



Government of **Western Australia**  
Department of **Water**

*Looking after all our water needs*

# Millstream status report

A review of management and consolidation of  
current understanding

*Looking after all our water needs*

Department of Water

Environmental water report series

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# 1 Introduction

## 1.1 Purpose

The Millstream aquifer is one of two water resources supplying the West Pilbara water-supply scheme (the other is Harding Dam). The Water Corporation abstracts water for the scheme under licence from the Department of Water, according to the *Rights in Water and Irrigation Act 1914* (WA).

Before this review, detailed management plans protecting Millstream were prepared in 1984 (Dames & Moore 1984) and 1998 (Welker Environmental Consultancy 1998). These plans, by necessity, made water-resource management decisions based on a number of assumptions or uncertainties. As a result, management has evolved as our understanding of the system has improved.

This ‘Stage 1’ review is the first step towards a revised framework to manage this resource (Figure 1). The review aims to:

- consolidate our understanding of the aquifer and the environment it supports
- review the evolution of management to date
- identify assumptions and information gaps.

This review’s outcomes will provide the basis for a ‘Stage 2’ review, which will include revised estimates of Millstream’s ecological water requirements (EWR) and sustainable yield for the Millstream aquifer.

This process is part of the Department of Water’s development of *Statutory water resource management plans* for the Pilbara, a project funded in part by the Australian Government’s Water Smart Australia program.

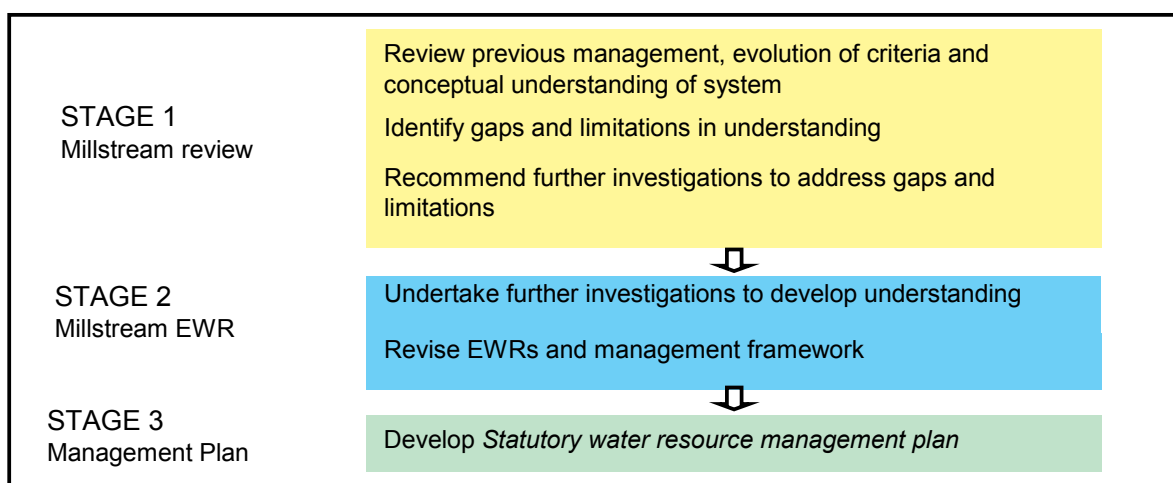


Figure 1: Flowchart showing the staged process for revising Millstream EWRs

## 1.2 Study area

Millstream is situated approximately 100 km south of Karratha in Western Australia's Pilbara region (Figure 2). It is a complex system of wetlands sustained by groundwater discharge from the Millstream aquifer and intermittent seasonal flow from the Fortescue River. The system occupies a broad ancestral valley between the Hamersley Range in the south and the Chichester Range in the north and is crossed by the Fortescue River.

The wetlands and adjacent areas are part of the Millstream National Park, which was established to protect and maintain areas of significant ecological, cultural and/or social value. Management has focused on the following key features of the system:

- pools along the Fortescue River including Deep Reach, Crossing, Palm and Livistona pools
- off-channel pools and wetlands including Chinderwarriner Pool and the Millstream Delta, Woodley Creek, Peters Creek and Palm Creek.

The pools and wetlands of the Millstream system are sustained by discharge from the Millstream aquifer. The aquifer holds a significant quantity of fresh water and is a vital component of the West Pilbara water-supply scheme (which provides water for industrial and domestic purposes to Karratha, Dampier, Roebourne, Wickham and Point Samson).

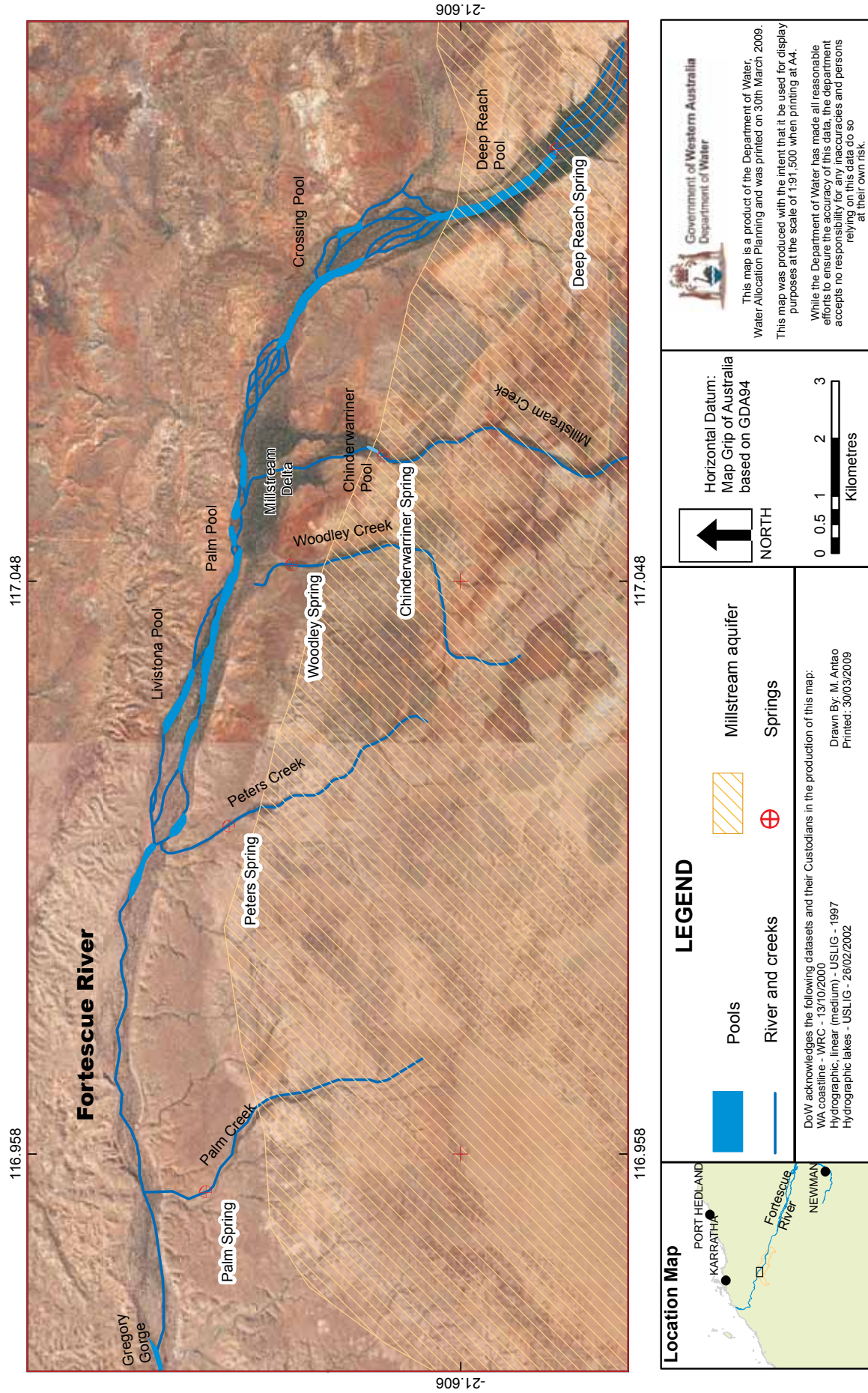


Figure 2: Location map showing Millstream and the Millstream aquifer

## 2 Background

### 2.1 Climate

#### Rainfall

The Pilbara coast's climate is arid-tropical with low and variable annual rainfall. The long-term-average annual rainfall at Millstream is 366 mm (110-year)<sup>1</sup> with totals ranging from 151 mm in 2003 to 899 mm in 1900.

This large variability is due to the episodic nature of tropical cyclones, or cyclone-related events, which cross the area in the summer months between December and April. These events provide the majority of total rainfall (80 per cent). Winter rainfall may also occur in May or June due to the influence of larger cold fronts that dominate winter weather patterns in the southern half of the state. The driest months are September to November and the wettest January to March.

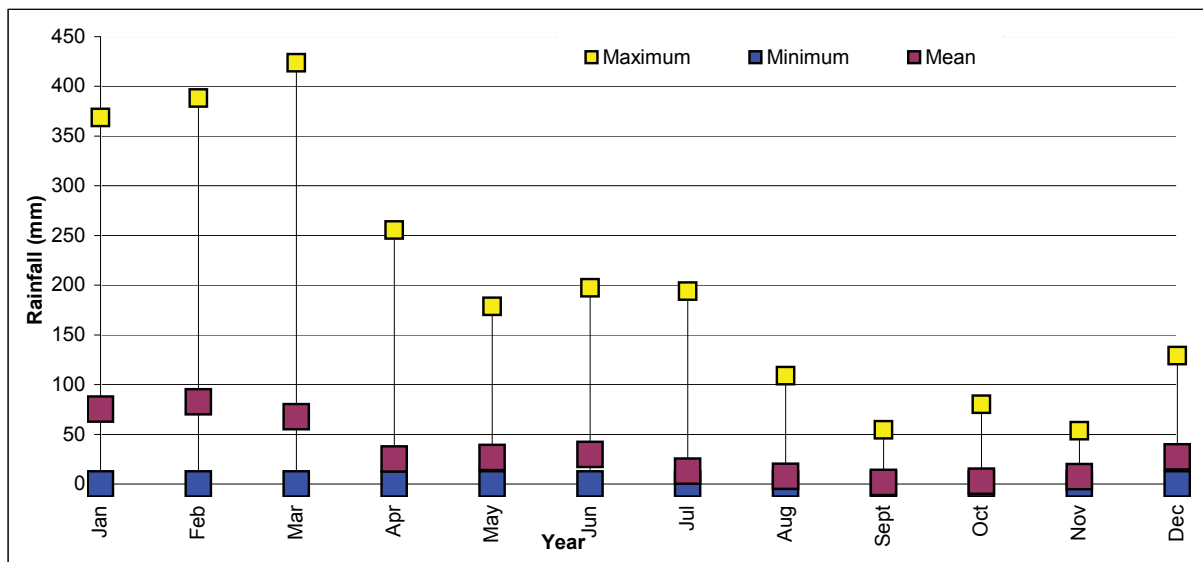


Figure 3: Millstream monthly rainfall statistics (Bureau of Meteorology station 5012)

A trend of increasing rainfall has occurred over the past 30 years. From 1970 to 2008 the average annual rainfall has increased to 402 mm, a 10 per cent increase from the long-term average of 366 mm a year.

<sup>1</sup> Rainfall data for Bureau of Meteorology station 5012 (Millstream) is incomplete during the period 1974–88 and has been supplemented with data from other nearby rain gauges.

## Temperature

Temperature data for Pannawonica, the nearest representative site with data from 1972 to 2005, indicates January has generally been the hottest month with a mean maximum of 41.0°C and a mean minimum of 27.7°C. July is the coolest month with a mean maximum of 26.7°C and a mean minimum of 24.6°C.

## Evaporation

Due to low rainfall and high temperatures, monthly evaporation greatly exceeds monthly rainfall for every month of the year (Figure 4). The average annual potential evaporation at Millstream is 3172 mm.

