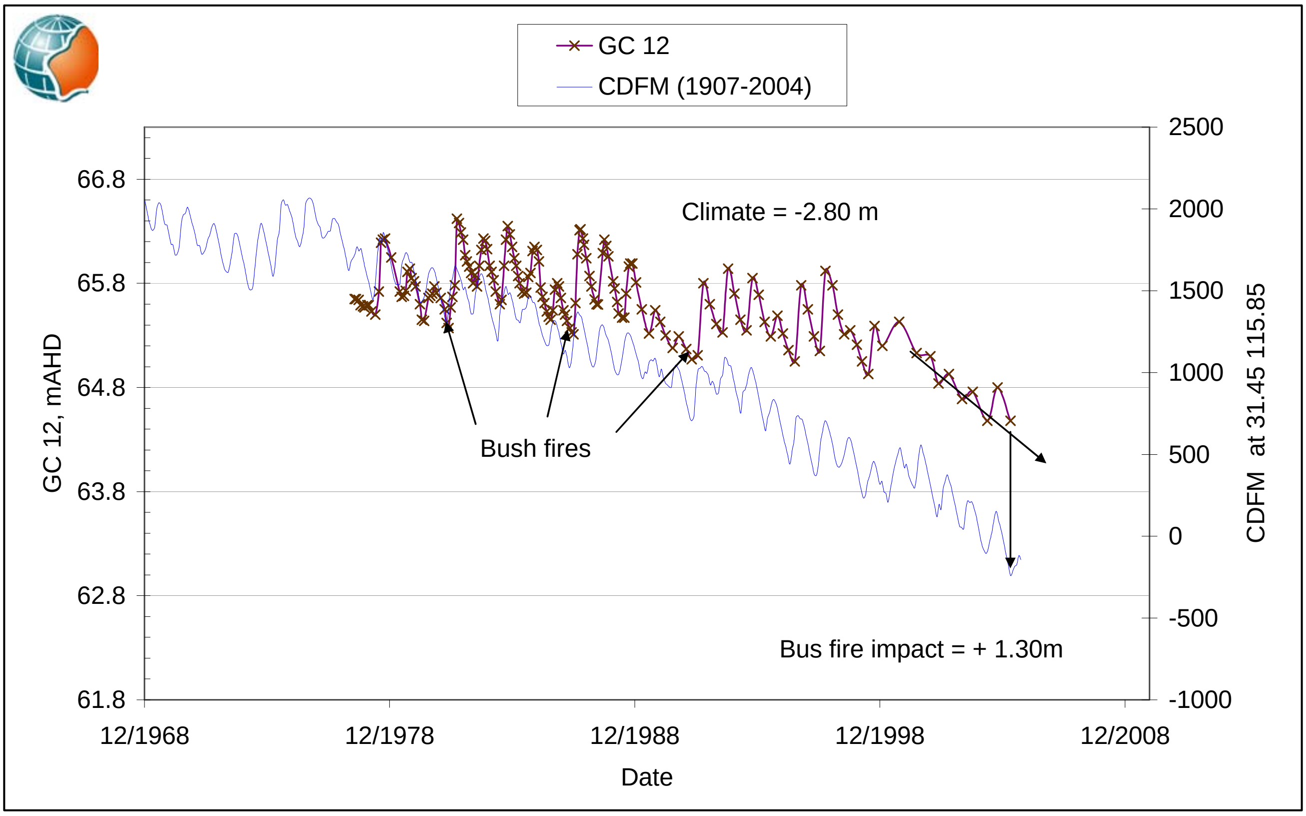

GB19
CDFM (1969-2004)
Climate impact = - 0.65m
GB19, mAHD
69.0
67.0
65.0
63.0
61.0
59.0
57.0
2,500
2,000
1,500
1,000
500
0
-500
-1,000
CDFM (31.4 115.80), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

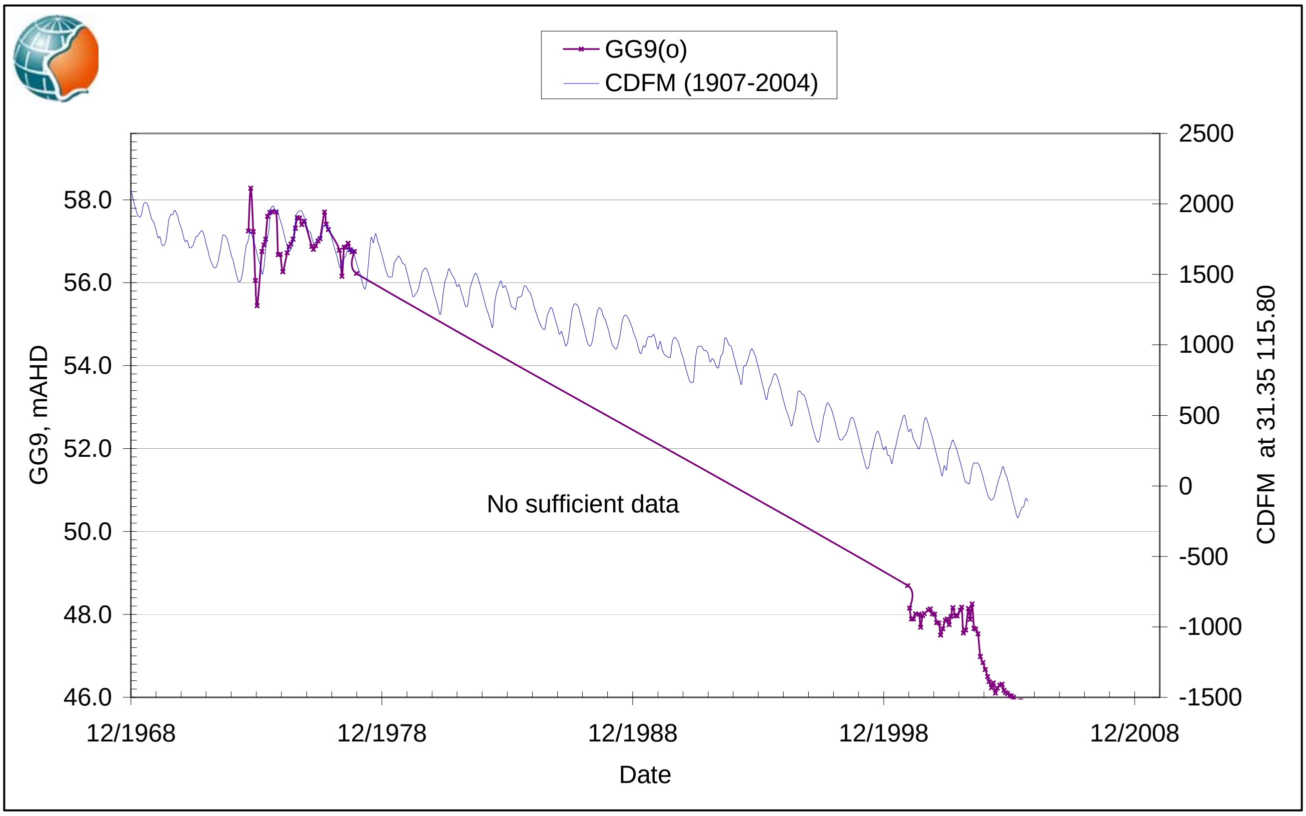

GB20
CDFM (1907-2004)
Climate impact = - 3.3m
Bush Fires
Bush
Bush fire impact = +1.5m
GB20, mAHD
60.0
58.0
56.0
54.0
52.0
CDFM (31.4 115.75), mm
2,500
2,000
1,500
1,000
500
0
-500
-1,000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

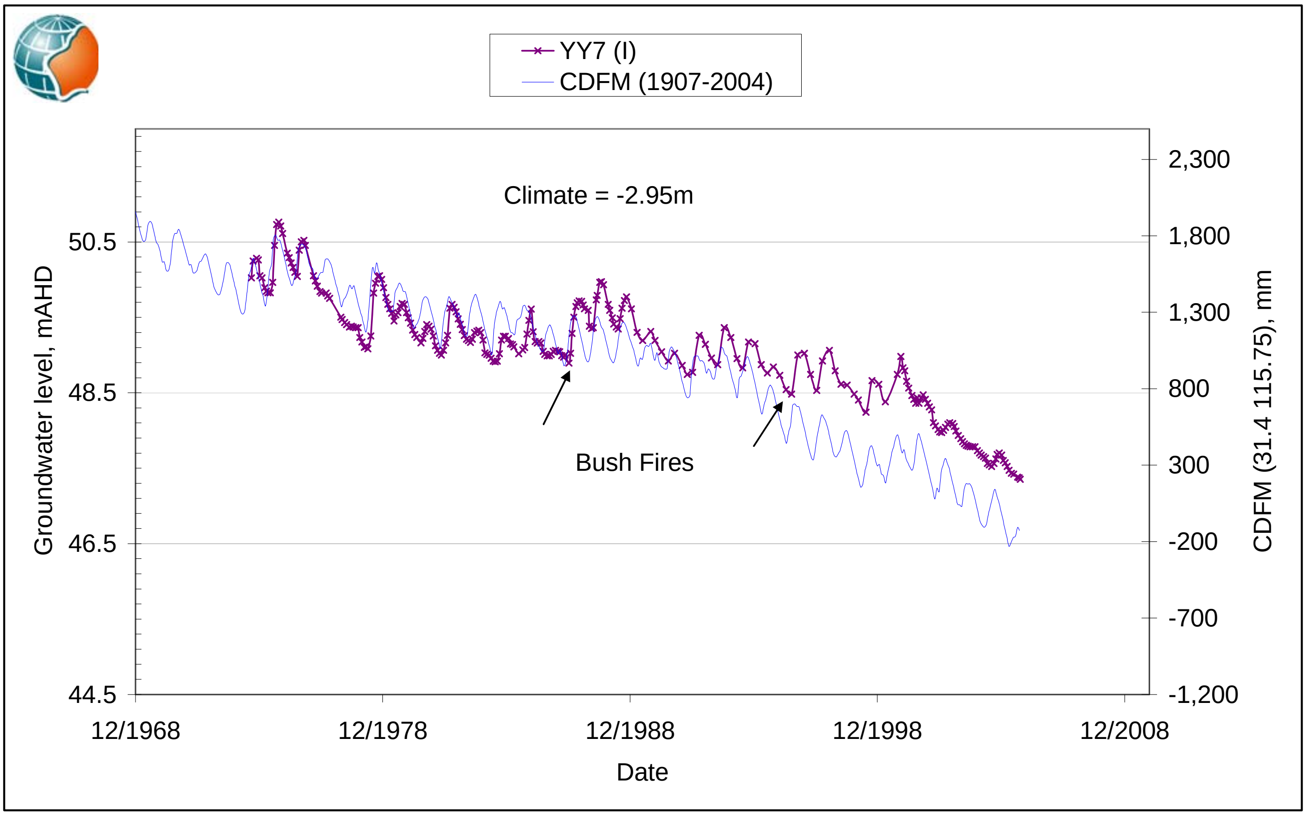

GB21
CDFM (1907-2004)
Climate = - 2.95m
Bush fires= +0.90m
LEVEL AHD(m)
63.00
62.00
61.00
60.00
59.00
58.00
CDFM 115.80 -31.40
2500
2000
1500
1000
500
0
-500
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
DATE

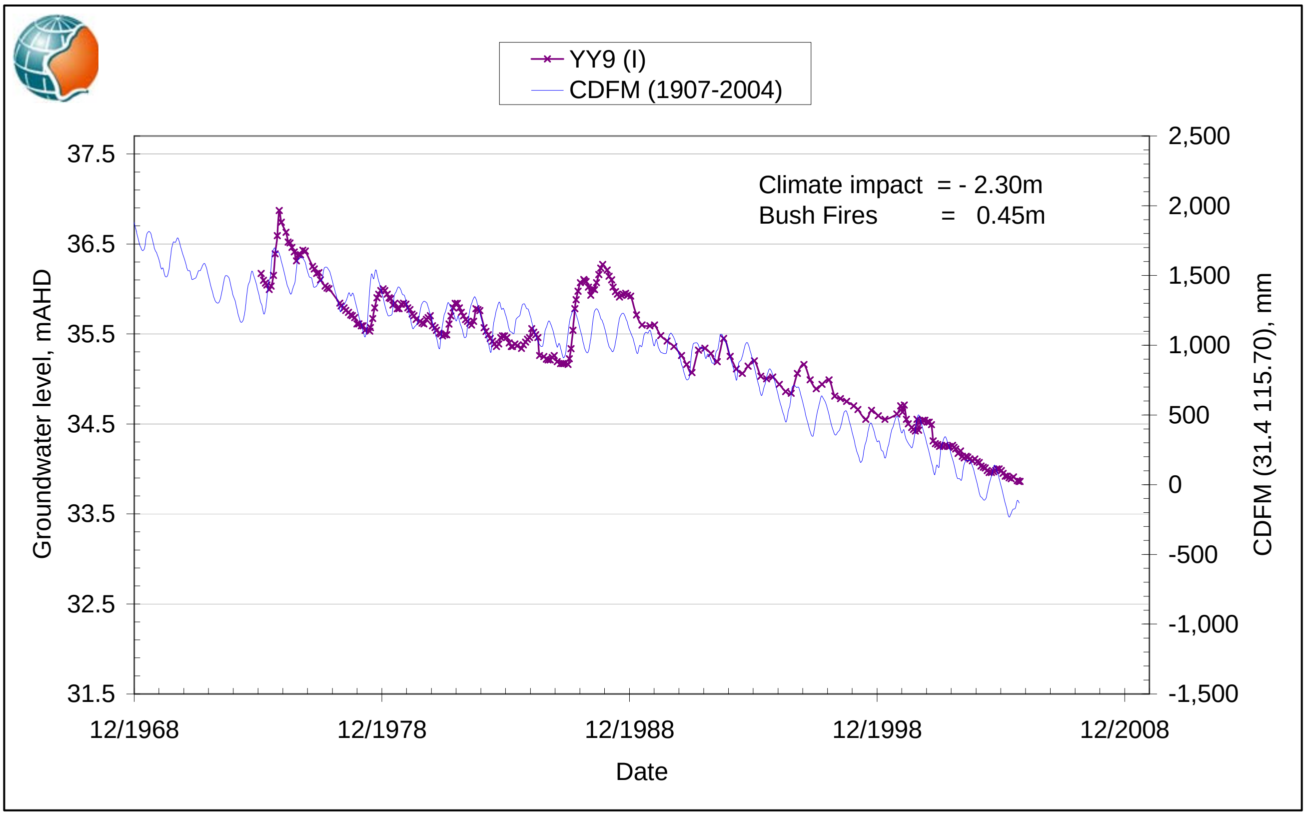

GB22
Climate = - 2.40m
Bush fires = + 0.90m
LEVEL AHD(m)
60.50
59.50
58.50
57.50
56.50
2500
2000
1500
1000
500
0
-500
CDFM 115.80 -31.40
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
DATE

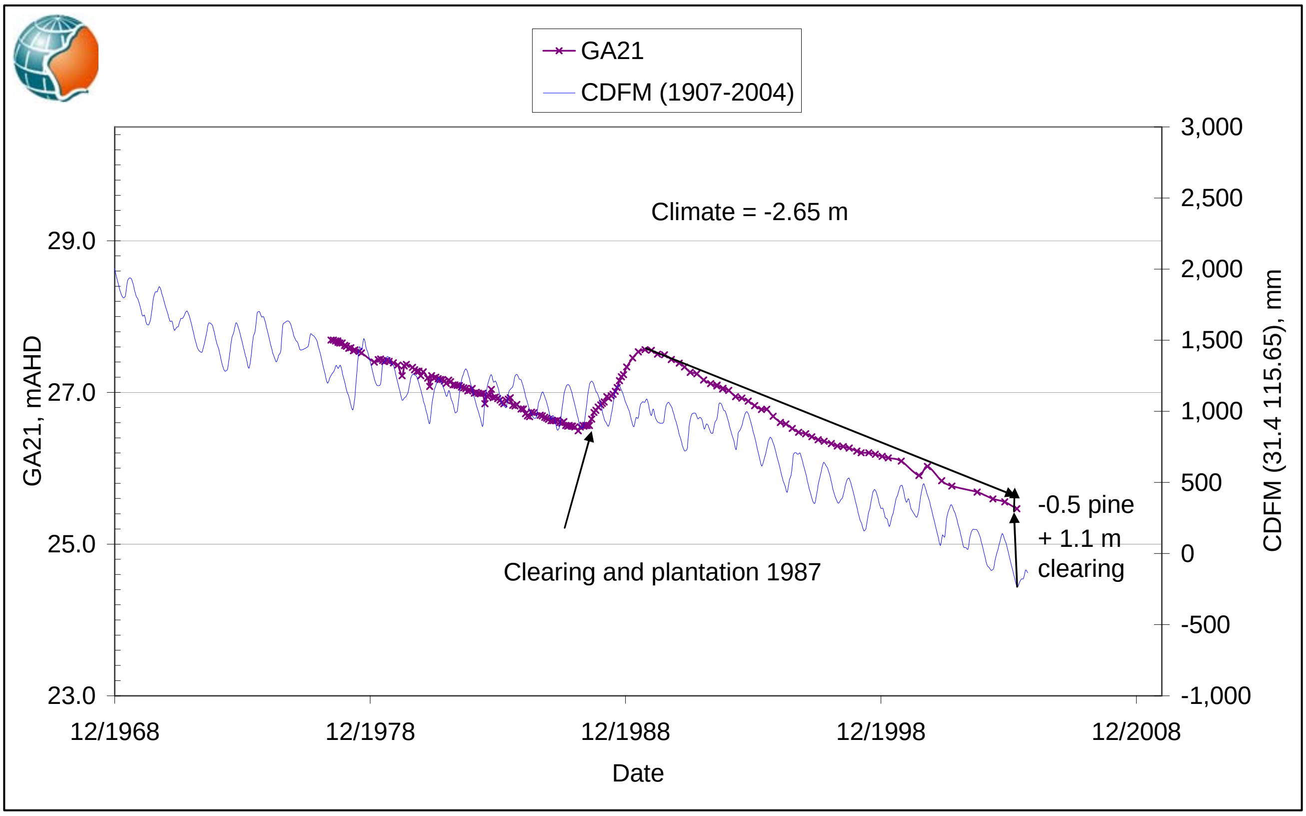

GC9
CDFM (1969-2004)
Climate
GC9, mAHD
72.4
70.4
68.4
66.4
64.4
62.4
60.4
58.4
2000
1500
1000
500
0
-500
-1000
-1500
-2000
CDFM at 31.45 115.85
12/1968
12/1978
12/1988
12/1998
12/2008
Date

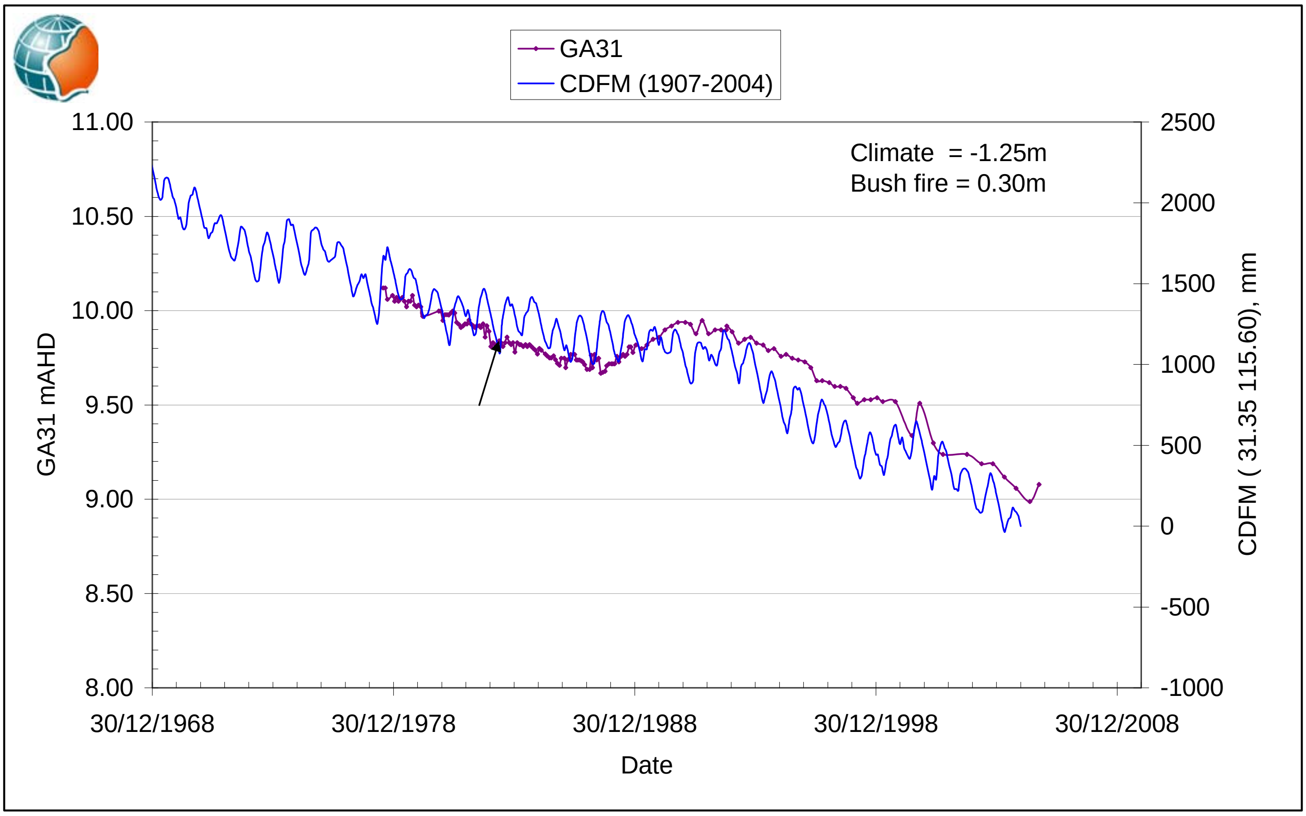

GC 12
CDFM (1907-2004)
Climate = -2.80 m
Bush fires
Bus fire impact = + 1.30m
GC 12, mAHD
66.8
65.8
64.8
63.8
62.8
61.8
CDFM at 31.45 115.85
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date


GG9(o)
CDFM (1907-2004)
No sufficient data
GG9, mAHD
58.0
56.0
54.0
52.0
50.0
48.0
46.0
CDFM at 31.35 115.80
2500
2000
1500
1000
500
0
-500
-1000
-1500
12/1968
12/1978
12/1988
12/1998
12/2008
Date


YY7 (I)
CDFM (1907-2004)
Climate = -2.95m
Bush Fires
Groundwater level, mAHD
50.5
48.5
46.5
44.5
2,300
1,800
1,300
800
300
-200
-700
-1,200
CDFM (31.4 115.75), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

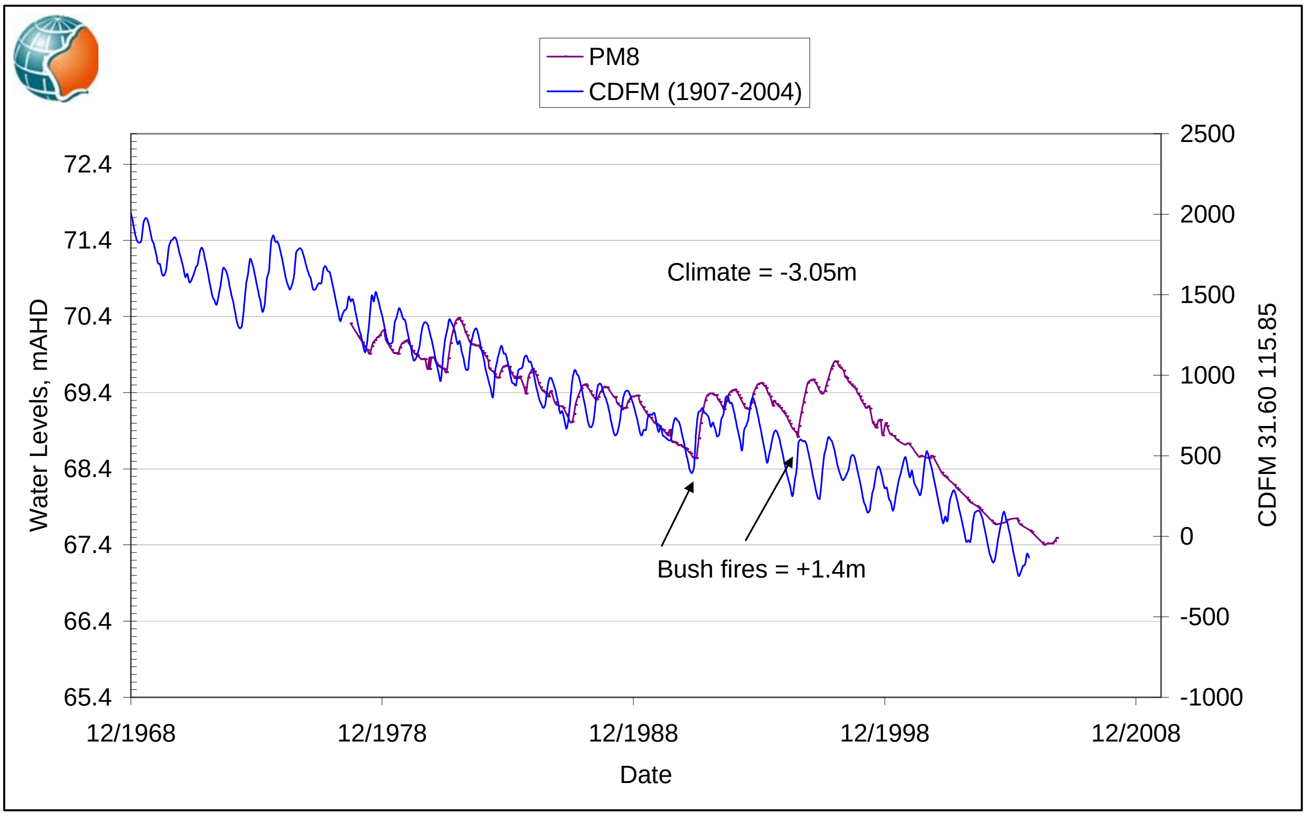

YY9 (I)
CDFM (1907-2004)
Climate impact = - 2.30m
Bush Fires = 0.45m
Groundwater level, mAHD
37.5
36.5
35.5
34.5
33.5
32.5
31.5
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
CDFM (31.4 115.70), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

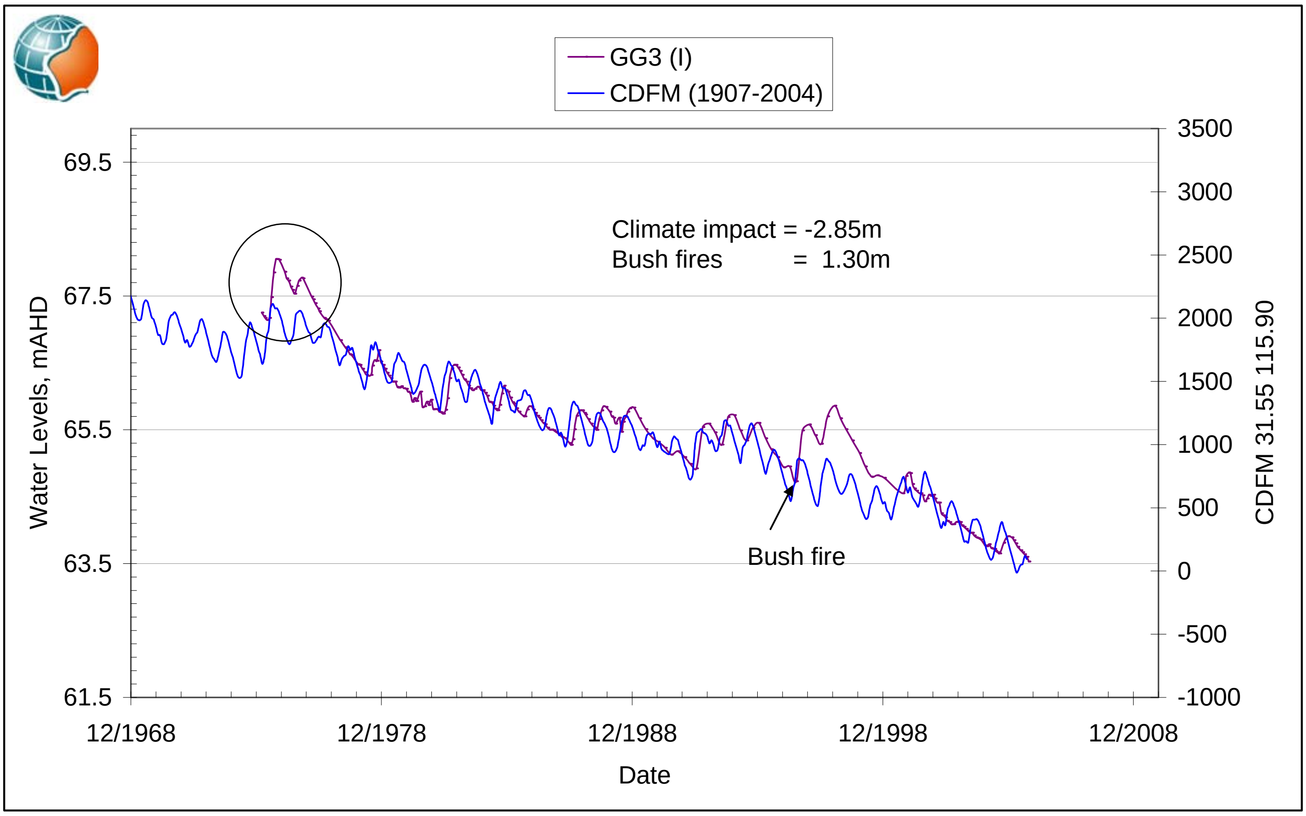

GA21
CDFM (1907-2004)
Climate = -2.65 m
Clearing and plantation 1987
-0.5 pine
+ 1.1 m
clearing
GA21, mAHD
29.0
27.0
25.0
23.0
CDFM (31.4 115.65), mm
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

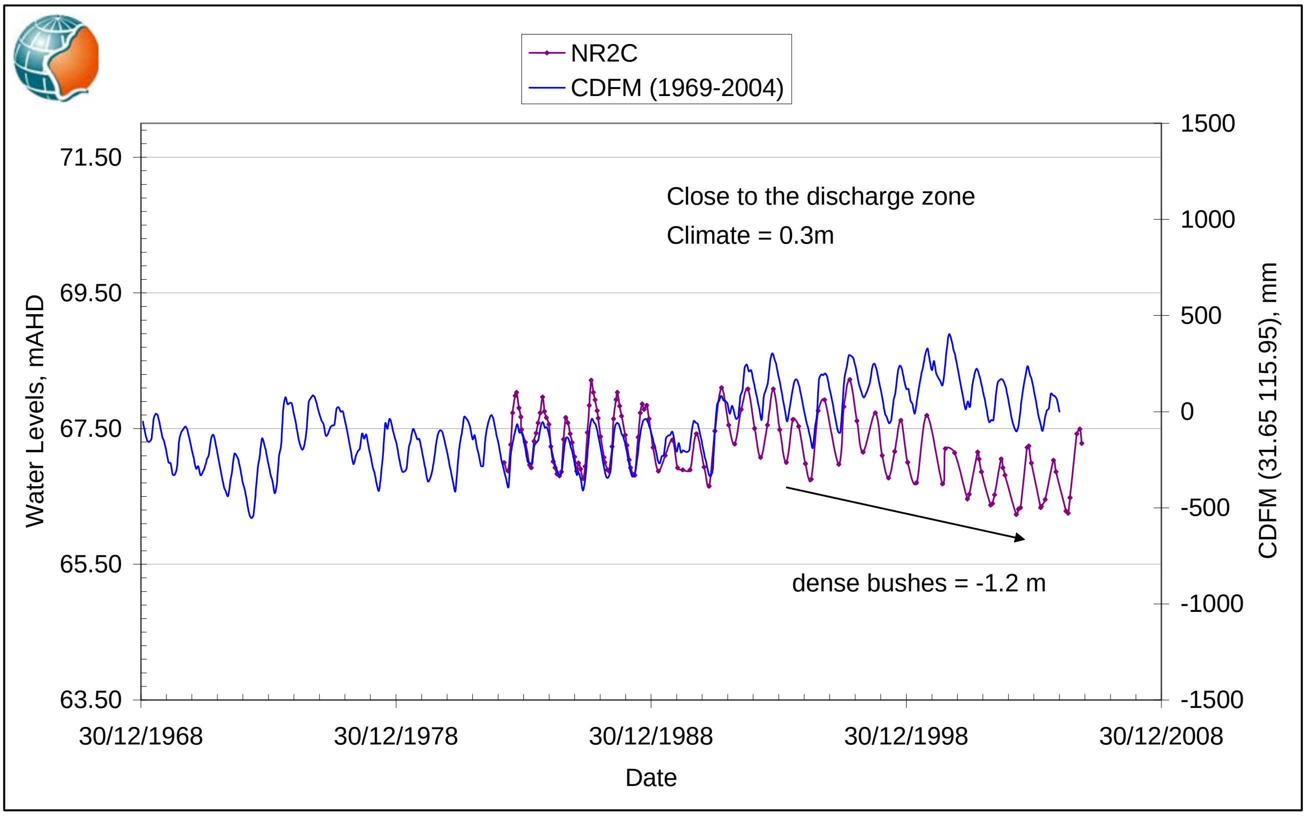

GA31
CDFM (1907-2004)
Climate = -1.25m
Bush fire = 0.30m
GA31 mAHD
11.00
10.50
10.00
9.50
9.00
8.50
8.00
CDFM (31.35 115.60), mm
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

