WLS SUB 43.

DEPARTMENT OF WATER

RESPONSE TO QUESTIONS ISSUED BY THE ECONOMICS AND INDUSTRY STANDING COMMITTEE INQUIRY INTO WATER LICENSING AND SERVICES FOLLOWING THE 24 JANUARY 2008 HEARING (Paragraphs 1 to 39 refer)

and

FURTHER INFORMATION ON OTHER RELEVANT ISSUES (Paragraphs 40 onwards refer)

6 February 2008

TABLE OF CONTENTS

INTRODUCTION

The Department of Water welcomes the opportunity to provide further input into the Economics and Industry Standing Committee's Inquiry into Water Licensing and Services.

The information provided at paragraph one to 39 below are in response to questions provided by the Committee, following the Department of Water's presentation on 24 January 2008. The information in paragraphs 40 onwards is provided to the Committee as additional information, for consideration in its deliberations.

RESPONSE TO QUESTIONS PROVIDED

Benefits, costs and imposts

1. The number of water licences subject to the annual administration fee for each licence class by region is provided at Attachment 1.

   For consistency in reporting the number of water licences is based on numbers current at November 2007 and was used to estimate the revenue from fees from the disallowed regulations. The table at Attachment 1 uses the same data but is related to the current schedule of fees introduced in December 2007.

   It is expected that the number of water licences will reduce slightly as a result of the introduction of the annual fee. The reduction will result from;

   - current licensees or new property owners surrendering unused licenses;
   - amendment of licenses to a lower class due to unused water entitlements; and
   - amalgamations of multiple licences in the same area.

   However, the number of licences required to be administered will increase for at least the next decade as development continues and while water is still available in many areas.

Costs of Licence Administration

2. Estimates for cost recovery for the administration of water licences are contained on page 46 of the Blueprint for Water Reform in Western Australia and were based on the Department of Water's costs for 2005-06. Subsequent changes to the way the Department manages its budgets and projects, whereby activities are rolled up under a single project, does not effectively allow for costs to be attributed to the discreet activities in administering licences.

   Therefore the detailed analysis, similar to that undertaken for 2005-06 cannot be replicated for 2006-07 onwards.

   Nevertheless, the two tables at Attachment 2 identify the relevant projects and costs associated with the administration of water licences and include estimates of both regional and corporate overheads for 2006-07 and 2007-08.

3. Western Australia, like all other jurisdictions in Australia, is awaiting guidance from the Commonwealth Government on the detailed reporting requirements of Paragraph 68 of the NWI. Consequently, no such reporting has been undertaken.

In regards to the "Water Planning and Management Stocktake" report, prepared by the National Water Commission, the reason that no information is available for Western Australia against the status of cost recovery questions is because the report was produced in February 2007, prior to the introduction of any form of licence administration fee. In fact, the report is useful in highlighting the lack of progress made by Western Australia when compared to that made by other jurisdictions in the recovery of costs for water resource management and planning (including licence administration).

4. Western Australia is a participating member of both the Urban and Rural Benchmarking (inter-jurisdictional) Working Groups, chaired by the Commonwealth Government, for the purpose of implementing the requirements of Paragraph 75 of the NWI.

   The 2005-06 National Urban Benchmarking Report was released in May 2007 by the Chairman of the National Water Commission, Mr Ken Matthews and a copy is available from its website (www.nwc.gov.au). The 2006-07 report is expected to be released in April 2008.

   The first Rural Benchmarking Report (2006-07) is expected to be finalised and released in April 2008 and will likely also be available on the Commission's website.

   The information required for the benchmarking exercise is collected by the Economic Regulation Authority, through the operating licences of the participating service providers (which it administers on behalf of the Government).

5. A part of the annual review of government tariffs, fees and charges, agencies are required to undertake a regular review (at least annually) of their tariffs, fees and charges. As part of that review all agencies are required to provide a review to their Minister through a completed certificate indicating that a review had been completed.

   The Department has complied with this request for the 2008-09 review.

   With respect to the licence administration fee the Department did submit to the Department of Treasury and Finance a proposal outlining the new fee including the proposed extent of cost recovery. The Department's Consolidated Fund appropriation was adjusted to account for the additional revenue being generated and its net appropriations from the Consolidated Fund.

6. The Department's internal costing and pricing policies are consistent with the Government's guidelines on "Costing and Pricing Government Services", which recommend the achievement of full cost recovery where it is possible and takes account and maintains existing Government Policy.

   The Government Response to the Final Report of the Irrigation Review Steering Committee agreed that it is appropriate to recover the costs associated with the administration of water licensing.

7. The aim of the water licence administration fee was to fully recover the $5.8 million in costs associated with administering and maintaining water licences and integral licensing systems. This included the costs for assessment of applications and licence renewals, checking compliance with licence conditions, maintaining licensing databases and management of appeals. To do this, the following information was defined:

- number of entitlement classes of licences according to the amount of work required for that volume;
- the portion of budget spent in that category; and
- the costs to be recovered.

8. The original fee schedule contained within the regulations disallowed by Parliament in November 2007 was intended to raise $5.8 million which was the total cost (in 2005-06) of administering the licensing regime.

   The fee schedule within the regulations that came into operation on 29 December 2007 will raise $3.05 million and therefore only partially recover the total cost in administering the water licensing regime.

9. For 2005-06 a detailed analysis of the Department's projects and budgets was undertaken that identified the cost for administering water licences at $5.8 million and is separate to the cost associated with water resource management. A breakdown of this information is provided at Attachment 3.

   The number of hours required to administer water licences of the different classes was based on internal estimated from within the water licensing business. An estimate of the annual fee for each class of licence to achieve full cost recovery was determined from the number of licences and hours required for each class. This information is provided at Attachment 4.

   The Department of Water's budget for 2007-08 was reduced by $5.8 million being the original estimate of the amount to be recovered by the annual fee.

10. Licences forming the subject of the current fees are issued under 5C or 26D of the *Rights in Water and Irrigation Act 1914* (the RIWI Act). Also included in the current fees are Permits issued under Sections 11, 17 and 21A of the RIWI Act. These Sections are all found in Part III of the RIWI Act which in effect establishes a single scheme for the protection and management of water resources.

    The costs incurred by functions involved in administering the regime established under Part III of the RIWI Act form the basis for cost recovery through the current fee structure.

    These functions include:

    - ***Licensing***: Refers to all receipting and assessment of applications for licences or permits. In undertaking the assessment the RIWI Act requires DoW to have regard to certain matters when assessing an application.
    - ***Compliance and enforcement***: There are costs associated with surveys and enforcement actions directly associated with water licences. These can be breaches of the terms and conditions of the licence. The very fact that compliance activities are undertaken necessarily generates the need to undertake enforcement. Both compliance and enforcement are necessary in order to maintain integrity of the licensing scheme. Accordingly there is no logical basis to distinguish between compliance and enforcement.
    - ***State Administrative Tribunal (SAT)***: The right to seek a SAT review is found in Part III of the RIWI Act and therefore the defence of appeals is part of the administration of licences. These appeals are mostly related to assessment and issue/refusal of licences.

A SAT review represented part of the decision making framework established under Part III of the RIWI Act. Accordingly expenses incurred in participating in such proceedings will represent expenses incurred in the administration of the scheme.

- ***Community Input***: The cost incurred relate to Advisory Committees established under the *Water and Rivers Commission Act 1995* and relate to expenses incurred in having Advisory Committees assist the Commission in the performance of its function under Part III of the RIWI Act.

- ***Licensing Support***: Licensing support includes costs for database maintenance and enhancements, including data validation and cleansing, delivery of training to regional licensing officers and providing supporting expertise for regional licensing staff.

  It should be noted that the Joint Standing Committee on Delegated Legislation undertook a review of the *Rights in Water and Irrigation Amended Regulations 2007* following a motion by the Committee to disallow the regulations. Following detailed information and justification for the cost recovery arrangements provided to the Committee by the Department in support of the regulations the Committee advised the Upper House that its concerns were satisfied and the Committee withdrew its motion to disallow.

Assessment of water licences is one component of administering water licences and generally includes activities associated with:

- assessment of applications for a new, amendment or renewal of a water licence;

- the regular assessment of the impacts from the authorised use of a licence, in particular on other users and the water resource to ensure that the water is being equitably shared. This assessment often follows compliance and audit inspections; and

- irregular assessment of activities and water use in response to concerns or complaints.

Averaging the cost over all licences in a particular class is an approach that is consistent in the way in which most fees are levied. This form of micro management is generally not required.

Virtually all fees and charges for both Government and private business are averaged as it is the most cost effective method as it is unrealistic to identify costs associated with an individual. Examples include, motor vehicle registration fee is the same for a particular make vehicle regardless of where it is garaged, electricity and water tariffs are averaged and not related to the cost of delivery to individual suburbs in the metropolitan area.

11. The $200 application fee will be deducted from the licence payable and will only have an impact where the licence fee for a licence in Class 3, $250 fee, or above.

In circumstance where the licence fee is less than the $200 application fee there will be no refund or credit of the difference. The application fee is non refundable and is set at a level that reflects the initial effort required to process, assess and create a new or amended licence.

The lowest licence fee, unlike its equivalent in the disallowed regulations, does not reflect the effort required or real cost recovery.

12. The cost of implementing and managing the collection of the water licence fee has not included in the current cost recovery model. It was not considered appropriate to include the one off cost for the establishment of new systems and processes.

    Once all systems are fully operational it would be appropriate that the on going cost of managing collection of the annual fee be include in any full cost recovery. This cost is not yet quantifiable.

13. Following additional resources being made available as a result of the Auditor General 2003 report the DoW made considerable progress in its ability to manage data collected and reduce backlogs. While the Department still has some backlogs they are significantly less the pre 2003 levels and effort is continually being directed to alleviate this situation.

14. The Department's Consolidated Fund budget has increased from $51.8 million in 2005-06 to $66.2 million in 2007-08 (which assumed $5.8 million in revenue from licence administration fees).

    The reforms contained in the State Water Plan, the National Water Initiative and the Government Response to the Blueprint for Water Reform will lead to better water resource management across Western Australia. The extent to which the Department can implement these reforms and the timeframes required to do so will be heavily dictated by the current budget process for 2008-09 and beyond.

15. At the time the original fees were calculated there were in excess of 13,000 licences that would be subject to the licence fee. In May 2007, prior to the introduction of regulations, the Minister for Water Resources announced that the licence fee would not apply to domestic bore uses. As a result, approximately 2,700 licences were exempted from the annual fee.

    The total number of licences (12,889) presented in the Department's previous submission to the Committee represented the total number of licences and permits, some of which are not subject to the annual fee. Approximately 9,376 licences are subject to the fee. The Department apologies for any confusion.

    The total number of water licences is dynamic and varies with the number of applications being processed at any given time. To maintain a degree of consistency in reporting, the number of licences at a given point in time is used.

    In the table at Attachment 1 the total number of licences on which the new projected income of $3.05 million from licence fees is based is shown as 9,376 (as of October 2007).

16. The Department was provided advice that the fees raised under the disallowed regulations are legal and can be retained by the Department. Furthermore, those licensees who did not pay their annual fee are still liable for that debt. However, it was agreed that all fees paid and those still outstanding will be adjusted to reflect the current fee schedule. Those who previously paid will receive a credit or refund and those with an outstanding fee will have the debt reduced and sent a new invoice for payment. They may chose to pay the invoice or have the debt carried forward and added to their next annual fee.

17. Licences were grouped into a number of classes that best represented the amount of effort required to administer licences with similar water entitlements. Originally five classes were proposed but following consultation with the regions responsible for administering licences, seven classes were agreed to as a best representation of the effort and time required.

For example the effort required to administer a licence with an entitlement of 60,000KL would be similar to one with 75,000KL.

18. The obligation on the State to introduce licence administration fees originates from the 1994 COAG Water Reform Agreement (and later reaffirmed through the NWI). The intent of the national committee is to pursue a nationally consistent approach to the cost recovery of broader resource management and planning activities (which includes the cost of licence administration). The objective of the national committee is to build on the cost recovery mechanisms already in place in each jurisdiction (informed by the February 2007 Water Management and Planning Stocktake report) and work towards a nationally consistent approach to charging principles.

19. Averaging the cost over all licences in a particular class is an approach that is consistent in the way in which most fees are levied.

    Few if any Government charges are based on regions or locality. It would be extremely difficult to determine the extent of a locality in which to apply specific fees.

20. The minimisation of transaction costs as referred to in Schedules D and F of the NWI relate to the associated transaction costs for water trading and other regulatory approvals. Such approvals are different in nature to the recovery of costs to administer the licensing regime.

NWI cost recovery requirements

21. The full cost recovery figures for licence administration fees do not include environmental externalities. The licence administration fees recover only those costs associated with administering the licensing regime. The recovery of environmental externalities is difficult given their generally intangible nature and most other Australian jurisdictions are yet to recover any component for externalities. Furthermore, Western Australia is unable to recover externalities under its existing legislation.

22. The reason for the Department of Water introducing licence administration fees before the Steering Group finalises its national principles is outlined in the response to Question 18 above.

    The licence administration fees are designed to recover the cost of administering the regime which the Department operates under powers provided by the RIWI Act and would be introduced irrespective of the intent to introduce water access entitlements. Water access entitlements are simply another form of authorisation and will themselves carry an administration cost that (pending the approval of the Government) would be appropriately recovered from entitlement holders.

    As for the consistency of the fees with the draft national principles, the principles being developed are based on advice from pricing regulators across the country and reflect best industry practice for the appropriate recovery of the associated fees. Consultation with the National Water Commission on the draft principles has led the Department of Water to be confident that the licence administration fees are consistent with the principles being developed.

23. There appears to be a number of issues included in this question which is addressed separately below.

    - The determination of costs of administering the licensing regime was provided in the Department's 14 December 2007 submission to the Standing

Committee. The costs have been accurately determined and clearly represent the costs attributable to administering the licensing regime.

- While there was no involvement of the ERA in the development of the licence fee structure, the Government's intention (as per the Government Response to the Blueprint for Water Reform) is to have the fees independently reviewed by the ERA within two years of their introduction.

- The enactment of the Water Resources Management Bill is not required for the introduction of a licence administration fee.

- The State's NWI Implementation Plan states that administration fees will be introduced from July 2007. The reference to implementing charges from July 2008 is for broader cost recovery mechanisms for water resource management and planning expenses.

- The licence administration fees were first introduced in July 2007 as a result of a longstanding obligation on the State (from both the 1994 COAG Water Reform Agreement and the NWI) to introduce cost recovery mechanisms for water resource management. The licence administration fee was introduced as a possible 'first-step' towards meeting those obligations.

- Nevertheless, irrespective of the obligations to introduce cost recovery mechanisms for water resource management, it is considered appropriate to do so on the following grounds:

  - It reflects the true cost to users of their water use.

  - It discourages over-use of the resource which can occur if the true cost is not reflected in the price paid.

  - Appropriate pricing (that includes the total cost of managing the resource) will lead to an efficient allocation of the resource to the most appropriate end user.

  - Consistent with its legislative requirement, the Department of Water must ensure that the demand on a resource is sustainable before issuing a licence for the use of the resource. If the costs of that investigation and management are not recovered efficiently and fairly from all users you have the problem of "free riders" where some users of the resource will be able to utilise the resource because the cost of the investigation and management has been borne by another (i.e. taxpayers).

24. The use of a 'phase-in' period by other jurisdictions relates to the introduction of broader cost recovery mechanisms for water resource management and planning, beyond a simple licence administration fee.

    As outlined above in response to Question 23 above, the use of the independent ERA has been considered for licence administration fees and is being investigated in regards to broader cost recover mechanisms.

Penalty or cost under the NWI for less than full cost recovery

25. Clause A10 (i) in Schedule A in the funding deeds is common across all of the Department of Water's four funding deeds for its projects. The penalties contained in Clause A10 (i) are not project specific and provide the Commonwealth with the ability to apply a penalty to all of the Department's projects concurrently.

As for the bore metering policy, the Department has commenced work on its development and intends to meet this obligation.

26. The Department of Water's understanding of the penalty clauses is limited to what is contained in the funding deed and is unable to speculate on any interpretation or application of those clauses by the Commonwealth.

27. The funding deed determines that failure by the Department to meet a project milestone can invoke a penalty of up to 15% of that milestone payment. However, failure to meet one of the broader funding requirements (introduction of further charging element and development of a bore metering policy) can invoke a penalty from the Commonwealth of 15% of the entire project funding.

Licenses for currently exempt extraction

28. The minimal cost to administer a water licence was estimated at $200 per annum. Therefore, licensing the 155,000 garden bores in Perth would cost the Department approximately $30 million to administer with no discernable benefit.

    Garden bores, like stock watering bores throughout the State, are widely spread, abstracting low amounts of water and do not compete with commercial users. There is minimal impact on the environment, water resource or other users from the use of these bores. In many situations, such as garden bores in Perth, the benefits out weigh any impacts as they use low quality water as opposed to using high quality treated scheme water that is often taken from more sensitive areas. Further information on this matter is provided at Paragraph 44 below.

29. The Water Corporation (which administers the rebate program on behalf of the Government) monitors the ongoing water use of properties after a rebate has been granted and determines whether the reduction in actual water use is noticeable and, collectively, warrants the rebate being retained. As a result of this analysis, rebates that were not saving scheme water were removed, such as soil wetting agents.

30. Included at Attachment 5 are two reports prepared by the Department of Water that cover the issues referred to in our 14 December 2007 submission, namely:

    - Water Level Monitoring Results for the Superficial Aquifer in the Perth Urban Area – Hydrogeology Report Series 225 (September 2004); and

    - Assessment of the Declining Groundwater Levels in the Gnangara Groundwater Mound – Hydrogeological Record Series, Report HG14 (January 2008).

31. It is proposed that the garden bore rebate will not be available in areas identified as unsuitable for additional garden bores. It will not prevent the sinking of more bores in these areas but it is a disincentive. Also, the irrigation industry has reported a reduction of bore installations as a result of the three day a week roster regulation of 1 October 2007.

    An estimate of garden bore groundwater usage is made as a result of the surveys, most recently the Aquaterra Report of 2001 and will be included by the Department in its allocation planning for the Perth region.

32. The Department is working on an approach to incorporating plantations into water management decisions. This process will need to address the complex issues of a drying climate, comparison with the water use of original vegetation and the benefits of trees. The Department does not currently licence plantations due to

restrictions in the RIWI Act, which are being addressed in the Water Resources Management Bill.

33. As a result of a Priority Action in the State Water Plan, the Department of Sport and Recreation are undertaking a project to review the water management of public open space. This includes recognition of the public benefit of local government managed public open space.

34. The Department of Water does not consider that a cross-subsidy exists. Garden bores are a sensible use of shallow groundwater for garden watering, rather than the use of potable water. If all garden bore owners switched to using potable water on gardens, then approximately 50GL of additional water would need to be sourced. This is equivalent to the potable water produced by the current Kwinana Desalination plant.

Recognition of costs incurred by self-supply farmers

35. The water licence is intended to reflect the amount of water actually taken out of the water resource and utilised. Licensees in the South West have been offered the opportunity to amend their licence so that the annual fee is based on the water used and not on the dam storage.

    Water used for fire fighting is not included on the licence and therefore not subject to any fee.

Range of systems possible under the NWI

36. Prior to responding to the range of questions provided by the Committee it would seem appropriate to clarify a number of points regarding trading and the current licensing system:

    - The Council of Australian Government (COAG) water law reforms (expressed through the 2000 amendments to the RIWI Act) introduced market mechanisms to the management of water resources. One aspect of those amendments was to create property rights in water. Property rights in water did not exist previously.

      Since the 2000 amendments to the RIWI Act, land and water titles have been separate (that is, they can be acquired, disposed of or mortgaged separately). They are governed by separate legislation using different legislative instruments. However, under Clause 3, Schedule 1, of the RIWI Act, land access is required to be eligible to hold a licence. This Section of the Act was put in place because the location at which water is taken is critical to its management (particularly for groundwater). It addressed issues such as people attempting to acquire a licence in an area before deciding where the water would be taken (making it impossible to determine impacts), or what would happen to a water licence if access to land (via a lease) was lost.

    - Trading is and always will be an option available to licence holders and has never been mandatory. The proposed further separation of land and water titles through the water access entitlements system will provide more opportunity for water to be traded and is designed to give irrigators and businesses alike, greater flexibility in their operations. This is particularly the case for temporary trades, when for example, if an irrigator were to choose to plant a less water-intensive crop in one season.

Even now, but more so under the proposed entitlement system, that irrigator will have the opportunity to temporarily trade that water and earn an income from the asset (the water entitlement) while he or she is not utilising that asset. Trading in this manner provides licence (or entitlement) holders the flexibility to manage their business and benefit from opportunistic trade. It is also worth noting that holding a water access entitlement will provide the business owner with a financially stronger asset than a licence.

With these clarifications in mind, the Department provides the following response to Question 36:

- The separation of land and water titles is not expected to detract from the sum value of the assets and in most instances will lead to an increase in the sum value as the water entitlement becomes more valuable as a separately tradeable commodity.

- Experiences in the Eastern States from the unbundling of water and land titles have shown that the net revenue base of the local councils is quite static over time. This is because while water may be traded from one property (which may experience a minor decrease in value), under the entitlements system that water is available to be traded to another property that may not have previously had access to water, which would then lead to an increase in its value. The net result is therefore expected to be minimal.

- The management of land will still remain subject to local council guidelines and building codes, environmental regulations and general land planning rules. This would be the case, with or without the separation of land and water titles. Furthermore, while it will be possible to hold a water entitlement without access to the land on which it occurs under the new regime, entitlement holders will still require regulatory approval from the Department of Water to extract and use the water.

- Water trading in Western Australia will be consistent with the Department of Water's management planning, which will ensure the sustainability of regions. Nevertheless, the largest deterrent for all water being traded out of an area is the lack of geographical continuance between most of the State's surface and groundwater areas. That is, without additional (capital intensive) transportation infrastructure it is generally impossible to move water from one region of the State to another as there are very limited inter-connected surface or groundwater systems.

- The issue of trading was considered in the State Water Plan and it was decided to take guidance from the Blueprint for Water Reform in Western Australia, which considered the various mechanisms required to further encourage trading throughout the State.

  Water trading is an opportunistic market mechanism that will operate from time to time when the demand for and supply of water is varied in different locations (where transport is possible).

- Given the remote locations of mines across the State it is not surprising that trading is restricted. The location of a mine is always determined by the location of the natural minerals and access to the necessary water is a subsequent operational decision. This is why many mines make use of dewatering water and hyper-saline water in their internal processes.

  If there was a situation where a mine site was deficient of water and wanted to purchase water from another mine site which had water surplus, then a commercial arrangement for a temporary or permanent trade could be brokered between the respective mine sites. In any event, under both the existing licensing system and the proposed entitlements system, the approval of the Department of Water would still be required for this trade under regulations governing the use of water and approvals to construct works.

- Where the Department of Water considers it necessary to develop a consumptive pool (through its statutory allocation planning which is approved by the Minister for Water Resources), then by definition, access to the pool will be via a water access entitlement.

37. Variable charging on the grounds of water use and catchment location is more of relevant for the water resource management and planning rather than the administration of the licensing regime, where there can exist a considerable difference in the management requirements. For simplicity purposes and to minimise the costs to licence holders it was considered appropriate to introduce a standard charge for licence administration fees across the State.

Other issues - Consultation

38. The NWI Implementation Plan refers to undertaking further public consultation prior to the introduction of broader cost recovery mechanisms for water resource management and planning and the Department of Water remains committed to this undertaking.

    In regards to the licence administration fees, the State undertook a significant and detailed consultation program across the State on the Draft Blueprint for Water Reform in which it sought specific comments on the introduction of a licence fee.

    The consultation process for the Draft Blueprint involved:

    - circulation of approximately 3,000 copies of the draft policy document;
    - 17 workshops in regional centres throughout Western Australia, to which there were 481 attendees;
    - numerous targeted briefings to industry groups and other interested parties; and
    - receipt of 71 formal written submissions.

    Furthermore and specifically for the licence administration fees, letters were sent to every licence holder prior to the introduction of the fees which led to a small number of refinements to the operation prior to its introduction.

Other issues - Future charges

39. As indicated in the response to Question 22 above, water access entitlements will themselves carry an administration cost that (pending the approval of the Government) would be appropriately recovered from entitlement holders, consistent with the State's NWI obligations for cost recovery.

ADDITIONAL INFORMATION

Following the Department's presentation to the Committee on 24 January 2008 and a review of the transcript of that hearing, it wishes to provide further information for the consideration of the Committee in its deliberations.

Correction to previous submission

40. The Department of Water wishes to delete Table 3 "Schedule of Fees (now disallowed)" in its submission to the Economic and Industry Standing Committee on 14 December 2007 and replace it with the following table.

Licence class	Entitlement class (kilolitres per year)	Fee
1	1,501 – 5,000	$200
2	5,001 – 50,000	$325
3	50,001 – 100,000	$600
4	100,001 – 500,000	$1,200
5	500,001 – 1,000,000	$1,800
6	1,000,001 – 5,000,001	$2,400
7	more than 5,000,001	$3,000

Benefits of a licence administration regime

41. The following is a list of benefits that accrue to licence holders under the current licensing system.

- A licence entitles the holder to a legally defensible right to take water.
- A licence entitles the holder to access water which is a valuable and irreplaceable input to most businesses, which before the introduction of an administration fee was provided free to the user and paid for by taxpayers.
- A licence administration system enables the Department of Water to balance the needs of all water users to ensure there is a sufficient and sustainable amount of water available for all licensees.
- A licence administration system ensures that each licence holder is taking their licensed amount of water and not over-extracting, which could negatively impact on other licensees.

Difference between cooperatives and self supply irrigators

42. In providing information on this issue, the Department wishes to present to the Committee an extract from a paper prepared by Harvey Water, which clearly articulates the difference between the operations of a cooperative and a self supplier and explains why the costs incurred by a cooperative member and a self supply irrigator are different.

    This extract is provided at Attachment 6 for information.

Unlicensed domestic bores

43. The rationale behind the licensing of water use is to enable the Department of Water to actively manage the resource and ensure the ongoing, sustainable use of the resource over time. The Department does not licence domestic or stock watering bores for the following reasons:

- the cumulative impact of water usage from bores (as estimated) is minimal;
- domestic and stock watering bores are 'scattered' across the State and the administrative burden of monitoring them is not considered effective as the impact from the use would in most areas be minimal;
- given the high cost that would be required to monitor all domestic and stock bores, the charges that would either be borne by the taxpayer or the bore owner would be prohibitively expensive;
- the State Government is already managing the use of domestic garden bores, in particular those in the Perth Metropolitan area, through the recently imposed sprinkler restrictions, which further minimise the impact of bores on the use of water;
- domestic bores are generally not competing with commercial users and therefore their minimal impact is not a major concern to the Department from a resource management perspective; and
- the water from domestic bores is untreated and of lower value which provides significant benefits both in environmental terms and cost as an alternate source to higher value, treated potable water for use on gardens.

As a result of these factors, the Department considers that on a cost-benefit basis (including potential environmental costs) there is minimal effort required to manage the impact of domestic and stock watering bores. Therefore, it is not proposed to licence these.

If the Department were to consider a more stringent management approach to domestic bores (despite the negative cost-benefit outcome) it would also be appropriate to enhance the management of farm dams, riparian and stock and domestic use. However, like domestic bores, the water usage in these instances is considered to be minimal. Therefore, stringent active management is considered unnecessary as it would create a considerable burden on either the taxpayer or water user to meet the cost of that management.

ATTACHMENT 1

NUMBER OF LICENCES AND REVENUE BY LICENCE CLASS (FEE) AND REGION

Licence		North West		Mid West		Swan		Kwinana Peel		South West		South Coast		Total Licences	Total Revenue
Class	Fee	Licenses	Revenue	Licences	Revenue	Licences	Revenue	Licences	Revenue	Licences	Revenue	Licences	Revenue		
1	$100	129	$12,900	69	$6,900	879	$87,900	281	$28,100	275	$27,500	51	$5,100	1,684	$168,400
2	$150	302	$45,300	321	$48,150	2,718	$407,700	984	$147,600	817	$122,550	107	$16,050	5,249	$787,350
3	$250	63	$15,750	218	$54,500	415	$103,750	124	$31,000	238	$59,500	14	$3,500	1,072	$268,000
4	$700	59	$41,300	47	$32,900	436	$305,200	76	$53,200	268	$187,600	13	$9,100	899	$629,300
5	$1,600	17	$27,200	13	$20,800	91	$145,600	10	$16,000	28	$44,800	4	$6,400	163	$260,800
6	$2,500	33	$82,500	33	$82,500	120	$300,000	18	$45,000	34	$85,000	5	$12,500	243	$607,500
7	$4,000	8	$32,000	2	$8,000	12	$48,000	0	$0	10	$40,000	0	$0	32	$128,000
8	$6,000	8	$48,000	1	$6,000	12	$72,000	0	$0	13	$78,000	0	$0	34	$204,000
Total		619	$304,950	704	$259,750	4,683	$1,470,150	1,493	$320,900	1,683	$644,950	194	$52,650	9,376	$3,053,350

ATTACHMENT 2

ESTIMATED PROJECTS AND COSTS OF ADMINISTERING WATER LICENCES

Table 1: 2006-07 projects and costs

Programme	Direct costs of licence administration	Regional administration costs	Total
Pilbara Licensing and Compliance	$196,753	$43,286	$240,039
South Coast Licensing and Compliance	$99,948	$21,989	$121,937
Licensing and Compliance Swan Avon	$1,139,935	$250,786	$1,390,721
Kwinana Peel Licensing and Compliance	$333,743	$73,424	$407,161
Licensing and Compliance Goldfields	$55,787	$12,273	$68,060
Mid West Licensing and Compliance	$560,494	$123,309	$683,803
South West Licensing and Compliance	$936,507	$206,032	$1,142,539
Kimberley Licensing and Compliance	$125,256	$27,556	$152,812
Water Licensing and Support	$367,082	$0	$367,082
Management Water Corporation	$236,584	$0	$236,584
Sub-total	**$4,052,090**	**$758,653**	**$4,810,744**
Pro-rata corporate overheads (30%)			$1,443,223
Total			**$6,253,966**

Note: totals may not add due to rounding.

Table 2: 2007-08 projects and costs (budgeted)

Programme	Direct costs of licence administration	Regional administration costs	Total
Pilbara Licensing and Compliance	$223,590	$49,190	$272,779
South Coast Licensing and Compliance	$136,686	$30,071	$166,756
Swan Avon Licensing and Compliance	$1,232,206	$271,085	$1,503,292
Kwinana Peel Licensing and Compliance	$397,161	$87,375	$484,537
Goldfields Licensing and Compliance	$55,510	$12,212	$67,722
Mid West Licensing and Compliance	$574,143	$126,311	$700,454
South West Licensing and Compliance	$1,070,630	$235,539	$1,306,169
Kimberley Licensing and Compliance	$191,064	$42,034	$233,098
Goldfields Licensing and Compliance	$55,510	$12,212	$67,722
Water Licensing and Support	$191,293	$0	$191,293
Water Corporation Licensing	$102,698	$0	$102,698
Sub-total	**$4,230,491**	**$866,030**	**$5,096,521**
Pro-rata corporate overheads (30%)			$1,528,956
Total			**$6,625,477**

Note: totals may not add due to rounding.

ATTACHMENT 3

DEPARTMENT OF WATER COSTS ASSOCIATED WITH ADMINISTERING WATER LICENCES FOR 2005-06

Deliverable	Cost	Number of projects
Licensing	$4,145,918	12
Compliance	$812,875	7
State Administrative Tribunal	$237,965	4
Community Input (water resource management committees)	$243,653	4
Licensing Support (database administration)	$386,986	3
Total	**$5,827,397**	**30**

Note: totals may not add due to rounding.

ATTACHMENT 4

BUDGET REQUIREMENTS FOR LICENCE CLASSES PRIOR TO THE EXCLUSION OF LICENCES FOR STOCK AND DOMESTIC (JUNE 2007)

Licence class	Number of licences	Hours of administration per licence	Total cost of administration	Cost per licence per annum for administration
1	5279	7	$1,098,644	$208
2	5,752	11	$1,881,131	$327
3	1,114	20	$662,404	$595
4	898	40	$1,067,932	$1,190
5	179	60	$319,309	$1,784
6	253	80	$601,753	$2,378
7	66	100	$196,224	$2,973
Total	**13,541**		**$5,827,397**	

Note: totals may not add due to rounding.

ATTACHMENT 5

REPORTS PREPARED BY THE DEPARTMENT OF WATER

WATER LEVEL MONITORING RESULTS FOR THE SUPERFICIAL AQUIFER IN THE PERTH URBAN AREA – HYDROGEOLOGY REPORT SERIES 225 (SEPTEMBER 2004)

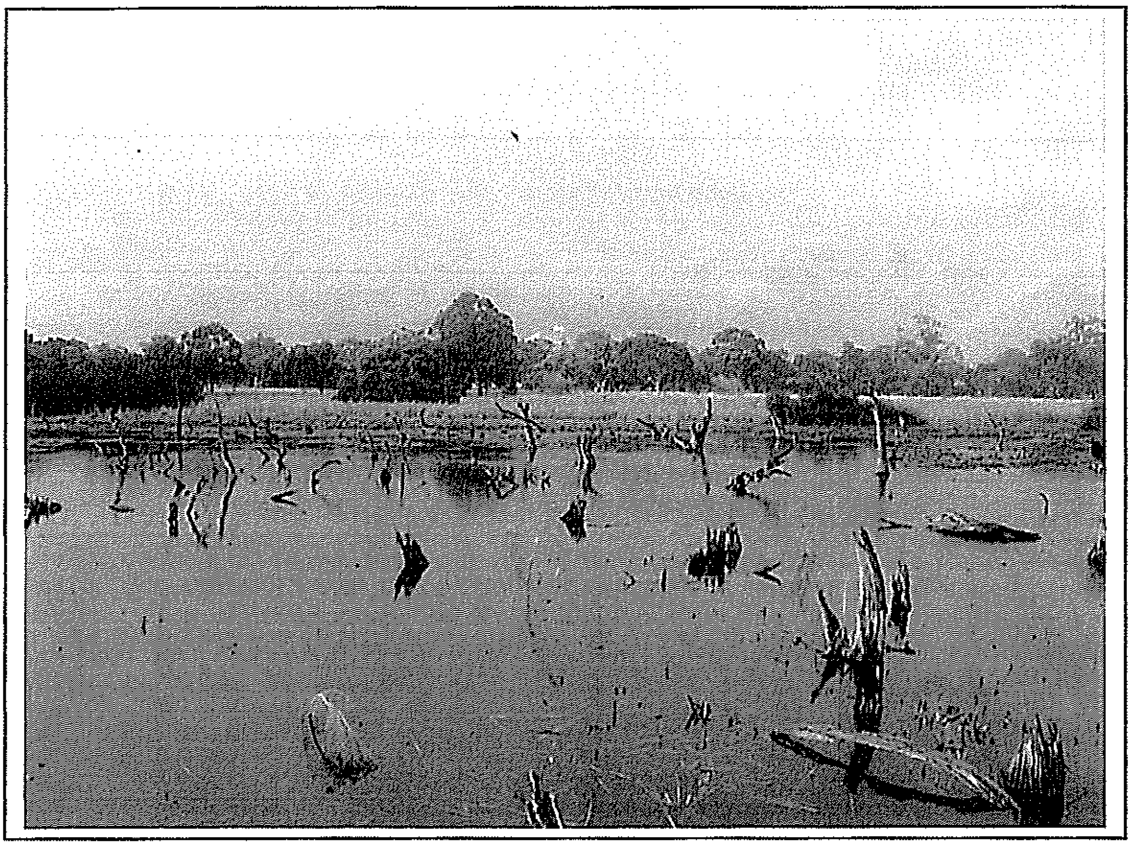
AND

ASSESSMENT OF THE DECLINING GROUNDWATER LEVELS IN THE GNANGARA GROUNDWATER MOUND – HYDROGEOLOGICAL RECORD SERIES, REPORT HG14 (JANUARY 2008).

WATER LEVEL MONITORING RESULTS FOR THE SUPERFICIAL AQUIFER IN THE PERTH URBAN AREA

R.P.Lindsay
Resource Science Division

DEPARTMENT OF ENVIRONMENT
HYDROGEOLOGY REPORT SERIES
REPORT NO. 225
SEPTEMBER, 2004



Lake Claremont (formerly called Butlers Swamps) taken on 5th August 2004. A depth pole in the lake showed there to be 30cm of water. The old tree stumps are probably paperbark trees, (Evans and Sherlock, 1950). The area was believed to have been a dampland in the early 19th Century, with rising water levels from 1915 until the late 1960s. Lake levels have since declined since the late 1960s.

Photo by R.Lindsay

Acknowledgments

This report was prepared by R.P.Lindsay of the Resource Science Division. The work was supervised by D.P. Commander and C.A. O'Boy.

Resource Science Division

3-5 Plain Street

East Perth
WA, 6004

Telephone 08 2780300

Recommended Reference

Lindsay, R.P. 2004, Water Level Monitoring Results for the superficial aquifer in the Perth Urban Area. Dept. of Environment Hydrogeology Report 225.

Printed on recycled stock

September 2004

Contents

Figures

Summary

There are forty-six monitoring bores for the superficial aquifer in the Perth urban area covered by this study. The oldest bore was drilled in 1922, however many of the older bores have incomplete records and it was not until the early 1970s that a broad network of bores was established and regular readings were taken. Of these bores, twenty three bores show that watertables have been gradually declining over the last 30 years, with an average decline of 0.79m (2.5cm/year). Two bores show stable water levels, two have risen and nineteen have data for less than 30 years.

A long-term indication of how watertables levels may have behaved over the last 160 years can be obtained from Lake Claremont. Early reports indicate that there was no lake at the present site of Lake Claremont until about 1918. The watertable level subsequently increased from 1918 until the late 1960s, inundating the area to a depth of 2 metres during the 1940s. Since approximately 1969, water levels have made a partial decline, such that water levels in the lake today are less than 1 metre. As the lake is hydraulically connected to the ground watertable, this fluctuation of watertable may be indicative of magnitude of variation over much of the Perth urban area.

A comparison of bore hydrographs with Cumulative Departure from the Mean (CDFM) rainfall records shows that rainfall was the primary controlling factor from 1969 until the mid 1980's, after which time most areas show a departure from the short-term CDFM curve. The relative slowing in the rate of climatic change since the early 1980s is not reflected by a comparable change in the bore hydrographs

Two possible causes were examined to explain the de-coupling of the primary climatic control and the water level. Neither cause was confirmed for the monitoring bore network in this study. Variations in watertable behaviour cannot be explained by either leakage to the underlying confined aquifers nor by the density of garden bores, although there is anecdotal evidence from verbal reports that water levels in some garden bores are declining faster than recorded in monitoring bores. If these verbal reports are correct, it supports the case that the monitoring bore network is insufficient in some suburbs to represent local water levels.

Local urban effects may have important impacts upon watertables. The development of stormwater sumps, increased paving, the way of handling storm water runoff and the conversion from septic tanks to main line sewerage systems are likely to affect watertable behavior. However, the implementation of drains during the 1970s and 1980s are probably have the biggest impact on lowering and controlling the levels of water levels.

It is recommended that the monitoring schedule for water level readings be standardised. Peaks and troughs in the water levels are not captured with some of the current observation schedules and a revised schedule of monthly readings between March to June and August to November is recommended.

There are no active monitoring bores in the developing eastern suburbs from High Wycombe to Armadale. There are also gaps in the monitoring network in other urban areas that should be addressed by drilling 28 new bores. The approximate cost to drill these bores is expected to be $110,000.

1 Introduction

This study was conducted to identify the distribution and adequacy of the groundwater monitoring bore network in the superficial aquifer in the Perth urban area and to assess the monitoring results.

Perth is situated on an unconfined, superficial aquifer. The watertable comes to the surface at wetlands and is deepest in the Tamala Limestone area below the dunes where the watertable is up to 65m below surface at Bold Park. In eastern and southern areas of the city, drains control areas of shallow watertables.

Watertable levels respond to land use and climate change. Early stages of urbanisation have been reported as tending to raise watertable levels as clearing and increased run off from roofs and paved areas increases recharge (Savini and Kammerer 1961, Appleyard, 1995 and 2001). Appleyard considers that developing urbanisation in Perth causes an initial rise in watertables due to land clearing, the channeling of runoff from roofs and pavements, and the installation of septic tanks. In maturing urban environments main line septic systems replace septic tanks and the increasing use of garden bores may cause watertables to decline. In some Perth suburbs run off is diverted through drains into the river or ocean (e.g. Morley, Maylands and the eastern suburbs), while in central and western suburbs infiltration pits and soak wells are used (e.g. East Victoria Park, Kewdale, Welshpool), which tends to increase groundwater recharge. Appleyard and others (1999) and McFarlane (1984) have described the impacts of urbanisation on groundwater recharge and quality.

The environment of Perth however, has a number of other features that have a positive effect on the quantity of recharge to the watertable in the urban area (Appleyard, 1995). These factors are: a sandy (porous) nature of the surficial geology, intensive garden watering during summer using water from outside of the Swan Coastal Plain, and the common use of infiltration and retention basins. Compounding the early urbanisation effect of increasing recharge, Perth's rainfall increased above the long term average from about 1914 to 1968 (Yesertener, 2002).

Recently, there has been concern that water levels in the superficial aquifer have been declining. Studies of the Gnangara and Jandakot Mounds have found that abstraction, climate and land use impacts can be separated by using a techniques called Cumulative Departure From the Mean (CDFM), (Yesertener, 2002). In the urban area, increased abstraction from confined aquifers, climatic drying since 1969, increasing use of garden bores and the conversion of septic tanks to main line sewerage has led to the belief that watertables may have been declining over the last 20-30 years

This study assesses the water level data from the urban area, but excludes the northwest corridor (north of Trigg), and Mirrabooka, Gwelup and Jandakot where there are public water supply well fields. The study aims to identify the available water level information, the adequacy of the monitoring network and the adequacy of the monitoring program. It attempts to identify the causes of the water level changes over the last 30 years and recommends future action.

Yesertener (2002) has previously reported water level changes to the north and south of the Perth urban area.

1.1 Historical Water Levels

An indication of historical water levels in the superficial aquifer can be found at Lake Claremont. The earliest records of water levels at Lake Claremont are from the Dutch maritime explorer Willem de Vlamingh (translated by Playford 1998, p35). De Vlamingh landed in Perth (probably near Swanbome) and walked to an inland lake in 1697. The lake was probably Lake Claremont, which he said contained 'significant water'. This was the time of the little ice age in Europe and probably corresponds with a wetter climate than at present along the Swan Coastal Plain (Rich, 2004).

A study by Evans and Sherlock (1950) gives an account of the history of the formation of the lake from the mid 19th century up to 1950. The lake is in hydraulic connection with the watertable (Perth Groundwater Atlas, 1997). These authors document the rise of water at Lake Claremont (formerly Butlers Swamp) from 1918 to 1950. They also showed that Butlers Swamp was essentially a dry and agriculturally productive area from the mid 19th century until early 20th century, by using a combination of soil and vegetation maps and records of early roadways from maps and press clippings. The study found that only small areas had been occasionally inundated from 1844 until the early 1900's. Water levels began to rise after 1918 to form a semi permanent lake, increasing to a maximum of 3.3m ASL. in August 1947. The base of the lake is approximately 1.5m ASL, therefore there was approximately 1.8 metres of water in the lake in 1947. Water level records in the report showed that August lake levels have varied from between approximately 0.7m to 1.8 metres between 1937 to 1950. The authors attributed the rise in lake levels to increasing rainfall, a fact that is supported by an analysis of rainfall using the Cumulative Departure From the Mean (CDFM) method (Yesertener, 2002).

Lake Claremont was visited on August 5th 2004. A depth pole in the lake showed 30cm of water in the lake. This indicates that water levels have fallen by about 1.5 metres since 1947. The observation is confirmed by water levels in Claremont 142, a monitoring bore located just south of the lake and commissioned in 1946. There is a gap in the monitoring schedule between 1960 and 1984, during which no readings were taken. The hydrograph of bore 142 shows that water levels in Lake Claremont have declined by 1.96 metres between 1958 and 2003.

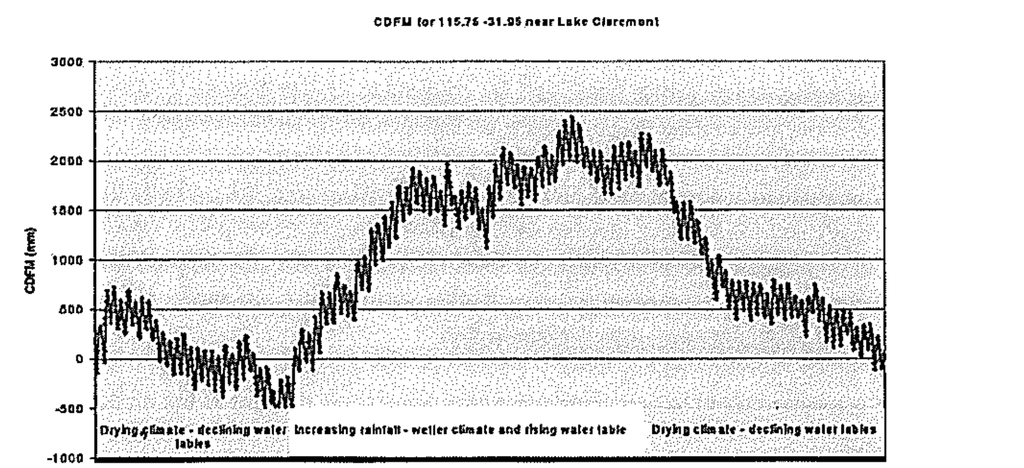


Figure 1. CDFM for rainfall near Lake Claremont. Lake water levels are controlled by the watertable, and in turn by climate (Diagram adapted from Yesertener, 2002)

Appleyard (2001) considered that the rise in water level at Lake Claremont during the early part of the last century was due to early urbanisation effects, while the more recent partial decline is linked to maturing urbanisation impacts. This study shows that the rise and partial decline in watertable levels are consistent with CDFM analysis of rainfall (Yesertener, 2002), which shows increasing rainfall from 1915 until 1968, then decreasing rainfall from 1969 until present (Figure 1). A few bores with records dating before 1950 tend to confirm this trend (e.g. bore 149 and 8283). The rise and subsequent partial decline of lake levels at Lake Claremont is therefore more likely to reflect maximum water levels in the superficial aquifer due to climatic change than impacts caused by urban development, which are related to an established residential environment at some distance from the lake.

Rich (2004,) describes a similar history for several lakes in the Perth metro area, particularly water levels at Perry Lakes, which are flow through lakes hydraulically connected to the watertable. Rich cites early records and photographs that lake water levels were high by 1919 and had risen considerably by 1921 and continued to rise intermittently until about 1970 (p.2-25). Records prior to 1921 are sketchy but the area was apparently drier than in the early 1920s on evidence of the distribution of mature *Baumea articulata,* although the Nyungar aboriginal people hunted tortoises from the area, indicating that there was at least some permanent water before European settlement. During the early 1970s lake levels began to decline rapidly and since the early 1980s at least one of the lakes (East Lake) has been augmented by pumping of local groundwater bores while West Lake has been allowed to dry out in very dry summers.

1.2 Methodology

Groundwater monitoring data is held in the WIN database. In order to identify all the monitoring records, a search was conducted to identify all monitoring bores that passed the following criteria:

- Geographical limits East 380000 to 411000; North 6447000 to 6479000 (990 km^2),
- Bore depth ≤ 50 m,
- Bores that have at least one water level reading.

Some bores have been intentionally omitted. These are bores that were drilled either for contaminant monitoring or bores that are close to the sea of major rivers, because major water bodies have a controlling influence upon adjacent groundwater levels.

Figure 2 shows the location of all operating bores in the superficial aquifer that can be used as representative of the watertable in the inner suburbs. The figure also shows the relative decline in watertable over the last 30 years (1973-2003). Operating bores are those bores that have current records to at least the end of 2003. Figure 3 shows non-operating bores in the area.

The earliest available records of monitoring bores start in 1922. The majority of monitoring bores were drilled during the period from the mid 1950s to the late 1970s. Initiatives to drill monitoring bores over the 30 year period focused upon monitoring surface drainage levels, sea water intrusion, contaminant plume migration and monitoring of watertable levels in public water supply areas (Table 1).

Table 1. Summary Details of Operating Bores used in this study

Name - this study	Depth (m)	Bore location	Comments	WL change in last 30 years (m)	Year of first record	WL change over last 10 years
Trigg (GD23)	13	Edge of sports field, irrigation bore 110m away	Water levels rose 0.3m from 1998 to 2000 and have since fallen against comparative rise in CDFM rainfall. Site is 1km south of Star Swamp (wetland). May indicate wetland dewatering	-	1997	-
City Beach (GD4)	42	Between school and park	CDFM analysis, declining 0.5m in 26 years	-	1978	0
Embleton (2069)		Residential, next to Embleton Primary. Bore not located	CDFM analysis, declined 2.5m since 1969	1.65	1958	0.3
East Midland 3/85)	30	New residential housing	Declined 0.91m in 18 years but stable since 1999 (clearing of site?)	-	1985	0.6
Claremont 142	5	Playing fields	WL dropped sometime between 1960 and 1984	1.96	1946	0.44
Cloverdale 2288)	6	Cnr Goodall & Sydenam St.	Water levels declined 0.75m in last 20 years. Water levels follow climate (but with smaller fluctuations) until 1987 then break from relative rise in CDFM curve (drain controlled)	1.90	1970	0.00
Como 2025A	8	North edge of Collier Reserve and golf course, Como. 20m from irrigation bore. Small stand of mature pines.	Water levels generally stable except for a period from 1992-1995, when WL's declined 0.84m.	-	1983	0.25
Wilson (1606)	4	Road verge, park irrigation bore 15m	CDFM analysis shows water levels followed rainfall until mid 1998, after which fluctuations in WL's became very restricted. Declines have been erratic, occurring over short periods eg. 1975-1978 (dry years) and after 2000 (both very dry periods). Influence of a nearby bore may exaggerate declines since 1988.	1.10	1950	0.20
Winthrop (T10)	41	Bore in middle of Ross Park Road	CDFM analysis shows water levels trend similar to rainfall with smaller wavelength 1977-1992.	+1.6	1973	0.5
Swanborne (GE1)	26	In Bold Park	Water levels declined 0.27m in last 26 years. Steepest decline is from 1988.	-	1978	0.00
Shenton park (GE4)	22	Edge of Park and residential	Decline of 0.7m in water levels since 1982.	-	1978	0.35
East Vic Park (2729)	7	Next to storm water sump at side of road	Water Levels declined 0.75m in last 20 years. Upper levels controlled by sump	1.85	1970	0.45
Churchlands GD5)	17	Not seen. Edge of herdsman Lake	Declined 0.6m over last 26 years	-	1978	.25
Leederville (GD6)	16	Not seen	Water levels stable since 1978	-	1978	0.00
Yokine (GD7)	15	Northern edge of Wordsworth Park 50m from irrigation bore and 30m from infiltration sump.	Water levels declined 0.65m since 1978. Steepest drop was between 1993-1995	-	1978	0.35
Morley (637)	8	Between bush and residential. Irrigation bore 15m away.	Stable WL's since 1980. Apparent sudden decline of 1.5m in 1978,possibly due to irrigation bore	0.35	1947	0.10
Guildford (GD8)	18	Not seen	Decline of 1.25m over 26 years	-	1978	0.45
Kewdale (144B)		Cnr Armdale/Oats road. 50m to Tomato Lake & 30m from drain	Hydrograph declines from 1974 to 1980, then is stable. Upward water level controlled by drain.	0.45	1974	0.20
Ferndale (2436)	5	NE cnr Bentley Hospital, waste land	Stable since 1977. CDFM analysis shows WL's followed climate until 1988, after which WL's declined compared with a relative rise in rainfall.	0.60	1956	0.20
Bull Creek (T5)	46	On top of 10m high bank, residential service road	Water levels declined 2.7m over last 29 years. Drain impact (late 1970's)	2.70	1974	0.0
Maylands (678)		Bore in private garden, next to Brooks Park	Stable since 1973. Apparent dislocation in data monitoring in 1973	0.00	1922	0.3
Claremont (GE3)	31	Cnr of cemetery and residential	WL's declined 0.3m over 26 years.	-	1978	0

Name - this study	Depth (m)	Bore location	Comments	WL change in last 30 years (m)	Year of first record	WL change over last 10 years
Dalkeith (8279)		Edge of small park and residential	Stable WL's since 1979. (sump possibly dug in 1979)	0.55	1970	0.0
Meltham (135A)	7	Next to open drain, Wymond Park	Bore commissioned in late 2001.upward water level controlled by drain	0.15	1999	0.15
Subiaco (SU6)	15	In Shenton Park	Steady decline of 0.15m from 1993-1997 No data after 1997	-	1993-97	-
Klara MM43	not known	Not seen	declined 1.4m in 29years	-	1974	0.50
Cottesloe GE2	not known	Not seen	Stable. Some reduction in seasonal variation since 1999. Some sea level control	-	1978	0.00
Trigg 793	not known	Not seen	Declined 0.35m since 1993	0.35	1953	0.35
Waterman 7597	not known	Not seen	Declined 0.5m since 1993. Some sea level influence.	0.00	1967	0.50
Kardinya 8283	not known	Not seen	Rising WL's from 1965 to 1991, then falling to present. Drains dug in late 1980's.	+0.75	1928	0.20
Rossmoyne 1081	not known	Not seen	Steady decline of 1.65m in last 30 years. Rain dug in 1977/1978.	1.65	1961	0.00
Willetton 1072	not known	Not seen	Steady decline of .5m in 30 years. Possible impacts of drains in late 1960s.	0.50	1961	0.02
Morley 7970	not known	Not seen	Stable over 30 years	0.00	1969	0.00
Noranda MM67	not known	Not seen	Stable since 1981	-	1981	0.00
Noranda 649	not known	Not seen	Cyclical, sharp decline from 1965 until 1973, then partial recovery	0.40	1952	0.20
Welshpool 149	not known	Light industrial 75% paved	Steady decline of 0.60m in last 30 years. Drain/sumps installed at various times during late 1970s-early 1980s.	0.60	1948	0.40
Malaga 7382	not known	Not seen	Stable WL's	0.2	1966	0.00
Morley 821	not known	Not seen	slow decline of 1.9m since 1950, decline of 0.75m since 1973	0.75	1947	0.00
Beechboro 44B	not known	Not seen	slight decline of 0.07m over 22 years	-	1981	0.00
E.Vic.Pk 3020	not known	Not seen	Declined 2m since 1957. Declined 1.4m in last 30 years	1.40	1957	0.6
Kewdale 1005	not known	Residential	steady decline of 0.69m since 1985	0.69	1985	0.25
Malaga 8259A	not known	Not seen	Records since mid 2000. Stable	-	2000	0
Dianella 3578A	6	Not seen	Records since mid 1997. Stable	-	1997	0
Malaga MM36	not known	Not seen	declined 1.8m in last 30 years	1.80	1974	0.7
Yokine 643	not known	Not seen	Declined 1.4m since 1952. Declined 0.8m in last 30 years	0.80	1952	0.3
Kewdale 675B	not known	20m from large storm water sump. Lake WL is 0.3m below storm water outlet	Relatively steep decline of 1.7m from 1952 to 1988, then decline 0.2 in last 14 years. Seasonal fluctuation decreases from 1974 to present.	0.90	1952	0.1
			average decline in WL of declining bores only	0.79		0.22

Forty-six operating monitoring bores were identified that could be used to measure water levels in the superficial aquifer. The bore density is equivalent to one monitoring bore per 15km^2. Bores in densely monitored areas such as borefields, (e.g. Gwelup, Mirrabooka) and groundwater mounds outside of the urban area (e.g. Jandakot) were excluded as they are well monitored. Bores that are adjacent to the Swan or Canning Rivers or the seashore were excluded from this study, as they are not representative of the watertable changes. No monitoring bores exist in the southeastern suburbs, between High Wycombe and

Gosnells. For this study, each bore has been given a suburb name to make the description and discussion easier. Further details of bore locations are held on file at the DoE's Kew Street depot.

Figure 2 shows the operating monitoring bores and watertable declines over the last 30 years. Figure 3 shows non-operating bores.

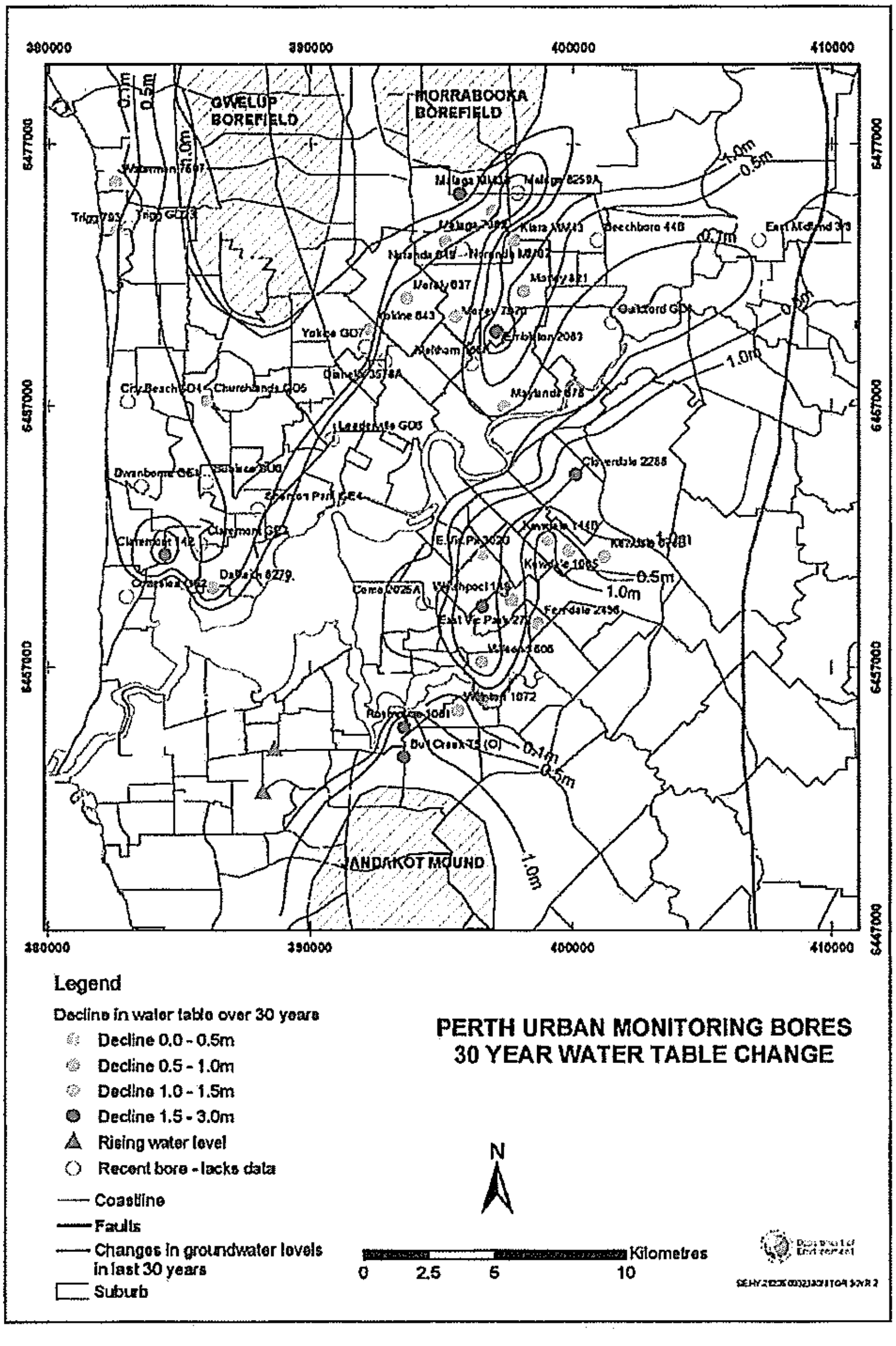
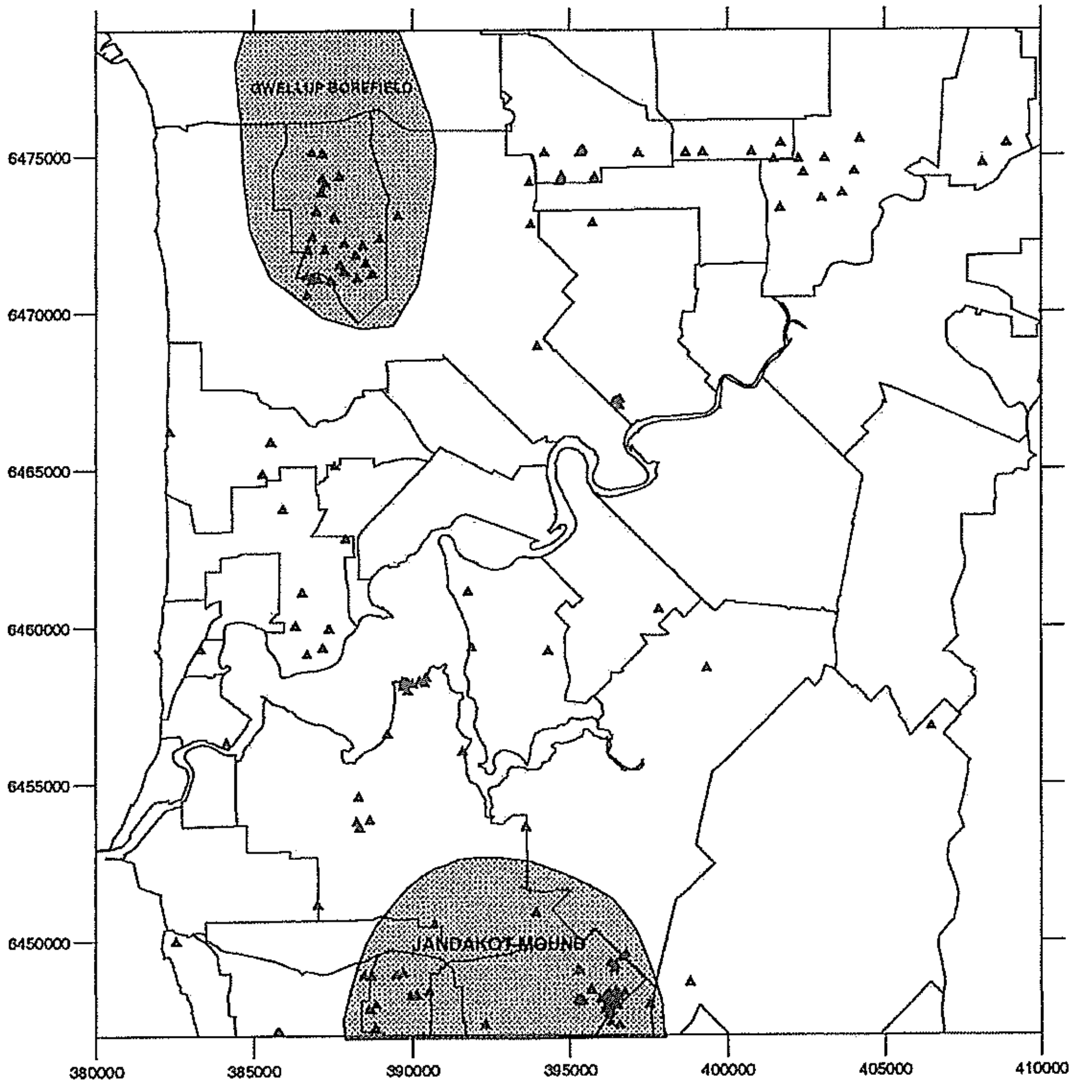


Figure 2. Perth Metro Area: 30 Year Watertable Change in the Perth Unconfined Aquifer

Perth Urban non Operating Monitoring Bores



Legend

▲ Non Operating bore

Figure 3

Information on these bores other than water levels on the WIN database is sparse. There is a geological log for one borehole (T10(O)), but no water quality data exists for any of the bores of interest. One bore (135A) has been added to the monitoring network since 1993 and has insufficient records to be used for long term assessment of the watertable. Several bores have no construction details or depth in the WIN database. These bores were judged to be in the superficial aquifer based upon their project name (e.g. lakes and Wetlands) or their prefix and the form of the hydrograph.