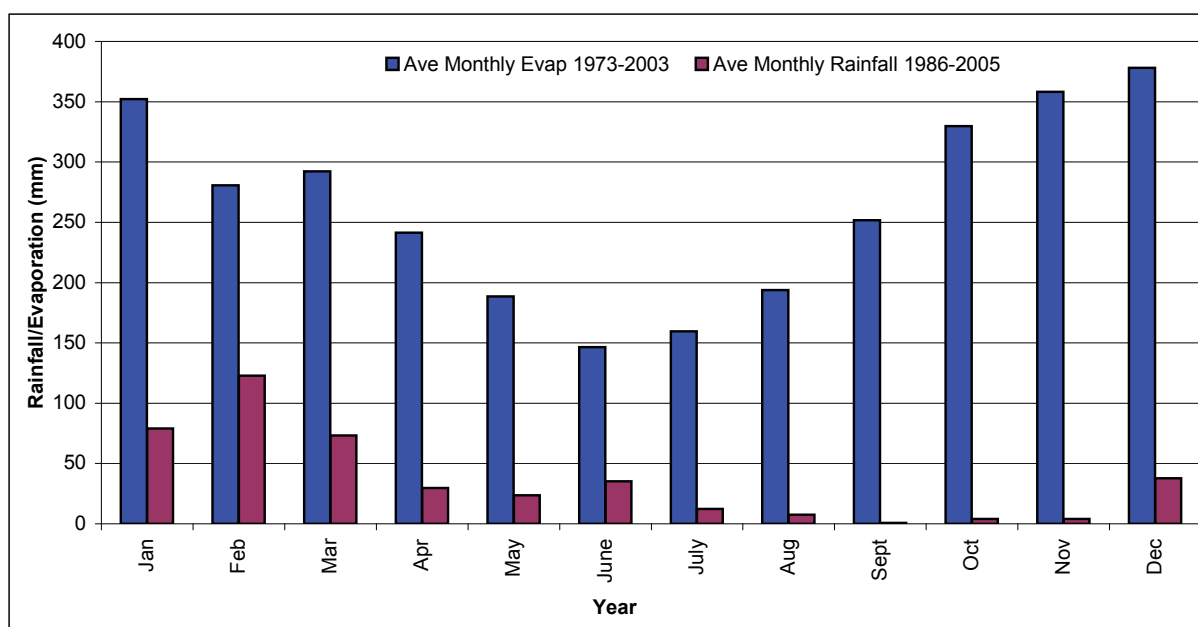


Figure 4: Average monthly evaporation and rainfall at Millstream (Bureau of Meteorology station 5012)

## Climate change

Global warming is expected to result in a small decrease in annual rainfall and higher evaporation (CSIRO 2006).

These predictions are complicated by climate modelling indicating that aerosol build-up over Asia – the Asian Haze – is affecting the hydrological cycle in north-west Australia. Since the 1950s this has generated increasing rainfall and associated cloudiness (CSIRO 2006). This is thought to be masking the predicted upward trend in global temperatures and expected local decrease in precipitation at the regional scale. As aerosols are short-lived in the atmosphere, it is expected that the Asian Haze effect may be reversed later in the century and the current trend of increasing rainfall will discontinue<sup>2</sup>.

<sup>2</sup> The Department of Water is investigating the impacts of climate change on regional water resources including changes to inflow- and outflow-related hydrological environments.

## 2.2 Hydrogeology

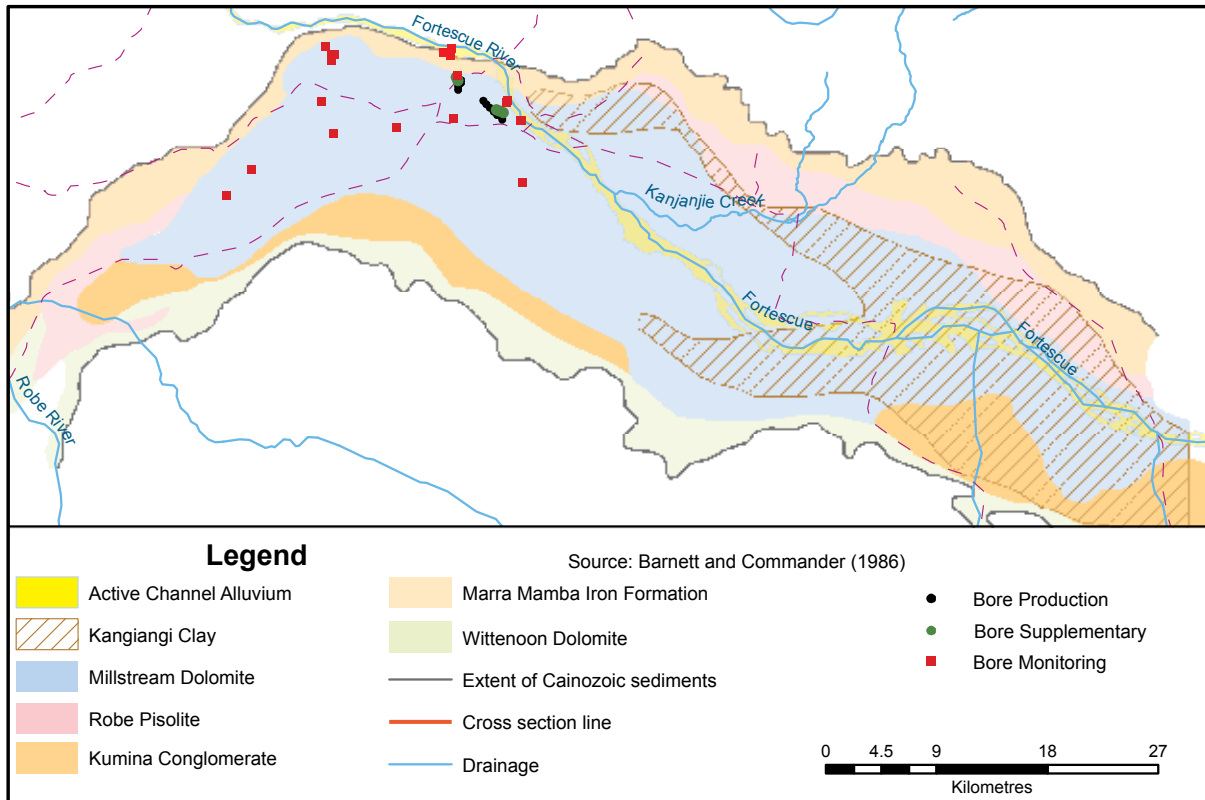
This section gives a general account of the geology and hydrogeology of the Millstream Dolomite aquifer, compiled from a review of previous work (Table 1). Haig (2008) provides the most recent review of regional hydrogeology and includes additional technical information on Millstream.

*Table 1: Significant investigations carried out to determine the specific yield and geology of the Millstream aquifer system*

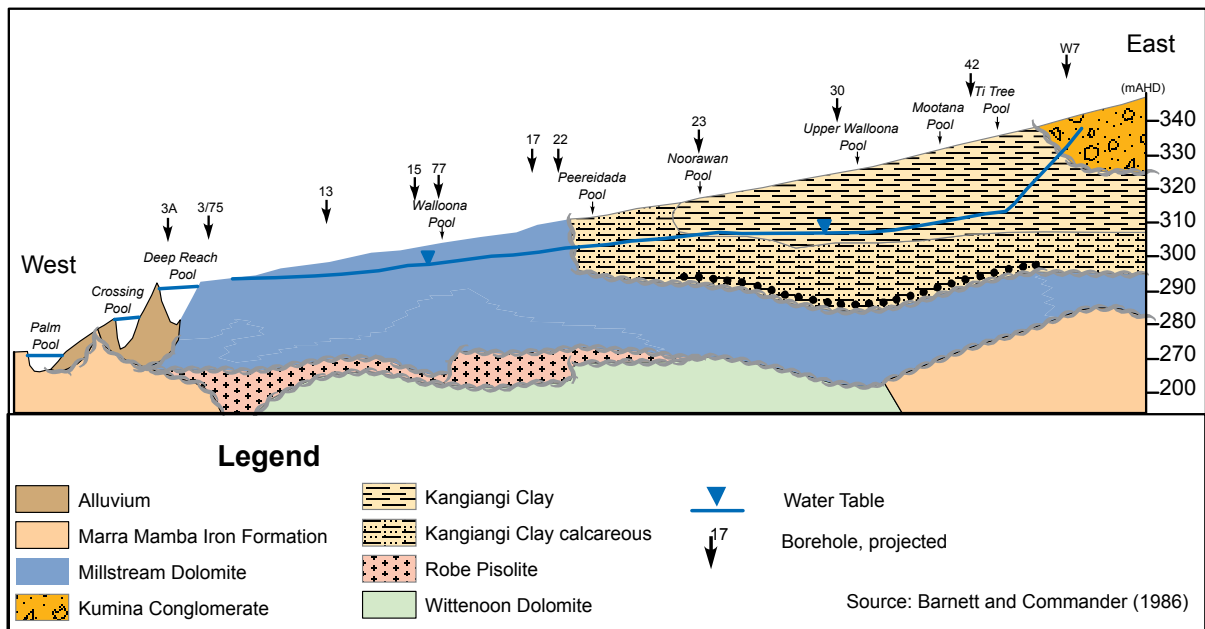
Study	Detail of significant geological investigations
Davidson 1969	25 exploratory bores
Forth 1971	12 production bores
Sadler & Parker 1974	
Barnett et al. 1977	5 fully cored boreholes for test pumping
Barnett & Commander 1986	42 bores drilled by the Geological Survey
Haig 2008	Regional review of hydrogeology

The Millstream aquifer system occupies a broad palaeovalley between the Hamersley and Chichester ranges. From 1969 to 1986, more than 80 investigation bores were drilled (see Table 1). Three main aquifers were identified: the Millstream Dolomite aquifer, the Robe Pisolite aquifer and the Kumina Conglomerate (Figure 5). Of these the Millstream Dolomite aquifer was found to be the most extensive and productive. This is referred to as the Millstream aquifer or the aquifer.

The system is best described as a basin filled with dolomite and calcrete with layers of silcrete and clay. The dolomite and clay are alluvial deposits and silcrete and calcrete are secondary products formed from weathering of parent materials. The aquifer is of varying thickness with a maximum depth of 50 m and a varying saturated thickness of up to 33 m (Haig 2008). It has an area of 950 km<sup>2</sup> and is largely unconfined except for a portion to the east that is overlain by the Kangiangi Clay (Figure 6).



**Figure 5:** *Geology of the Millstream aquifer system showing the Millstream Dolomite aquifer, which abuts and exchanges water with the Robe Pisolite aquifer and the Kumina Conglomerate*



**Figure 6:** *Geological cross-section of the Millstream aquifer system showing the Kangiangi Clay which confines part of the Millstream Dolomite aquifer*

Even though the dolomite has a very low primary porosity, secondary porosity in the form of solution channels and voids around the watertable/air interface is very high (Haig 2008). As a result of these channels, transmissivity is also extremely high – as indicated by a very small drawdown in the aquifer during pumping tests (SMEC 1975).

While the specific yield varies considerably – largely due to the dominance of secondary porosity – an average specific yield of 0.1 has been estimated (Barnett et al. 1977 and Barnett & Commander 1986). Based on this, total storage estimates for the Millstream aquifer are reported to be 1425 GL (Haig 2008).

## Recharge

Much of the recharge is attributed to flood events in the Fortescue River, with flows passing over outcrops of the aquifer and resulting in direct infiltration (Figure 7). The occurrence of flood events (as measured at Gregory Gorge) is closely correlated with observed recharge to the aquifer, as demonstrated by increases in mean aquifer level (MAL)<sup>3</sup>. MAL is defined as the average groundwater level in nine monitoring bores in an area of very low gradient where the production bores are located (Figure 8).

The size and duration of river-flow events are both important factors in determining the magnitude of recharge to the aquifer. For example, the passing of Cyclone Joan in 1975 resulted in the largest recorded river flow with peak flows of 3166 m<sup>3</sup>s and a corresponding increase in MAL of 0.393 m (Figure 9). By comparison, smaller peak river flows between 100 m<sup>3</sup>s and 1200 m<sup>3</sup>s maintained over a longer period, such as those that occurred in 2006, resulted in an increase in MAL of approximately 1.0 m (Figure 9).

---

<sup>3</sup> Mean Aquifer Level. For operational and management purposes the aquifer level is represented by a mean aquifer level (MAL) from water levels in nine monitoring bores in the Millstream borefield. These bores are monitored monthly and used as a measure for changes in aquifer levels.