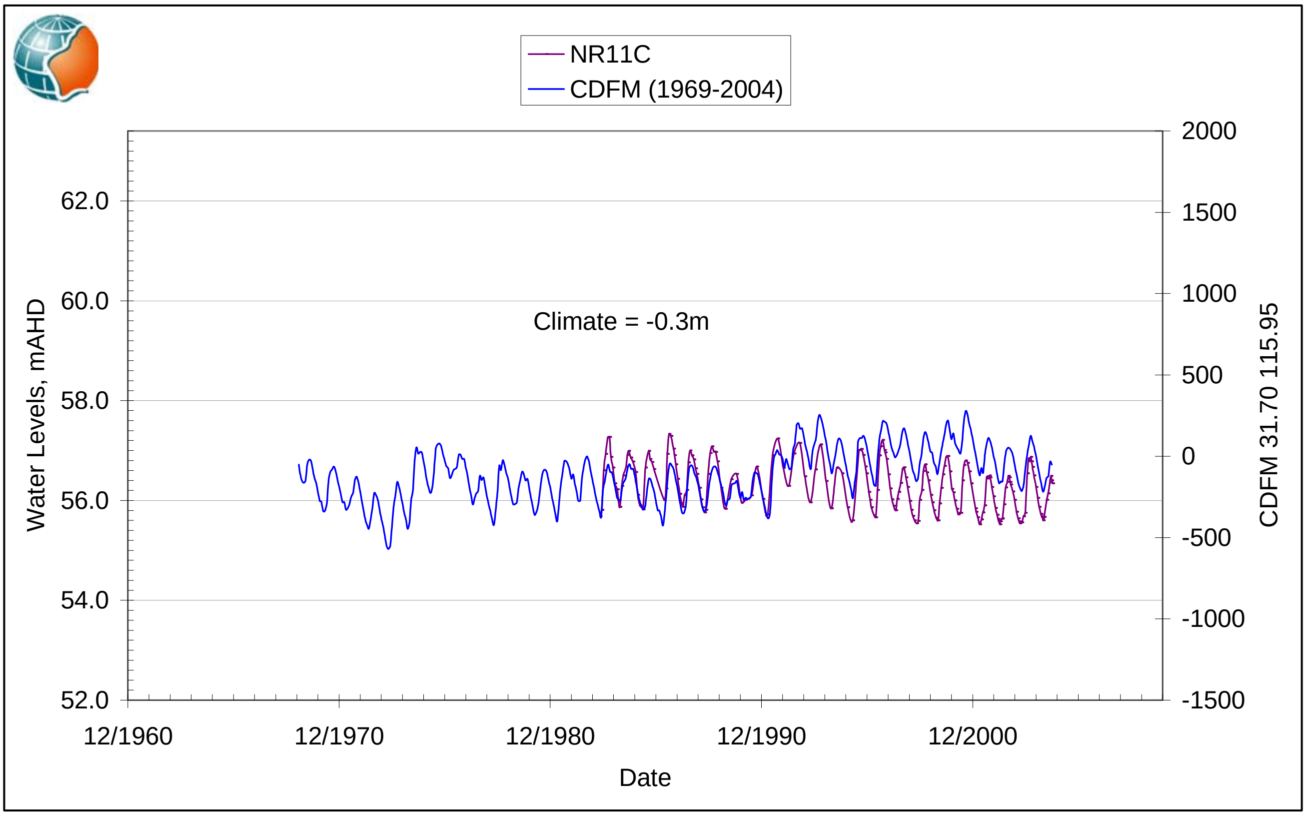
3. Muchea and Pearce Rainfall Zones

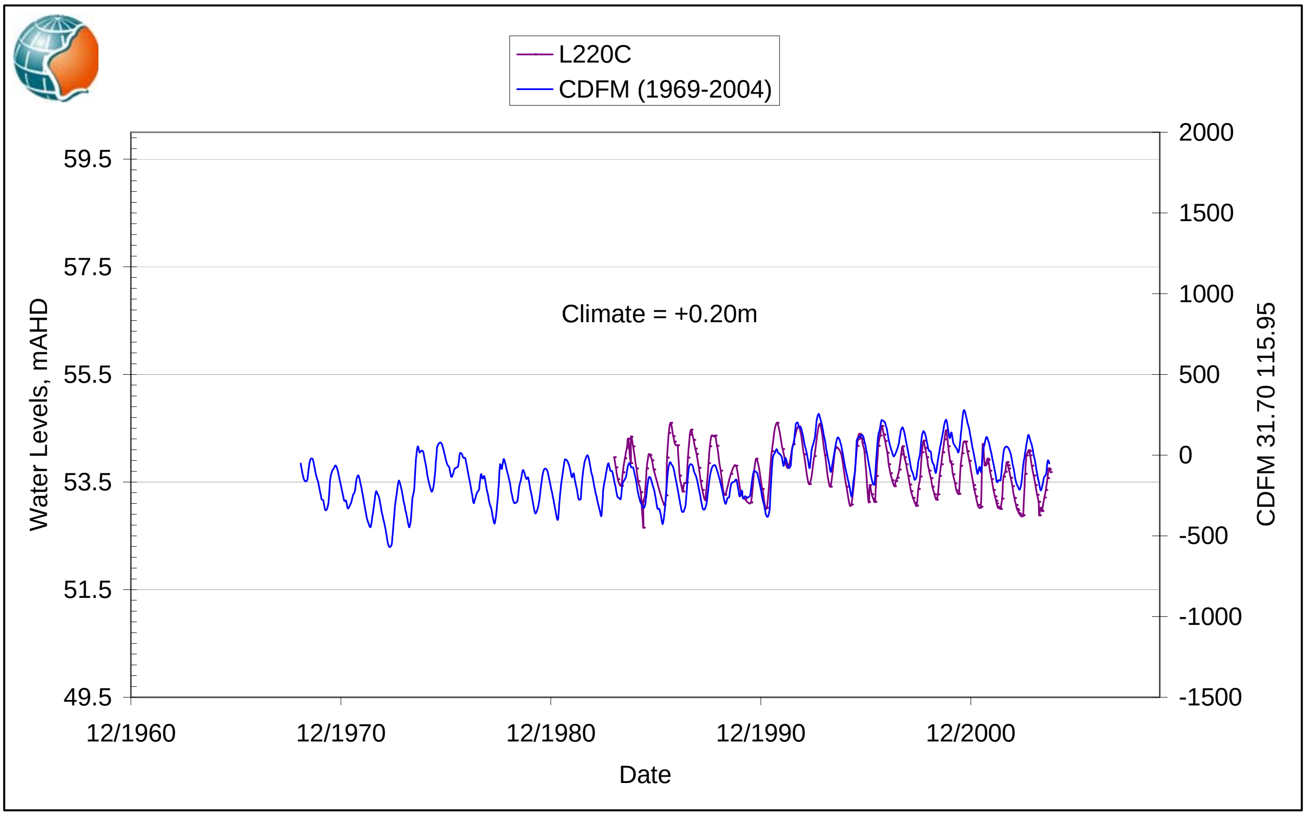
(PM8, GG3, NR2C, NR11C, L220C)


PM8
CDFM (1907-2004)
Climate = -3.05m
Bush fires = +1.4m
Water Levels, mAHD
72.4
71.4
70.4
69.4
68.4
67.4
66.4
65.4
CDFM 31.60 115.85
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date


GG3 (I)
CDFM (1907-2004)
Climate impact = -2.85m
Bush fires = 1.30m
Bush fire
Water Levels, mAHD
69.5
67.5
65.5
63.5
61.5
CDFM 31.55 115.90
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

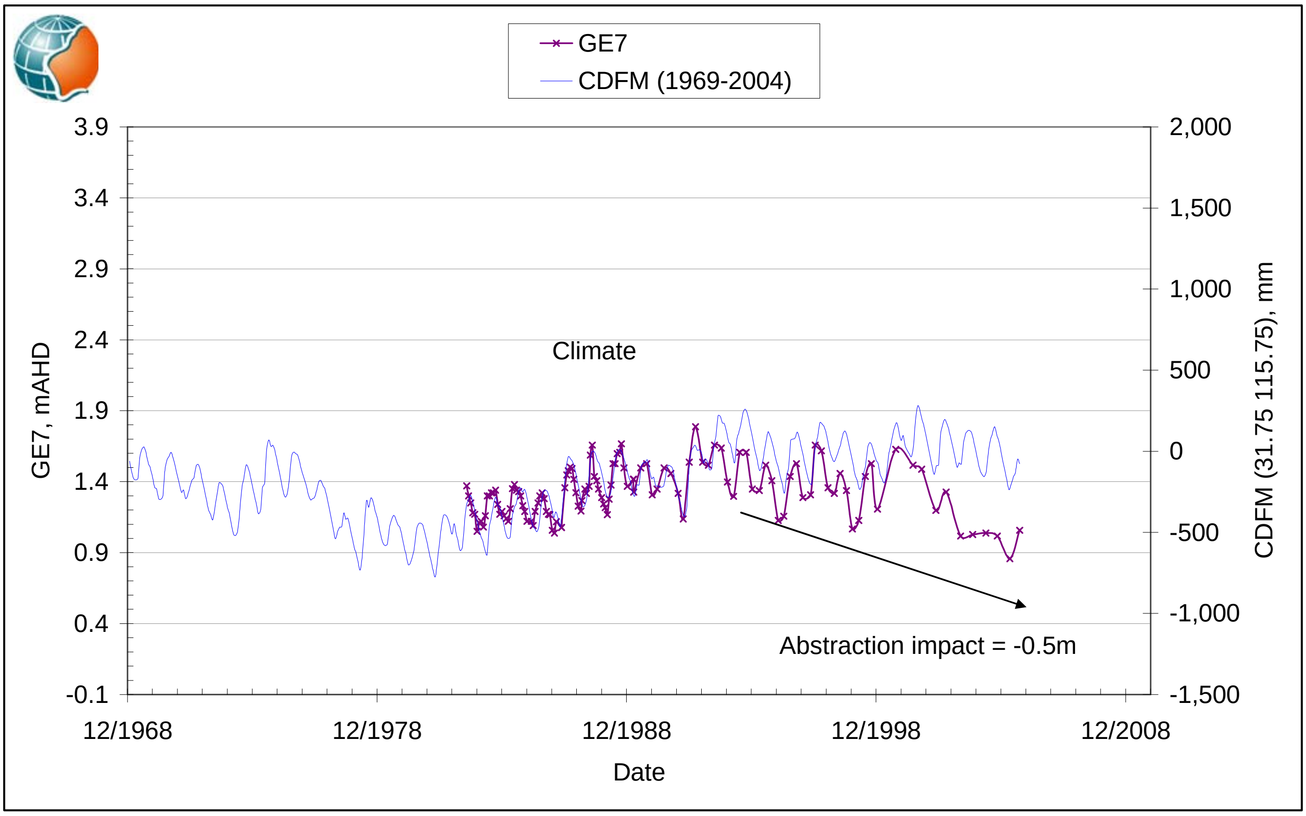

NR2C
CDFM (1969-2004)
Close to the discharge zone
Climate = 0.3m
dense bushes = -1.2 m
Water Levels, mAHD
71.50
69.50
67.50
65.50
63.50
CDFM (31.65 115.95), mm
1500
1000
500
0
-500
-1000
-1500
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

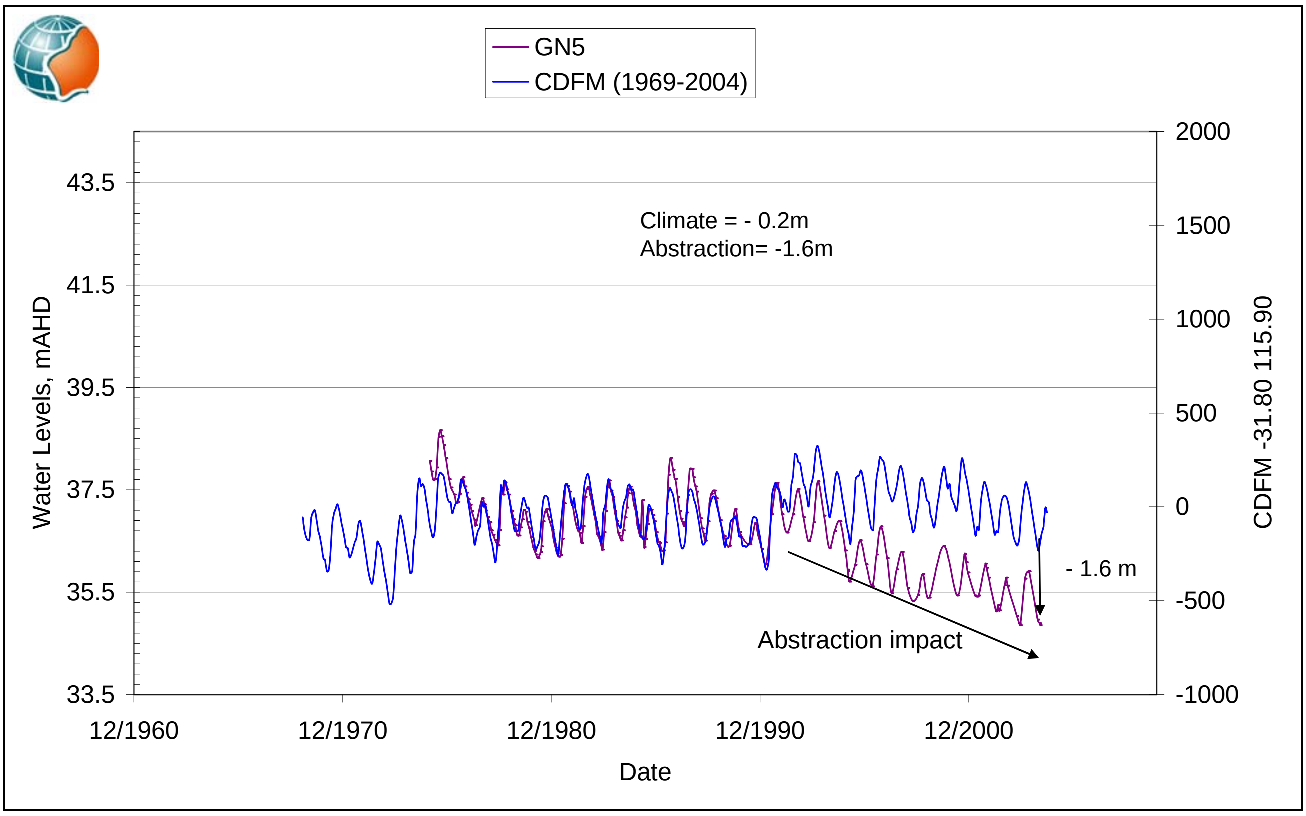

NR11C
CDFM (1969-2004)
Climate = -0.3m
Water Levels, mAHD
62.0
60.0
58.0
56.0
54.0
52.0
CDFM 31.70 115.95
2000
1500
1000
500
0
-500
-1000
-1500
12/1960
12/1970
12/1980
12/1990
12/2000
Date

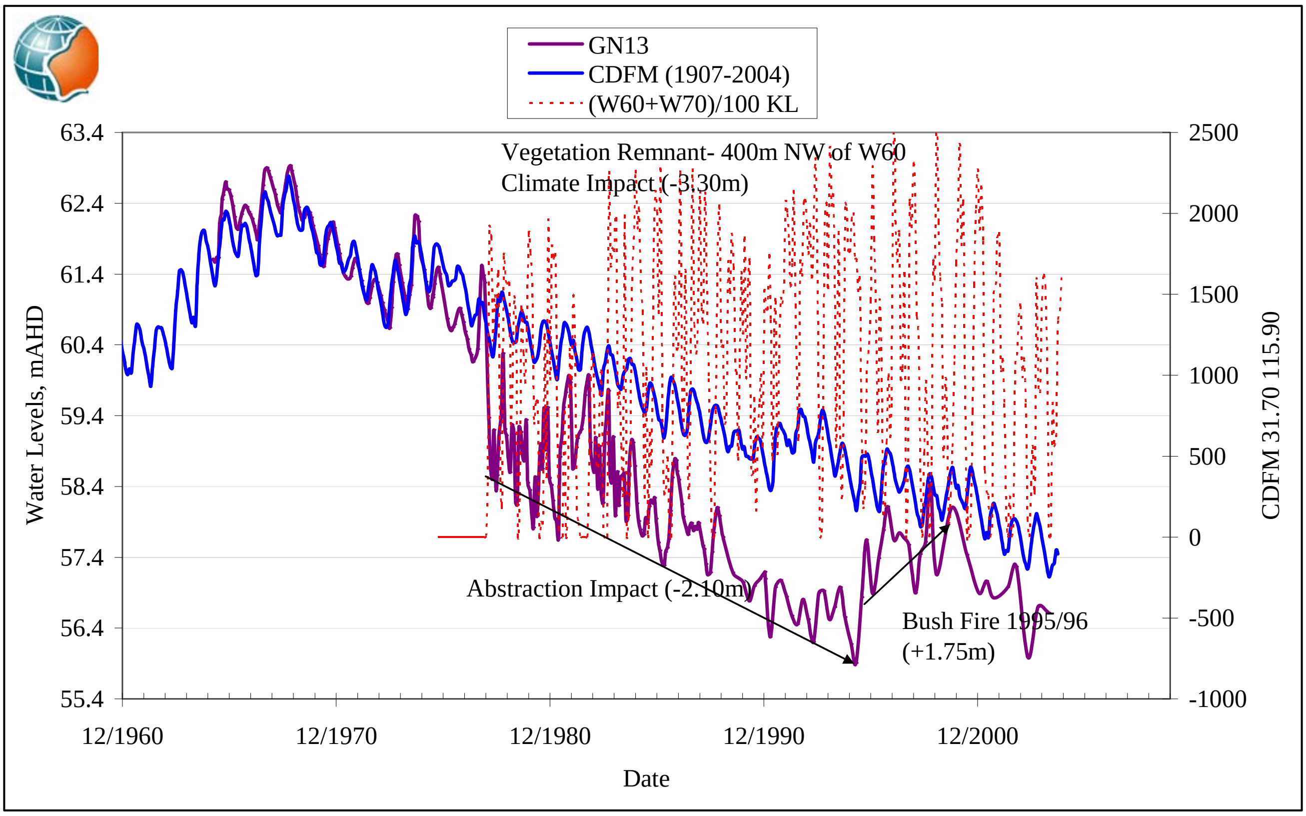

L220C
CDFM (1969-2004)
Climate = +0.20m
Water Levels, mAHD
59.5
57.5
55.5
53.5
51.5
49.5
CDFM 31.70 115.95
2000
1500
1000
500
0
-500
-1000
-1500
12/1960
12/1970
12/1980
12/1990
12/2000
Date

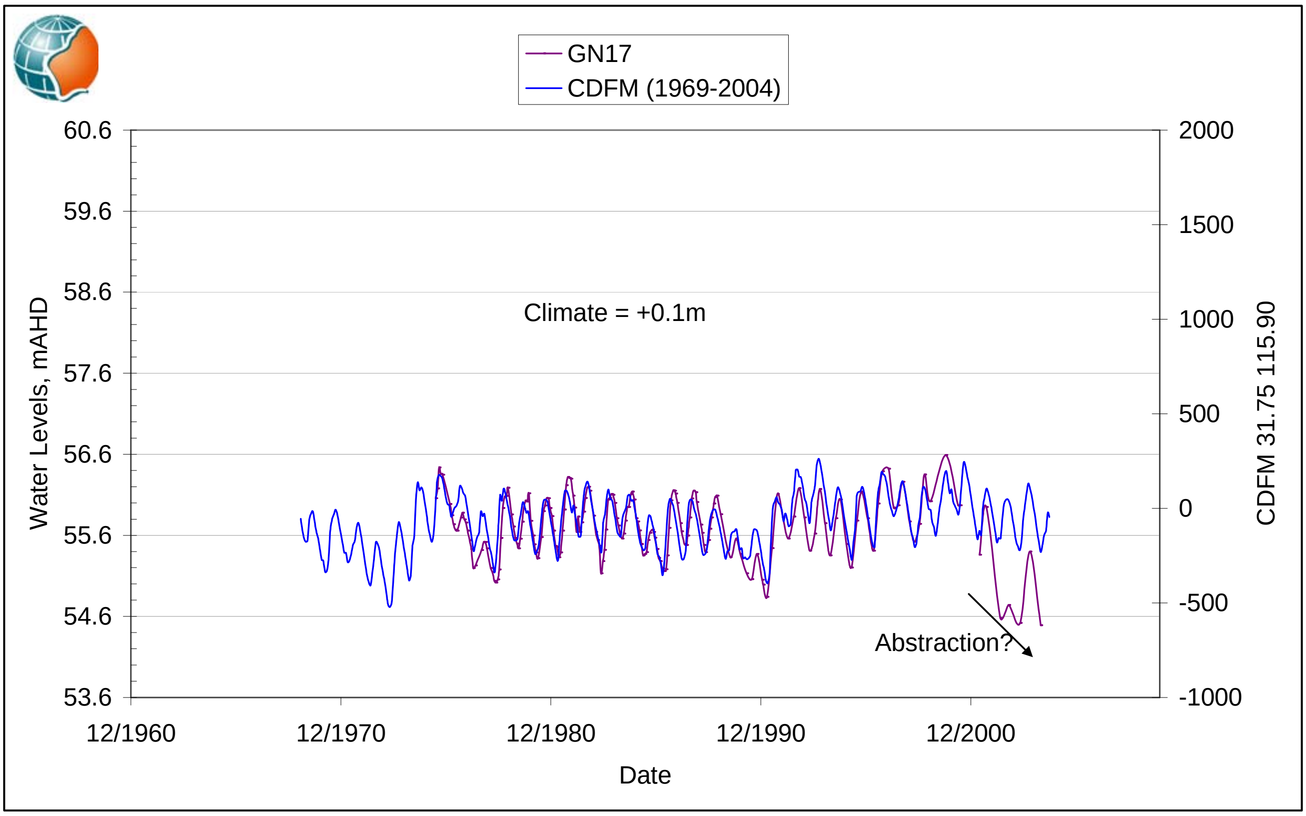
4. Wanneroo Rainfall Zone

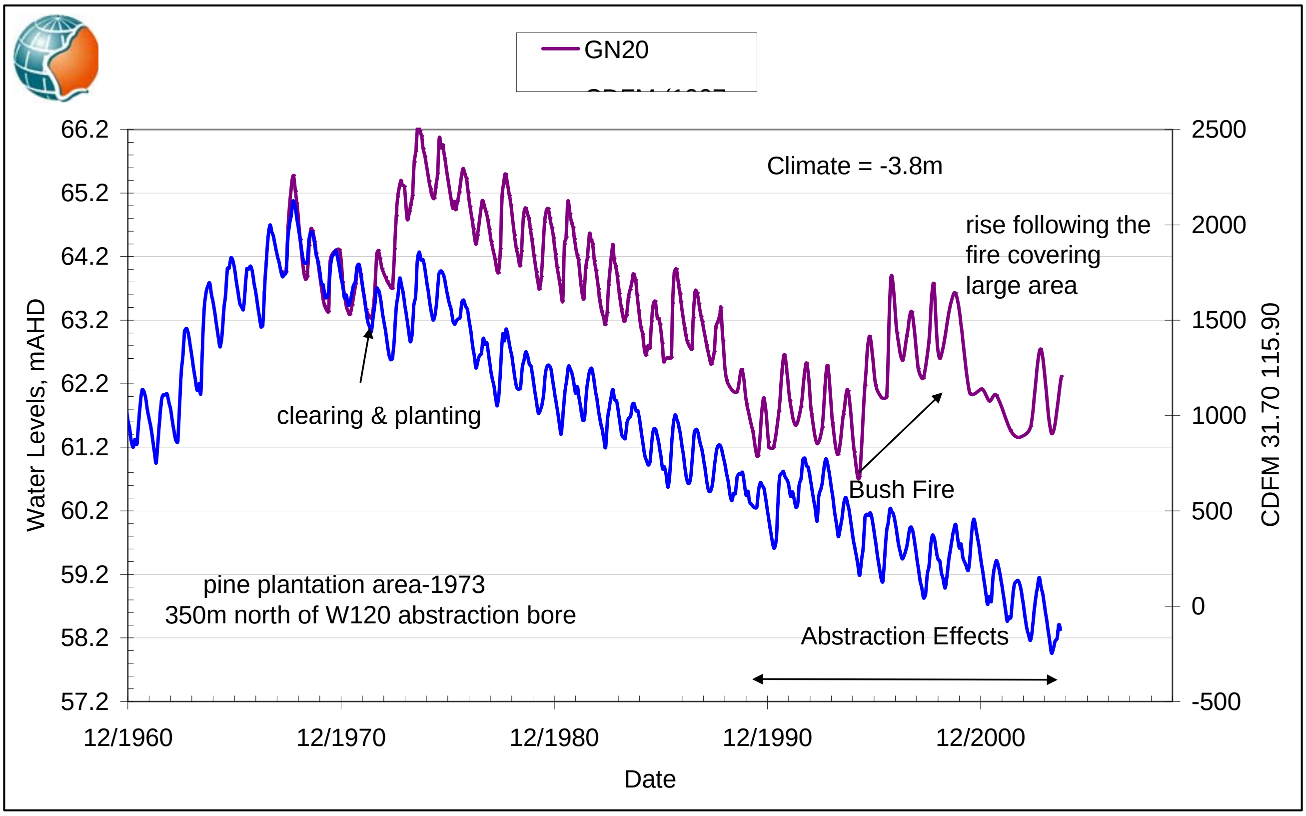
(GE7, GN5, GN13, GN17, GN20, GN23, JB5, MS10, 8281, 459, NR3C, PM13, WM1, WM2, WM4, WM5, WM13, WM24, WM28, MM9, MM14, WH100, WF12)

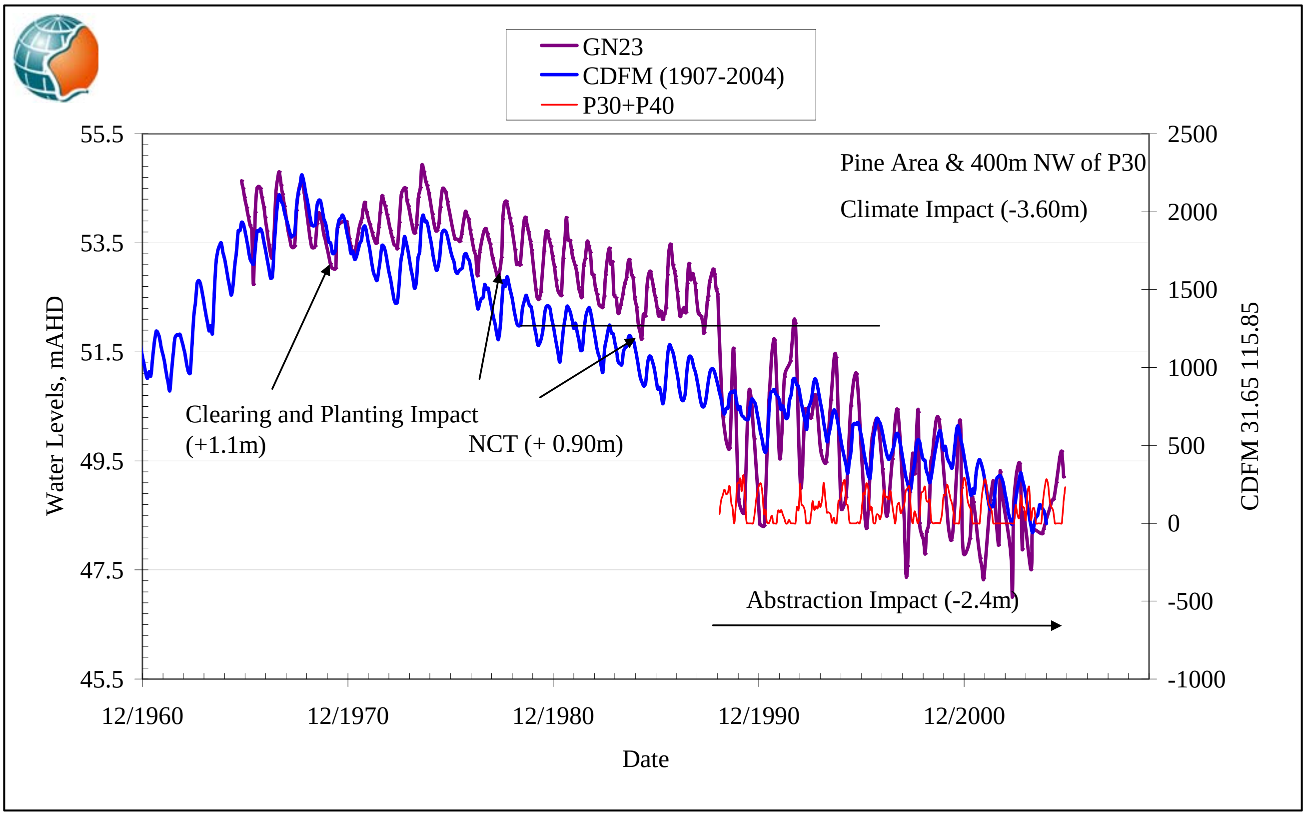

GE7
CDFM (1969-2004)
GE7, mAHD
3.9
3.4
2.9
2.4
1.9
1.4
0.9
0.4
-0.1
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
CDFM (31.75 115.75), mm
Climate
Abstraction impact = -0.5m
12/1968
12/1978
12/1988
12/1998
12/2008
Date