Water level readings were taken monthly until 1988 on most bores, reducing to quarterly until 1999. After 1999, monitoring schedules were reduced in some bores to 6 monthly, while others are still read quarterly.

All monitor bores were grouped according to operating and non-operating status. The operating monitor bores were further subdivided on the basis of their distribution, to provide a representative distribution throughout the built-up area of Perth.

Hydrographs were drawn for the selected bores and comparisons of the hydrographs for seven bores were made with Cumulative Departure from the Mean (CDFM) for rainfall, using the Perth Silo data where there is no rainfall station within 2.5 km of the bore. The short-term graph for CDFM was chosen for comparison (1969-present). The short term CDFM graph is more useful as a comparason where the aquifer is thin and has relatively lower storage capacity than more northerly areas, for example the Gnangara Mound (Yesertener, 2002).

Monitoring bores were plotted on the geological map of subcrop beneath the superficial aquifer to determine if the underlying geology influenced watertable behavior. Bores were also plotted against garden bore density to assess whether there is a relationship between garden bore density and watertable levels.

Non operating bores that might be of use if they could be re-opened were either closed or abandoned for a variety of reasons. Several were closed in April 1997, relating to a cut back in borehole monitoring. These bores would have to be field checked should they be required to be re-commissioned.

2 Results

2.1 Water Levels in the Superficial Aquifer

2.1.1 Medium Term Changes in Watertable Levels (1973-2003)

Hydrographs of bores in the superficial aquifer show that groundwater levels in the Perth urban area are generally stable or have declined slightly over the last 30 years. The largest decline was at bore T5 at Bull Creek, with a decline of 2.7m since 1974. The cause of this is almost certainly due to the lowering of watertables through the area by digging drains in the late 1970s and 1980s. In other areas of declining watertables, watertable falls are in the range between 0.1 to 2.5m over the last 30 years. Comments on the individual hydrographs of bores are provided in Table 1. In general, the greatest declines in water levels have occurred in the central suburbs from Malaga in the north to Bull Creek in the south (Figure 2). The Swan River dissects the trend because it tends to stabilise the watertable by loosing water to the aquifer in summer and receiving water through base flow in winter.

Of the forty-five monitor bores that have long term data available, 33 bores show declining water levels within the last 30 years, ten are stable and two have risen. Water levels have declined by an average of 0.93m over the last 30 years in those bores that have long-term records. Bores that show erratic water levels such as GD23, and 1606 may be affected by irrigation pumping bores.

Some hydrographs show that watertables stabilised after declining through the 1970's. Examples are 144B Kewdale, 2436 Bentley Hospital and T5 (O) Bull Creek where levels have stabilised after falling steadily until about 1980 (bores 144, T5 (O), 2288). This correlates with a relatively stable climatic period, when rainfalls were stable from 1980 to 1989, although still less than the long term average.

Examination of the CDFM for rainfall against the bore hydrographs shows that in most cases the water levels are changing in harmony with the short term CDFM trend, at least until the early 1980's. Watertable level behavior in the Perth urban area can be categorised into three main types according to the shape of the hydrograph response, as follows:

1. Watertable is controlled by climate (hydrograph is sympathetic with CDFM, e.g. Figure 4),

2. Watertable is controlled by climate until the mid 1980's, after which there is a separation between climatic control and water level (e.g. Figure 5),

3. Watertable is controlled by climate until the mid 1980's, after which the CDFM response rises but local factors such as drains control the water level (Figure 6).

Figure 4 shows that the hydrograph of bore T10 (O) is almost coincident with the CDFM (rainfall) curve, indicating that watertable levels are controlled principally by rainfall in the Winthrop area. Close inspection of the hydrograph and CDFM curves between 1978 and 1989 shows that the watertable has risen slightly faster than the CDFM. This period is coincident with the clearing of pine plantations in the Kardinya-Winthrop area during the late 1970s to make way for new housing. Water levels respond positively to clearing of pine trees for a period of up to about 10 years (Yesertener 2001). Bore 8283 at Kardinya shows a similar hydrograph to T10(O), confirming that the trend in the two adjacent areas. The rise and subsequent fall of watertable led Appleyard et al. (1999) to believe that this was an early urbanisation effect. The close relationship of water level with the CDFM rainfall curve suggest that the rise and fall in the watertable level is more likely to be related primarily to climate and secondly to pine clearing, although urbanisation may have had a compounding effect.

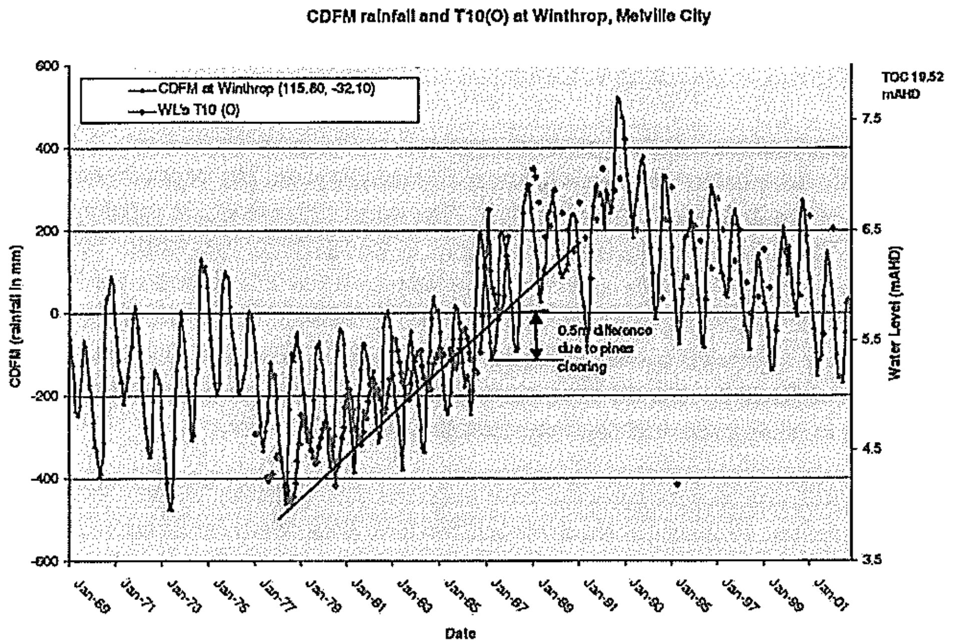


Figure 4. CDFM for rainfall and bore T10 (O), Winthrop – hydrograph and CDFM almost coincident except for small positive impact (0.5m) of pines clearing.

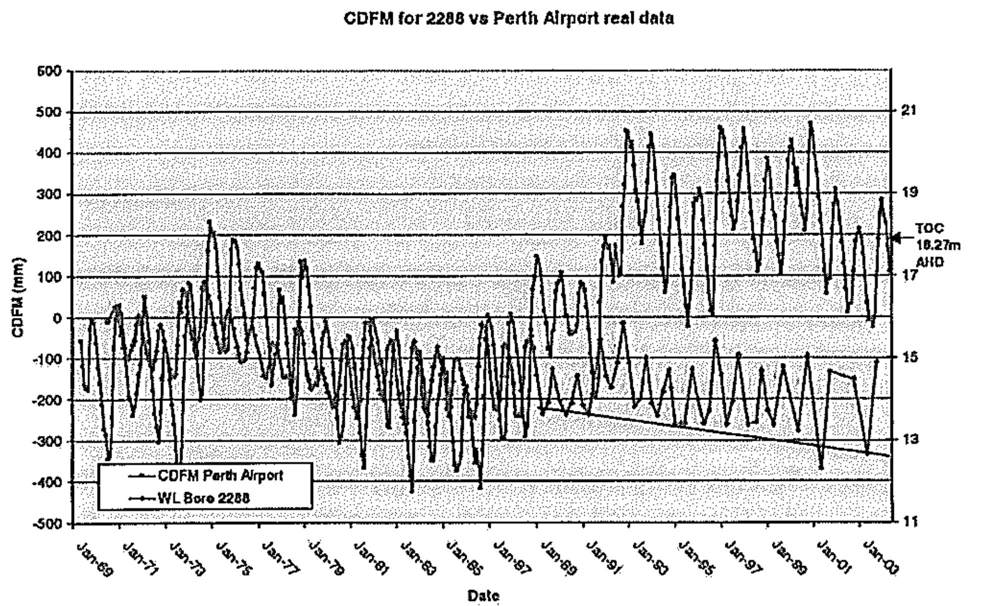


Figure 5. CDFM for rainfall and bore 2288 in Cloverdale –hydrograph response departs from CDFM after 1988

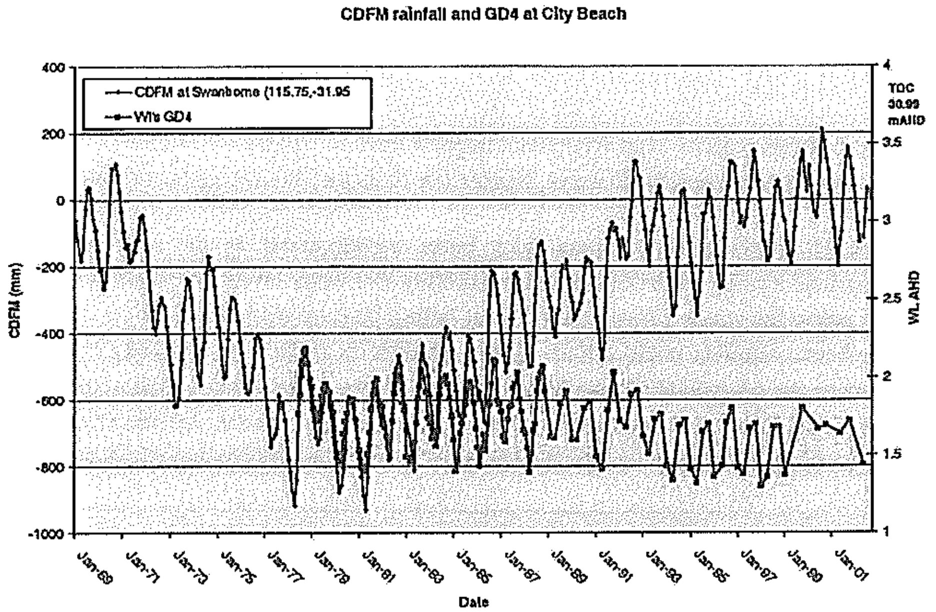


Figure 6. CDFM for rainfall and bore GD4 at City Beach –influence of sea level

In many other bores, the hydrograph and CDFM curves diverge during the mid-1980's (Figures 5 and 6). The hydrograph response in bore 2288 (Figure 5, bore located at Cloverdale) reflects that the watertable did not respond to the relatively rapid change in the rainfall from 1989 (Figure 7). Water levels declined despite a relative increase in rainfall from previous years (rising CDFM response). This bore is located about 1km from a major drain along the western edge of Perth airport. The drain would have a controlling influence upon the upper level of water levels and preventing the level to respond to the relative rise in CDFM.

Figure 6 shows the hydrograph of GD4 and CDFM. The CDFM of rainfall and bore hydrograph are almost coincident until 1986, after which the hydrograph response remains stable but the CDFM response rises. This bore is drilled in Tamala Limestone approximately 1 km from the sea, hence sea level has a stabilising influence on the water level which restricts its upward movement.

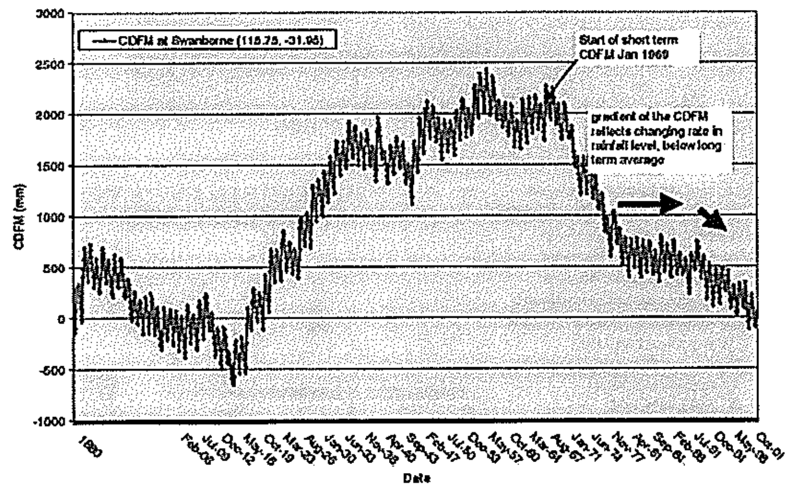


Figure 7. Long term CDFM of rainfall showing relative change in the in the rate of declining rainfall since 1980.

Two possible reasons apart from drain impacts were investigated to explain the divergence of the water levels away from the CDFM curve. Neither are confirmed but are explained here for completeness.

Figure 8 shows a plot of monitoring bores superimposed on the subcrop geology underlying the superficial aquifer. This examines the possibility that water levels are influenced by the nature of the sub unit below the aquifer. It was thought that falling potentiometric heads in the underlying Leederville and Mirabooka aquifers could induce falling watertables if there is relatively good hydraulic connection between the superficial and confined aquifers. However, from the limited number of bores available for comparison, there does not appear to be any relationship between declining watertables and the relative permeability of the sub crop (i.e. the hydraulic connection between superficial and confined aquifers).

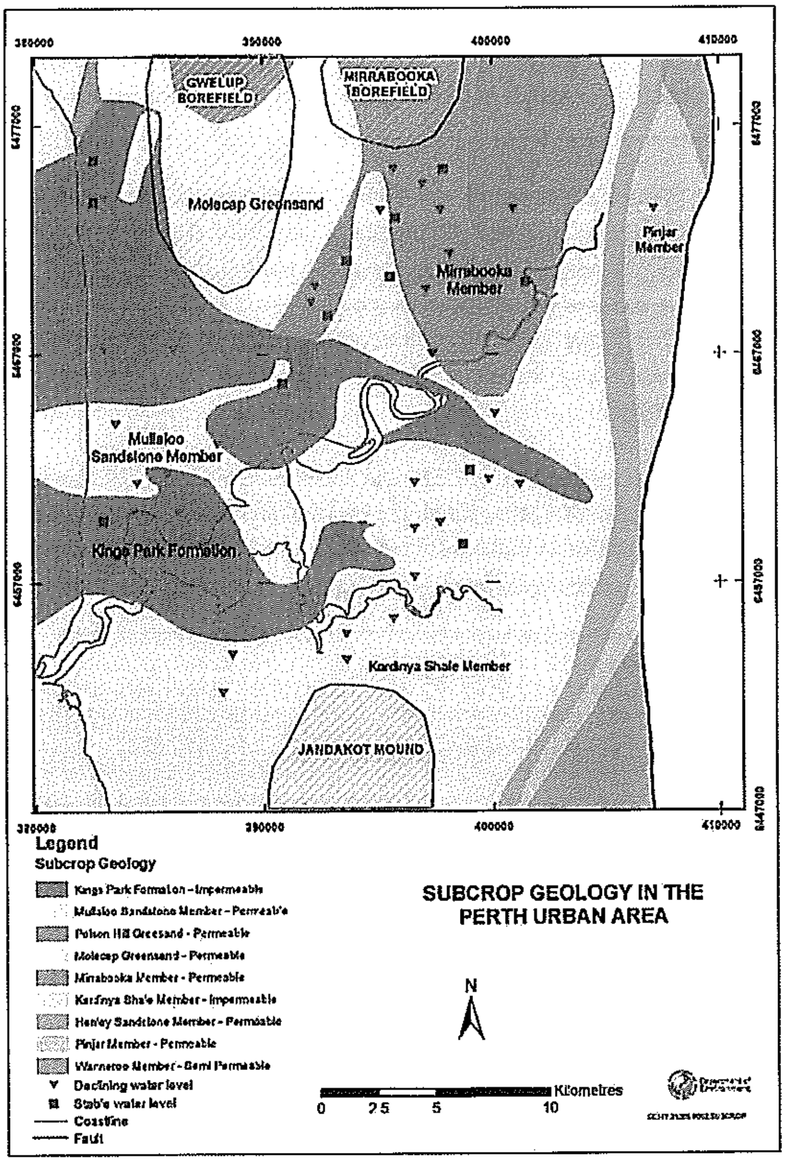


Figure 8. Subcrop Geology in the Perth Urban Area

Figure 9 shows a comparison of water levels with a distribution map of garden bores (adapted from Aquaterra 2001). Following scheme water restrictions in 1978, there was a sudden increase in garden bores (Metropolitan Water Authority, 1985). It is possible that this could have lead to a general decline of water levels in the 1980's. However, there appears to be no general correlation between declining watertables and garden bore density evident from the map, although there is anecdotal evidence that garden bores may locally cause a decline in watertable. The evidence stems from verbal reports from residents in some suburbs that have noticed substantial declines in water level in their garden bores (R.Coleman, pers com, 2004). However in most cases monitoring bores are too far to reflect any cone of depression.

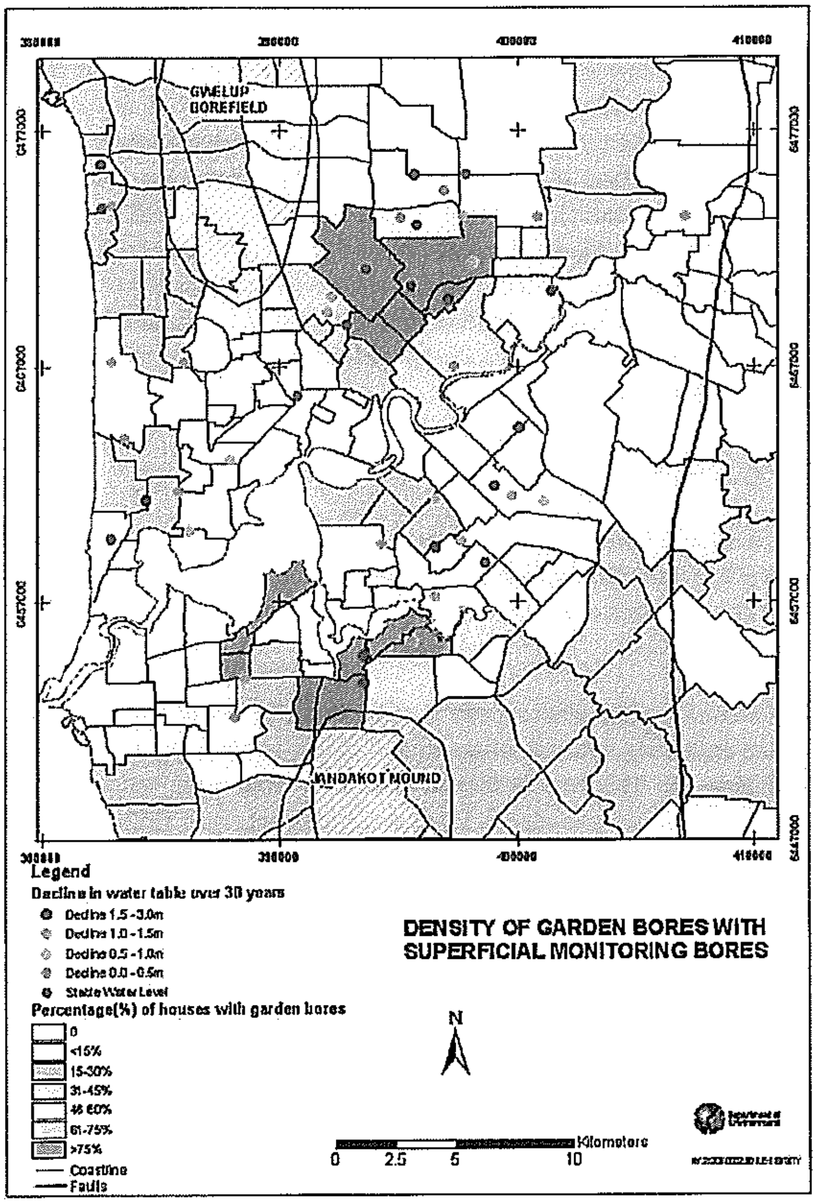


Figure 9. Density of garden bores with superficial aquifer monitoring bores

The variable behavior of the watertable in bores after the mid 1980's may be due to a combination of complex urban impacts. These impacts may include the following:

- The nature of disposal of storm and run off water, whether by infiltration or discharge to the river or ocean by open drains,
- The excavation of drains close to the monitoring bore, controlling water level rise,
- The density of building and paving (surface sealing reducing infiltration),
- The conversion of septic tanks to main line sewerage system
- The increase and increased usage of garden bores.

Drains appear to have a major lowering impact on water levels in some bores such as in the Winthrop-Bull Creek area (e.g.T5, 1081), which had an extensive network of drains commissioned in the early 1980's (R.Hammond, pers com.). Other areas that appear to be impacted by drains are Kewdale (144B, 675B) Meltham (135A), and Morley (637). Water Corporation owns and manages main open field drains, however there are many other minor drains, the exact locations of which are not well known and not on a central database. Figure 10 presents a map of the distribution of the main drains in the Perth metro area. Although any correlation between drains presented at this scale and reduction of watertable is difficult, it shows that drains heavily influence a large part of the Perth metro area. From the examples given above it can be extrapolated that the upward movement of water tables in many older and lower lying areas of Perth are stabilised by drains.

2.1.2 Recent Changes in Watertables (1993-2003)

Changes in watertable levels over the last ten years are shown in Figure 11. Most areas show declines of water levels of less than 0.5m over the ten-year period, with a maximum decline of 0.7m at Malaga. Other suburbs that show declines of at least 0.5m in ten years are at Kiara, East Midland, East Victoria Park, Winthrop and Waterman.

The rate of decline in some areas appears to stabilise during the last 10 years, however this may be an artifact of the controlling influence of drains and sumps, as shown by the hydrograph of bore 675B in Kewdale (Figure 12). This bore is located close to a large storm water sump that now supports a permanent lake. Maximum groundwater levels declined sharply from 1952 until about 1972 with seasonal variations of up to 2metres. Since 1972, the seasonal variation has reduced to less than 1 metre, and the decline in groundwater levels has stabilised. The control of the upward movement of groundwater level and the relatively stabile watertable is consistent with the development of a storm water sump sometime in the early 1980's at Kewdale. In some other cases the relative stable rate of decline of the watertable is attributed to the relative slowing of the rate of decrease in rainfall, which began in the early 1980's.

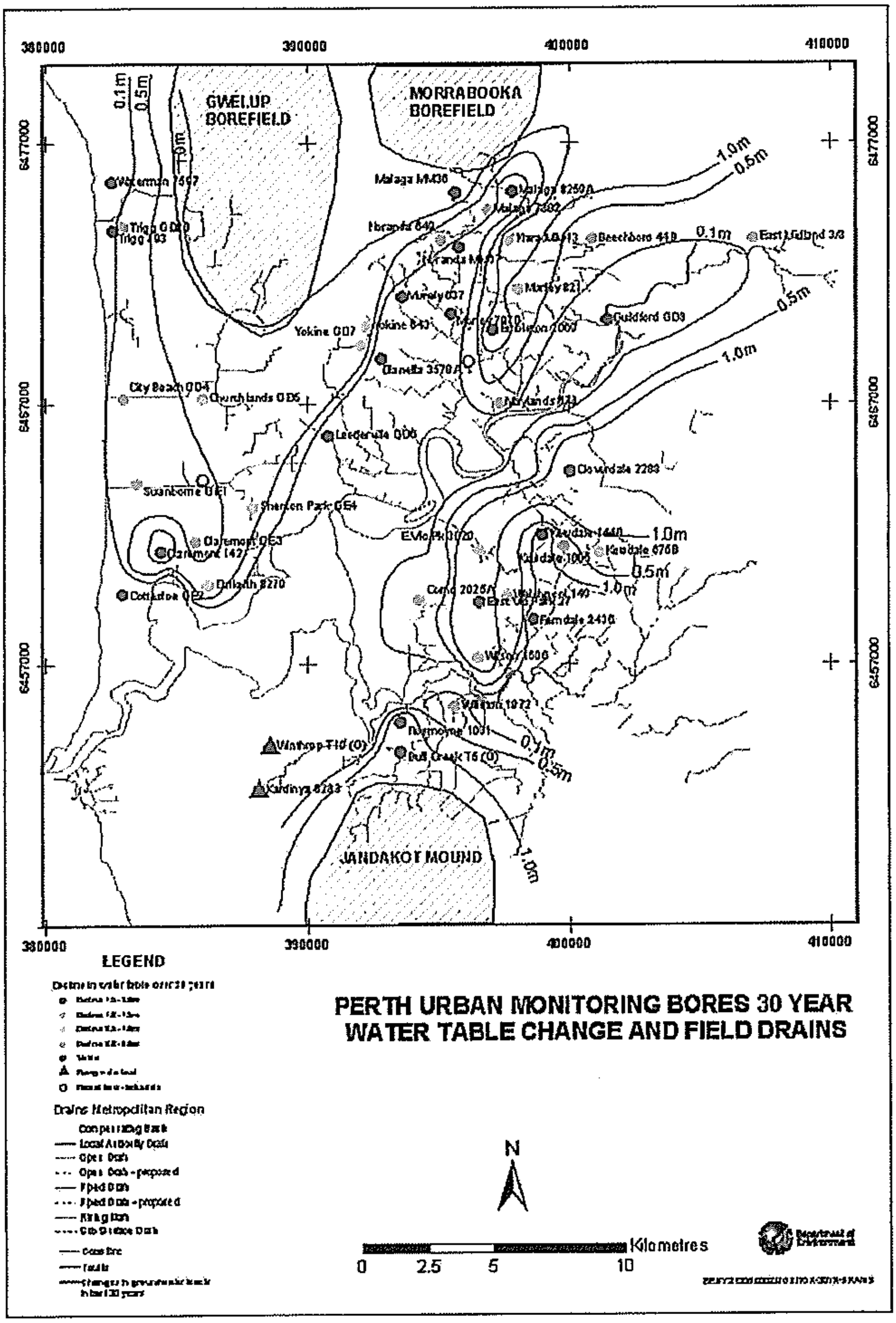


Figure 10. Main Field Drains in the Perth Metro Area

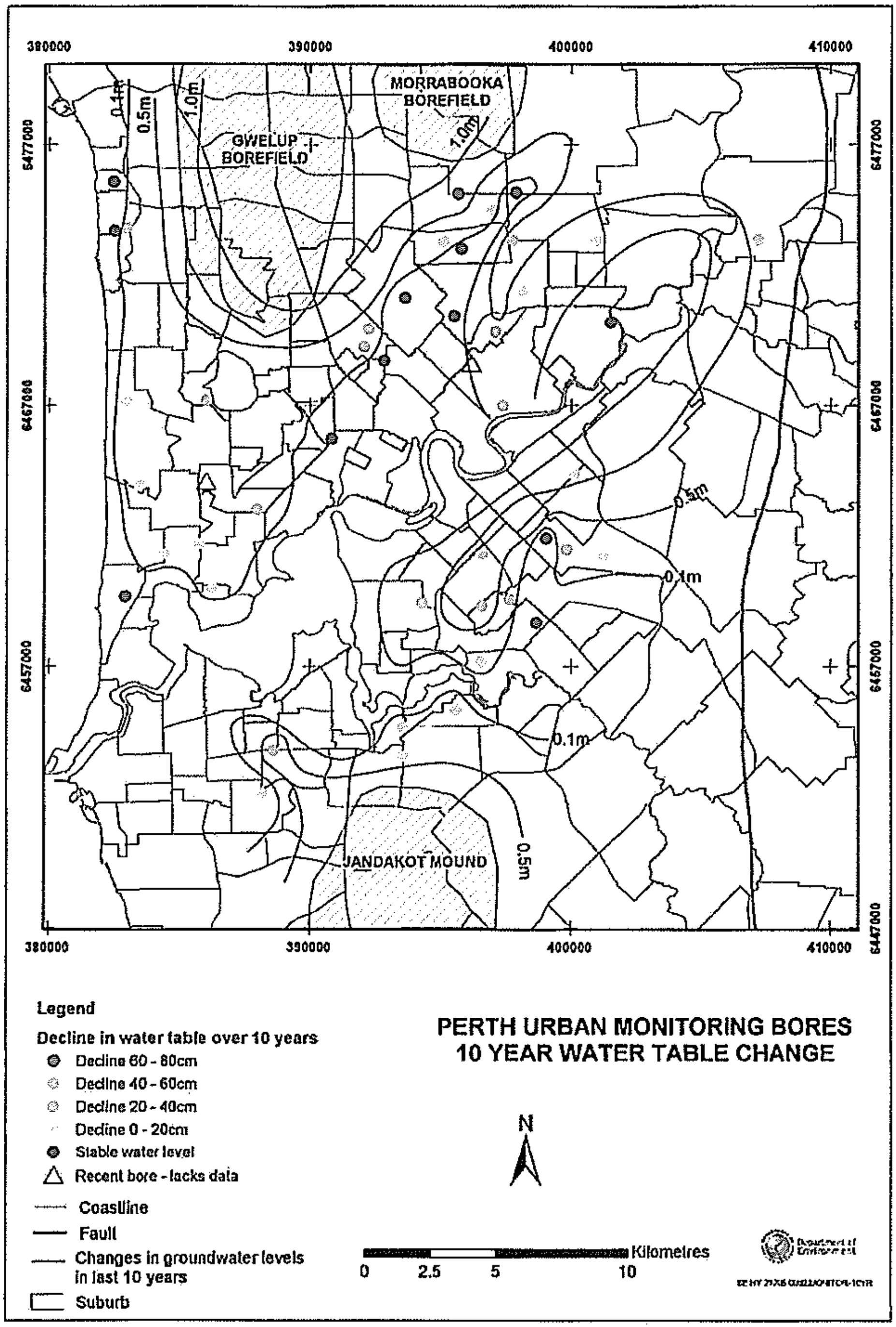


Figure 11. Changes in Water Level in the Superficial Aquifer in last 10 years

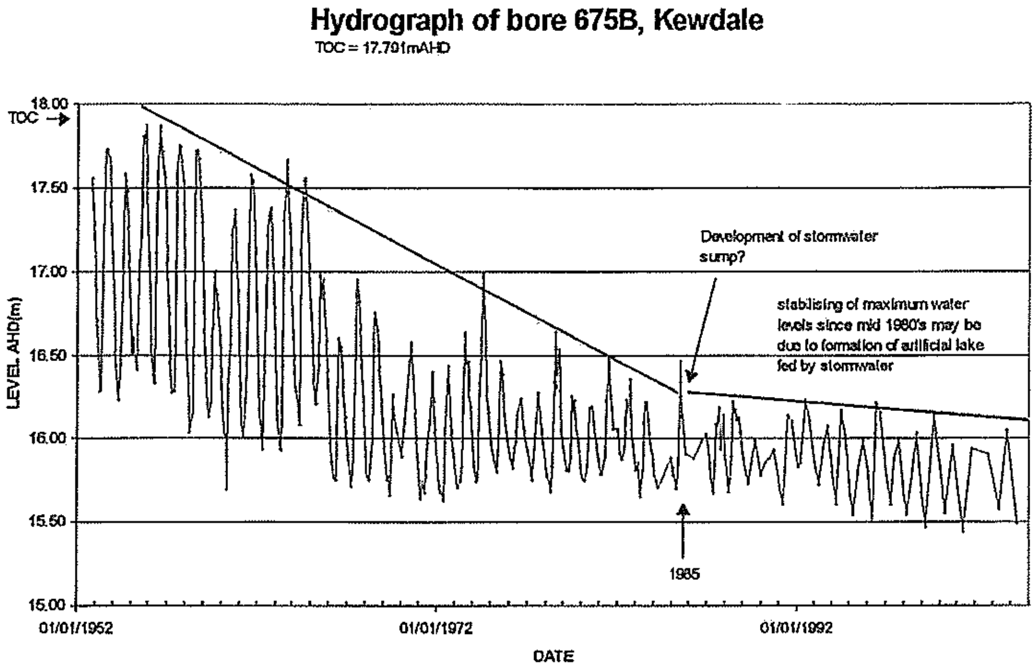


Figure 12. Hydrograph of Bore 675B at Kewdale, showing impact of artificial lake fed by stormwater.

3 Conclusions

There are forty-six operating monitor bores in the superficial aquifer that can be used to monitor groundwater levels in the Perth urban area covered by this study.

Watertables in the Perth urban area have declined steadily but only slightly in about two thirds of urban suburbs over the last 30 years. The average rate of decline in these suburbs is about 2.5cm per year.

The greatest declines have been in the central suburbs and in suburbs where main open drains have been commissioned.

The main causes of declining watertable are result of declining rainfall and implementation of open drains.

About one third of suburbs have had stable water levels over the last 30 years. Notable exceptions are at Kardinya and Winthrop where groundwater levels have risen over 25 years overall, but have since declined since 1991.

Watertable changes at Lake Claremont (which is in hydraulic connection with the lake water) over the last 120 years are more likely to be as a result of climate variability than to urban impacts.

There has been a de-coupling of the relationship between rainfall (expressed by CDFM of rainfall) and watertable level starting in the 1980's. The cause cannot be explained by leakage to the underlying confined aquifers. Installation of open drains may account for controls on water levels in several areas.

The network of monitoring bores does not show any general decline in watertable levels that can be attributed to garden bores.

There are reports from residents in some suburbs that water levels in garden bores are declining more rapidly than in monitoring bores. This would indicate that the current bore network does not reflect local depressions in the watertable.

Local urban effects, such as the siting of stormwater sumps, de-commissioning of septic tanks and changes in land use are implicated on an individual and local basis. An example is in the Kardinya – Winthrop area, where the clearing of pines may have contributed to a rise in water levels of about 0.5m over the rise that would have been caused by climate alone.

Monitoring bores in some areas do not accurately represent watertables due to conditioning influences. Three monitor bores are located close to irrigation pumping bores for parks (2025A, 1606, and 637) and five others (142, 144B, GD7, 675B and 135A) are close to drains or holding ponds, which regulate the upward levels of the watertable.

There is a lack of monitoring bores in the eastern suburbs, form High Wycombe through to Armadale. These are relatively new and rapidly developing fringe suburbs where the aquifers are relatively poorly understood. Gaps in other parts of the urban area are in the Victoria Park, East Fremantle and Scarborough-Wembley Downs areas (Figure 13).

There are relatively newly developed urban areas, particularly in the eastern suburbs where there are no monitoring bores.

4 Recommendations

The frequency of readings for monitoring bores has been decreased progressively over time. Water level readings are now commonly taken quarterly or every six months. The timings of maximum and minimum peaks vary slightly between bores depending on the depth to water. Defining monitoring schedules to suit each individual bore is probably not practical, hence a schedule of monthly readings from (inclusive) March to June and August to November is recommended in order to define peaks and troughs.

New monitoring bores should be established in under-represented areas, particularly between High Wycombe and Armadale, East Fremantle and the Scarborough-Wembley Downs areas (Figure 13).

The cost to drill the 28 recommended new bores would be approximately $110,000, assuming an average depth of 30 metres each.

City councils and shires should be encouraged to report water levels of their own monitor bores.

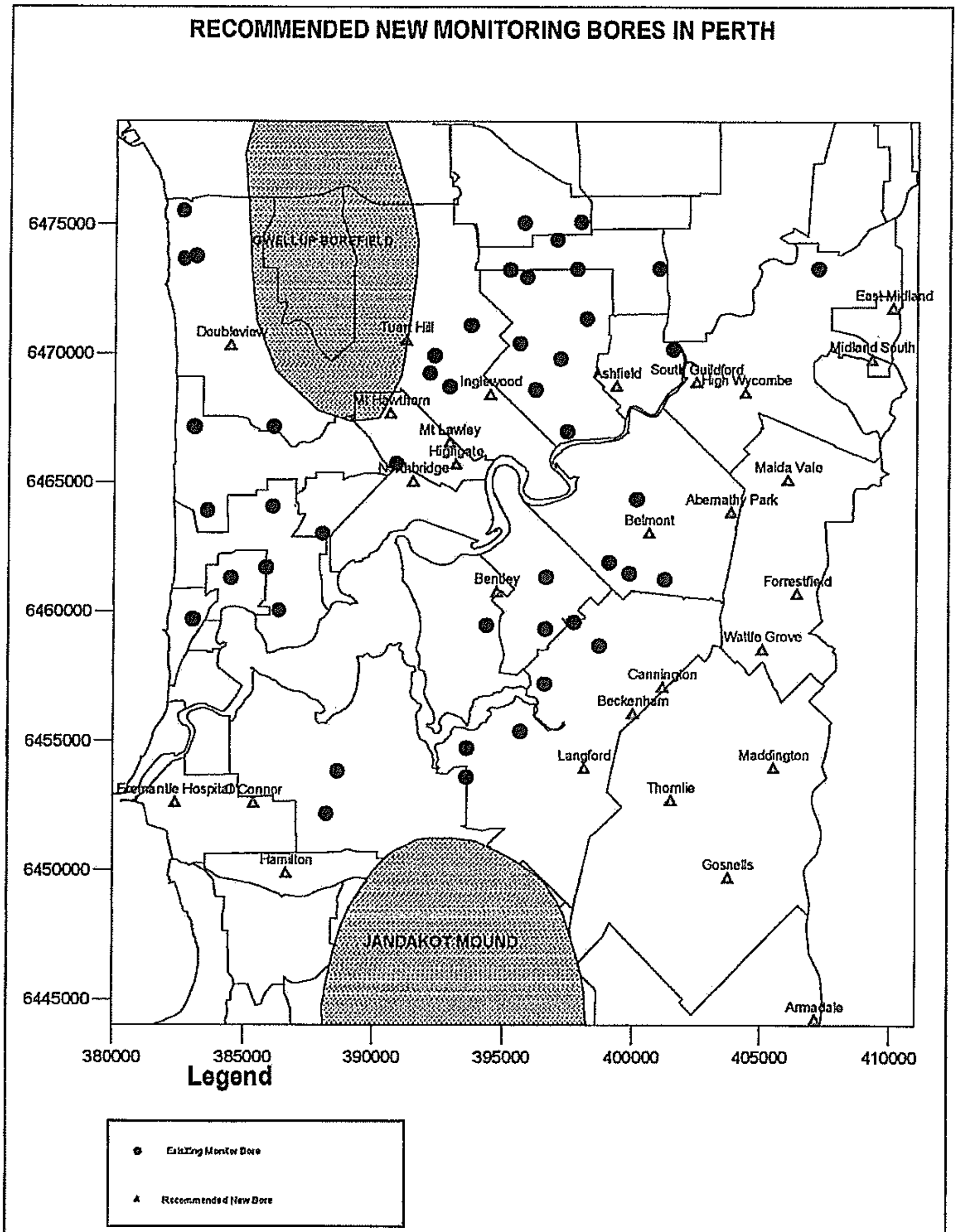


Figure 13. Recommended new bores for the Perth Urban area.

5. References

Appleyard, S.J., 1995 The impact of urban development on recharge and groundwater quality in a coastal aquifer near Perth, Western Australia. Hydrogeology Journal, v.3, 2.

Appleyard, S.J, Davidson, W.A., and Commander, D.P., 1999 The effects of urban development on the utilisation of groundwater resources in Perth, Western Australia. *In*: Groundwater in the Urban Environment, ed. J.Chilton, Internat.Assoc.of Hydrogeologists.

Appleyard, S.J., 2001 The Environmental Setting – Watertable Levels and Changes Over Time. *In*: Land Development in Areas of High Watertable, Institute of Engineers, Australia.

Aquaterra 2001, Perth's Groundwater Demand, internal report prepared for the WRC by Aquaterra Consulting.

Evans, G.A. and Sherlock, N.V., 1950, Butlers Swamp, Claremont. W.A. Naturalist, vol2. P152-160.

McFarlane, D.J., 1984, The Effect of Urbanisation on groundwater quantity and quality in Perth, Western Australia. PhD thesis, Univ. Western Australia.

Metropolitan Water Authority, 1985, Domestic Water Use in Perth, Western Australia, chapter 7.

Playford, P.E., 1998, Voyage of Discovery of Terra Australis by Willem de Vlamingh 1696-1697. Western Australian Museum, Perth

Rich, J.F., 2004, Integrated mass, solute isotopic and thermal balances of a coastal wetland. Phd thesis, Murdoch University, Western Australia.

Savini, J., and Kammerer, J.C., 1961, Urban growth and water regime. U.S. Geol.Survey Water Supply Paper 1591-A

Yesertener C. 2002, Declining water levels in the Gnanagara and Jandakot Mounds (Stage 1), WRC report HR199

Publication feedback form

The Water and Rivers Commission welcomes feedback to help us to improve the quality and effectiveness of our publications. Your assistance in completing this form would be greatly appreciated.

Please consider each question carefully and rate them on a 1 to 5 scale, where 1 is poor and 5 is excellent (please circle the appropriate number).

How did you rate the quality of information?

1 2 3 4 5

How did you rate the design and presentation of this publication?

1 2 3 4 5

How can it be improved?

1 2 3 4 5

....

How effective did you find the tables and figures in communicating the data?

1 2 3 4 5

How can they be improved?

....

....

....

How did you rate this publication overall?

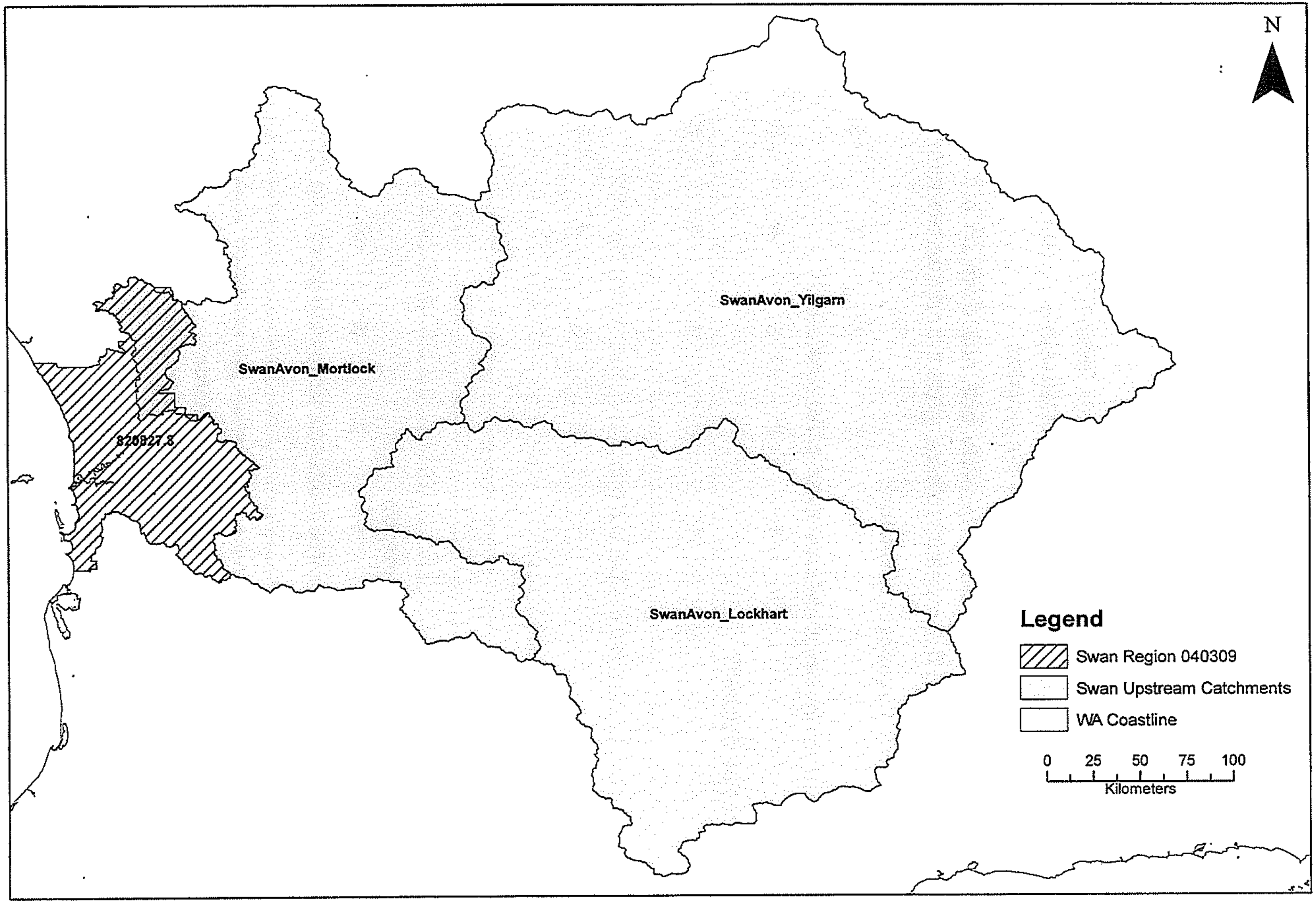
1 2 3 4 5

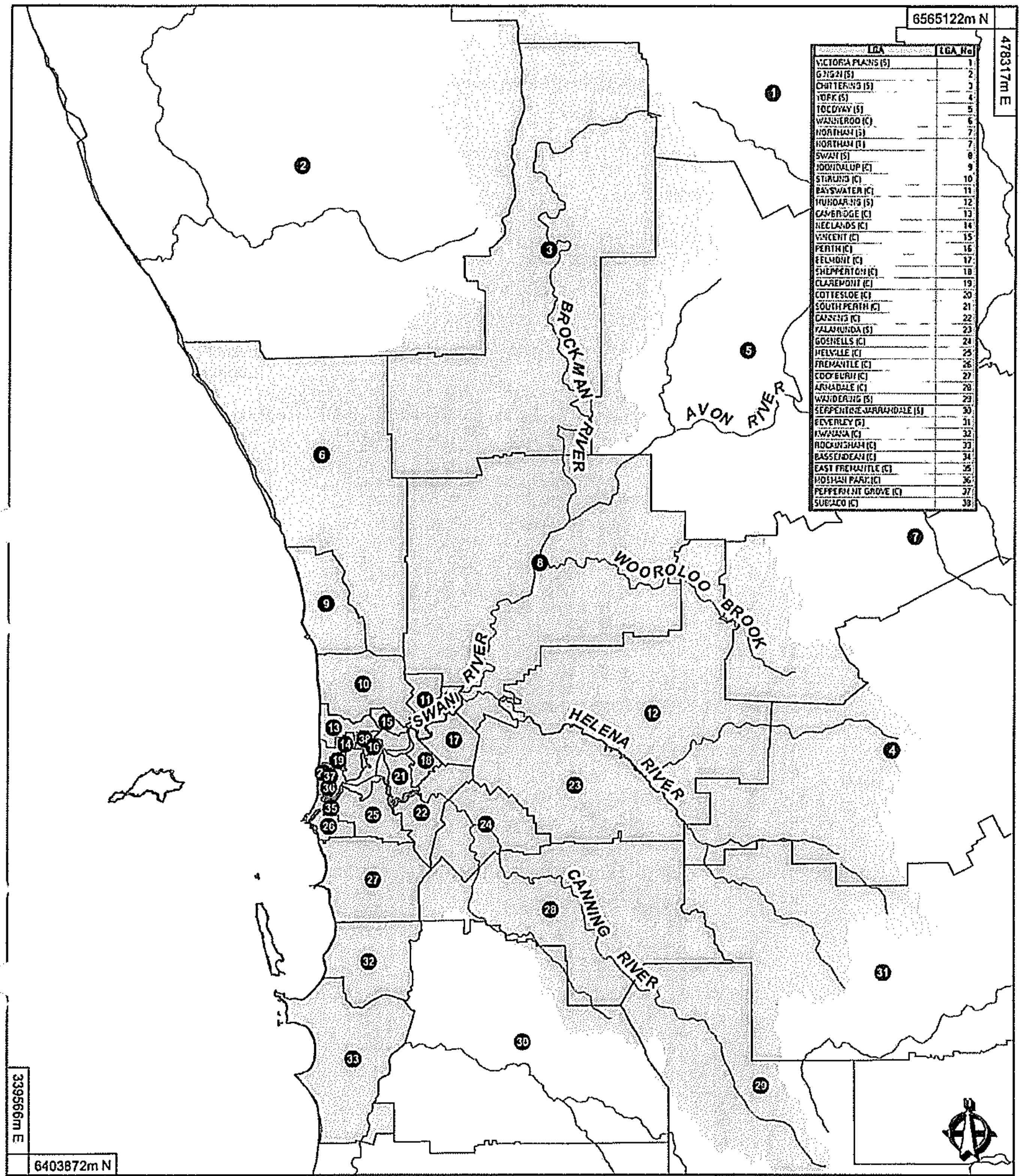
If you would like to see this publication in other formats, please specify. (Eg. CD)

....

Please cut along the dotted line on the left and return your completed response to:

Publications Coordinator
Water and Rivers Commission
Level 2, Hyatt Centre
3 Plain Street
East Perth WA 6004
Fax: (08) 9278 0639


N
SwanAvon_Yilgarn
SwanAvon_Mortlock
SwanAvon_Lockhart
820827.8
Legend
Swan Region 040309
Swan Upstream Catchments
WA Coastline
0 25 50 75 100
Kilometers



LGA	LGA_No
VICTORIA PLAINS (S)	1
GINGIN (S)	2
CHITTERING (S)	3
YORK (S)	4
TOODYAY (S)	5
WANNEROO (C)	6
NORTHAM (S)	7
NORTHAM (T)	7
SWAN (S)	8
JOONDALUP (C)	9
STIRLING (C)	10
BAYSWATER (C)	11
MUNDARING (S)	12
CAMBRIDGE (C)	13
NEDLANDS (C)	14
VINCENT (C)	15
PERTH (C)	16
BELMONT (C)	17
SHEPPERTON (C)	18
CLAREMONT (C)	19
COTTESLOE (C)	20
SOUTH PERTH (C)	21
CANNING (C)	22
KALAMUNDA (S)	23
GOSNELLS (C)	24
MELVILLE (C)	25
FREMANTLE (C)	26
COCKBURN (C)	27
ARMADALE (C)	28
WANDERING (S)	29
SERPENTINE-JARRAHDALE (S)	30
BEVERLEY (S)	31
KWINANA (C)	32
ROCKINGHAM (C)	33
BASSENDEAN (C)	34
EAST FREMANTLE (C)	35
MOSMAN PARK (C)	36
PEPPERMINT GROVE (C)	37
SUBIACO (C)	38

LEGEND

- Major Rivers
- Local Government Authorities
- Swan Region

NOTE THAT POSITIONAL ERRORS CAN BE > 5M IN SOME AREAS

SCALE

5 0 5 10 15 20 25 km

1:750000 at A4

LOCALITY MAP

Metropolitan Area

COPYRIGHT

CREATED BY	CHECKED	APPROVED
MD		

HORIZONTAL DATUM: GDA 94 PROJECTION: MGA Zone 50

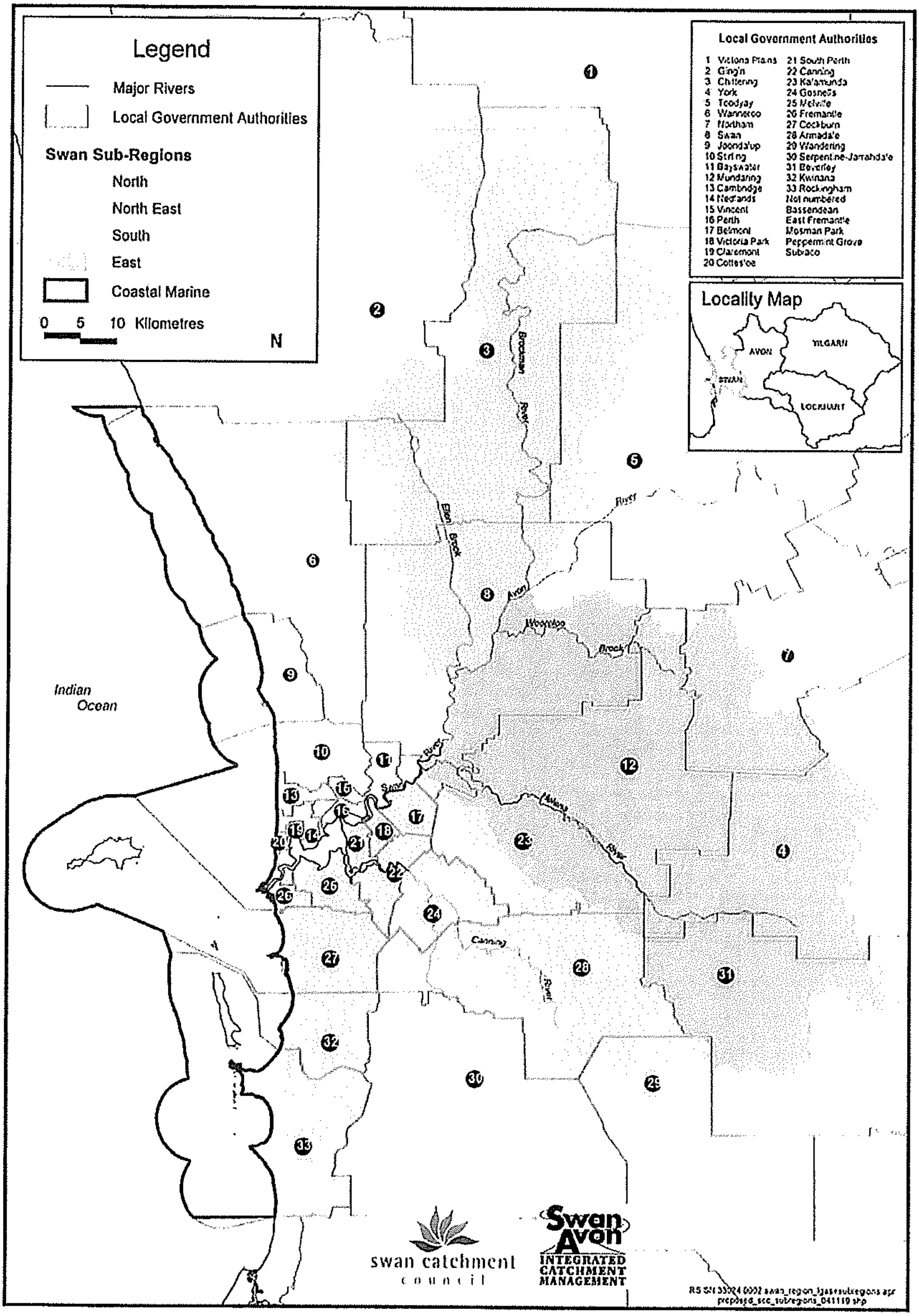
HEIGHT DATUM: N/A METADATA RECORDED: 100%

DATE	FILE LOCATION
12.09.06	N:\61\18096\GIS\MXD\6118096-G1.MXD

REVISION	DRAWING NO
0	6118096-G1

**SWAN CATCHMENT COUNCIL
SUPERFICIAL AQUIFER
TASK A: DATA REVIEW**

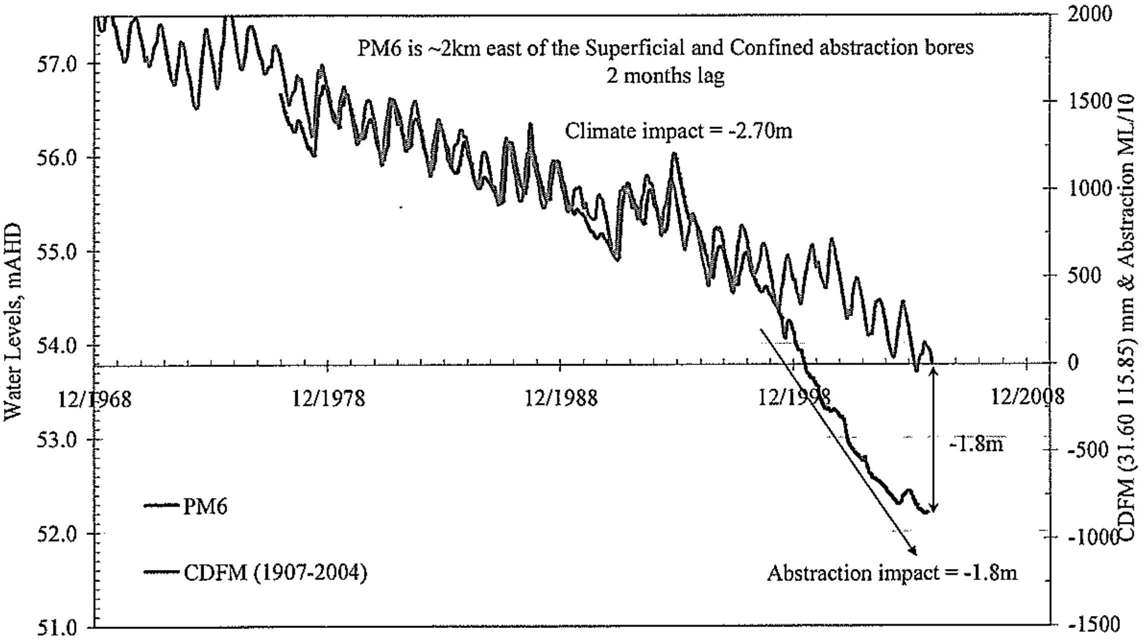
**FIGURE 1
Swan Catchment Council Boundary**



The Swan Region including Local Government boundaries.

Department of Water
Government of Western Australia

Assessment of the declining groundwater levels in the Gnangara Groundwater Mound



Cumulative effect of the abstraction on monitoring bore PM6

Department of Water
Hydrogeological Record Series
Report HG14
January 2008

Department of Water
168 St Georges Terrace
Perth Western Australia 6000
<www.water.wa.gov.au>
Telephone +61 8 6364 7600
Facsimile +61 8 6364 7601

January 2008

ISSN 1329-542X (print)
ISSN 1834-9188 (PDF)
ISBN 978-1-921468-35-3 (print)
ISBN 978-1-921468-36-0 (PDF)

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.

Contents

Appendices

Figures

Tables

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.

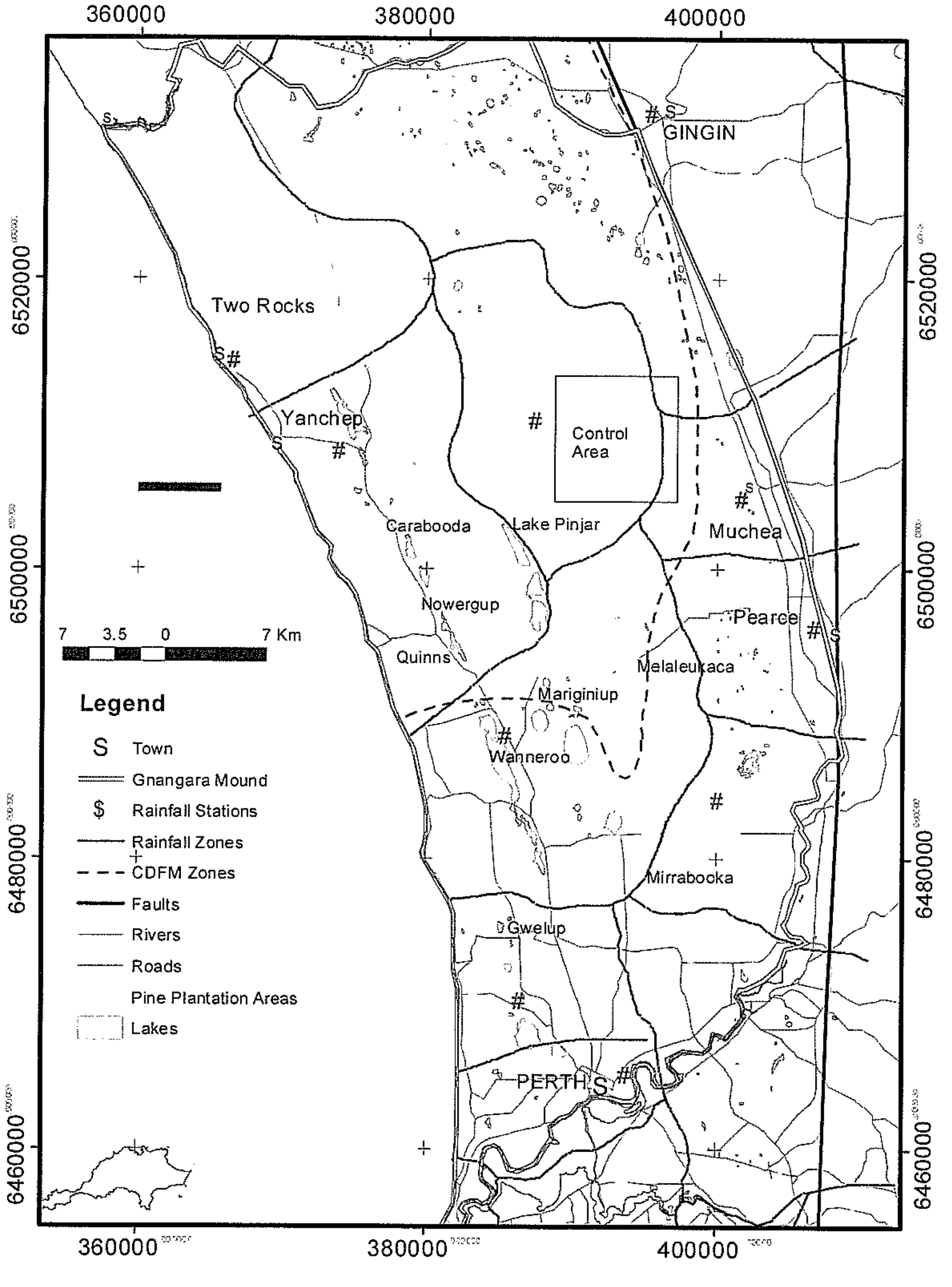


Figure 1 Gnangara Groundwater Mound

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.