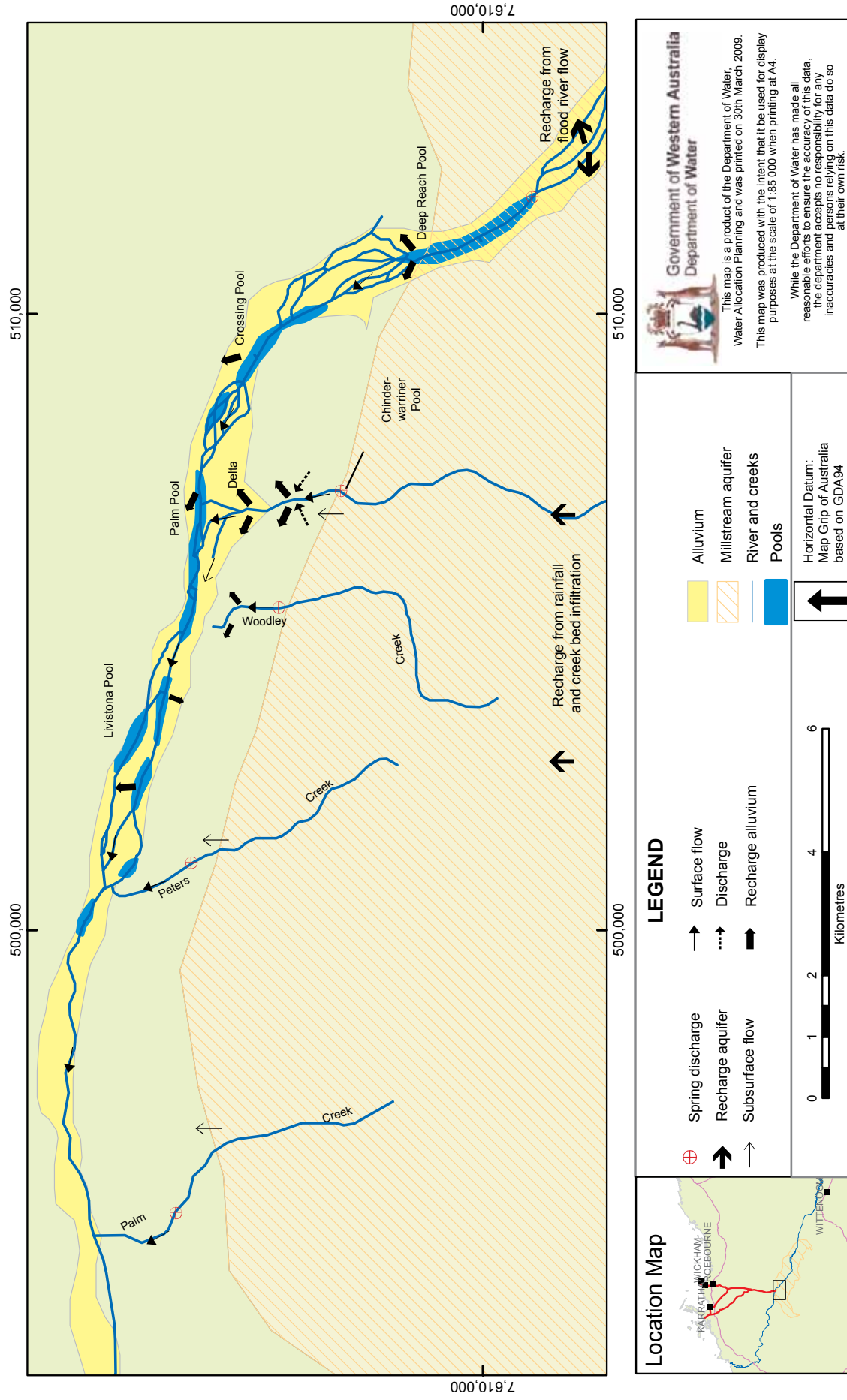


Figure 7: Hydrology of the Millstream aquifer showing recharge and discharge points and surface flow down the Fortescue River

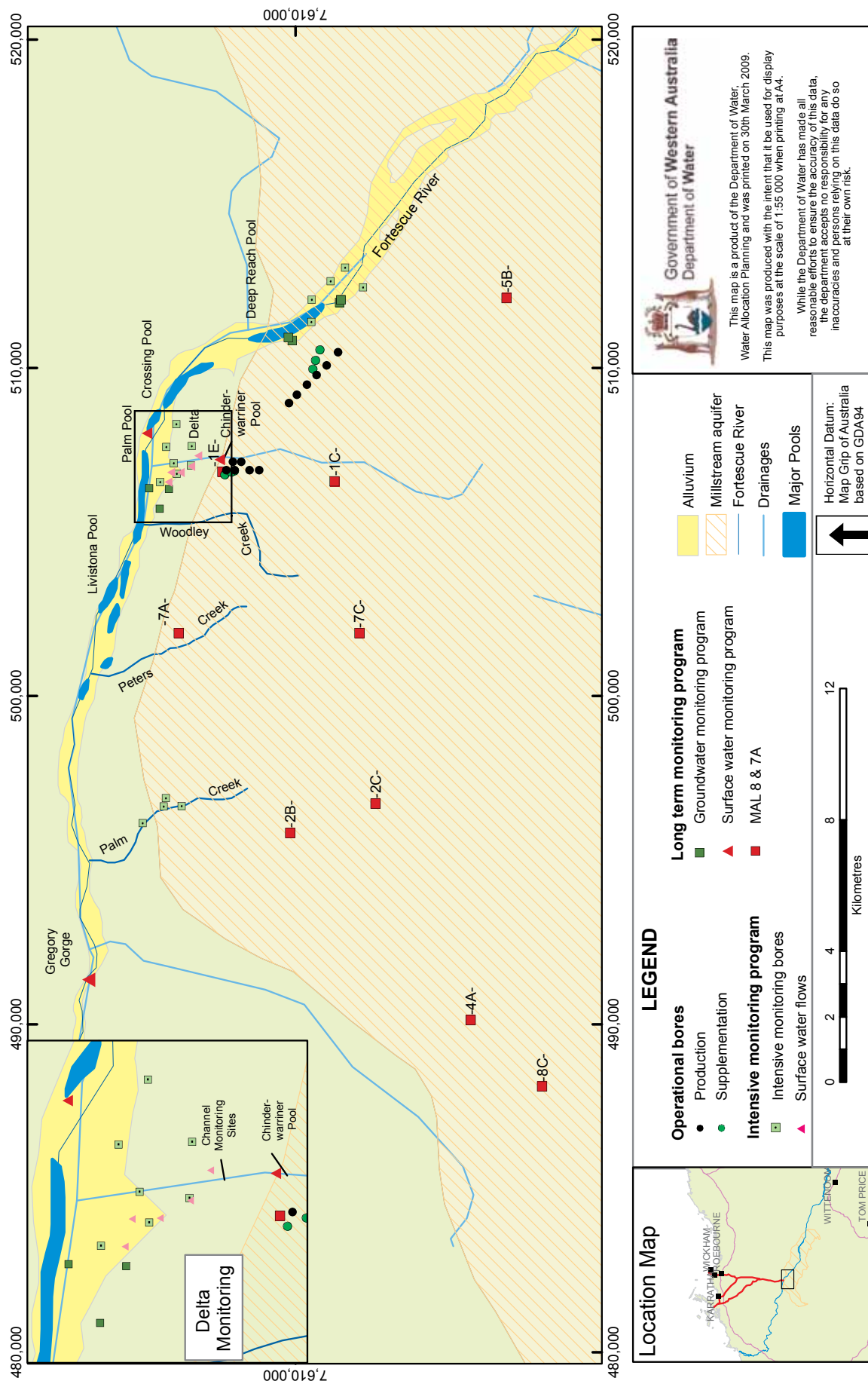


Figure 8: Millstream monitoring network and production bores

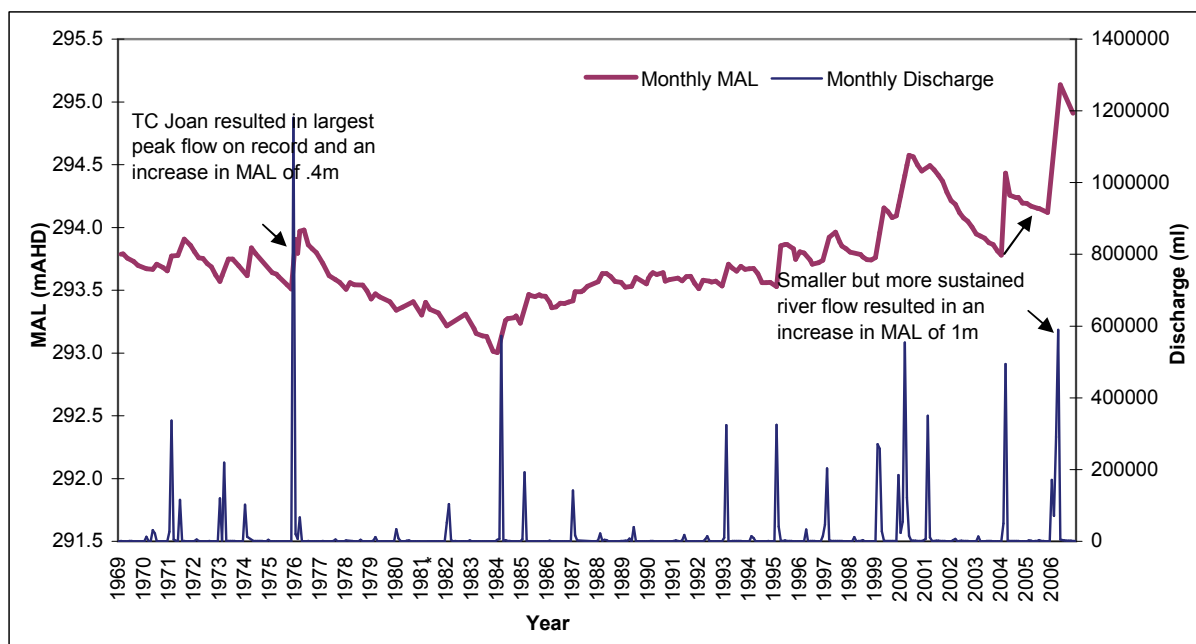


Figure 9: Fortescue River monthly river flows (measured at Gregory Gorge) and MAL

Some recharge also occurs as a result of surface runoff into creeks from the Hamersley Range and direct rainfall infiltration across the unconfined parts of the aquifer and the Kumina Conglomerate. The highly conductive Kumina Conglomerate is in physical contact with the aquifer (Figure 5), which ensures that secondary recharge to the aquifer occurs rapidly.

Estimates show that recharge from runoff and direct rainfall on the dolomite only accounts for a small proportion of total recharge (Barnett & Commander 1986).

## Discharge

The major discharge points for the aquifer are the springs discharging into Deep Reach Pool and Chinderwarriner Pool. Minor discharges also occur into Palm Creek, Peters Creek and Woodley Creek (Figure 7). Additional minor discharges also occur via groundwater throughflow and from minor discharges into the Robe River at the western margin of the aquifer. A groundwater divide west of Millstream separates groundwater discharging to the Fortescue River from that discharging to the Robe River.

It is difficult to physically measure actual spring discharges. A relationship has been developed based on measured pool outflows corrected for evapotranspiration losses incurred between the springs and the actual downstream measuring point (Figure 10).