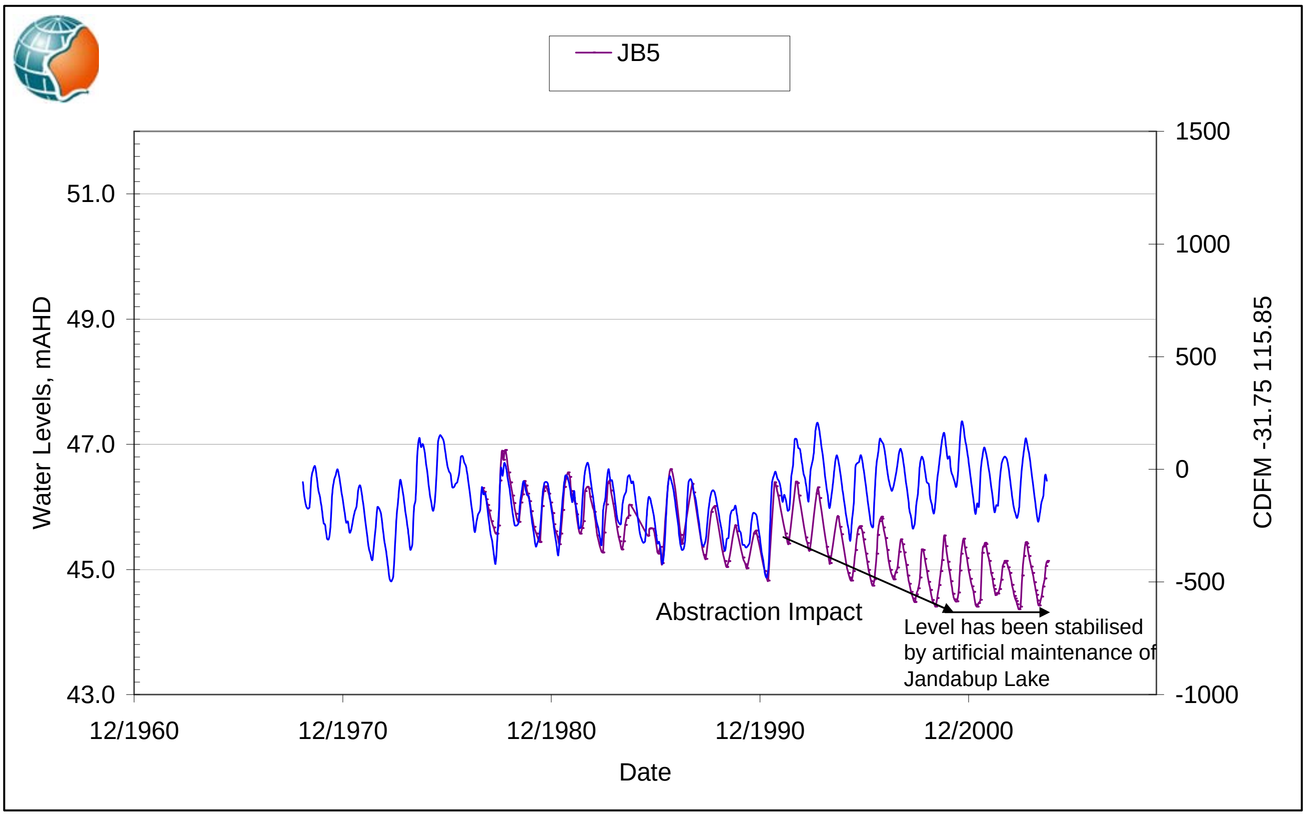

GN5
CDFM (1969-2004)
Water Levels, mAHD
43.5
41.5
39.5
37.5
35.5
33.5
2000
1500
1000
500
0
-500
-1000
CDFM -31.80 115.90
Climate = - 0.2m
Abstraction= -1.6m
- 1.6 m
Abstraction impact
12/1960
12/1970
12/1980
12/1990
12/2000
Date

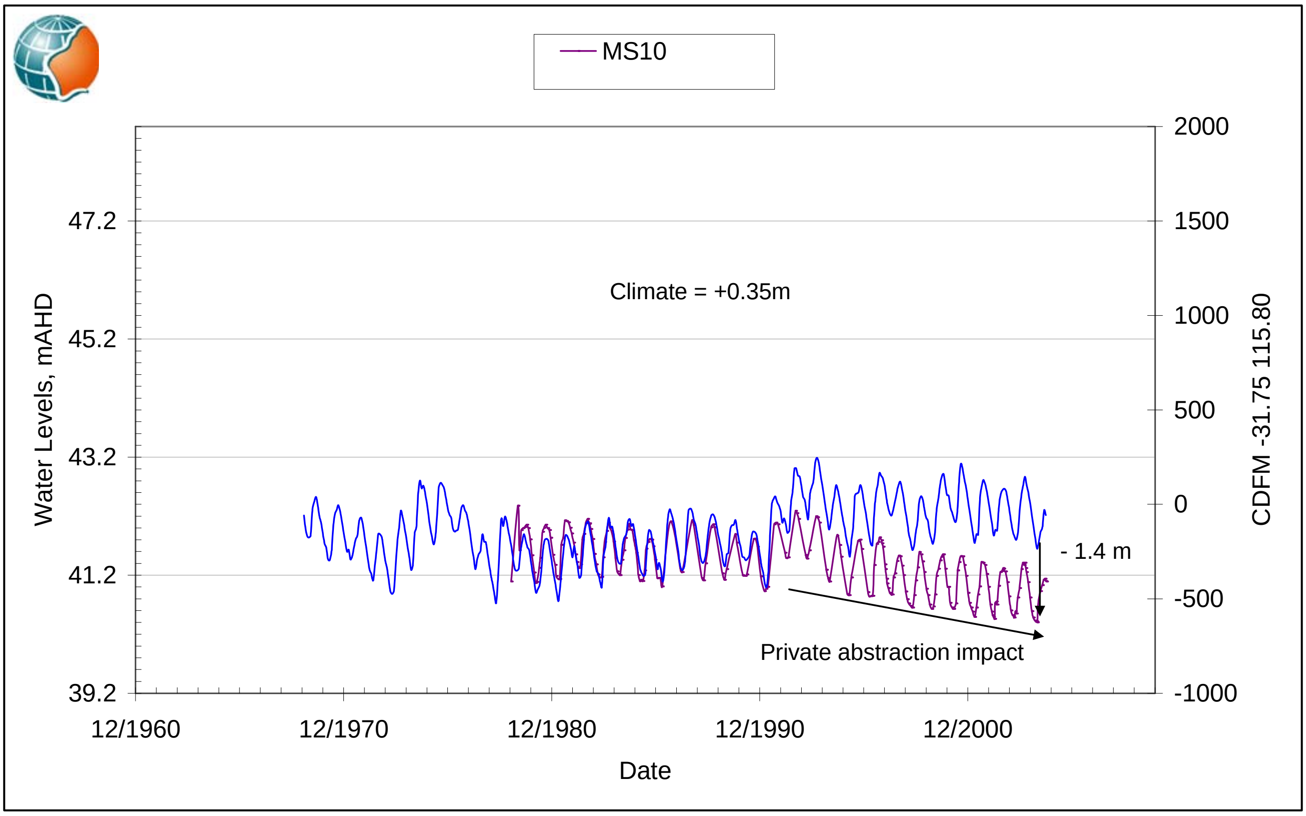

GN13
CDFM (1907-2004)
(W60+W70)/100 KL
Vegetation Remnant- 400m NW of W60
Climate Impact (-3.30m)
Abstraction Impact (-2.10m)
Bush Fire 1995/96
(+1.75m)
Water Levels, mAHD
63.4
62.4
61.4
60.4
59.4
58.4
57.4
56.4
55.4
CDFM 31.70 115.90
2500
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000
Date

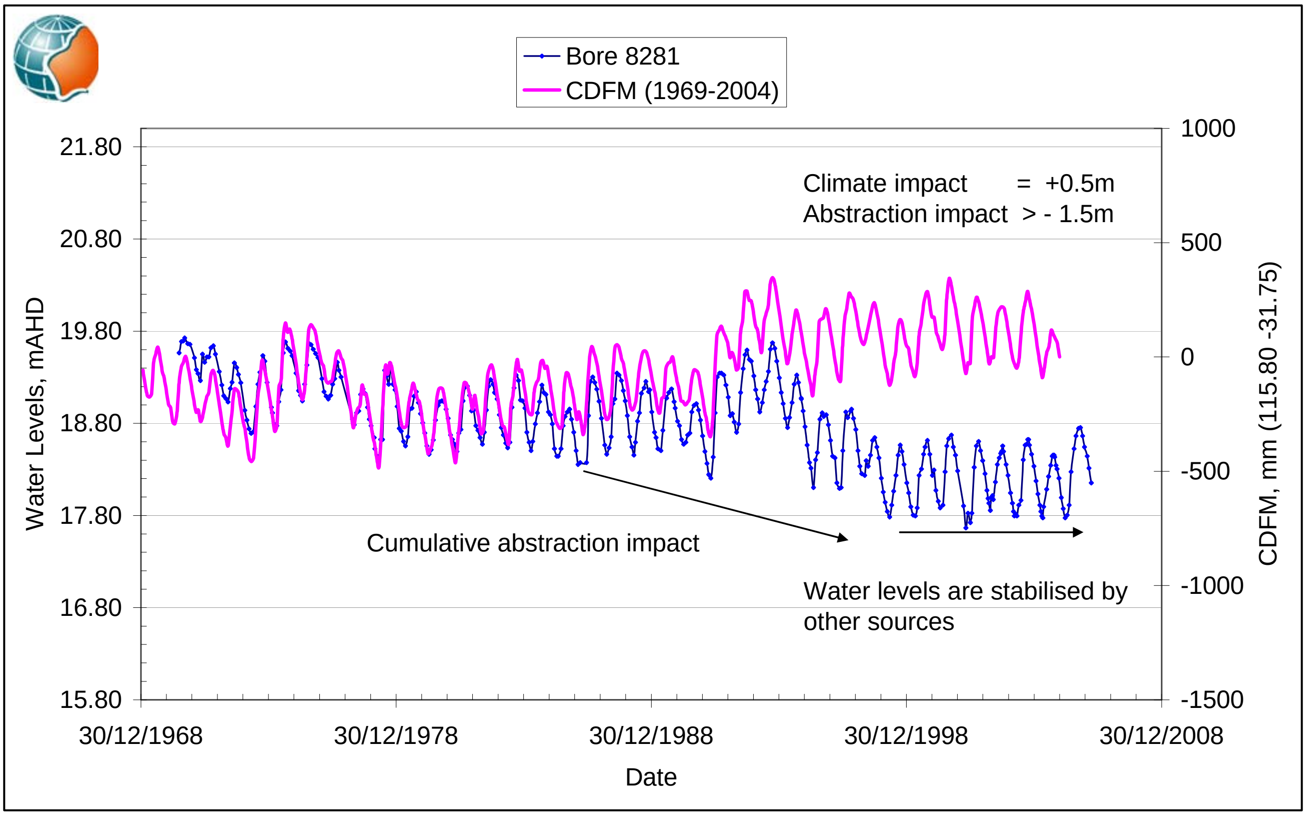

GN17
CDFM (1969-2004)
Climate = +0.1m
Abstraction?
Water Levels, mAHD
60.6
59.6
58.6
57.6
56.6
55.6
54.6
53.6
CDFM 31.75 115.90
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000
Date

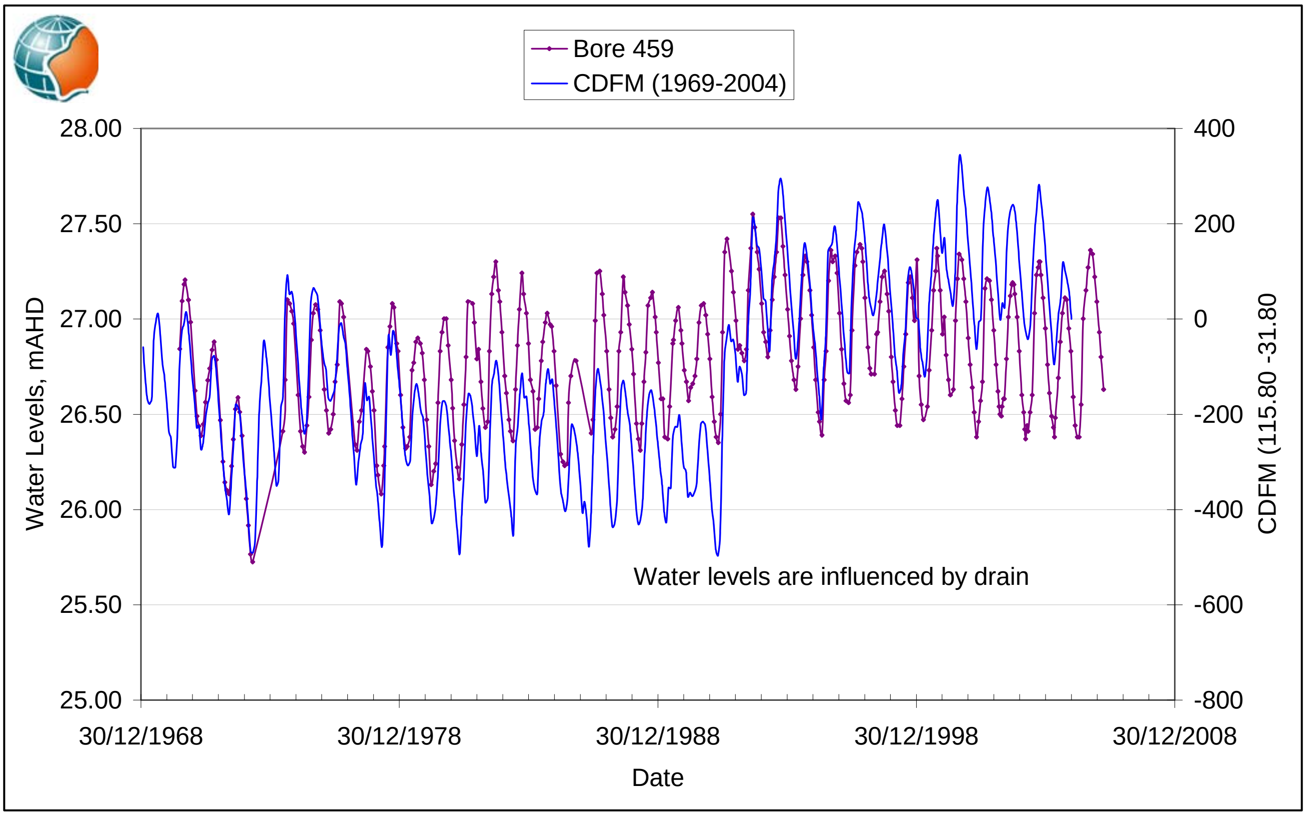

GN20
66.2
65.2
64.2
63.2
62.2
61.2
60.2
59.2
58.2
57.2
Water Levels, mAHD
2500
2000
1500
1000
500
0
-500
CDFM 31.70 115.90
Climate = -3.8m
rise following the fire covering large area
clearing & planting
Bush Fire
pine plantation area-1973
350m north of W120 abstraction bore
Abstraction Effects
12/1960
12/1970
12/1980
12/1990
12/2000
Date

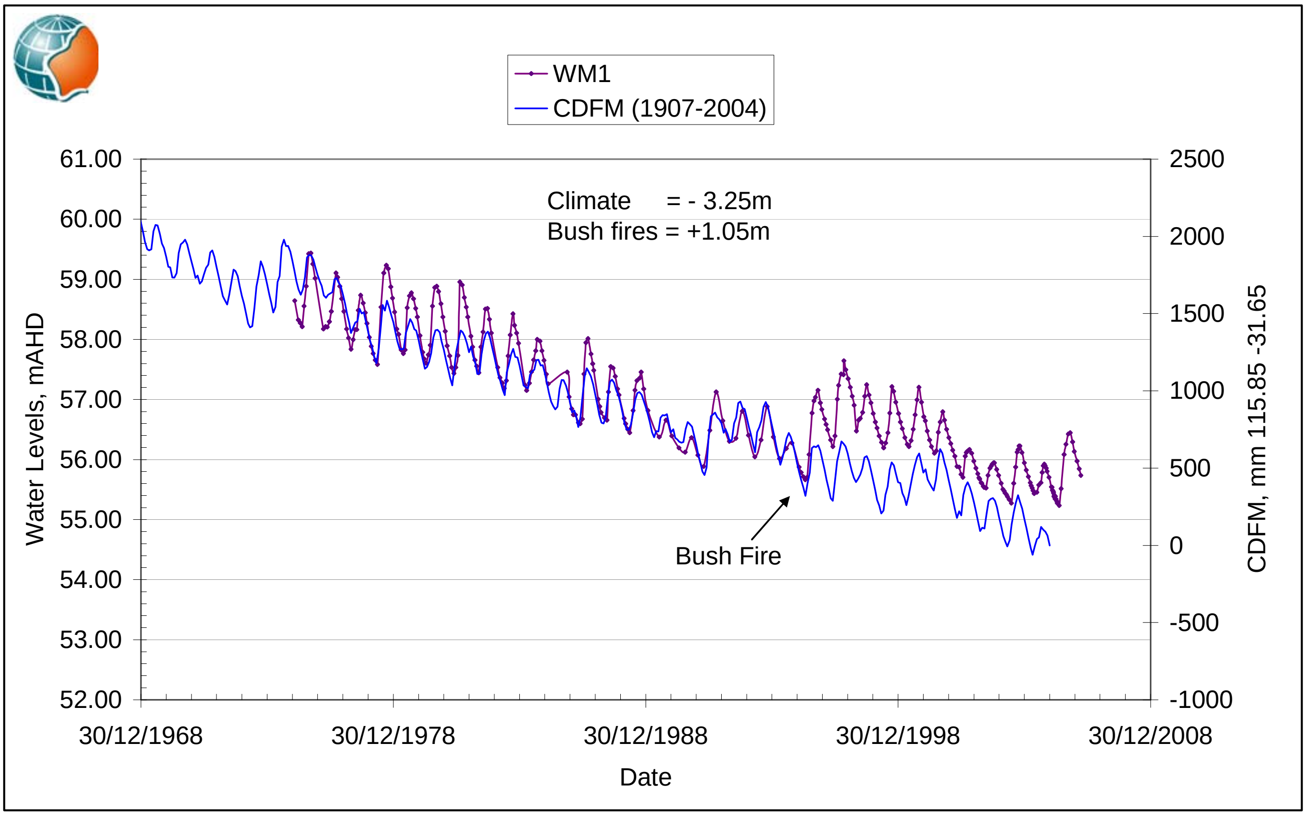

GN23
CDFM (1907-2004)
P30+P40
55.5
53.5
51.5
49.5
47.5
45.5
Water Levels, mAHD
2500
2000
1500
1000
500
0
-500
-1000
CDFM 31.65 115.85
Pine Area & 400m NW of P30
Climate Impact (-3.60m)
Clearing and Planting Impact
(+1.1m)
NCT (+ 0.90m)
Abstraction Impact (-2.4m)
12/1960
12/1970
12/1980
12/1990
12/2000
Date

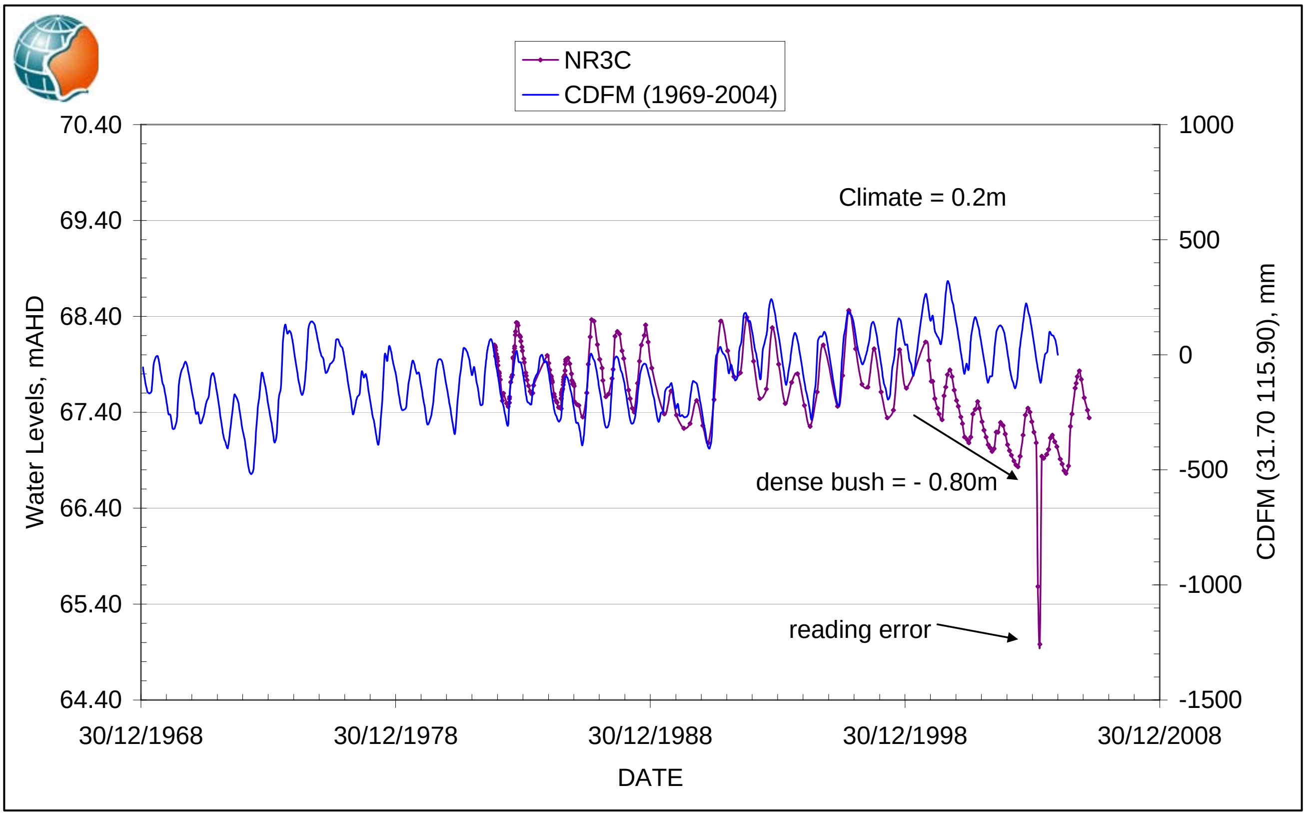

JB5
Water Levels, mAHD
51.0
49.0
47.0
45.0
43.0
1500
1000
500
0
-500
-1000
CDFM -31.75 115.85
12/1960
12/1970
12/1980
12/1990
12/2000
Date
Abstraction Impact
Level has been stabilised by artificial maintenance of Jandabup Lake

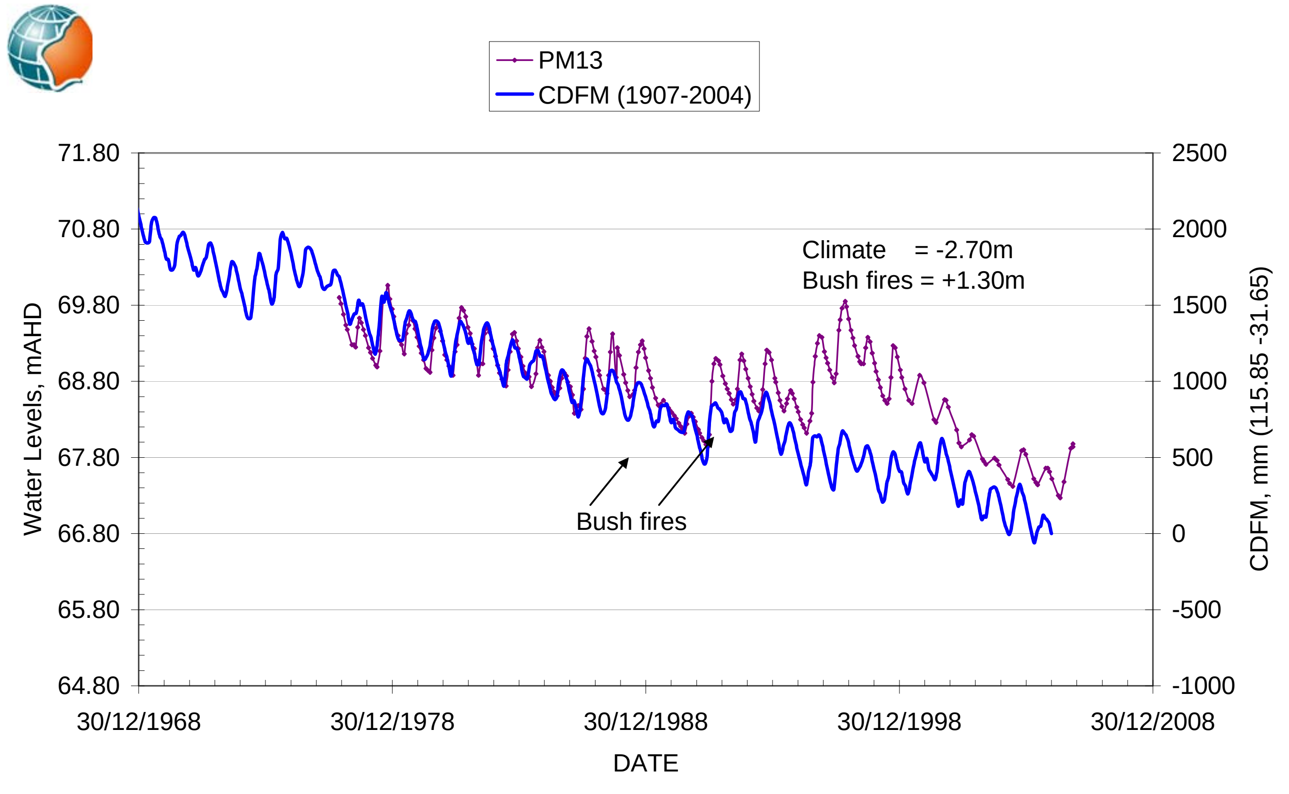

MS10
Water Levels, mAHD
47.2
45.2
43.2
41.2
39.2
2000
1500
1000
500
0
-500
-1000
CDFM -31.75 115.80
12/1960
12/1970
12/1980
12/1990
12/2000
Date
Climate = +0.35m
- 1.4 m
Private abstraction impact

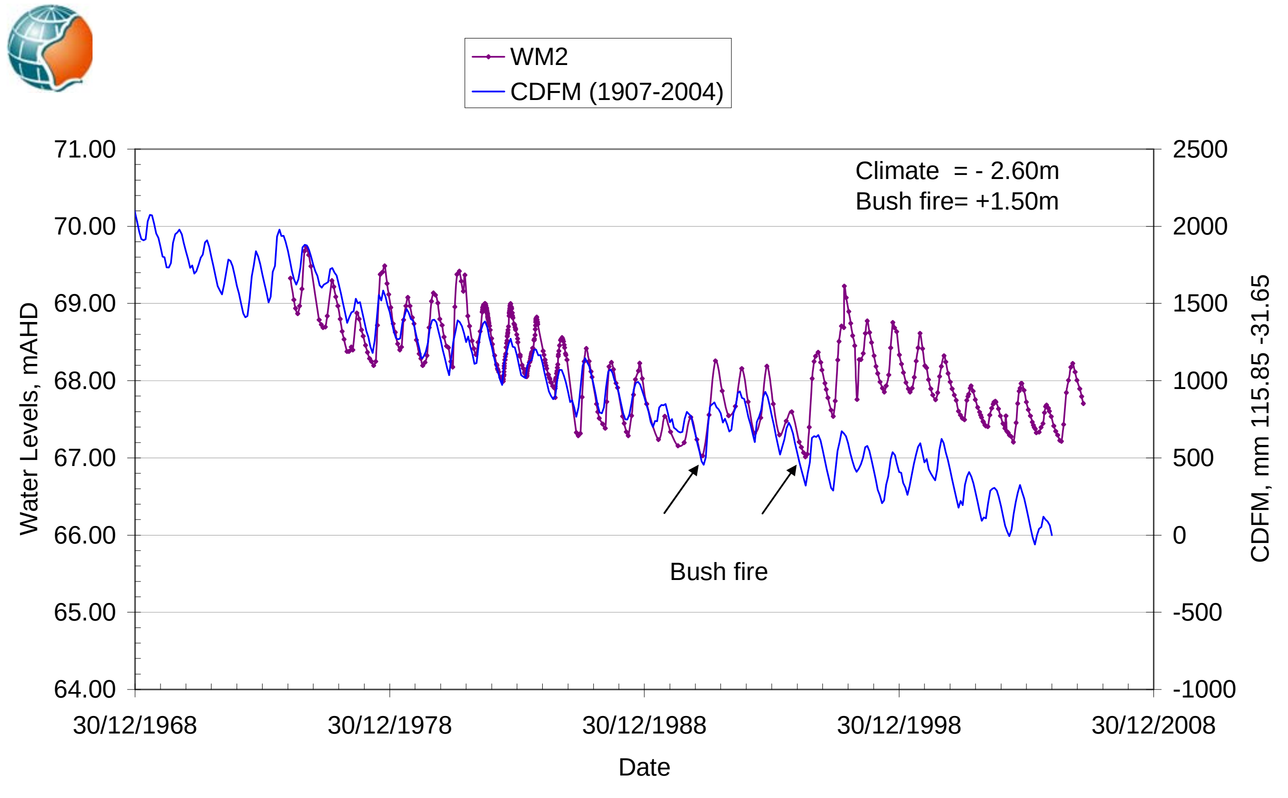

Bore 8281
CDFM (1969-2004)
Water Levels, mAHD
21.80
20.80
19.80
18.80
17.80
16.80
15.80
CDFM, mm (115.80 -31.75)
1000
500
0
-500
-1000
-1500
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date
Climate impact = +0.5m
Abstraction impact > - 1.5m
Cumulative abstraction impact
Water levels are stabilised by other sources

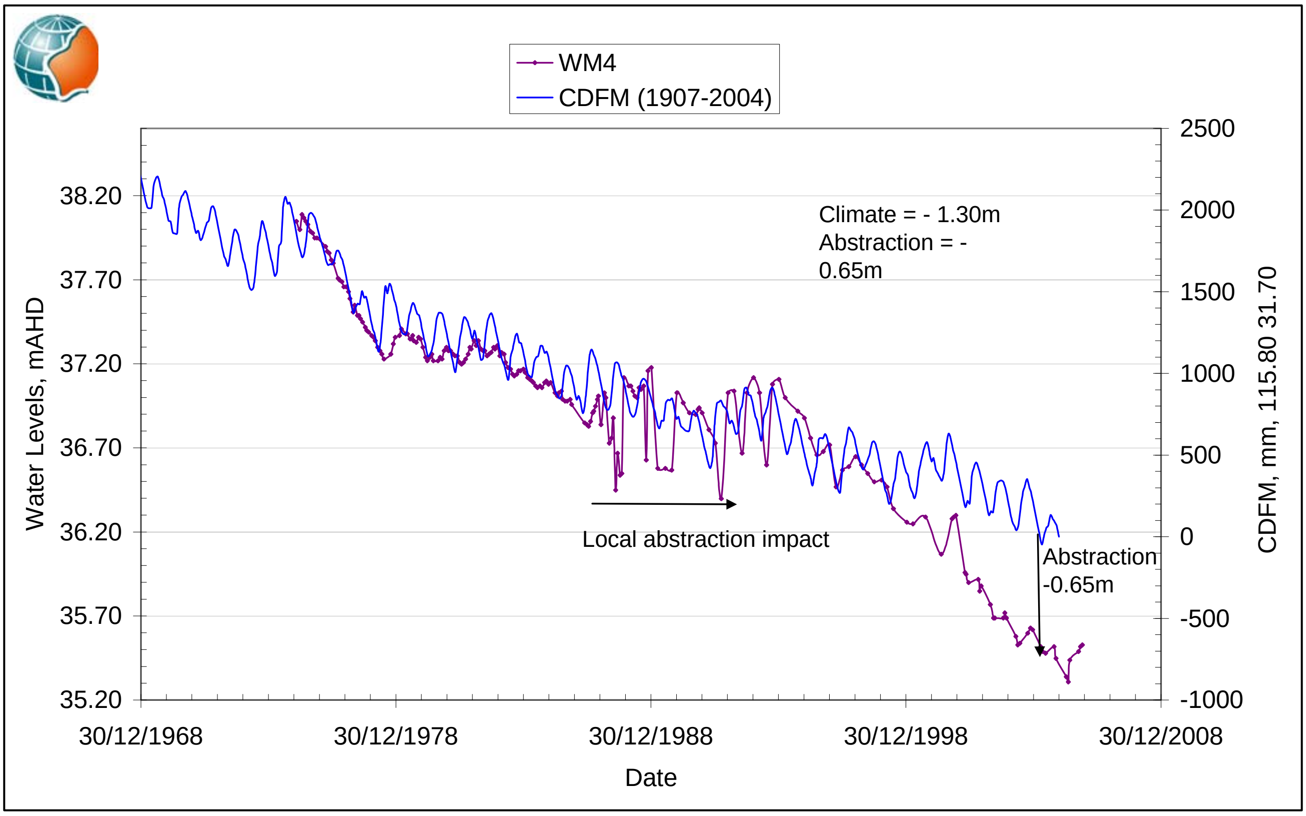

Bore 459
CDFM (1969-2004)
Water Levels, mAHD
28.00
27.50
27.00
26.50
26.00
25.50
25.00
CDFM (115.80 -31.80
400
200
0
-200
-400
-600
-800
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date
Water levels are influenced by drain