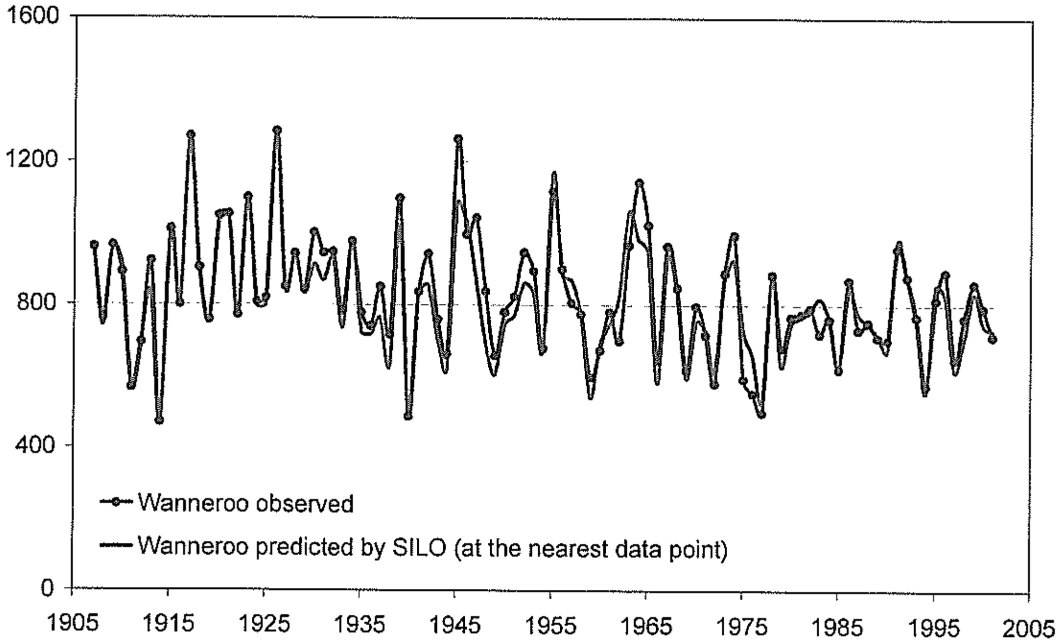


Figure 2 Comparison between Observed Rainfall and SILO Data

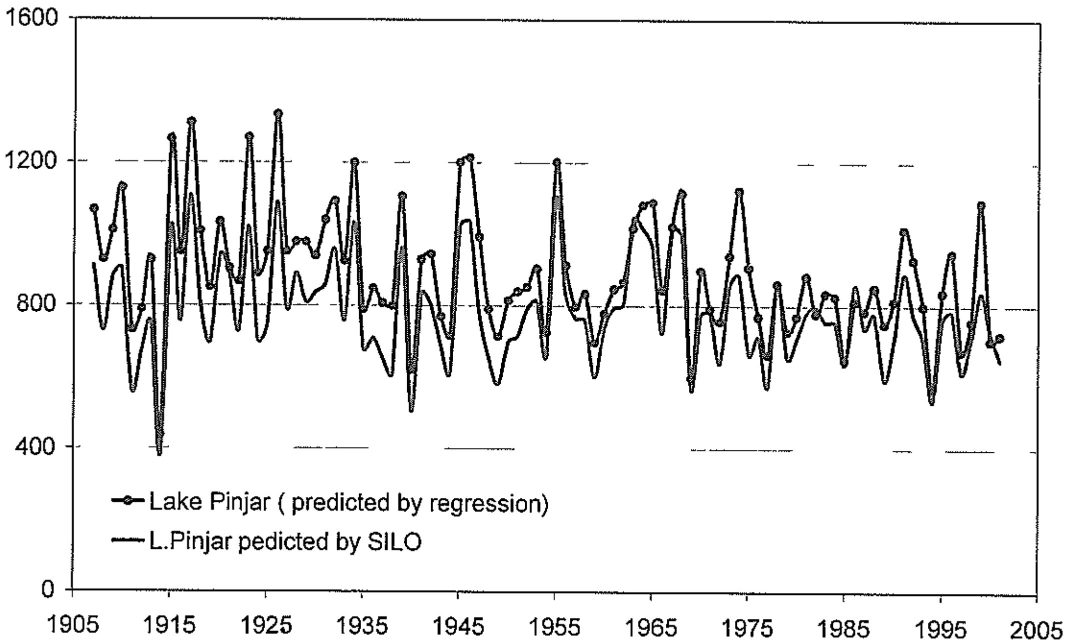


Figure 3 Comparison between regression analysis and SILO in predicting missing rainfall data when observed data is limited

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.

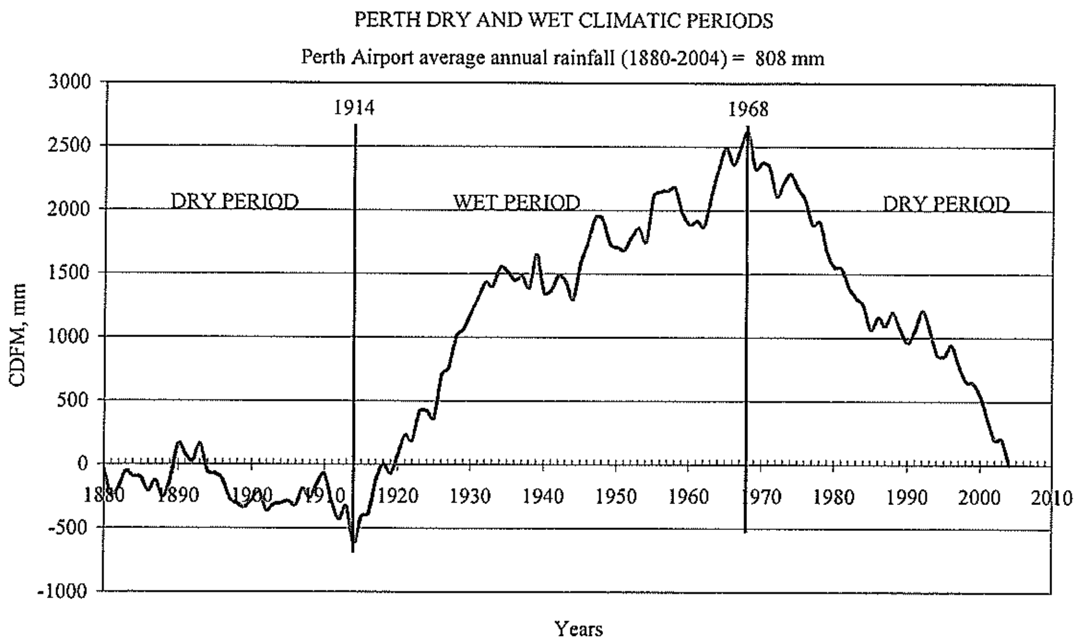


Figure 4 Perth dry and wet climatic periods shown by cumulative deviation from mean (CDFM) rainfall

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.

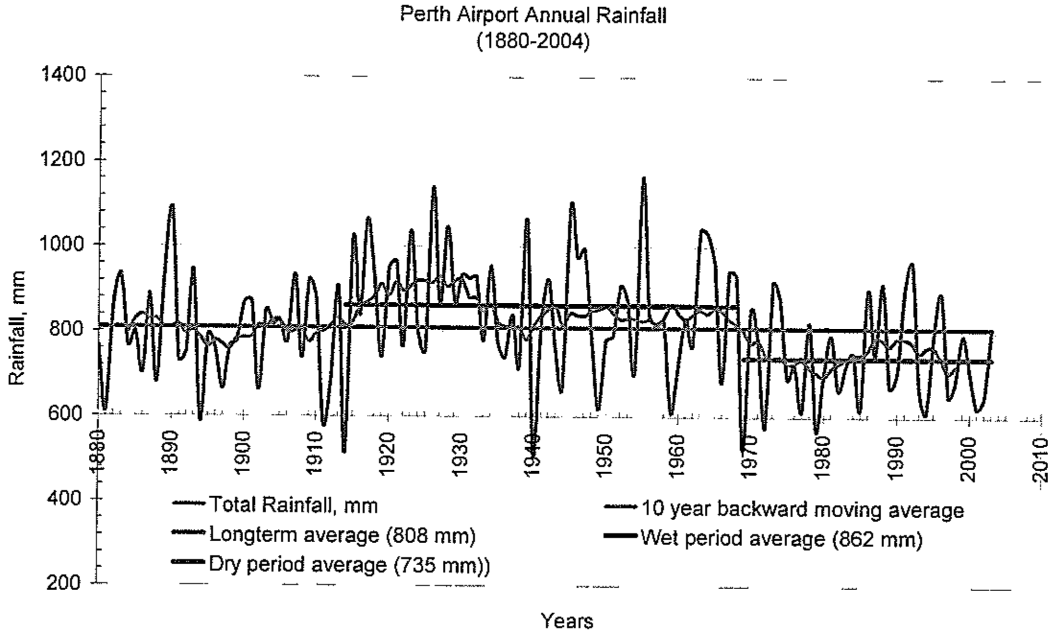


Figure 5 Perth Airport (9021) long term, wet period and dry period mean precipitation, mm

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.

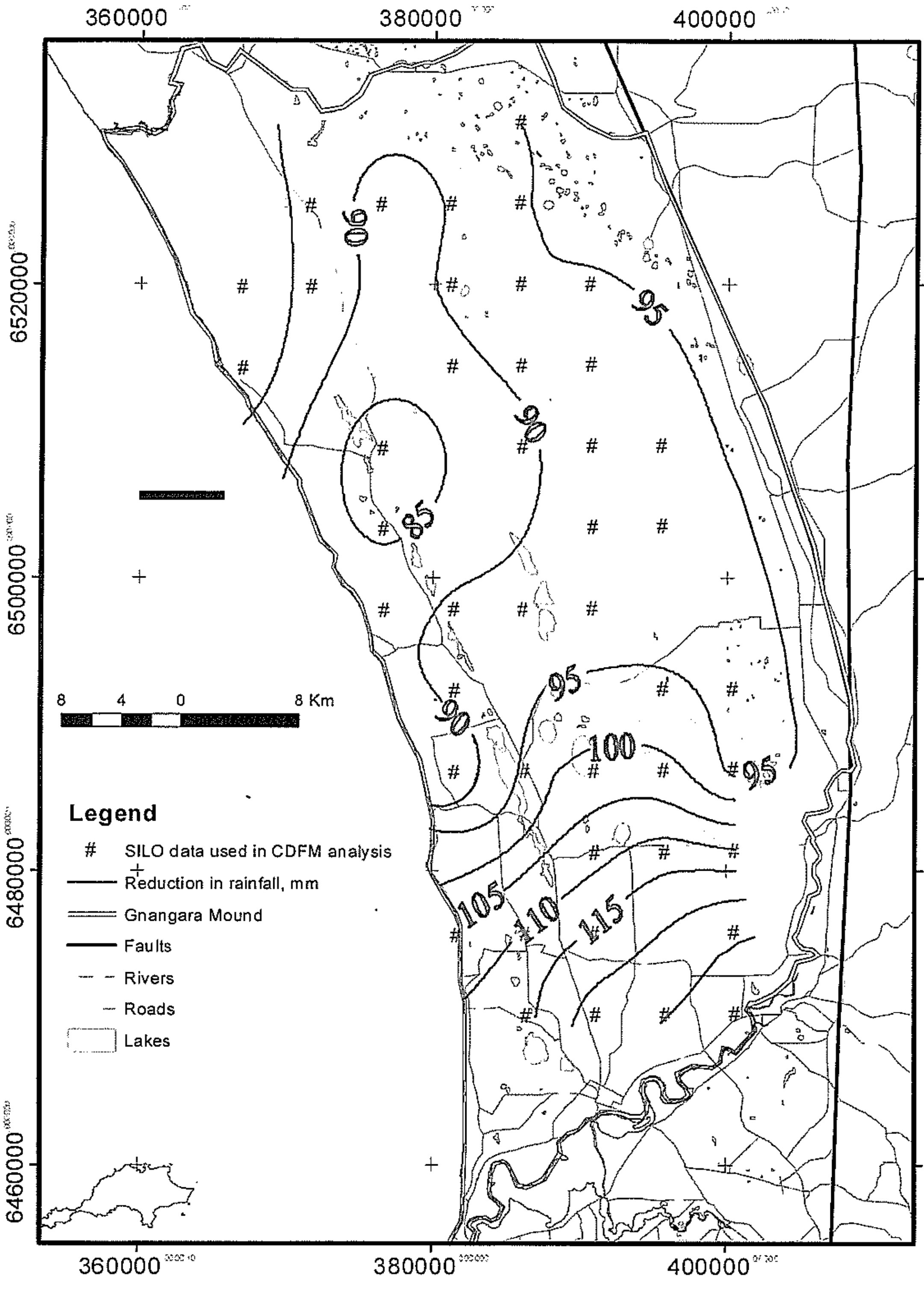


Figure 6 Distribution of the reduction in rainfall (mm) within the Gnangara Groundwater Mound

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.

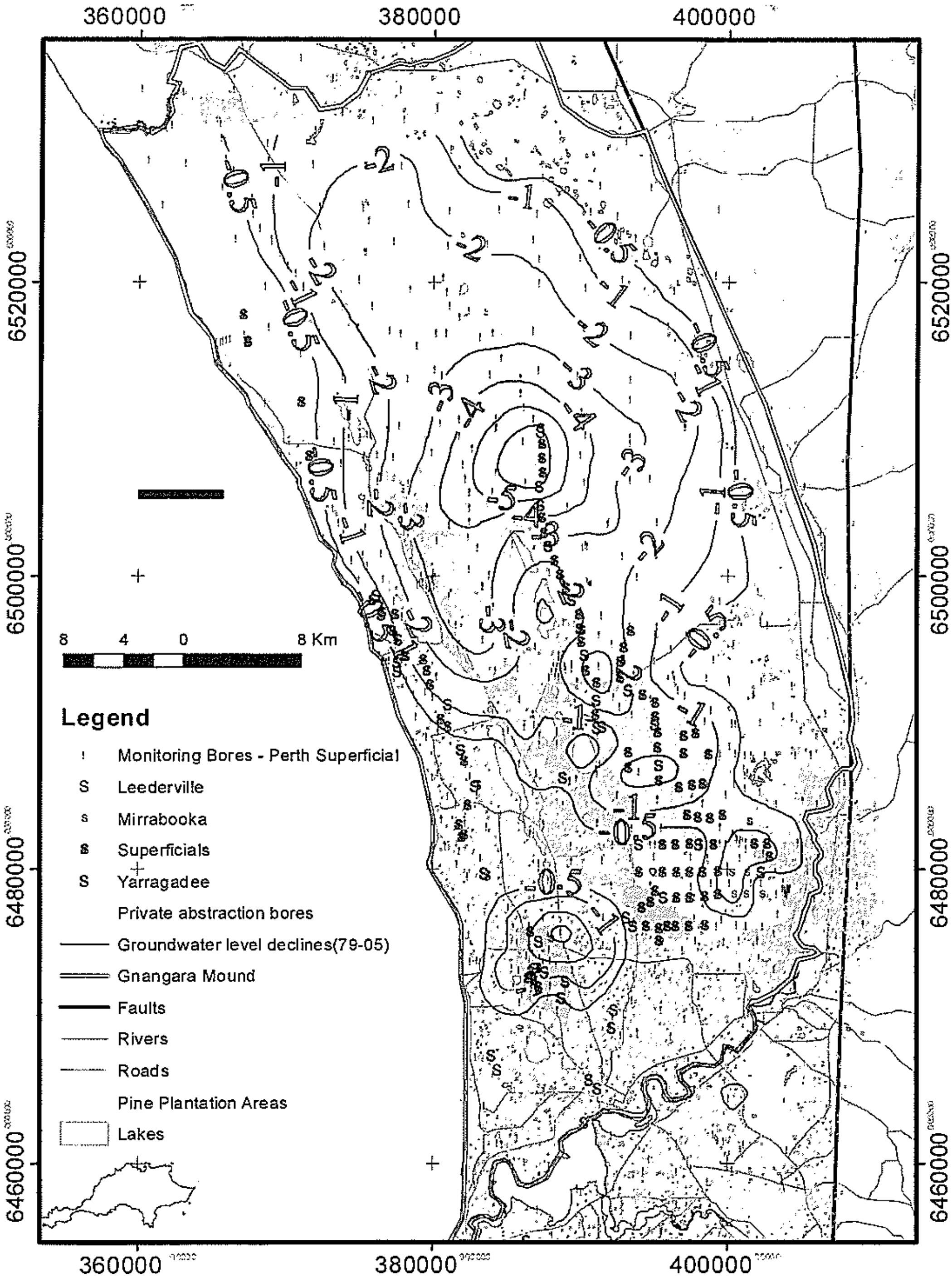


Figure 7 Groundwater level changes between 1979 and 2005 across the Gnangara Groundwater Mound

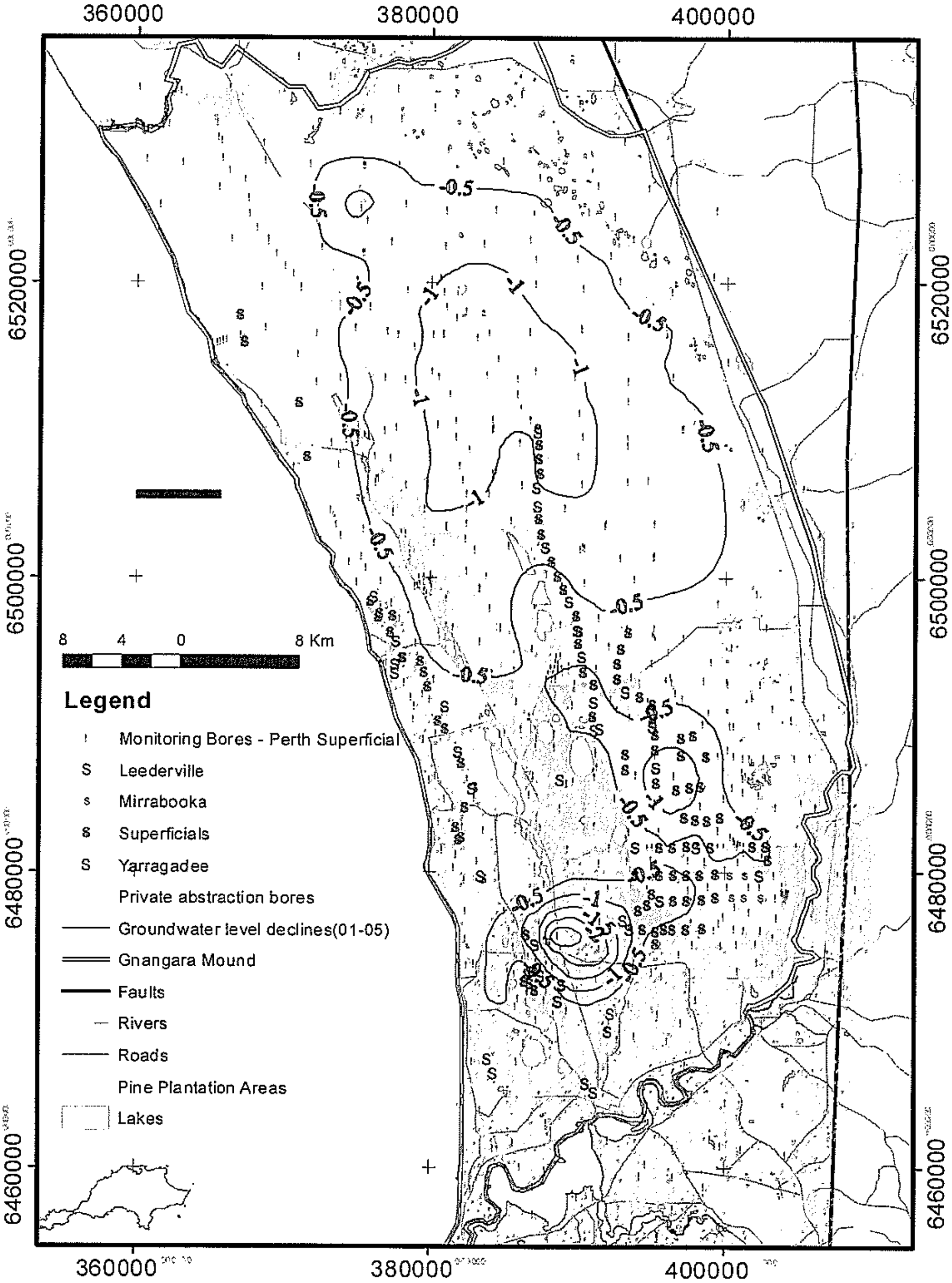


Figure 8 Groundwater level changes between 2001 and 2005 across the Gnangara Groundwater Mound

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.

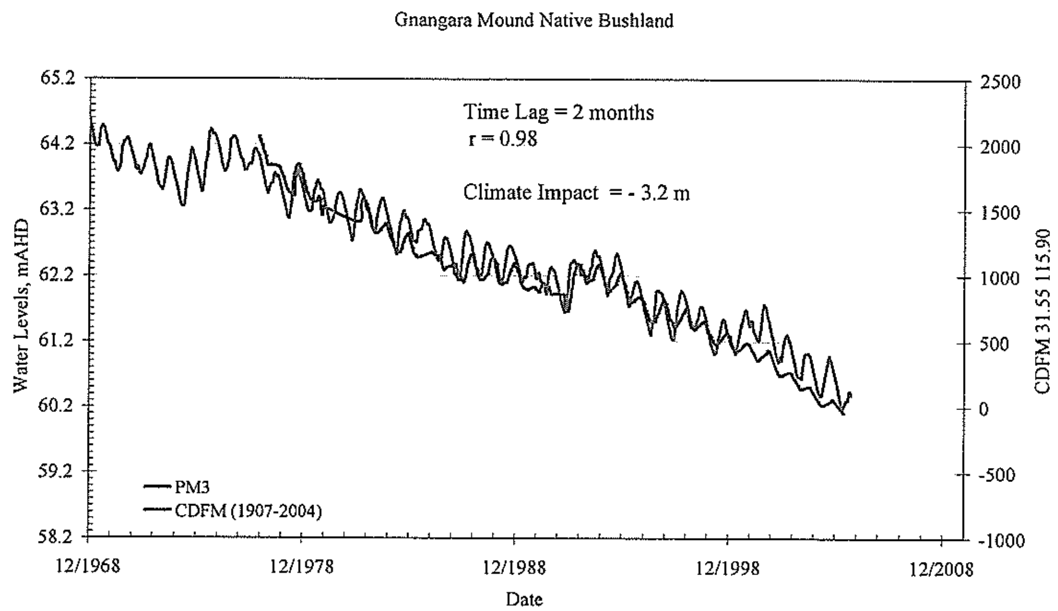


Figure 9 PM3 groundwater hydrograph evaluation using the CDFM graph of SILO rainfall data next to the bore

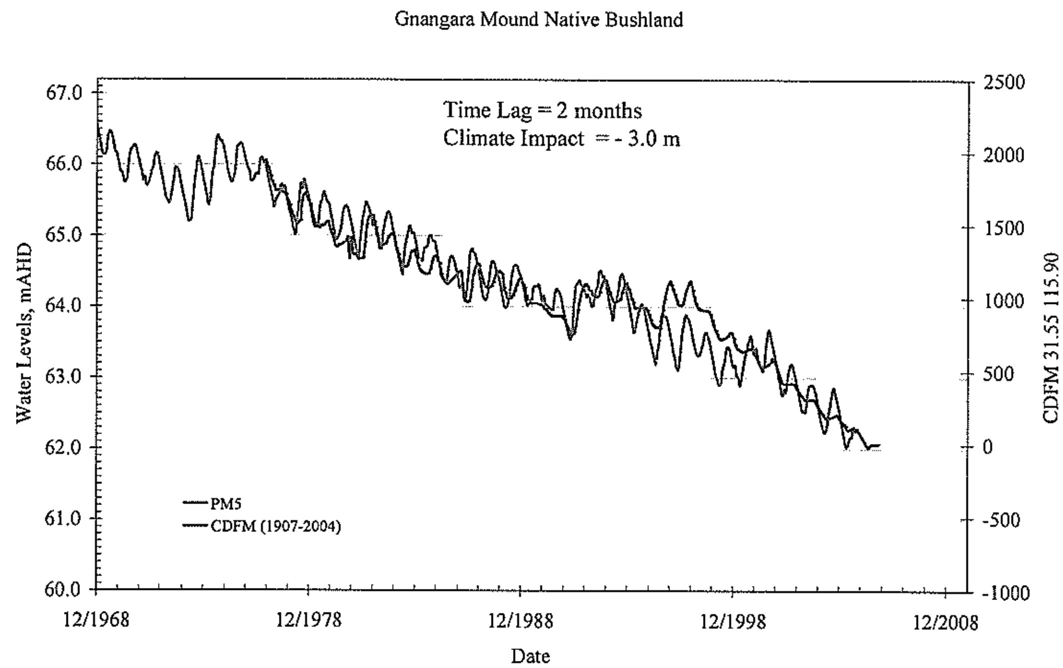


Figure 10 PM5 groundwater hydrograph evaluation using the CDFM graph of SILO rainfall data next to the bore

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.

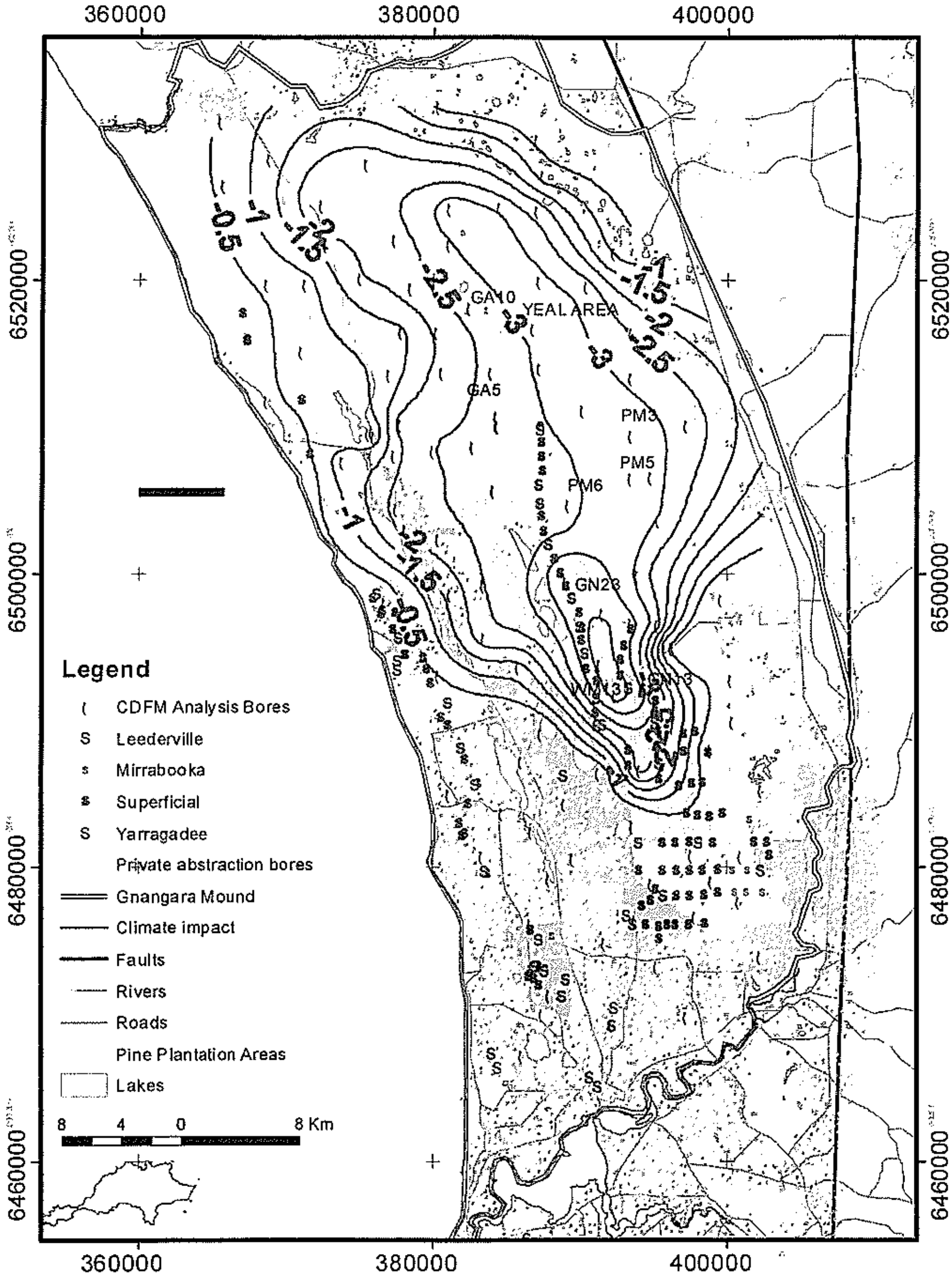


Figure 11 Predicted groundwater level decline due to reduced rainfall (1979–2005)

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.

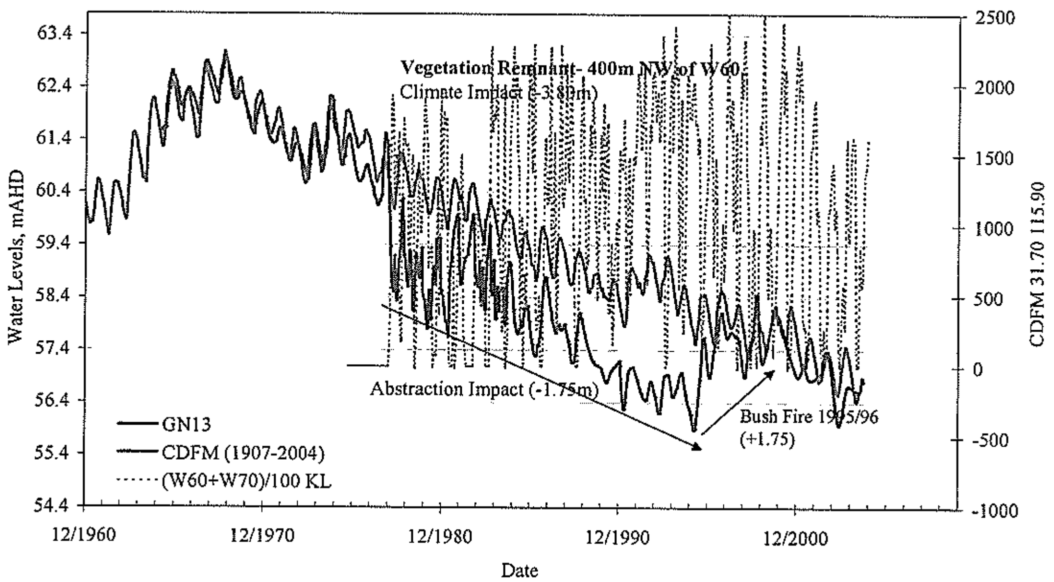


Figure 12 The impact of groundwater abstraction on groundwater levels; GN13

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).

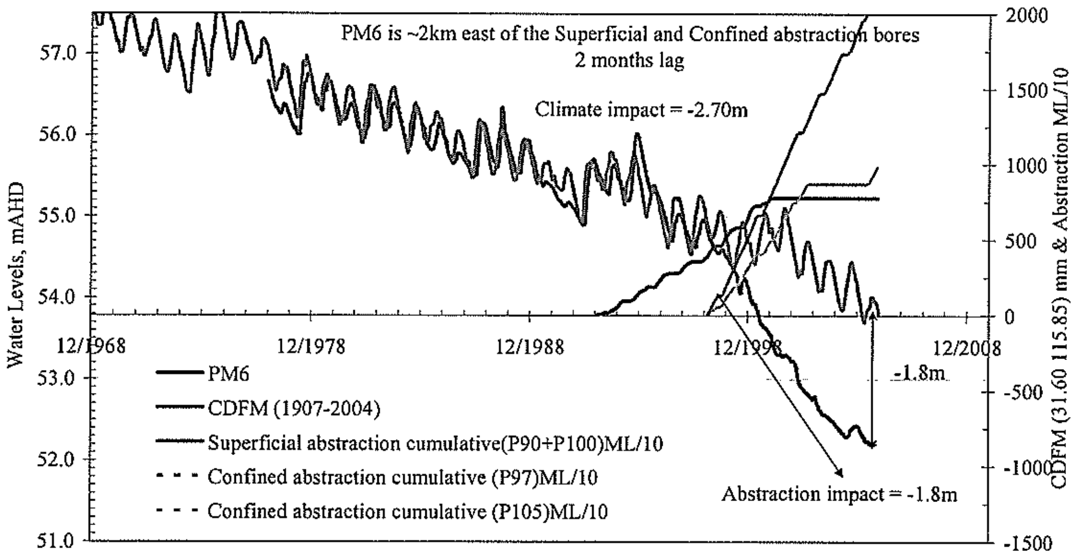


Figure 13 Cumulative effect of the abstraction on PM6

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).

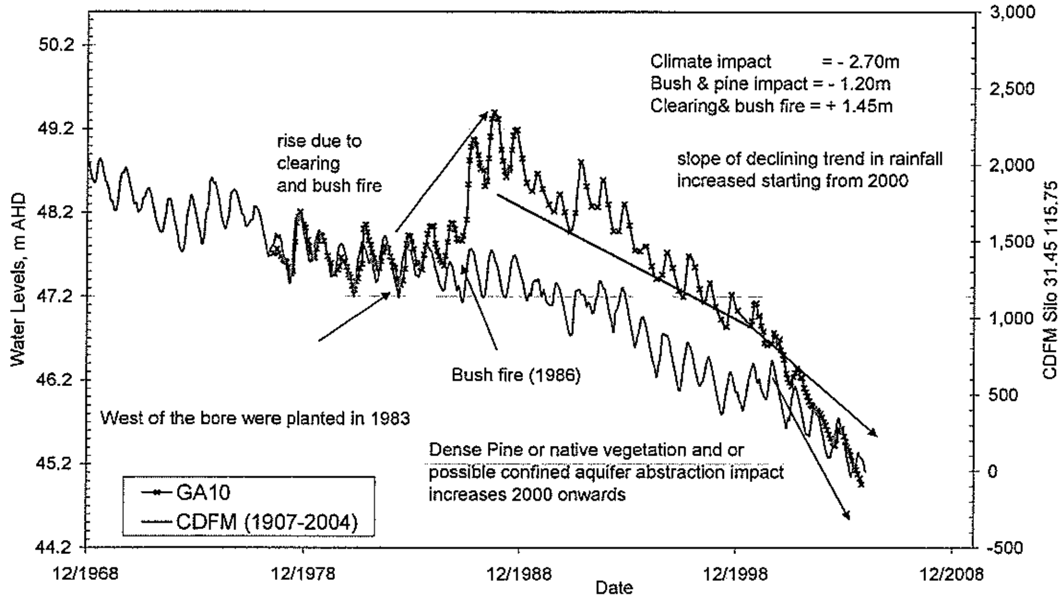


Figure 14 Comparison of the groundwater fluctuations before and after pine planting

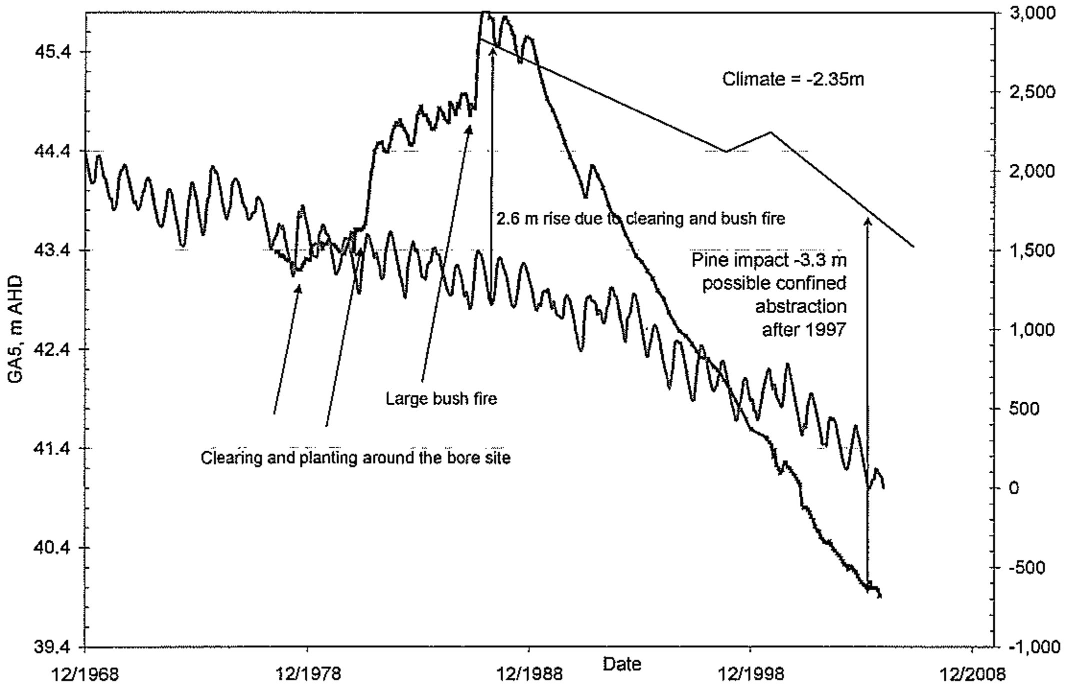


Figure 15 Groundwater level rise resulting from clearing and bush fire, followed by decline resulting from reduced rainfall and dense pine trees

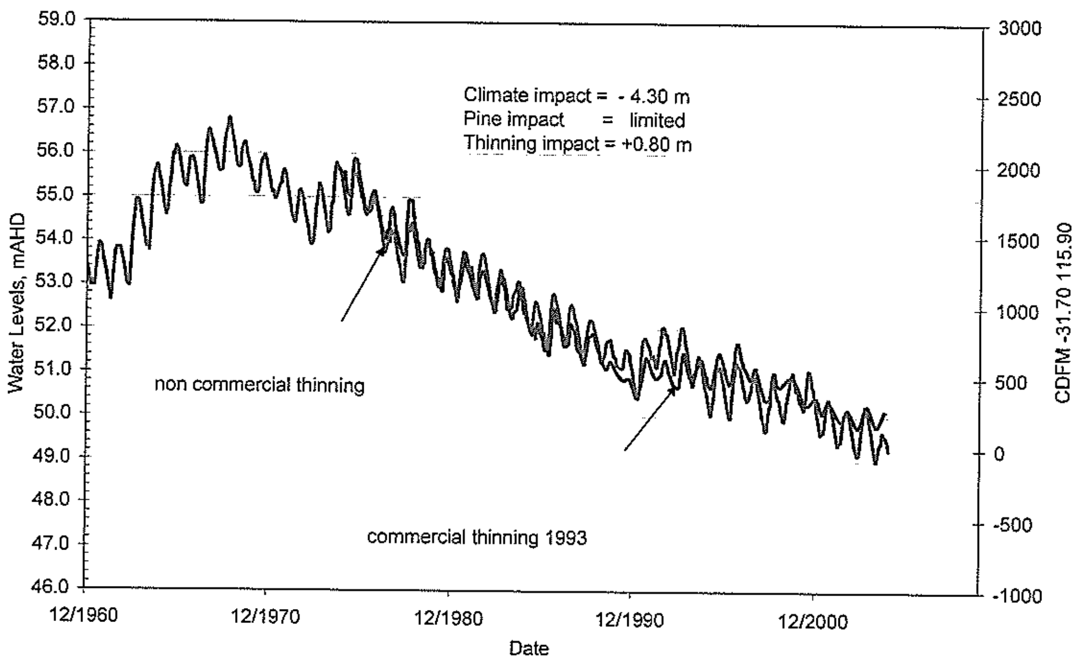


Figure 16 Impact of thinning on groundwater levels in the vicinity of monitoring bore WM13

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.

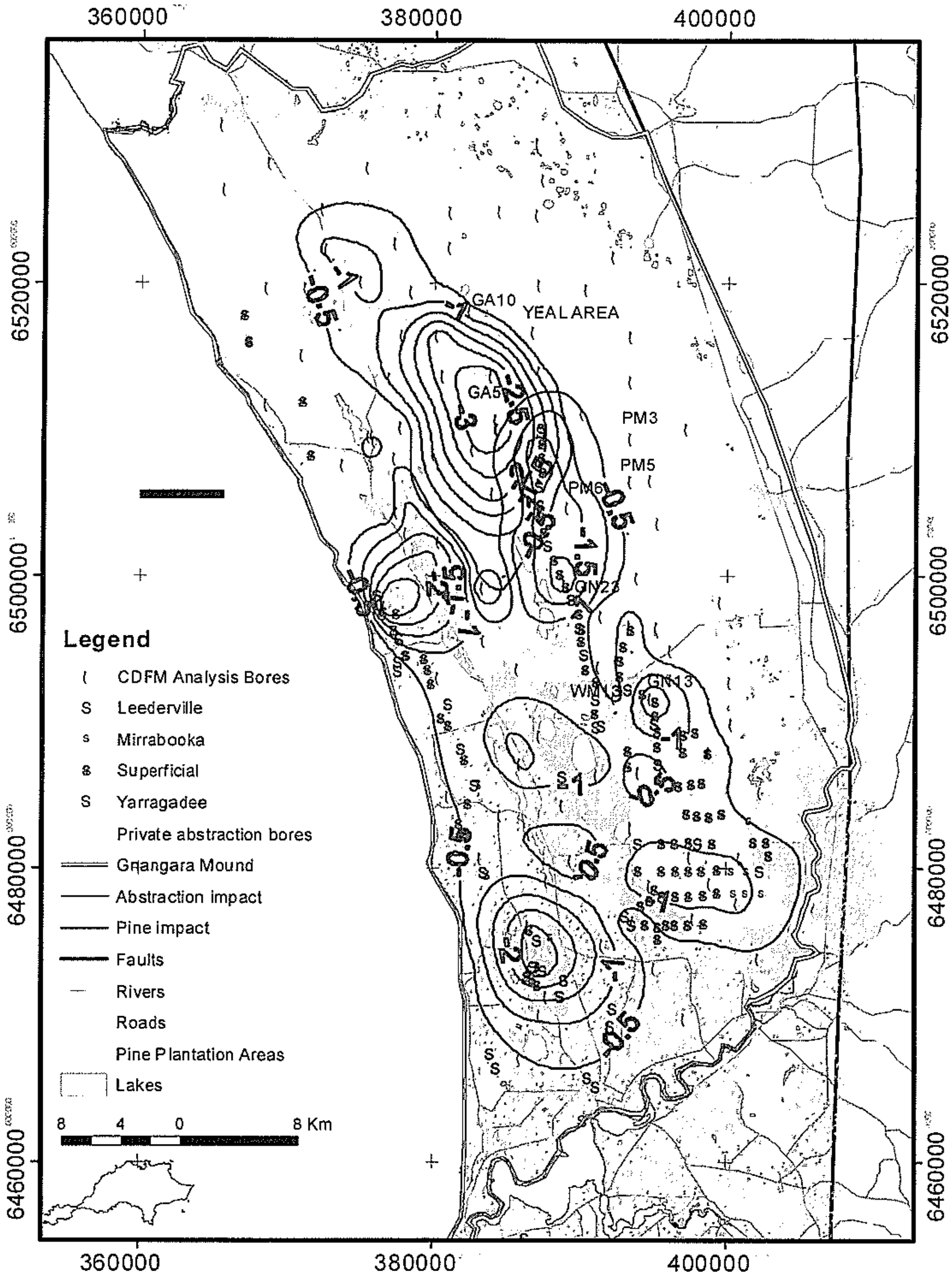


Figure 17 Predicted impact of abstraction and pine trees in the Gnangara Groundwater Mound

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:

$$Y = k_0 + k_1 * CDFM_{t-L} + k_2 * t \qquad (1)$$

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_0, k_1 and k_2 are the parameters to be estimated by regression analysis. Parameter k_0 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:

$$Y = k_0 + k_1 * CDFM_{t-L} + k_2 * t + k_3 * D_t + k_4 * S_t \qquad (2)$$

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.

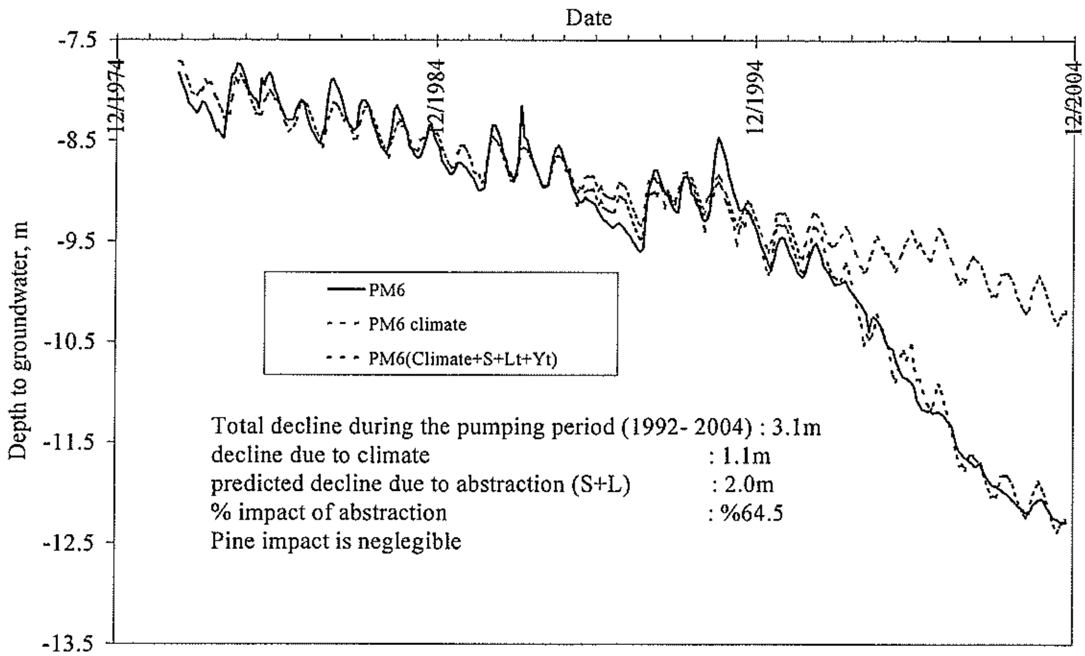


Figure 18 Quantitative determinations of the effects of abstraction on groundwater levels at PM6 using multiple regression analysis.

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.

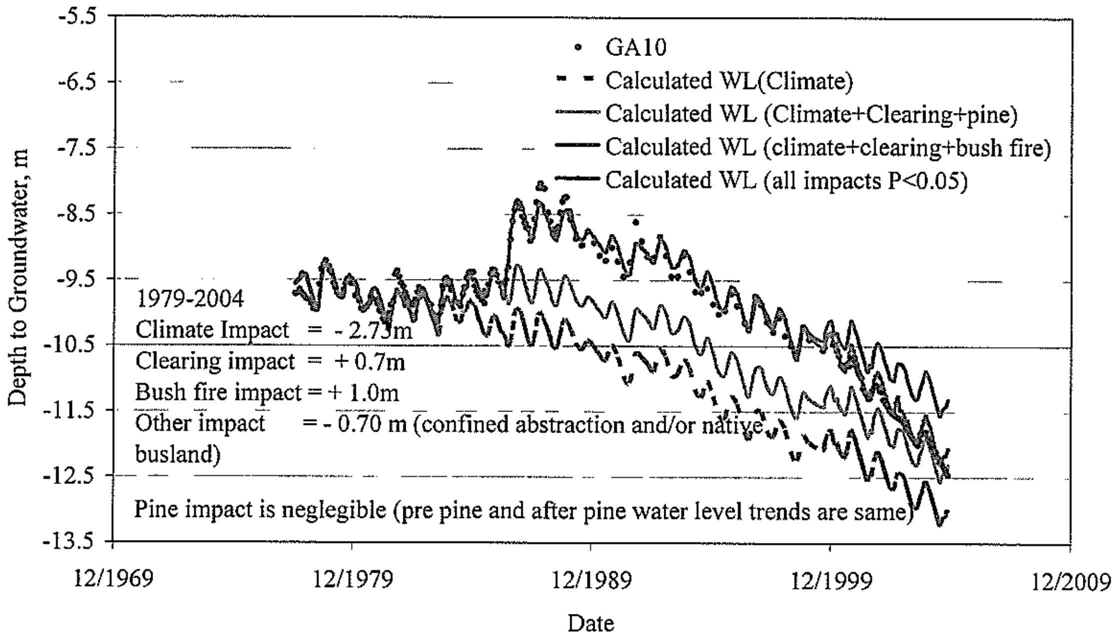


Figure 19 Quantitative determination of the effects of climate, clearing and bush fire on groundwater levels at GA10.

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.

8 References

Boehmer WK, 1998, Re-Assessment of sustainable abstraction from groundwater basins of different size in semi-arid and arid areas, International Groundwater Conference Proceedings, Groundwater: Sustainable Solutions, University of Melbourne, Melbourne, Australia

Davidson WA, 1995, Hydrogeology and groundwater resources of the Perth region, Western Australia: Western Australia Geological Survey, Bulletin 142

Eakin TA, 1964, Groundwater appraisal of Coyote spring and Kane spring valleys and Muddy River springs area, Lincoln and Clark counties, Nevada, Nevada Geological Survey, Groundwater resources Reconnaissance Series Report 25

Ferdowsian R and McCarron C, 2001, Hartt Manual, Hydrograph Analysis: Rainfall and Time Trends, Department of Agriculture of Western Australia and Lote-Tree Software

Temperley BN, 1980, Groundwater in the half dolomitic Six Mile Spruit Basin, South of Pretoria, Proc. Groundwater 80 Conference of the Groundwater Division of the Geological Society of South Africa

WRC, 2001,Environmental management of groundwater abstraction on the Gnangara Groundwater Mound, Triennial report to the Environmental Protection Authority, July 1997 to June 2000, Western Australia, Water and Rivers Commission, Policy and Planning Division, Allocation Branch

Yesertener C, 1986, Karst hydrogeological investigation of the Lower Dalaman River Basin (NW of Fethiye)", MEng Thesis, Hacettepe University, Ankara, Turkey

Yesertener C, 1995, Hydrogeological investigation of the Upper Ermenek River Basin", PhD Thesis, Hacettepe Uni., Ankara, Turkey

Yesertener, C., 2002, Declining water levels in the Gnangara and Jandakot Groundwater Mounds (Stage I), Western Australia, Water and Rivers Commission, Resource Science Division, Hydrogeology Report No: HR199

Yesertener, C., 2005, Impacts of climate, land and water use on declining groundwater levels in the Gnangara Groundwater Mound, Perth, Australia, Australian Journal of Water Resources, Vol 8, No 2, pp143-152.

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.

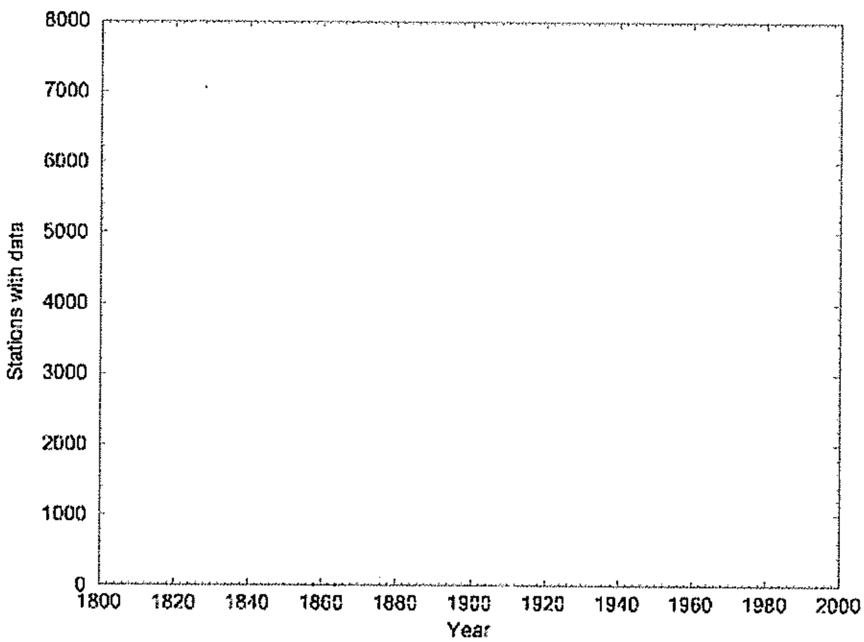


Figure 20. Number of stations reporting rainfall data, as at April 2000.

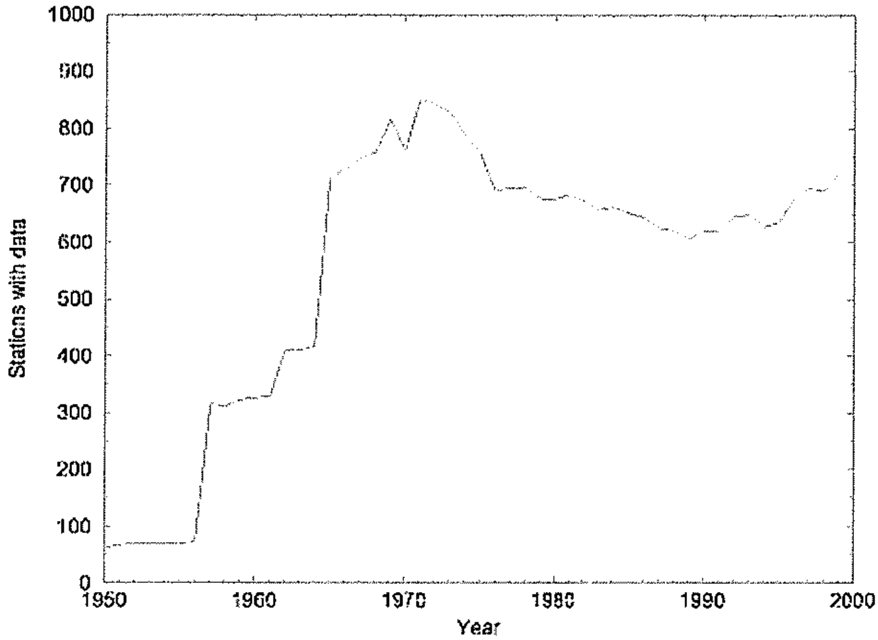


Figure 21. Number of stations reporting climate data, as at April 2000.

1. Interpolation Procedure

The interpolated surfaces were computed on a regular 0.05 degree grid extending from 10° S to 44° S, and 112° E to 154° 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.

References for Appendix A

1. Jeffrey, S.J., Carter, J.O., 2001, Moodie, K.M and Beswick, A.R.. "Using spatial interpolation to construct a comprehensive archive of Australian climate data", Environmental Modelling and Software, Vol 16/4, pp 309-330.

2. Carter et al. (1996) Development of a National Drought Alert Strategic Information System: Vol III, "Development of data rasters for model inputs." Final Report on QPI 20 to Land and Water Resources Research and Development Corporation. 76 pp.

3. Hutchinson, M.F. (1995) "Interpolating mean rainfall using thin plate smoothing splines", International Journal of Geographical Information Systems, 9:385-403.

4. Wahba, G. and Wendelberger, J. (1980) "Some new mathematical methods for variational objective analysis using splines and cross validation", Monthly Weather Review, 108:1122-1143.