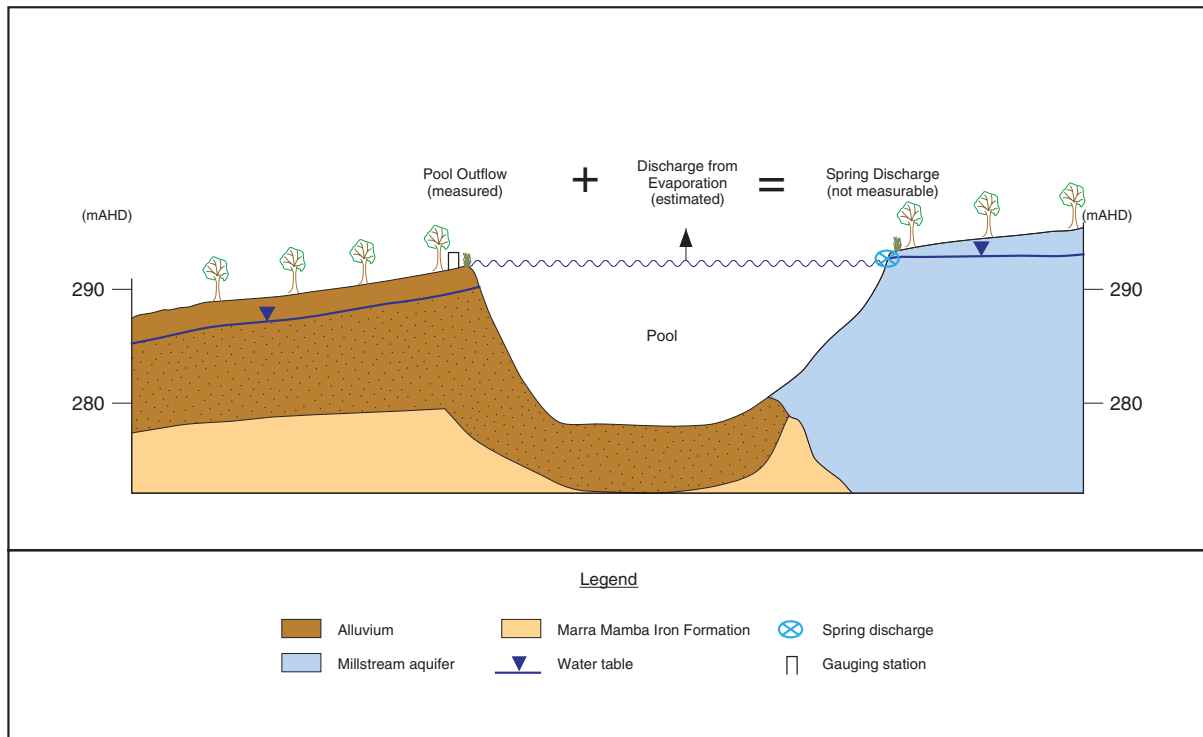


Figure 10: Conceptual diagram showing the relationship between estimated spring discharge and measured flow

Modelling demonstrates a clear relationship between MAL and rates of discharge into Deep Reach Pool and Chinderwarriner Pool (SMEC 1975; SMEC 1982) (Figure 11). This modelling suggests a MAL of 293.6 mAHd would result in an annual spring discharge of about 15 GL/a. At a MAL of 293.1 mAHd, the outflow from Chinderwarriner Pool would be negligible while the corresponding discharge at Deep Reach Pool would be about 8.086 GL/a. A numerical model of the aquifer currently being constructed will provide updated MAL - spring discharge relationships.

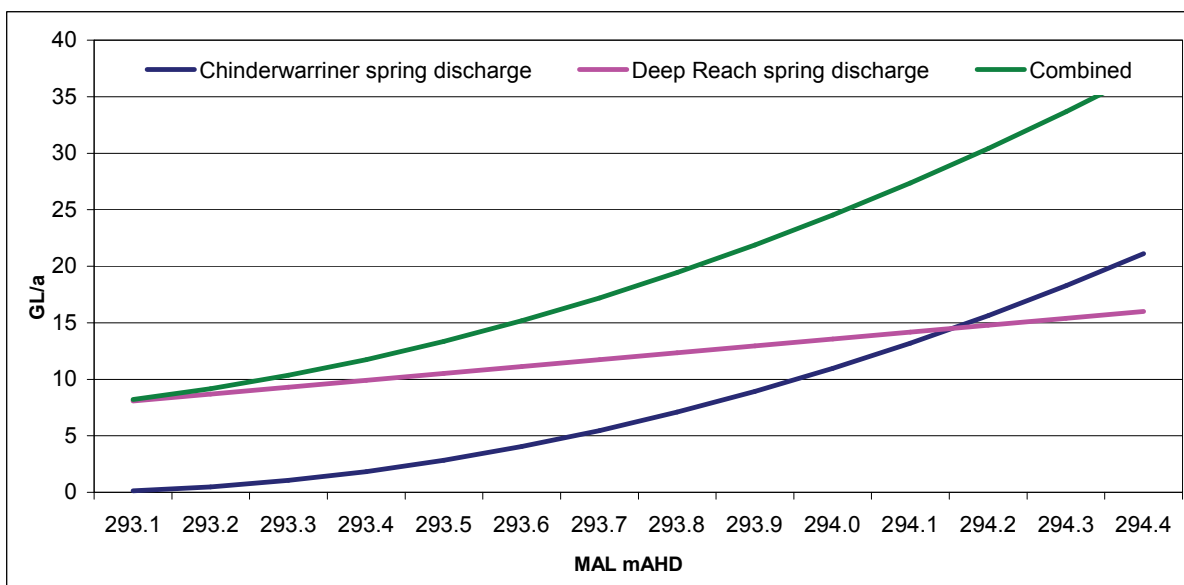


Figure 11: Modelled spring discharge for Chinderwarriner Pool and Deep Reach Pool (SMEC 1982)

In addition to spring discharge, estimates of additional losses predict throughflow to be approximately 1.5 GL/a (Welker Environmental Consultancy 1998).

## 2.3 Environmental features

The Millstream wetland system comprises approximately 20km of the Fortescue River and tributaries. It includes four major permanent river pools (Deep Reach, Crossing, Livistona and Palm Pools) interconnected by permanent flowing channels, spring-fed pools on tributaries (e.g. Chinderwarriner Pool) and large areas of riparian and wetland vegetation.

The area is incorporated into the Millstream National Park and is listed on the Register of the National Estate and in the Directory of Important Wetlands. It is a significant area of isolated habitat for wetland flora and fauna and supports a number of regionally under-represented species. It is an outstanding example of a system of permanent river pools and springs in the semi-arid tropics and the best known in north Western Australia (Semeniuk, 2000). As such it is also being considered for Ramsar listing under the Convention on Wetlands (DEC 2007).

The links between ecosystems and groundwater and the mechanisms of hydrological support of ecosystems have previously been described (e.g. Muir 1995, Dames & Moore 1975). Ecosystems that rely on groundwater directly (e.g. stygofauna or phreatophytic vegetation utilising water from shallow water tables) or indirectly (e.g. wetland vegetation or aquatic ecosystems sustained by groundwater discharge) have been identified as groundwater dependent. Specifically at Millstream the following ecosystems are reliant on access to or discharge from the Aquifer: wetlands (including river pools); phreatophytic vegetation and aquifer ecosystems.

The wetlands sustained by the Millstream aquifer include Deep Reach, Crossing, Palm, Livistona and Chinderwarriner pools. There are also extensive areas of flowing channels and intermittent pools which extend as far downstream as Gregory Gorge depending on the rate of discharge and season. The wetlands provide a diverse array of habitats which in turn supports high biological diversity.

By Pilbara standards the wetlands support a relatively large and diverse fish population (May and McKenzie 2002). Nine of ten freshwater species recorded for the Fortescue River occur at Millstream (Beesley 2006). This includes species that have a preference for or are found only in deep permanent pools such as the salmon catfish (*Arius graeffei*), the northern eel (*Anguilla bicolor*) and bony bream (*Nematolosa erebi*) (Morgan et al. 2003, Beesley 2006). The relatively high number of species recorded for Millstream is likely to be mainly due to the permanency or stability of the pools (Beesley 2006, Burbidge 1971).

The permanency of water in the wetlands and the diversity of habitats including fast and slow flowing channels are also likely to be the reasons behind high diversity of aquatic plants or macrophytes. Fifteen species of vascular aquatic macrophytes including submerged and emergent species and two species of algae occur at Millstream.

Aquatic macrophytes are an ecologically significant component of the Millstream system. They provide habitat for macroinvertebrates and fish, with some species showing specific species-species associations (Charlton 1994). Macrophytes also significantly influence water quality and movement through the system.

The Millstream wetlands also support a diverse and unique assemblage of macroinvertebrates. This includes damselfly and dragonfly species found only at Millstream and species known elsewhere but as disjunct populations (Kimberley) (Burbidge 1971; Dames and Moore 1984). Millstream has also been identified as one of a small number of spring or spring fed permanent wetlands in the Pilbara that support a specific suite of macroinvertebrate fauna (A. Pinder pers. comm. 2008).

The area's stability (in terms of long term water availability) is also a likely reason for a diverse assemblage of stygofauna. Bicarbonate rich aquifers such as Millstream have been demonstrated to exhibit a particularly abundant and diverse assemblage of stygofauna (Reeves et al. 2007). Additional information on the stygofauna communities of the Millstream aquifer will become available when the results of the Pilbara Biological Survey are published by the Department of Environment and Conservation.

A total of 24 vegetation communities have been identified at Millstream (Dames & Moore 1975). Of these, the riverine forest ecosystems, the Millstream fan palm (*Livistona alfredii*) community and the healthlands and sedgeland are of particular environmental significance.

The riverine forest ecosystems are dominated by *Melaleuca argentea* and *Eucalyptus camaldulensis*. These two species are reliant on access to groundwater or spring fed surface water at Millstream. Also of significance are the large stands of the Millstream fan palm, *Livistona alfredii*. *Livistona alfredii* is a relictual species with a distribution restricted to the Fortescue Valley around Millstream and only a few other sites in the Pilbara. It is currently listed by the Department of Environment and Conservation (DEC) as a Priority 4 species in recognition of its conservation significance. An additional 10 priority flora species have been recorded in the Millstream area (DEC 2007).

The wetlands and vegetation communities found at Millstream provide important bird habitat. A total of 146 species have been recorded from the Millstream-Chichester National Park including 31 migratory species listed under the Bonn Convention or under JAMBA and CAMBA (DEC 2007). Burbidge (1971) recorded 38 species of water birds and at least eight of these use the wetlands for breeding.

The permanent availability of water either directly from groundwater or indirectly from groundwater discharge into pools and wetlands is the key feature that has allowed the establishment and maintenance of the Millstream environment.

## 2.4 Abstraction from the aquifer

### West Pilbara water-supply scheme

Abstraction of groundwater from the Millstream aquifer for public water-supply purposes began in 1969. The borefield (Figure 8) originally consisted of six production bores (PB1–PB6) with an additional six bores commissioned in 1971 (PB7–PB12). Production from PB11 and PB12 ceased in 1988 due to high salinity levels and both were subsequently decommissioned in 2000. Ten bores are currently commissioned for production.

In addition to the production bores, two supplementation schemes consisting of three bores each are located near Chinderwarriner Pool and Deep Reach Pool (Figure 8). These bores abstract water from the aquifer and allow supplementation directly into each of the pools during periods of low spring flow. No supplementation schemes exist at Peters Creek, Woodley Creek or Palm Spring.

In 1985 Harding Dam was brought online to relieve pressure on the aquifer and help meet increasing demand. The conjunctive scheme consisting of Harding Dam and the borefield at Millstream is known as the West Pilbara water-supply scheme (WPWSS). The scheme is operated to maximise use from the dam: when water is available and of suitable quality. At such times there is typically minimal or no abstraction of groundwater from Millstream.

The Water Corporation holds a licence under the *Rights in Water and Irrigation Act 1914* (WA), which allows for the abstraction of up to 15 GL/a from the conjunctive scheme with a long-term abstraction rate from the aquifer of 6 GL/a. Provision is also made within the licence to abstract the total 15 GL from the aquifer if required, as long as aquifer water-level criteria (as detailed in Section 4) are not breached and vegetation condition does not decline.

### Abstraction

Abstraction from the aquifer increased steadily from 1.62 GL in 1970 to 15 GL in 1983 and 1984 (Figure 12). As a result of Harding Dam's construction and the conversion to a conjunctive scheme, since 1986 abstraction has averaged 4.57 GL/a. During this time, relatively high rates of abstraction occurred in 2002, 2003 and 2004 at 9.34, 9.35 and 9.29 GL/a respectively. These abstraction rates coincide with low or no recorded inflows to Harding Dam and a period of low flow in the Fortescue River.