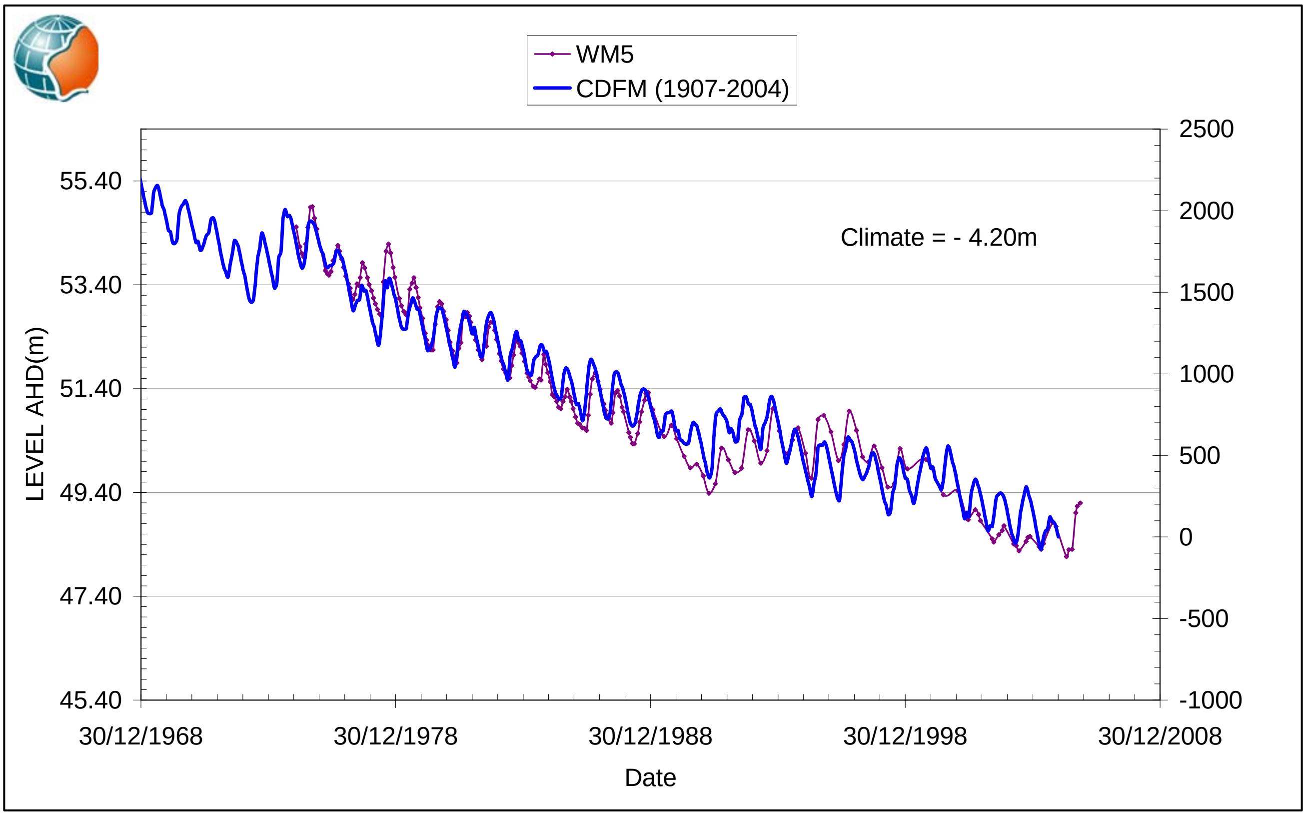

WM1
CDFM (1907-2004)
Climate = - 3.25m
Bush fires = +1.05m
Bush Fire
Water Levels, mAHD
61.00
60.00
59.00
58.00
57.00
56.00
55.00
54.00
53.00
52.00
2500
2000
1500
1000
500
0
-500
-1000
CDFM, mm 115.85 -31.65
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

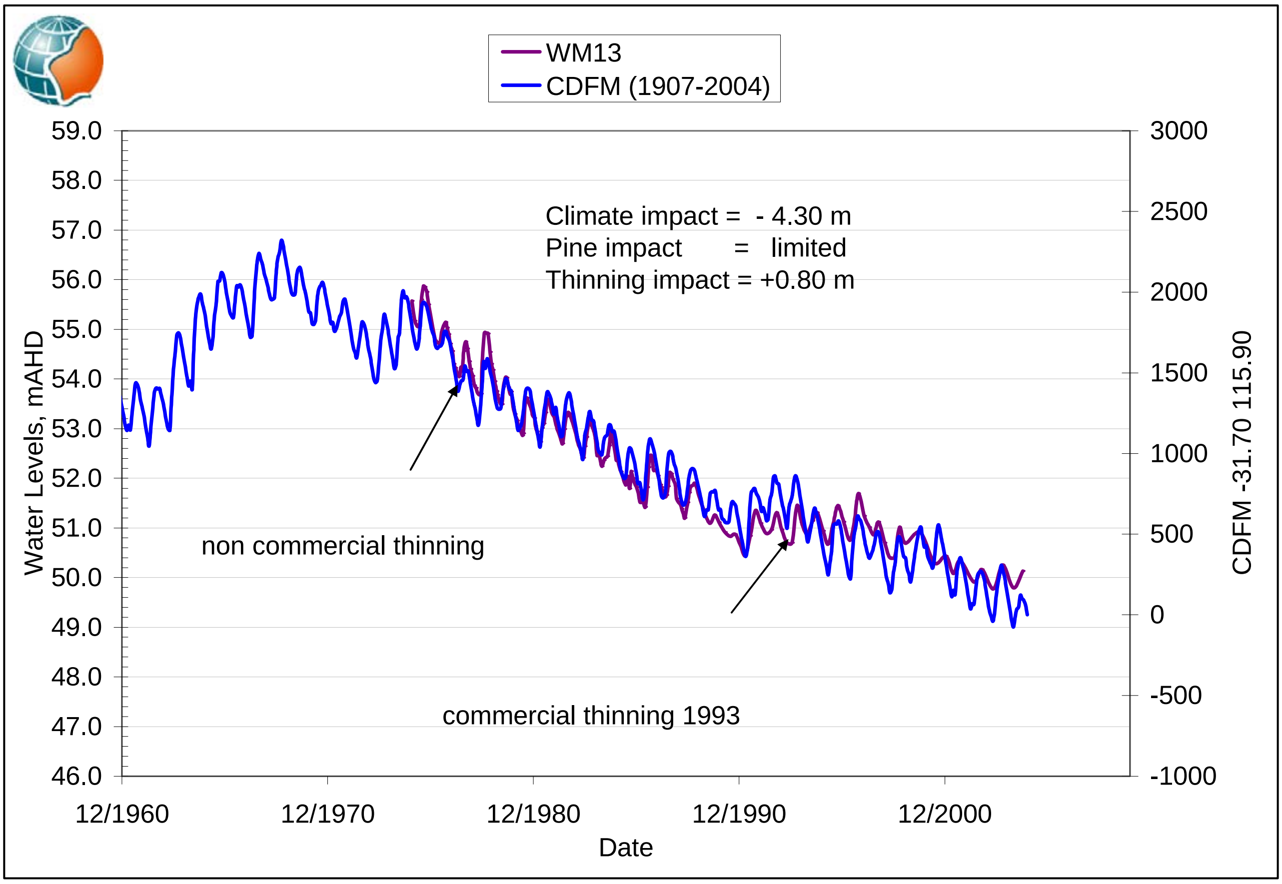

NR3C
CDFM (1969-2004)
Climate = 0.2m
dense bush = - 0.80m
reading error
Water Levels, mAHD
70.40
69.40
68.40
67.40
66.40
65.40
64.40
1000
500
0
-500
-1000
-1500
CDFM (31.70 115.90), mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
DATE

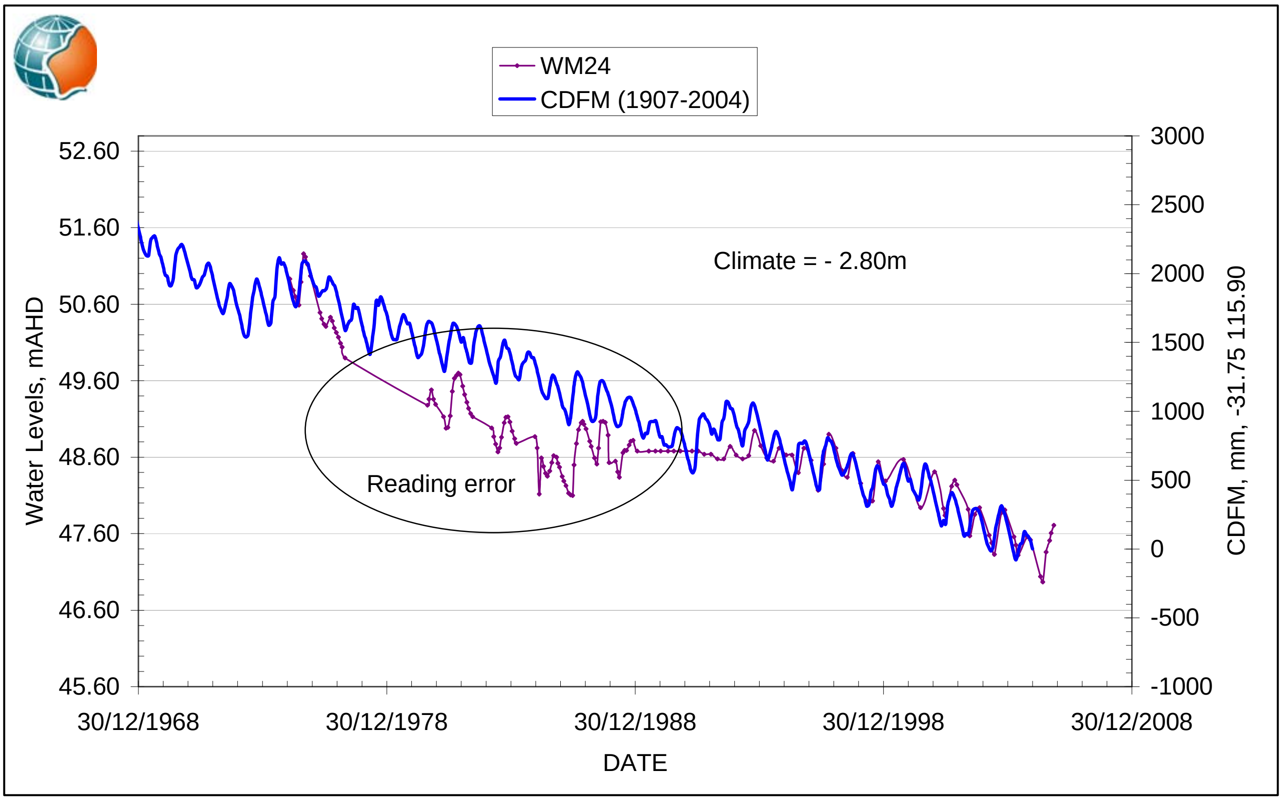

PM13
CDFM (1907-2004)
Climate = -2.70m
Bush fires = +1.30m
Bush fires
Water Levels, mAHD
CDFM, mm (115.85 -31.65)
DATE
71.80
70.80
69.80
68.80
67.80
66.80
65.80
64.80
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008

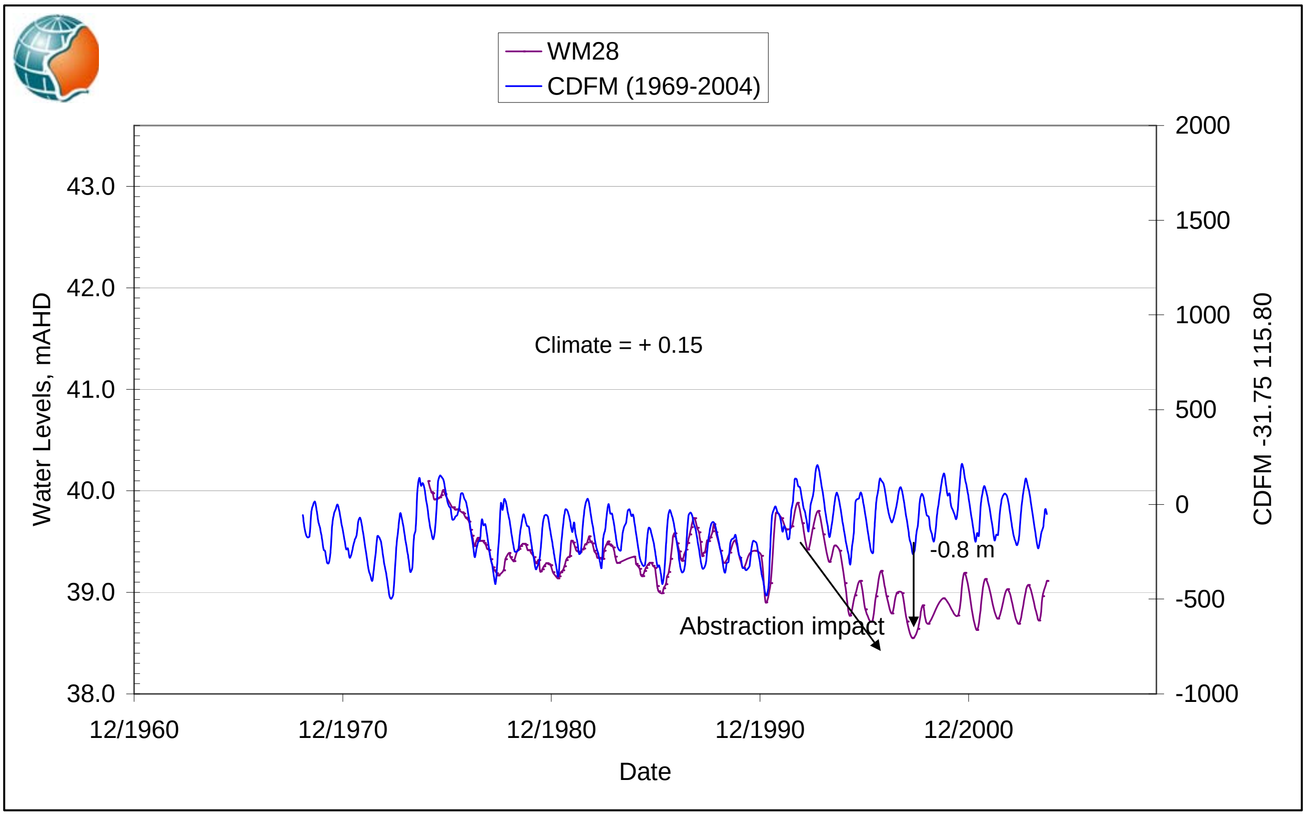

WM2
CDFM (1907-2004)
Climate = - 2.60m
Bush fire= +1.50m
Bush fire
Water Levels, mAHD
CDFM, mm 115.85 -31.65
Date
71.00
70.00
69.00
68.00
67.00
66.00
65.00
64.00
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008

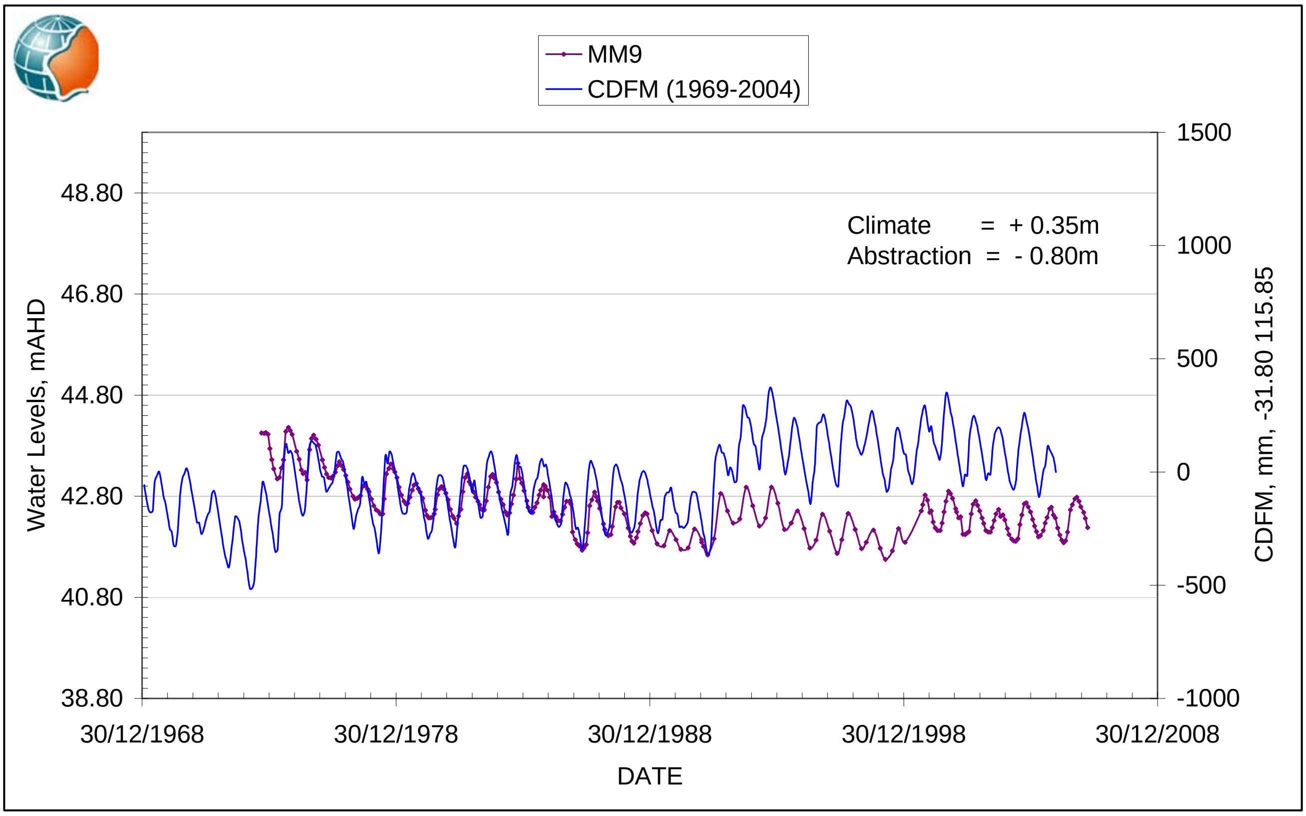

WM4
CDFM (1907-2004)
Climate = - 1.30m
Abstraction = -
0.65m
Local abstraction impact
Abstraction
-0.65m
Water Levels, mAHD
38.20
37.70
37.20
36.70
36.20
35.70
35.20
CDFM, mm, 115.80 31.70
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

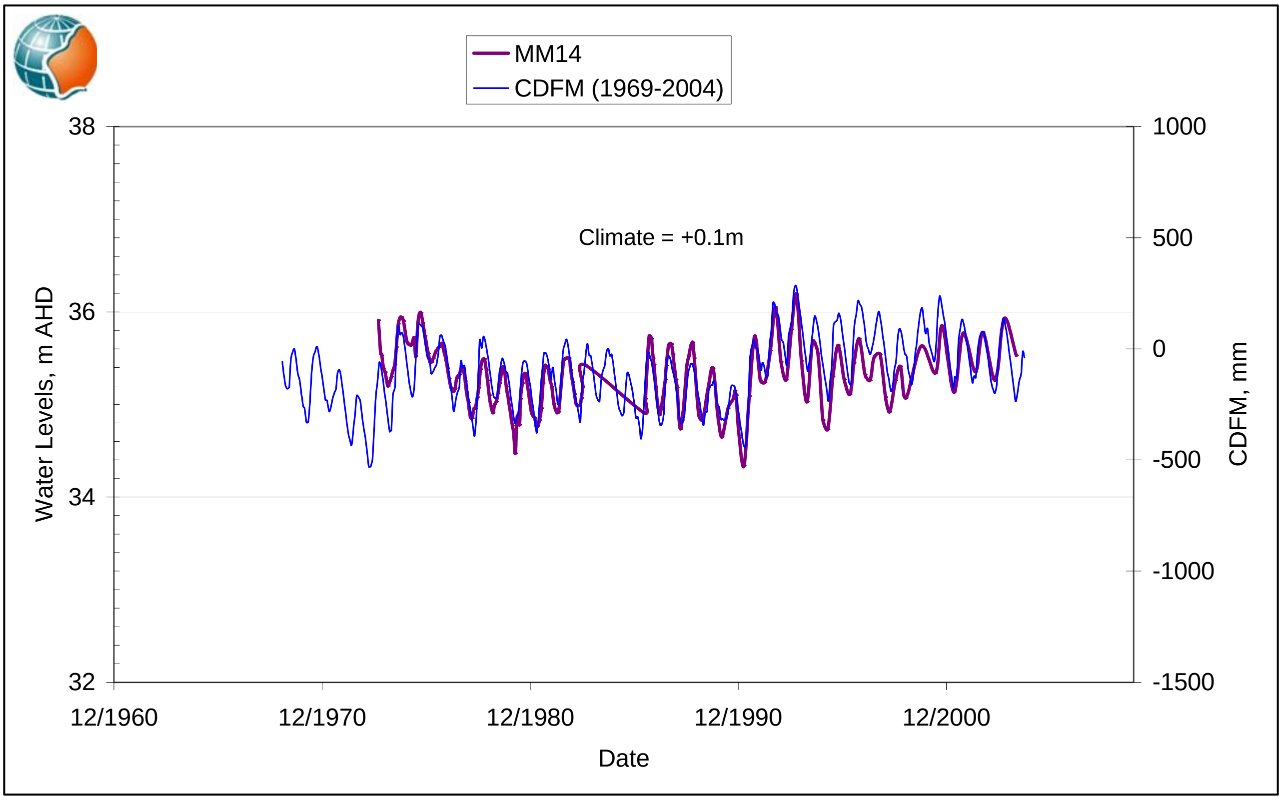

WM5
CDFM (1907-2004)
Climate = - 4.20m
LEVEL AHD(m)
55.40
53.40
51.40
49.40
47.40
45.40
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

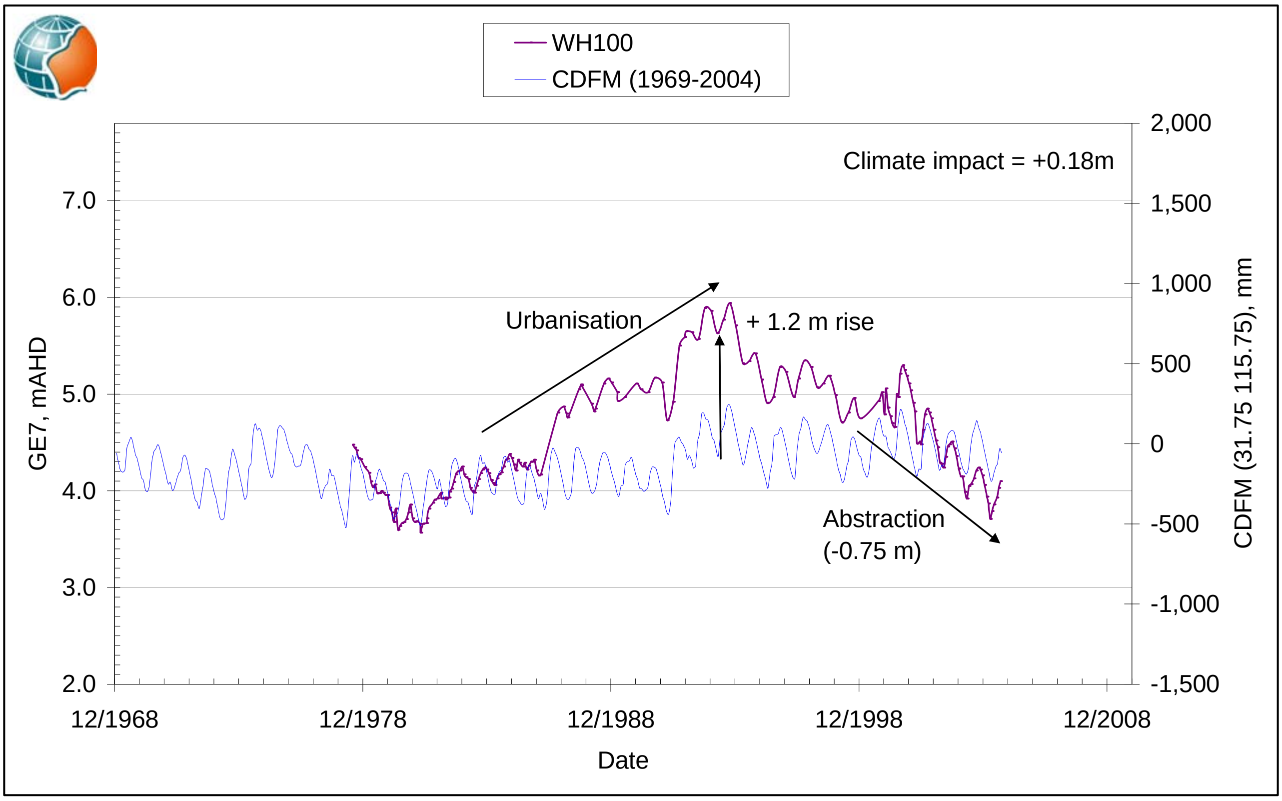

WM13
CDFM (1907-2004)
Climate impact = - 4.30 m
Pine impact = limited
Thinning impact = +0.80 m
non commercial thinning
commercial thinning 1993
Water Levels, mAHD
59.0
58.0
57.0
56.0
55.0
54.0
53.0
52.0
51.0
50.0
49.0
48.0
47.0
46.0
12/1960
12/1970
12/1980
12/1990
12/2000
Date
CDFM -31.70 115.90
3000
2500
2000
1500
1000
500
0
-500
-1000

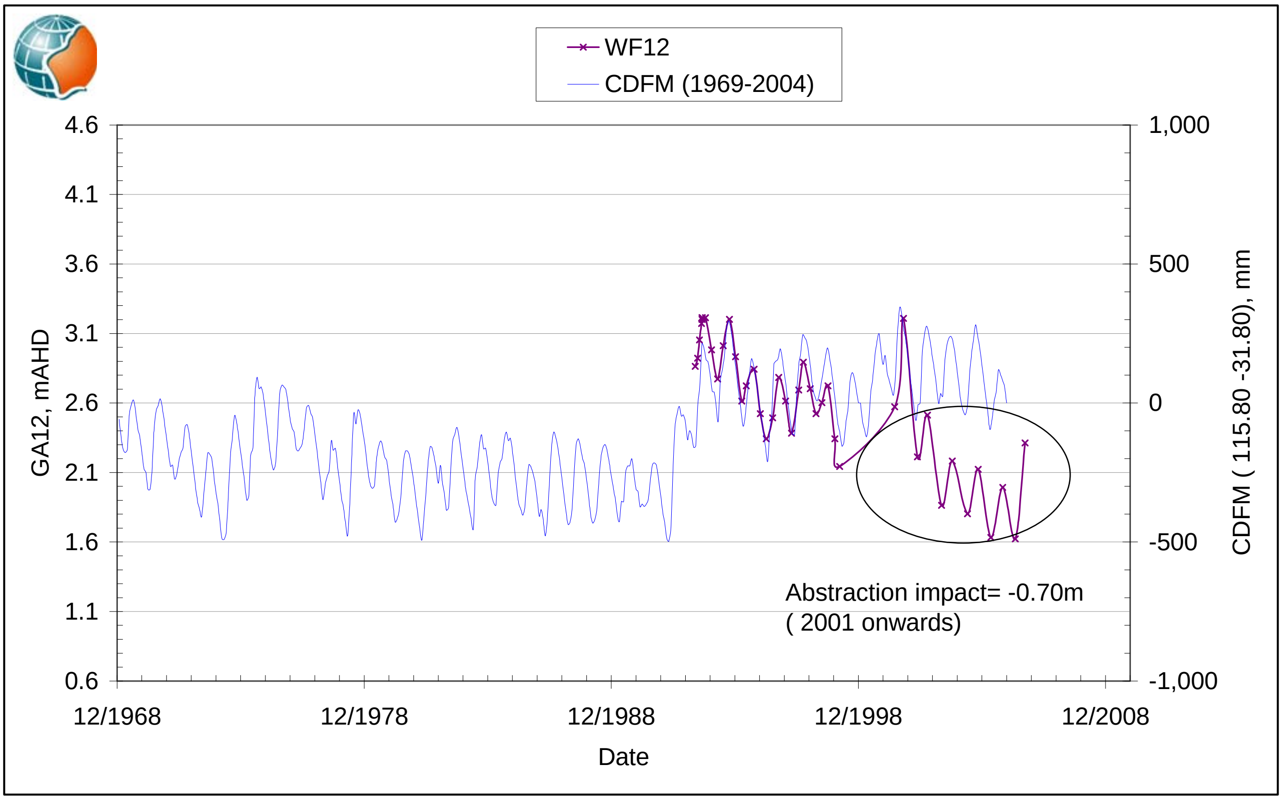

WM24
CDFM (1907-2004)
Climate = - 2.80m
Reading error
Water Levels, mAHD
52.60
51.60
50.60
49.60
48.60
47.60
46.60
45.60
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
DATE
CDFM, mm, -31.75 115.90
3000
2500
2000
1500
1000
500
0
-500
-1000


WM28
CDFM (1969-2004)
Water Levels, mAHD
43.0
42.0
41.0
40.0
39.0
38.0
2000
1500
1000
500
0
-500
-1000
CDFM -31.75 115.80
Climate = + 0.15
-0.8 m
Abstraction impact
12/1960
12/1970
12/1980
12/1990
12/2000
Date


MM9
CDFM (1969-2004)
Water Levels, mAHD
48.80
46.80
44.80
42.80
40.80
38.80
1500
1000
500
0
-500
-1000
CDFM, mm, -31.80 115.85
Climate = + 0.35m
Abstraction = - 0.80m
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
DATE

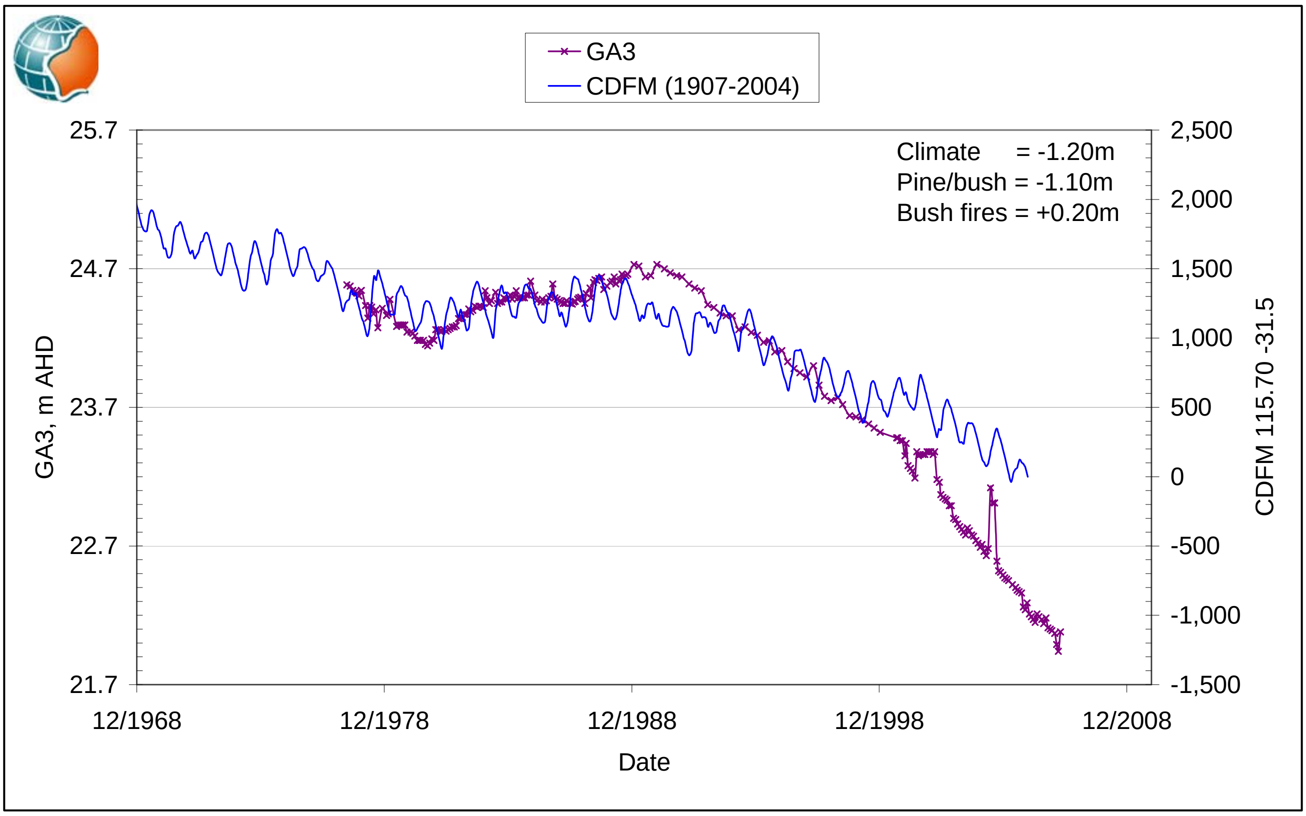

MM14
CDFM (1969-2004)
Climate = +0.1m
Water Levels, m AHD
38
36
34
32
1000
500
0
-500
-1000
-1500
CDFM, mm
12/1960
12/1970
12/1980
12/1990
12/2000
Date