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	

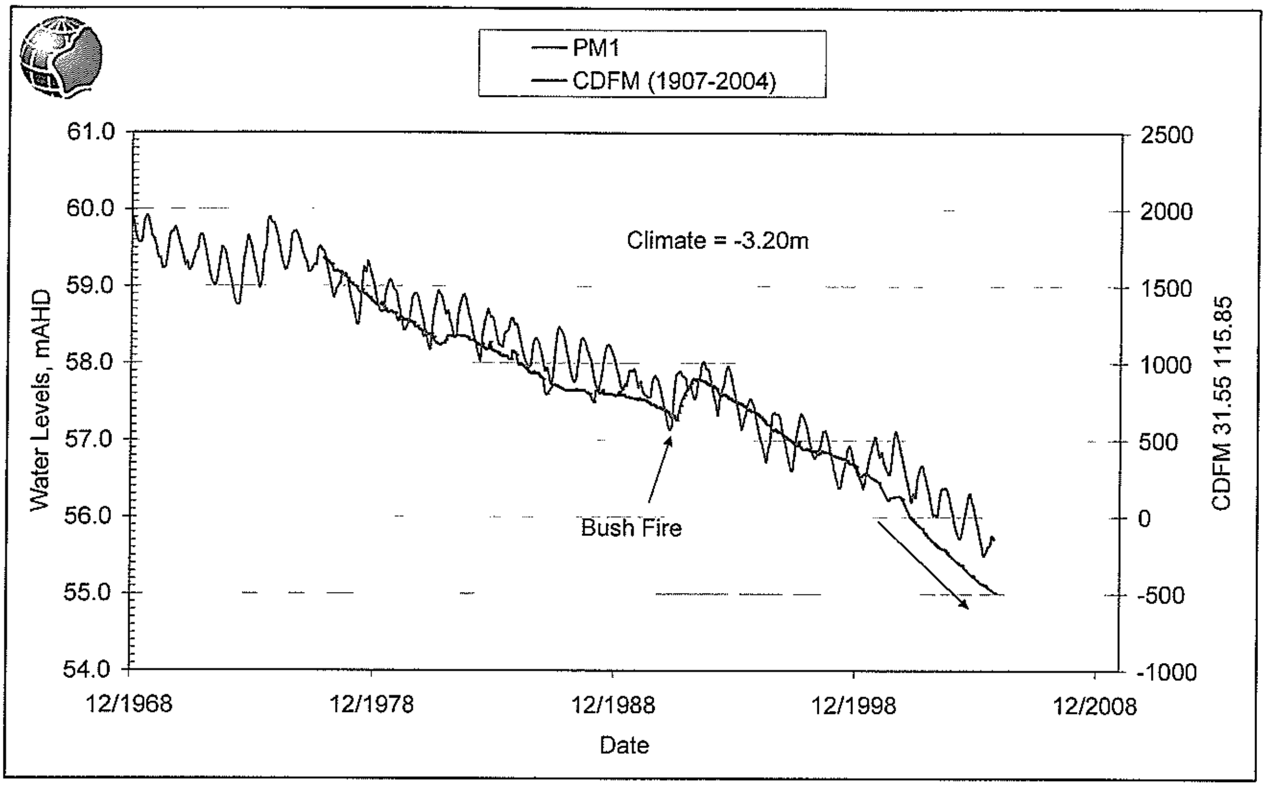
Name	Easting	Northing	Datum mAHD	Climate (m)	Abstraction (m)	Pine (m)	Clearing (m)	Thinning (m)	Fires (m)	Urbanisation (m)	Native Bush (m)	Comments
PM31	380399	6502357	53.61	-2.3	-1.95	0	0	0	0	0	0	
PM33	381171	6498585	51.74	-1.65	-1.7	0	0	0	0	0	0	
PM36	383526	6495618	60.77	-2.35	-1	0	0	0	0	0	0	
PM5	393390	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	

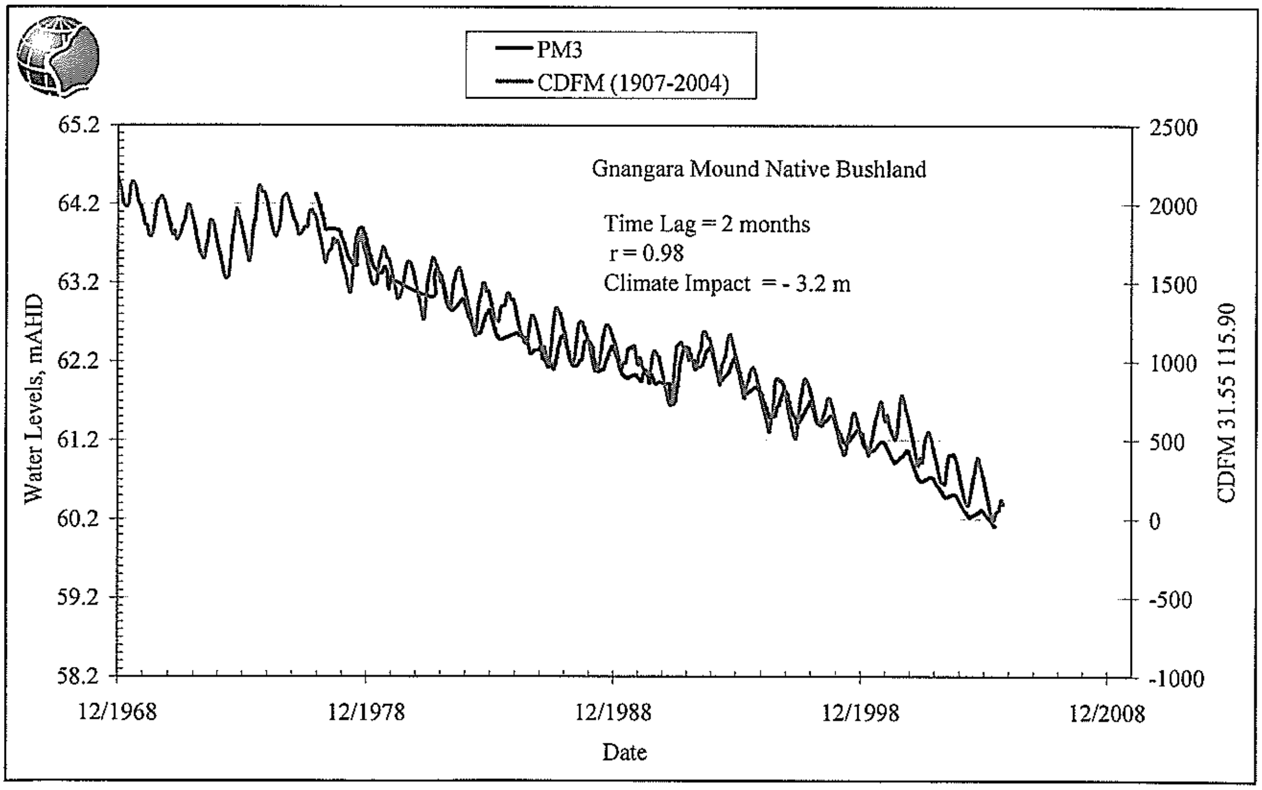
Appendix D – Gnangara groundwater hydrographs

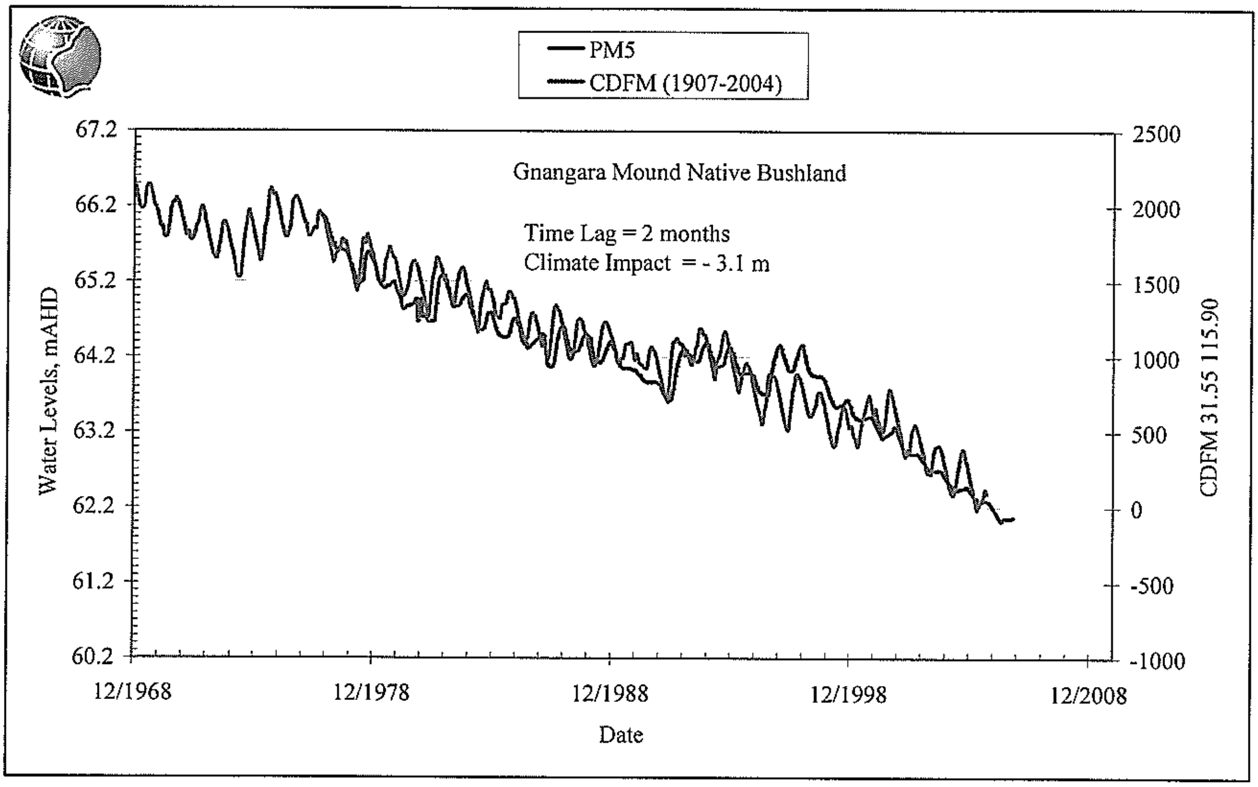
1. Lake Pinjar Rainfall Zone
2. Gingin Rainfall Zone
3. Muchea and Pearce Rainfall Zones
4. Wanneroo Rainfall Zone
5. Yanchep Rainfall Zone
6. Two Rocks Rainfall Zone
7. Gnangara Forestry Rainfall Zone

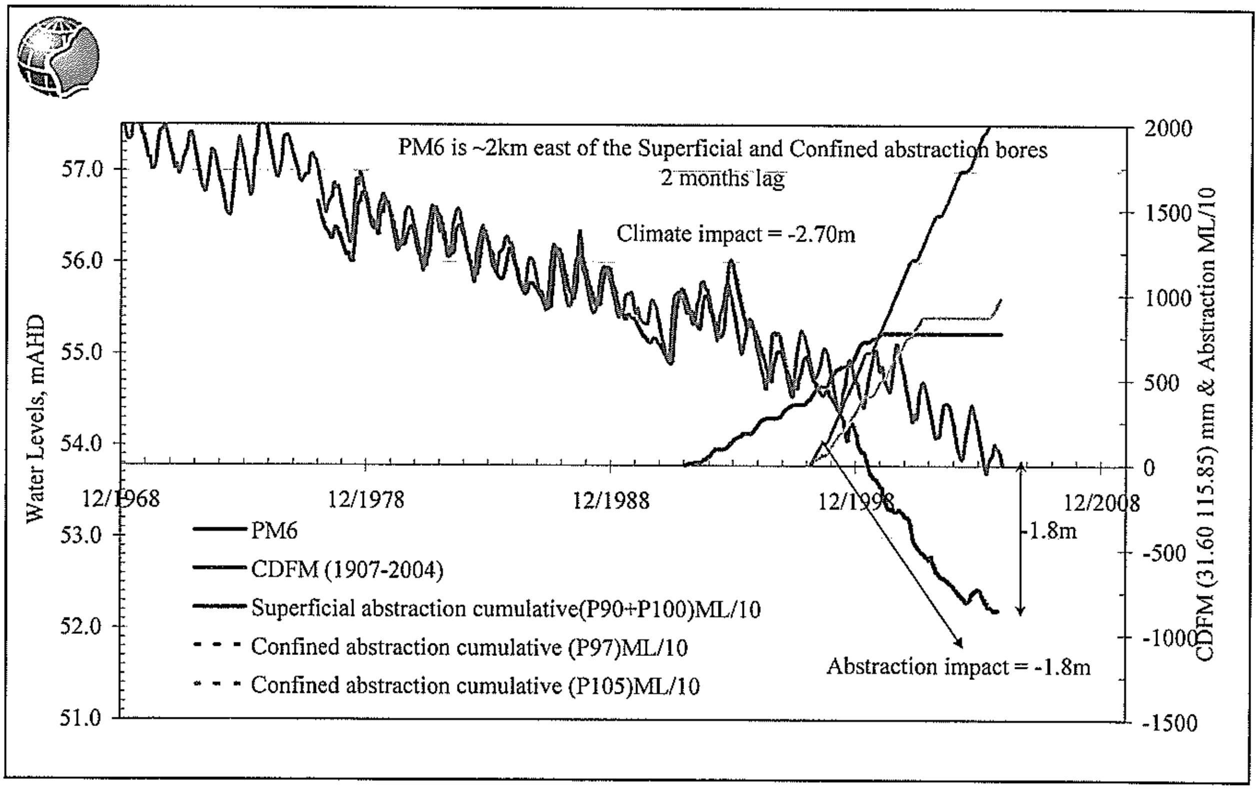
1. Lake Pinjar Rainfall Zone

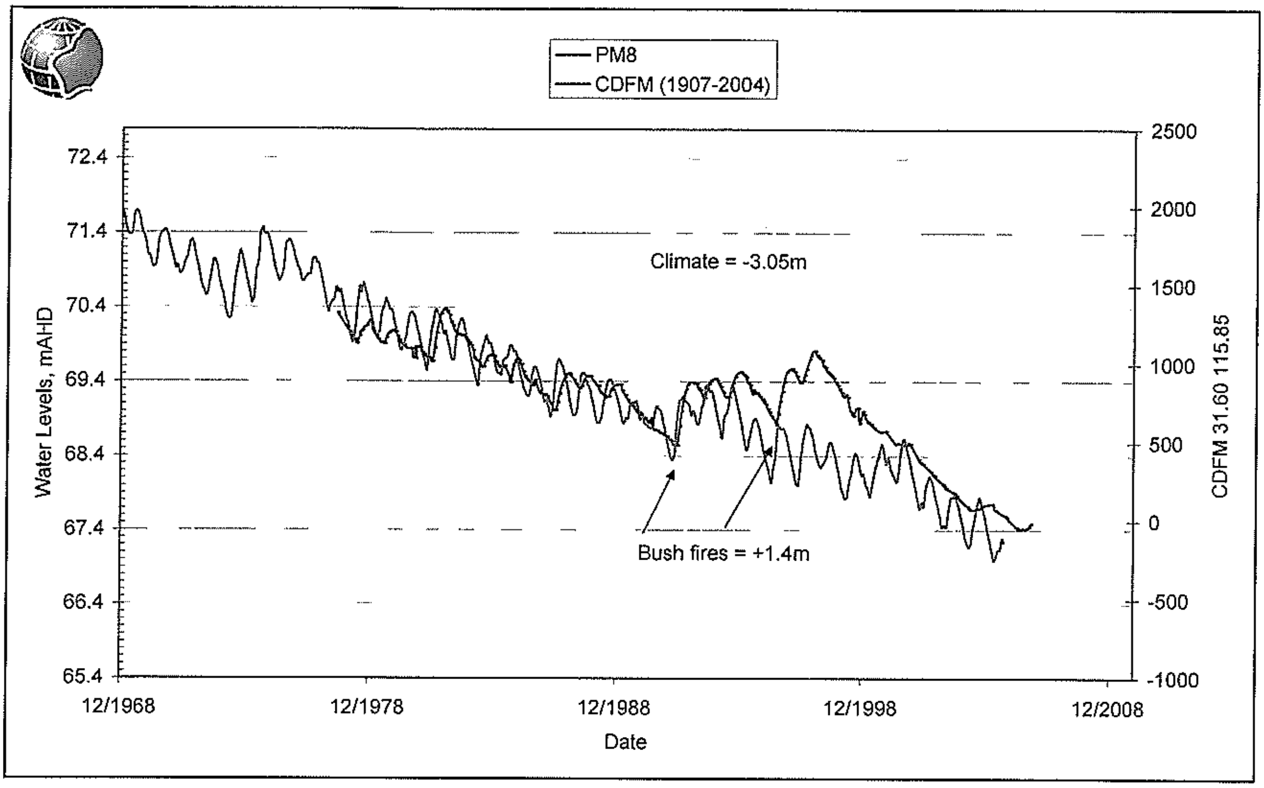
(PM1, PM3, PM5, PM6, PM8, PM15, PM19, GG2, PE1, PE2, GC11, GG5, GC20, GN30, GG4, GA5, GA6, GA10)

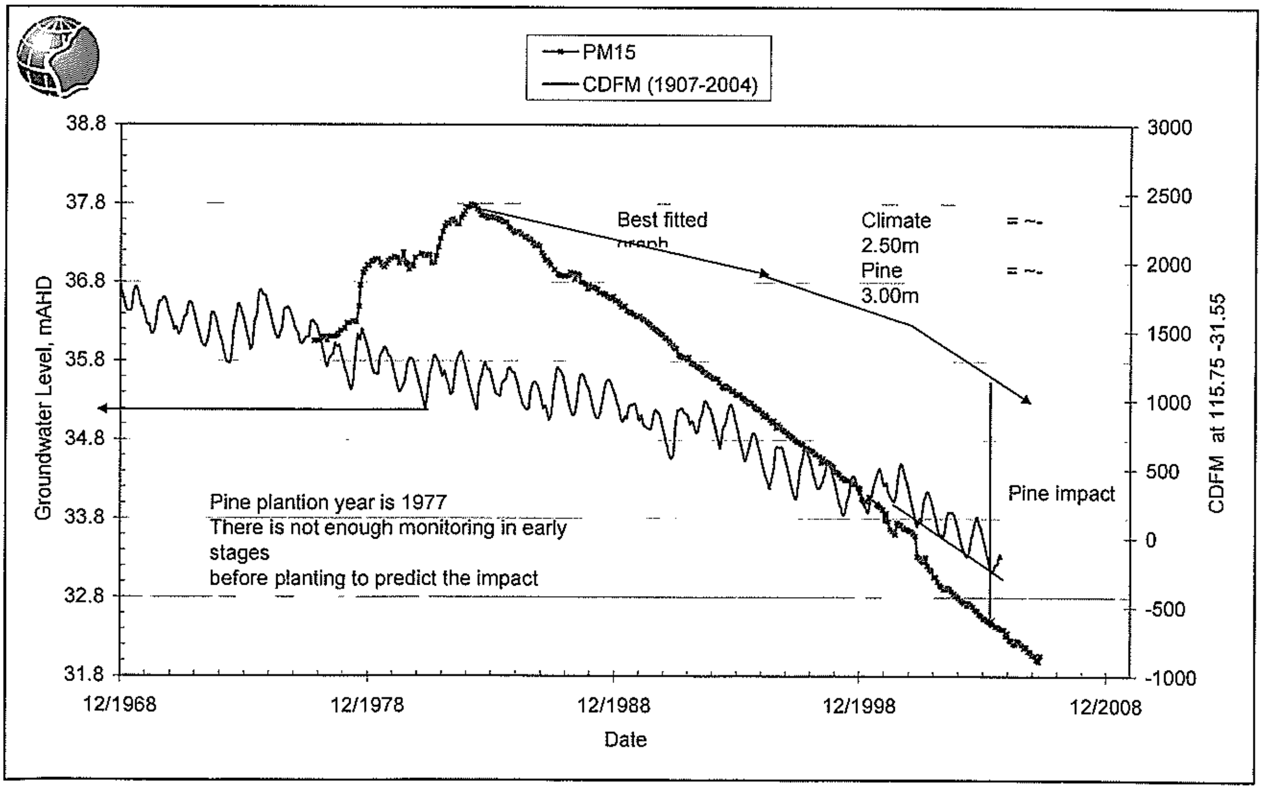

PM1
CDFM (1907-2004)
Climate = -3.20m
Bush Fire
Water Levels, mAHD
CDFM 31.55 115.85
Date
61.0
60.0
59.0
58.0
57.0
56.0
55.0
54.0
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008

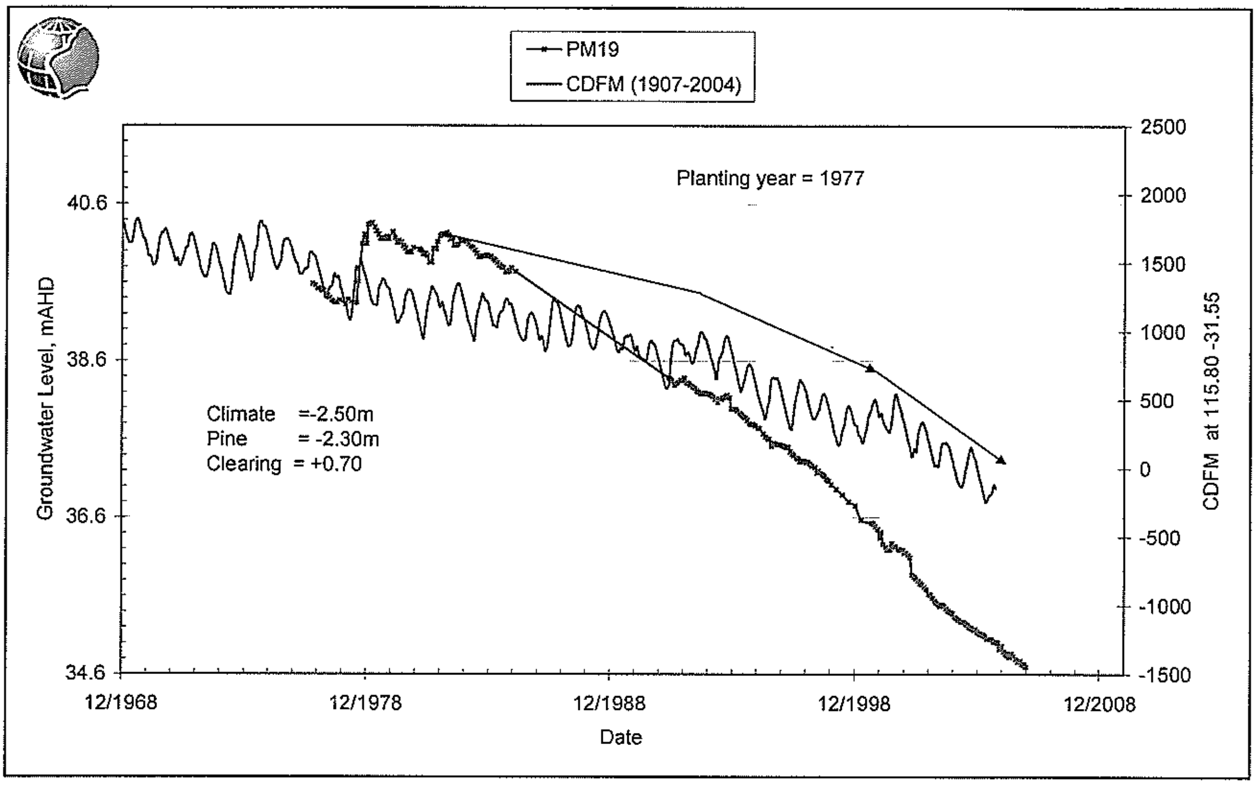

PM3
CDFM (1907-2004)
Gnangara Mound Native Bushland
Time Lag = 2 months
r = 0.98
Climate Impact = - 3.2 m
Water Levels, mAHD
CDFM 31.55 115.90
Date
65.2
64.2
63.2
62.2
61.2
60.2
59.2
58.2
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008


PM5
CDFM (1907-2004)
Gnangara Mound Native Bushland
Time Lag = 2 months
Climate Impact = - 3.1 m
Water Levels, mAHD
CDFM 31.55 115.90
Date
12/1968
12/1978
12/1988
12/1998
12/2008

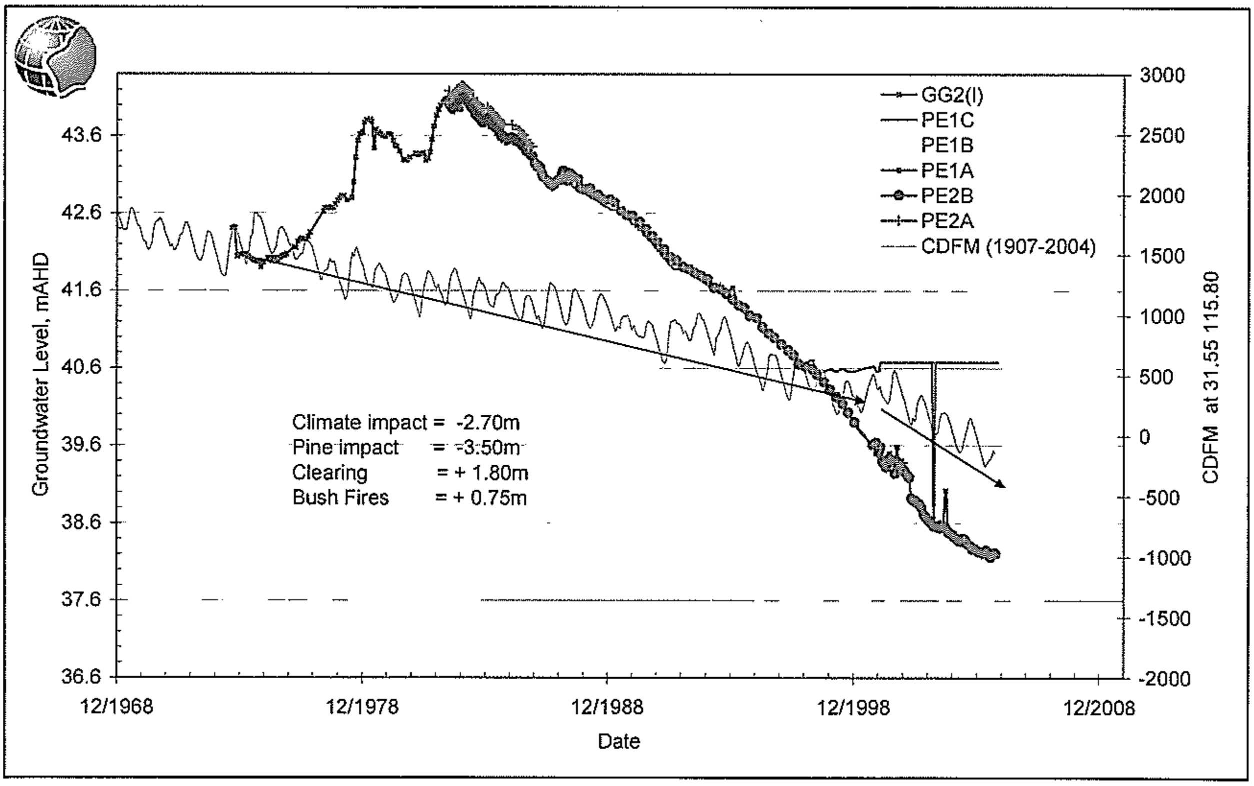

PM6 is ~2km east of the Superficial and Confined abstraction bores
2 months lag
Climate impact = -2.70m
Water Levels, mAHD
CDFM (31.60 115.85) mm & Abstraction ML/10
PM6
CDFM (1907-2004)
Superficial abstraction cumulative(P90+P100)ML/10
Confined abstraction cumulative (P97)ML/10
Confined abstraction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


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

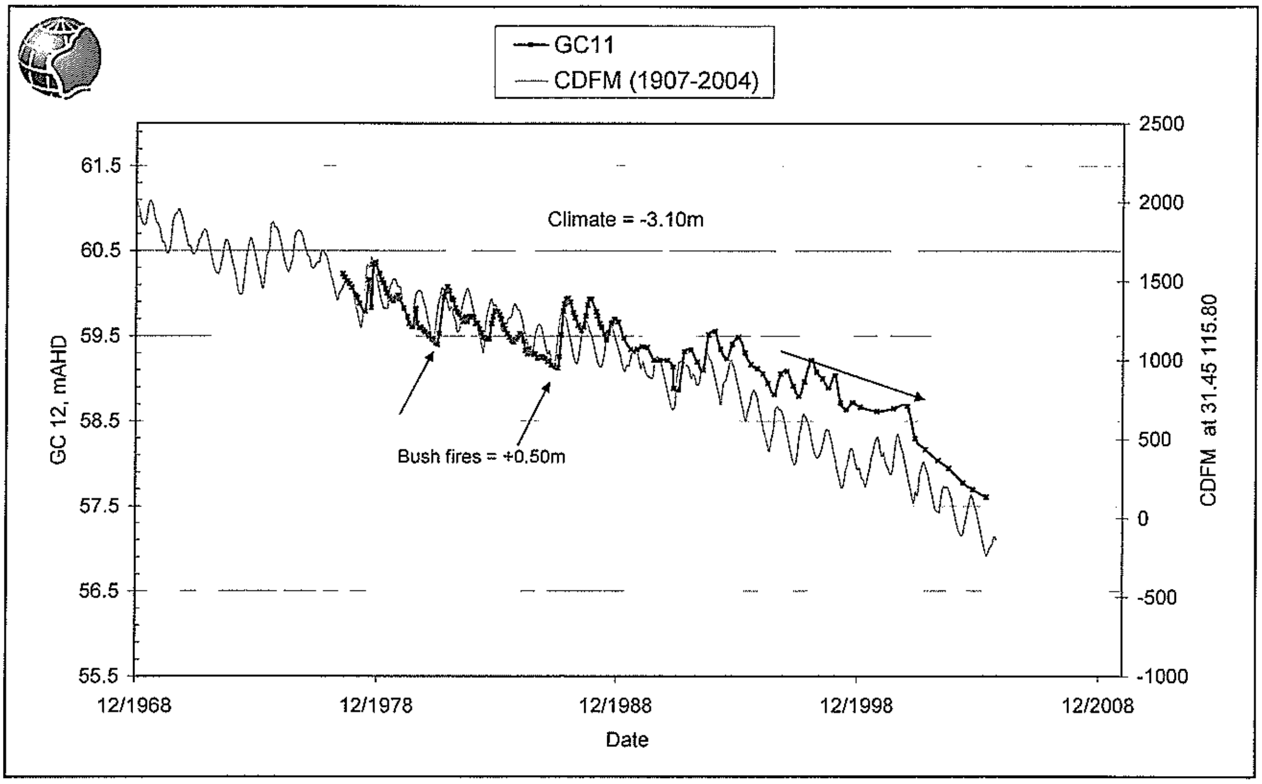

PM15
CDFM (1907-2004)
Best fitted
Climate = ~-
2.50m
Pine = ~-
3.00m
Pine impact
Pine plantion year is 1977
There is not enough monitoring in early stages
before planting to predict the impact
Groundwater Level, mAHD
CDFM at 115.75 -31.55
Date
38.8
37.8
36.8
35.8
34.8
33.8
32.8
31.8
3000
2500
2000
1500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

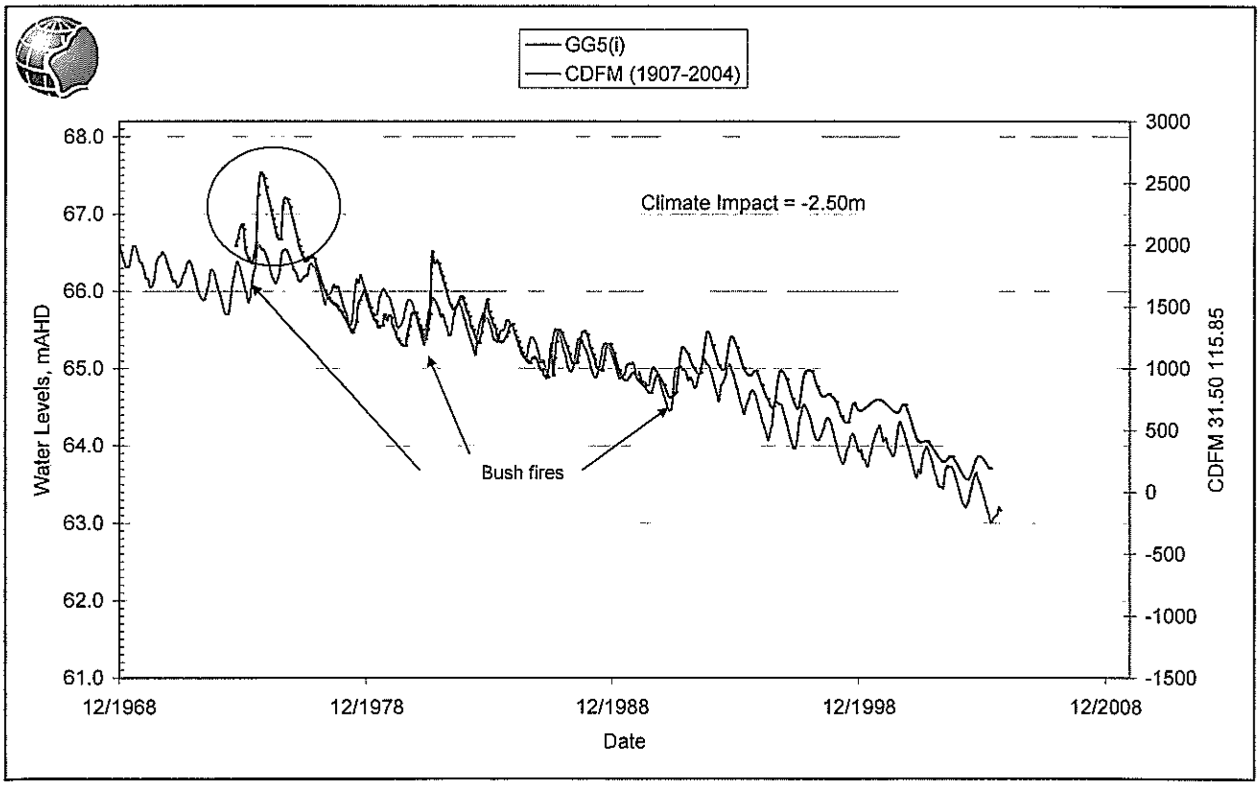


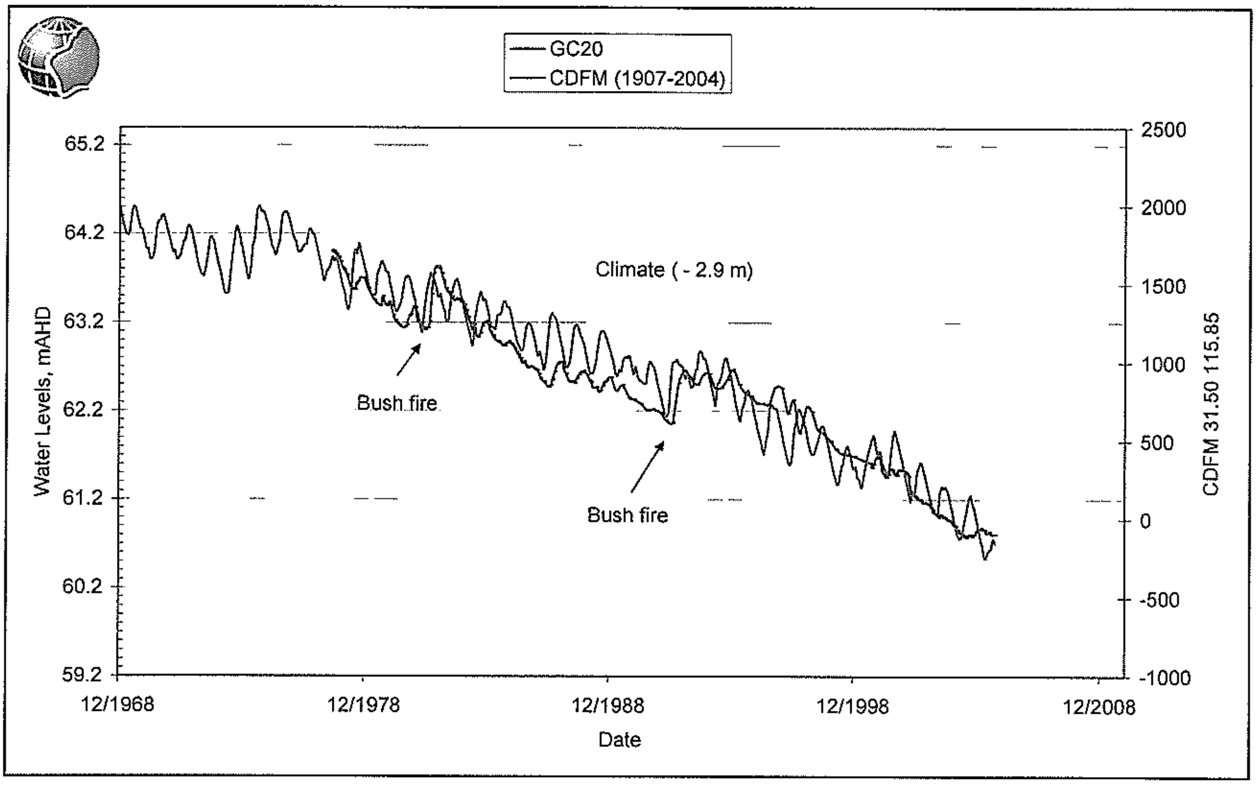
PM19
CDFM (1907-2004)
Planting year = 1977
Climate =-2.50m
Pine = -2.30m
Clearing = +0.70
Groundwater Level, mAHD
40.6
38.6
36.6
34.6
12/1968
12/1978
12/1988
12/1998
12/2008
Date
2500
2000
1500
1000
500
0
-500
-1000
-1500
CDFM at 115.80 -31.55

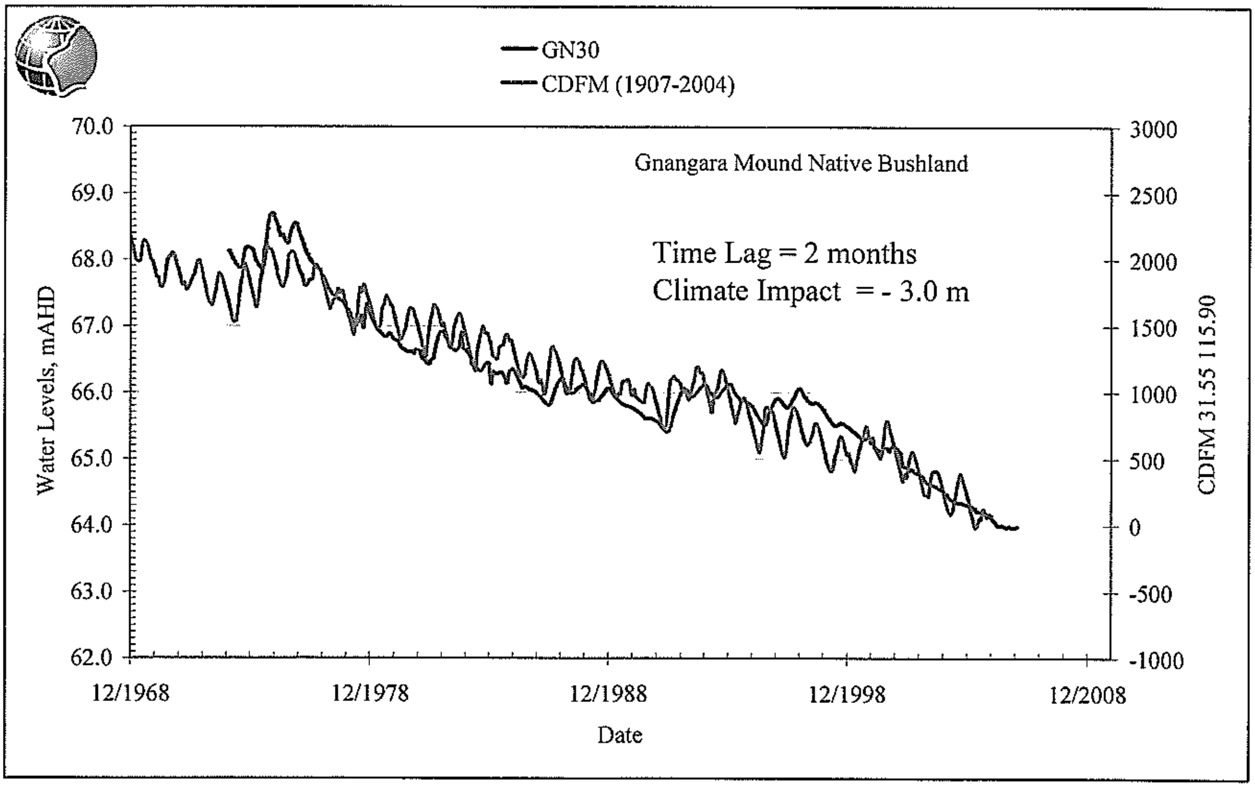


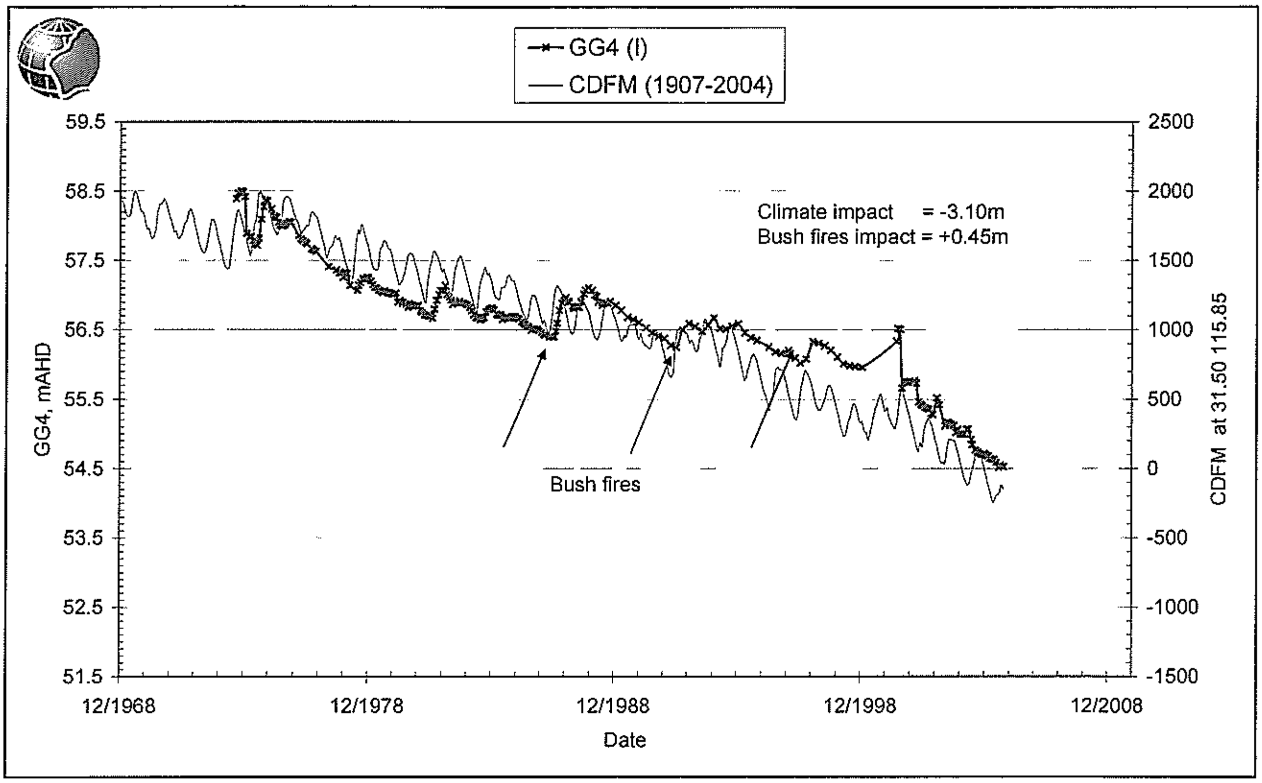
GG2(I)
PE1C
PE1B
PE1A
PE2B
PE2A
CDFM (1907-2004)
Climate impact = -2.70m
Pine impact = -3.50m
Clearing = + 1.80m
Bush Fires = + 0.75m
Groundwater Level, mAHD
43.6
42.6
41.6
40.6
39.6
38.6
37.6
36.6
12/1968
12/1978
12/1988
12/1998
12/2008
Date
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
CDFM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

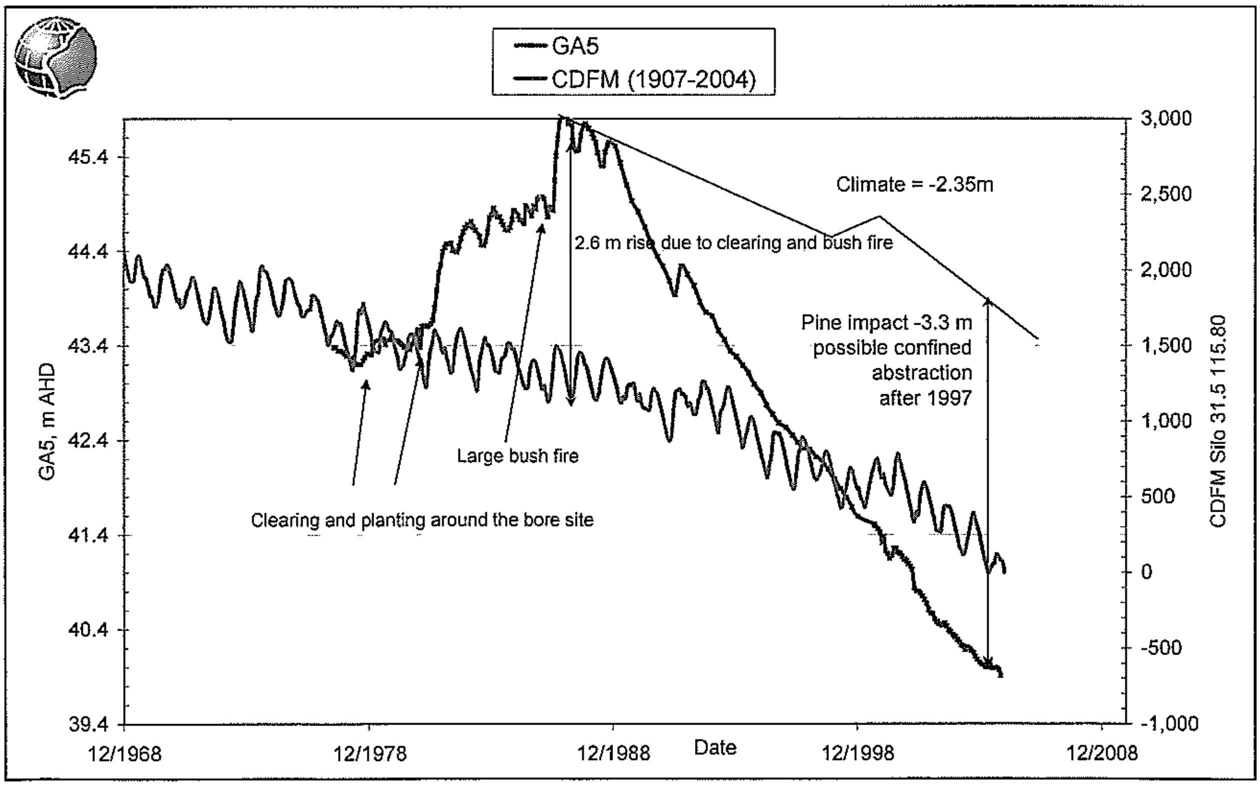

GC11
CDFM (1907-2004)
Climate = -3.10m
Bush fires = +0.50m
GC 12, mAHD
CDFM at 31.45 115.80
Date
61.5
60.5
59.5
58.5
57.5
56.5
55.5
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008

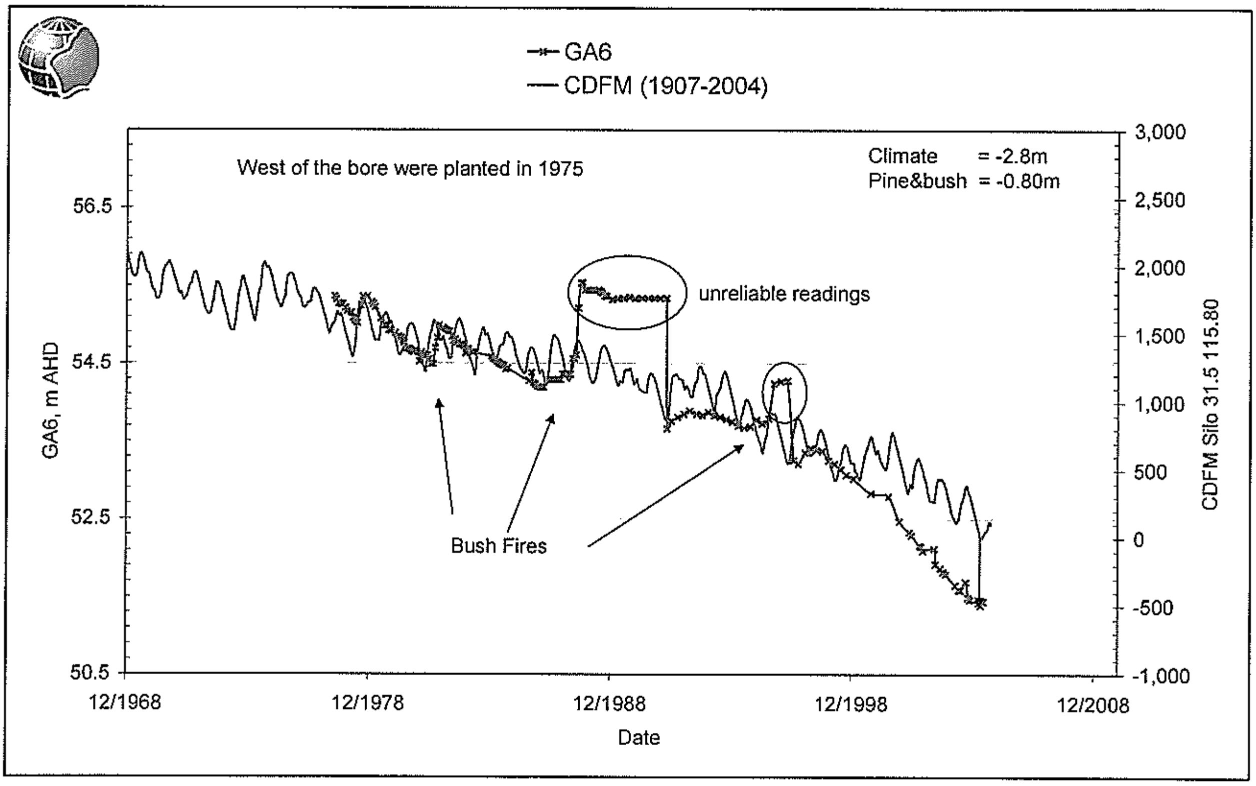

GG5(i)
CDFM (1907-2004)
Climate Impact = -2.50m
Bush fires
Water Levels, mAHD
CDFM 31.50 115.85
Date
68.0
67.0
66.0
65.0
64.0
63.0
62.0
61.0
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
12/1968
12/1978
12/1988
12/1998
12/2008

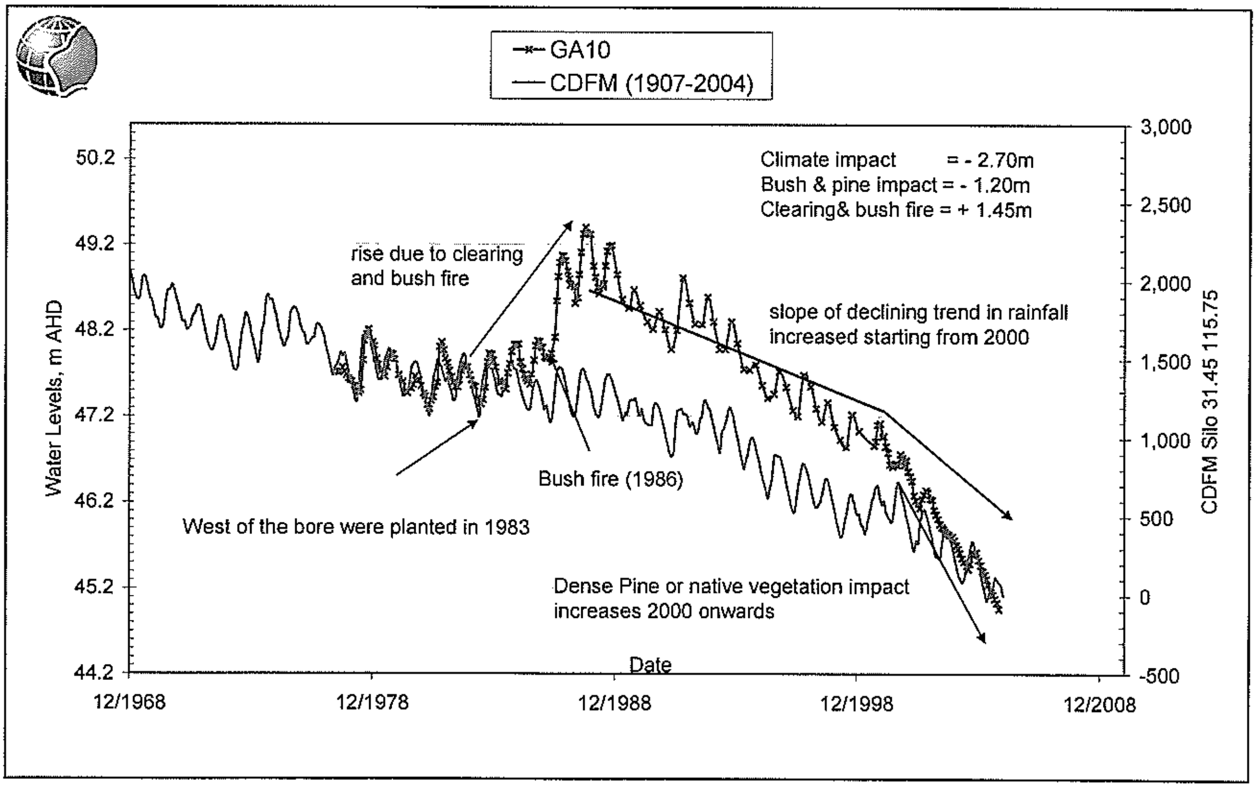

GC20
CDFM (1907-2004)
Climate (- 2.9 m)
Bush fire
Bush fire
Water Levels, mAHD
65.2
64.2
63.2
62.2
61.2
60.2
59.2
2500
2000
1500
1000
500
0
-500
-1000
CDFM 31.50 115.85
12/1968
12/1978
12/1988
12/1998
12/2008
Date


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
3000
2500
2000
1500
1000
500
0
-500
-1000
CDFM 31.55 115.90
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
CDFM at 31.50 115.85
59.5
58.5
57.5
56.5
55.5
54.5
53.5
52.5
51.5
2500
2000
1500
1000
500
0
-500
-1000
-1500
12/1968
12/1978
12/1988
12/1998
12/2008
Date

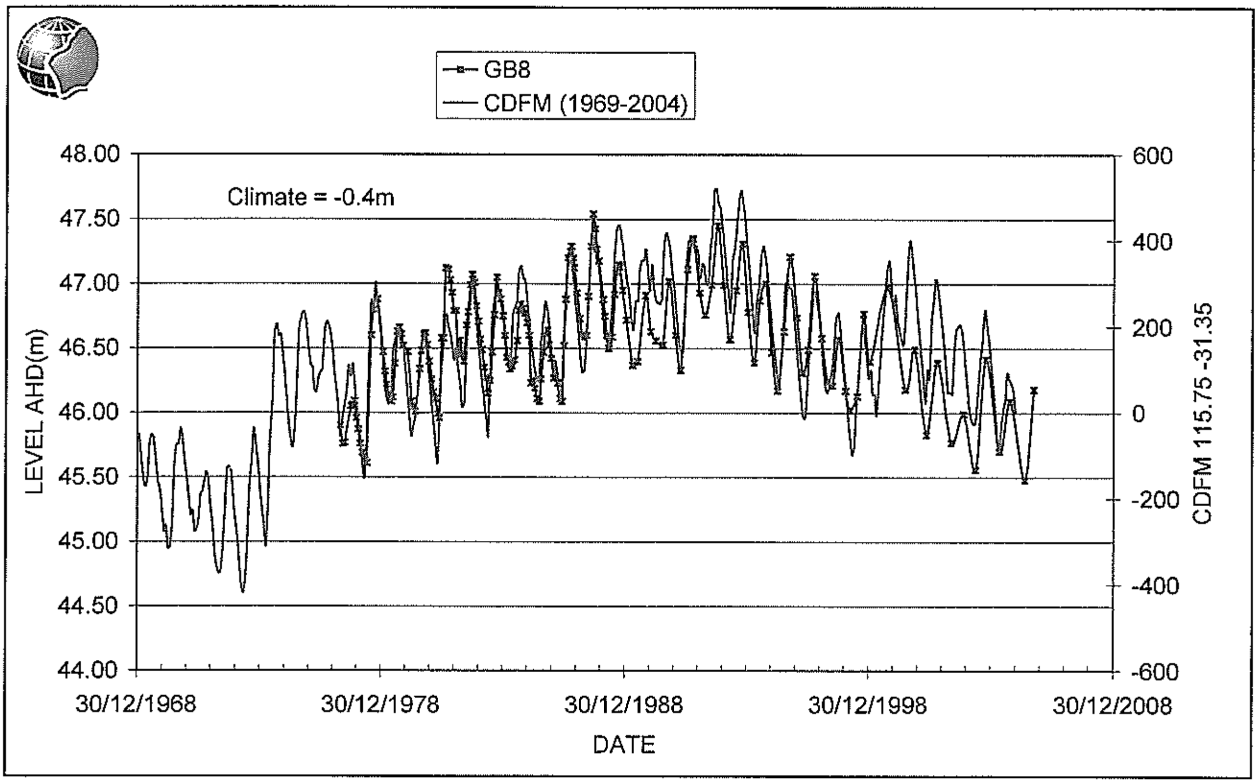

GA5
CDFM (1907-2004)
Climate = -2.35m
2.6 m rise due to clearing and bush fire
Pine impact -3.3 m
possible confined
abstraction
after 1997
Large bush fire
Clearing and planting around the bore site
GA5, m AHD
CDFM Silo 31.5 115.80
45.4
44.4
43.4
42.4
41.4
40.4
39.4
3,000
2,500
2,000
1,500
1,000
500
0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

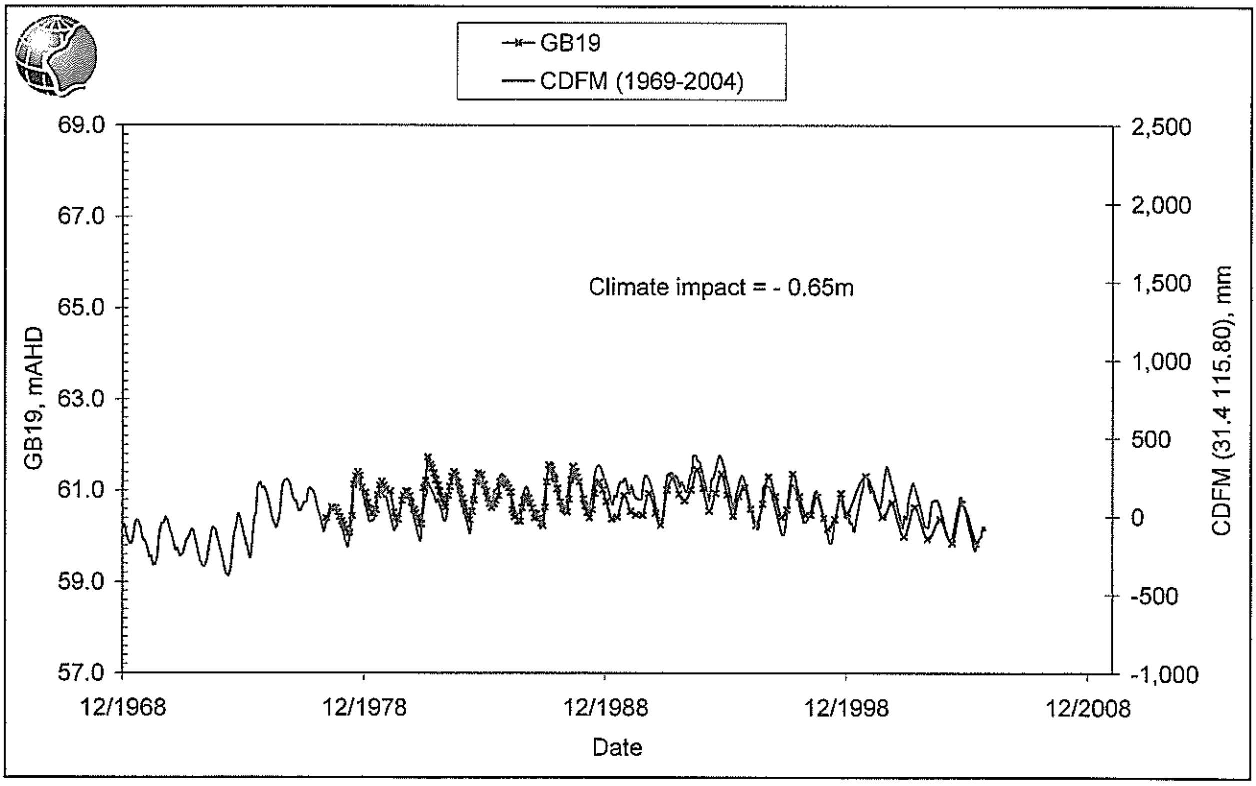

GA6
CDFM (1907-2004)
West of the bore were planted in 1975
Climate = -2.8m
Pine&bush = -0.80m
unreliable readings
Bush Fires
GA6, m AHD
CDFM Silo 31.5 115.80
56.5
54.5
52.5
50.5
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

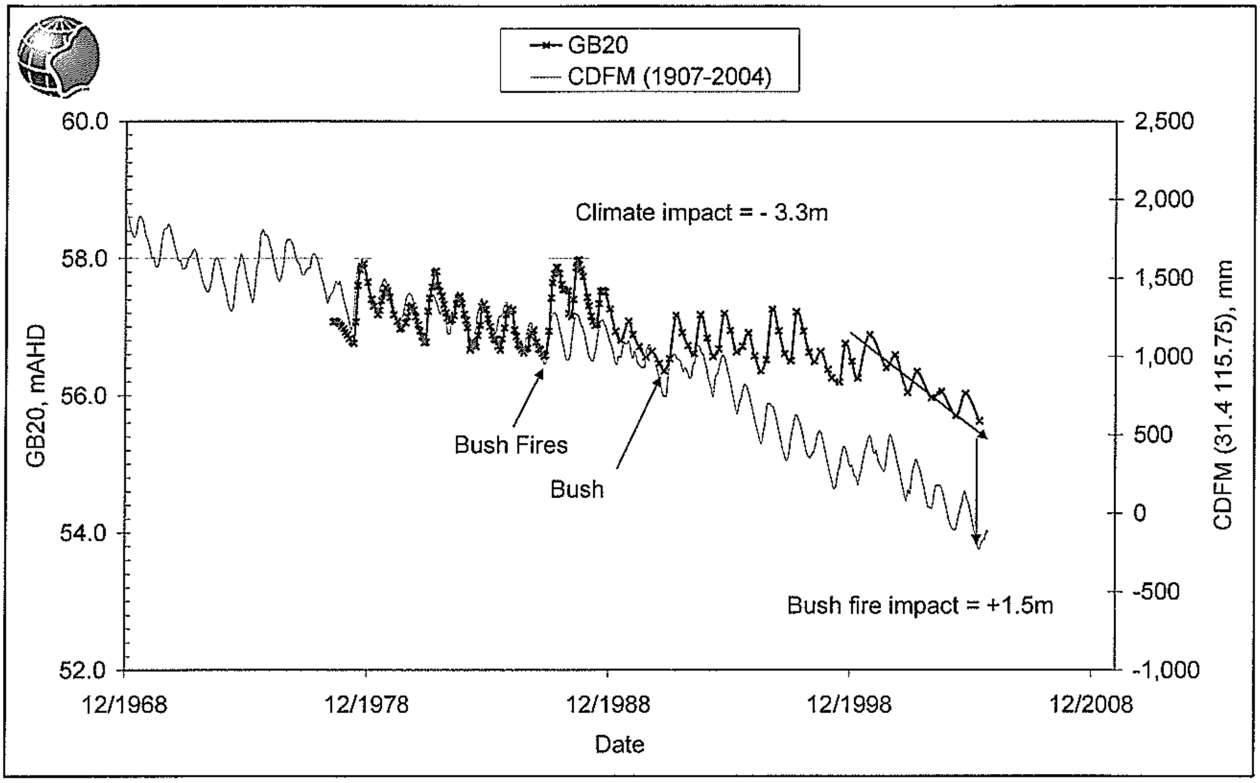

GA10
CDFM (1907-2004)
Climate impact = - 2.70m
Bush & pine impact = - 1.20m
Clearing& bush fire = + 1.45m
rise due to clearing
and bush fire
slope of declining trend in rainfall
increased starting from 2000
Bush fire (1986)
West of the bore were planted in 1983
Dense Pine or native vegetation impact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

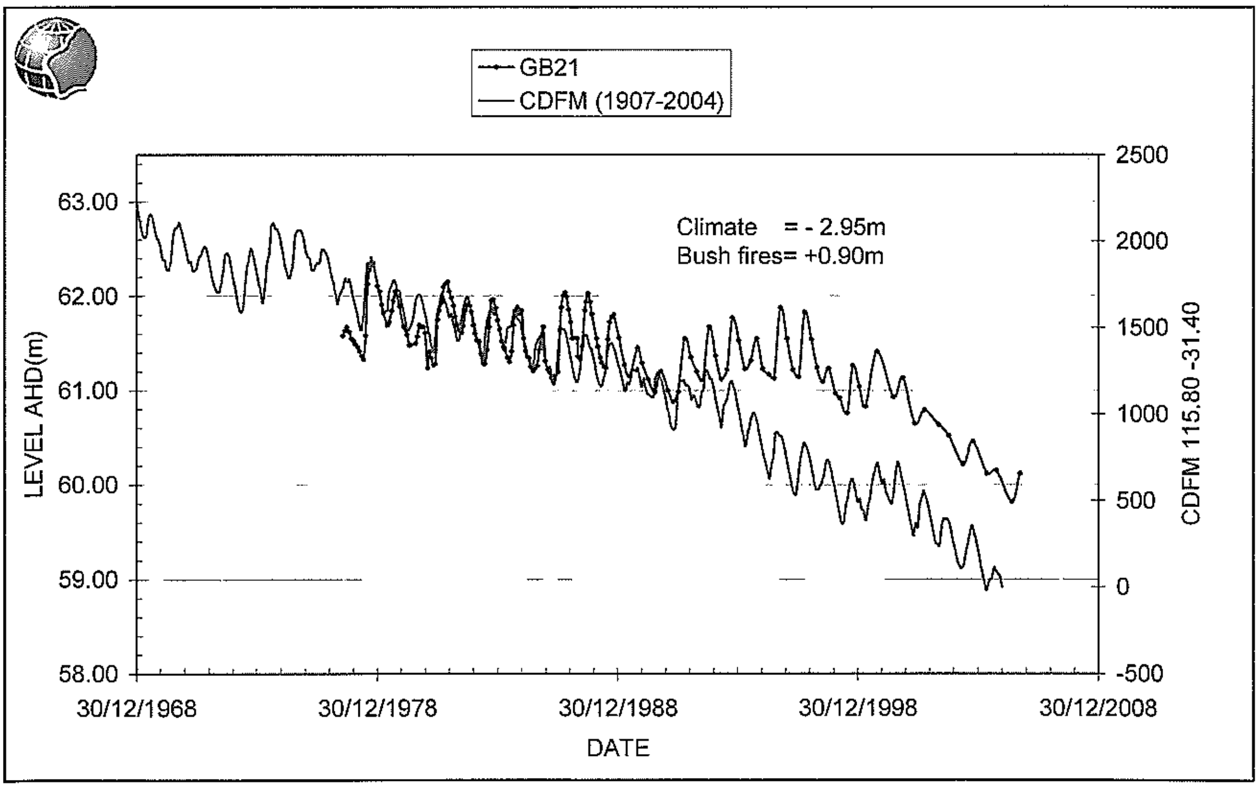
2. Gingin Rainfall Zone

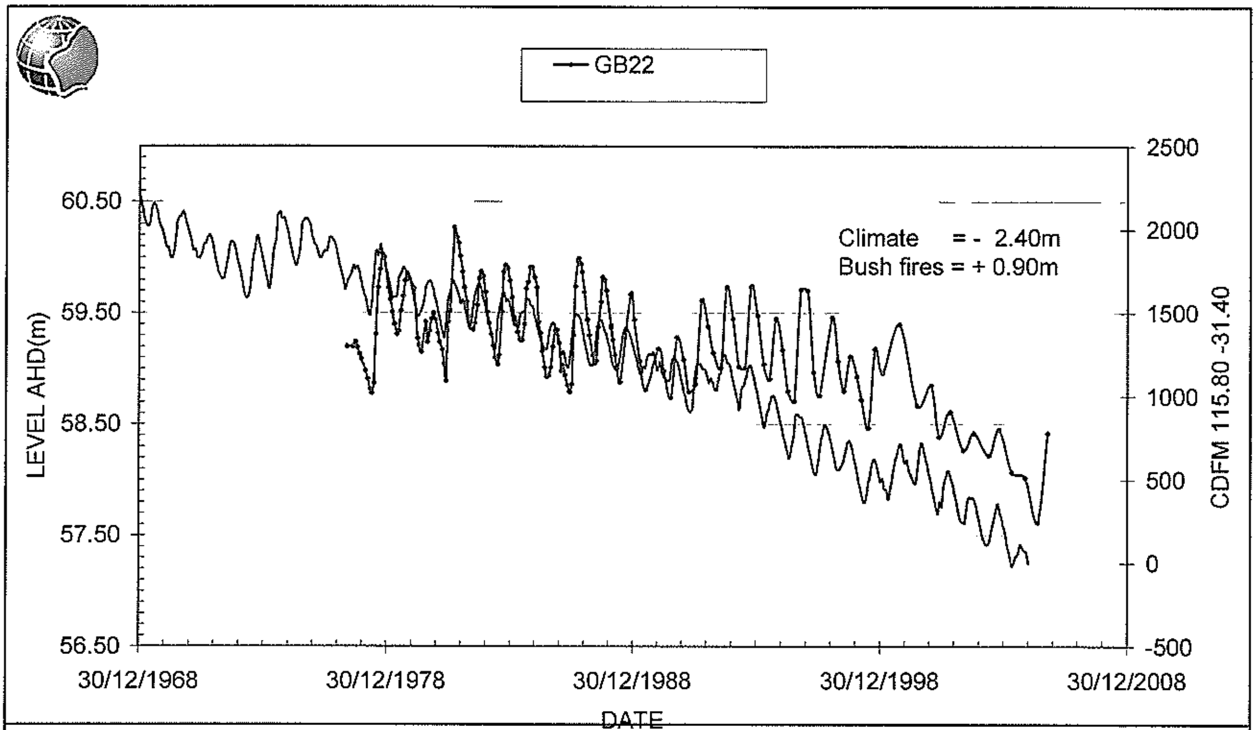
(GB8, GB19, GB20, GB21, GB22, GC9, GC12, GG9, YY7, YY9, GA21, GA31)