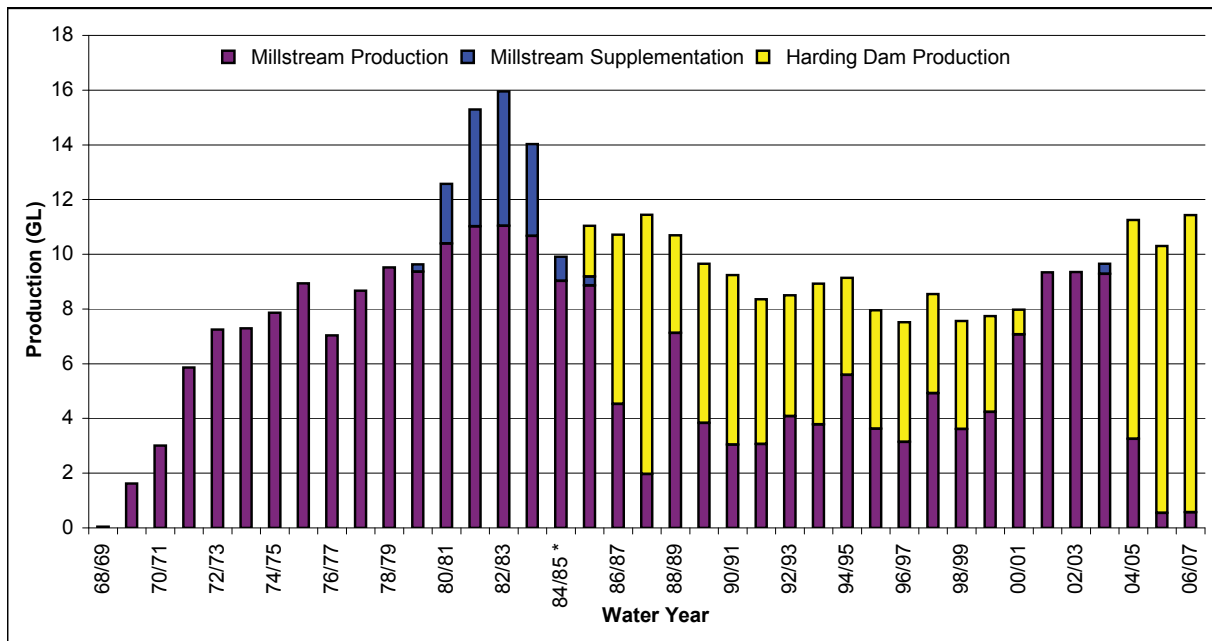


Figure 12: Total annual production for the West Pilbara water-supply scheme

\* Before 1985 the water accounting year was January to December, at which time it changed to April to March.

### Impacts of abstraction on aquifer level and ecosystems

In the absence of recharge, aquifer levels as defined by MAL, naturally decline as a result of discharge and other losses. This decline rate, as show on a hydrograph, follows a recession curve with the greatest rate of decline being experienced during higher aquifer levels. With the addition of abstraction for consumptive use, the natural rate of decline of the aquifer's water level is accelerated.

Observed changes in MAL between February 1977 and January 1978 suggested that abstraction of 8 GL/a could result in rates of watertable-decline being accelerated by approximately 0.07 m/a. Between October 1982 and November 1983, when MAL was 293.310 mAHD, abstraction rates of 15 GL/a resulted in watertable-decline being accelerated by approximately 0.20m/a (Figure 13).

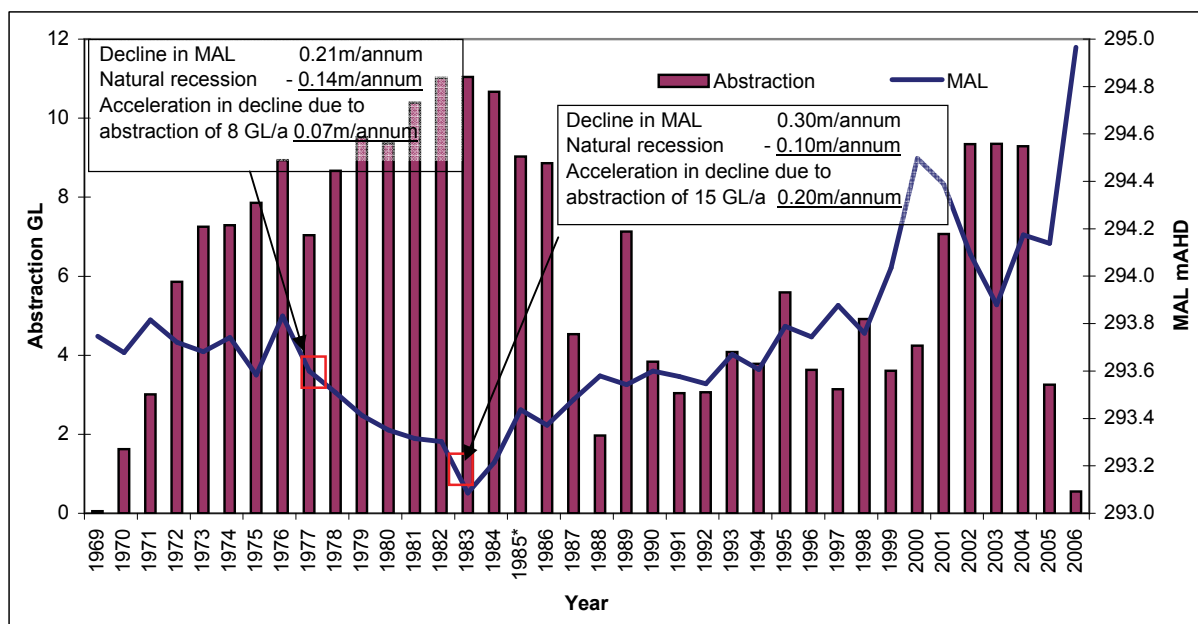


Figure 13: Yearly abstraction rates (excluding supplementation) and MAL

\* Before 1985 the water accounting year was January to December, at which time it changed to April to March.

As a consequence of MAL decline in the 1970s and 1980s (due to drought and abstraction), large reductions in spring flows to Chinderwarriner Pool and small changes in spring flows to Deep Reach Pool occurred. Considerable thinning of the tree canopy was observed across the Millstream Delta and the health of river gums to the west of Woodley's Delta declined substantially (Dames & Moore 1984). In the Millstream Delta the increase in *Eucalyptus camaldulensis* and *Acacia ampliceps* at the expense of *Melaleuca argentea* (Welker Environmental Consultancy 1995) was further evidence of the impact of drying.

In 1985 Harding Dam came online to alleviate pressure on the aquifer and meet future demand on the scheme (Figure 12). This resulted in considerably lower rates of abstraction from the aquifer and enabled the MAL to recover. Abstraction rates peaked again during 2000 to 2004 while Harding Dam was offline. Again, in combination with low recharge, this resulted in a steady decline in MAL.

Harding Dam came back online in early 2004 relieving pressure on the Aquifer. This along with increased recharge events, resulted in a MAL of 295.137 mAHd in May 2006, an historic high level.

## 3 Management

### 3.1 Previous management

Since formal management began in 1984, three plans have guided the development of management practices and environmental criteria for Millstream. The objectives and management frameworks of these plans are outlined in the following sections, and as a guide, a chronology of the agencies involved is represented in Figure 14. The development and evolution of management criteria is addressed in the following chapter.

#### **Millstream water management program 1984**

The *Millstream water management program (MMP)*, prepared by Dames and Moore (1984) was initiated by the Public Works Department (PWD). This was in response to Environment Protection Agency (EPA) concerns about the effects of the West Pilbara water-supply scheme (WPWSS) on Millstream. The EPA accepted the program in July 1984 (WC 1999). The program was also driven by the need to address problems of tree deaths and declining vegetation health linked to reduced environmental flows and declining water levels.

The program involved a coordinated response to management of the aquifer and associated ecosystems by having representatives of lead agencies form an overarching management committee (see Figure 14). Management consisted of a two-tiered structure: a Perth committee responsible for overall review of the program and a Pilbara committee responsible for implementation of the program.

Other outcomes of the program included levels of environmental supplementation being determined for protection of ecosystems between Deep Reach Pool and Livistona Pool including the Millstream Delta. Biological and hydrological monitoring programs were also established to enable monitoring against criteria, record changes in the level of the Millstream aquifer and detect environmental change.

#### *Management committee structure*

The Perth committee was responsible for the formation, modification and review of management procedures. It assessed the results of the management plan and PWD annual reporting for submission to the EPA, starting in June 1985.

The Pilbara committee consisted of regional representatives from the lead agencies. It was responsible for implementing the plan, carrying out the monitoring and forwarding the results to the Perth committee.

## Millstream environmental management program 1992

A review of the *Millstream water management program* resulted in the publication of the *Millstream environmental management program (MEMP)* prepared by the Water Authority of Western Australia (WAWA 1992). This program essentially retained the ecological water requirements (EWR) established by the previous plan, but simplified them to overcome the resourcing and technical difficulties encountered during implementation of the previous management plan (WAWA 1992).

The main objective of the plan was:

To maintain sufficient quality, distribution, variation and quantity of water in the Millstream area, and to support ecological processes and the essential natural environmental values of the Millstream area (WAWA 1992).

The main mechanism for achieving this objective was to supplement spring flow from Deep Reach and Chinderwarriner pools through to Livistona Pool with water abstracted from the aquifer. An emphasis was also placed on controlling water distribution across the delta to be managed by the Department of Conservation and Land Management (CALM) – now the Department of Environment and Conservation (DEC).

### *Management committee structure*

The Pilbara committee was reconvened as the Millstream management committee (MMC). The MMC included senior representatives from WAWA, CALM and EPA with the majority sourced from regional offices. The committee, which met annually, was responsible for overall implementation of the *MEMP* and reporting back to the review committee (the reconvened Perth committee). However, the review committee never met in the form proposed in the *MEMP* (Deegan 1999) and due to a lack of staff expertise in Millstream issues, the EPA allowed management to continue solely through the MMC. Accountability was to be achieved through mechanisms such as community membership and public reporting (Deegan 1999).

## Millstream water management plan 1998

In 1994 concerns were raised that predicted regional development would place additional pressure on current water sources in the WPWSS and consequently the Millstream wetland ecosystems. This prompted the Department of Environmental Protection to urge that a new management plan be progressed (DEP 1995). The review was also timely because it preceded the splitting of WAWA into two separate agencies with different responsibilities for management and supply of water: the Water and Rivers Commission (WRC) (now the Department of Water) and the Water Corporation (WC) respectively.

A *Millstream environmental water requirements* study was undertaken in 1995 (Welker Environmental Consultancy 1995) to gain a better understanding of the relationship between the aquifer and its dependent ecosystems. The study extended the management area to include southern tributaries (e.g. Palm Creek and Peter Creek) and encompassed the area immediately upstream of Deep Reach Pool and through to Gregory Gorge (Figure 1).

The outcomes of this study informed the *Millstream water management plan (MWMP)* (Welker Environmental Consultancy 1998), which addressed the environmental implications of abstraction from the aquifer on the adjoining environment. The management recommendations included revised spring discharge requirements and new criteria for aquifer drawdown limits and rates of decline, as detailed in Section 4.

The primary management objective defined in the *MWMP* for the abstraction of water from the Millstream aquifer was stated as:

To ensure that the existing aesthetic, ecological and cultural values of the key areas of environmental and cultural significance are not adversely affected by the supply of water to the West Pilbara water-supply scheme (Welker Environmental Consultancy 1998).

The 1996 draft version of the *MWMP* informed the 1998 *Water resource management operation strategy (WRMOS)* (WC 1998), while the final version (Welker Environmental Consultancy 1998) informed the 2001 *WRMOS* (WC). The WRC did not formally accept the 1998 *MWMP* until August 2001, and only with the provision that some of the flow criteria be reviewed (Millstream Harding consultative committee, minutes of meeting, August 2001).

When the *MWMP* was being written, DEC was also preparing a management plan for the Millstream-Chichester National Park. To make the objectives of the two plans consistent, it was originally intended that the *MWMP* would go out for public comment with the Millstream-Chichester management plan. However, due to delays with the latter plan, the *MWMP* was implemented independently, without public review.

DEC released a draft management plan for the Millstream-Chichester National Park in late 2007. The plan was open for public comment until January 2008.