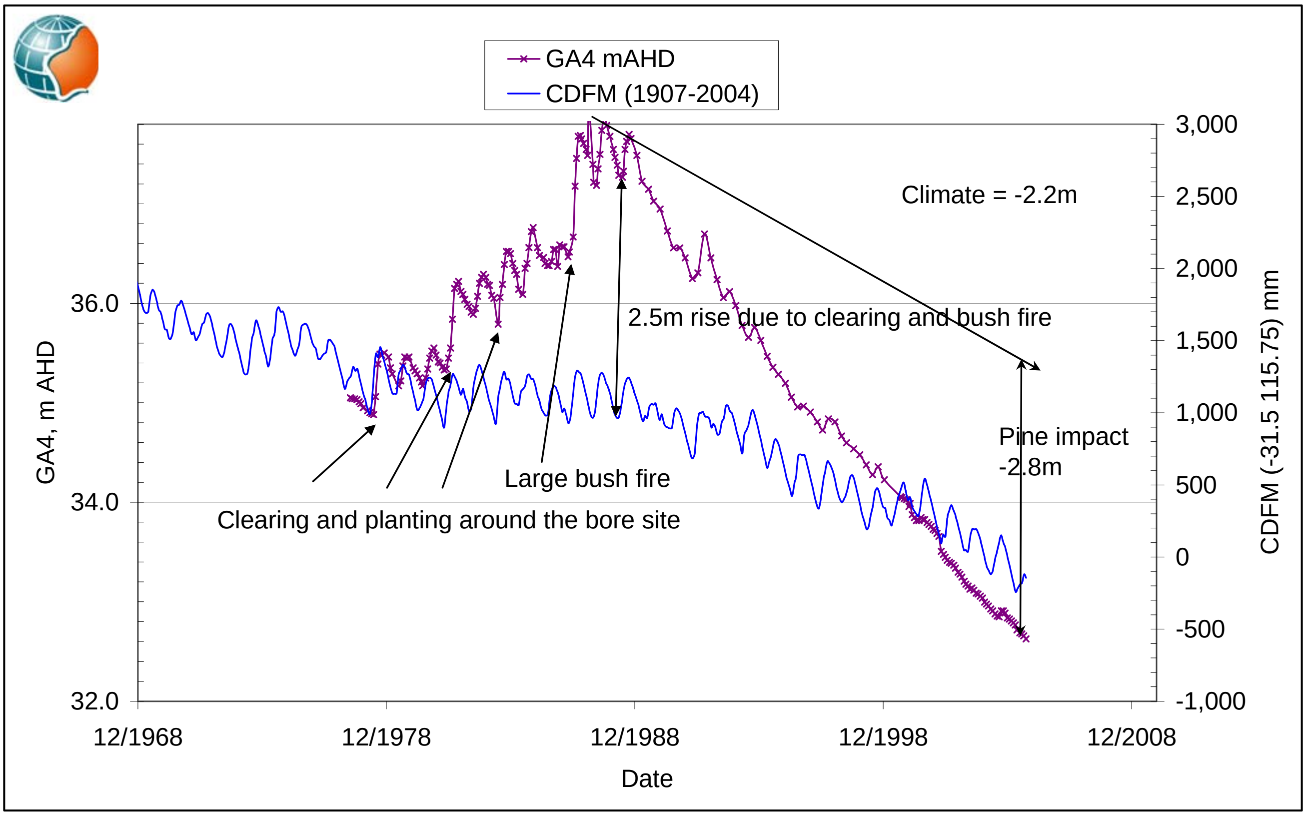

WH100
CDFM (1969-2004)
Climate impact = +0.18m
Urbanisation
+ 1.2 m rise
Abstraction
(-0.75 m)
GE7, mAHD
7.0
6.0
5.0
4.0
3.0
2.0
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
CDFM (31.75 115.75), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

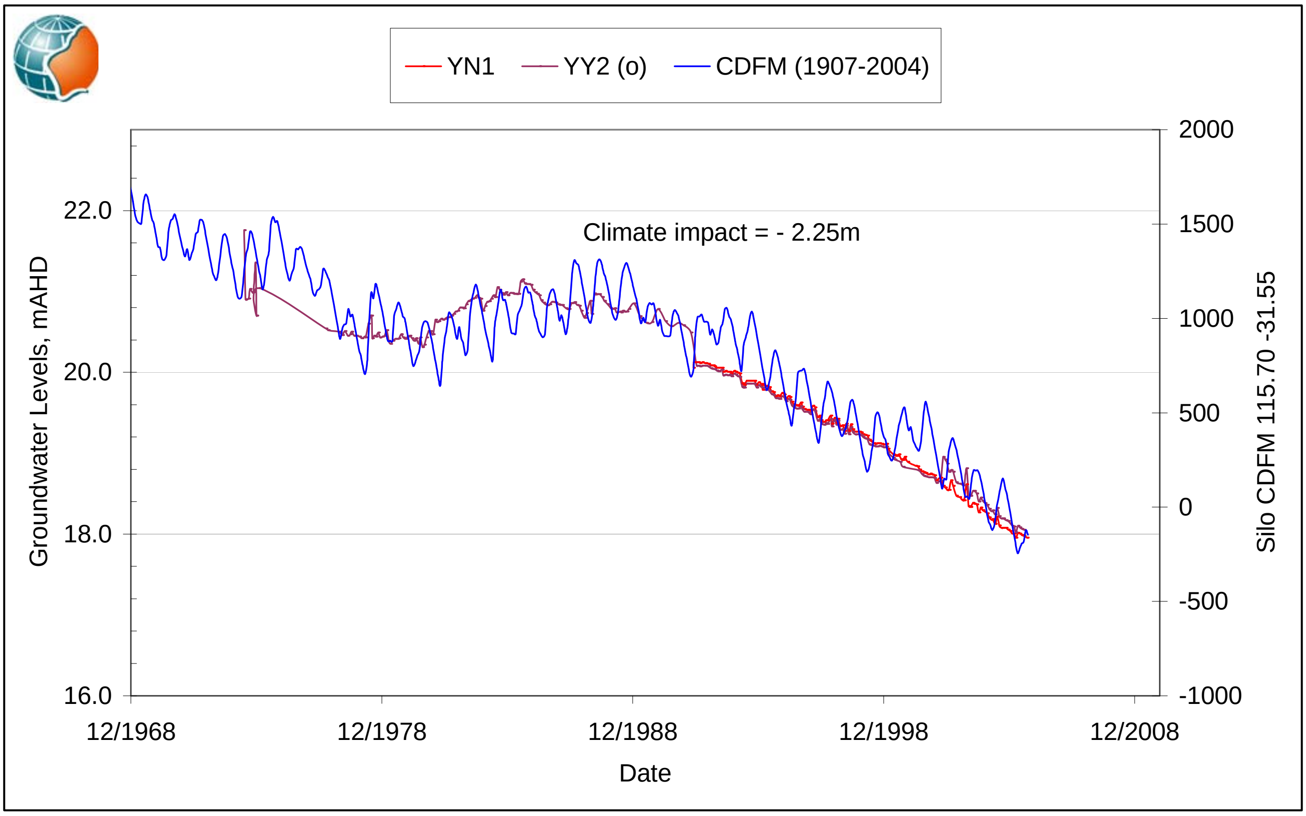

WF12
CDFM (1969-2004)
4.6
4.1
3.6
3.1
2.6
2.1
1.6
1.1
0.6
GA12, mAHD
1,000
500
0
-500
-1,000
CDFM (115.80 -31.80), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date
Abstraction impact= -0.70m
(2001 onwards)

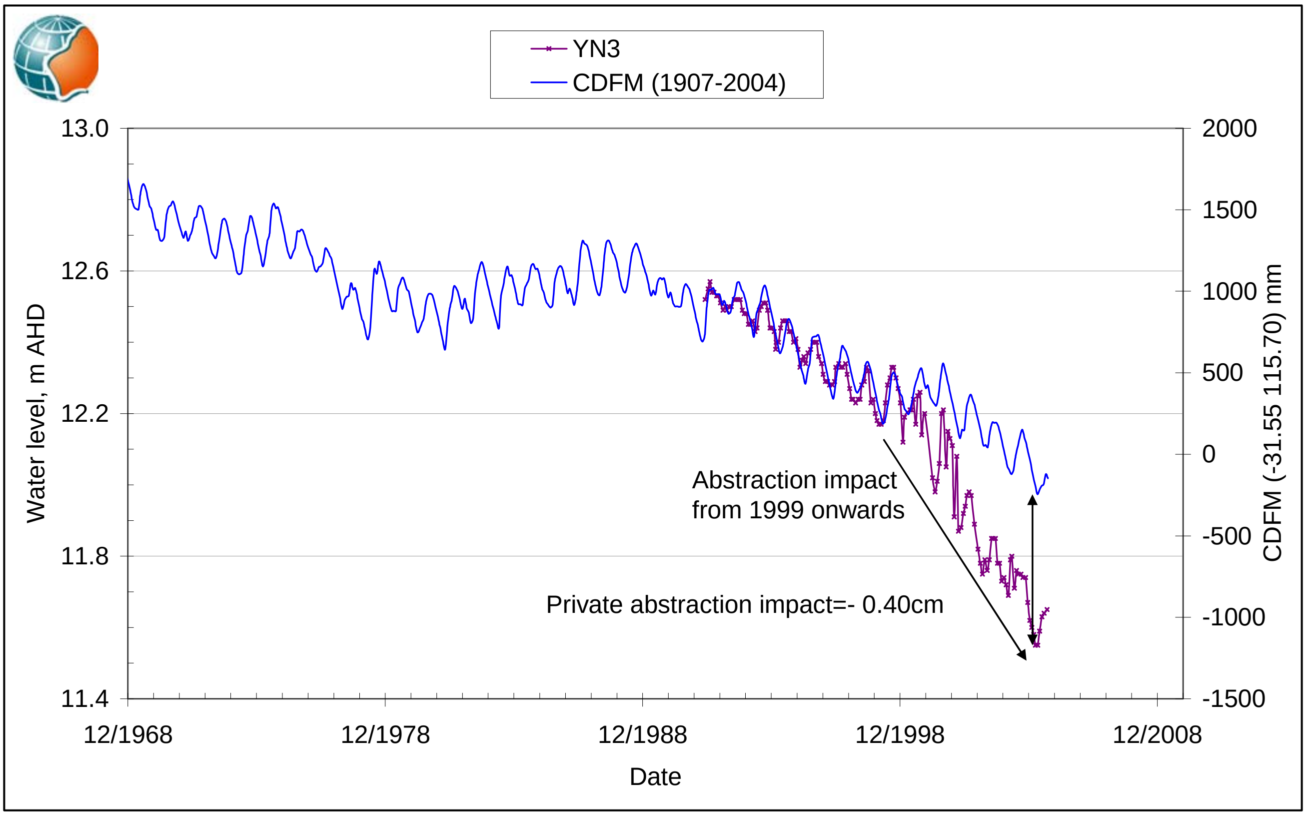
5. Yanchep Rainfall Zone

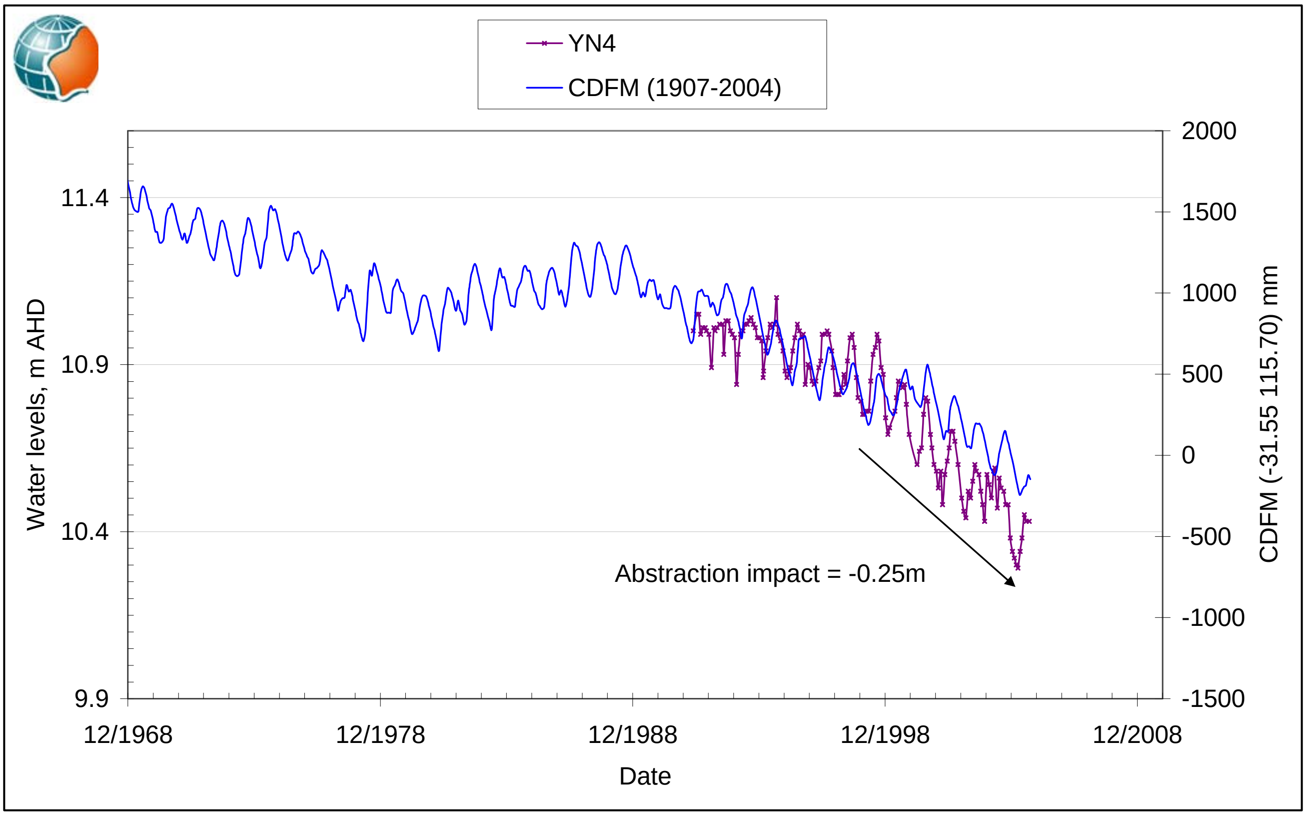
(GA3, GA4, YN1, YY2, YN3, YN4, Crystal Cave, YB11, CG4-90, PM27, PM28, PM31, PM33, PM36, YCM, JP3D, JP12, JP16B, JP19)

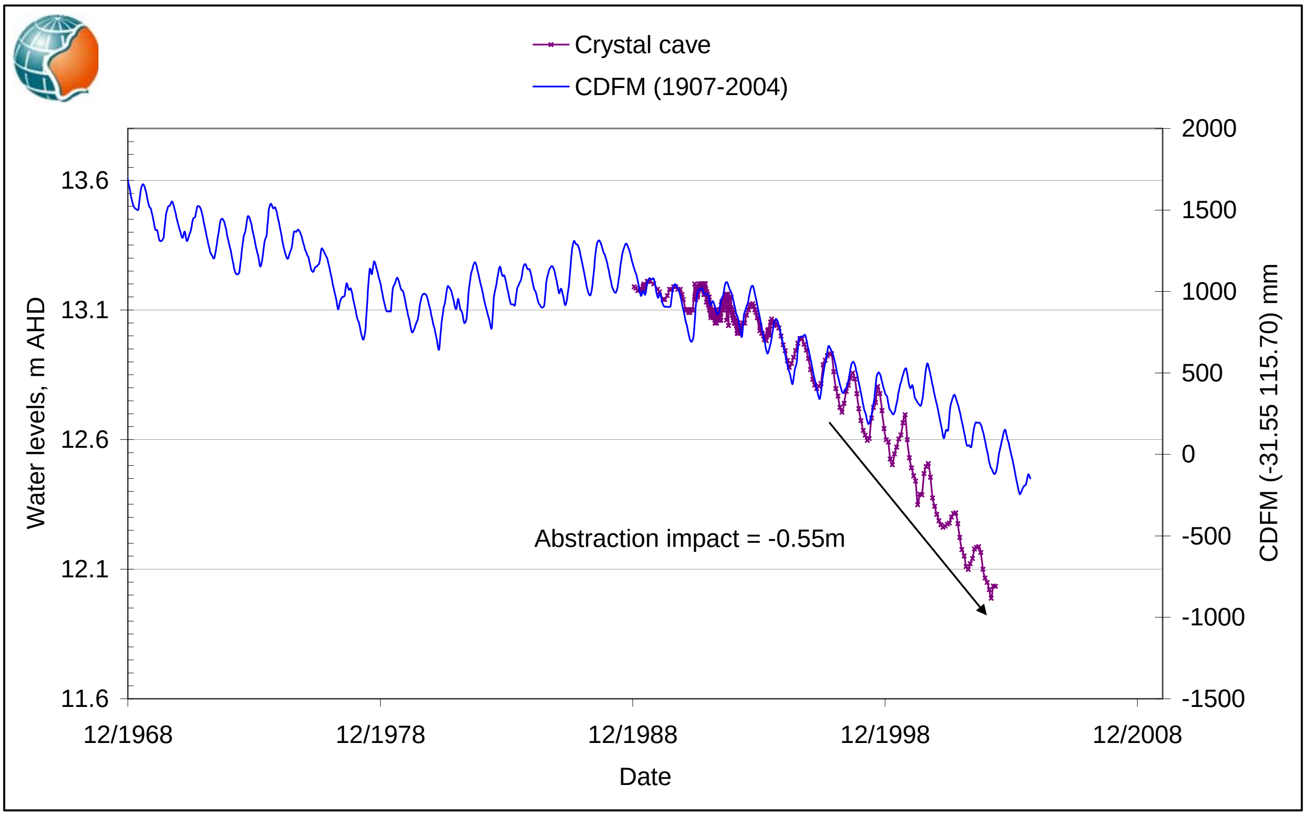

GA3
CDFM (1907-2004)
Climate = -1.20m
Pine/bush = -1.10m
Bush fires = +0.20m
GA3, m AHD
25.7
24.7
23.7
22.7
21.7
CDFM 115.70 -31.5
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
12/1968
12/1978
12/1988
12/1998
12/2008
Date

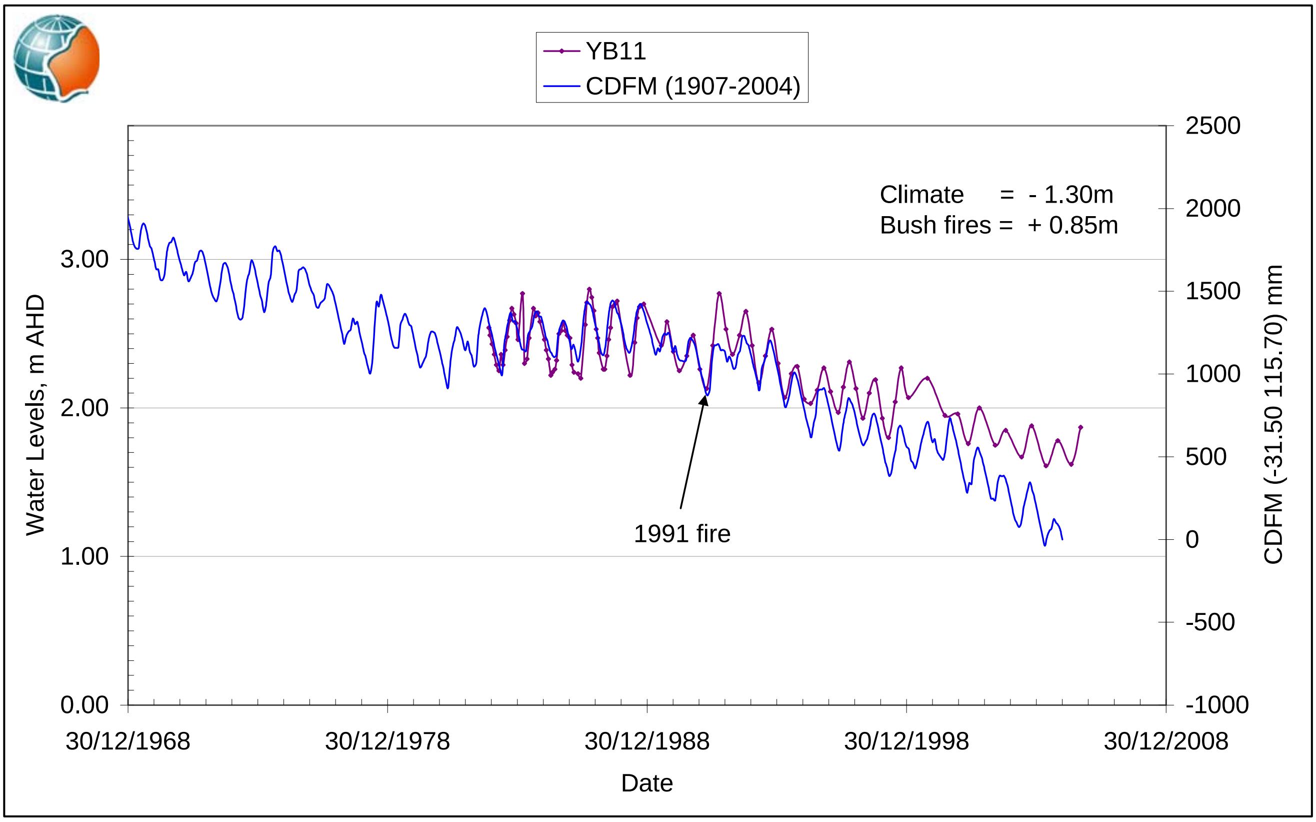

GA4 mAHD
CDFM (1907-2004)
Climate = -2.2m
2.5m rise due to clearing and bush fire
Pine impact -2.8m
Large bush fire
Clearing and planting around the bore site
GA4, m AHD
36.0
34.0
32.0
CDFM (-31.5 115.75) mm
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

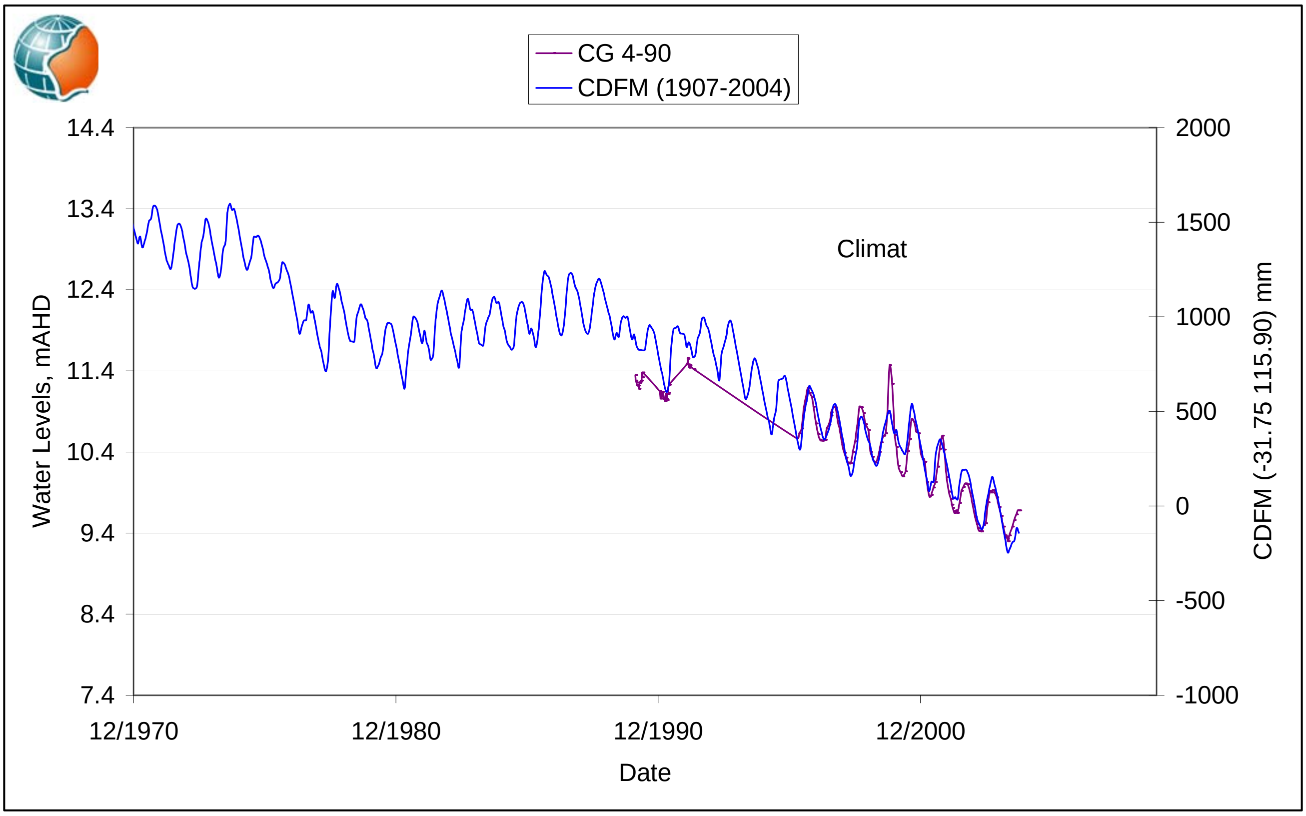

YN1
YY2 (o)
CDFM (1907-2004)
Climate impact = - 2.25m
Groundwater Levels, mAHD
22.0
20.0
18.0
16.0
Silo CDFM 115.70 -31.55
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

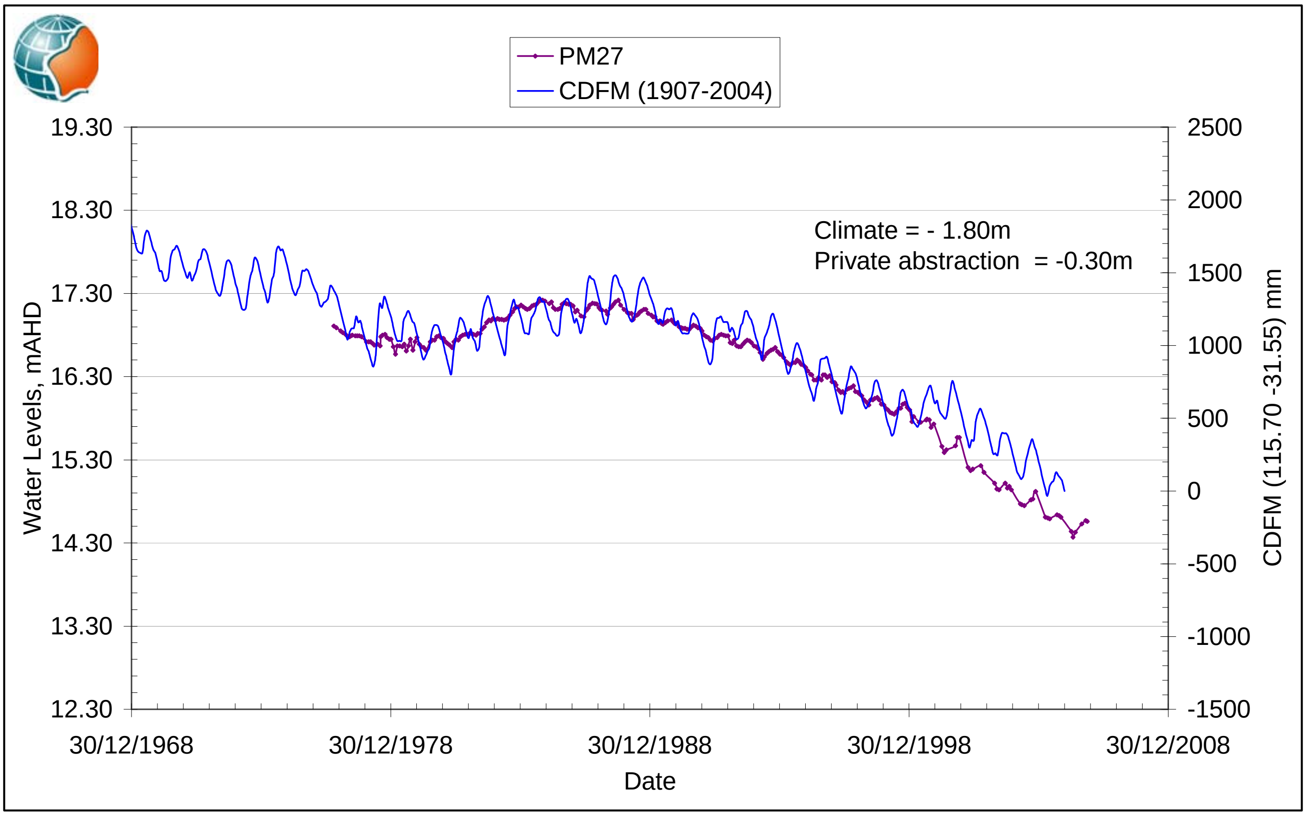

YN3
CDFM (1907-2004)
Water level, m AHD
13.0
12.6
12.2
11.8
11.4
CDFM (-31.55 115.70) mm
2000
1500
1000
500
0
-500
-1000
-1500
Abstraction impact
from 1999 onwards
Private abstraction impact=- 0.40cm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