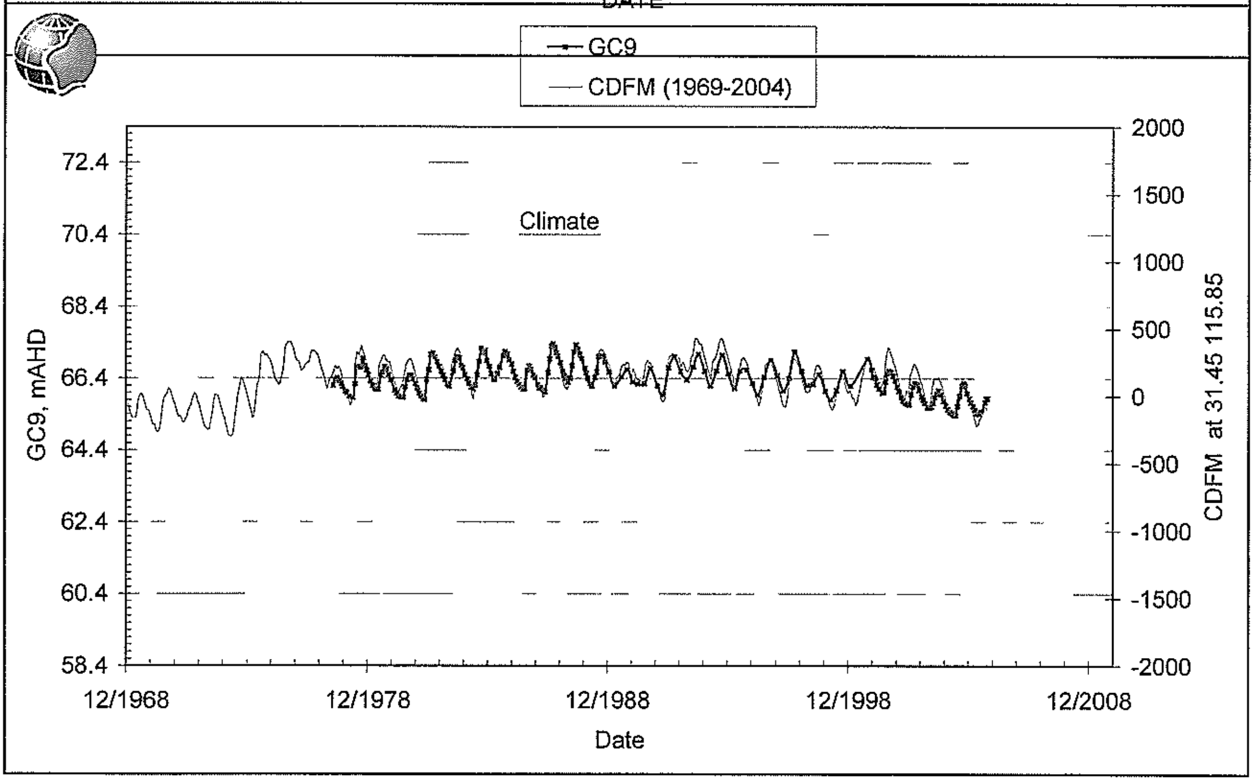

GB8
CDFM (1969-2004)
Climate = -0.4m
48.00
47.50
47.00
46.50
46.00
45.50
45.00
44.50
44.00
LEVEL AHD(m)
600
400
200
0
-200
-400
-600
CDFM 115.75 -31.35
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
DATE

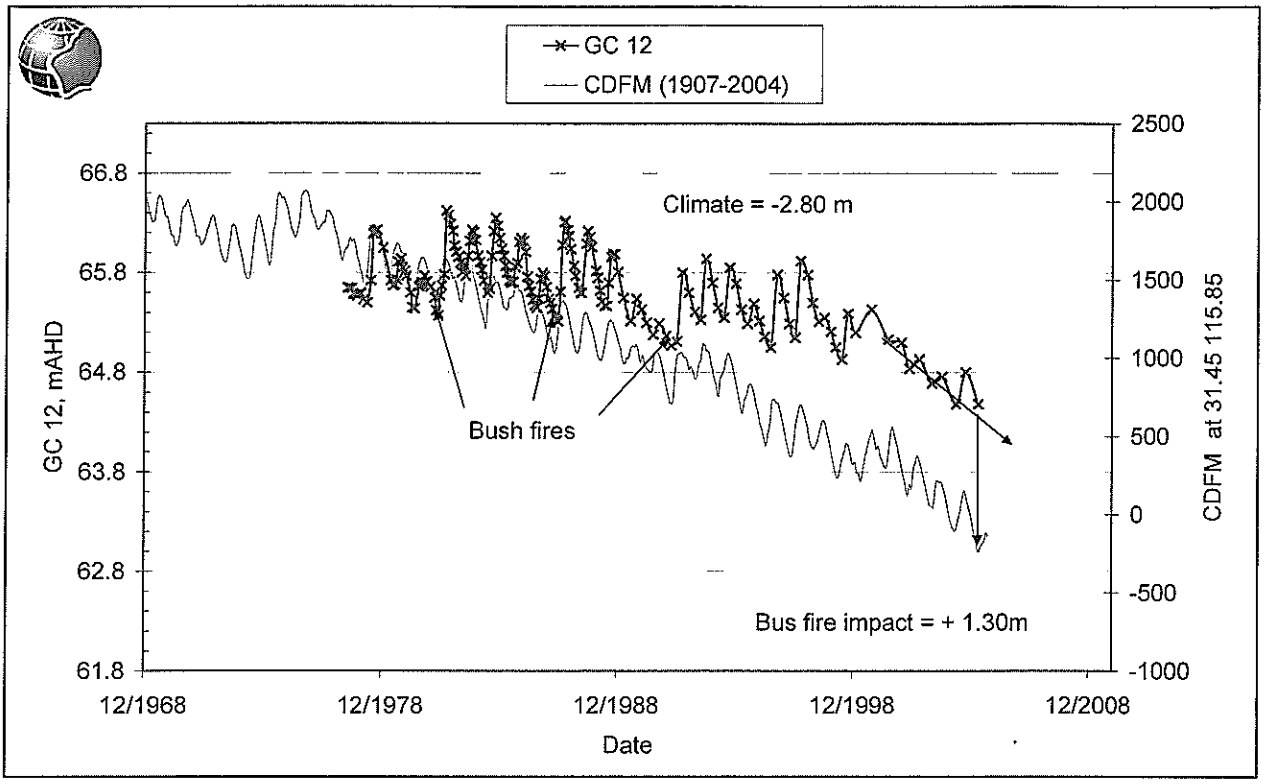

GB19
CDFM (1969-2004)
Climate impact = - 0.65m
69.0
67.0
65.0
63.0
61.0
59.0
57.0
GB19, mAHD
2,500
2,000
1,500
1,000
500
0
-500
-1,000
CDFM (31.4 115.80), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

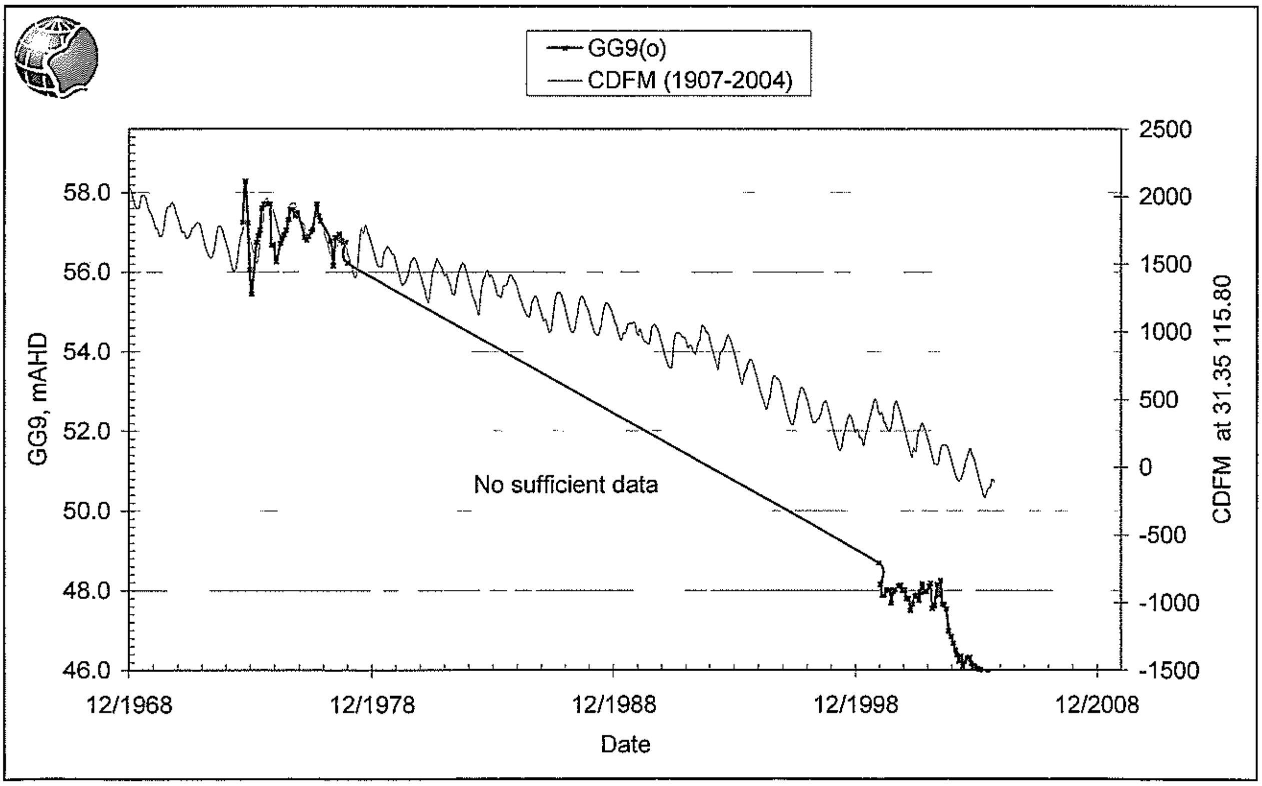

GB20
CDFM (1907-2004)
Climate impact = - 3.3m
Bush Fires
Bush
Bush fire impact = +1.5m
GB20, mAHD
CDFM (31.4 115.75), mm
Date
60.0
58.0
56.0
54.0
52.0
2,500
2,000
1,500
1,000
500
0
-500
-1,000
12/1968
12/1978
12/1988
12/1998
12/2008

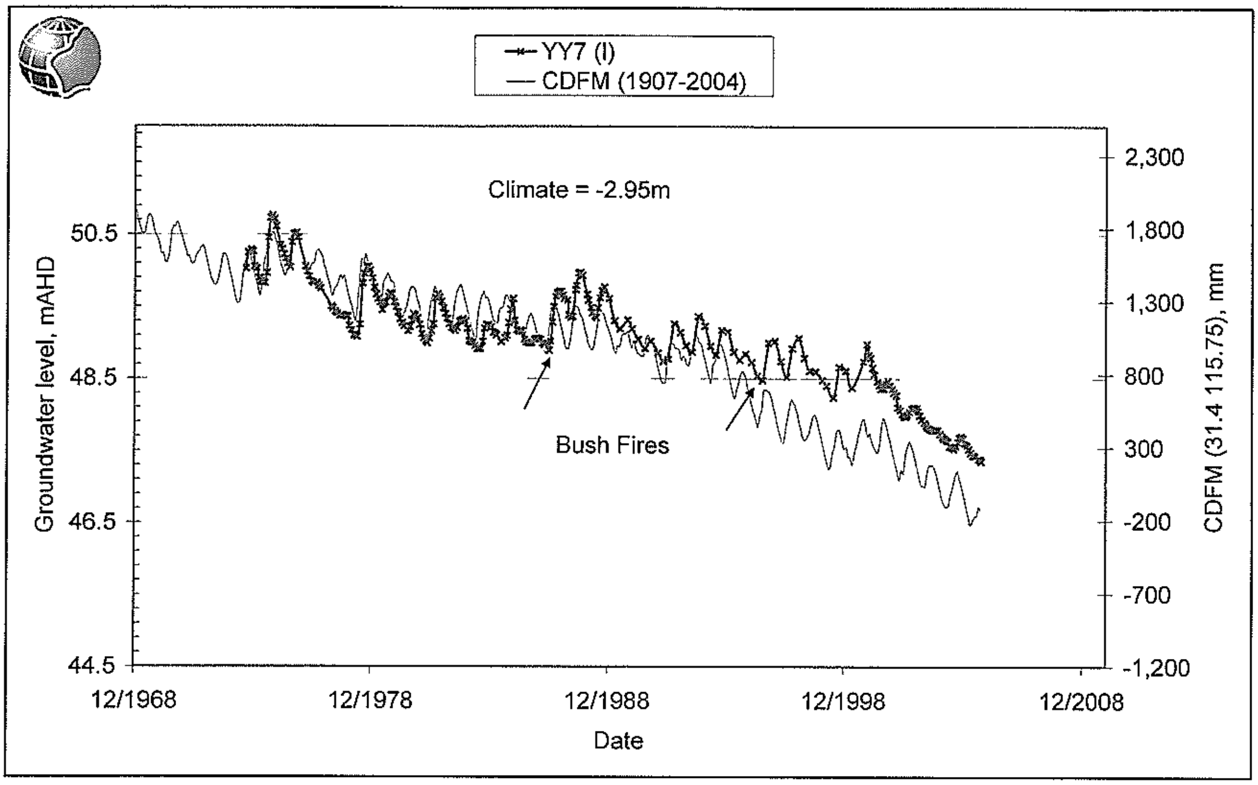

GB21
CDFM (1907-2004)
Climate = - 2.95m
Bush fires= +0.90m
LEVEL AHD(m)
CDFM 115.80 -31.40
DATE
63.00
62.00
61.00
60.00
59.00
58.00
2500
2000
1500
1000
500
0
-500
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008

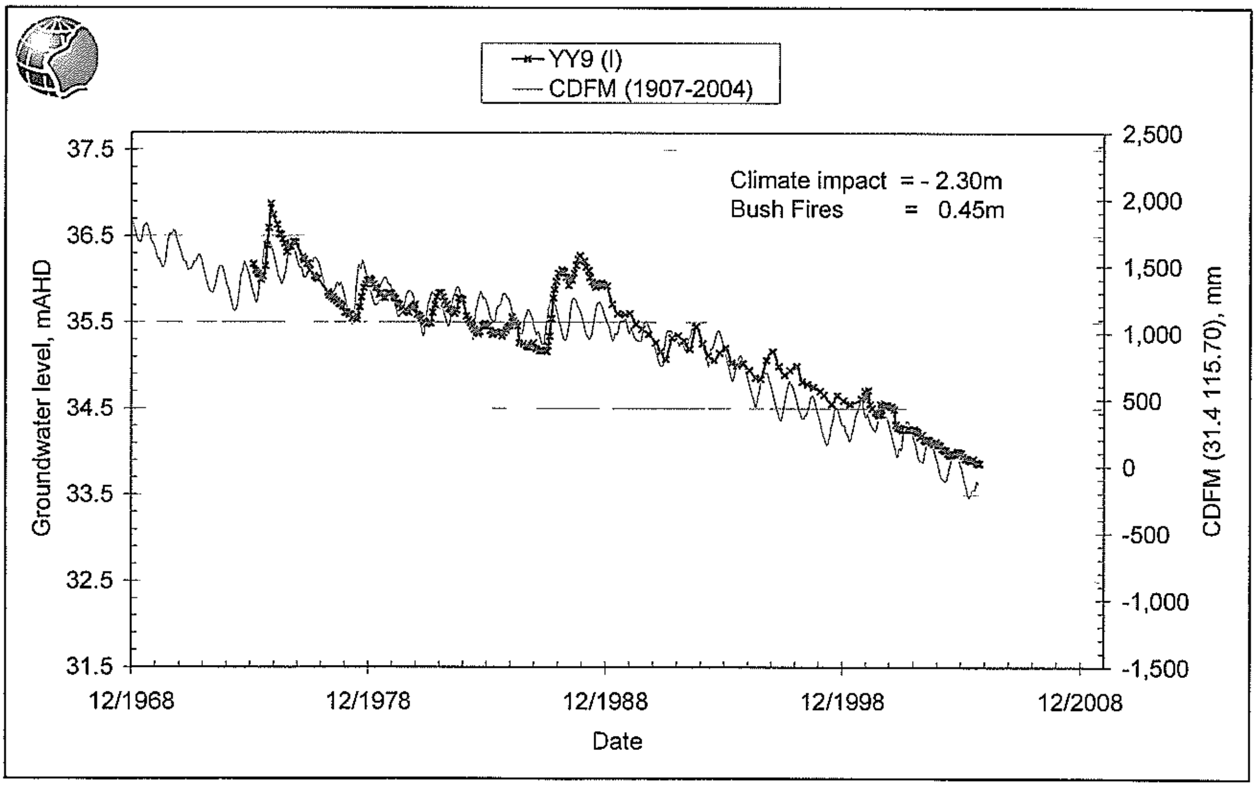

GB22
Climate = - 2.40m
Bush fires = + 0.90m
LEVEL AHD(m)
60.50
59.50
58.50
57.50
56.50
CDFM 115.80 -31.40
2500
2000
1500
1000
500
0
-500
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
DATE

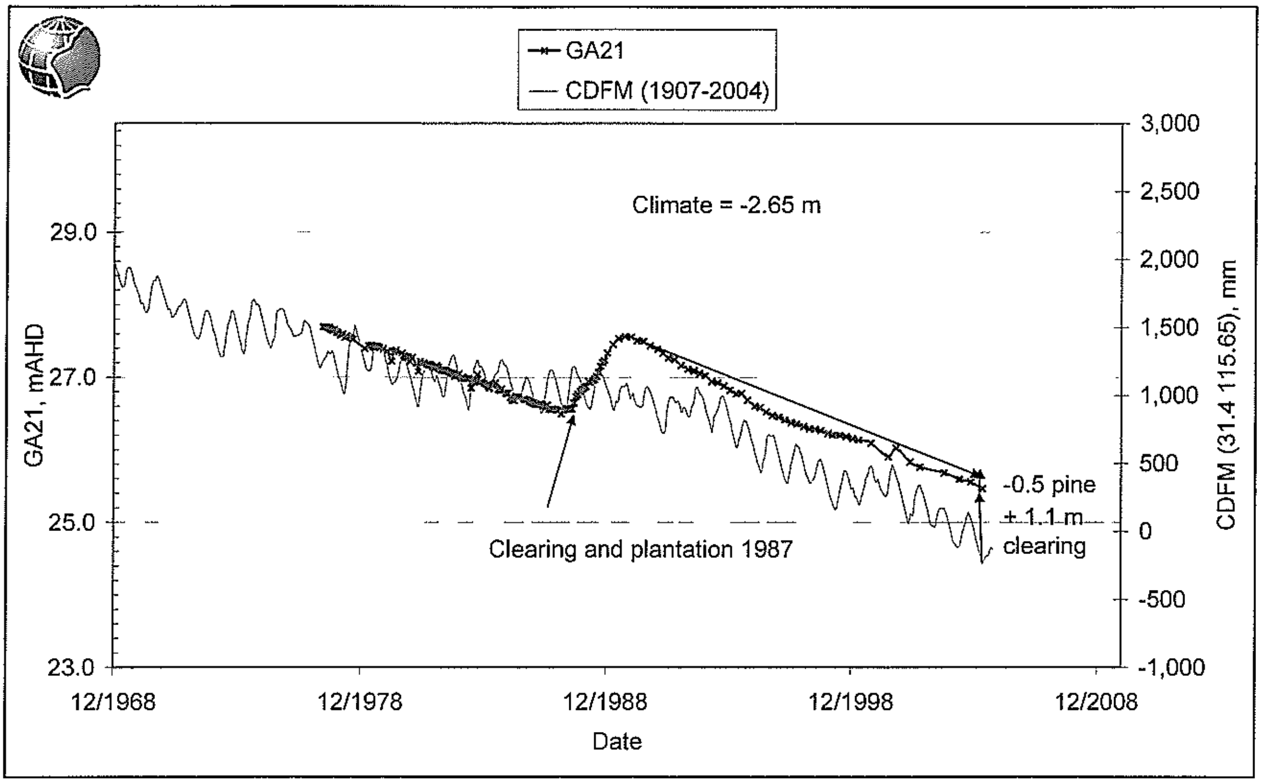

GC9
CDFM (1969-2004)
Climate
GC9, mAHD
72.4
70.4
68.4
66.4
64.4
62.4
60.4
58.4
CDFM at 31.45 115.85
2000
1500
1000
500
0
-500
-1000
-1500
-2000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

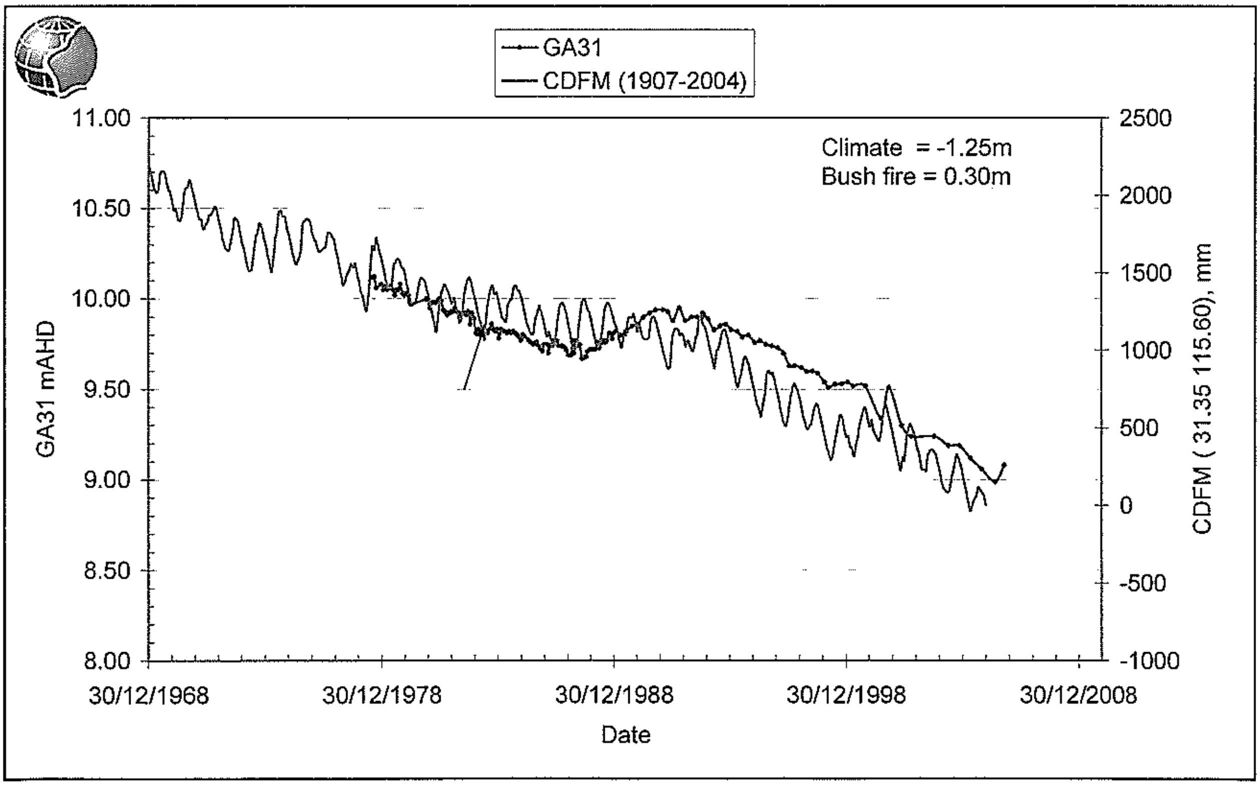

GC 12
CDFM (1907-2004)
Climate = -2.80 m
Bush fires
Bus fire impact = + 1.30m
GC 12, mAHD
CDFM at 31.45 115.85
66.8
65.8
64.8
63.8
62.8
61.8
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date


GG9(o)
CDFM (1907-2004)
No sufficient data
GG9, mAHD
CDFM at 31.35 115.80
58.0
56.0
54.0
52.0
50.0
48.0
46.0
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
CDFM (31.4 115.75), mm
Date
50.5
48.5
46.5
44.5
2,300
1,800
1,300
800
300
-200
-700
-1,200
12/1968
12/1978
12/1988
12/1998
12/2008

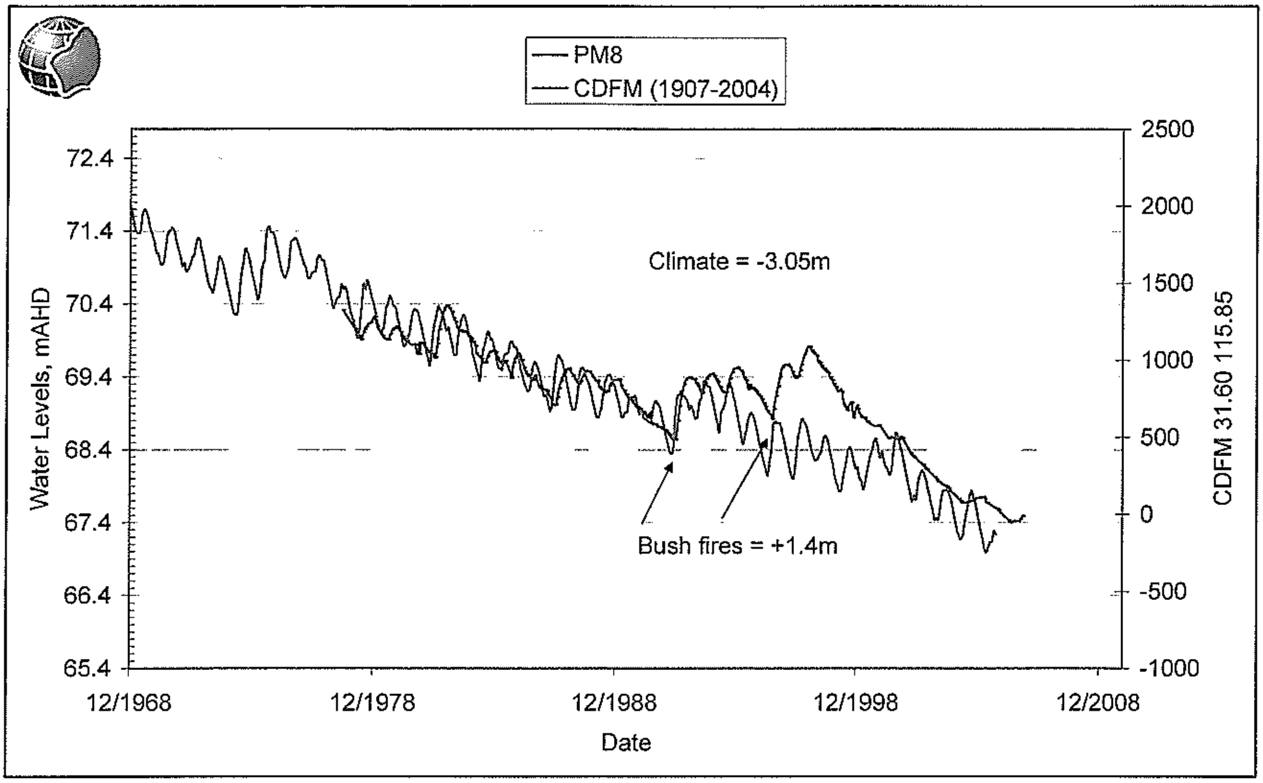

YY9 (I)
CDFM (1907-2004)
Climate impact = - 2.30m
Bush Fires = 0.45m
Groundwater level, mAHD
CDFM (31.4 115.70), mm
Date
37.5
36.5
35.5
34.5
33.5
32.5
31.5
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
12/1968
12/1978
12/1988
12/1998
12/2008


GA21
CDFM (1907-2004)
Climate = -2.65 m
Clearing and plantation 1987
-0.5 pine
+1.1 m
clearing
GA21, mAHD
CDFM (31.4 115.65), mm
29.0
27.0
25.0
23.0
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

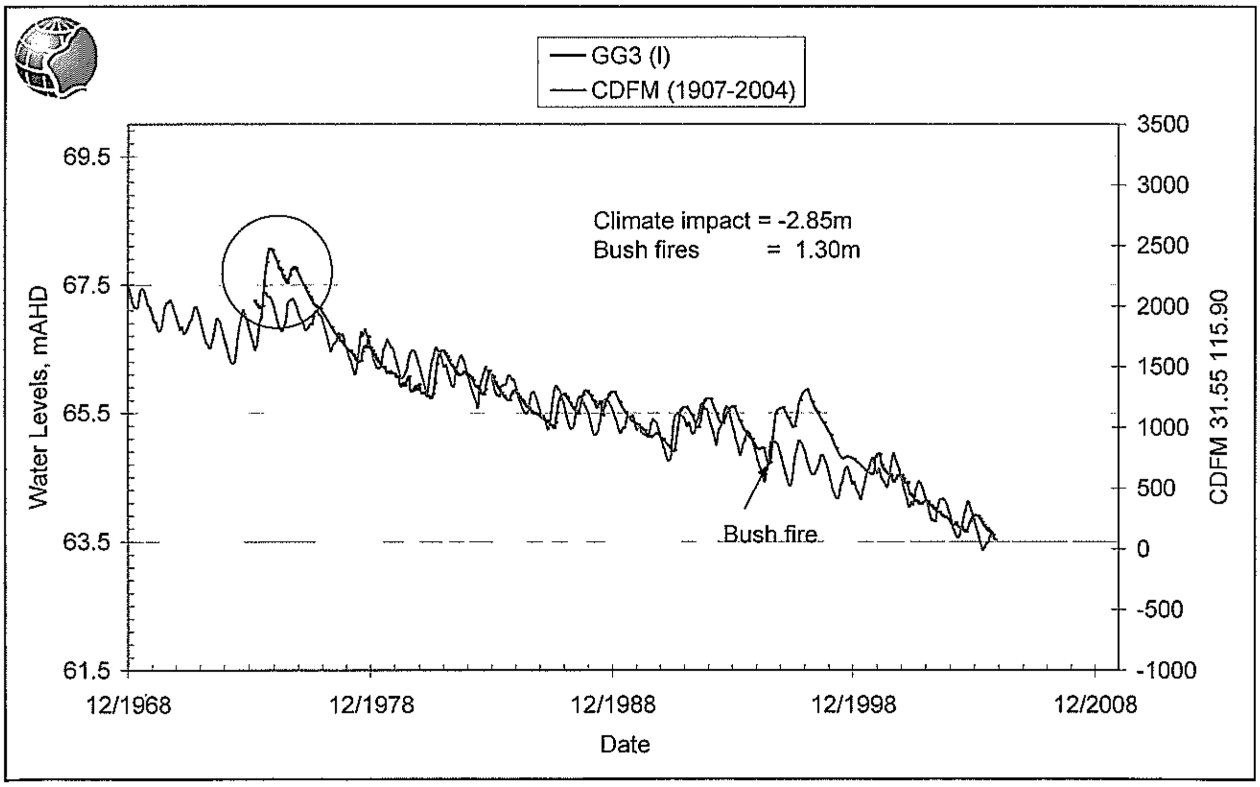

GA31
CDFM (1907-2004)
Climate = -1.25m
Bush fire = 0.30m
GA31 mAHD
CDFM (31.35 115.60), mm
11.00
10.50
10.00
9.50
9.00
8.50
8.00
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

3. Muchea and Pearce Rainfall Zones

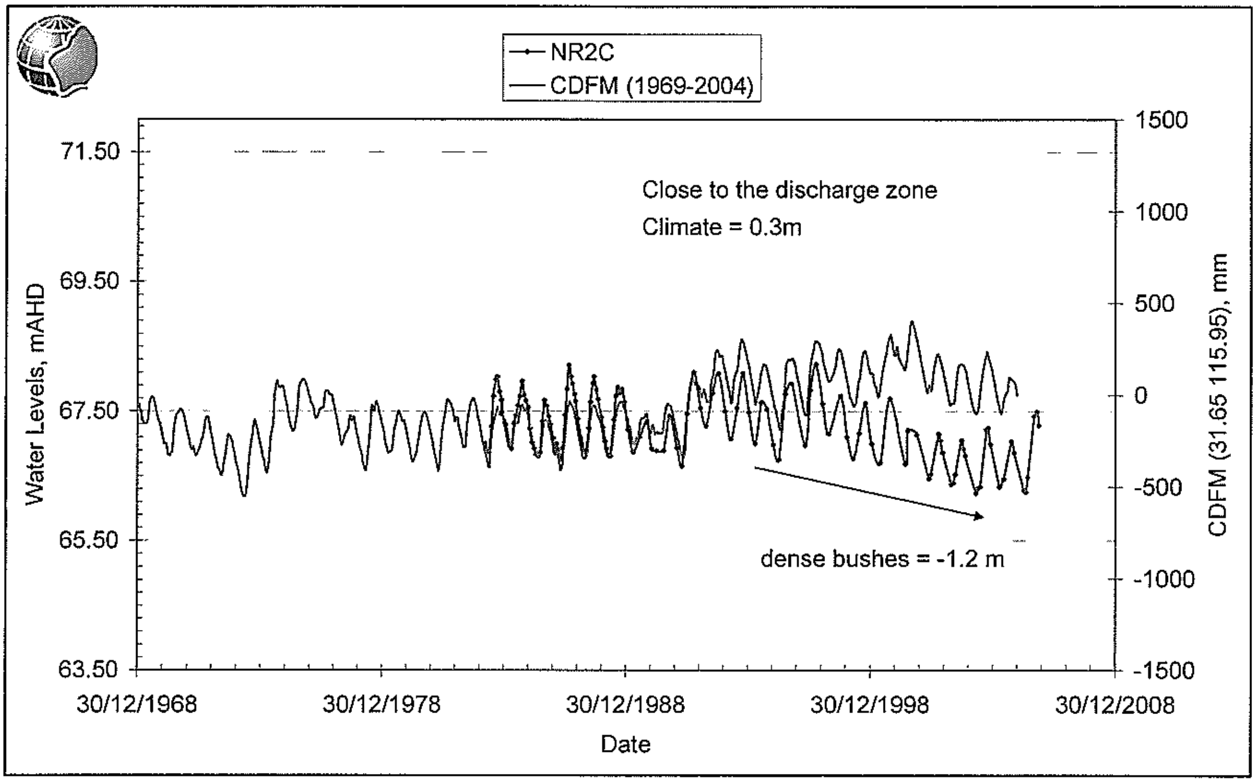
(PM8, GG3, NR2C, NR11C, L220C)

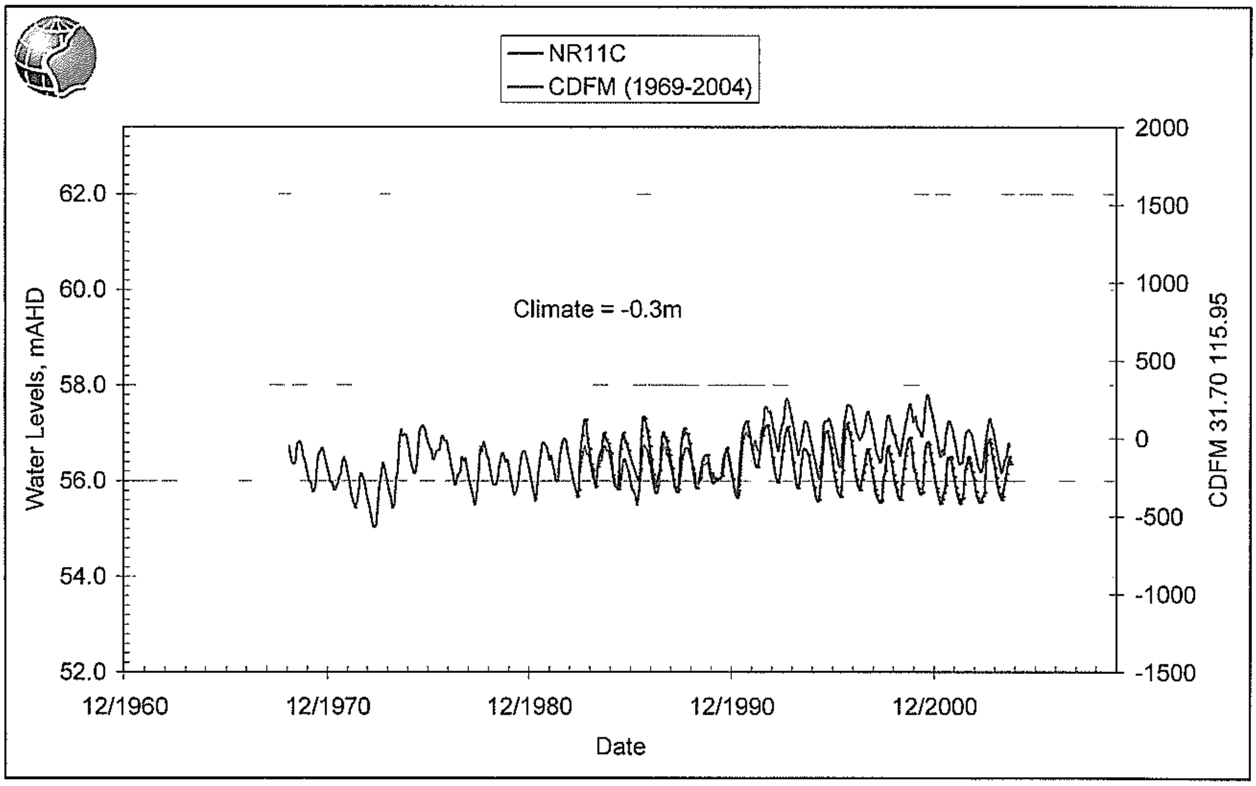


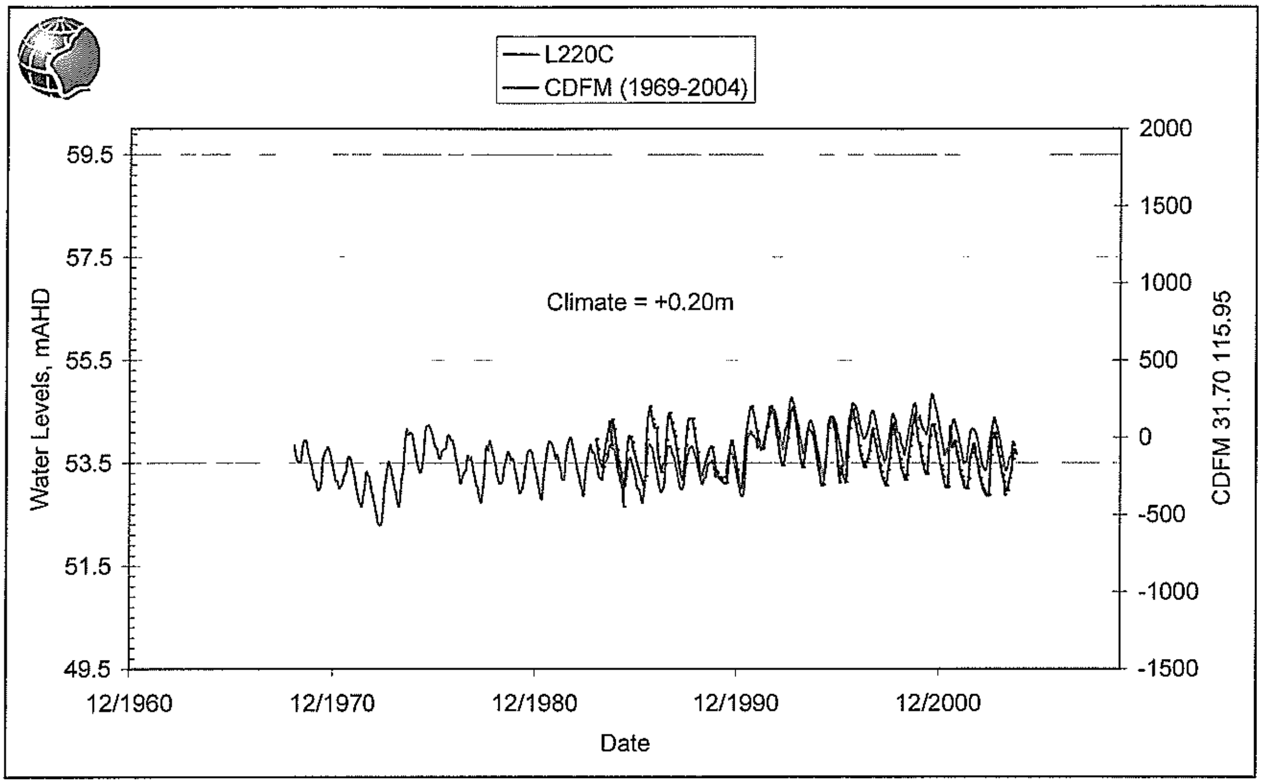
PM8
CDFM (1907-2004)
Climate = -3.05m
Bush fires = +1.4m
Water Levels, mAHD
72.4
71.4
70.4
69.4
68.4
67.4
66.4
65.4
2500
2000
1500
1000
500
0
-500
-1000
CDFM 31.60 115.85
12/1968
12/1978
12/1988
12/1998
12/2008
Date



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
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
CDFM 31.55 115.90
12/1968
12/1978
12/1988
12/1998
12/2008
Date

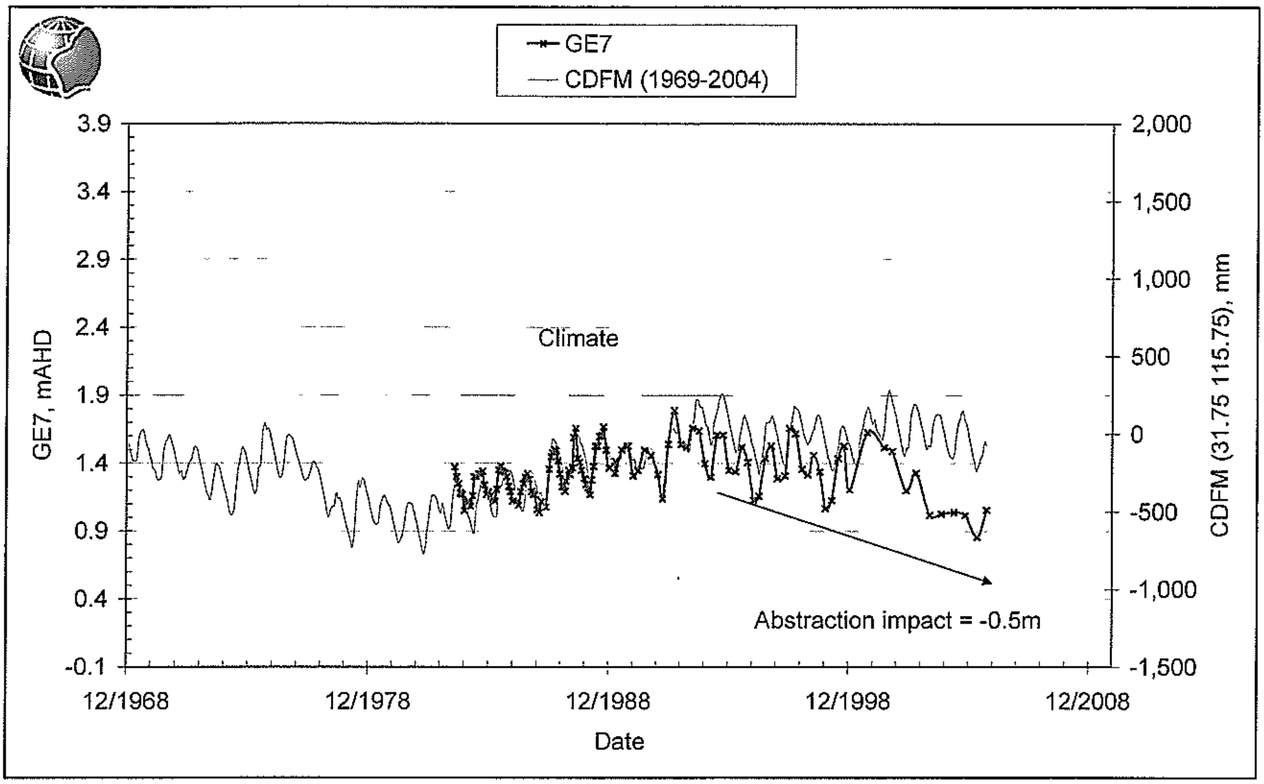

NR2C
CDFM (1969-2004)
Close to the discharge zone
Climate = 0.3m
dense bushes = -1.2 m
Water Levels, mAHD
71.50
69.50
67.50
65.50
63.50
CDFM (31.65 115.95), mm
1500
1000
500
0
-500
-1000
-1500
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

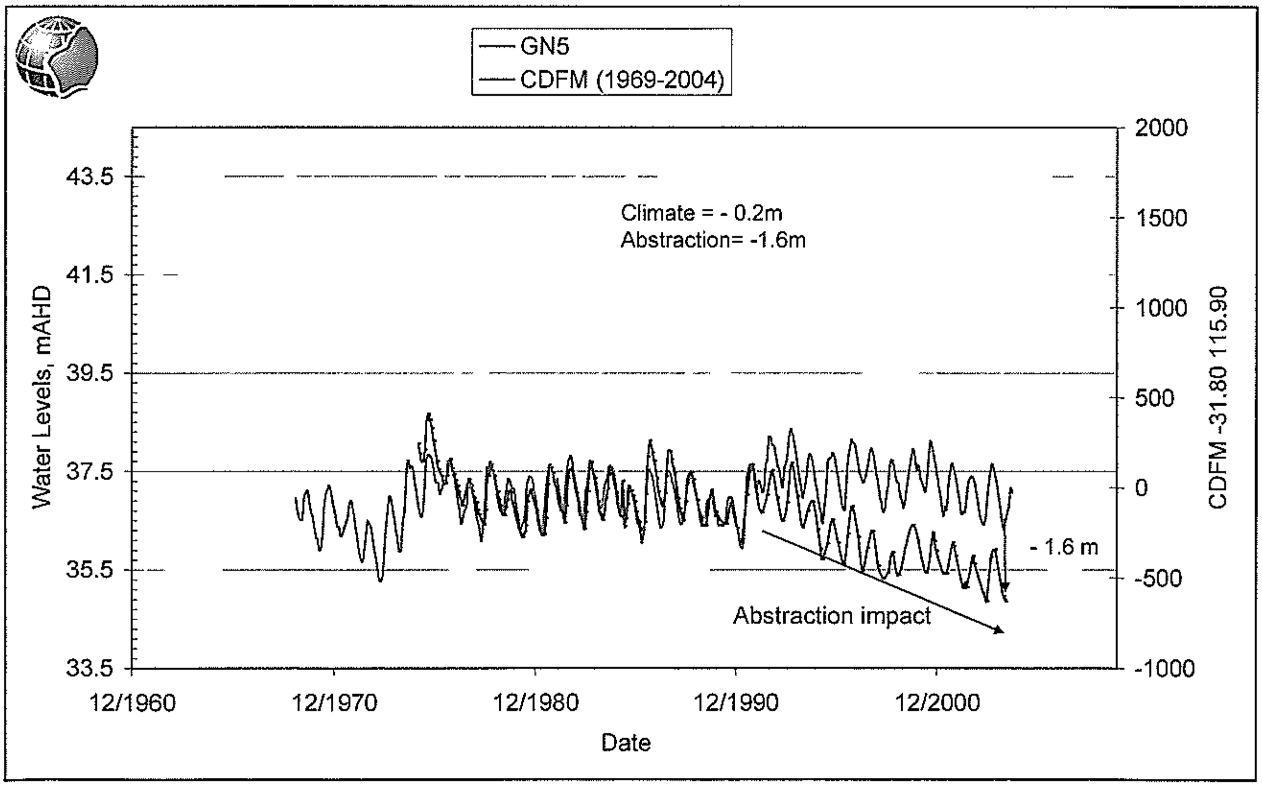

NR11C
CDFM (1969-2004)
Climate = -0.3m
Water Levels, mAHD
62.0
60.0
58.0
56.0
54.0
52.0
CDFM 31.70 115.95
2000
1500
1000
500
0
-500
-1000
-1500
12/1960
12/1970
12/1980
12/1990
12/2000
Date

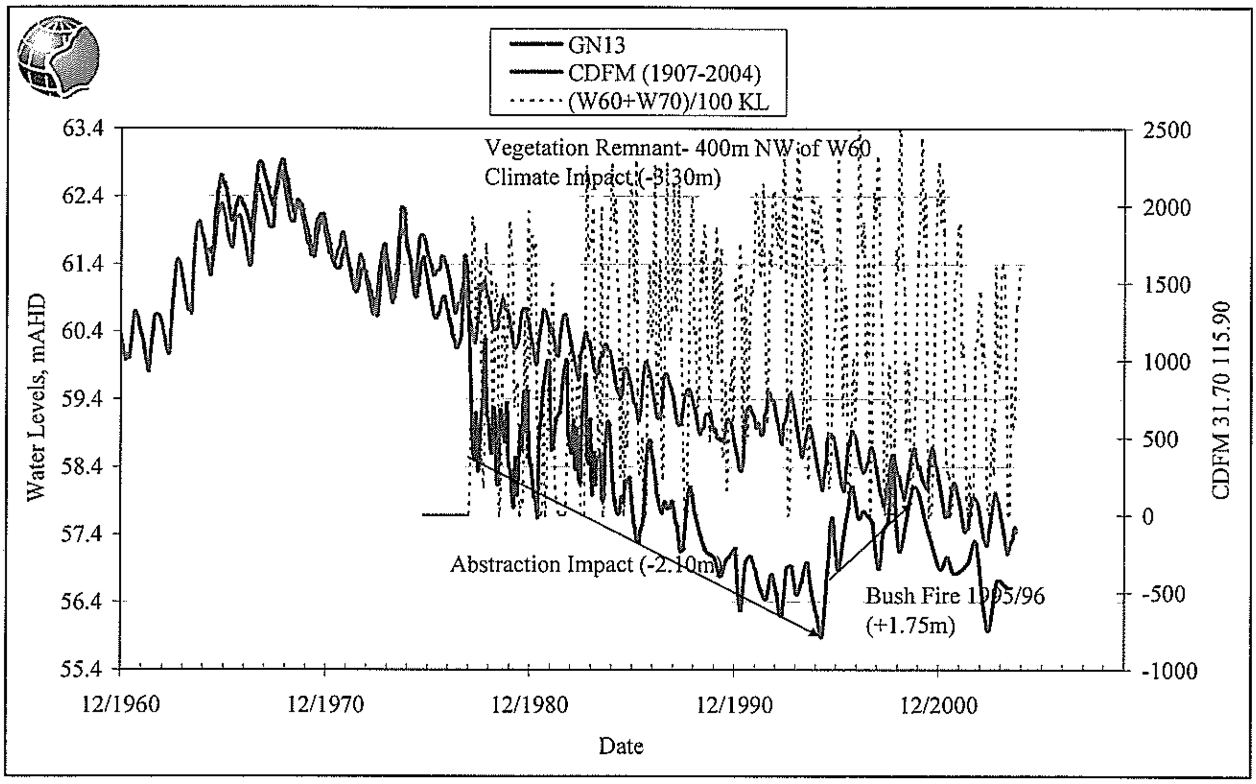

L220C
CDFM (1969-2004)
Climate = +0.20m
Water Levels, mAHD
59.5
57.5
55.5
53.5
51.5
49.5
2000
1500
1000
500
0
-500
-1000
-1500
CDFM 31.70 115.95
12/1960
12/1970
12/1980
12/1990
12/2000
Date

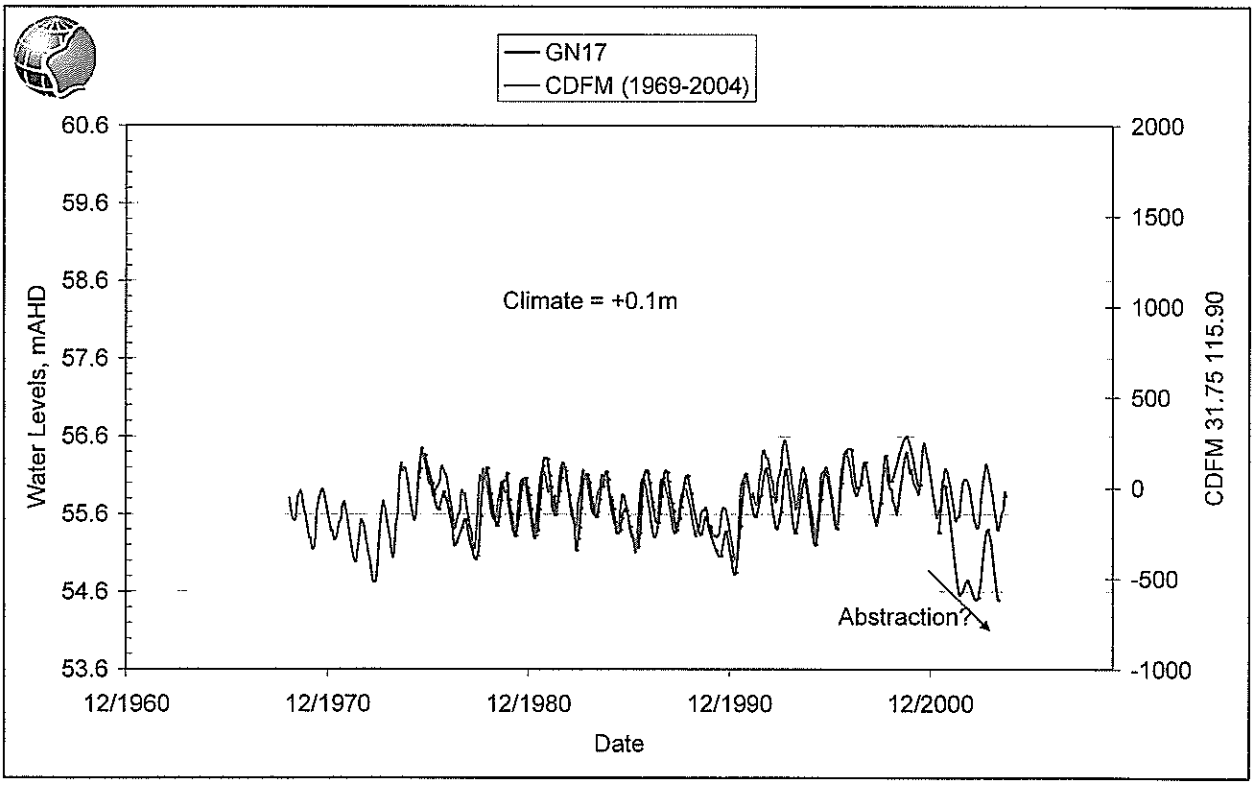
4. Wanneroo Rainfall Zone

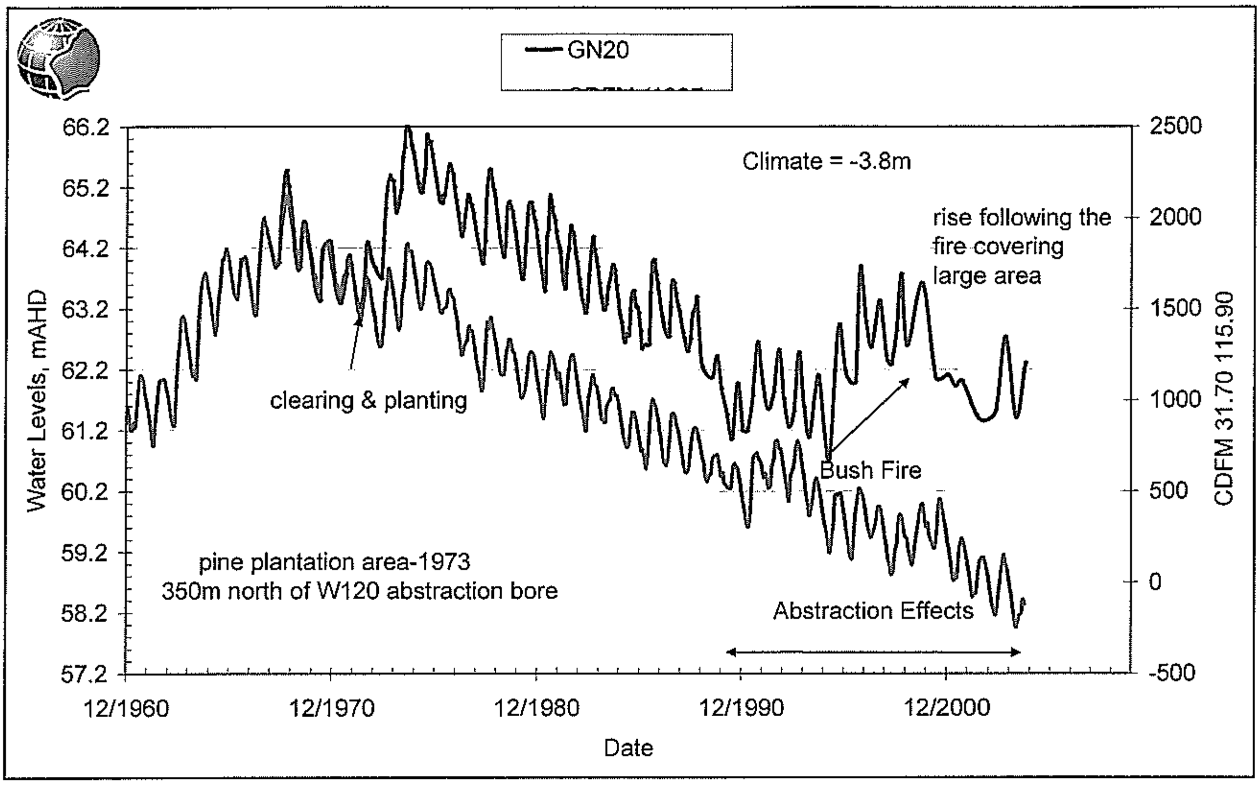
(GE7, GN5, GN13, GN17, GN20, GN23, JB5, MS10, 8281, 459, NR3C, PM13, WM1, WM2, WM4, WM5, WM13, WM24, WM28, MM9, MM14, WH100, WF12)

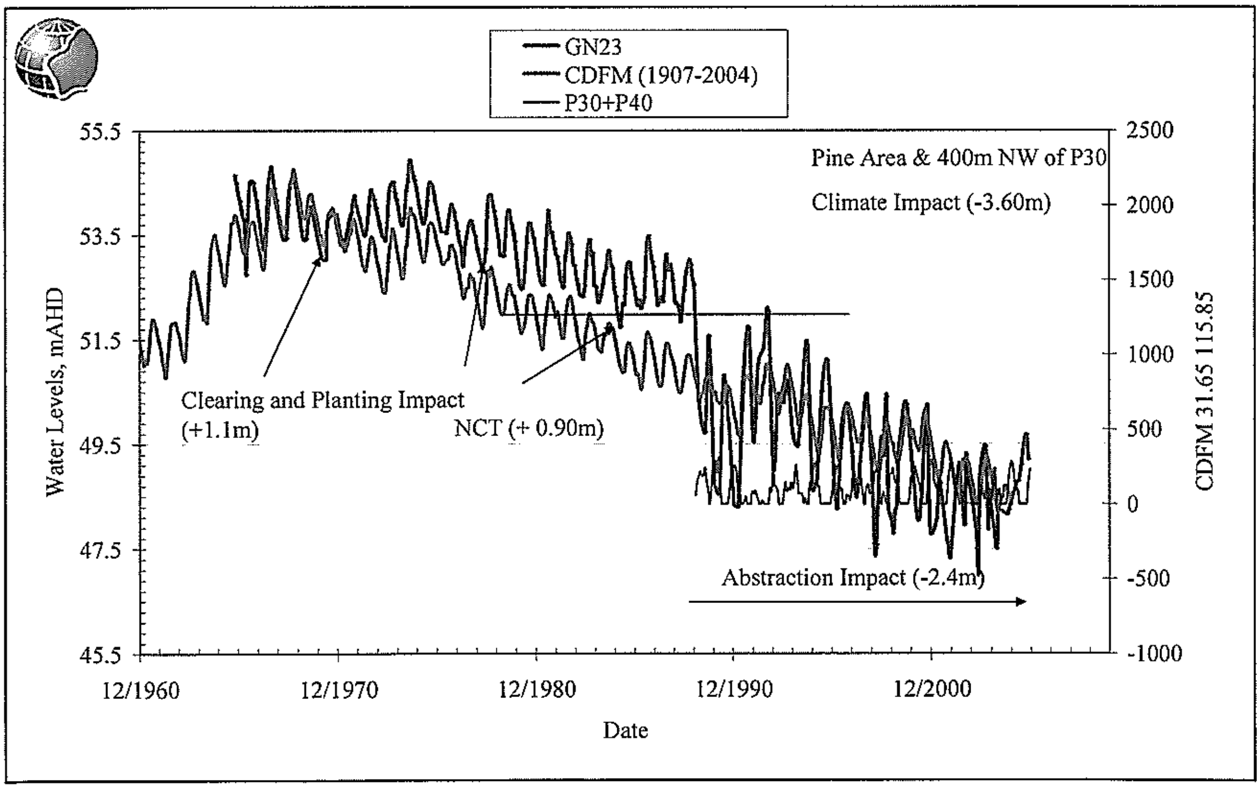

GE7
CDFM (1969-2004)
3.9
3.4
2.9
2.4
1.9
1.4
0.9
0.4
-0.1
GE7, mAHD
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
CDFM (31.75 115.75), mm
Climate
Abstraction impact = -0.5m
12/1968
12/1978
12/1988
12/1998
12/2008
Date

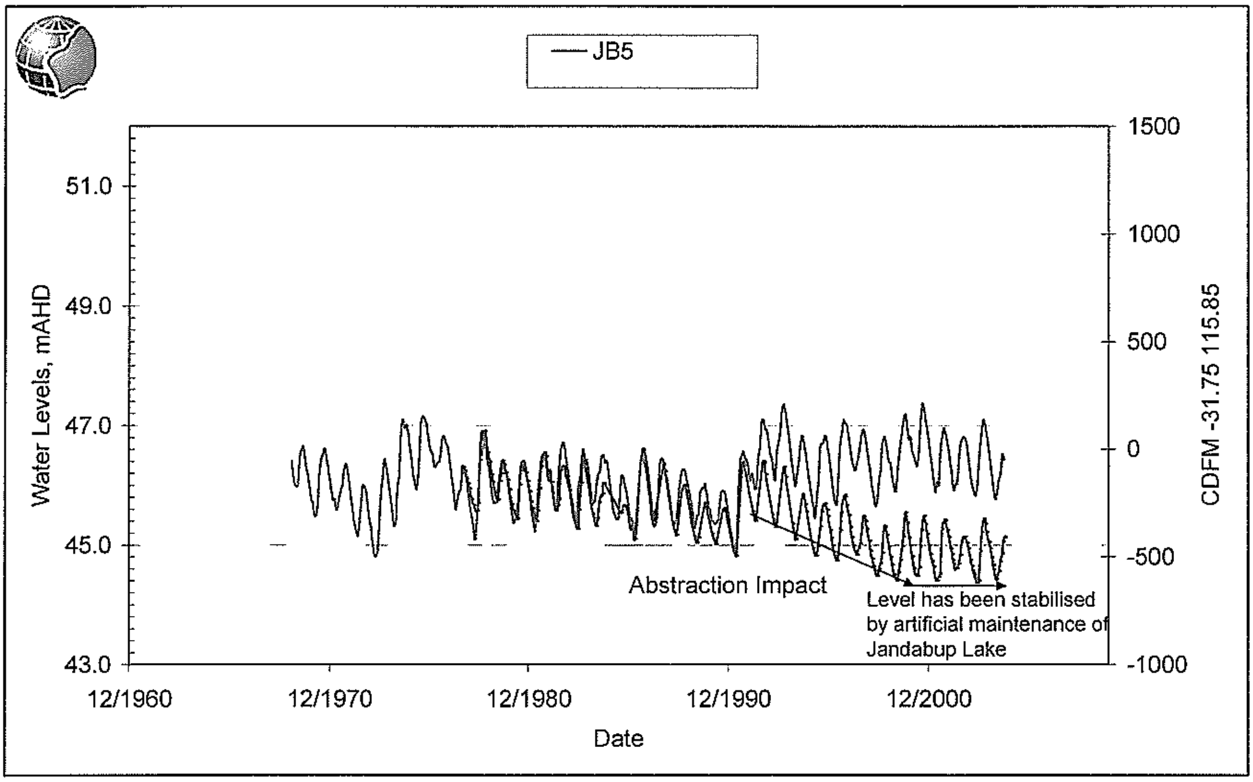

GN5
CDFM (1969-2004)
43.5
41.5
39.5
37.5
35.5
33.5
Water Levels, mAHD
2000
1500
1000
500
0
-500
-1000
CDFM -31.80 115.90
Climate = - 0.2m
Abstraction= -1.6m
- 1.6 m
Abstraction impact
12/1960
12/1970
12/1980
12/1990
12/2000
Date