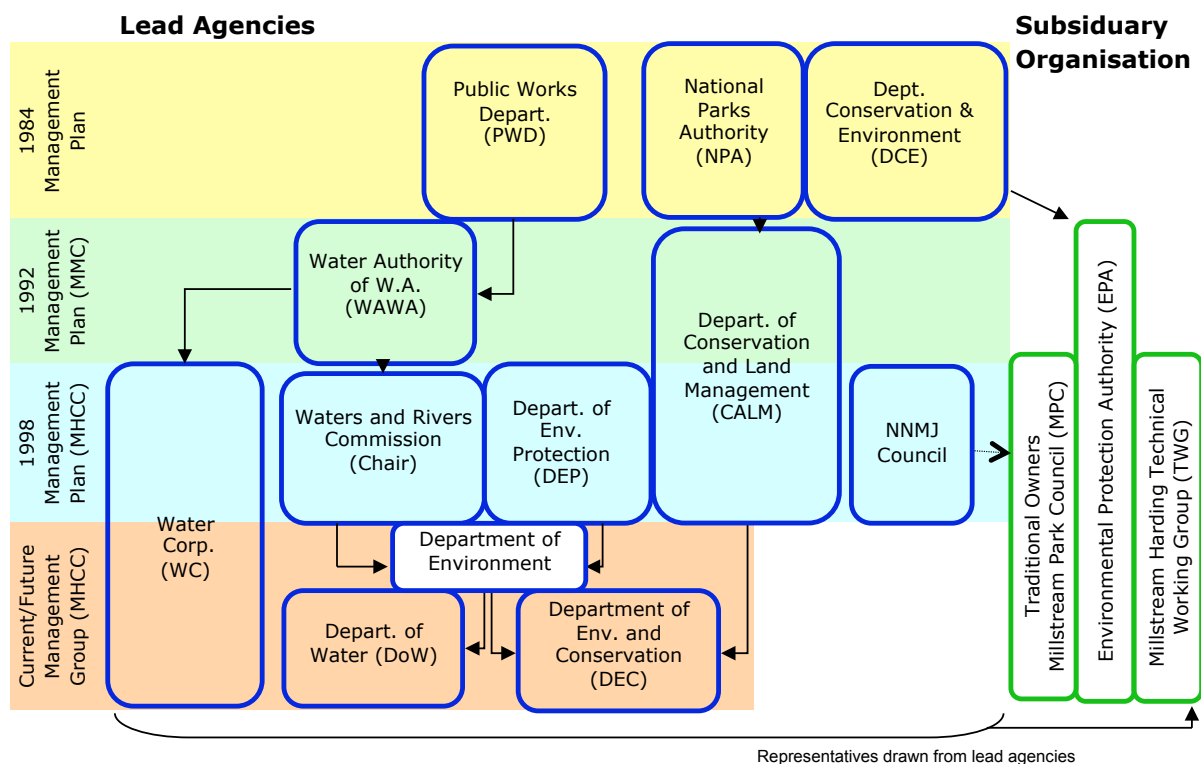
### *Management committee structure*

The 1998 *MWMP* recommended that a water management liaison group be formed to help the WRC assess annual reports. The MMC reconvened in this role with representatives from the then WRC, DEP, CALM, WC and the Ngoona Moora Joorga Land Council (periodically). It was also recommended that a member of the public be included in the MMC.

At the July 1997 MMC meeting, the committee was renamed the Millstream Harding consultative committee (MHCC). The new MHCC was to continue as the coordinating, controlling and reporting body for the *MWMP* and extend its role

to include consideration of the Harding Dam water resource. This management structure remains in place and the MHCC has met at least annually (with the exception of 2006) since 1997. The MHCC's terms of reference, which are currently under review, are included in Appendix 1.

A subgroup of the MHCC, the Millstream Harding technical working group (TWG) was formed in 1997 and was comprised of operational and regional expert staff from the WC, WRC and CALM. The TWG meets monthly to discuss ongoing management and monitoring issues, undertake monthly reviews of monitoring data and carry out long- and short-term projects relating to the Millstream and Harding water systems. The group recommends changes to programs for approval by the MHCC. The TWG's terms of reference, which are currently under review, are included in Appendix 1.



**Figure 14:** Chronology of the lead departments that constituted the various Millstream management committees (as detailed above) and the external organisations that provide a supporting role

## 3.2 Reporting and review mechanisms

The 1998 MWMP recommended an adaptive approach to management due to limited understanding of the system. The aim was to reduce uncertainty over time through system monitoring and then revise management criteria as new knowledge of the system was gained.

This was to be facilitated by analyses of data from the monitoring and investigations programs and annual reporting (detailed in section 5). Effective management relied on inter-agency cooperation with each lead agency taking on responsibility for both internal and external reporting and review requirements.

The reporting and review framework as outlined in Table 2 closely approximates the current arrangements that exist. The reporting requirements for each agency are determined as follows:

- WC – licence and operation strategy requirements
- DEC –responsibilities as outlined in the MWMP
- *Department of Water (DoW) – responsibilities as outlined in the MWMP*
- *MHCC – terms of reference (Appendix 1)*
- *TWG – terms of reference (Appendix 1).*

**Table 2:** *Report and review structure for management of the Millstream aquifer. Includes both formal and informal reporting and review responsibilities*

Type of report	Reporting agency: deadlines					Reviewing agency: action			
	WC	DoW	DEC	TWG	MHCC	DoW	TWG	MHCC	Other
Near breach of licence	ASAP						Recommend action		
Breach of licence	within 10 working days					Advise actions to be taken			
Monthly monitor report	1st Wed of Month	1st Wed of Month					Review in monthly meeting		
Annual report	DAS due 31 July					Review compliance to WRMOS		Review in annual meeting	
Annual update		report to MHCC in meeting	report to MHCC in meeting	report to MHCC in meeting				Review in annual meeting	
Annual update					Provide yearly review				CC and EPA
Triennial status report		Due 2012							EPA to review
5 yearly source review	Due 2012					Review compliance to WRMOS		Review management	

## 4 Current management criteria

### 4.1 Development of current management criteria

This Section summarises the development and performance of management criteria from inception to current status (Table 3). As discussed previously, the 'original criteria' were developed for the 1984 *MMP* (Dames & Moore 1984), and superseded by the 'revised criteria' for the 1998 *MWMP* (Welker Environmental Consultancy 1998). The 'current criteria' takes account of adaptive management actions that have changed the criteria since the 1998 *MWMP*. This section does not cover the 1992 *MEMP* (WAWA, 1992).

*Table 3: Environmental management criteria – showing 'original', 'revised' and 'current' status of criteria*

Key area	Original criteria MMP 1984	Revised criteria MWMP 1998	Current criteria
<b>Deep Reach Pool and Riverine</b>			
Pool outflow	Target outflow from Deep Reach Pool ranging from 0.16–0.30 kL/s Total 7.6 GL/a Maintain CTF: 291.77	Minimum Annual Average Discharge (MAAD) of 6.5 GL/a (0.20 kL/s) to the riverine system below Deep Reach. For Nov/Dec > 0.27kL/s	Monitoring point no longer maintained, replaced by monitoring at Crossing Pool. Assumes Deep Reach outflow criteria are being met. (ED: 6.67 GL/a)
<b>Upstream</b>		<b>Aquifer decline limits apply</b>	<b>Aquifer decline limits apply</b>
Crossing Pool outflow	Maintain the pool level above its cease-to-flow level currently 282.5 mAHD		Instantaneous flow rate of 0.08 kL/s and ≥ 0.11 kL/s during Nov and Dec. MAAD of 2.5 GL/a*.
<b>Chinderwarriner Pool and Millstream Delta</b>			
Pool outflow	Target outflow from Chinderwarriner Pool ranging from 0.06–0.11kL/s Total 2.71 GL/a	Minimum Annual Average Discharge (MAAD) of 4.7 GL/a (0.15 kL/s). For Nov/Dec > 0.2 kL/s	Instantaneous flow rate of 0.15 kL/s and ≥ 0.2 kL/s during Nov and Dec. MAAD of 4.7 GL/a**.
Pool cease-to-flow	Maintain CTF around 293 mAHD	Water level not to fall > 0.3 m below the present cease-to-flow level (about 293.15 mAHD) <sup>3</sup> . Install equip to allow adjustments of outlet height	Obsolete: fixed at 292.959 mAHD by artificial structures
Pool salinity		Average annual salinity not > than 10 per cent above existing levels (960 mg/L TDS)	WRMOS, 2001: Not > 1086 mg/L. WRMOS, 2008: This criterion has been removed subject to review.

Millstream Delta channels	Maintain flow into the west and north-west channels to maintain P3/79 at or above RL274, flow down north channel to reach river and down east channel past ref point	No reduction in flow down channels 1 & 2, target for flow down channel 2 to reach river, flow down channel 6a to at least 250 m past ref. point	Criteria have not been formally removed but monitoring is no longer undertaken
<b>Other creeks</b>			
		Aquifer decline limits apply	Aquifer decline limits apply
<b>General</b>			
Riverine flow	Maintain discharge to Livistona Pool between April–Oct, allow to decline 0.5m below CTF (269.83 mAHD) Nov–Mar	Maintain historical flow at Gregory Gorge	Two consecutive years should not have > 4 months each of no flow at Gregory Gorge
Total environmental requirement	Environmental demand = 10.31 GL/a	MAAD = 9.7 GL/a† (0.31 kL/s) in the interim	MAAD = 11.66 GL/a (includes seasonal increase)
<b>Aquifer decline limit where the watertable is within 4 m of the surface</b>			
Short term		Should not fall > 20 cm over 12 months	MAL decline of no more than 20 cm over 12 months††
Medium term		Should not fall > 28 cm over 18 months	MAL decline of no more than 28 cm over 18 months††
Long term (5–7 years)		Not to exceed a total of 0.5 m and 7–10 cm per year on a 3-monthly rolling average	WRMOS, 2001: MAL shall not fall > 0.5 m from the long-term average currently at 293.60 mAHD. WRMOS, 2008: MAL not to fall below what is considered to be the historical minimum of MAL of 293.10 mAHD
<b>Aquifer decline limit where the watertable is 4 m or more below the surface</b>			
Long term		Not to exceed a total of 1.5 m and 20 cm/a on a 3-monthly rolling average	

\* The calculated MAAD for Crossing Pool does not include the seasonal increase. If the seasonal increase is included the correct MAAD is 2.7 GL/a.

\*\* The calculated MAAD for Chinderwarriner Pool does not include the seasonal increase. If the seasonal increase is included the correct MAAD is 4.99 GL/a.

† The calculated MAAD does not include the seasonal increase and has incorrectly used 0.11 kL/s as Chinderwarriner Pools instantaneous outflow.

†† The 2008 WRMOS (WC 2008) provides guidance on applicability of this criteria during periods of high natural MAL decline rates.

This Section also synthesises our current understanding of Millstream and the conceptual links between its hydrogeology and ecology. In doing so, this report acknowledges and highlights for further consideration the assumptions on which previous management decisions were made, as well as outstanding issues that have emerged but not yet been addressed.

Section 6 provides information on how we intend to address these issues and where they feed into the development of revised Millstream environmental water requirements (EWR).

## **Deep Reach Pool**

### *Overview*

Deep Reach Pool is a deep, permanent pool lying in a bed of alluvium on the Fortescue River (Figure 9). It has high recreational and aesthetic value, and being the home of the mythological serpent or Warlu, has considerable cultural significance for the Traditional Owners.

The pool supports populations of fish, macroinvertebrates, water birds and vegetation. The downstream pools and wetland environments rely on sufficient outflows from Deep Reach Pool.

The permanence of Deep Reach Pool is the result of a constant supply of spring discharge from the aquifer, which the pool intersects (Figure 15). Surface water leaves the pool through a number of surface channels. Outflow then proceeds downstream along the Fortescue River valley through a series of pools and channels, including Crossing, Palm and Livistona pools.

Depending on aquifer levels and the resulting discharge rate, surface-water flows from Chinderwarriner Pool may supplement Deep Reach Pool outflows to sustain pool levels downstream.