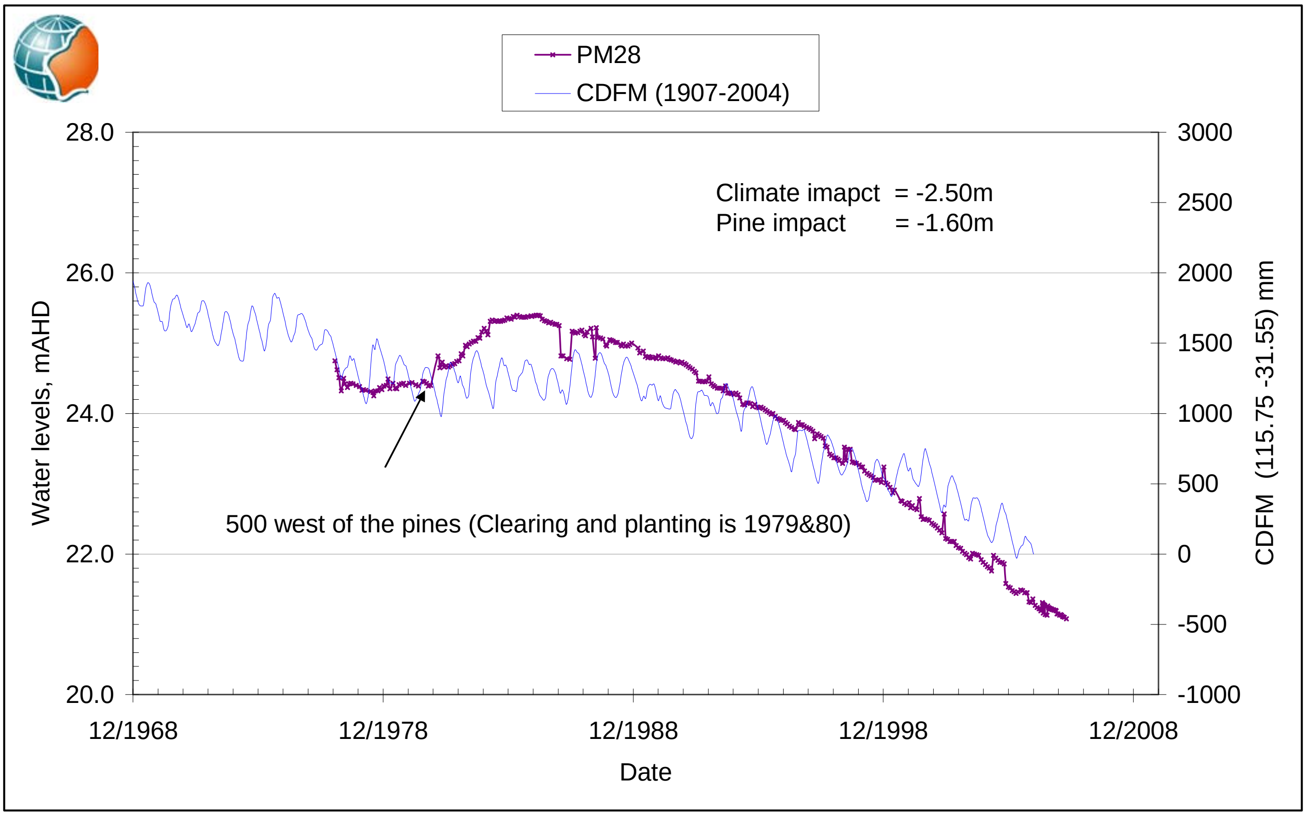

YN4
CDFM (1907-2004)
Water levels, m AHD
11.4
10.9
10.4
9.9
CDFM (-31.55 115.70) mm
2000
1500
1000
500
0
-500
-1000
-1500
Abstraction impact = -0.25m
12/1968
12/1978
12/1988
12/1998
12/2008
Date

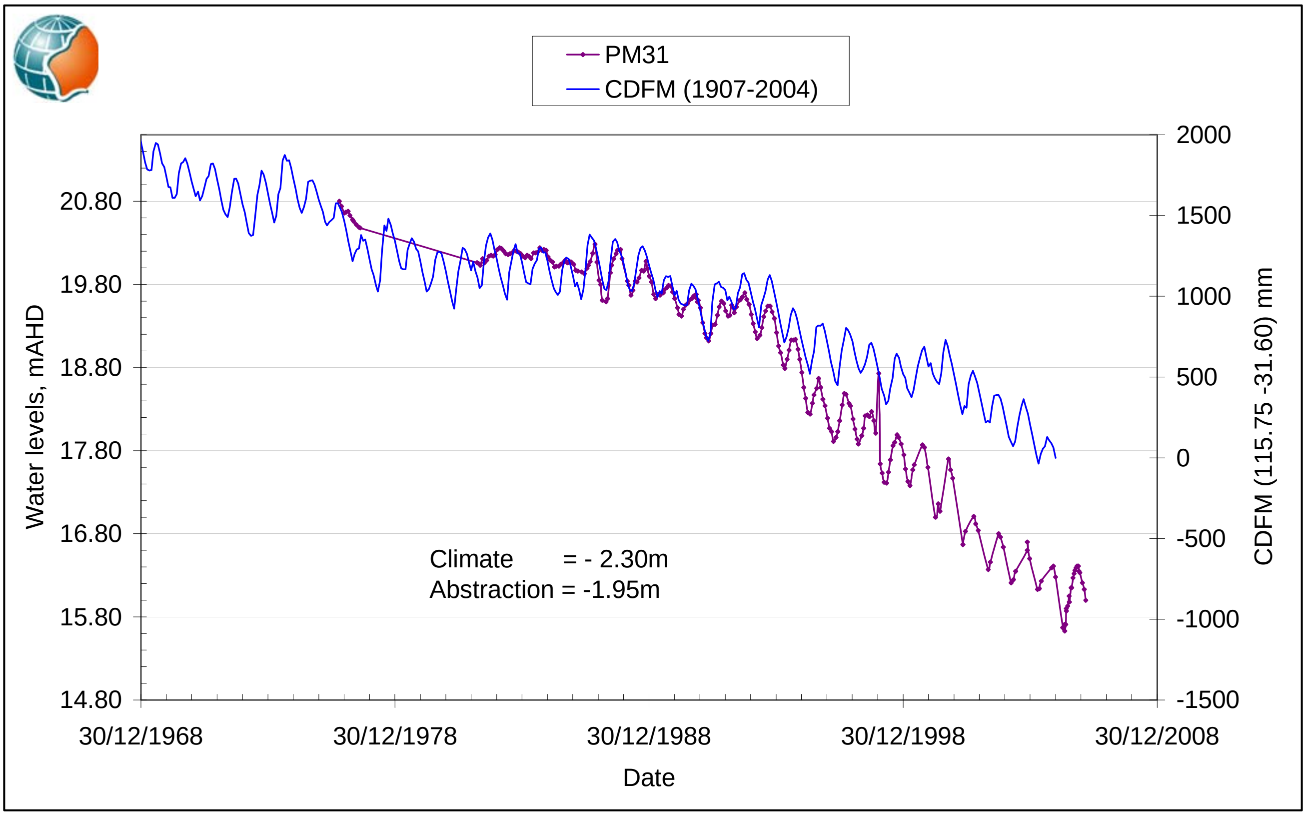

Crystal cave
CDFM (1907-2004)
Water levels, m AHD
13.6
13.1
12.6
12.1
11.6
CDFM (-31.55 115.70) mm
2000
1500
1000
500
0
-500
-1000
-1500
Abstraction impact = -0.55m
12/1968
12/1978
12/1988
12/1998
12/2008
Date

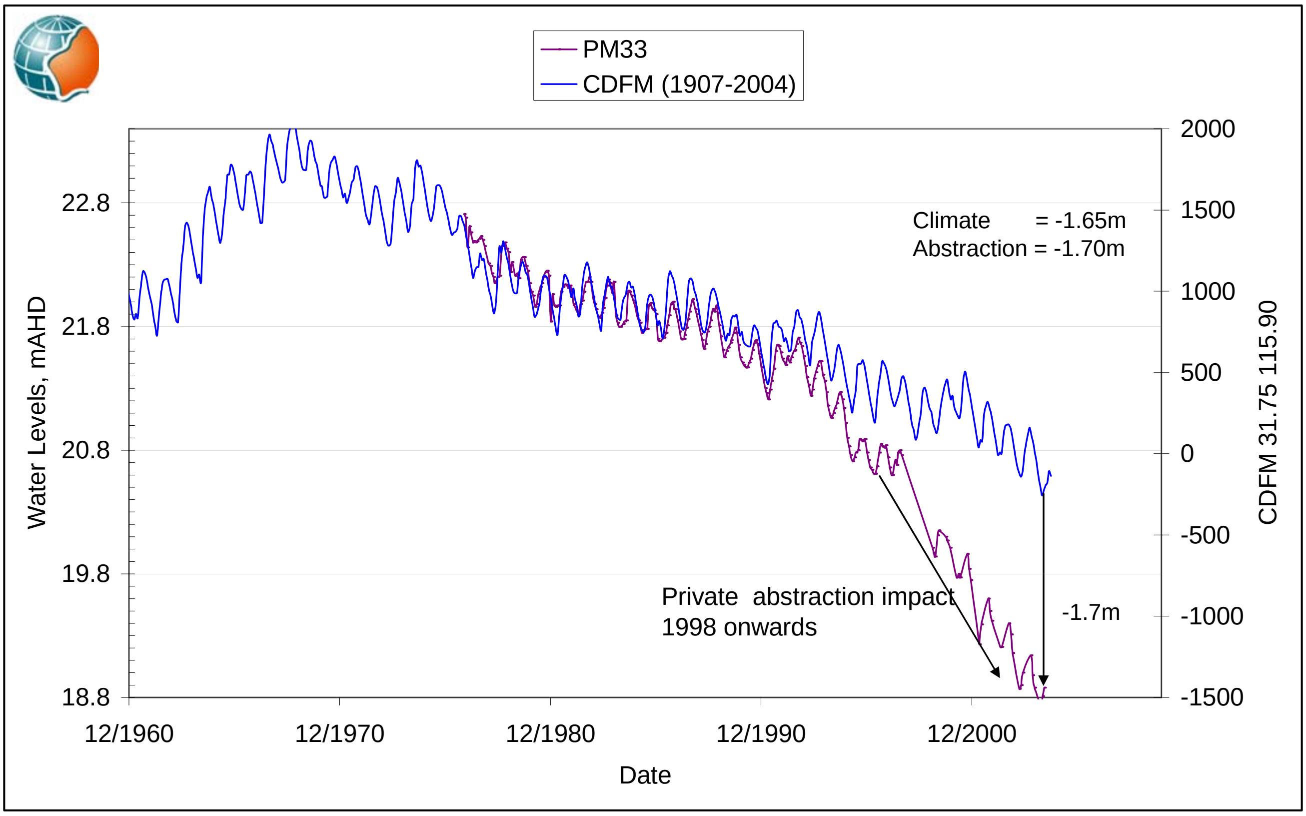

YB11
CDFM (1907-2004)
Climate = - 1.30m
Bush fires = + 0.85m
1991 fire
Water Levels, m AHD
0.00
1.00
2.00
3.00
CDFM (-31.50 115.70) mm
-1000
-500
0
500
1000
1500
2000
2500
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

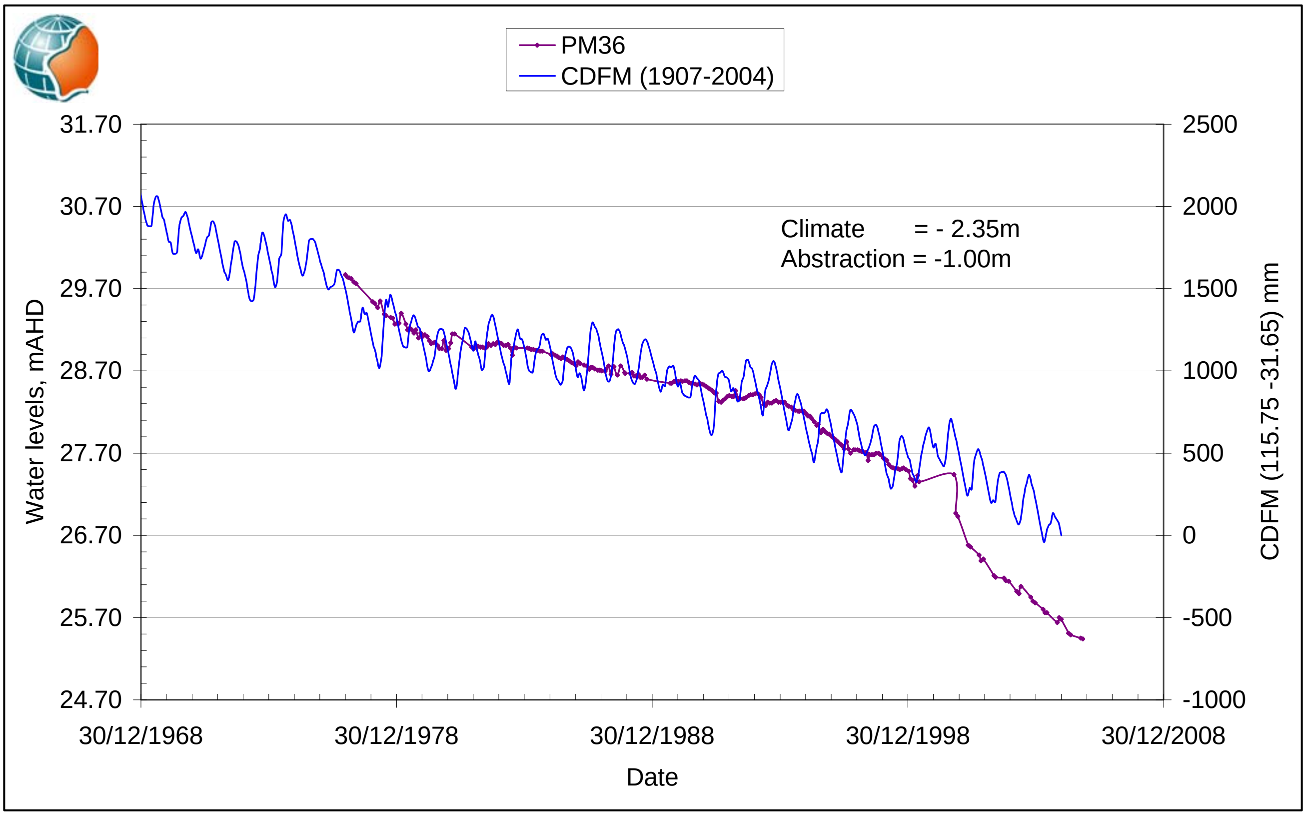

CG 4-90
CDFM (1907-2004)
Climat
Water Levels, mAHD
7.4
8.4
9.4
10.4
11.4
12.4
13.4
14.4
CDFM (-31.75 115.90) mm
-1000
-500
0
500
1000
1500
2000
12/1970
12/1980
12/1990
12/2000
Date

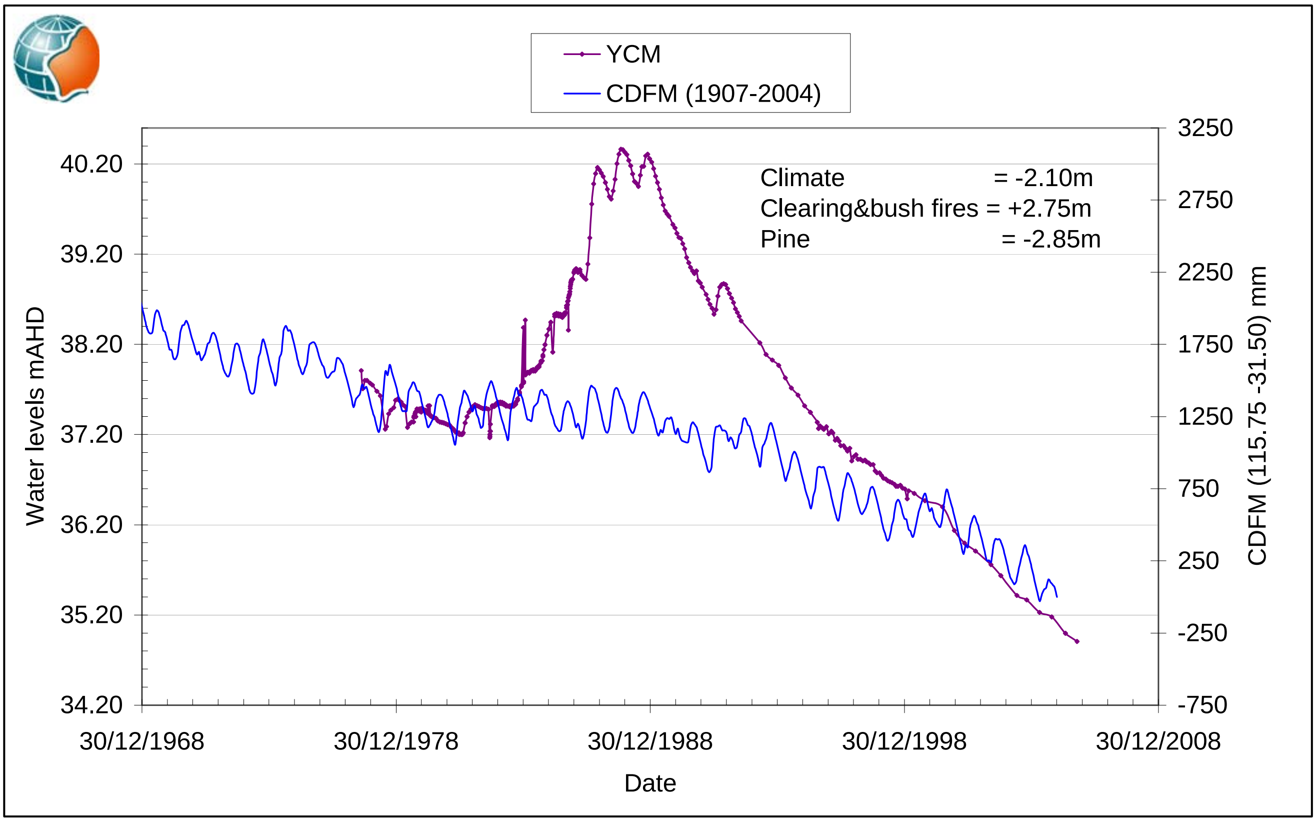

PM27
CDFM (1907-2004)
Climate = - 1.80m
Private abstraction = -0.30m
Water Levels, mAHD
19.30
18.30
17.30
16.30
15.30
14.30
13.30
12.30
CDFM (115.70 -31.55) mm
2500
2000
1500
1000
500
0
-500
-1000
-1500
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

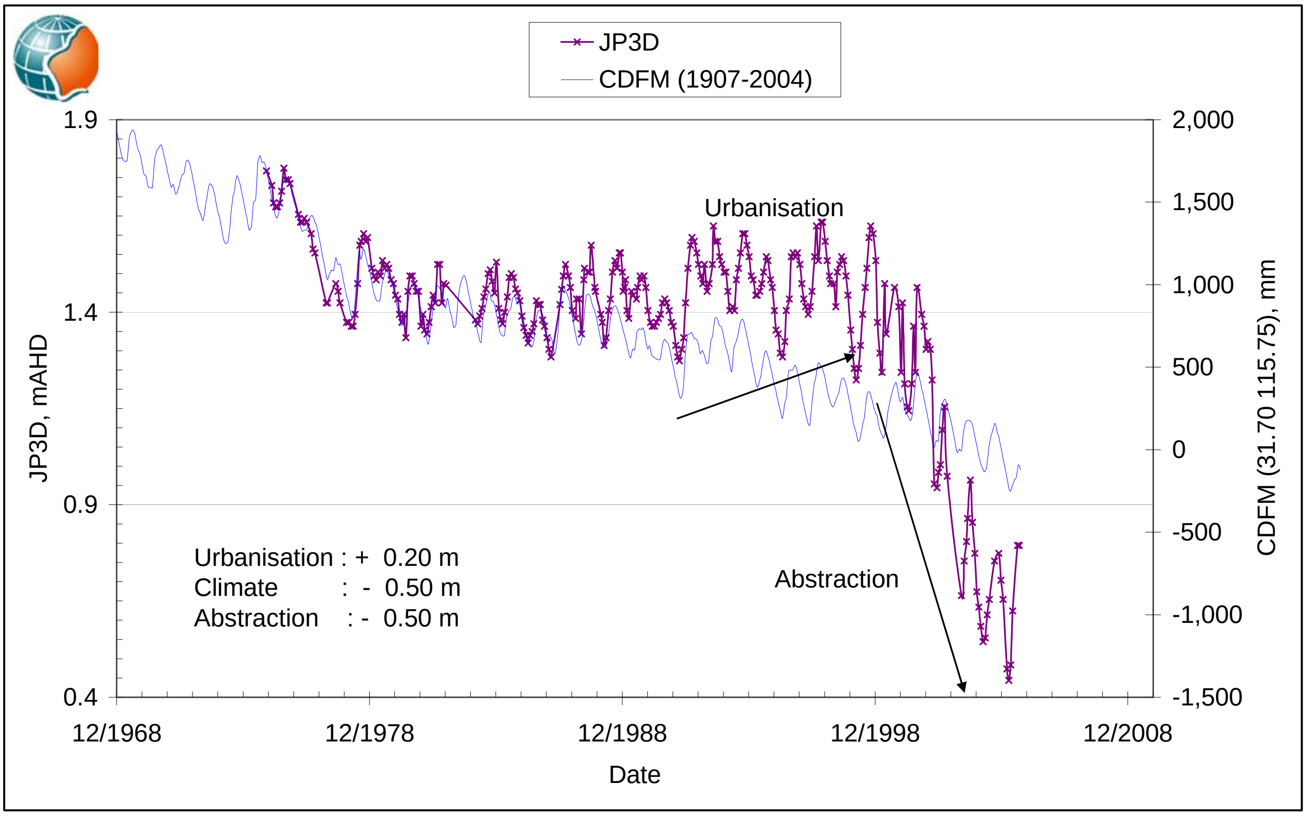

PM28
CDFM (1907-2004)
Climate imapct = -2.50m
Pine impact = -1.60m
500 west of the pines (Clearing and planting is 1979&80)
Water levels, mAHD
28.0
26.0
24.0
22.0
20.0
CDFM (115.75 -31.55) mm
3000
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

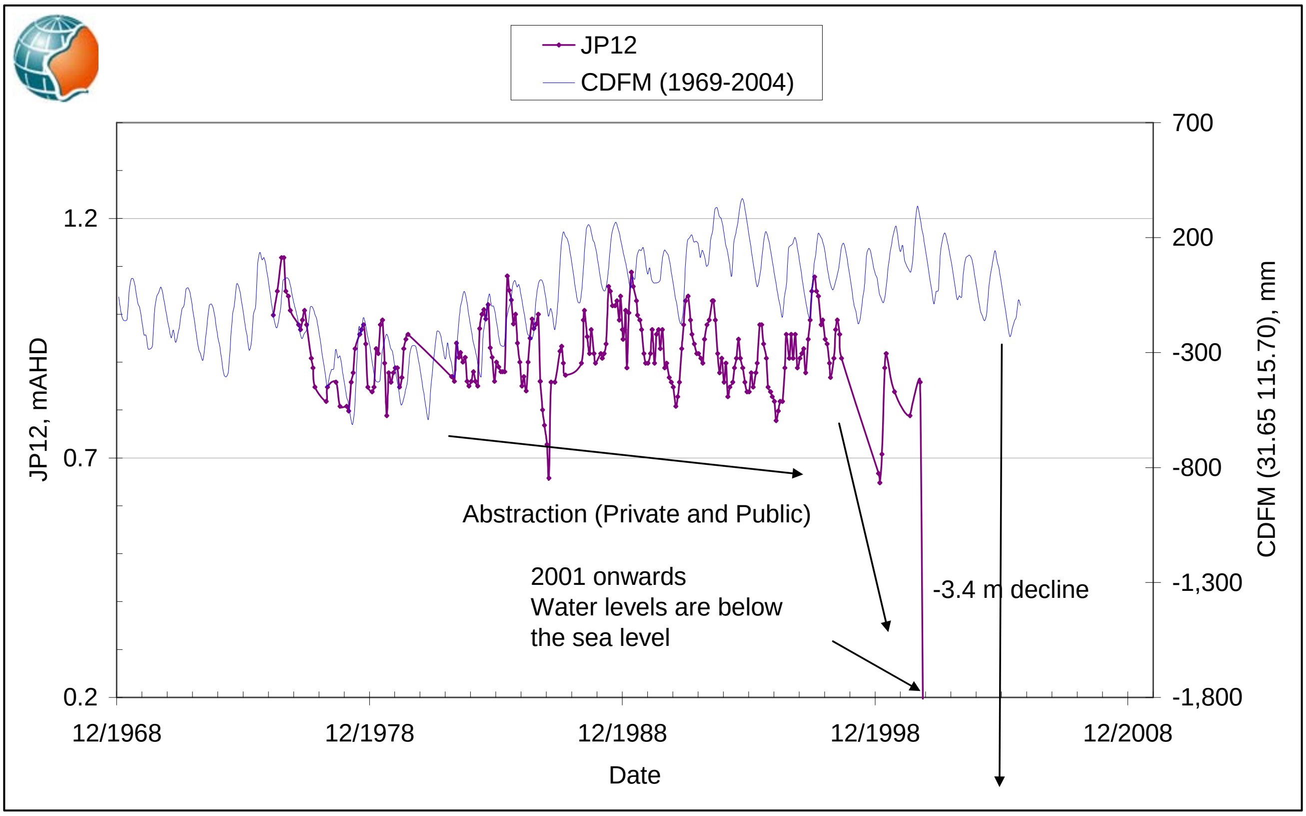

PM31
CDFM (1907-2004)
Water levels, mAHD
20.80
19.80
18.80
17.80
16.80
15.80
14.80
2000
1500
1000
500
0
-500
-1000
-1500
CDFM (115.75 -31.60) mm
Climate = - 2.30m
Abstraction = -1.95m
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

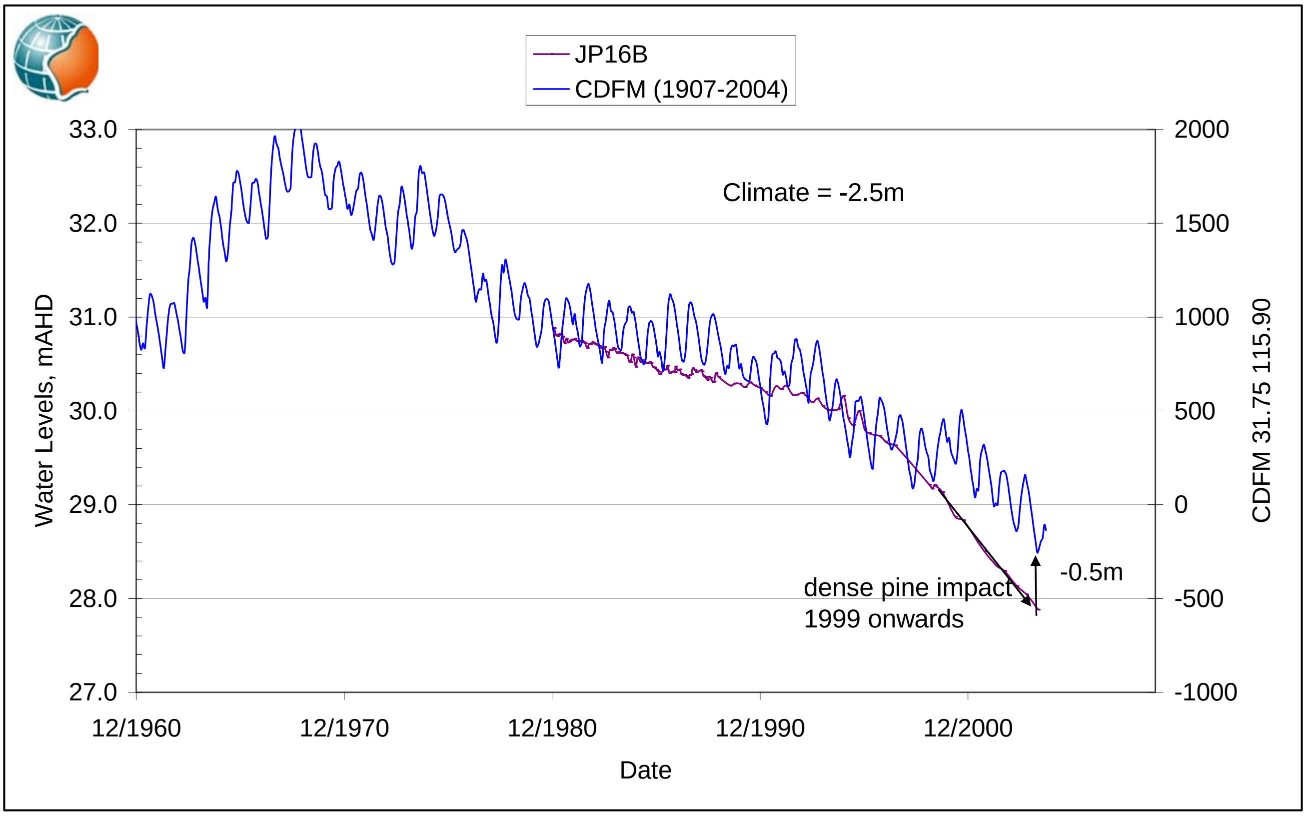

PM33
CDFM (1907-2004)
Water Levels, mAHD
22.8
21.8
20.8
19.8
18.8
2000
1500
1000
500
0
-500
-1000
-1500
CDFM 31.75 115.90
Climate = -1.65m
Abstraction = -1.70m
Private abstraction impact
1998 onwards
-1.7m
12/1960
12/1970
12/1980
12/1990
12/2000
Date

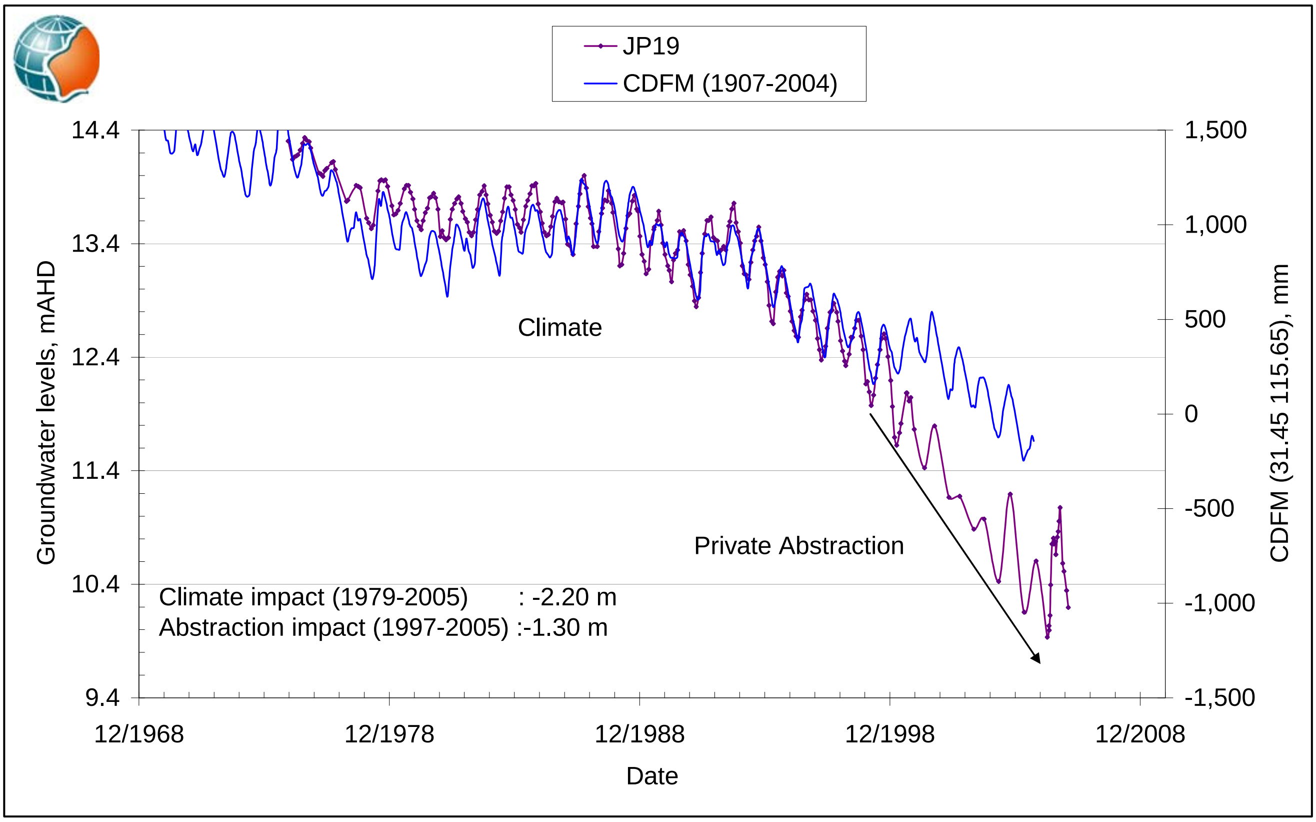

PM36
CDFM (1907-2004)
Climate = - 2.35m
Abstraction = -1.00m
Water levels, mAHD
31.70
30.70
29.70
28.70
27.70
26.70
25.70
24.70
CDFM (115.75 -31.65) mm
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


YCM
CDFM (1907-2004)
Climate = -2.10m
Clearing&bush fires = +2.75m
Pine = -2.85m
Water levels mAHD
40.20
39.20
38.20
37.20
36.20
35.20
34.20
CDFM (115.75 -31.50) mm
3250
2750
2250
1750
1250
750
250
-250
-750
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


JP3D
CDFM (1907-2004)
1.9
1.4
0.9
0.4
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
JP3D, mAHD
CDFM (31.70 115.75), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date
Urbanisation
Abstraction
Urbanisation : + 0.20 m
Climate : - 0.50 m
Abstraction : - 0.50 m