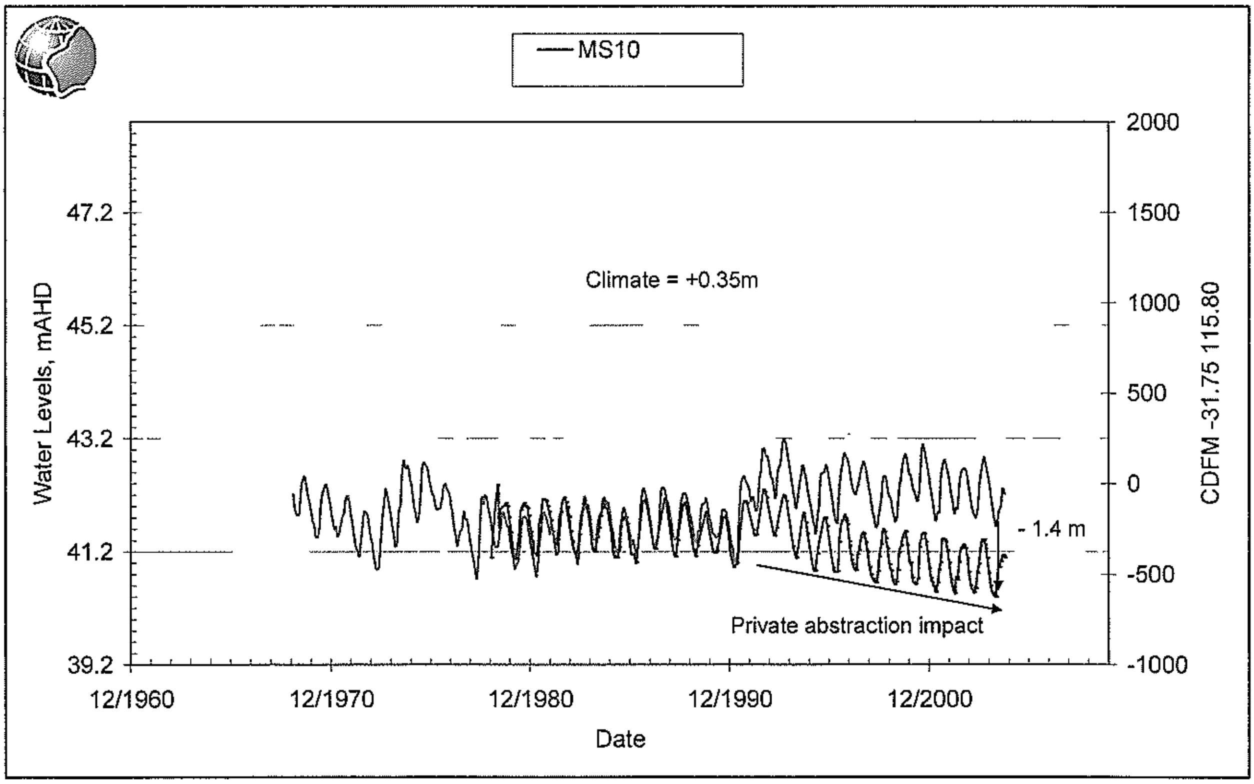

GN13
CDFM (1907-2004)
(W60+W70)/100 KL
Vegetation Remnant- 400m NW of W60
Climate Impact (-3.30m)
Abstraction Impact (-2.10m)
Bush Fire 1995/96
(+1.75m)
Water Levels, mAHD
63.4
62.4
61.4
60.4
59.4
58.4
57.4
56.4
55.4
CDFM 31.70 115.90
2500
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990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

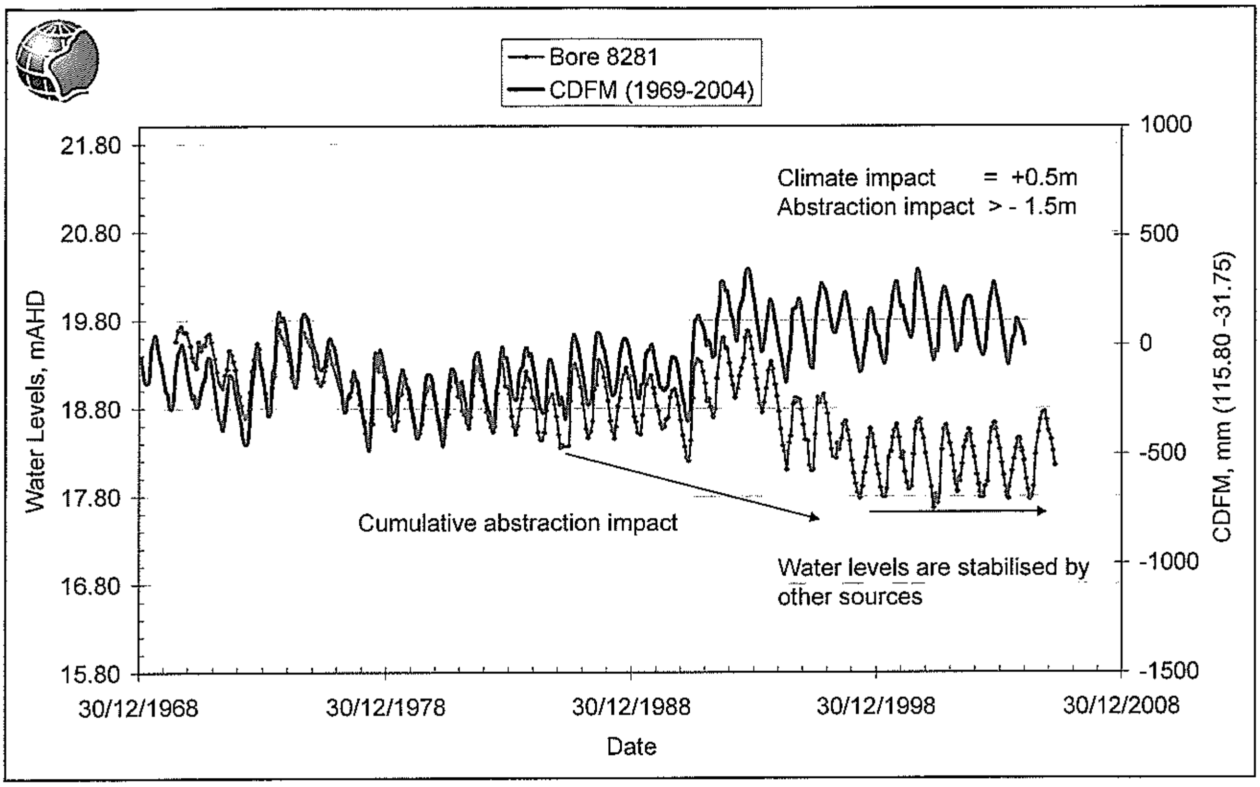

GN17
CDFM (1969-2004)
Climate = +0.1m
Abstraction?
Water Levels, mAHD
60.6
59.6
58.6
57.6
56.6
55.6
54.6
53.6
CDFM 31.75 115.90
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000
Date

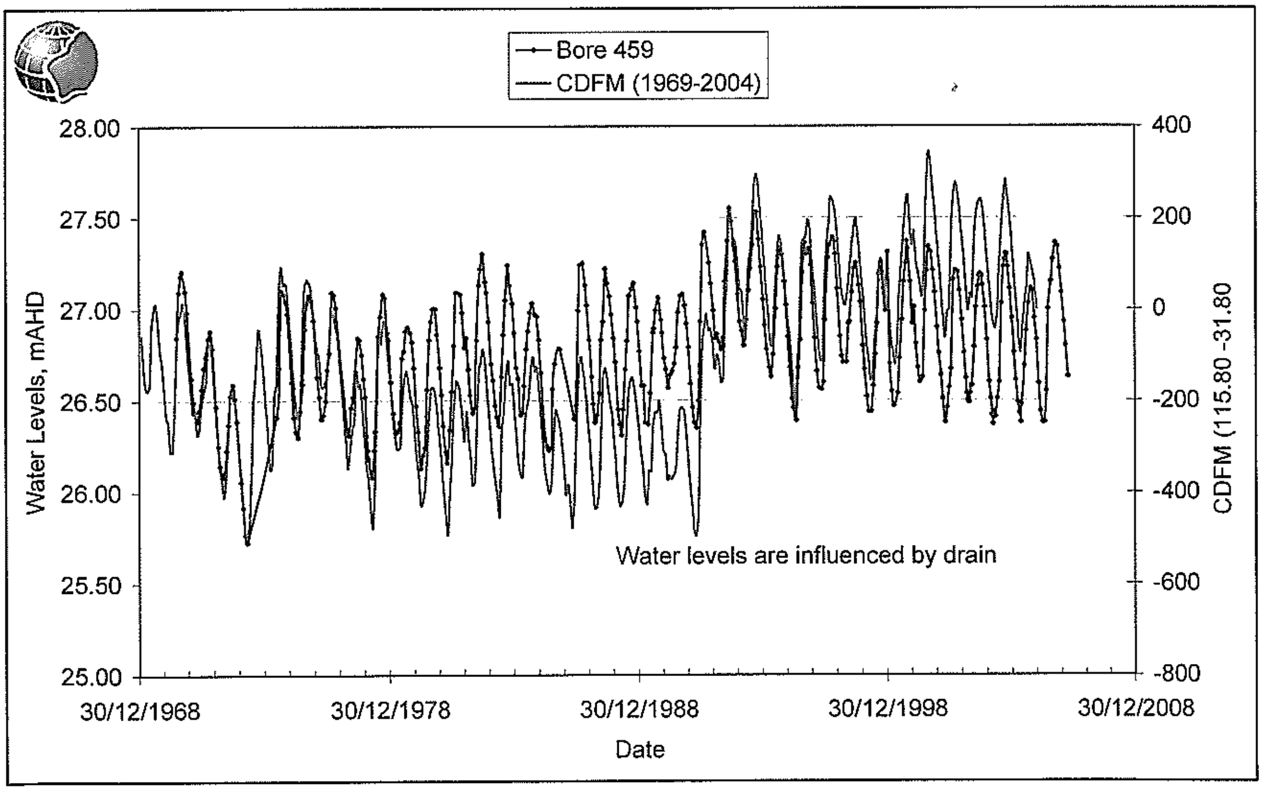

GN20
66.2
65.2
64.2
63.2
62.2
61.2
60.2
59.2
58.2
57.2
Water Levels, mAHD
Climate = -3.8m
rise following the fire covering large area
clearing & planting
Bush Fire
pine plantation area-1973
350m north of W120 abstraction bore
Abstraction Effects
2500
2000
1500
1000
500
0
-500
CDFM 31.70 115.90
12/1960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

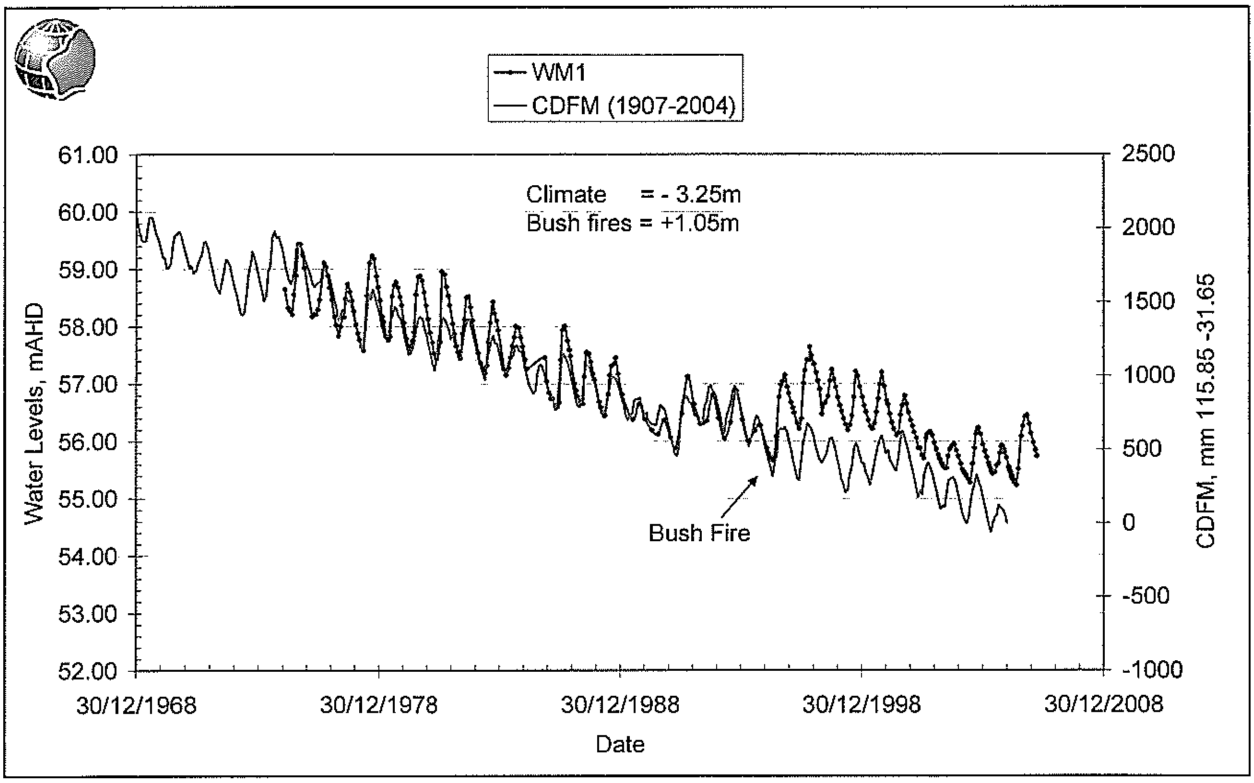

GN23
CDFM (1907-2004)
P30+P40
55.5
53.5
51.5
49.5
47.5
45.5
Water Levels, mAHD
Pine Area & 400m NW of P30
Climate Impact (-3.60m)
Clearing and Planting Impact (+1.1m)
NCT (+ 0.90m)
Abstraction Impact (-2.4m)
2500
2000
1500
1000
500
0
-500
-1000
CDFM 31.65 115.85
12/1960
12/1970
12/1980
12/1990
12/2000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

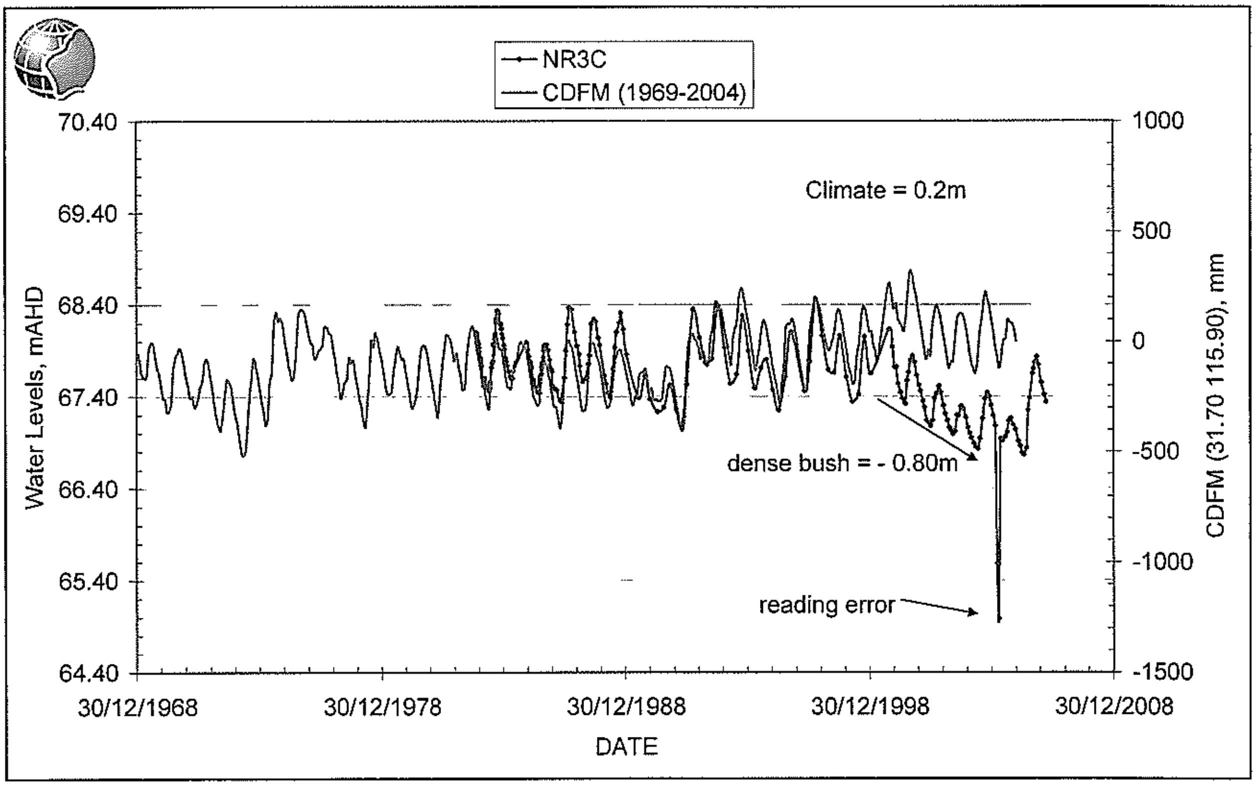

JB5
Water Levels, mAHD
CDFM -31.75 115.85
51.0
49.0
47.0
45.0
43.0
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000
Date
Abstraction Impact
Level has been stabilised by artificial maintenance of Jandabup Lake

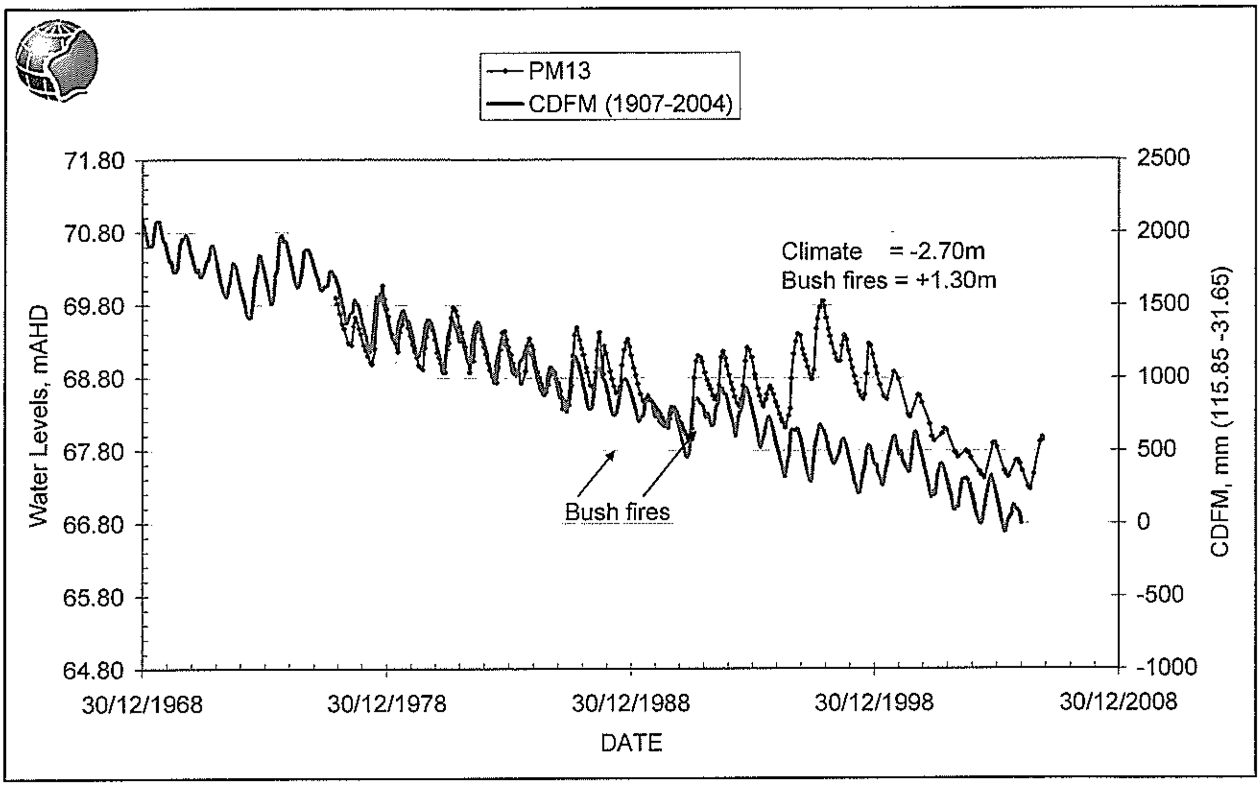

MS10
Water Levels, mAHD
CDFM -31.75 115.80
47.2
45.2
43.2
41.2
39.2
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000
Date
Climate = +0.35m
- 1.4 m
Private abstraction impact

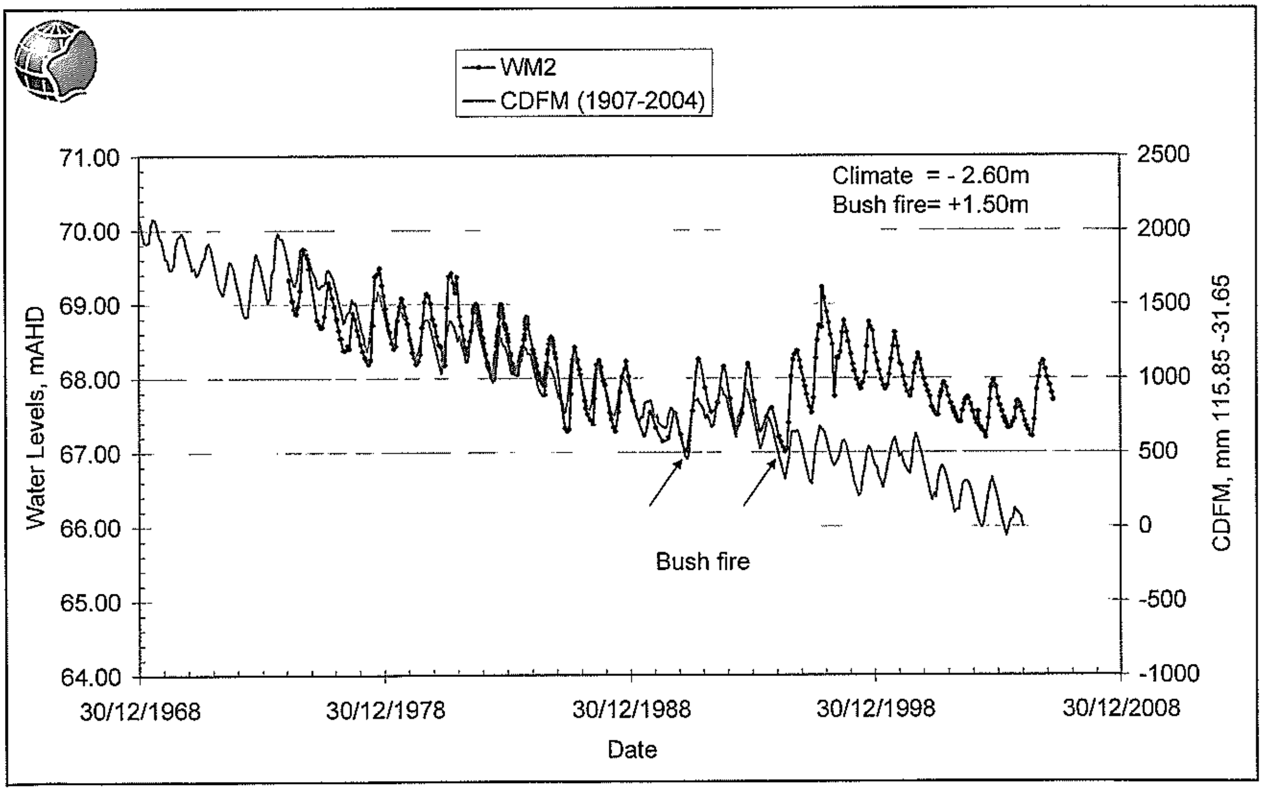

Bore 8281
CDFM (1969-2004)
Climate impact = +0.5m
Abstraction impact > - 1.5m
Cumulative abstraction impact
Water levels are stabilised by other sources
Water Levels, mAHD
CDFM, mm (115.80 -31.75)
21.80
20.80
19.80
18.80
17.80
16.80
15.80
1000
500
0
-500
-1000
-1500
30/12/1968
30/12/1978
30/12/1988
30/12/1998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

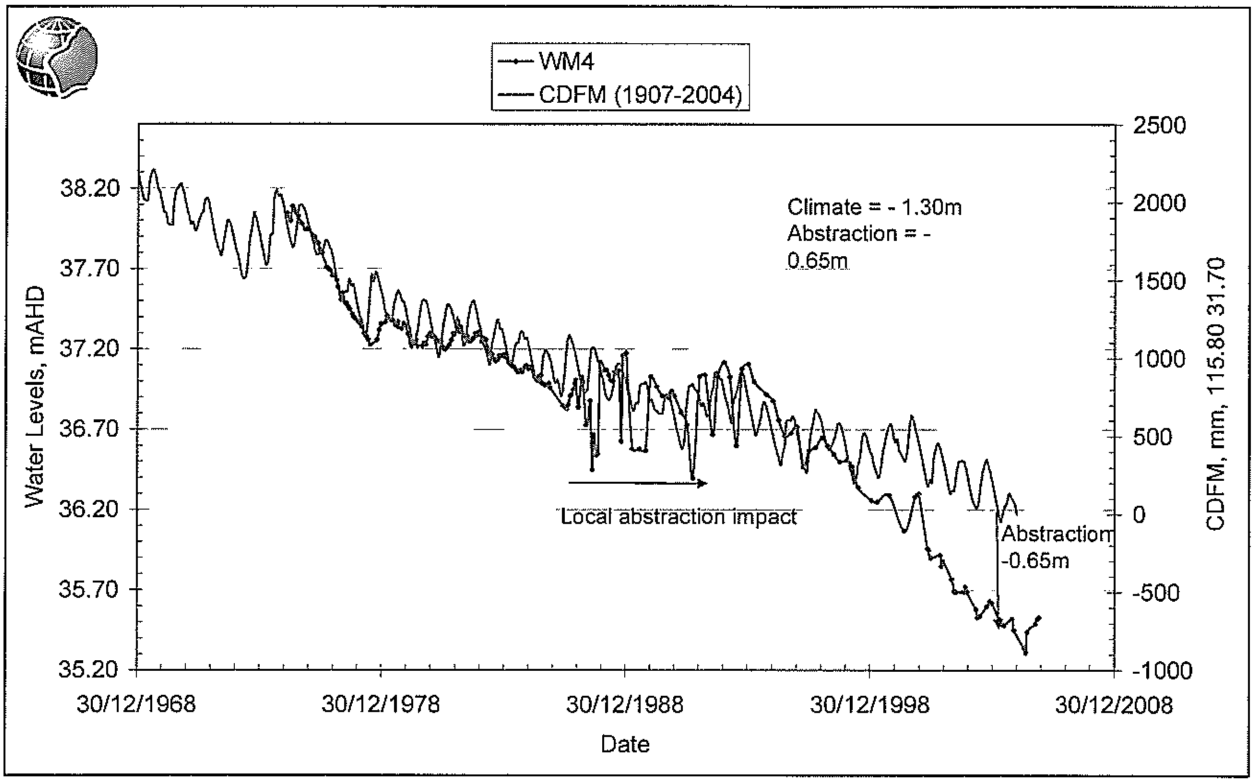

Bore 459
CDFM (1969-2004)
Water levels are influenced by drain
Water Levels, mAHD
CDFM (115.80 -31.80
28.00
27.50
27.00
26.50
26.00
25.50
25.00
400
200
0
-200
-400
-600
-800
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


WM1
CDFM (1907-2004)
Climate = - 3.25m
Bush fires = +1.05m
Bush Fire
61.00
60.00
59.00
58.00
57.00
56.00
55.00
54.00
53.00
52.00
Water Levels, mAHD
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

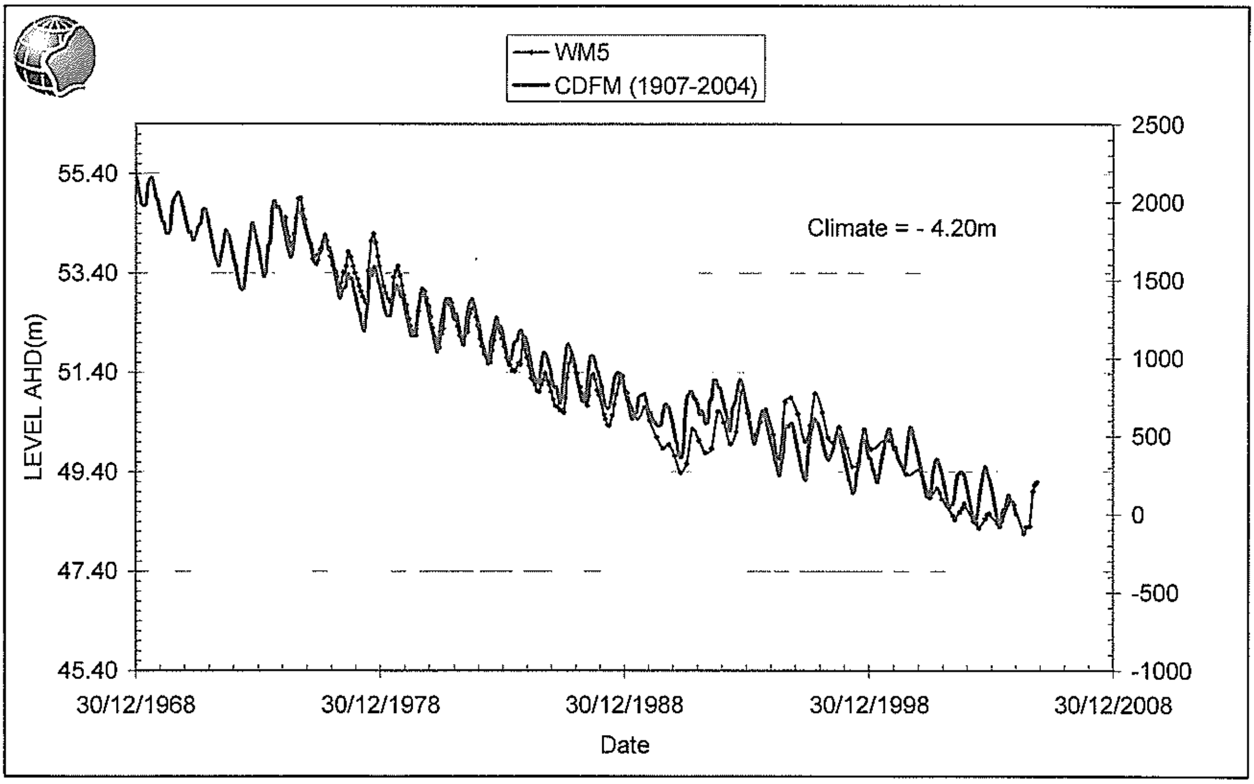

NR3C
CDFM (1969-2004)
Climate = 0.2m
dense bush = - 0.80m
reading error
70.40
69.40
68.40
67.40
66.40
65.40
64.40
Water Levels, mAHD
1000
500
0
-500
-1000
-1500
CDFM (31.70 115.90), mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
DATE


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

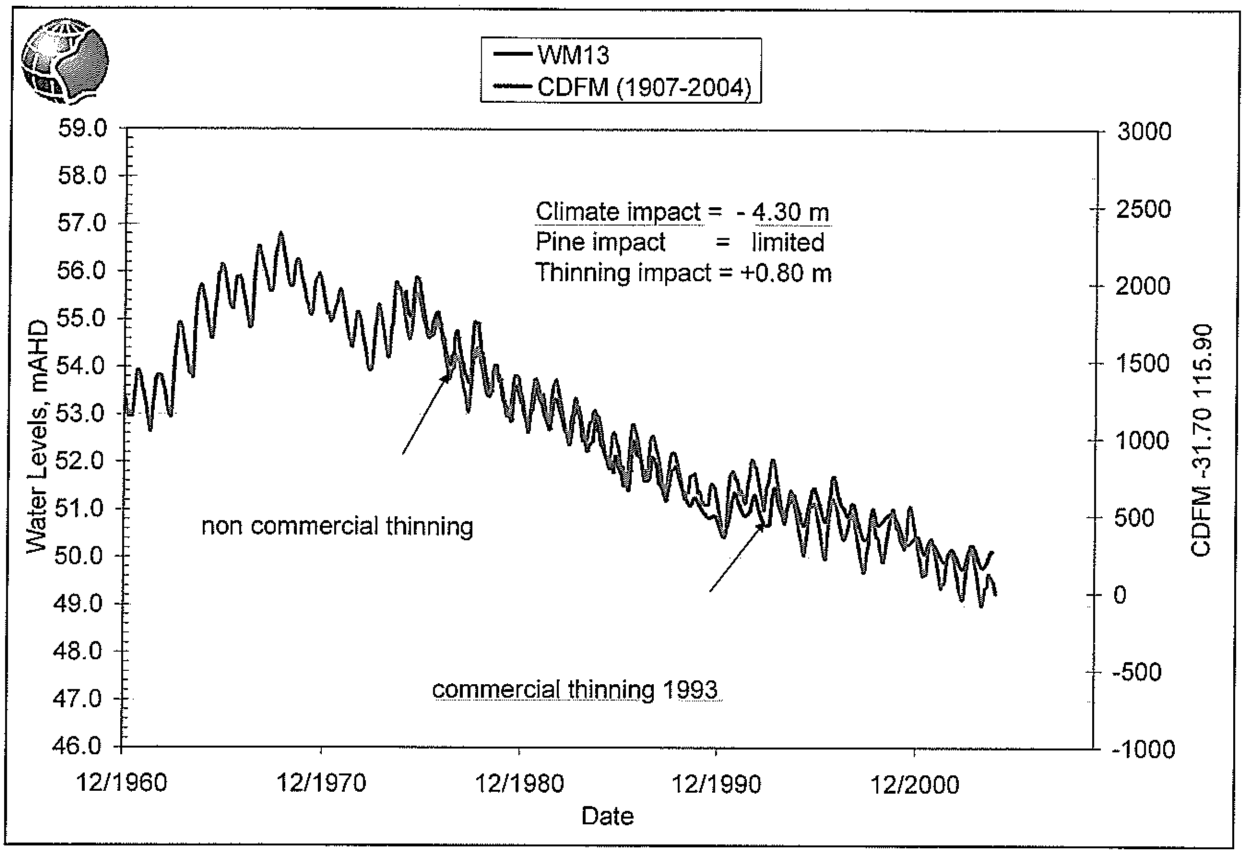

WM2
CDFM (1907-2004)
71.00
70.00
69.00
68.00
67.00
66.00
65.00
64.00
Water Levels, mAHD
2500
2000
1500
1000
500
0
-500
-1000
CDFM, mm 115.85 -31.65
Climate = - 2.60m
Bush fire= +1.50m
Bush fire
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

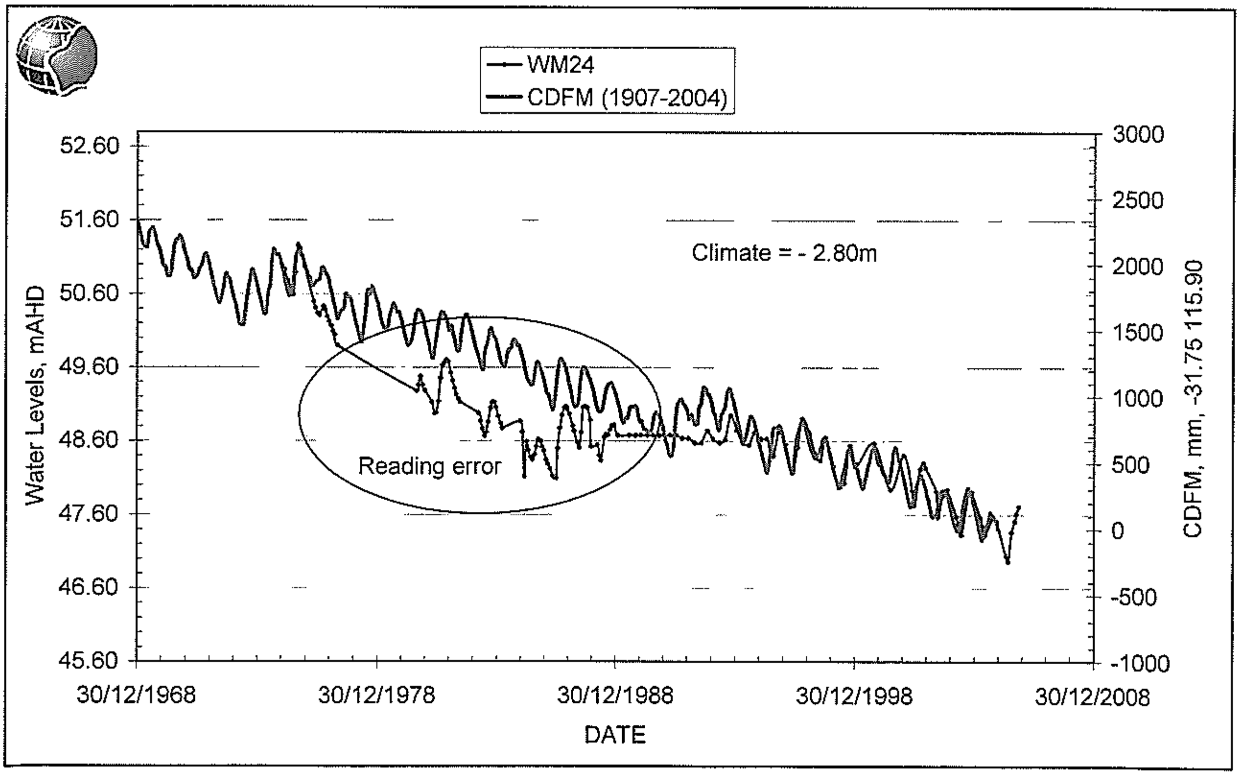


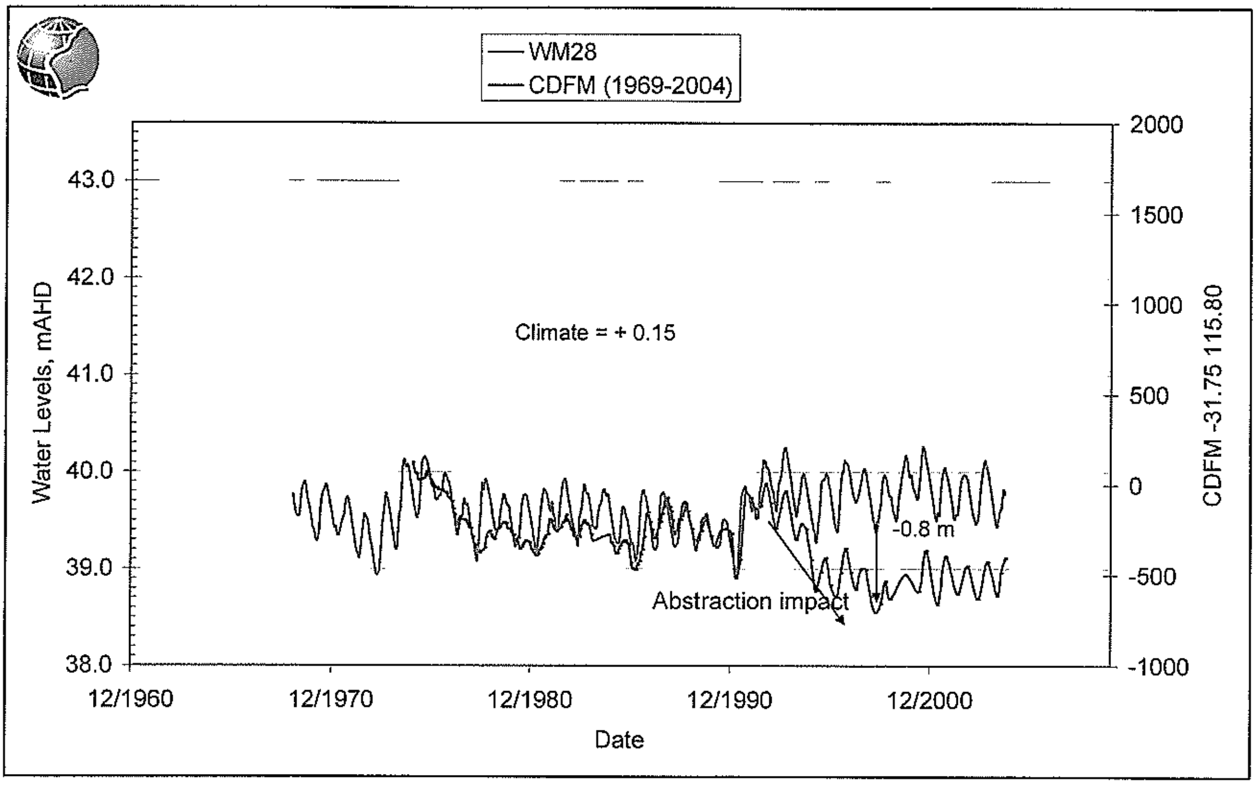
WM4
CDFM (1907-2004)
Climate = - 1.30m
Abstraction = -
0.65m
Local abstraction impact
Abstraction
-0.65m
Water Levels, mAHD
CDFM, mm, 115.80 31.70
Date
38.20
37.70
37.20
36.70
36.20
35.70
35.20
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008

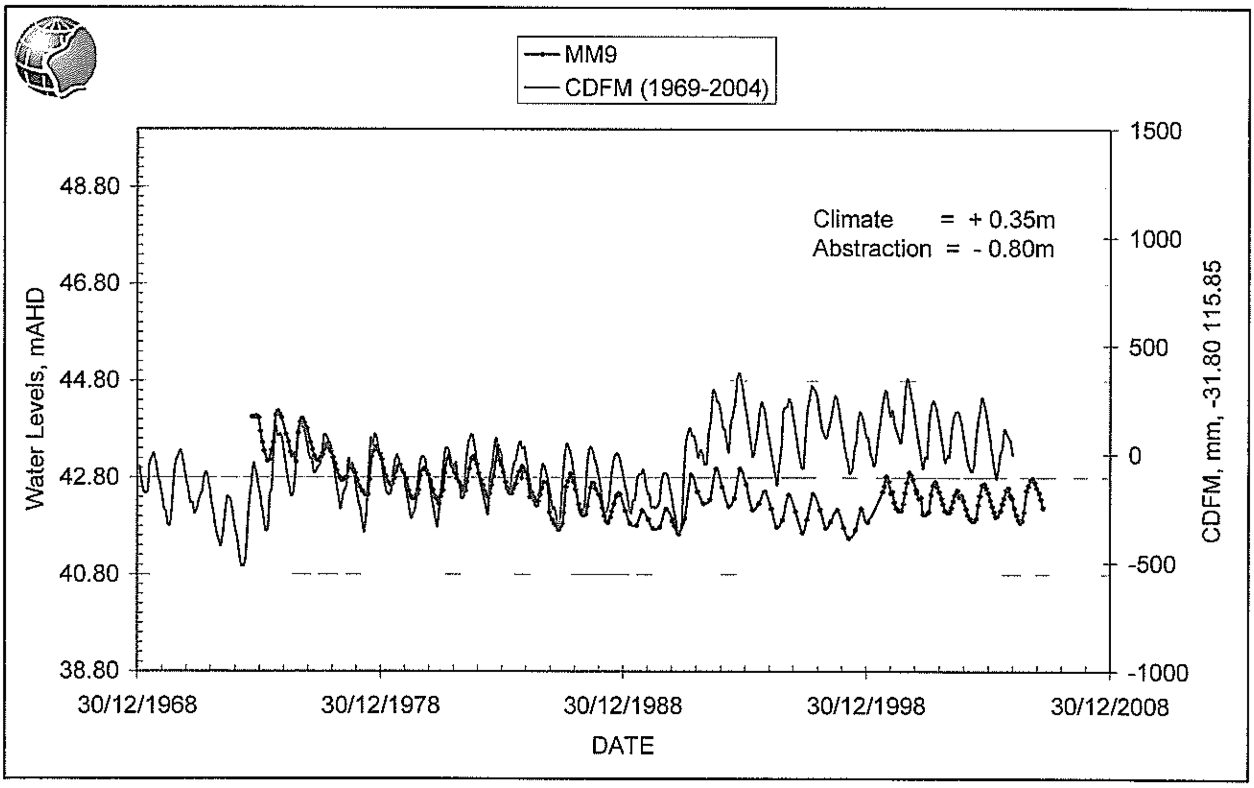


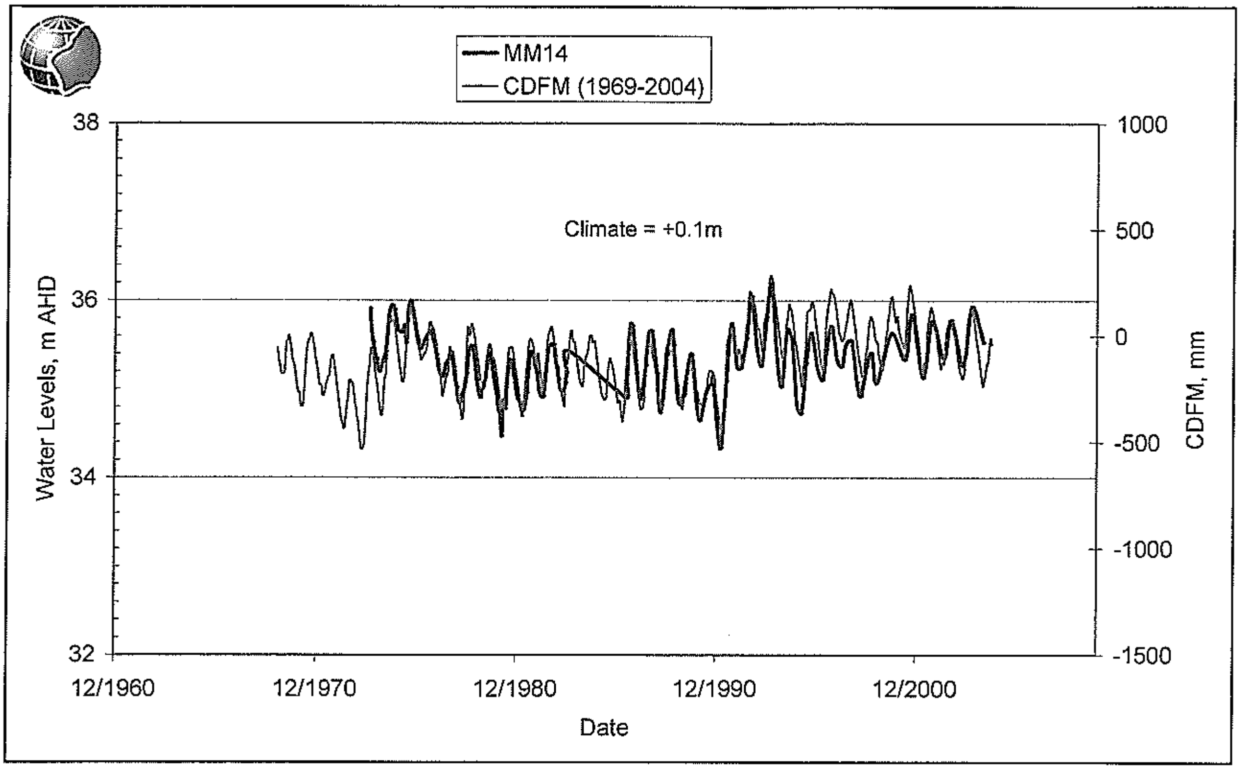
WM5
CDFM (1907-2004)
Climate = - 4.20m
LEVEL AHD(m)
Date
55.40
53.40
51.40
49.40
47.40
45.40
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008

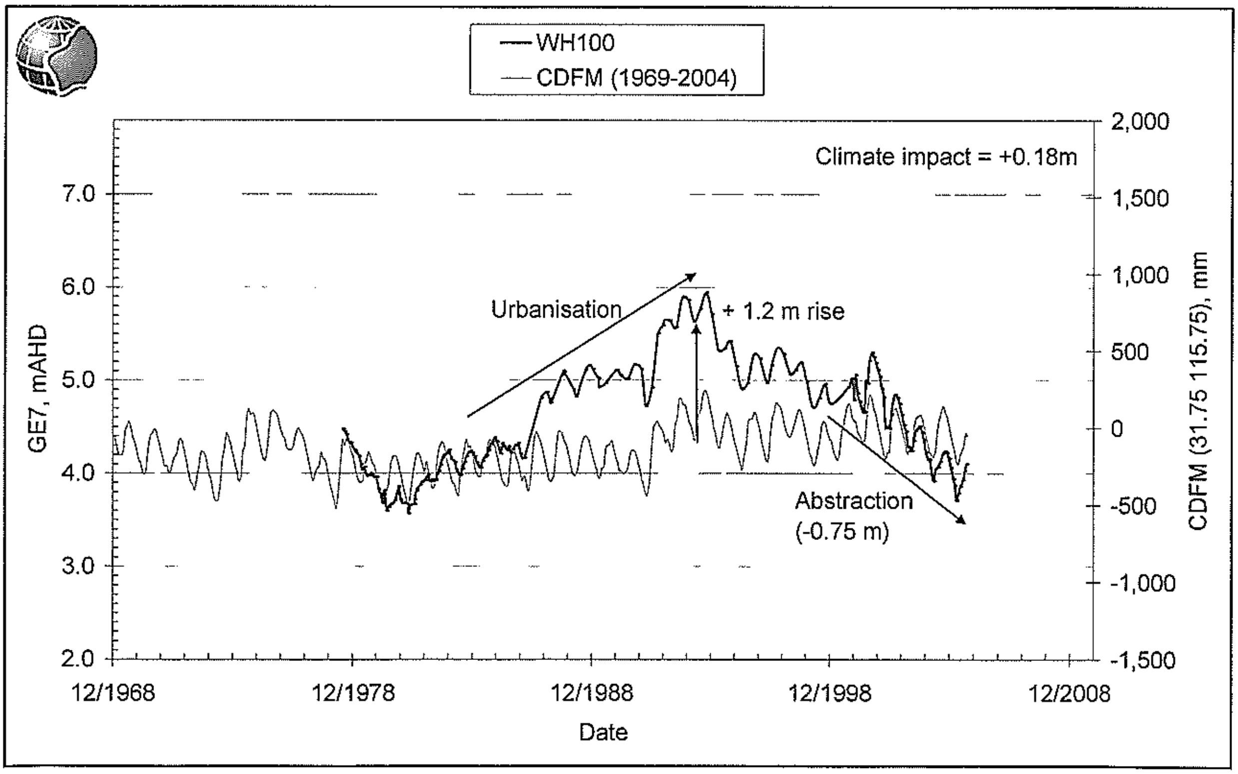

WM13
CDFM (1907-2004)
Climate impact = - 4.30 m
Pine impact = limited
Thinning impact = +0.80 m
non commercial thinning
commercial thinning 1993
Water Levels, mAHD
CDFM -31.70 115.90
Date
59.0
58.0
57.0
56.0
55.0
54.0
53.0
52.0
51.0
50.0
49.0
48.0
47.0
46.0
3000
2500
2000
1500
1000
500
0
-500
-1000
12/1960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

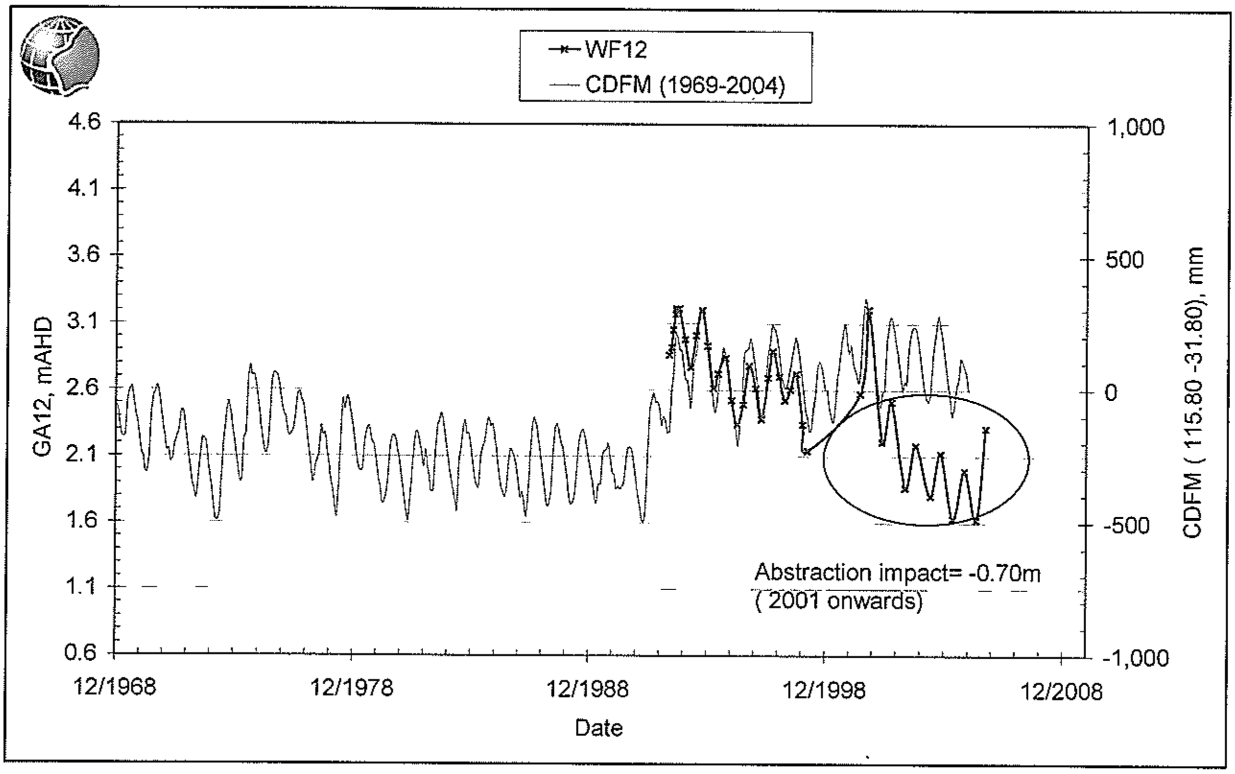

WM24
CDFM (1907-2004)
Climate = - 2.80m
Reading error
Water Levels, mAHD
CDFM, mm, -31.75 115.90
DATE
52.60
51.60
50.60
49.60
48.60
47.60
46.60
45.60
3000
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008


WM28
CDFM (1969-2004)
Climate = + 0.15
-0.8 m
Abstraction impact
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
12/1960
12/1970
12/1980
12/1990
12/2000
Date


MM9
CDFM (1969-2004)
Climate = + 0.35m
Abstraction = - 0.80m
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
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

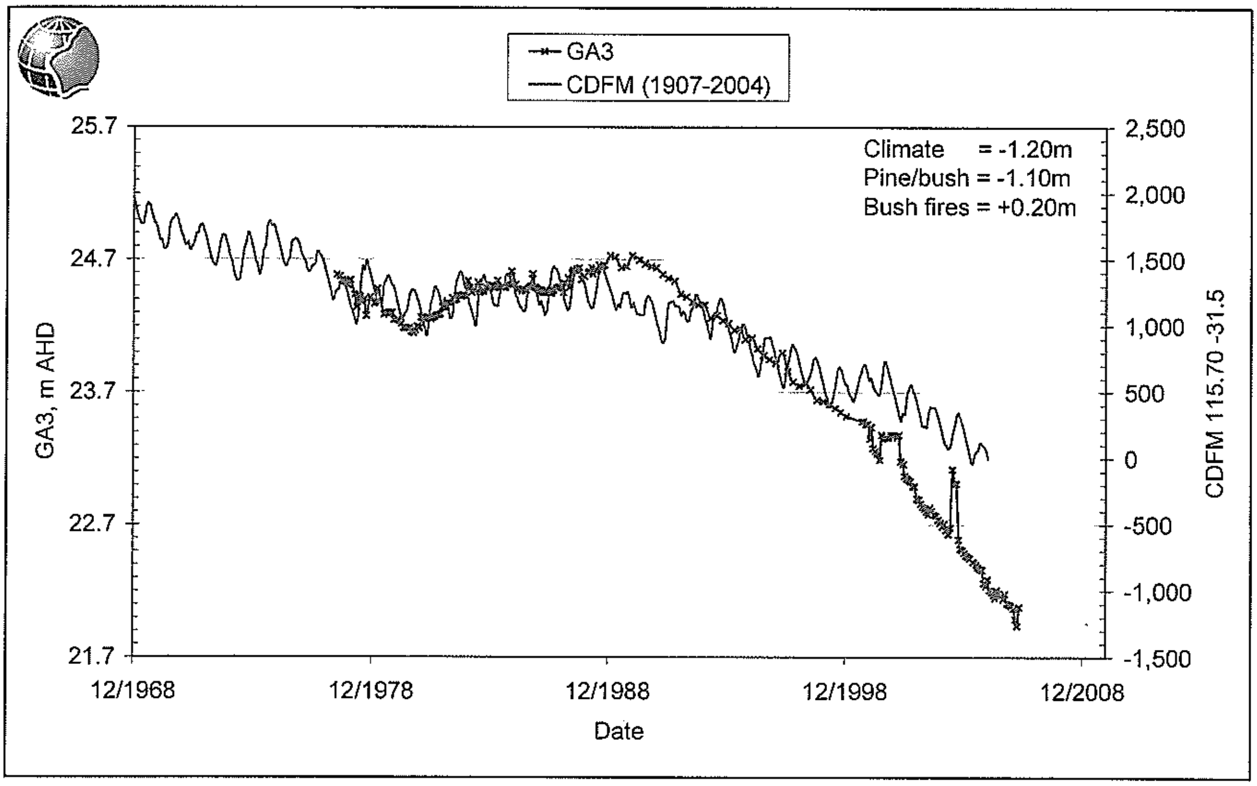

WH100
CDFM (1969-2004)
Climate impact = +0.18m
Urbanisation
+ 1.2 m rise
Abstraction
(-0.75 m)
GE7, mAHD
7.0
6.0
5.0
4.0
3.0
2.0
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
CDFM (31.75 115.75), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

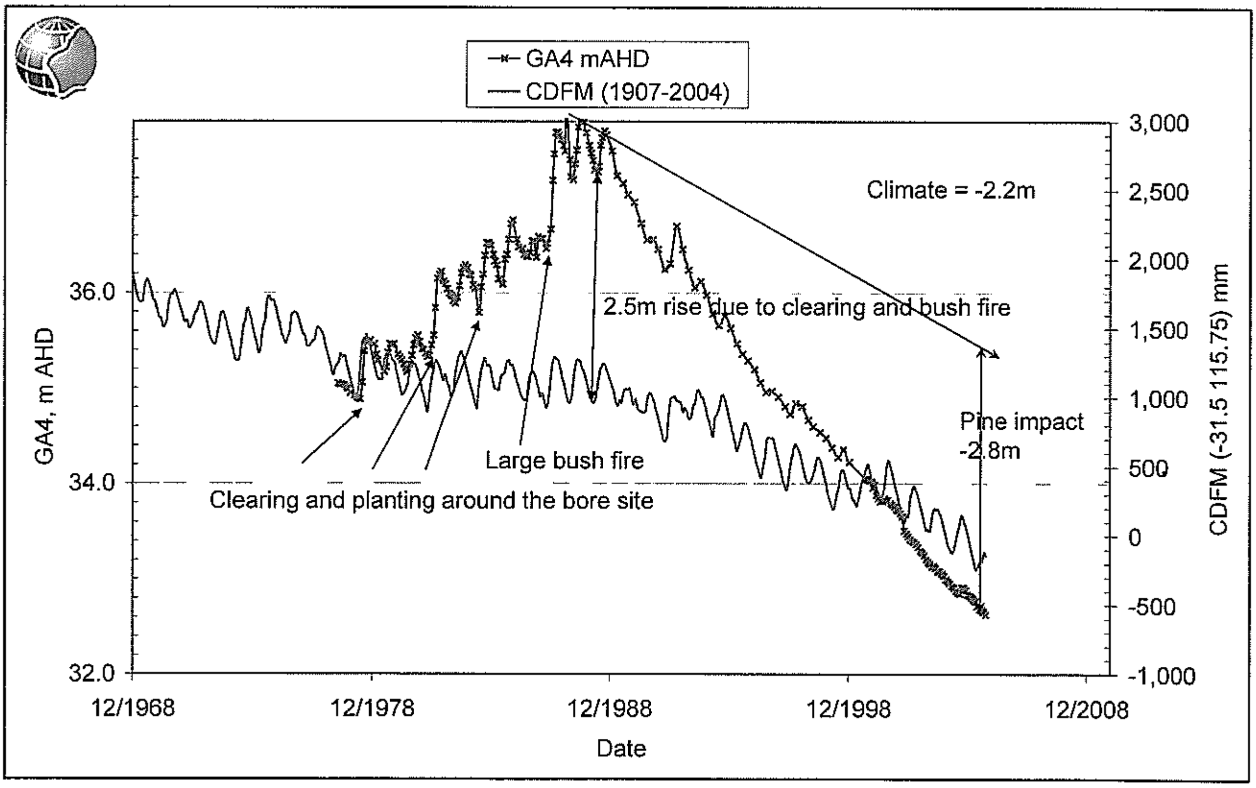


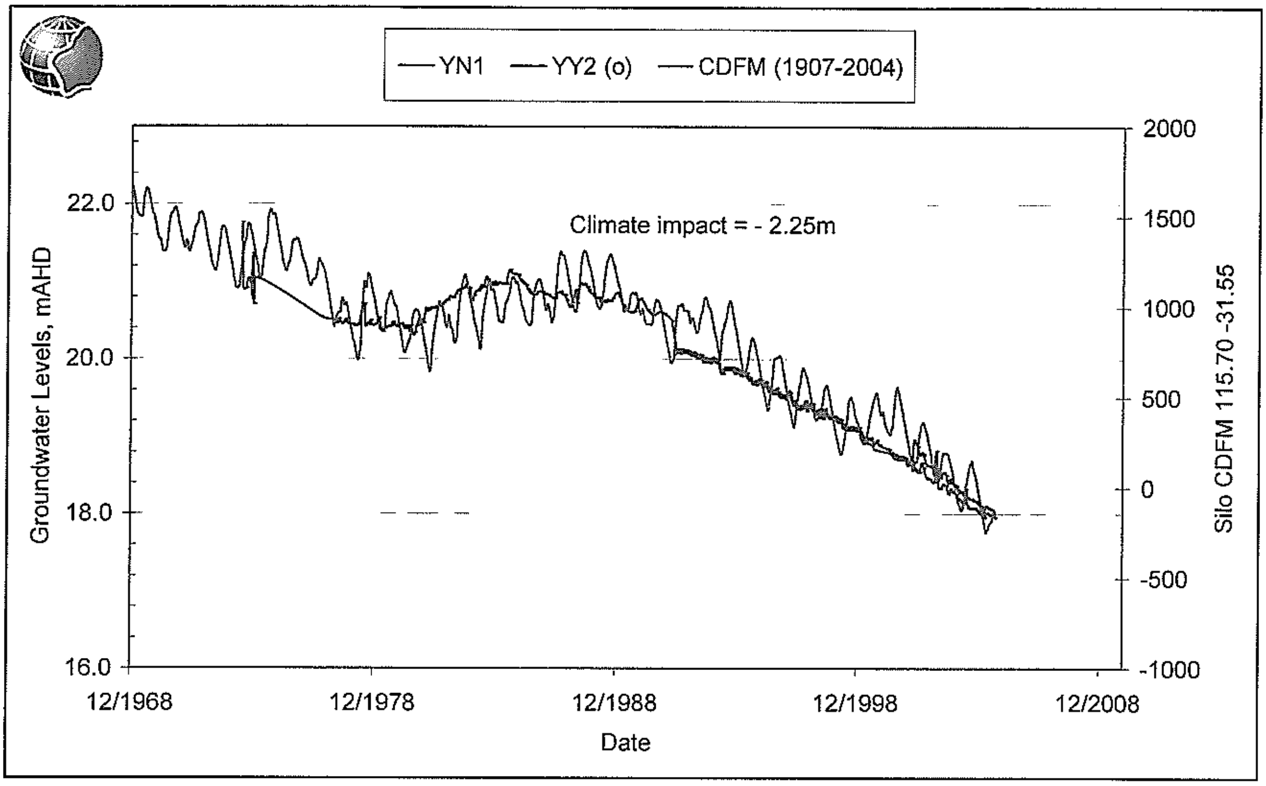
WF12
CDFM (1969-2004)
4.6
4.1
3.6
3.1
2.6
2.1
1.6
1.1
0.6
GA12, mAHD
1,000
500
0
-500
-1,000
CDFM (115.80 -31.80), mm
Abstraction impact= -0.70m
(2001 onwards)
12/1968
12/1978
12/1988
12/1998
12/2008
Date