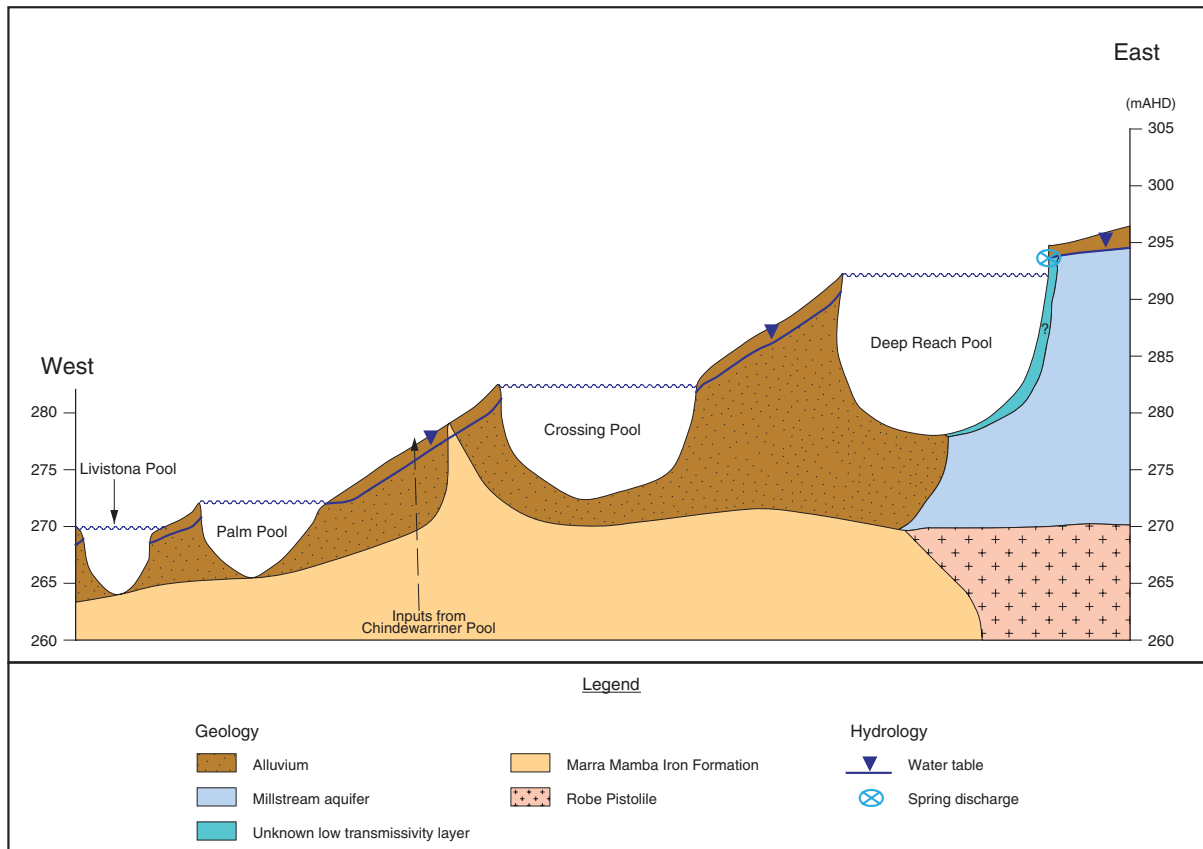


Figure 15: Longitudinal cross-section along Fortescue River (revised from DEC 2007)

Management criteria have been implemented to maintain sufficient outflow rates from the pool to meet the environmental demand (ED) of downstream groundwater-dependent values.

#### Spring discharge into Deep Reach Pool

The volume of water entering Deep Reach Pool as spring discharge is largely determined by the aquifer's water level (as represented by Mean Aquifer Level – MAL). That is, with any rise or fall in MAL, a subsequent increase or decrease occurs in spring flows.

The relationship between aquifer level and spring discharge was modelled by SMEC (1975 and 1982) using corrected spring discharge flows (as discussed in Section 2.2) and corresponding MAL data, and can be represented by the following equation:

$$\text{Spring discharge into Deep Reach (kL/s)} \quad Q_d = 0.1928 (\text{MAL} - 291.77) \quad (1)$$

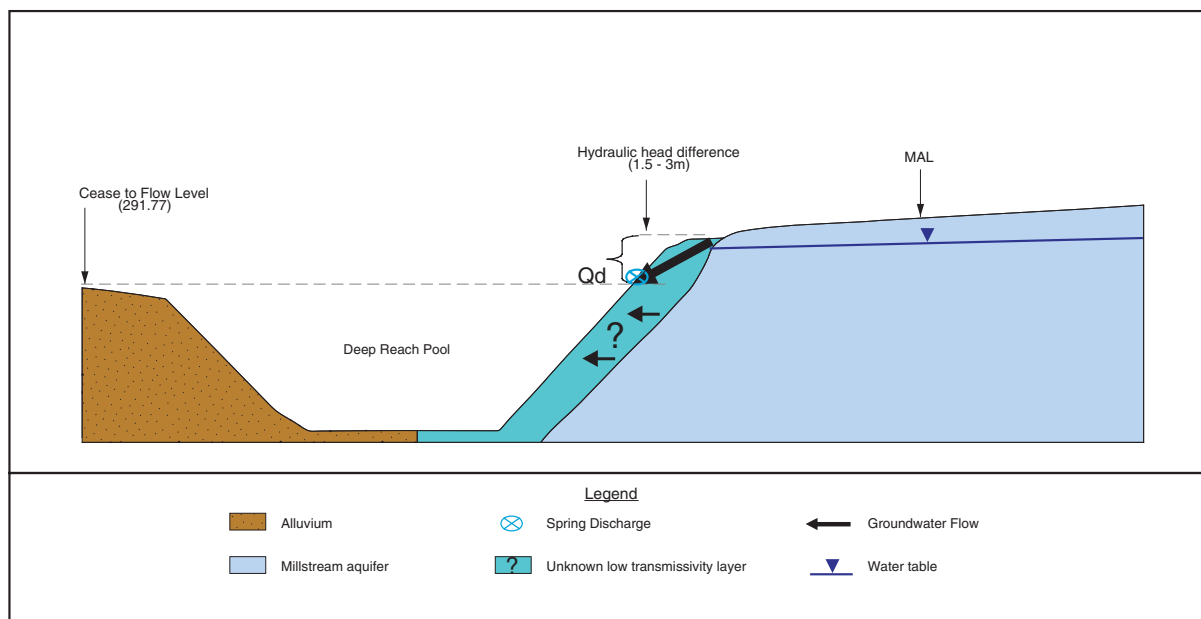
↑  
A factor determined by  
calibration of the  
Millstream aquifer model

↑  
Cease-to-flow level for  
outflow from pool

As suggested by this equation, the rate of spring discharge into Deep Reach Pool is controlled by the difference between MAL and the cease-to-flow level (CTF) or pool outlet height. This is known as the hydraulic gradient: the greater the difference between the two measures, the greater the hydraulic gradient (Figure 16). Therefore, as MAL declines so does the hydraulic gradient between MAL and the CTF resulting in less discharge into the pool.

To examine this relationship, Welker Environmental Consultancy (1998) modelled the effect of reducing the CTF (as may occur through erosion). The results indicated that if the CTF was reduced by 0.5 m, there would be a predicted increase in spring discharge into Deep Reach Pool of approximately 21–24 per cent with a corresponding increase in outflow from the pool.

In the medium term (approximately 15 years), this increase in annual discharge would produce a minor decrease in MAL of approximately 0.13 m. In turn, this reduction in MAL would significantly affect outflows from Chinderwarriner Pool, with a possible reduction in spring flow of up to 56 per cent. Other springs at Palm Creek and Peters Creek would experience more severe impacts, with discharge declining by up to 99 per cent.



*Figure 16: Conceptual diagram showing factors affecting discharge into Deep Reach Pool*

This formula was used in the 1984 *MMP* (Dames & Moore 1984) to predict spring discharge rates under declining MAL scenarios. This enabled supplementation requirements to be calculated to ensure ED could continue to be met during periods of high abstraction.

The 1998 *MWMP* calculated ED criteria based on pool outflow rates rather than spring discharge into the pool. As such, the spring discharge equation is no longer being used for any practical management purposes. Even so, it is useful to note its assumptions and limitations.

***Box 1: Assumptions and limitations with Deep Reach Pool spring discharge equation***

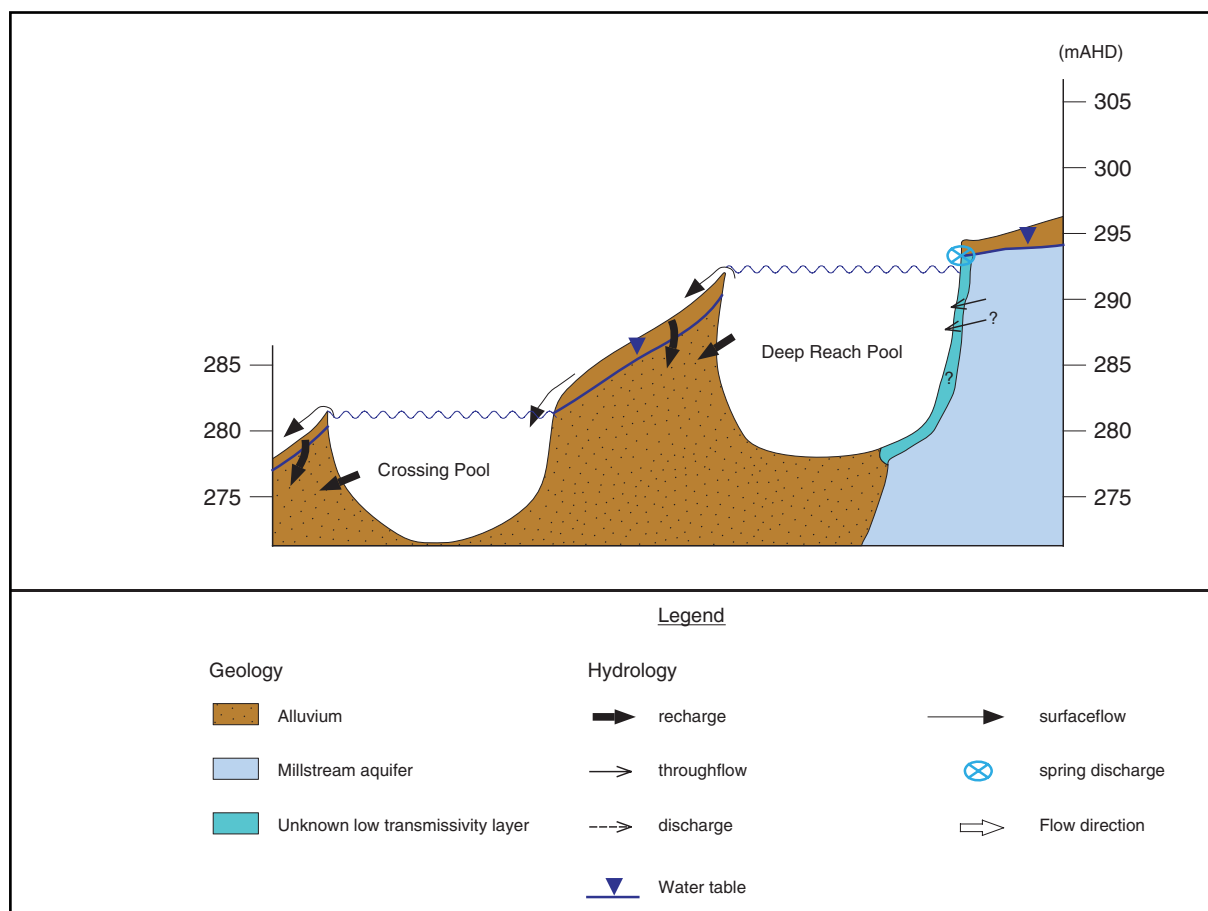
- The model used to determine this relationship assumes there is no barrier between the aquifer and Deep Reach Pool (SMEC 1975). However, a 1.5–2 m drop in water level between the Deep Reach Pool water level and aquifer level adjacent to the pool indicates that transmissivity is low and groundwater throughflow, while apparent, is likely to be constrained (Welker Environmental Consultancy 1998).
- The equation also assumes the rate of spring discharge is independent of the actual pool water levels. This is a limitation, as the water level of Deep Reach Pool is often 0.5 m or more above the CTF, a factor which should be taken into account in spring discharge calculations.
- The equation relies on a stable cease to flow, however, due to ongoing erosion being experienced at the toe of Deep Reach Pool the cease to flow is likely to be highly variable.

#### Discharge from Deep Reach Pool

Spring discharge that is not lost through evapotranspiration leaves the pool either as surface flow to the downstream environment or as recharge to the riverine alluvium surrounding the pools and channels (Figure 17).

From the middle of Deep Reach Pool through to the toe of Crossing Pool, this spring-derived water is the primary source of recharge to the local riverine alluvium (in the absence of rainfall-derived surface-water flows). This recharge maintains local groundwater levels, which in turn support local groundwater-dependent vegetation.

Downstream of the toe of Crossing Pool, spring-fed surface-flow contributions from Chinderwarriner Pool may also become relevant (Figure 15). It has also been suggested that subsurface flows from the aquifer contribute recharge to the local riverine alluvium around Palm Pool (Dames & Moore 1984).



*Figure 17: Longitudinal view showing the conceptual understanding of the hydrology of Deep Reach Pool and riverine areas*

### *Management criteria*

#### Outflow criteria

Management criteria were developed to ensure outflow rates from Deep Reach Pool were sufficient to meet downstream ED and the local environment supported by the riverine alluvium. Criteria were first developed in 1984 and revised again in 1998. The Millstream Harding consultative committee has been responsible for ongoing revision of the criteria since 1998 (Table 4).