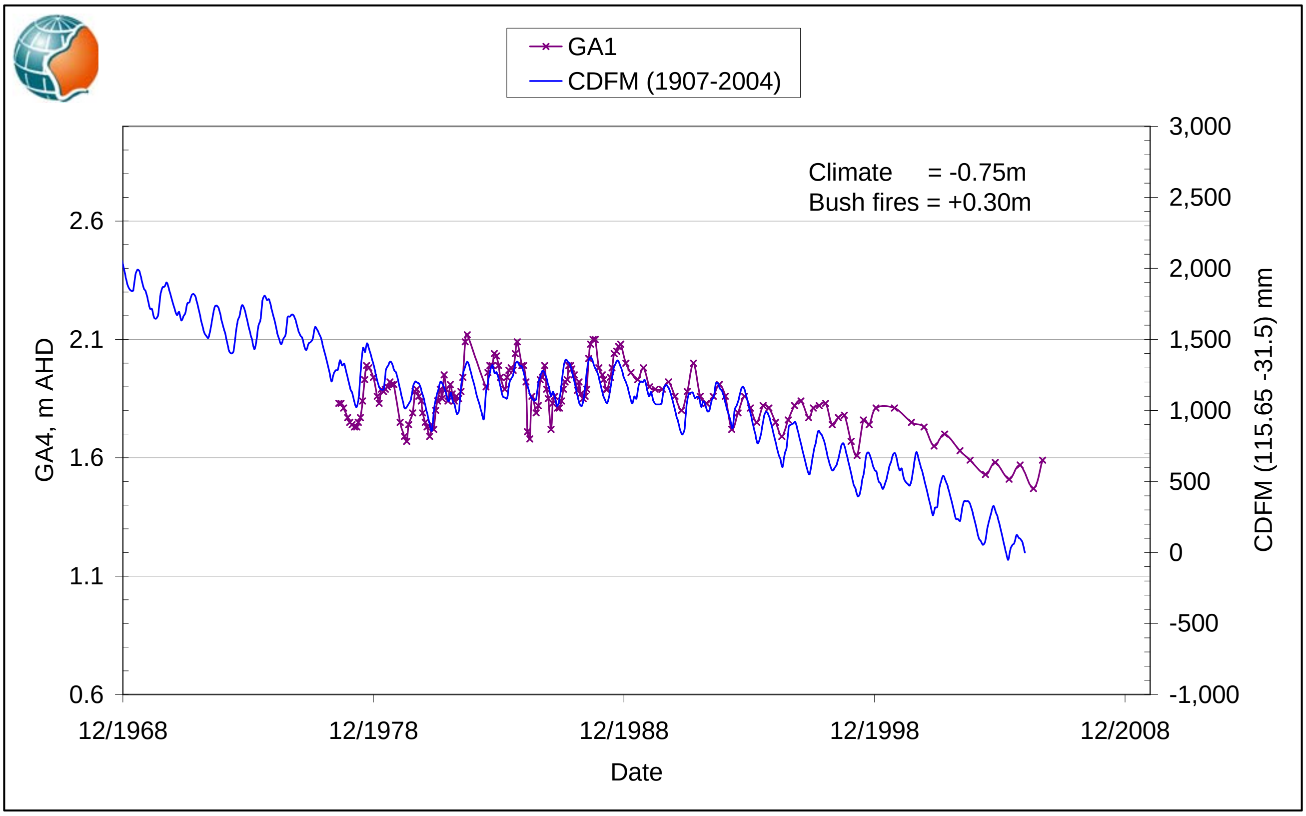

JP12
CDFM (1969-2004)
1.2
0.7
0.2
700
200
-300
-800
-1,300
-1,800
JP12, mAHD
CDFM (31.65 115.70), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date
Abstraction (Private and Public)
2001 onwards
Water levels are below
the sea level
-3.4 m decline

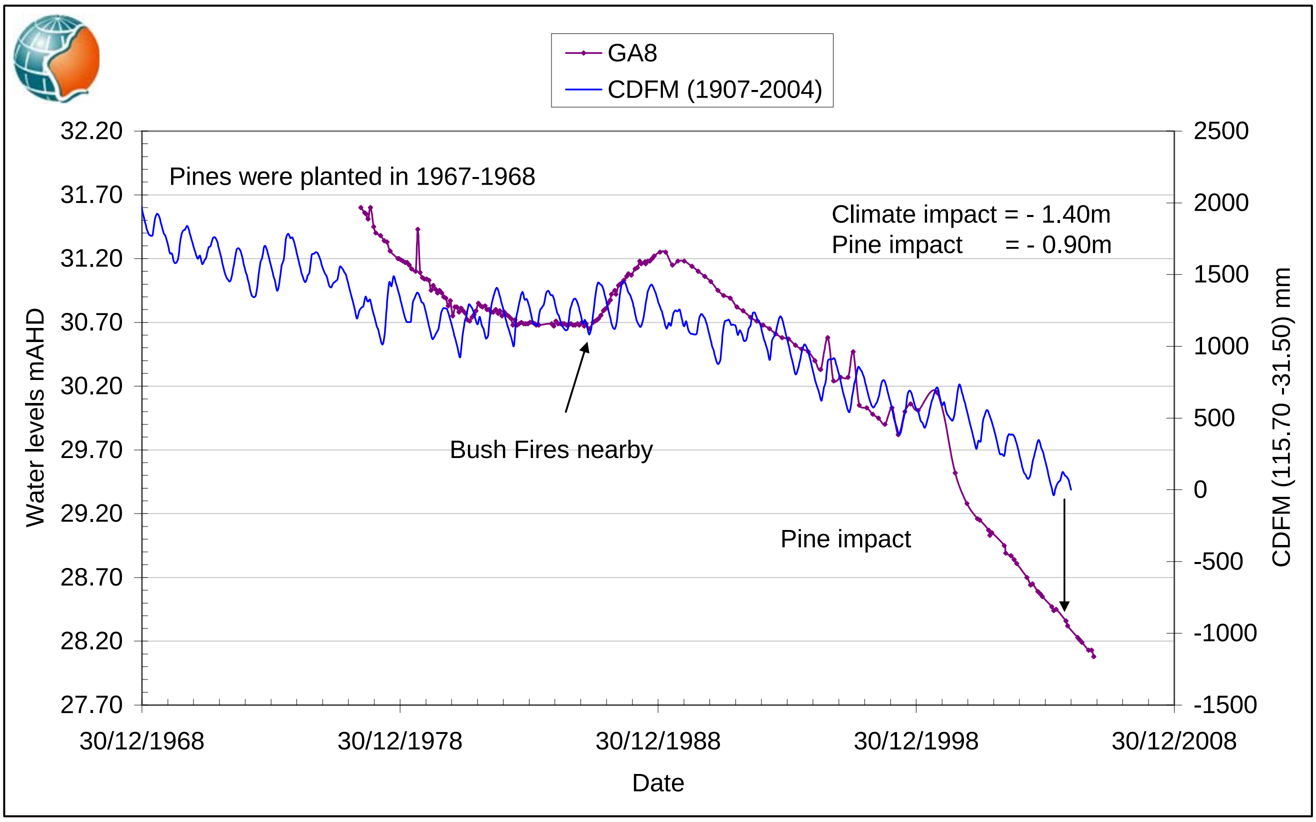

JP16B
CDFM (1907-2004)
Climate = -2.5m
dense pine impact
1999 onwards
-0.5m
Water Levels, mAHD
CDFM 31.75 115.90
33.0
32.0
31.0
30.0
29.0
28.0
27.0
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000
Date

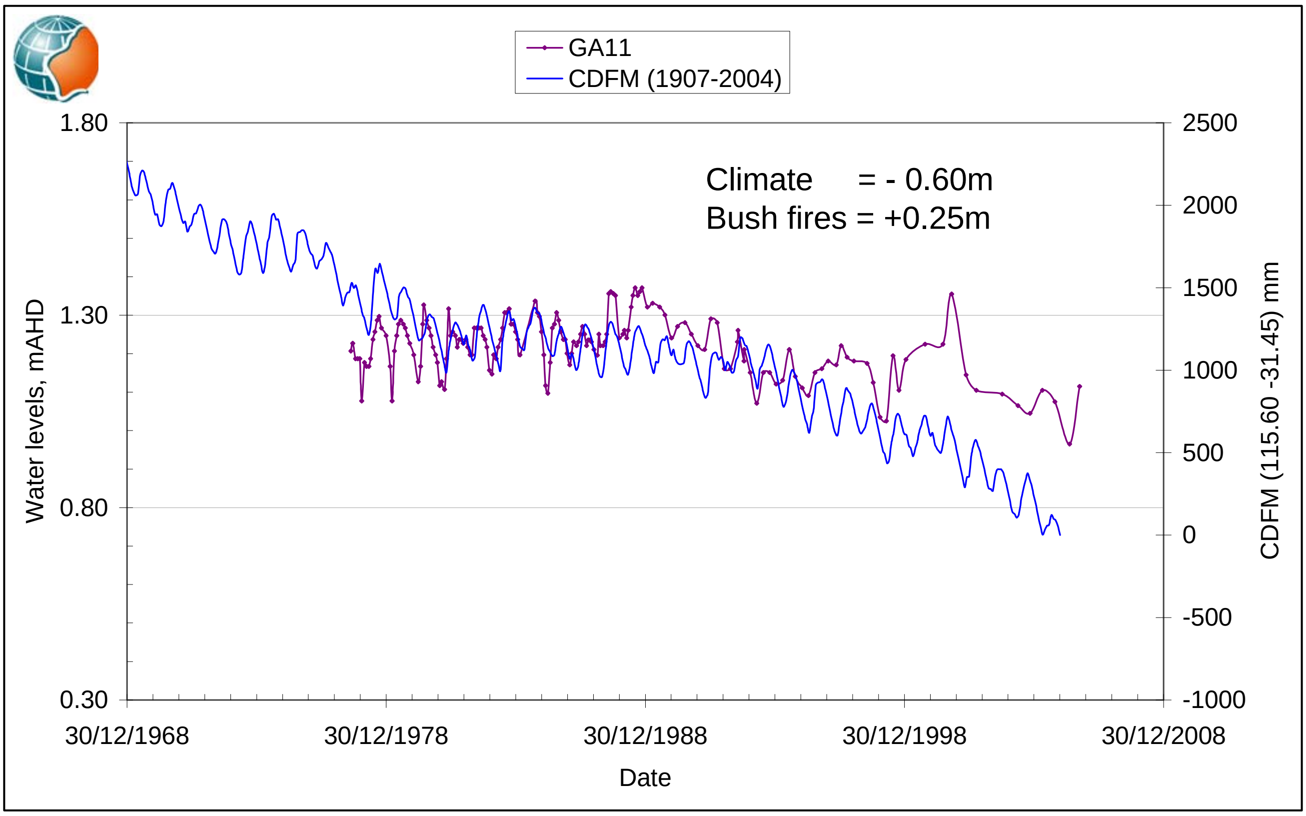

JP19
CDFM (1907-2004)
Climate
Private Abstraction
Climate impact (1979-2005) : -2.20 m
Abstraction impact (1997-2005) :-1.30 m
Groundwater levels, mAHD
CDFM (31.45 115.65), mm
14.4
13.4
12.4
11.4
10.4
9.4
1,500
1,000
500
0
-500
-1,000
-1,500
12/1968
12/1978
12/1988
12/1998
12/2008
Date

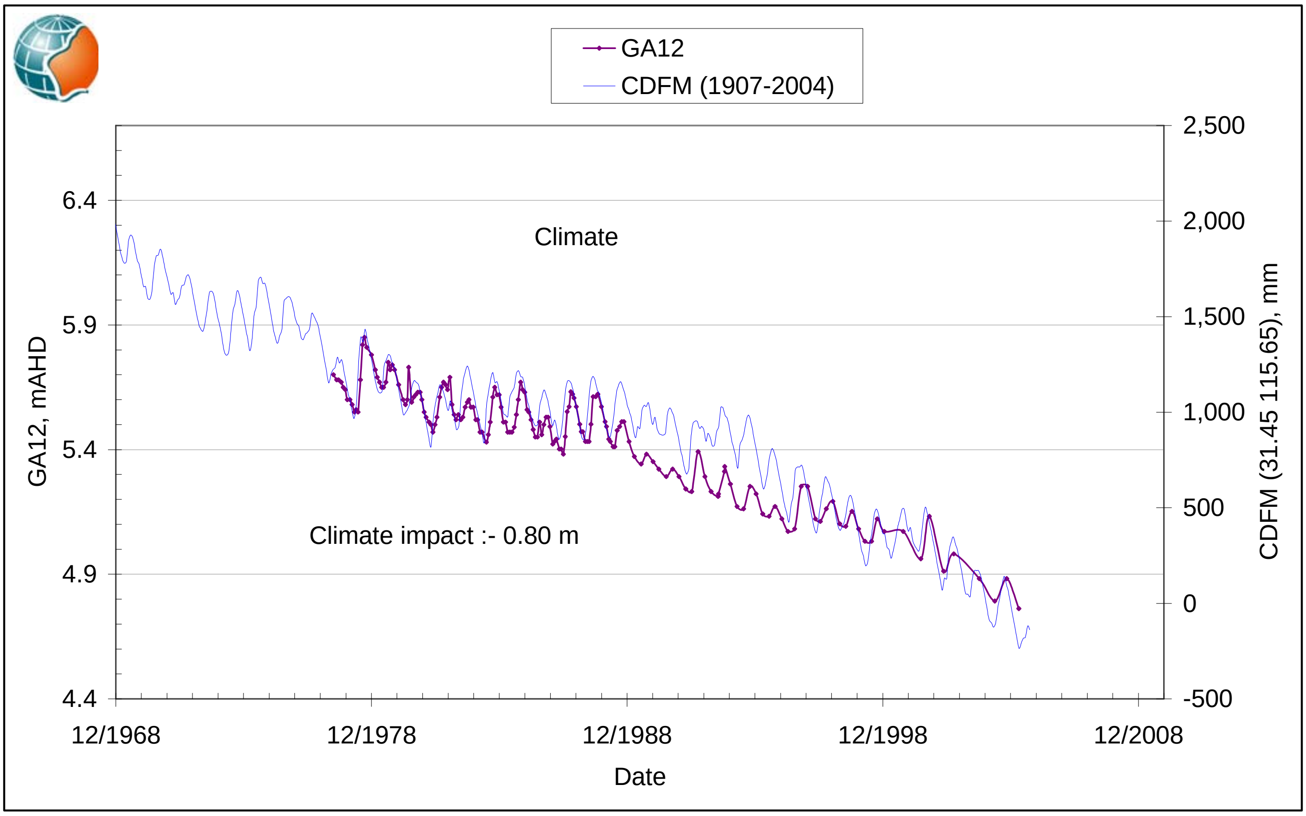
6. Two Rocks Rainfall Zone

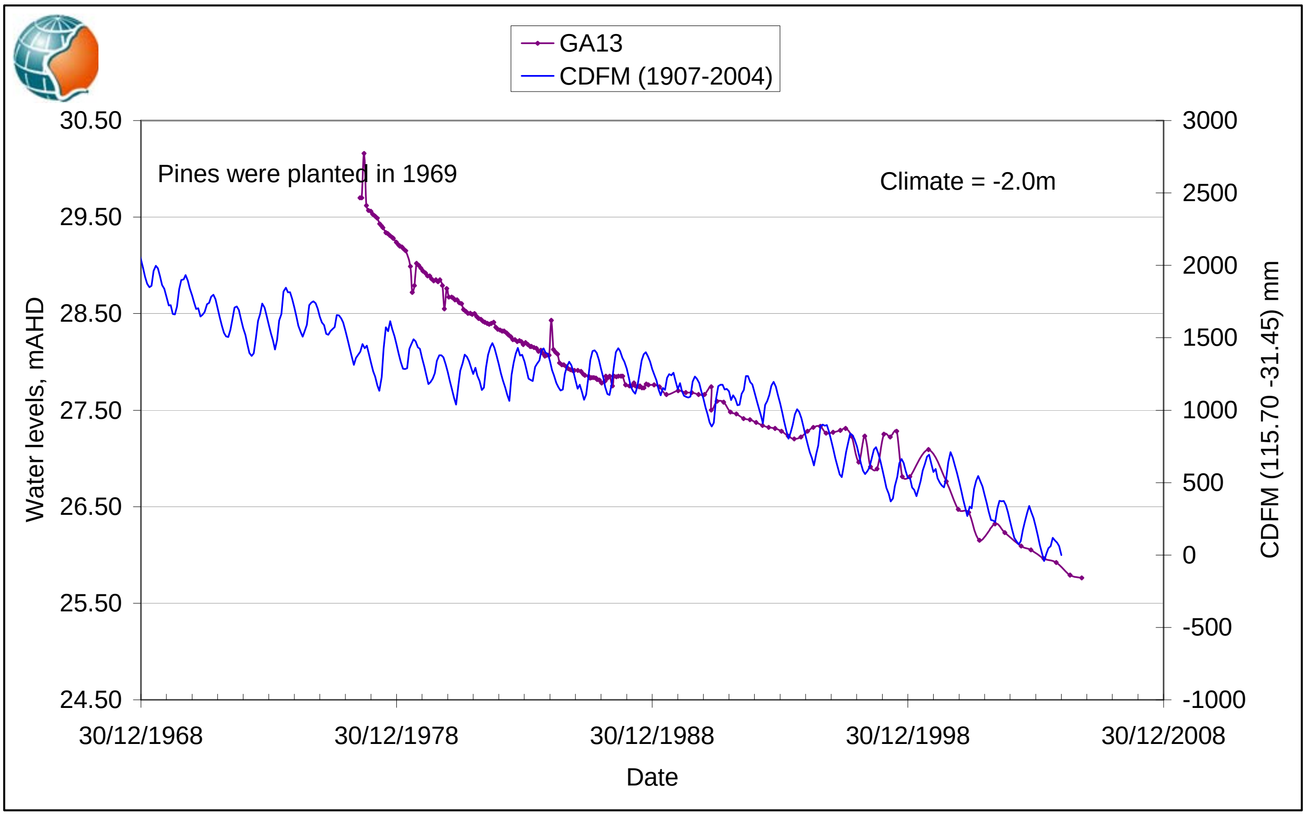
(GA1, GA8, GA11, GA12, GA13, GA14, GA17, GA18, GA24, GA29, GA33)

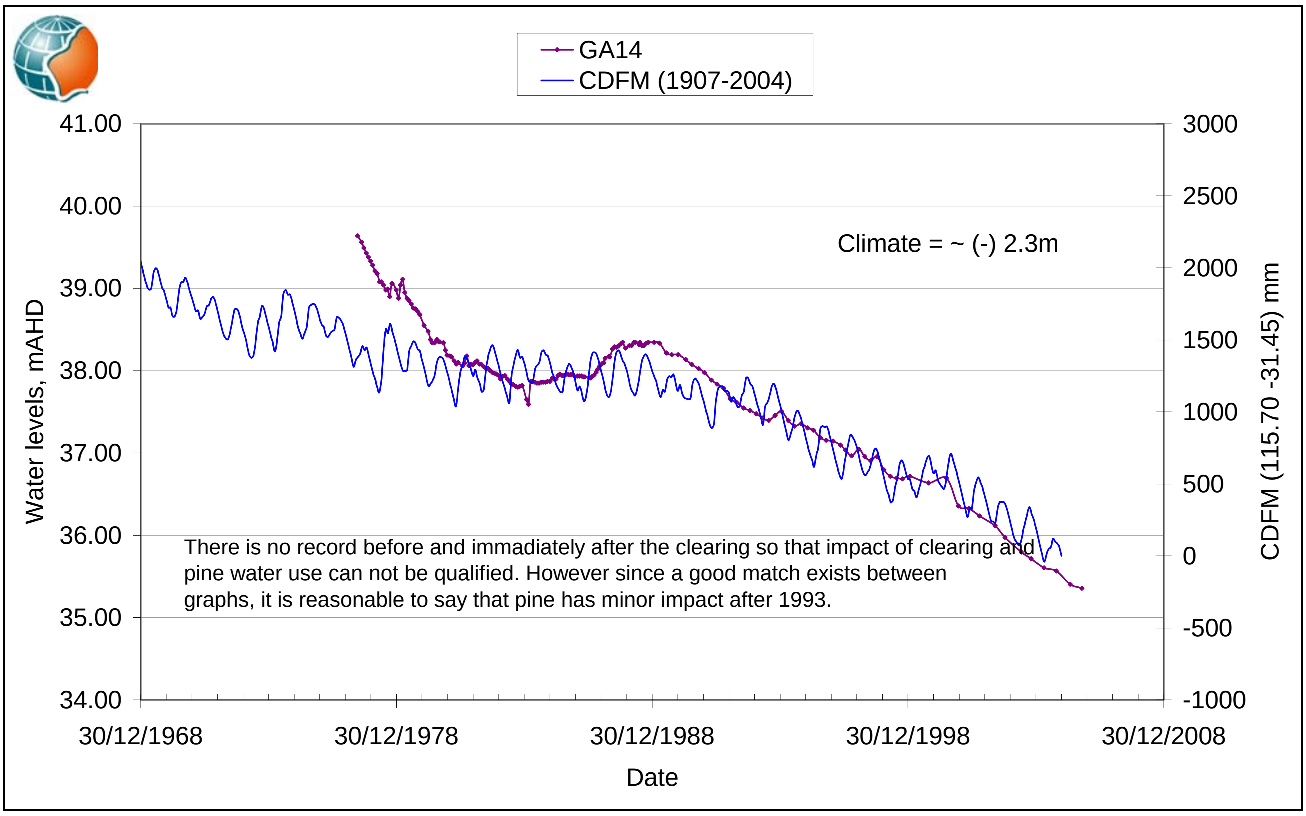

GA1
CDFM (1907-2004)
Climate = -0.75m
Bush fires = +0.30m
GA4, m AHD
2.6
2.1
1.6
1.1
0.6
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
CDFM (115.65 -31.5) mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

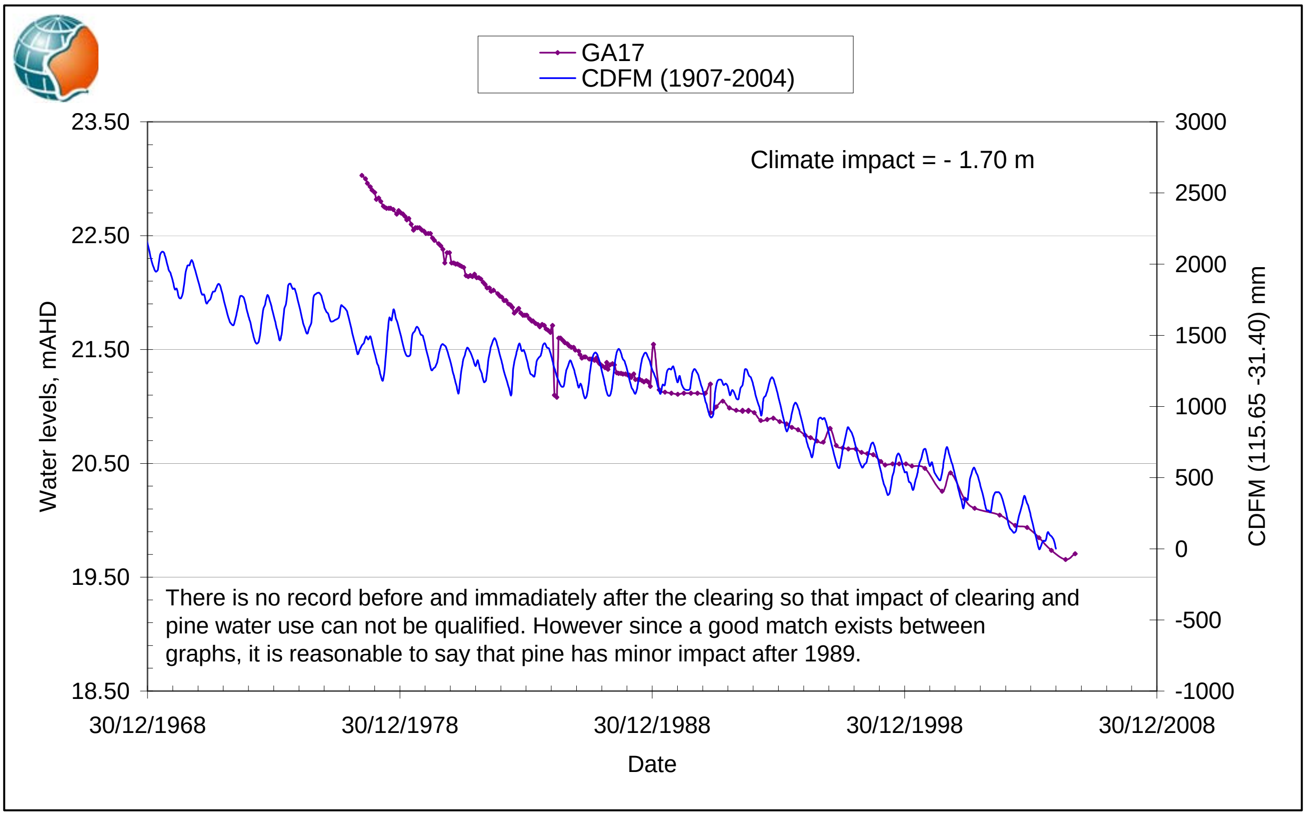

GA8
CDFM (1907-2004)
Pines were planted in 1967-1968
Climate impact = - 1.40m
Pine impact = - 0.90m
Bush Fires nearby
Pine impact
Water levels mAHD
32.20
31.70
31.20
30.70
30.20
29.70
29.20
28.70
28.20
27.70
2500
2000
1500
1000
500
0
-500
-1000
-1500
CDFM (115.70 -31.50) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

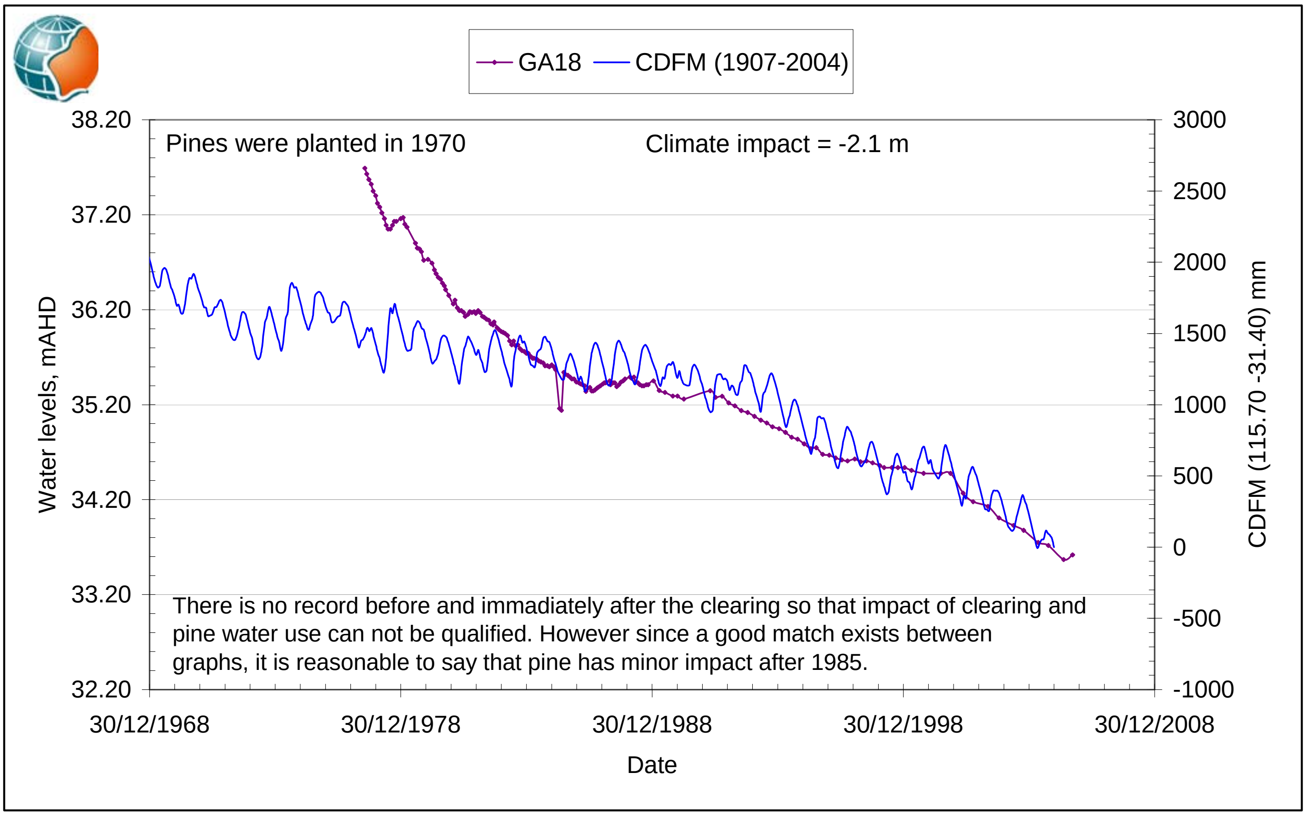

GA11
CDFM (1907-2004)
Climate = - 0.60m
Bush fires = +0.25m
1.80
1.30
0.80
0.30
Water levels, mAHD
2500
2000
1500
1000
500
0
-500
-1000
CDFM (115.60 -31.45) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

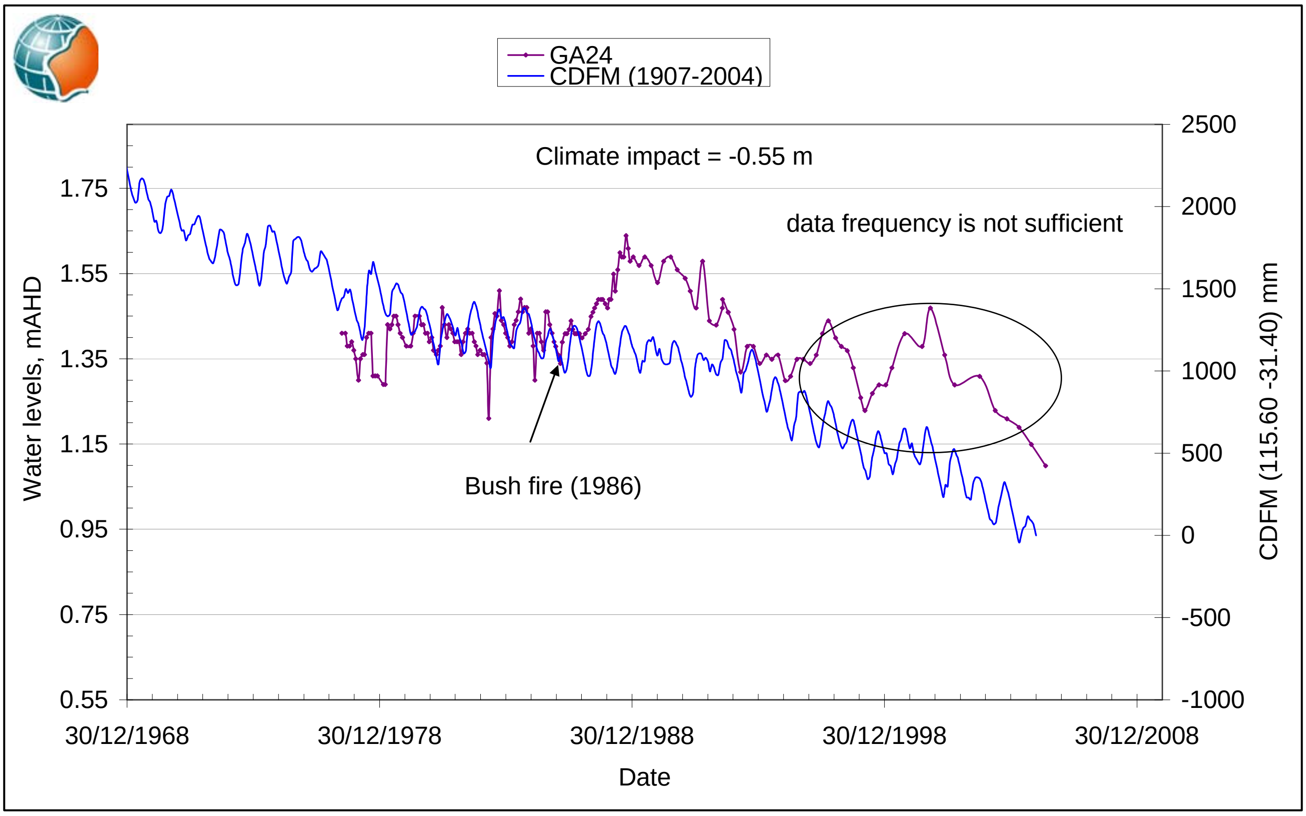

GA12
CDFM (1907-2004)
Climate
Climate impact :- 0.80 m
6.4
5.9
5.4
4.9
4.4
GA12, mAHD
2,500
2,000
1,500
1,000
500
0
-500
CDFM (31.45 115.65), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