5. Yanchep Rainfall Zone

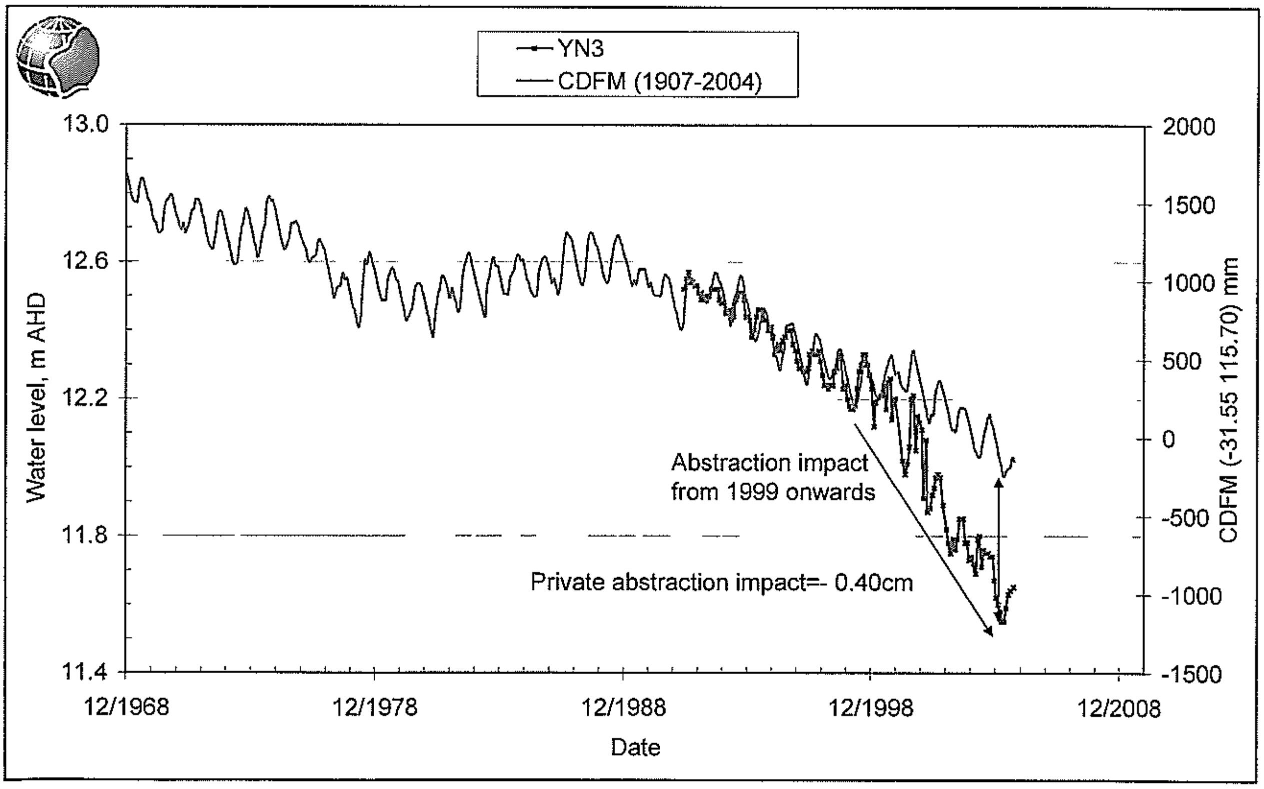
(GA3, GA4, YN1, YY2, YN3, YN4, Crystal Cave, YB11, CG4-90, PM27, PM28, PM31, PM33, PM36, YCM, JP3D, JP12, JP16B, JP19)


GA3
CDFM (1907-2004)
Climate = -1.20m
Pine/bush = -1.10m
Bush fires = +0.20m
GA3, m AHD
CDFM 115.70 -31.5
Date
25.7
24.7
23.7
22.7
21.7
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

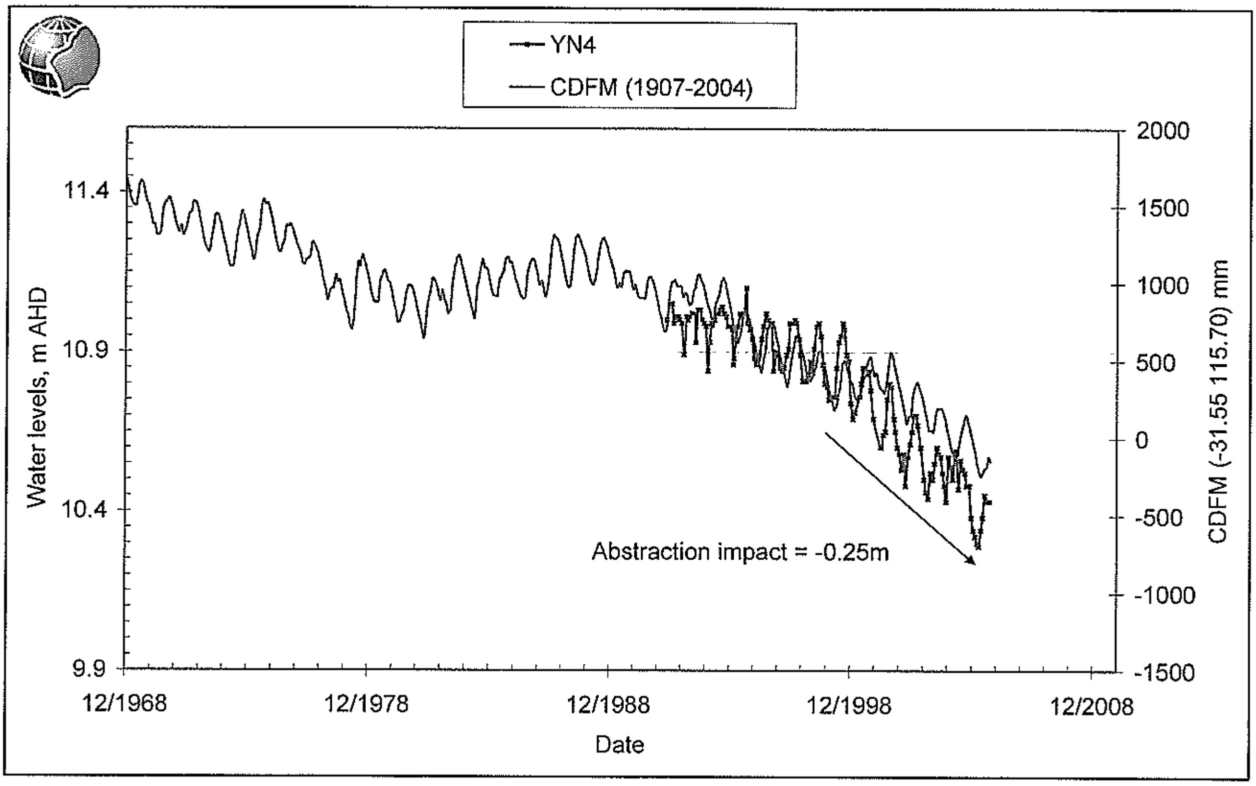

GA4 mAHD
CDFM (1907-2004)
Climate = -2.2m
2.5m rise due to clearing and bush fire
Pine impact -2.8m
Large bush fire
Clearing and planting around the bore site
GA4, m AHD
CDFM (-31.5 115.75) mm
Date
36.0
34.0
32.0
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
12/1968
12/1978
12/1988
12/1998
12/2008

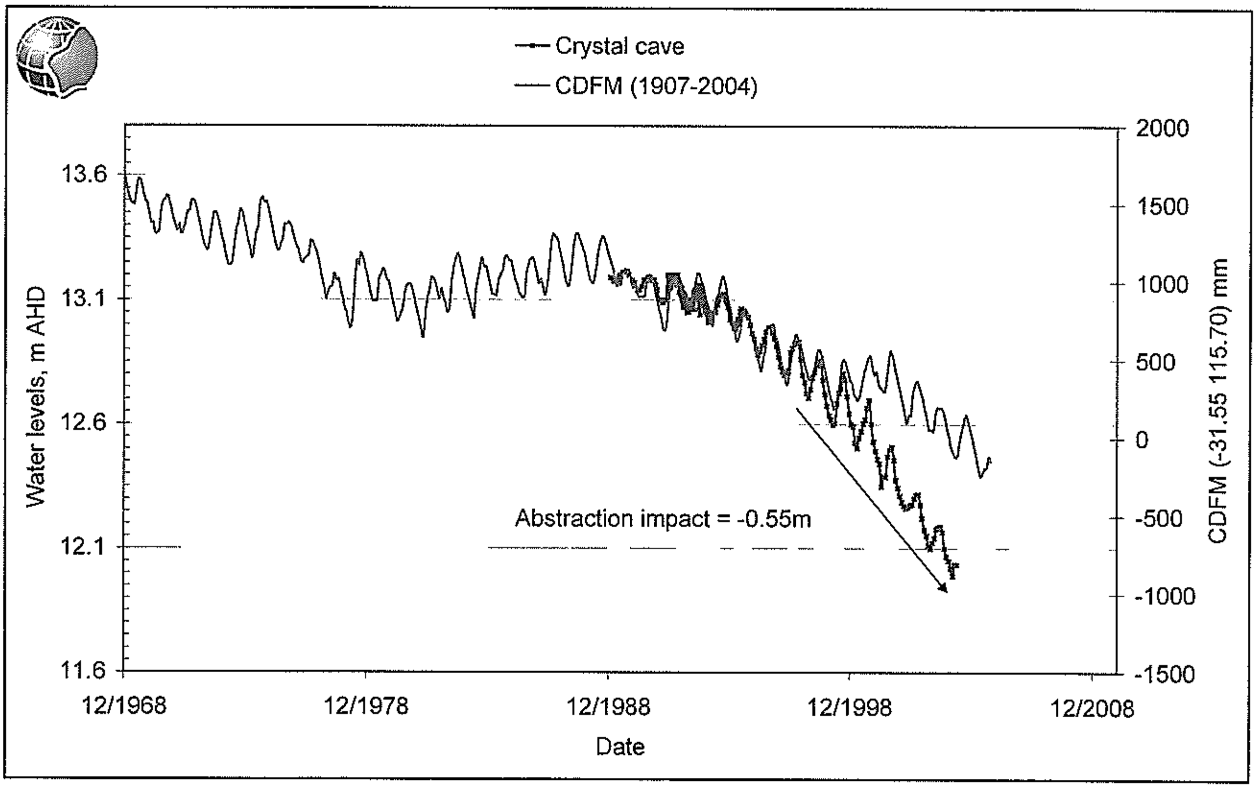


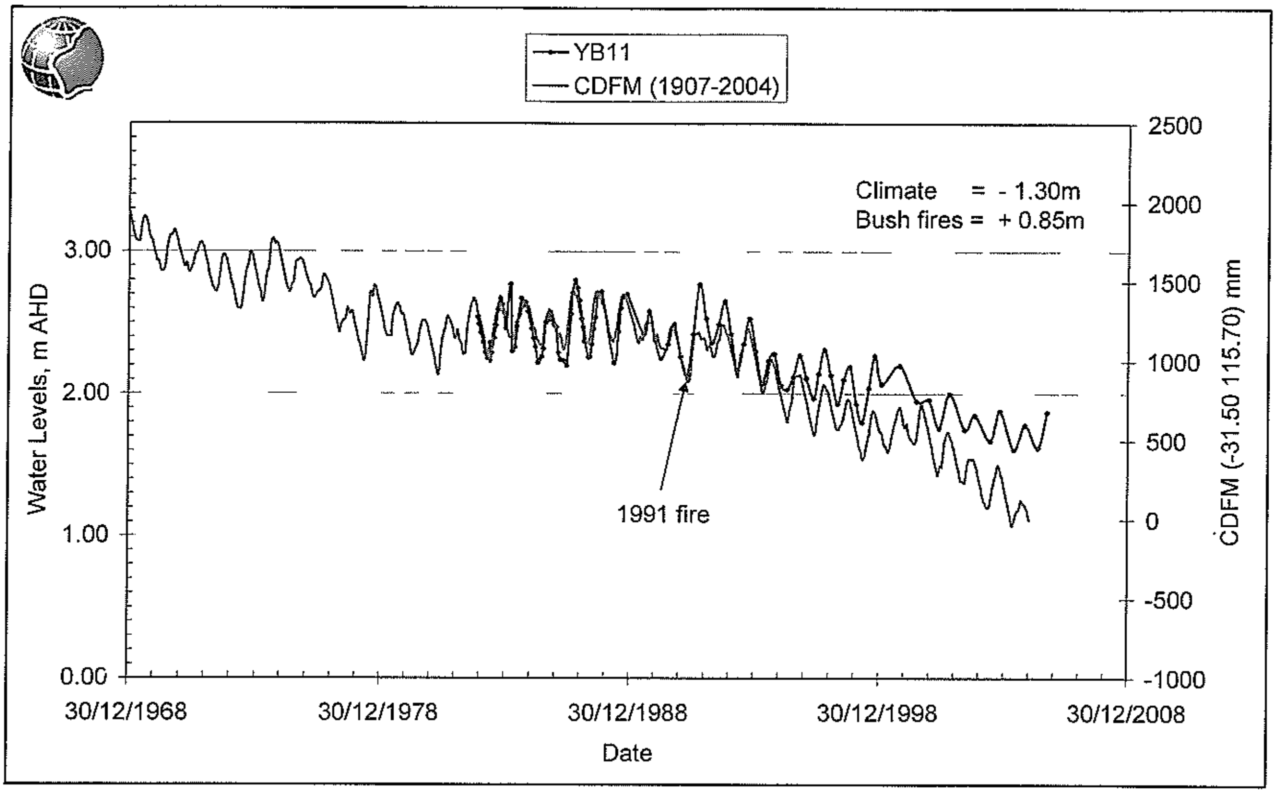
YN1
YY2 (o)
CDFM (1907-2004)
Climate impact = - 2.25m
Groundwater Levels, mAHD
22.0
20.0
18.0
16.0
2000
1500
1000
500
0
-500
-1000
Silo CDFM 115.70 -31.55
12/1968
12/1978
12/1988
12/1998
12/2008
Date

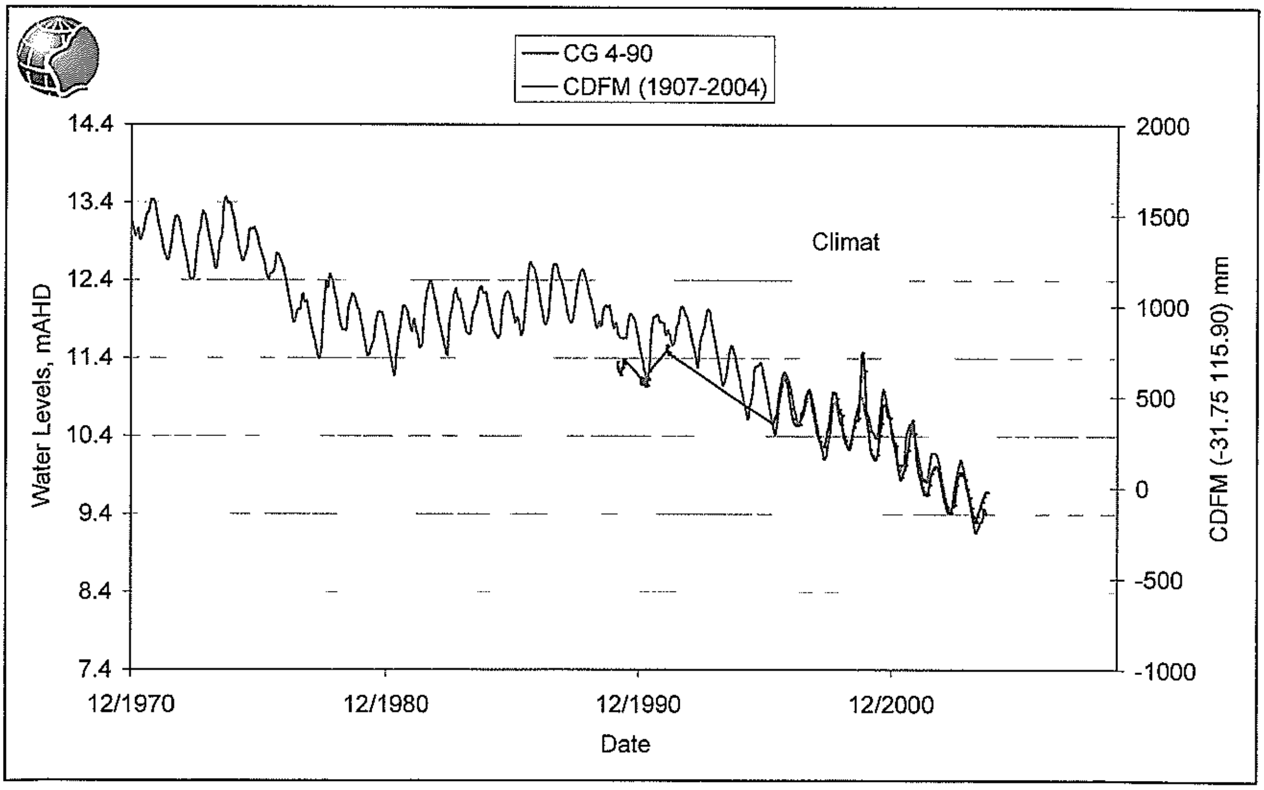


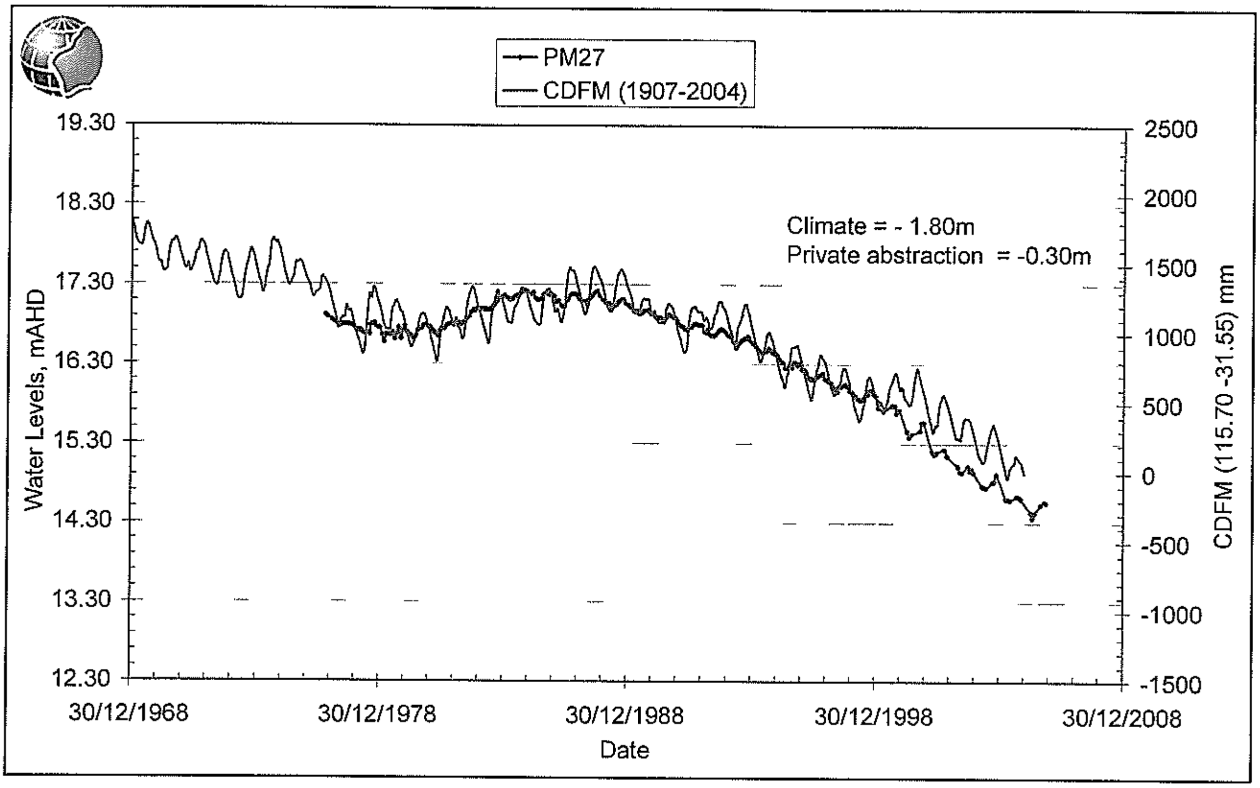
YN3
CDFM (1907-2004)
Abstraction impact from 1999 onwards
Private abstraction impact=- 0.40cm
Water level, m AHD
13.0
12.6
12.2
11.8
11.4
2000
1500
1000
500
0
-500
-1000
-1500
CDFM (-31.55 115.70) mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

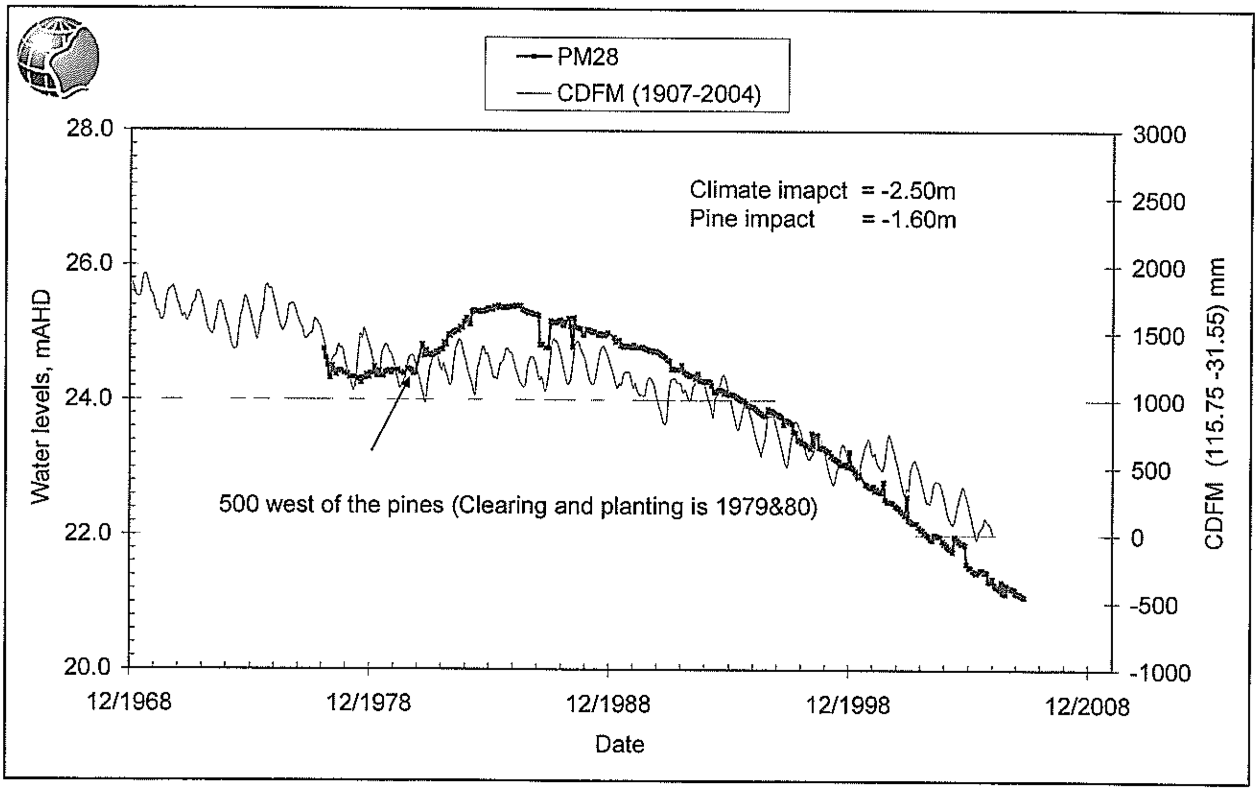

YN4
CDFM (1907-2004)
Water levels, m AHD
CDFM (-31.55 115.70) mm
11.4
10.9
10.4
9.9
2000
1500
1000
500
0
-500
-1000
-1500
Abstraction impact = -0.25m
12/1968
12/1978
12/1988
12/1998
12/2008
Date

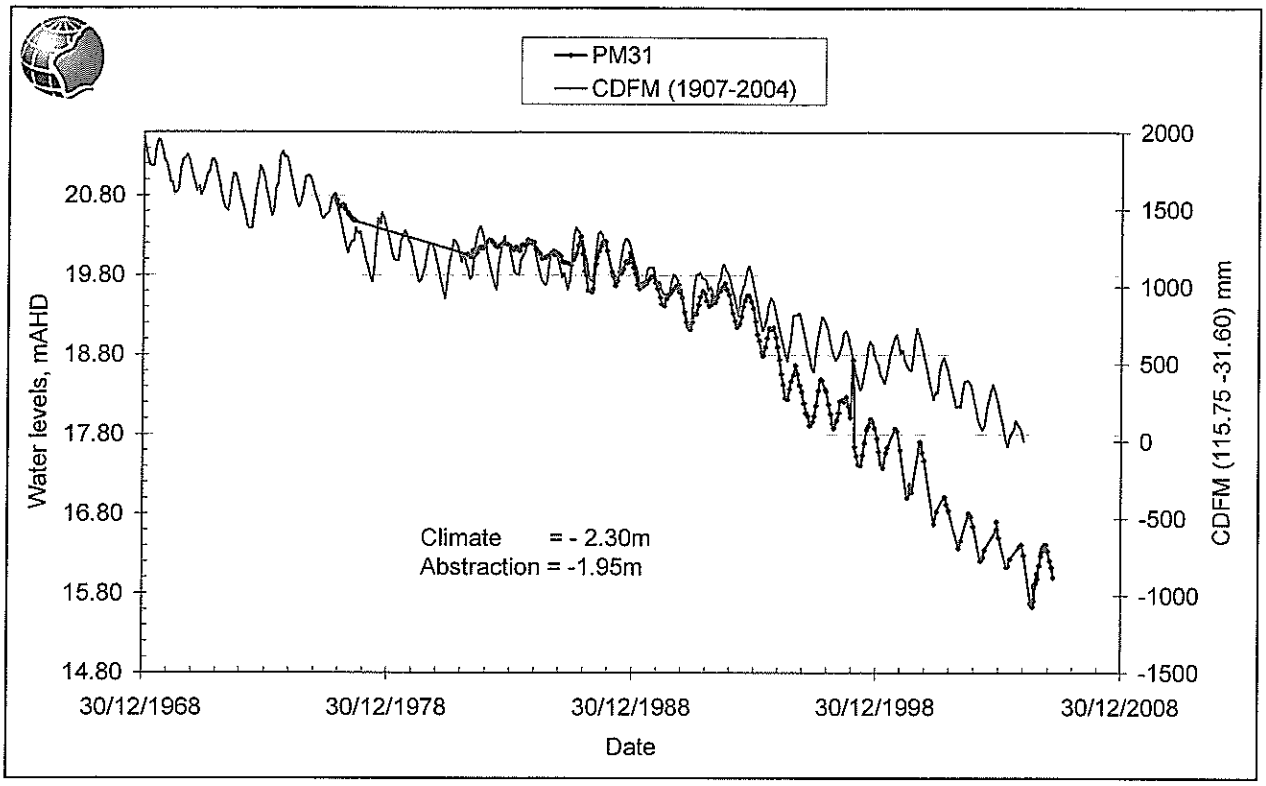

Crystal cave
CDFM (1907-2004)
Water levels, m AHD
CDFM (-31.55 115.70) mm
13.6
13.1
12.6
12.1
11.6
2000
1500
1000
500
0
-500
-1000
-1500
Abstraction impact = -0.55m
12/1968
12/1978
12/1988
12/1998
12/2008
Date

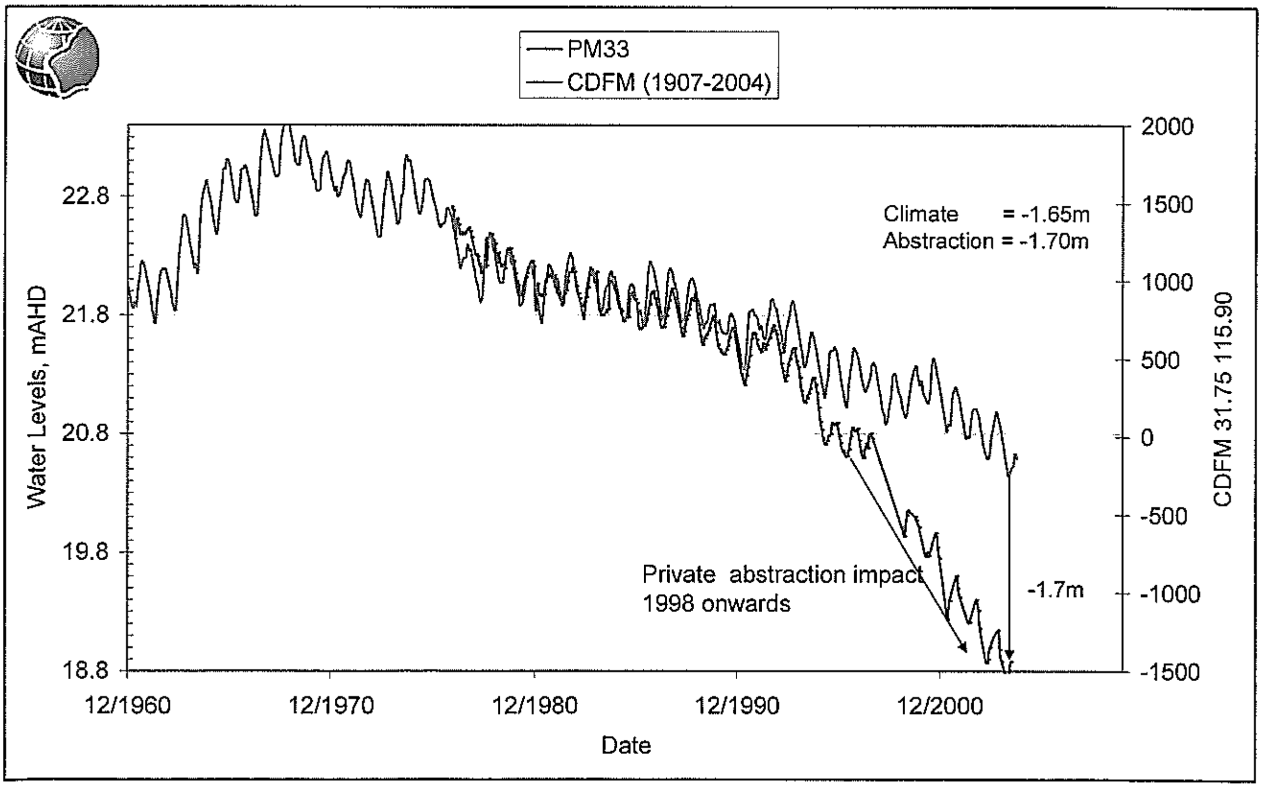

YB11
CDFM (1907-2004)
Climate = - 1.30m
Bush fires = + 0.85m
1991 fire
3.00
2.00
1.00
0.00
Water Levels, m AHD
2500
2000
1500
1000
500
0
-500
-1000
CDFM (-31.50 115.70) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

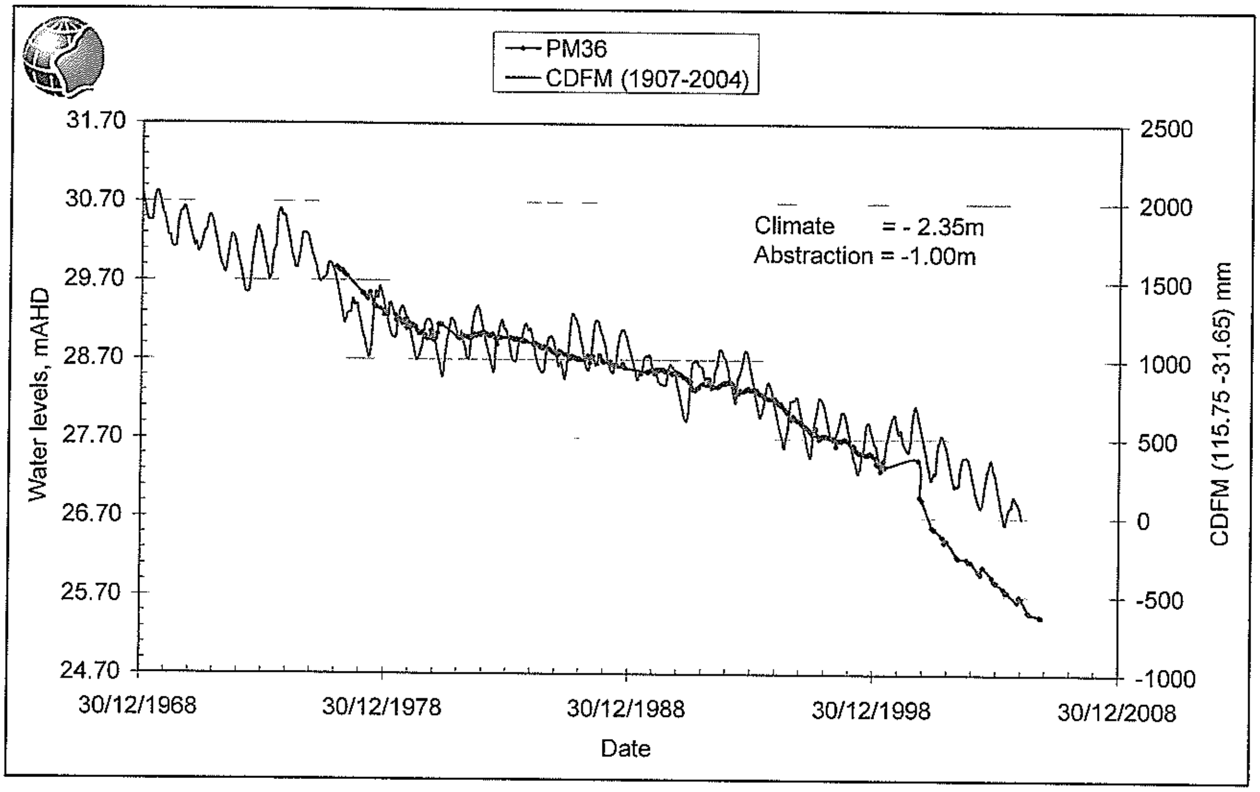

CG 4-90
CDFM (1907-2004)
Climat
14.4
13.4
12.4
11.4
10.4
9.4
8.4
7.4
Water Levels, mAHD
2000
1500
1000
500
0
-500
-1000
CDFM (-31.75 115.90) mm
12/1970
12/1980
12/1990
12/2000
Date

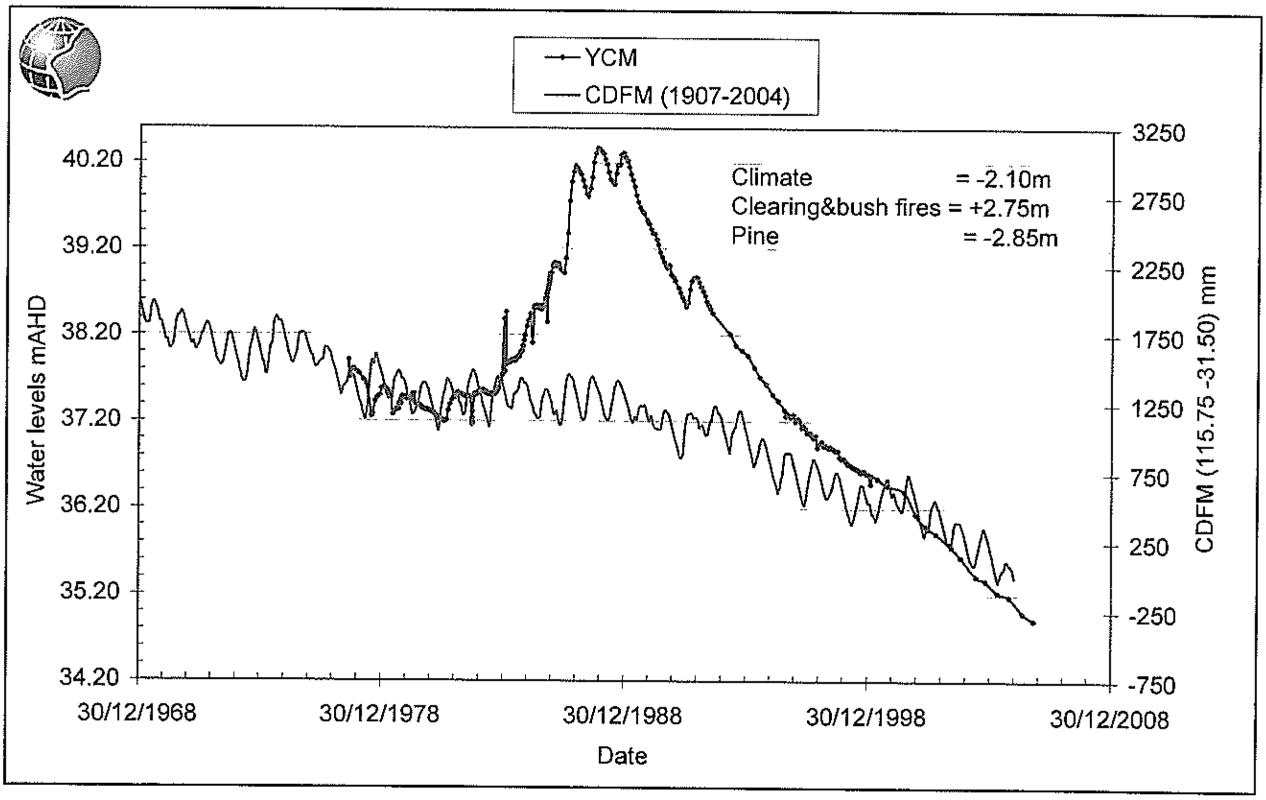

PM27
CDFM (1907-2004)
Climate = - 1.80m
Private abstraction = -0.30m
Water Levels, mAHD
CDFM (115.70 -31.55) mm
19.30
18.30
17.30
16.30
15.30
14.30
13.30
12.30
2500
2000
1500
1000
500
0
-500
-1000
-1500
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

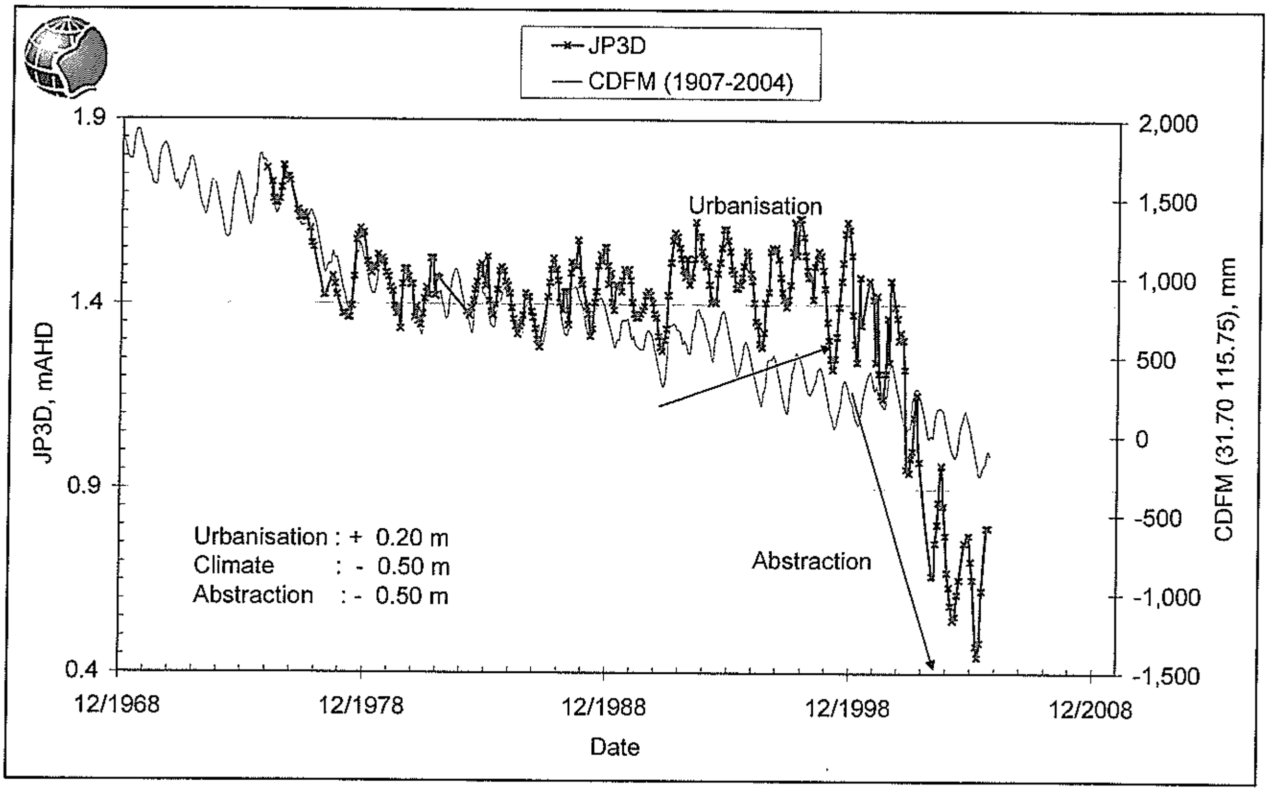

PM28
CDFM (1907-2004)
Climate imapct = -2.50m
Pine impact = -1.60m
500 west of the pines (Clearing and planting is 1979&80)
Water levels, mAHD
CDFM (115.75 -31.55) mm
28.0
26.0
24.0
22.0
20.0
3000
2500
2000
1500
1000
500
0
-500
-1000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

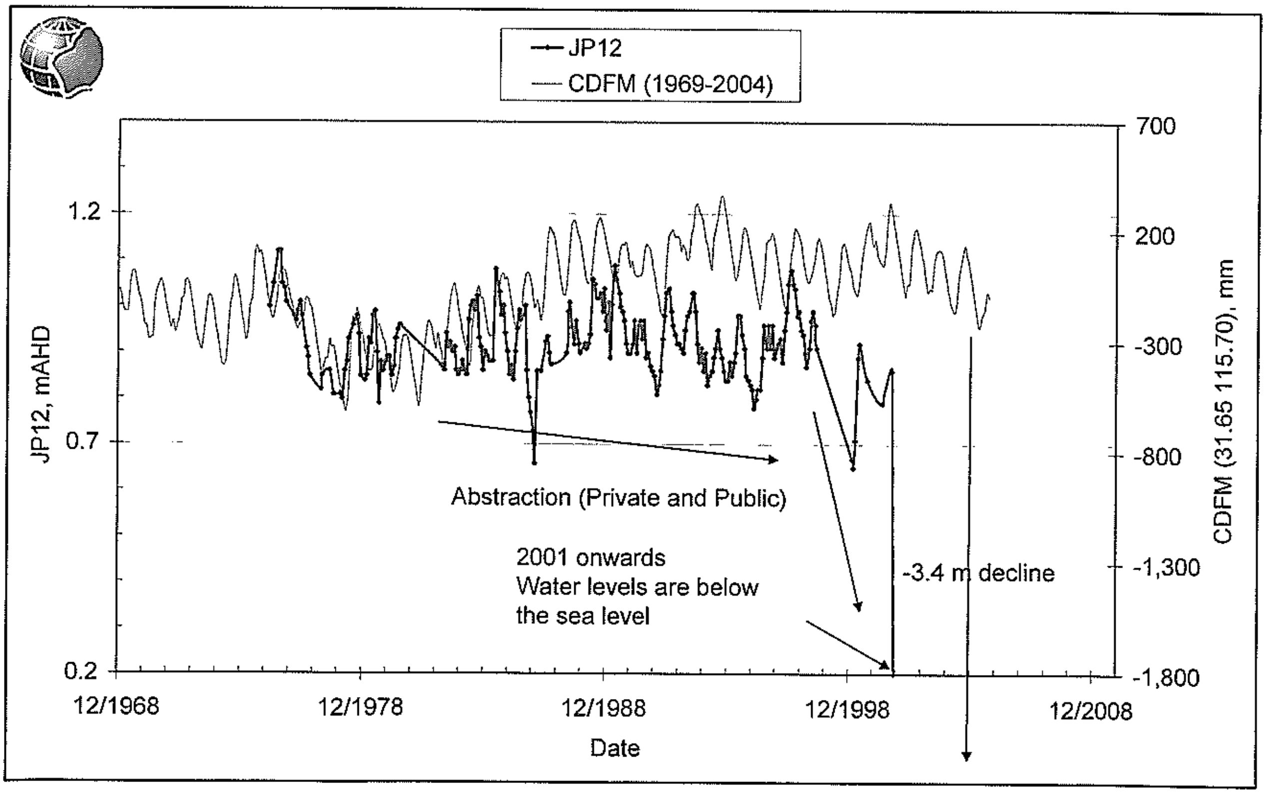

PM31
CDFM (1907-2004)
Water levels, mAHD
20.80
19.80
18.80
17.80
16.80
15.80
14.80
2000
1500
1000
500
0
-500
-1000
-1500
CDFM (115.75 -31.60) mm
Climate = - 2.30m
Abstraction = -1.95m
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

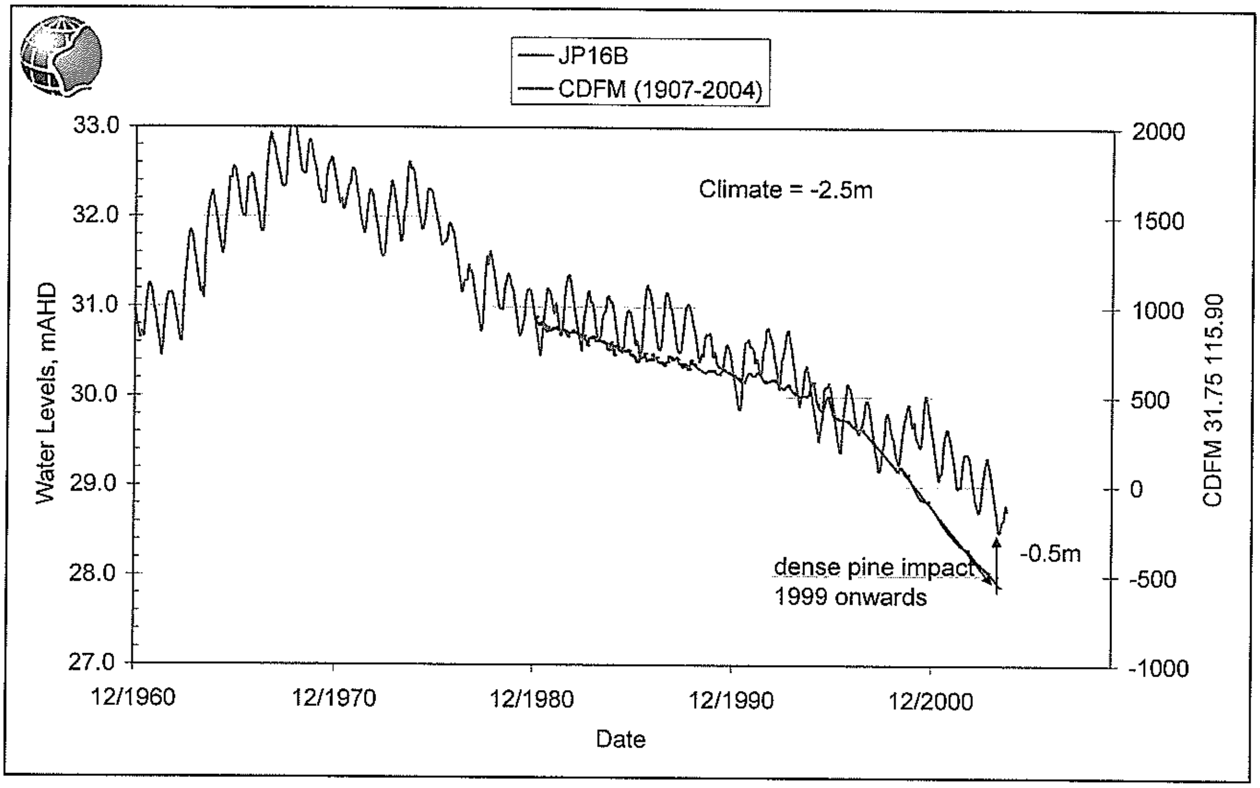

PM33
CDFM (1907-2004)
Water Levels, mAHD
22.8
21.8
20.8
19.8
18.8
2000
1500
1000
500
0
-500
-1000
-1500
CDFM 31.75 115.90
Climate = -1.65m
Abstraction = -1.70m
Private abstraction impact
1998 onwards
-1.7m
12/1960
12/1970
12/1980
12/1990
12/2000
Date

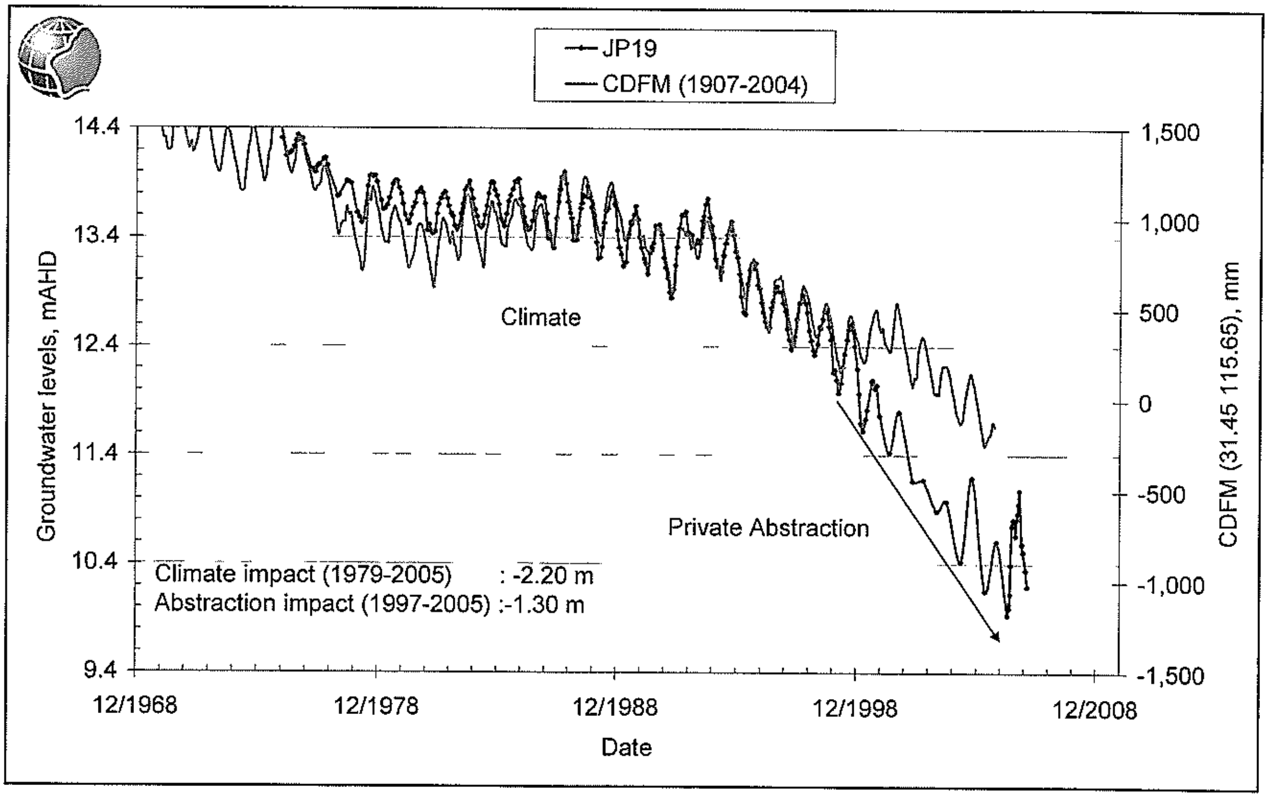

PM36
CDFM (1907-2004)
Climate = - 2.35m
Abstraction = -1.00m
Water levels, mAHD
31.70
30.70
29.70
28.70
27.70
26.70
25.70
24.70
2500
2000
1500
1000
500
0
-500
-1000
CDFM (115.75 -31.65) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


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
3250
2750
2250
1750
1250
750
250
-250
-750
CDFM (115.75 -31.50) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


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

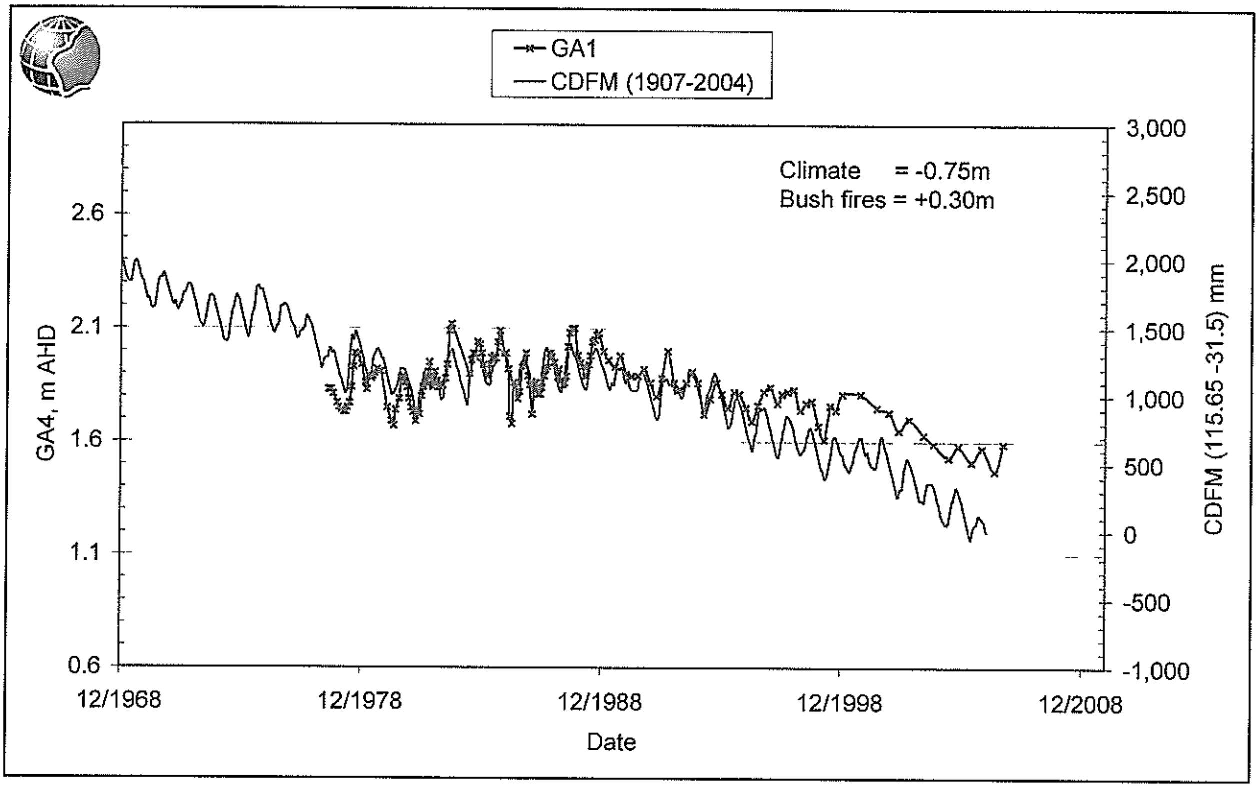

JP12
CDFM (1969-2004)
Abstraction (Private and Public)
2001 onwards
Water levels are below
the sea level
-3.4 m decline
JP12, mAHD
CDFM (31.65 115.70), mm
Date
1.2
0.7
0.2
700
200
-300
-800
-1,300
-1,800
12/1968
12/1978
12/1988
12/1998
12/2008

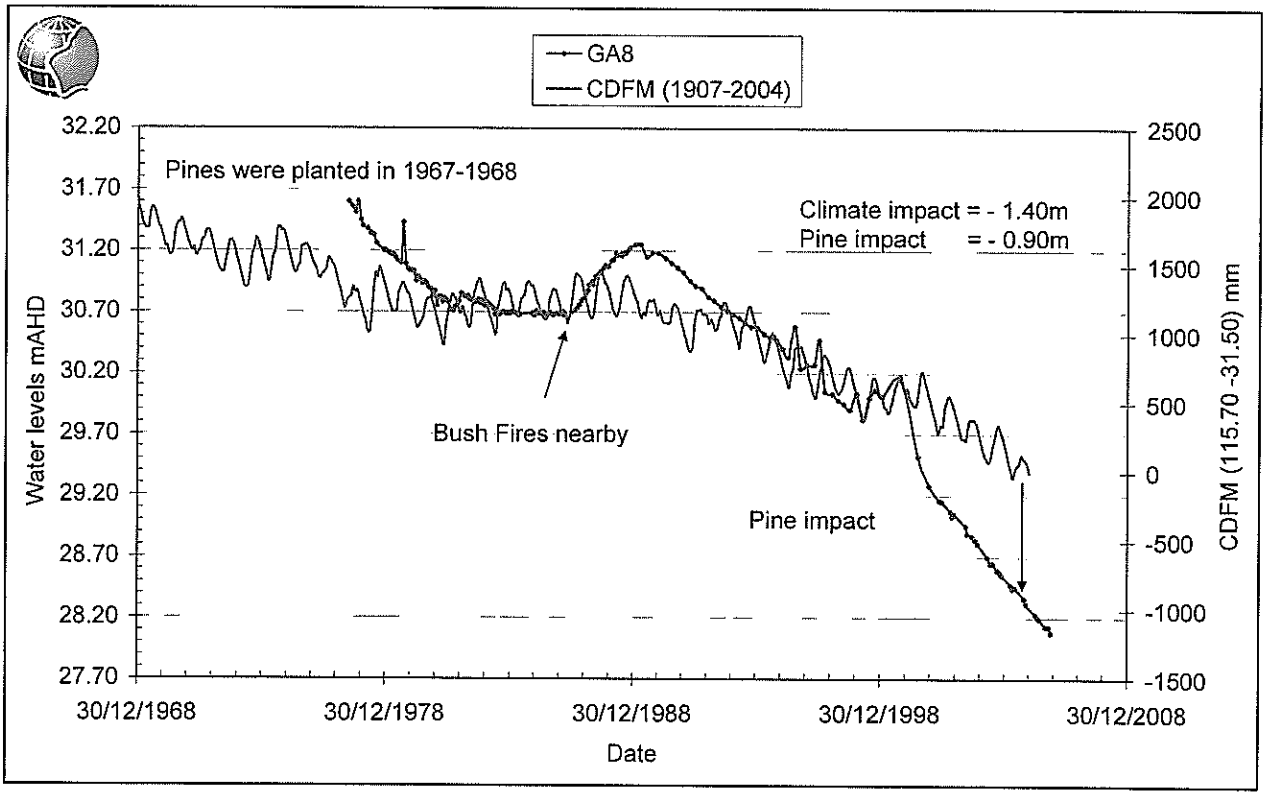

JP16B
CDFM (1907-2004)
Climate = -2.5m
dense pine impact
1999 onwards
-0.5m
Water Levels, mAHD
CDFM 31.75 115.90
Date
33.0
32.0
31.0
30.0
29.0
28.0
27.0
2000
1500
1000
500
0
-500
-1000
12/1960
12/1970
12/1980
12/1990
12/2000

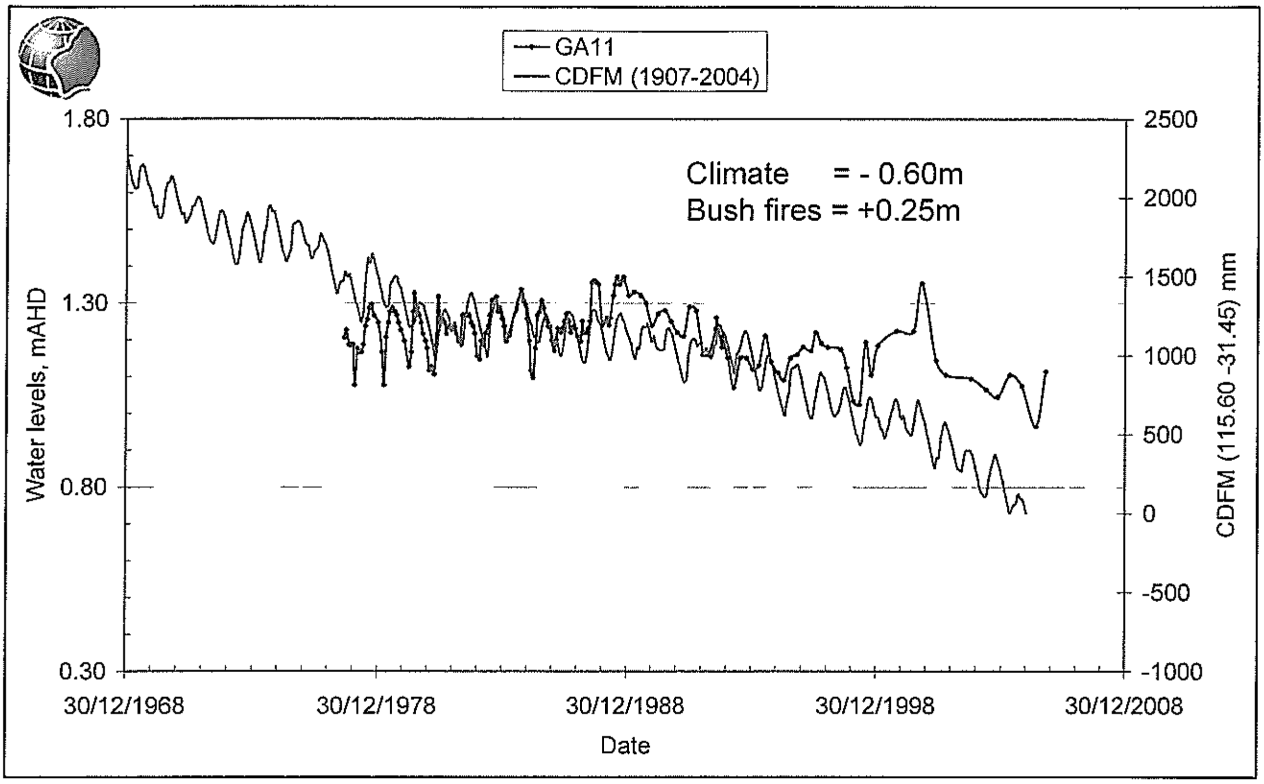

JP19
CDFM (1907-2004)
Climate
Private Abstraction
Climate impact (1979-2005) : -2.20 m
Abstraction impact (1997-2005) :-1.30 m
Groundwater levels, mAHD
CDFM (31.45 115.65), mm
Date
14.4
13.4
12.4
11.4
10.4
9.4
1,500
1,000
500
0
-500
-1,000
-1,500
12/1968
12/1978
12/1988
12/1998
12/2008

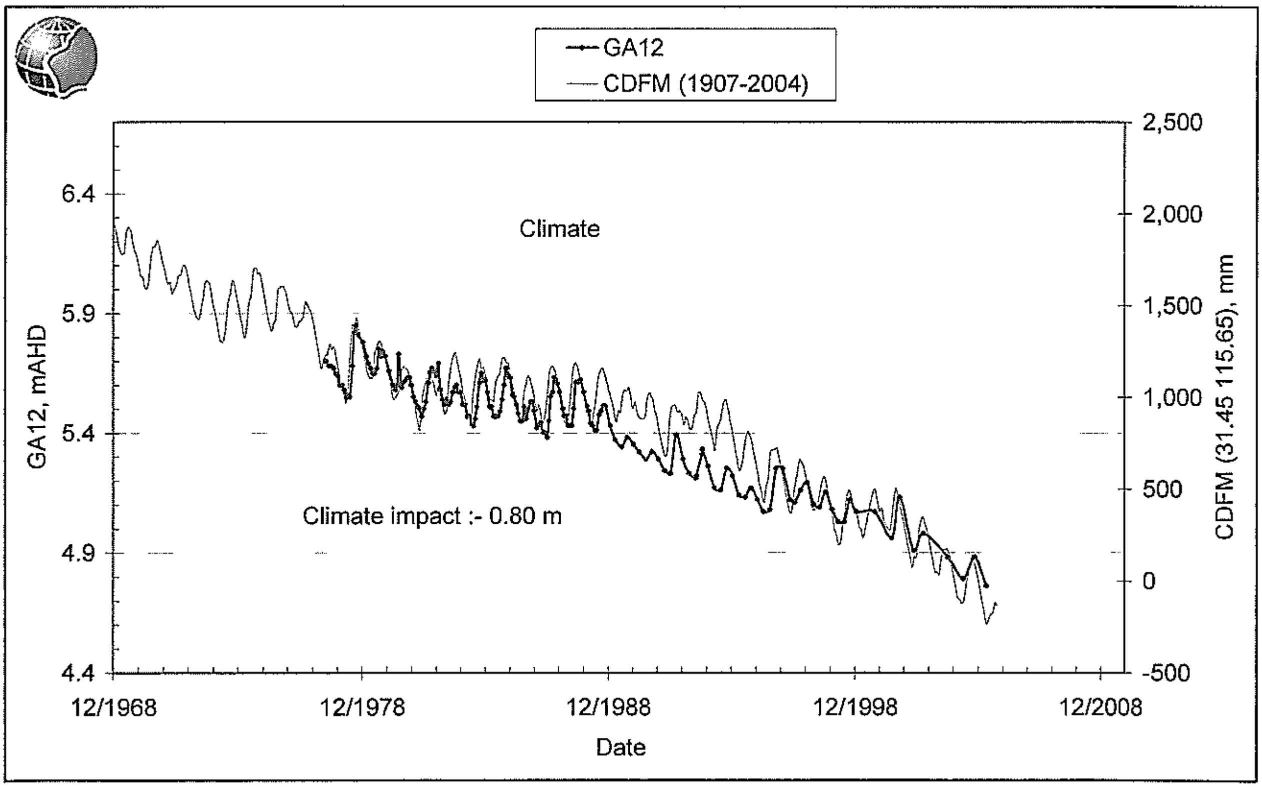
6. Two Rocks Rainfall Zone

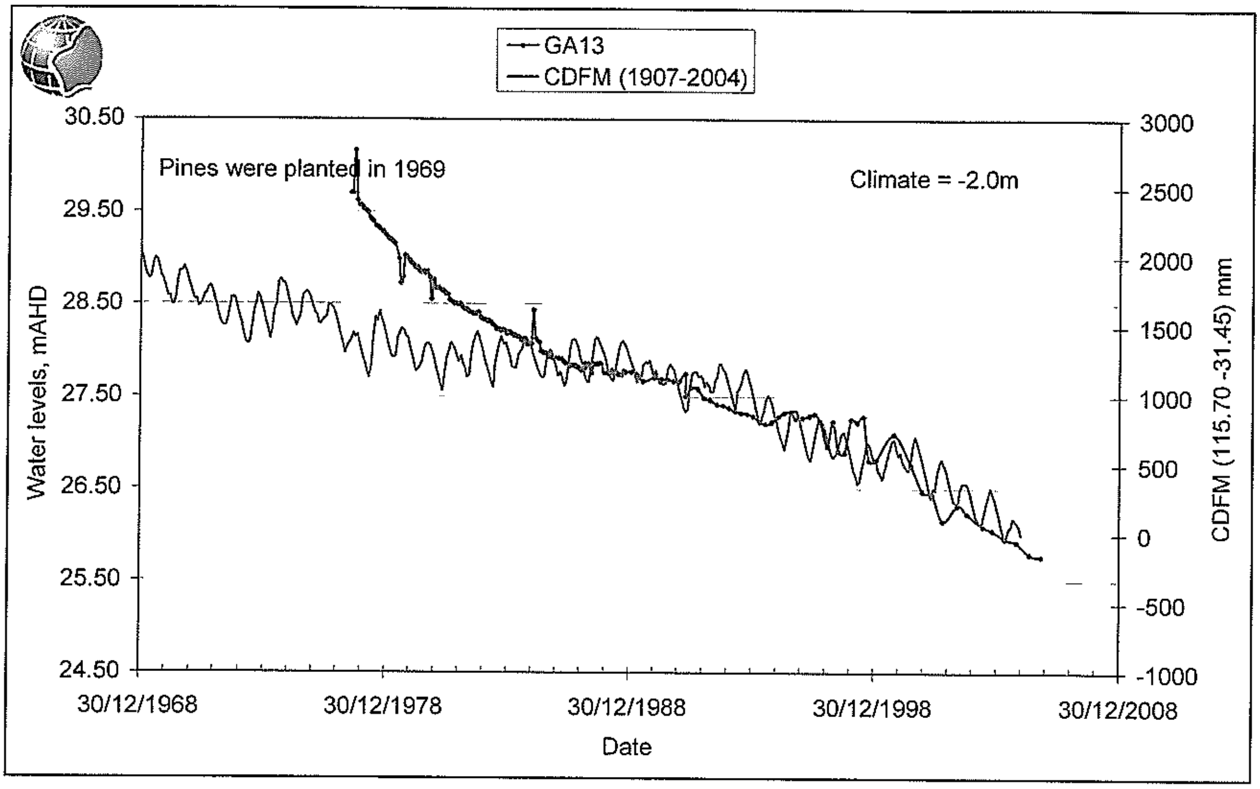
(GA1, GA8, GA11, GA12, GA13, GA14, GA17, GA18, GA24, GA29, GA33)

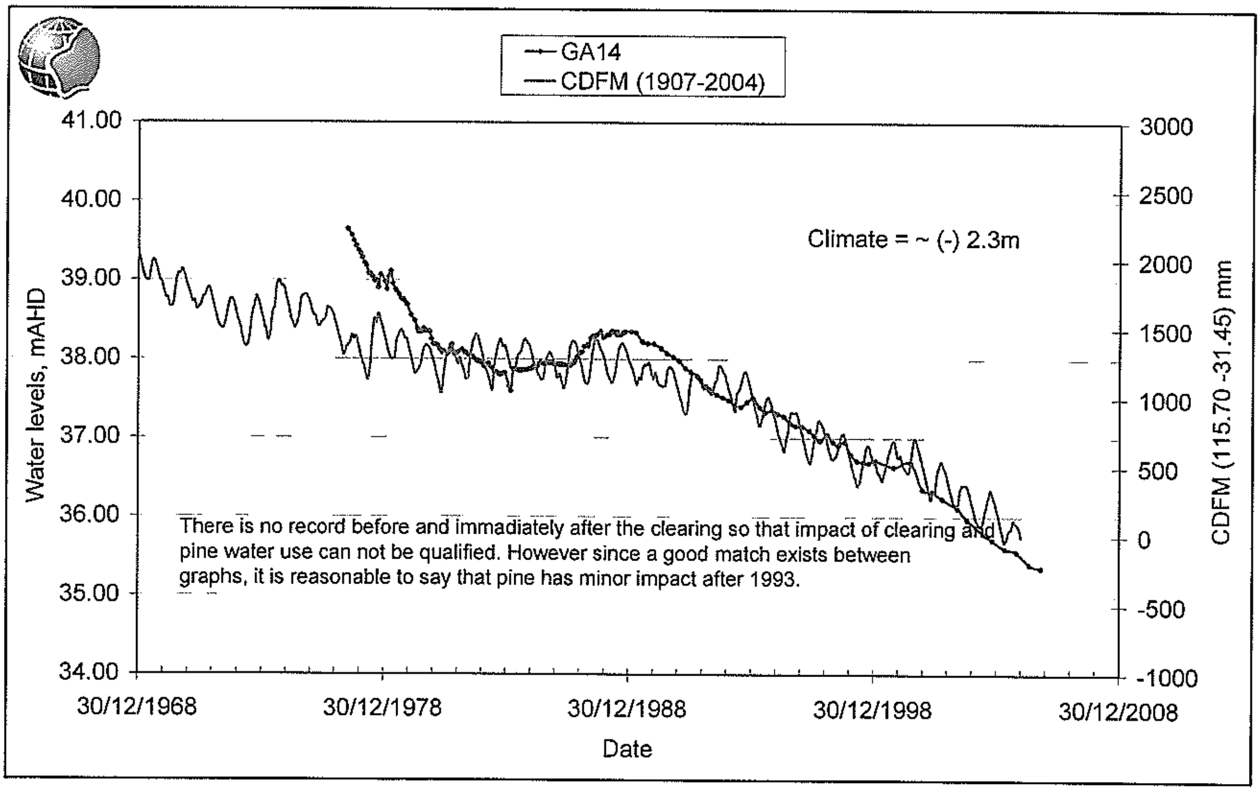

GA1
CDFM (1907-2004)
Climate = -0.75m
Bush fires = +0.30m
GA4, m AHD
CDFM (115.65 -31.5) mm
2.6
2.1
1.6
1.1
0.6
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
12/1968
12/1978
12/1988
12/1998
12/2008
Date

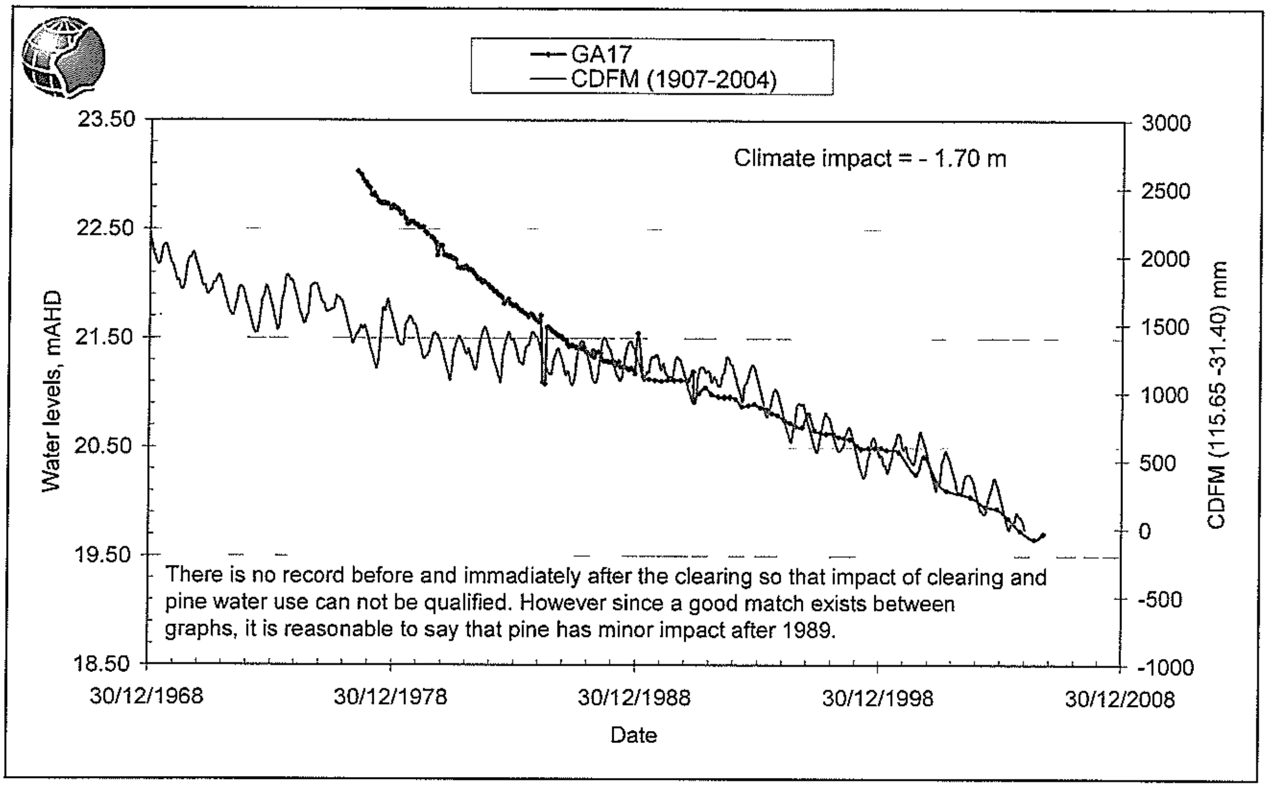

GA8
CDFM (1907-2004)
Pines were planted in 1967-1968
Climate impact = - 1.40m
Pine impact = - 0.90m
Bush Fires nearby
Pine impact
Water levels mAHD
CDFM (115.70 -31.50) mm
32.20
31.70
31.20
30.70
30.20
29.70
29.20
28.70
28.20
27.70
2500
2000
1500
1000
500
0
-500
-1000
-1500
30/12/1968
30/12/1978
30/12/1988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

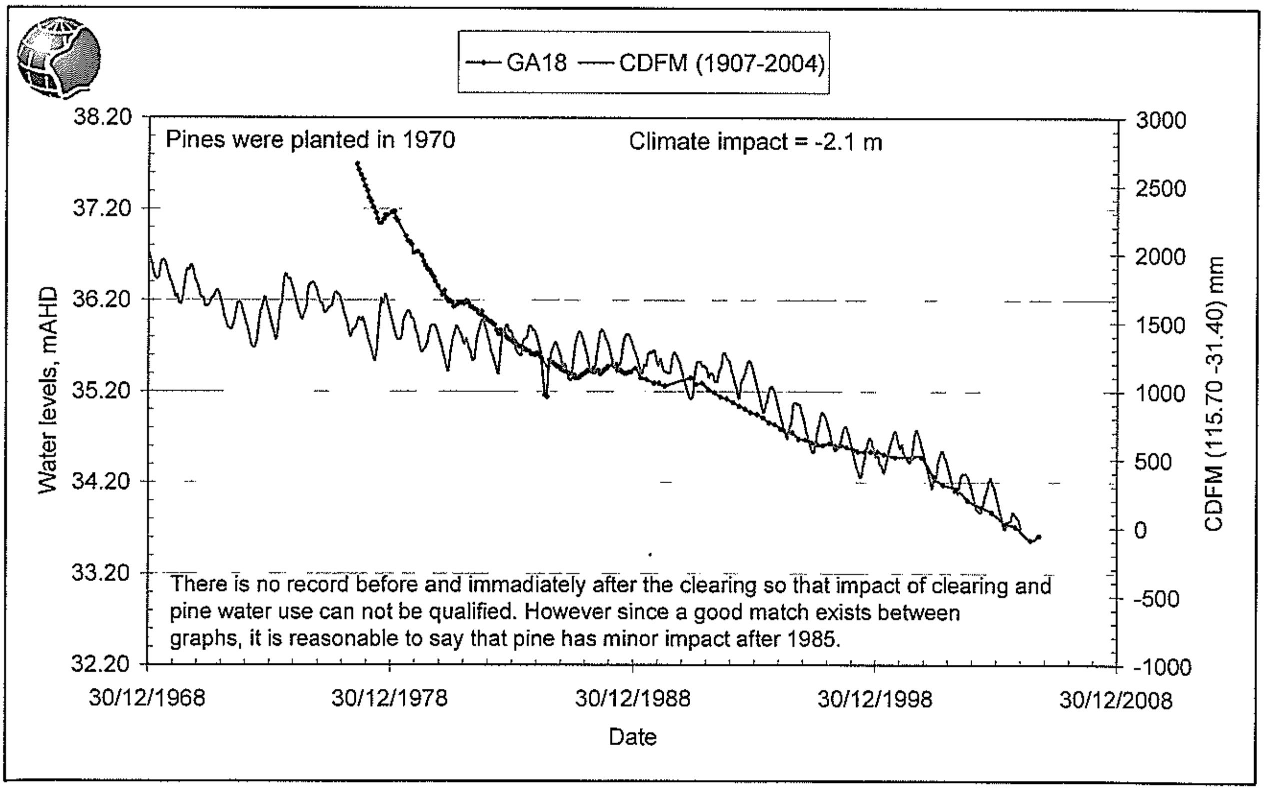

GA11
CDFM (1907-2004)
Climate = - 0.60m
Bush fires = +0.25m
1.80
1.30
0.80
0.30
Water levels, mAHD
2500
2000
1500
1000
500
0
-500
-1000
CDFM (115.60 -31.45) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

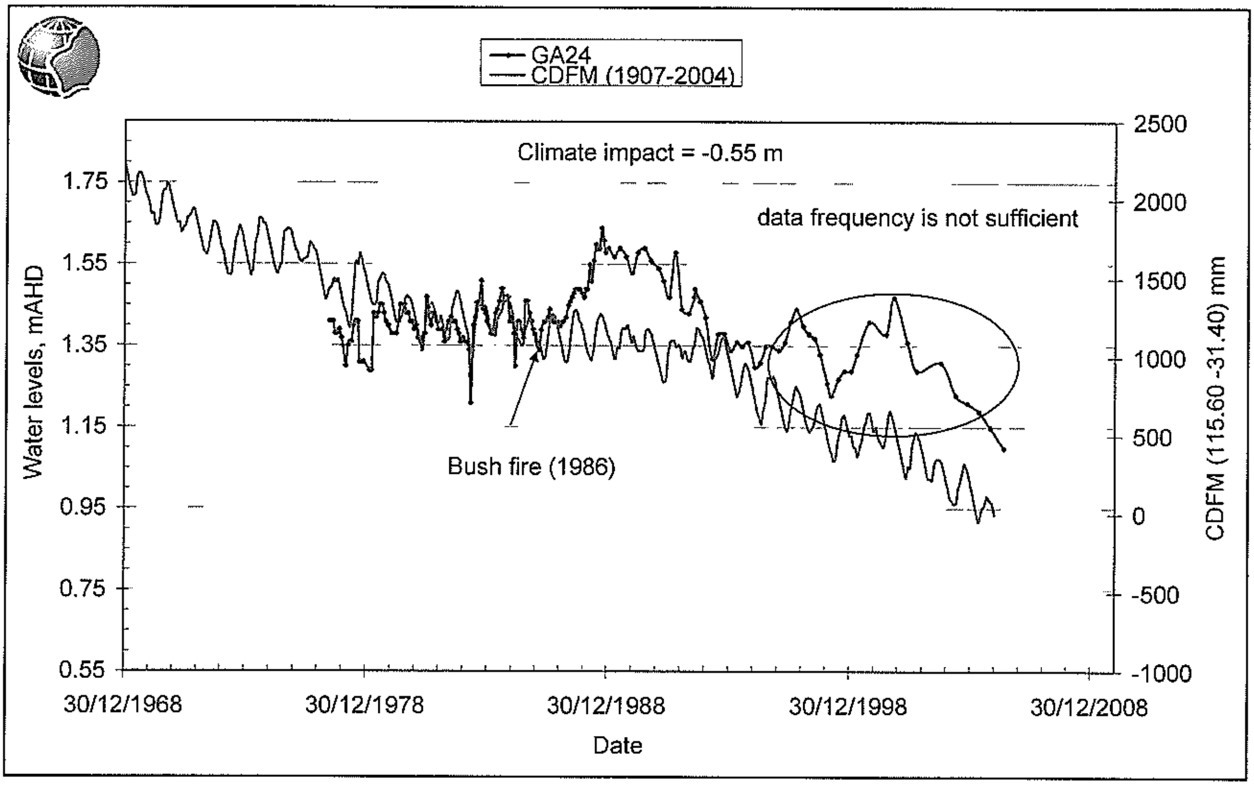

GA12
CDFM (1907-2004)
Climate
Climate impact :- 0.80 m
6.4
5.9
5.4
4.9
4.4
GA12, mAHD
2,500
2,000
1,500
1,000
500
0
-500
CDFM (31.45 115.65), mm
12/1968
12/1978
12/1988
12/1998
12/2008
Date

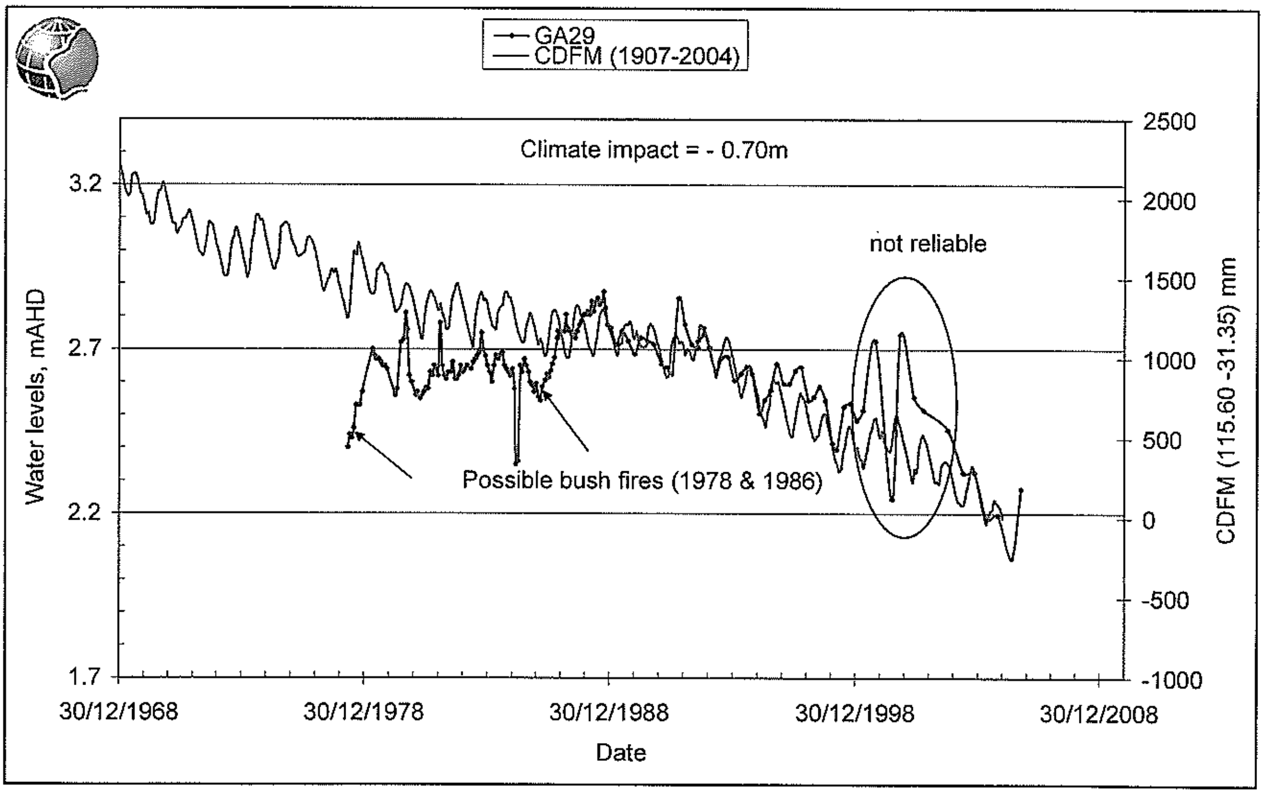

GA13
CDFM (1907-2004)
Pines were planted in 1969
Climate = -2.0m
Water levels, mAHD
30.50
29.50
28.50
27.50
26.50
25.50
24.50
3000
2500
2000
1500
1000
500
0
-500
-1000
CDFM (115.70 -31.45) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

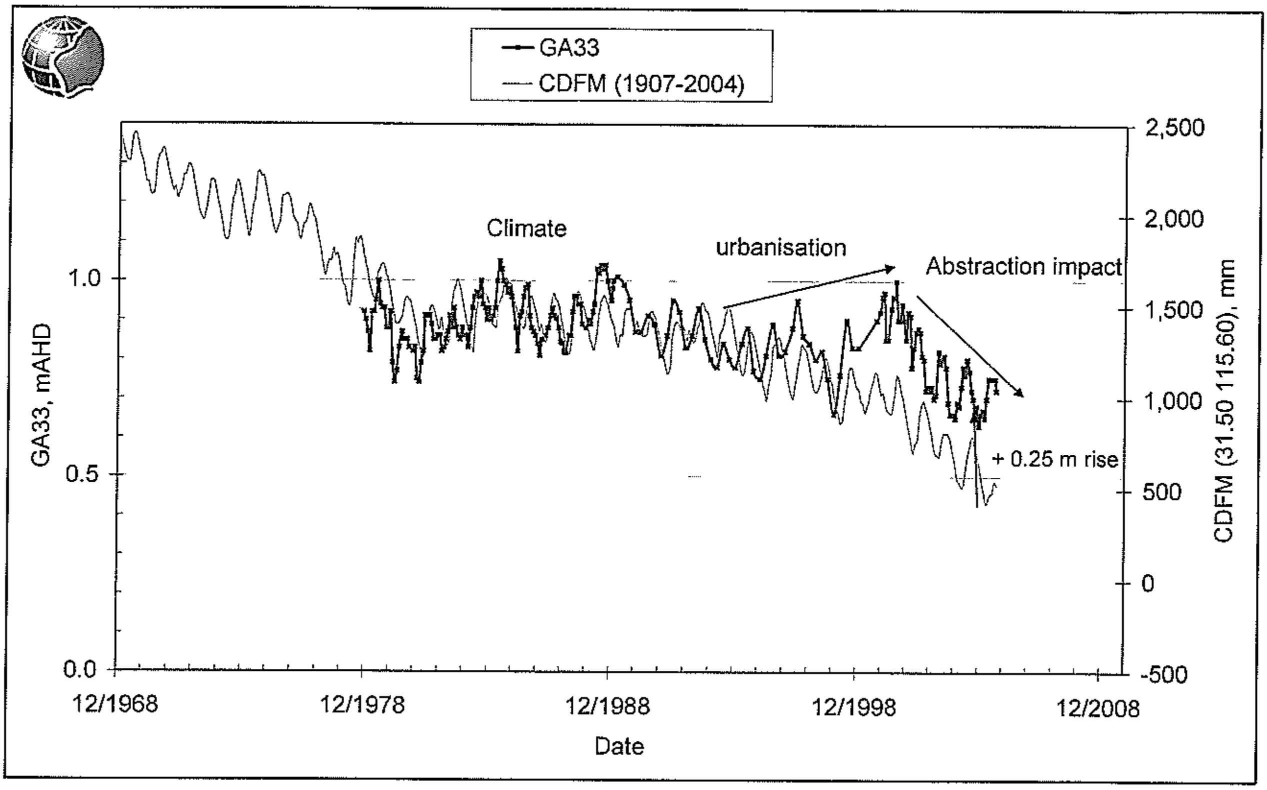

GA14
CDFM (1907-2004)
Climate = ~ (-) 2.3m
There is no record before and immadiately after the clearing so that impact of clearing and pine water use can not be qualified. However since a good match exists between graphs, it is reasonable to say that pine has minor impact after 1993.
Water levels, mAHD
41.00
40.00
39.00
38.00
37.00
36.00
35.00
34.00
3000
2500
2000
1500
1000
500
0
-500
-1000
CDFM (115.70 -31.45) mm
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
CDFM (115.65 -31.40) mm
Date
23.50
22.50
21.50
20.50
19.50
18.50
3000
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008


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
CDFM (115.70 -31.40) mm
Date
38.20
37.20
36.20
35.20
34.20
33.20
32.20
3000
2500
2000
1500
1000
500
0
-500
-1000
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008

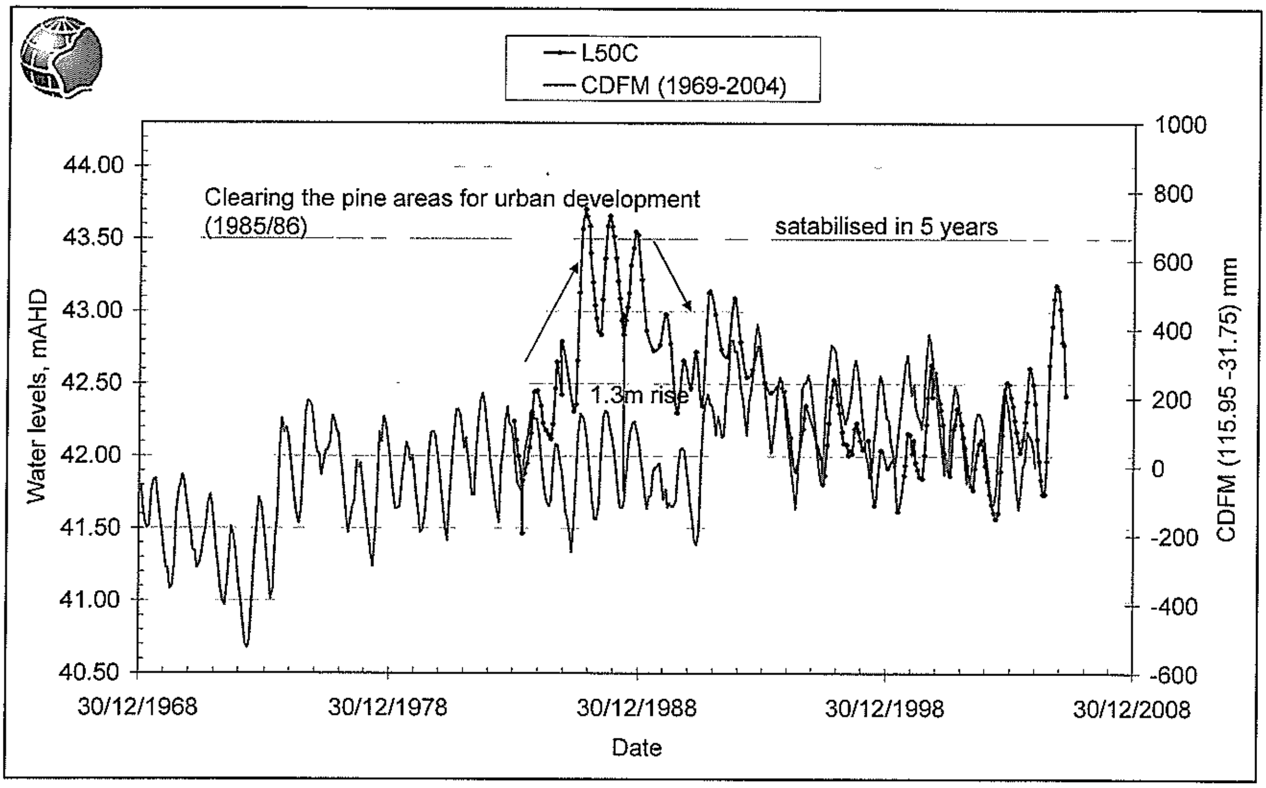

GA24
CDFM (1907-2004)
Climate impact = -0.55 m
data frequency is not sufficient
Bush fire (1986)
Water levels, mAHD
1.75
1.55
1.35
1.15
0.95
0.75
0.55
2500
2000
1500
1000
500
0
-500
-1000
CDFM (115.60 -31.40) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

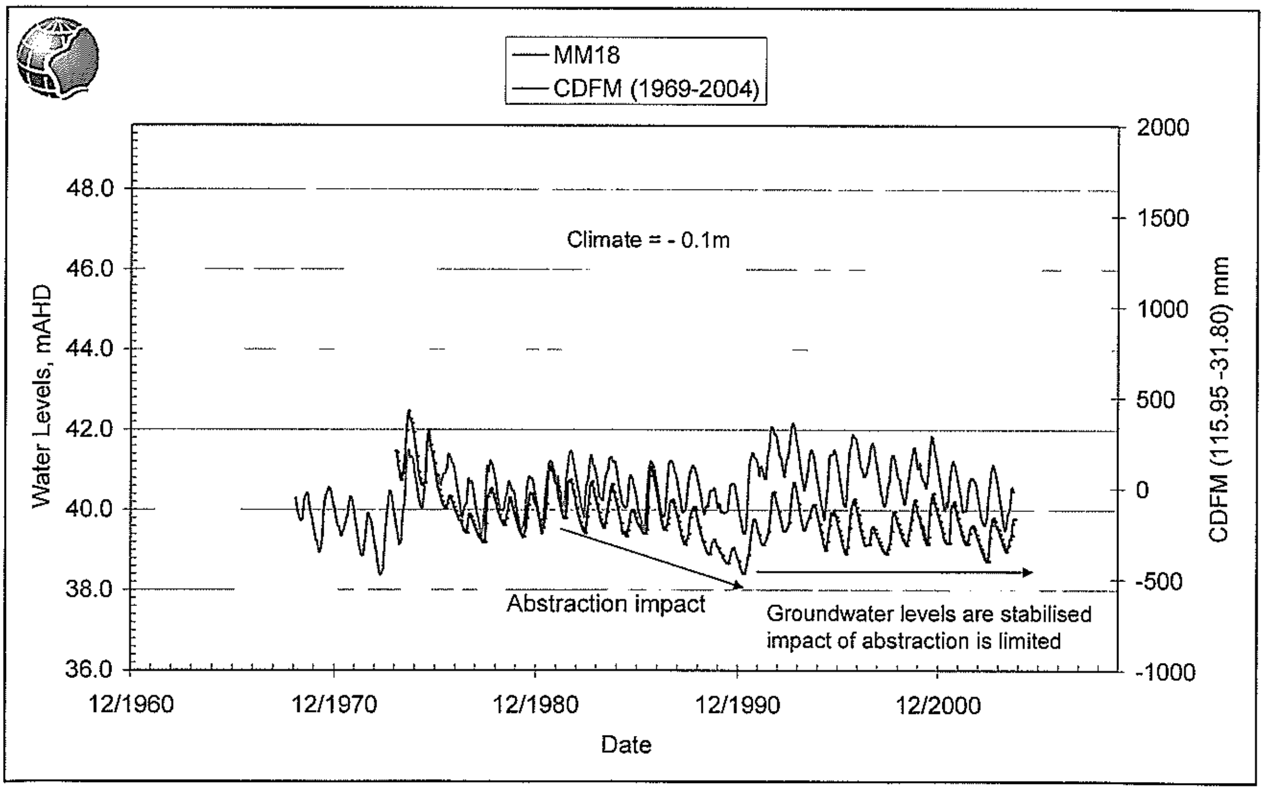

GA29
CDFM (1907-2004)
Climate impact = - 0.70m
not reliable
Possible bush fires (1978 & 1986)
Water levels, mAHD
3.2
2.7
2.2
1.7
2500
2000
1500
1000
500
0
-500
-1000
CDFM (115.60 -31.35) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date

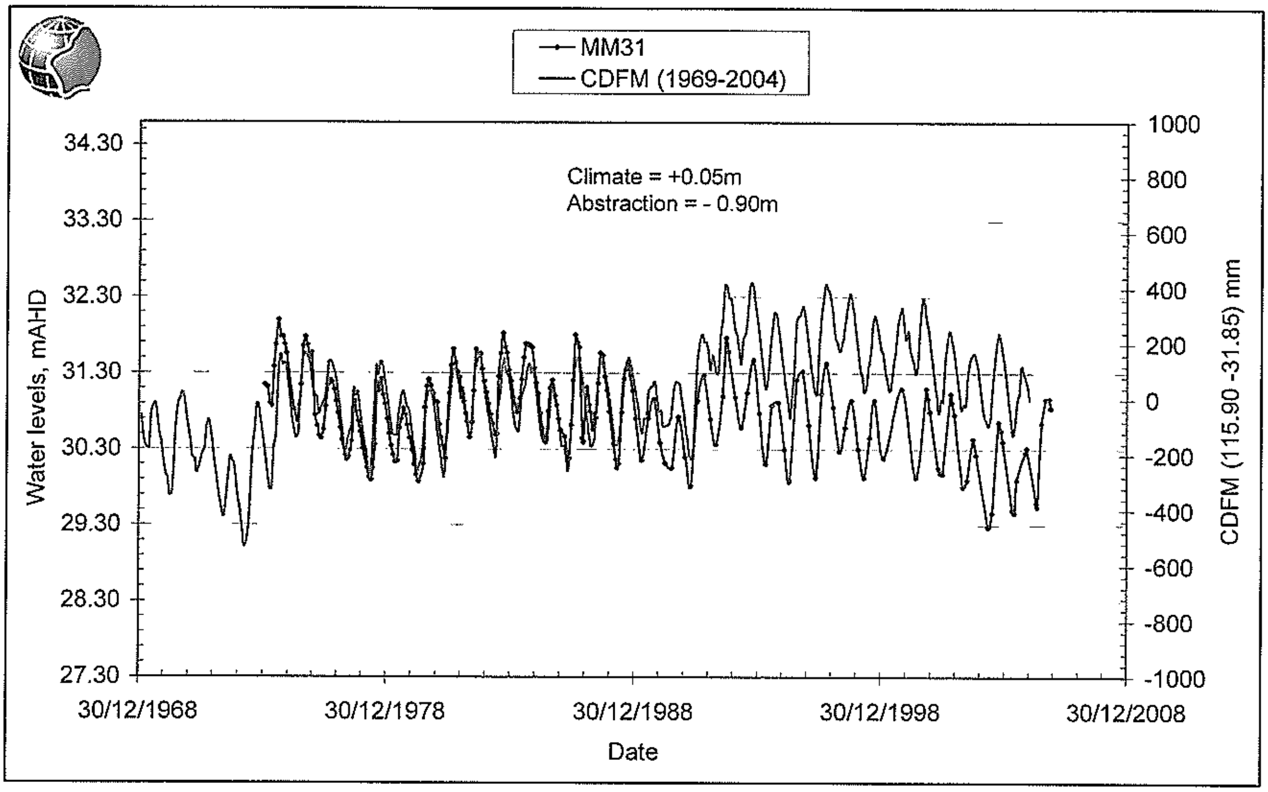

GA33
CDFM (1907-2004)
Climate
urbanisation
Abstraction impact
+ 0.25 m rise
GA33, mAHD
1.0
0.5
0.0
CDFM (31.50 115.60), mm
2,500
2,000
1,500
1,000
500
0
-500
12/1968
12/1978
12/1988
12/1998
12/2008
Date

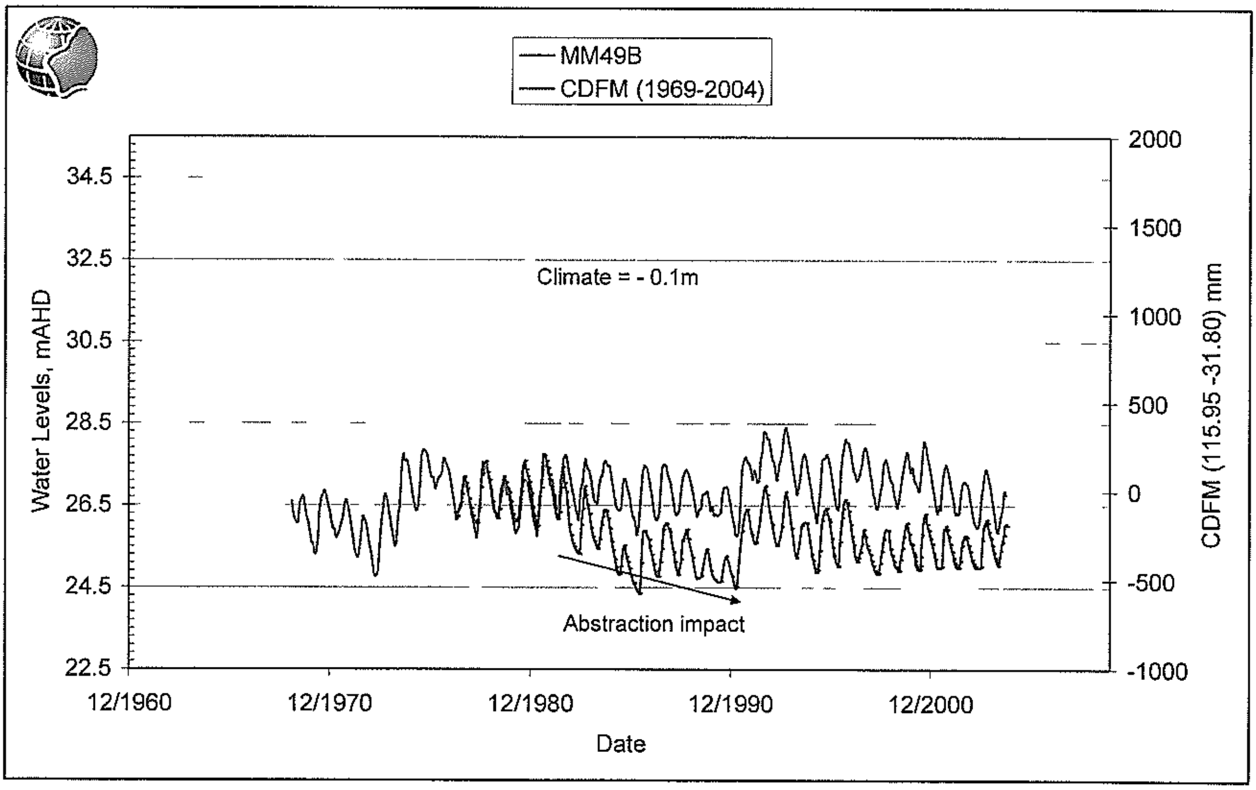
7. Gnangara Forestry Rainfall Zone

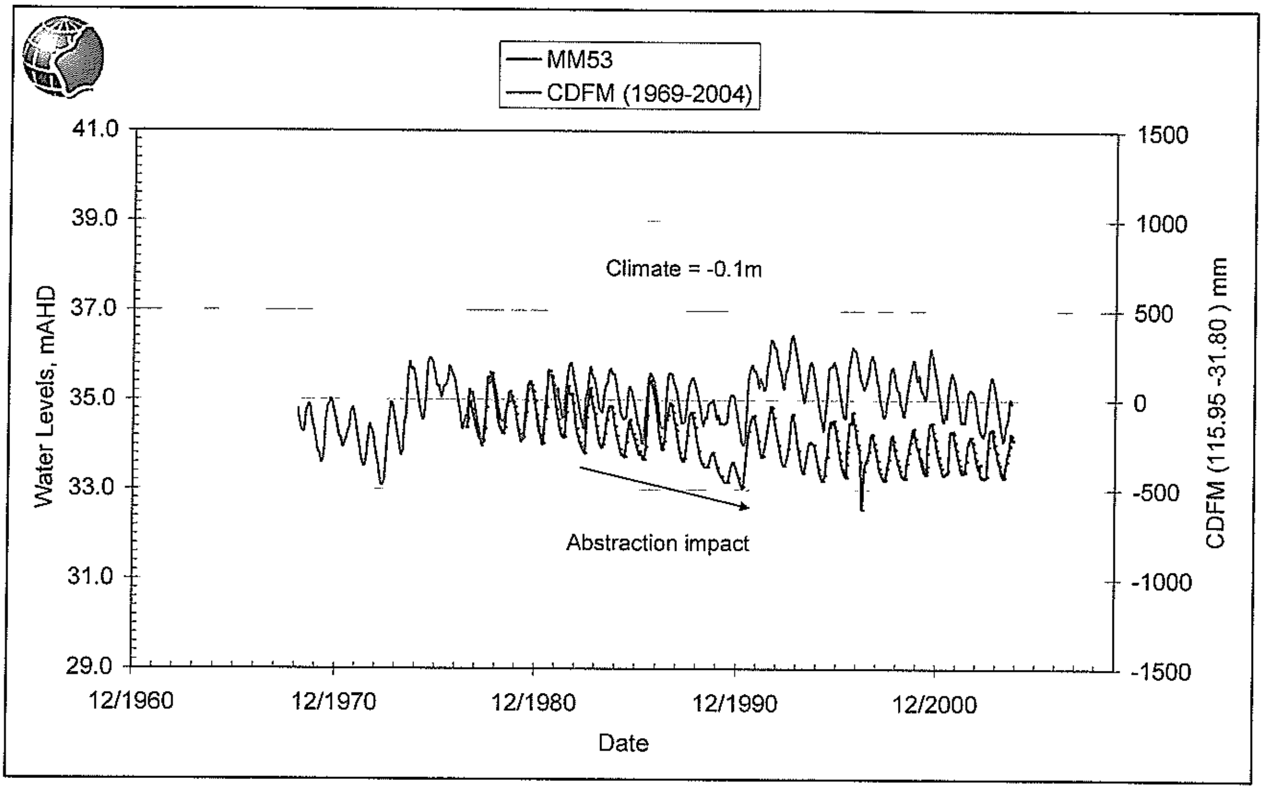
(L50C, MM18, MM31, MM49B, MM53, MM59B)

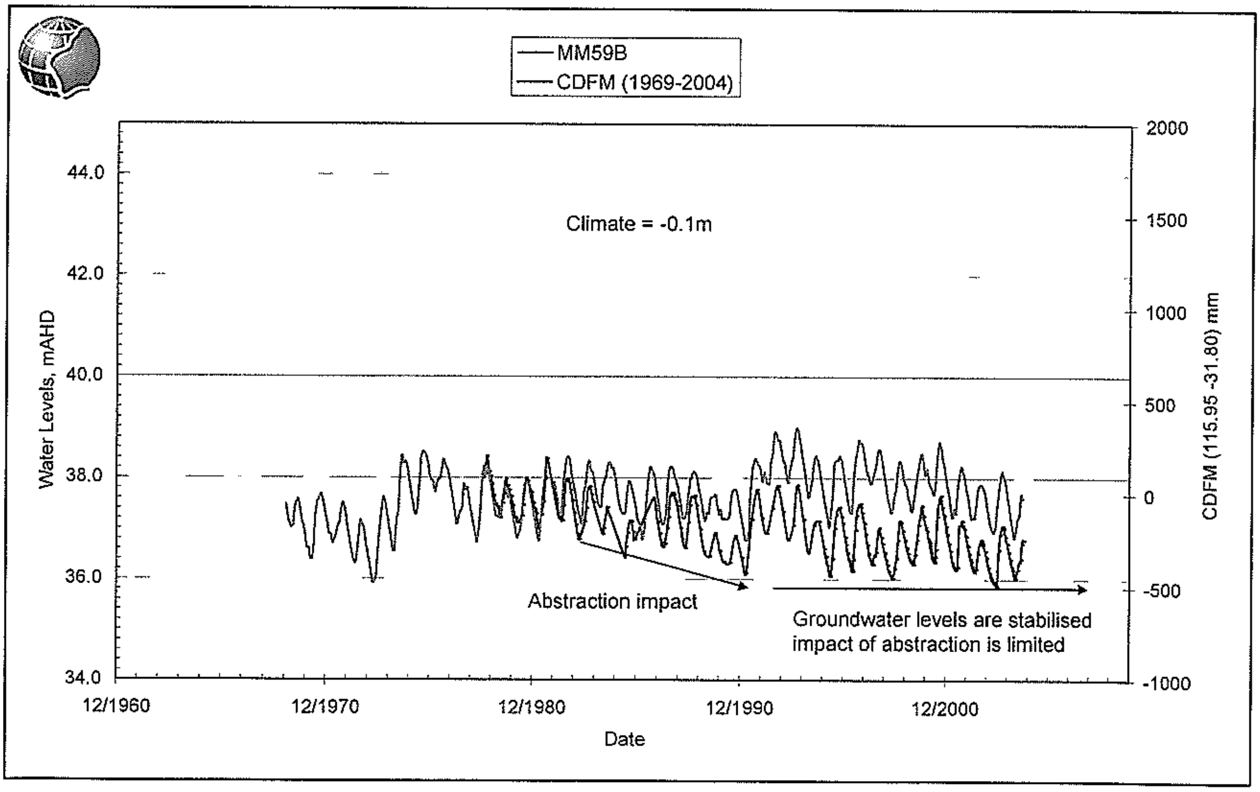

L50C
CDFM (1969-2004)
Clearing the pine areas for urban development (1985/86)
satabilised in 5 years
1.3m rise
Water levels, mAHD
CDFM (115.95 -31.75) mm
30/12/1968
30/12/1978
30/12/1988
30/12/1998
30/12/2008
Date


MM18
CDFM (1969-2004)
Climate = - 0.1m
Abstraction impact
Groundwater levels are stabilised impact of abstraction is limited
Water Levels, mAHD
CDFM (115.95 -31.80) mm
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
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
CDFM (115.90 -31.85) mm
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
2000
1500
1000
500
0
-500
-1000
CDFM (115.95 -31.80) mm
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
1500
1000
500
0
-500
-1000
-1500
CDFM (115.95 -31.80) mm
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
2000
1500
1000
500
0
-500
-1000
CDFM (115.95 -31.80) mm
12/1960
12/1970
12/1980
12/1990
12/2000
Date

EXTRACT FROM PAPER PREPARED BY HARVEY WATER TITLED: LICENCE ADMINISTRATION FEES - AN UNDERSTANDING OF THE TRUE COSTS OF ADMINISTERING WATER LICENCES IN IRRIGATION COOPERATIVES (OCTOBER 2007)

This extract from a paper prepared by Harvey Water illustrates the applicability of each of the five key activities undertaken by the Department of Water (DoW) in its licence administration regime, as it applies to an irrigation cooperative structure; and seeks to highlight the differences for a self supply irrigator.

LICENCE ADMINISTRATION FEE ACTIVITIES AND COOPERATIVES

Recommendation 42 of the Blueprint for Water Reform in Western Australia states that the licence administration fee (LAF) is to recover the costs associated with:

- Licensing -The assessment of licence applications and renewals
- Compliance - Checking compliance with licence conditions
- License Support - Maintaining licensing databases
- Appeals- Management of appeals, and
- Community awareness.

LICENSING and COMPLIANCE

LICENSING

Refers to all receipting and assessment of:

- *5C Licences to Take Water (including new applications, renewals, amendments);*
- *Transfer, trades and agreements to Take Water (5C);*
- *26D Licences to Construct or Alter Wells (including new applications and amendments); and*
- *11/17/21A Permits to Interfere or Obstruct Bed and Banks (including new applications and amendments).*

The Rights in Water Irrigation Act 1914 require DoW to have regard to certain matters when assessing an application that include but not limited to:

- *Determine eligibility to hold a licence;*
- *Advertising of application;*
- *Ecological sustainable;*
- *Environmentally acceptable;*
- *Prejudice current and future needs for water;*
- *Are in keeping with local practice, relevant by-laws and relevant decisions of Committees; and*
- *Consistent with land use planning instruments, policies of other Government Agencies and intergovernmental agreements.*

COMPLIANCE

There are costs associated with surveys and enforcement actions. Surveys form an integral part of ensuring the compliance with licence terms and conditions. Surveys are carried out, both during assessment and after the issuing of a licence and include inspection of properties.

Enforcement action refers to the action taken by the DoW when there is a breach of licence terms and conditions, or a breach of the Rights in Water and Irrigation Act 1914. This would include meetings and interviews with licensees and the physical gathering of evidences, as well as the preparation for and participation in legal proceedings.
Source: Original calculations to determine the water license application and administration fees (DOW, Sept 2007)

Cooperatives apply for and renew one or more collective licences on behalf of all their irrigators on a 5 year basis at present. They are required to supply all relevant information asked for by DoW and report annually against the many conditions of their license.

As well, each Cooperative licence is subject to Operating Conditions which may vary from year to year and include such responsibilities as the release and management of environmental flows. Not only is the management of the environmental water a cost to the irrigators, the release of that water reduces the volume effectively available to irrigators and also has an associated cost.

It should also be noted that in order to obtain a DoW water licence Cooperatives must also have previously obtained a Licence to Operate as a Utility which is issued by the Economic Regulation Authority (ERA). This ERA licence contains many more detailed conditions which have to be reported on and satisfied, including detailed biennial audits, all paid for by the Cooperative. This once again proves the point that comparison of SSL and other licences on a per Megalitre basis is invalid because the total licence structure is different and so are the costs of compliance involved.

Cooperatives continually collect data from individual irrigators at an indirect cost to them which enable the Cooperatives to carry out this work. If the Cooperatives didn't do this task each irrigator would have to apply for a separate licence and for its renewal. In effect, were the Cooperatives not capable of completing this task, DoW would have to collect all the data they require from Harvey Water's 770 irrigators, for example.

All transfers, trades and agreements to take water (more supply points or changes of them) are dealt with by the Cooperatives. All of these issues were previously dealt with by the regulatory arm of WAWA. Cooperatives are now required to provide to DoW a full summary report of all of this activity in relation to water supply and management annually. Cooperatives use their systems to do this. If they did not, DoW would need to do this and a fee would be justified.

It can also be noted that Harvey Water actually has 3 water licences because there are 3 different irrigation districts supplied from 7 different dams. This means that licence compliance costs are multiplied, if not in fact tripled.

Annual reports required by DoW from the Cooperatives can vary, but normally include information on:

- Water use and distribution efficiency
- Water use and demand projections
- All water traded permanently, temporarily or as sale of land
- Water quality monitoring (where required by license condition)
- Management systems
- On farm water use efficiency
- Land & water use trends
- Patterns of flow in water courses for environmental purposes (where license requires)
- Operating strategies (commonly developed in partnership with Water Corporation)
- Restrictions
- Breaches of licence
- Metering, measuring and monitoring (where required by license condition)

This reporting requires constant gathering of information that DoW would normally gather through survey, sites visits and the undertaking of one on one visits in SSA. The Cooperatives fulfil this information gathering, collating and reporting with staff employed by the irrigators.

In addition to these matters the Cooperatives have regularly paid for environmental, ecological and hydrogeology studies considered necessary by DoW for their various activities. Examples of this include the employment by the Ord of an environmental officer, full electromagnetic survey for salinity in the HWIA, comprehensive 3 year study on nutrient and drainage outflows, employment of GIS staff to correlate/ground truth data and multiple creek and river ecology studies within the areas of the Cooperatives' operations.

All Cooperatives financially contribute, in partnership with the DoW, for Western Australia's participation in the National Program for Sustainable Irrigation (NPSI) with Land & Water Australia which provides the opportunity for access to research funds to deliver information on water use and efficiency. Several projects funded through NPSI have had national recognition for the quality of the work and the usefulness of the information produced.

LICENSE SUPPORT

Licensing support includes costs for:

- *database maintenance and enhancements, including data validation and cleansing;*
- *delivery of training to regional licensing officers; and*
- *providing supporting expertise for regional licensing staff.*

Source: Original calculations to determine the water license application and administration fees (DOW, Sept 2007)

Prior to the Cooperatives licensing support was a task undertaken within WAWA which historically incorporated the regulatory function along with its irrigation storage and delivery functions in what are now the Cooperative irrigation areas. When WAWA was devolved into the Water Corporation and Waters & Rivers Commission it was determined that as part of privatization of the irrigation distribution assets to the Cooperatives they would be accountable for all licensing issues relating to individual irrigators. An individual irrigator's water entitlement was converted to a shareholding within the respective Cooperative.

The Cooperatives have the legal right to water through each DoW water licence held and individual irrigators have equitable rights to water through their shareholdings in the Cooperatives.

In SSA the database of individual irrigator entitlements is currently maintained by DoW. When a sale of land occurs, SSL irrigators must inform and get approval from DoW for a transfer of water ownership.

Cooperative irrigators must inform the Cooperatives who administer ownership database records. Cooperatives are legally responsible to ensure the validity of these records.

Cooperatives are now required to ensure that the water entitlement database they manage conforms with all NWI requirements to enable the WA State Government to, in turn, conform with its NWI obligations. DoW has made it clear that all aspects of Cooperatives' databases and irrigators' individual entitlements must be managed in accordance with the NWI/COAG requirements.

Failure to comply would see the Cooperatives' bulk water licence role reviewed and could be revoked. DoW recognises that each irrigator owns their own entitlement (which they do) with the Cooperatives holding an overarching license that requires water administration and delivery as per the previous WAWA regime. Each individual irrigator's entitlement must be database managed as if they were a SSL irrigator.

Prior to Cooperatives the regulatory arm of WAWA administered all matters relating to database maintenance, changes and oversight. When Cooperatives commenced the responsibility and cost of operations and administration of all the irrigators individual entitlements database was transferred to them by the State Government. This cost has been internally billed to individual irrigators ever since. In SSA it has remained a responsibility of the State and is undertaken by DOW who is now seeking payment for this function through the LAF on a user pays basis.

Put simply DOW maintains the individual water entitlement database of SSL irrigators but not those within Cooperatives regions. They do reserve a right to request this information. Under NWI Cooperatives must be able to provide this data in a timely manner. The WA Cooperatives are now working toward putting all their individual irrigator water entitlement data onto an online publicly accessible database. This is a national project being done in collaboration with other locally owned irrigation companies to ensure all Cooperatives comply with our individual States' NWI obligations. This project is largely being internally funded by Cooperative irrigators with some NWI funding support. DoW is also required to do this with all SSL irrigators but using State funds at this time while Cooperatives are charging their irrigators internally.

In regard to database management for individual irrigators Cooperatives manage this task. If Cooperatives didn't DoW would need to do this and charge individual irrigators accordingly.

APPEALS to STATE ADMINISTRATIVE TRIBUNAL (SAT)

Any appeals against the decision of the Commission are assessed by the State Administrative Tribunal (SAT). Actions include collation of papers, evidence and supporting documents for both the SAT Tribunal and the appellant.

With declining availability of water resources there is a corresponding increase in appeals against DoW decisions to refuse applications.

Source: Original calculations to determine the water license application and administration fees (DoW, Sept 2007)

Using Harvey Water as the example, to date neither HW nor any irrigator has ever had an issue go to the SAT over our 11 years of operation. Any disputes in the HW area in regard to allocations, water access or entitlement etc have all been dealt with internally under the customer complaints process required to be set up under our licence. Irrigators do have complaints and issues from time to time. Any resources, be they HW staff time or professional assistance, needed for resolution within the HWIA are collectively paid for by all irrigators of the region. Should any irrigator within the region contact DoW or ERA with an issue they are directed back to HW to first seek resolution there.

It is the responsibility of the Cooperatives to be administratively capable of sorting out disputes. Only a complete failure of Cooperative systems would see an issue end at the Water Ombudsman.

COMMUNITY AWARENESS (WATER RESOURCE MANAGEMENT COMMITTEES)

Costs associated with managing and supporting community based Water Resource Management Committees and Advisory Committees. The cost includes sitting fees and travelling expenses for members as well as venue and catering expenses.

A smaller proportion of the cost goes towards community education on water resources that include the provision of up to date information on water availability and other pressing local issues via the print media.

Source: Original calculations to determine the water license application and administration fees (DOW, Sept 2007)

Advisory Committees existed in Cooperative areas prior to the Cooperatives commencing, with the State paying fees and all supporting costs. These mechanisms ceased at the time of Cooperatives commencing operations about 10 years ago.

All costs such as attendance by irrigator directors of the Cooperatives, staff or general manager at any water management related meetings, workshops and functions are paid for by Cooperative irrigators. This means that all external liaison with DoW or WC or any other external stakeholder bodies at local, state and national level (and there are very many at present) on behalf of the irrigators is paid for by irrigators. This liaison allows the Cooperatives to keep involved in and well informed on matters in the ever evolving world of water management in Australia at present. Harvey Water has made the decision that it needs to be involved on behalf of its members so that we can have sensible conversations about water and make sensible decisions.

The Cooperative Boards are in every sense the "water resource management committee" due to the level of responsibility that they take on. Board costs (direct & indirect) vary between the Cooperatives but commonly exceed $100k a year.

Any pressing local water issues that require extension of information are handled by the Cooperatives. Cooperatives distribute and advertise to all individual irrigators via internal newsletters, meetings, websites and regular advertising in local papers and radio throughout the region they operate in. Liaison with DoW/WC does occur with any relevant information incorporated for extension to irrigators on a regular basis. This extension is paid for by the irrigators. DoW does not contribute to this. During the past two years almost all information that DoW has sought to have provided to individual irrigators about water reform has been via the Cooperative mechanisms paid for by the Cooperative irrigators.