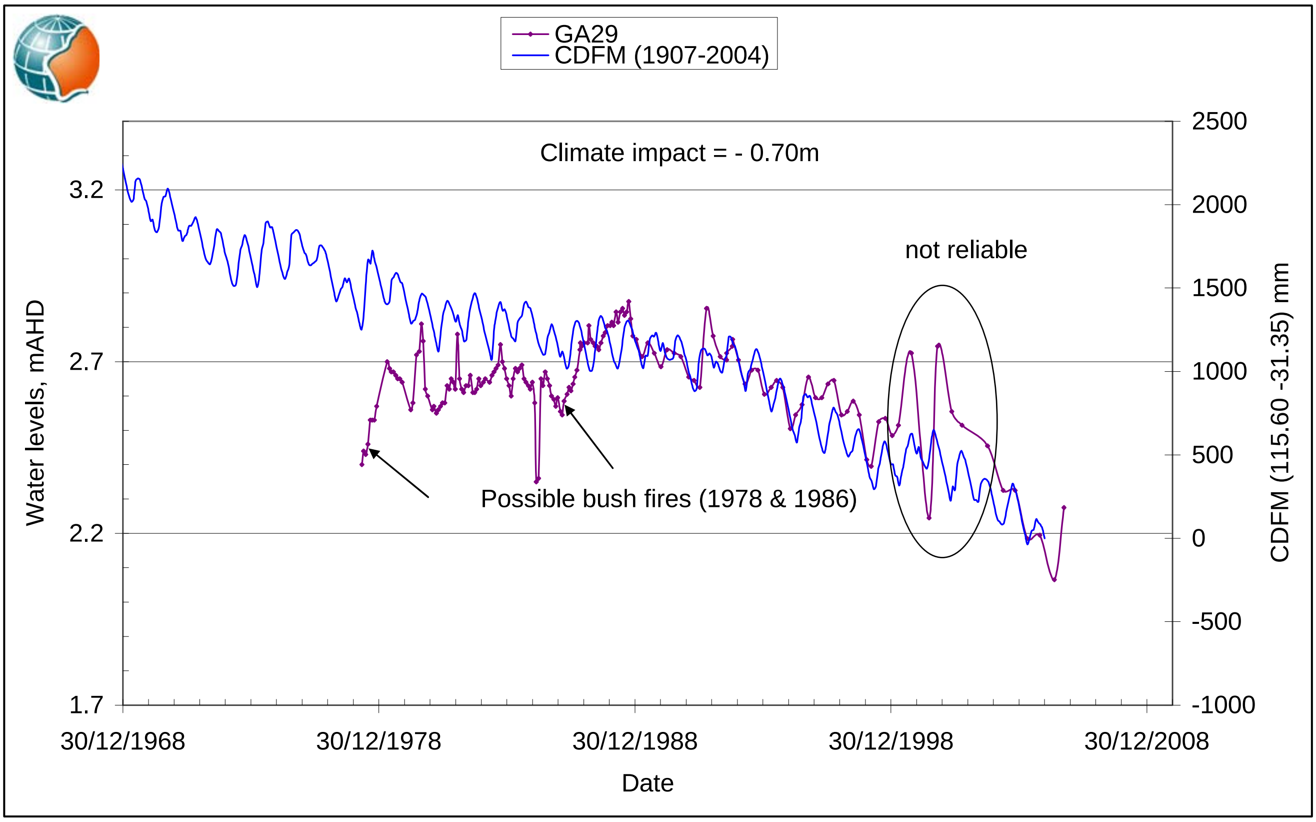

GA13
CDFM (1907-2004)
Pines were planted in 1969
Climate = -2.0m
Water levels, mAHD
30.50
29.50
28.50
27.50
26.50
25.50
24.50
CDFM (115.70 -31.45) mm
3000
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

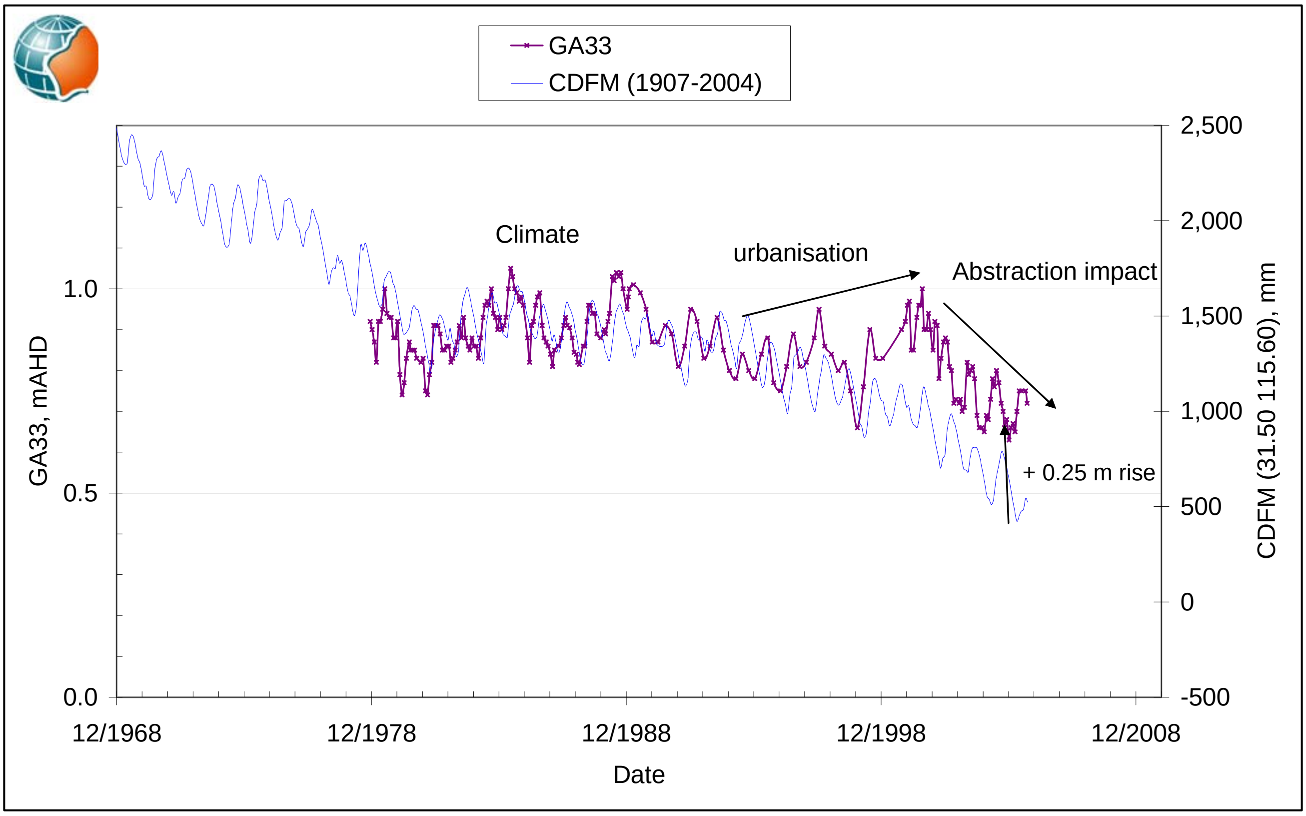

GA14
CDFM (1907-2004)
Climate = ~ (-) 2.3m
There is no record before and immadiately after the clearing so that impact of clearing and pine water use can not be qualified. However since a good match exists between graphs, it is reasonable to say that pine has minor impact after 1993.
Water levels, mAHD
41.00
40.00
39.00
38.00
37.00
36.00
35.00
34.00
CDFM (115.70 -31.45) mm
3000
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


GA17
CDFM (1907-2004)
Climate impact = - 1.70 m
There is no record before and immadiately after the clearing so that impact of clearing and pine water use can not be qualified. However since a good match exists between graphs, it is reasonable to say that pine has minor impact after 1989.
Water levels, mAHD
23.50
22.50
21.50
20.50
19.50
18.50
CDFM (115.65 -31.40) mm
3000
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


GA18
CDFM (1907-2004)
Pines were planted in 1970
Climate impact = -2.1 m
There is no record before and immadiately after the clearing so that impact of clearing and pine water use can not be qualified. However since a good match exists between graphs, it is reasonable to say that pine has minor impact after 1985.
Water levels, mAHD
38.20
37.20
36.20
35.20
34.20
33.20
32.20
CDFM (115.70 -31.40) mm
3000
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

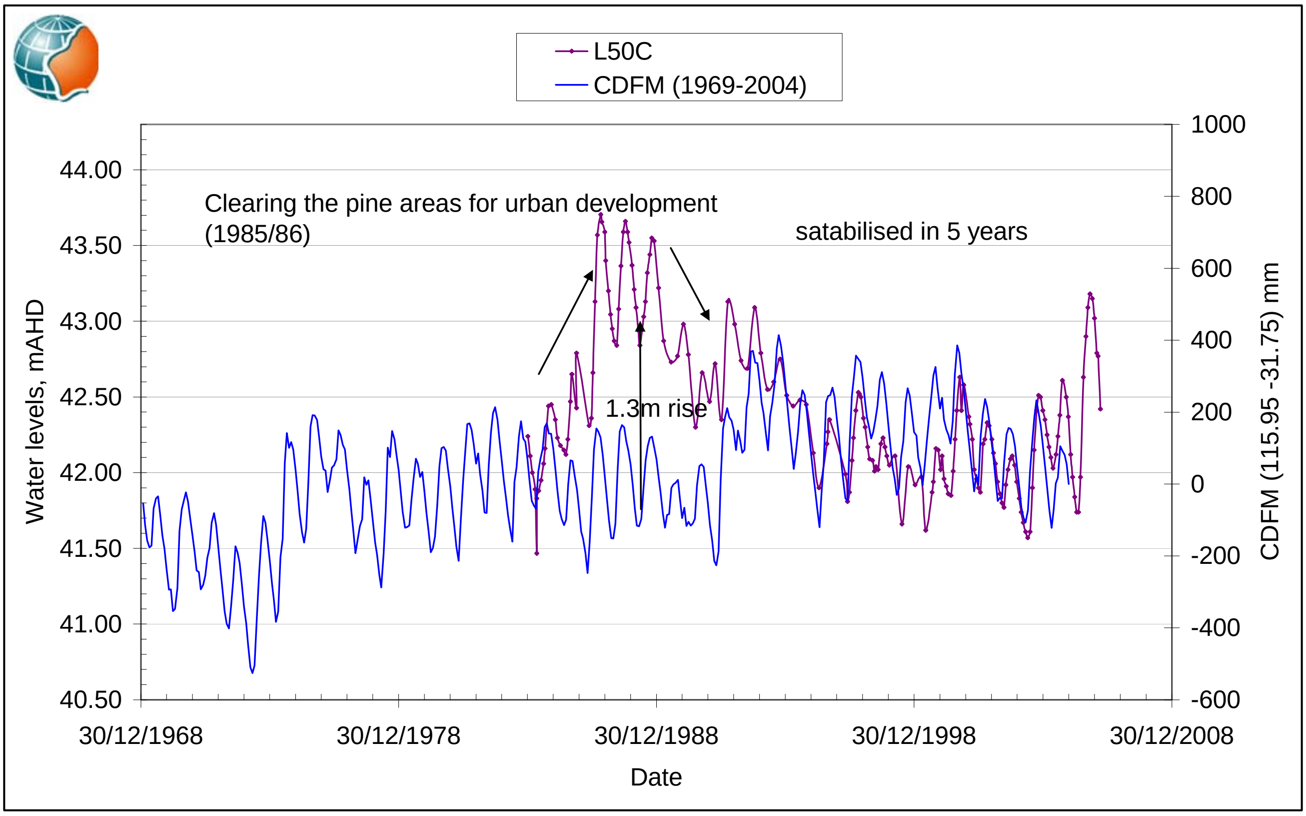

GA24
CDFM (1907-2004)
Climate impact = -0.55 m
data frequency is not sufficient
Bush fire (1986)
Water levels, mAHD
1.75
1.55
1.35
1.15
0.95
0.75
0.55
CDFM (115.60 -31.40) mm
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

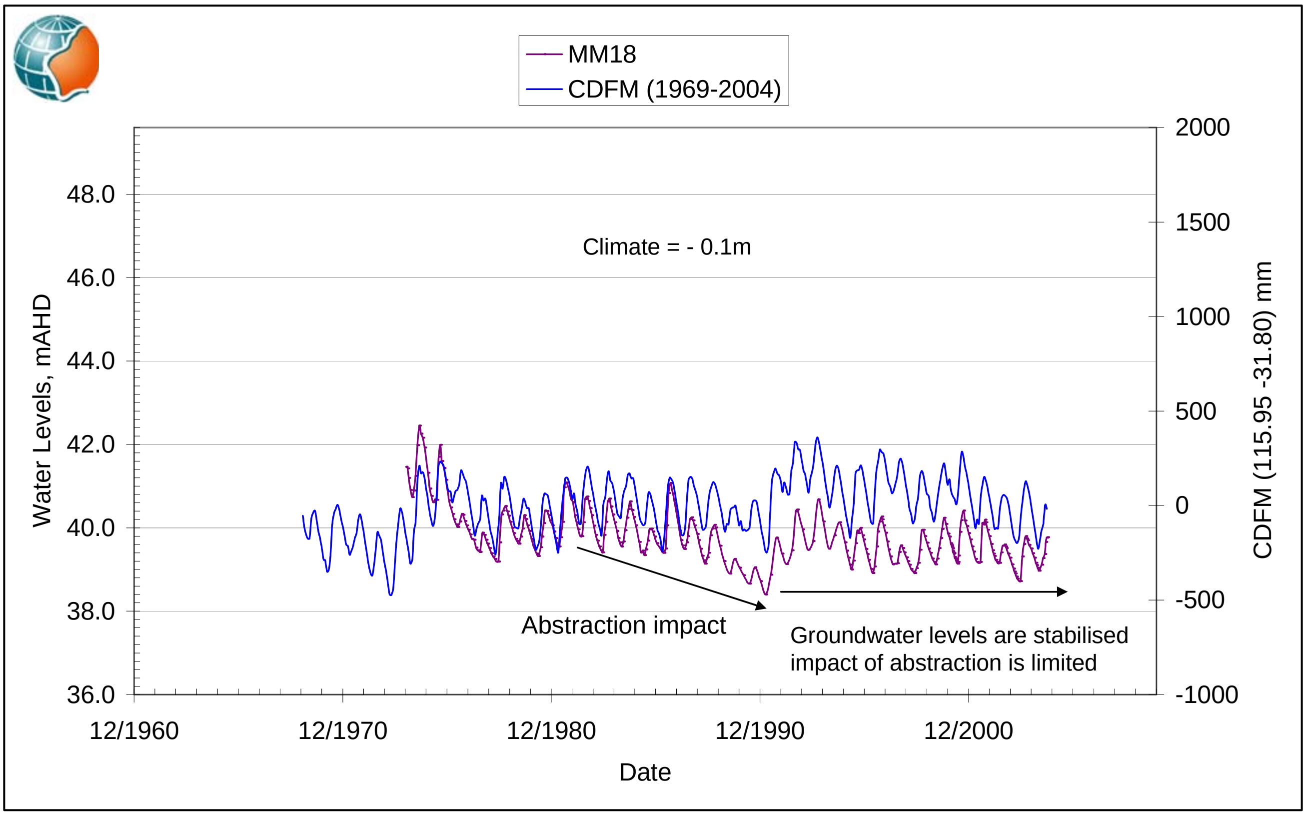

GA29
CDFM (1907-2004)
Climate impact = - 0.70m
not reliable
Possible bush fires (1978 & 1986)
Water levels, mAHD
3.2
2.7
2.2
1.7
CDFM (115.60 -31.35) mm
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

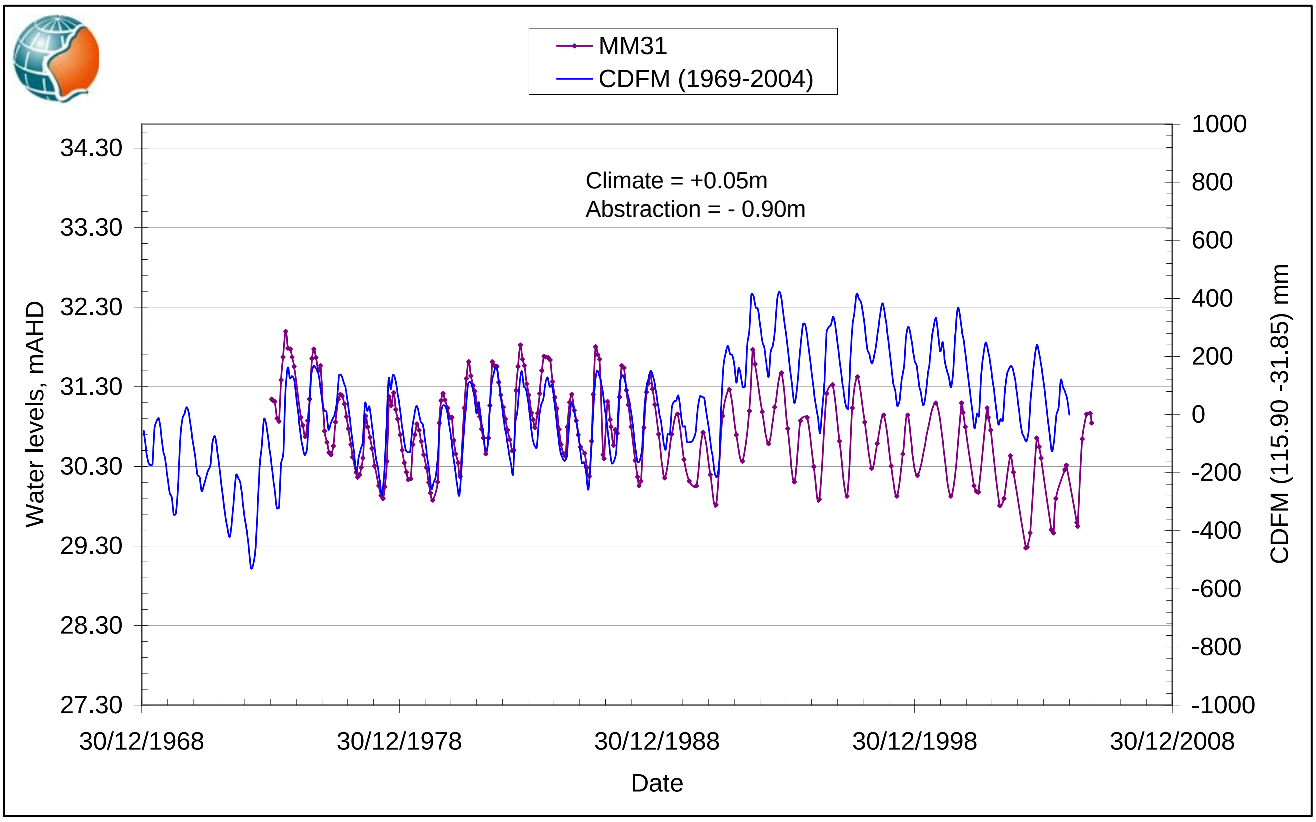

GA33
CDFM (1907-2004)
Climate
urbanisation
Abstraction impact
+ 0.25 m rise
GA33, mAHD
0.0
0.5
1.0
CDFM (31.50 115.60), mm
-500
0
500
1,000
1,500
2,000
2,500
12/1968
12/1978
12/1988
12/1998
12/2008
Date

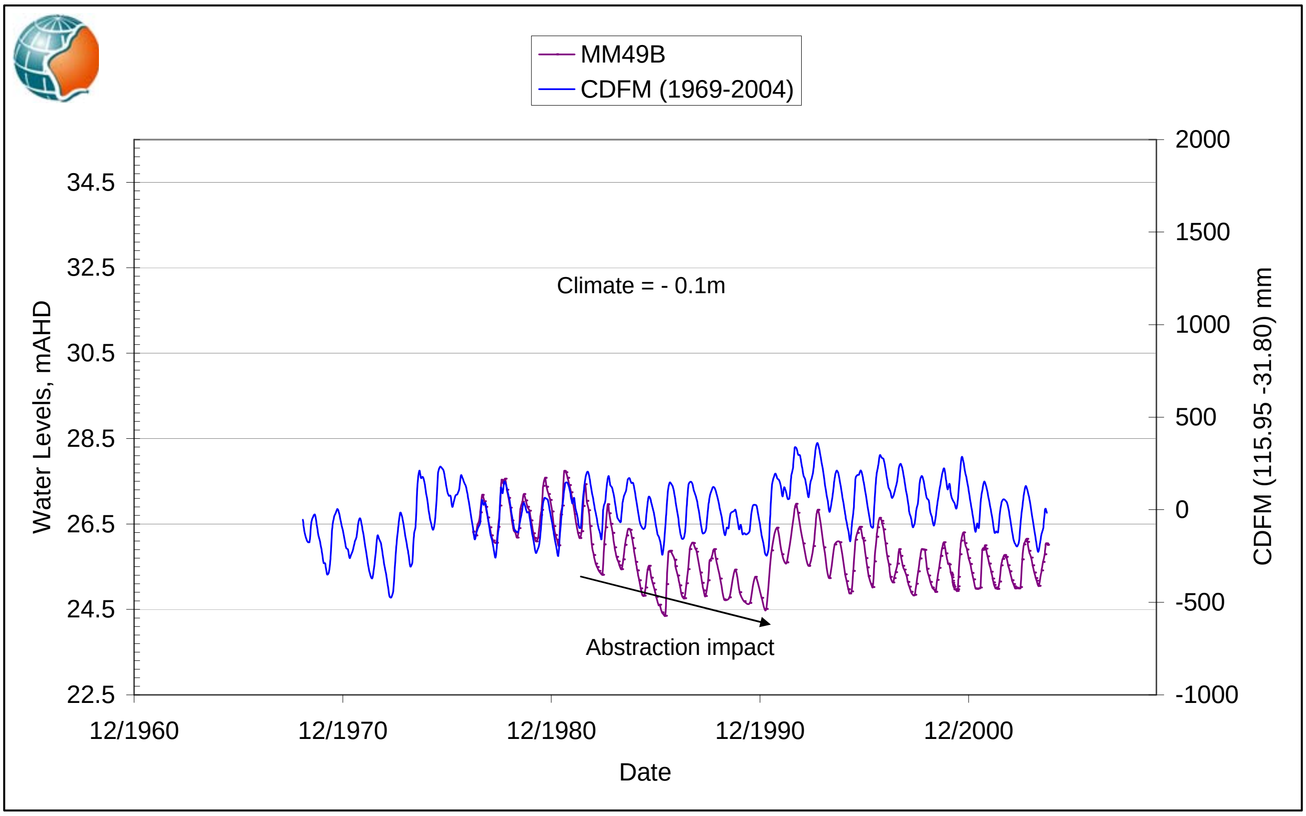
7. Gnangara Forestry Rainfall Zone

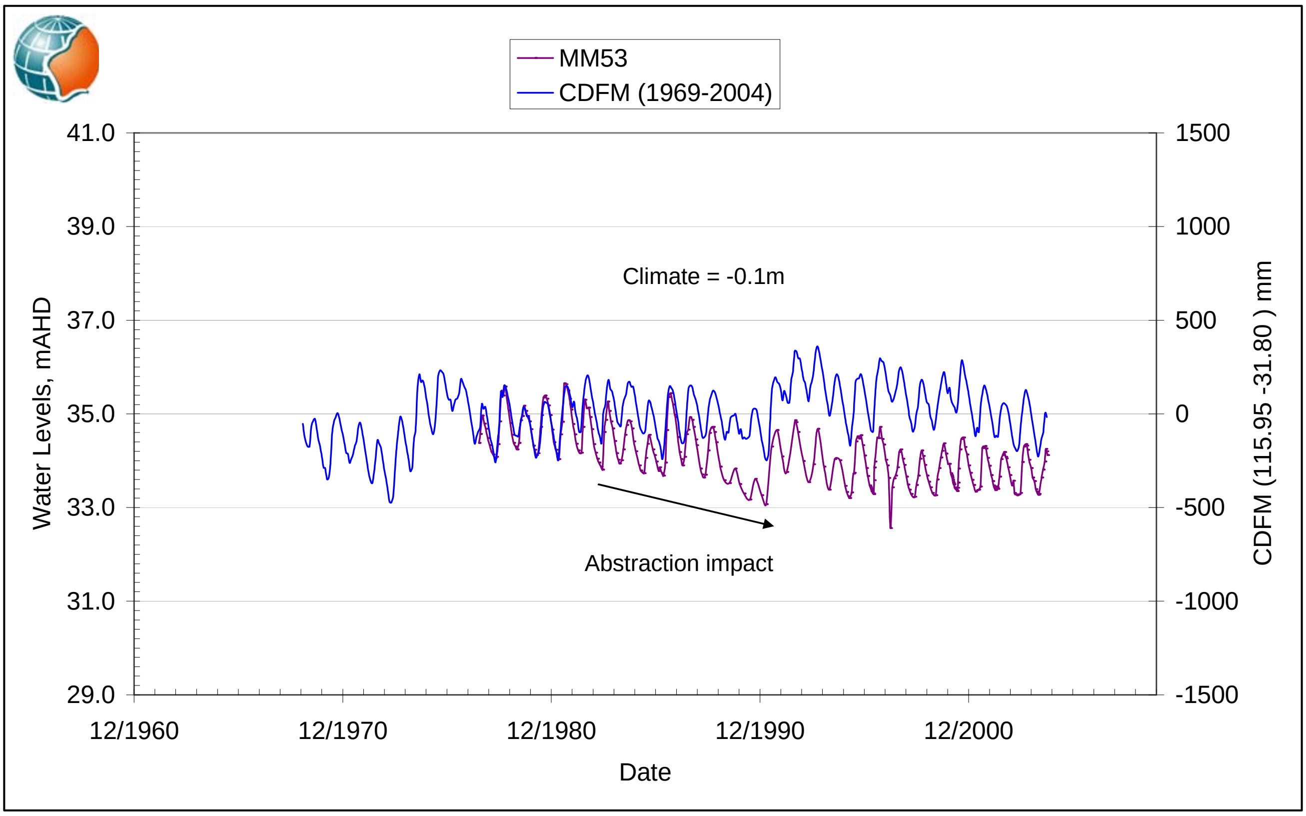
(L50C, MM18, MM31, MM49B, MM53, MM59B)

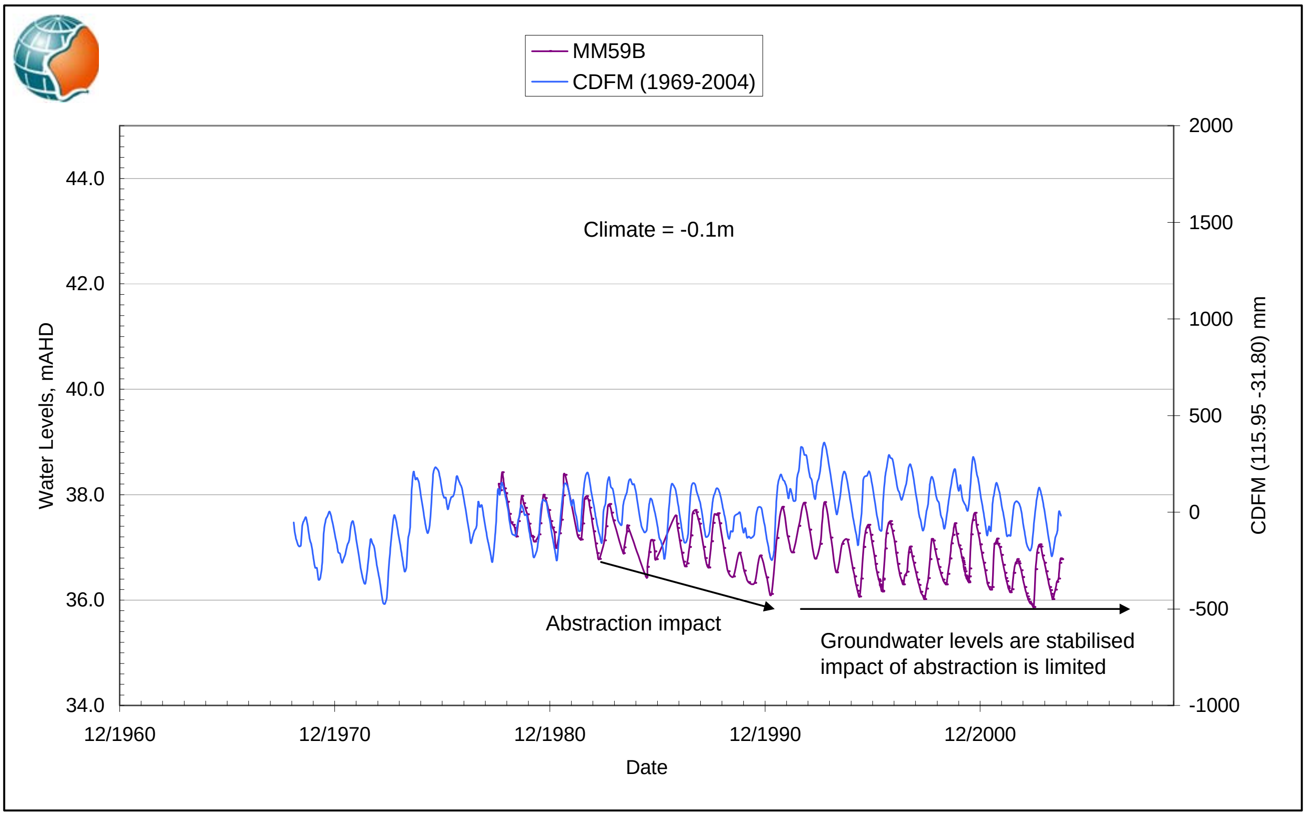

L50C
CDFM (1969-2004)
Clearing the pine areas for urban development (1985/86)
satabilised in 5 years
1.3m rise
Water levels, mAHD
44.00
43.50
43.00
42.50
42.00
41.50
41.00
40.50
CDFM (115.95 -31.75) mm
1000
800
600
400
200
0
-200
-400
-600
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


MM18
CDFM (1969-2004)
Climate = - 0.1m
Abstraction impact
Groundwater levels are stabilised impact of abstraction is limited
Water Levels, mAHD
48.0
46.0
44.0
42.0
40.0
38.0
36.0
CDFM (115.95 -31.80) mm
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000
Date


MM31
CDFM (1969-2004)
Climate = +0.05m
Abstraction = - 0.90m
Water levels, mAHD
34.30
33.30
32.30
31.30
30.30
29.30
28.30
27.30
CDFM (115.90 -31.85) mm
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


MM49B
CDFM (1969-2004)
Climate = - 0.1m
Abstraction impact
Water Levels, mAHD
34.5
32.5
30.5
28.5
26.5
24.5
22.5
CDFM (115.95 -31.80) mm
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000
Date


MM53
CDFM (1969-2004)
Climate = -0.1m
Abstraction impact
Water Levels, mAHD
41.0
39.0
37.0
35.0
33.0
31.0
29.0
CDFM (115.95 -31.80) mm
1500
1000
500
0
-500
-1000
-1500
12/1960
12/1970
12/1980
12/1990
12/2000
Date


MM59B
CDFM (1969-2004)
Climate = -0.1m
Abstraction impact
Groundwater levels are stabilised
impact of abstraction is limited
Water Levels, mAHD
44.0
42.0
40.0
38.0
36.0
34.0
CDFM (115.95 -31.80) mm
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000
Date