Table 4: Management criteria for Deep Reach Pool outflow

Deep Reach – Pool outflow	Original criteria (MMP, Dames & Moore 1984)	Revised criteria (MWMP, Welker 1998)	Current criteria
Criteria	Target outflow from Deep Reach Pool: ranging from 0.162 kL/s to 0.301 kL/s. Total 7.6 GL/a Maintain CTF: 291.77	Minimum Average Annual Discharge (MAAD): 6.5GL. 0.20 kL/s to the riverine system below Deep Reach increasing in Nov and Dec to 0.27 kL/s	Monitoring point no longer maintained, replaced by monitoring at Crossing Pool. Assumes Deep Reach outflow criteria are being met. ED: 6.67 GL/a)
Flow monitoring	Level: continuous Outflow: weekly	Level: continuous Outflow: monthly	Level: ongoing Outflow: unable to be monitored, replaced by Crossing Pool
Groundwater monitoring	P7/78, P8/77, P2/79 monthly	Bores P9/78, P7/78, P8/77 & P9/77 bi-monthly plus new bores (intensive monitoring bores)	Bores P9/78, P7/78, P8/77 & P9/77 bi-monthly (plus intensive monitoring bores 07/04, 08/04, 09/04, 10/04, 11/04 for a period yet to be defined)
Management actions	The Deep Reach supplementation scheme is available to ensure that flows to downstream pools are maintained if monthly monitoring indicates that the criteria are in danger of being breached.		
<b>Objectives</b> <i>To ensure no significant adverse impacts of water abstraction on the environment and cultural values of riverine vegetation from Deep Reach Pool to Gregory Gorge (Welker Environmental Consultancy 1998).</i>			

1. Original criteria (Dames & Moore 1984): ED from Deep Reach Pool to the bottom of Livistona Pool was estimated by using aerials to identify subareas based on vegetation density and then calculating the vegetation's water use based on the following:

ED (subarea) = potential evapotranspiration x vegetation coefficient x area m<sup>2</sup>

Where: potential evapotranspiration = a rate based on consideration of literature available at the time (2587 mm/a)

vegetation coefficient = a classification between 1.0 (very dense forest) to 0.1 depending on the density and height of the vegetation as determined from aerial photography and ground surveys.

This methodology was developed by SMEC (1975) during consideration of the Fortescue River dam proposal. The figures were redeveloped to help calculate ED during design of the conjunctive-use scheme (SMEC 1982) and consequently adopted into the 1984 *MMP*.

Estimated total and mean monthly water use is detailed in Table 5.

*Table 5: Targeted outflow required from Deep Reach Pool to meet the ED of the downstream environment through to Livistona Pool as calculated in Dames and Moore (1984)*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
GL/m	0.72	0.77	0.82	0.76	0.69	0.71	0.65	0.62	0.52	0.43	0.47	0.49	7.62
kL/s	0.27	0.30	0.30	0.28	0.28	0.27	0.25	0.20	0.16	0.17	0.18	0.23	

*Monitoring:* Pool water level and outflow rate were monitored against criteria for Deep Reach Pool. Local groundwater levels were also monitored to provide data that better characterised the hydrological system around the riverine environment.

*Non-compliance with original criteria:* Between 1980 and 1990 targeted outflow rates were consistently not met for one or more months during November to January. Supplementation into Deep Reach Pool was not available during this time, so supplementation into Chinderwarriner Pool was increased to attempt to meet riverine water requirements below Crossing Pool. As such, there were no management actions available to support the environment between Deep Reach Pool and Palm Pool.

Aerial photography and anecdotal evidence suggest that vegetation in this area underwent structural changes during this period (Chester 1998; Sinclair Knight Merz 1999). It is likely that these changes resulted from water stress; however, it is not possible to directly link these changes back to reduced surface flows.

**Box 2: Assumptions and limitations with original outflow criteria for Deep Reach Pool**

- Does not include consideration of precipitation inputs.
- Assumes throughflow inputs are insignificant: i.e. no additional inputs of groundwater downstream of Deep Reach Pool.
- Based on the limited knowledge of evapotranspiration and plant physiology available at the time.
- Does not consider general water status: i.e. period since flood or local recharge event, period since rainfall event and local groundwater levels.

2. *Revised criteria* (Welker Environmental Consultancy 1998): *For the MWMP*, ED was recalculated based on a water balance approach that assumed the loss of flow between pools was equal to ED for vegetation between the two pools. This methodology can be approximated by the following:

$$\text{Total ED} = (\text{annual loss of flow between pools}) + \text{rainfall}$$

Minimum Average Annual Discharge (MAAD) from Deep Reach Pool was calculated as follows:

$$\text{MAAD for Deep Reach Pool} = \frac{(\text{annual loss of flow between pools})}{\text{total area}} \times \text{subarea}$$

Based on this approach the ED was estimated to be 6.5 GL/a or equivalent to a minimum outflow from Deep Reach Pool of 0.2 kL/s for January to October and 0.27 kL/s for November and December.

The seasonal adjustment to 0.27 kL/s for November and December was based on the assumption that a 40 per cent increase in potential evapotranspiration during these hotter months would result in a proportional increase in ED.

Data input into the calculations was restricted to two years (1974 and 1983) when there was low or zero surface-water contribution from the Fortescue River above Deep Reach Pool.

*Monitoring:* Before 1999 outflow rates from Deep Reach Pool were measured using a flow metre. However, the dynamic nature of the channels at the toe of the pool that are subject to active erosion, and difficulty in gaining access to the monitoring points resulted in this monitoring becoming unfeasible. As a result, the criteria were replaced by Crossing Pool's criteria.

Subsequently, outflow data for Deep Reach Pool is only available until 1999. The gauging station is still operating and supplying continuous pool stage data.

*Non-compliance with revised criteria:* Outflow rates were non-compliant with criteria in 1997 and 1998 in November and December; however, it was reported that no action was taken due to good riverine flows being recorded during that time (WC 1999).

**Box 3: Assumptions and limitations with revised outflow criteria for Deep Reach Pool**

- Estimates of ED were based on flow data from only two years: 1977 and 1983. This presents two possible sources of error:
  - the representative years may not adequately cover the natural variability of the groundwater-derived flows into the system; and
  - the assumption that ED was adequately met during these two representative years may not be correct.
- Changes in soil- and tree-moisture storage were not taken into account. As the watertable was declining during this period, changes in water storage may have been significant.
- Contributions of throughflow and bank storage into the system were not considered.
- Management measures did not allow for consideration of general water status: i.e. period since flood or recharge event, period since rainfall event and local groundwater levels.
- Inflows from tributaries, such as Dawson Creek, were assumed to be insignificant.
- Assumption that a 40 per cent increase in evaporation during November and December is mimicked by ED.

3. **Current criteria:** The Deep Reach Pool criteria were included in the Water Corporation's 1998 *WRMOS*. They were subsequently removed because measuring outflow from Deep Reach Pool was proving difficult to collect due to overgrown channels and the variable nature of the channels.

The criteria were replaced by the Crossing Pool management criteria in July 1999 (MHCC meeting July 1999). The Deep Reach Pool criteria were reported against in the 1997 and 1998 *Detailed annual statement* (WC 1997; WC 1998).

*Monitoring:* Gauging station collects continuous stage data for Deep Reach Pool.

*Non-compliance with current criteria:* Water levels were compliant with criteria between 1998 and 1999 when the criteria became obsolete.

**Outstanding issues**

1. Need to resolve cause of difference in water level between Deep Reach Pool and adjacent aquifer level (illustrated in figure 16).

## Chinderwarriner Pool

### Overview

Chinderwarriner Pool is a shallow, permanent pool on Millstream Creek, a tributary of the Fortescue River. It has high aesthetic value and significant European and Indigenous cultural values. The delta environment downstream of Chinderwarriner Pool has high ecological values that rely primarily on outflows from the pool (see Section 4.1 – Millstream Delta).


The permanence of Chinderwarriner Pool is the result of a constant supply of spring discharge from the aquifer, which the pool intersects (Figure 7). Surface water leaves the pool through four surface channels and feeds a network of channels and wetlands that form the Millstream Delta.


Management criteria have been implemented to maintain sufficient pool levels and outflow rates to meet the environmental demand (ED) of the pool and downstream groundwater-dependent values.

### Spring discharge into Chinderwarriner Pool

The volume of water entering Chinderwarriner Pool as spring discharge depends on the aquifer's water level. The relationship between aquifer level (represented as MAL) and spring discharge into the pool can be represented by the following equation (SMEC 1975 and revised in SMEC 1982):

$$\text{Spring discharge into Chinderwarriner (kL/s)} \quad Q_c = 0.3475 (\text{MAL} - 292.959)^{1.95} \quad (2)$$

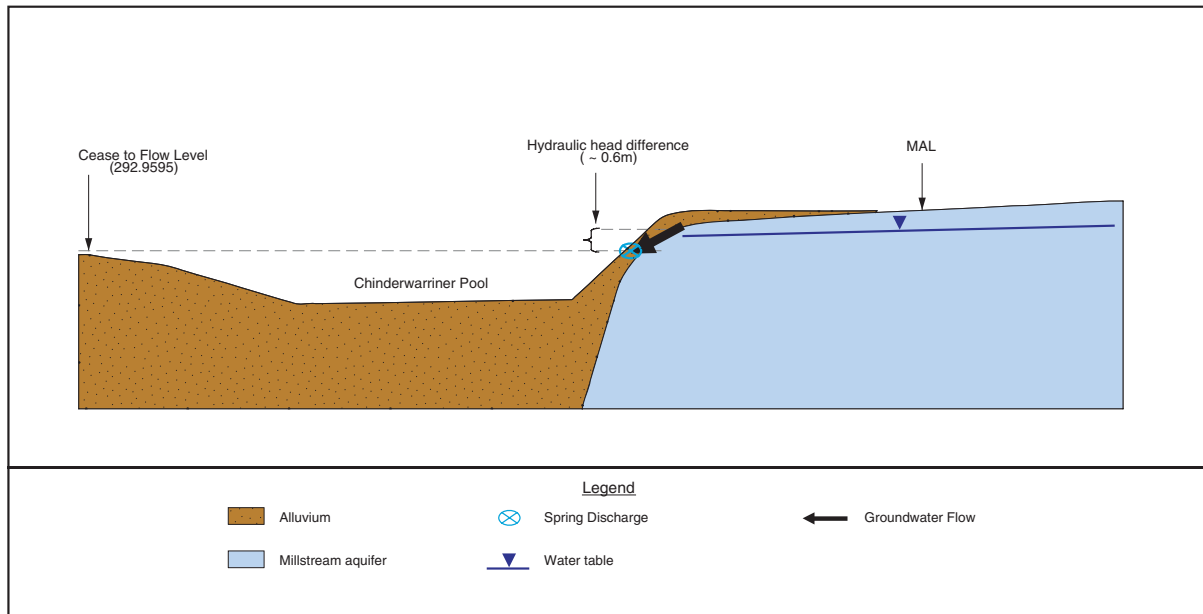
  
 A factor determined by  
calibration of the Millstream  
aquifer model

  
 Cease-to-flow level for outflow  
from pool

As suggested by this equation, the rate of spring discharge into Chinderwarriner Pool is controlled by the hydraulic gradient between the watertable and the pool water level. As MAL declines so does the hydraulic gradient, resulting in less discharge into the pool.

The exponential value of 1.95 indicates that this relationship is non-linear, with increases in MAL resulting in increasing rates of spring discharge in the pool. This may be due to the Karst nature of the aquifer, with the proportion of solution channels, and therefore the amount of discharge, increasing with height (P. Commander, personnel communication, March 2009).

As there is only a small difference of approximately 0.6 m between the water level in the pool and MAL, spring discharges and subsequent pool outflows are responsive to even small changes in MAL. For example, a small increase in MAL from 293.5 mAHD to 293.6 mAHD will result in a 20 per cent increase in the hydraulic gradient and a proportional 20 per cent increase in spring discharge (Figure 18).



*Figure 18: Conceptual diagram of Chinderwarriner Pool's hydrogeology, showing factors that affect the rate of discharge into the pool*

This formula was used in the 1984 *MMP* (Dames & Moore 1984) to predict spring discharge rates under declining MAL scenarios. This enabled supplementation requirements to be calculated to ensure ED could continue to be met during periods of high abstraction.

The 1998 *MWMP* calculated ED criteria based on pool outflow rates rather than spring discharge into the pool. As such, the spring discharge equation is no longer being used for any practical management purposes (see following sections for discussion about the management and criteria applied to Chinderwarriner Pool).

For this reason, a more applicable relationship for management purposes is that between MAL and outflow rates from Chinderwarriner Pool. Analysis of results of actual pool outflow data against recorded MAL suggests a strong relationship between these two variables (Figure 19). This relationship can provide guidance to managers on predicted outflow rates from this pool.

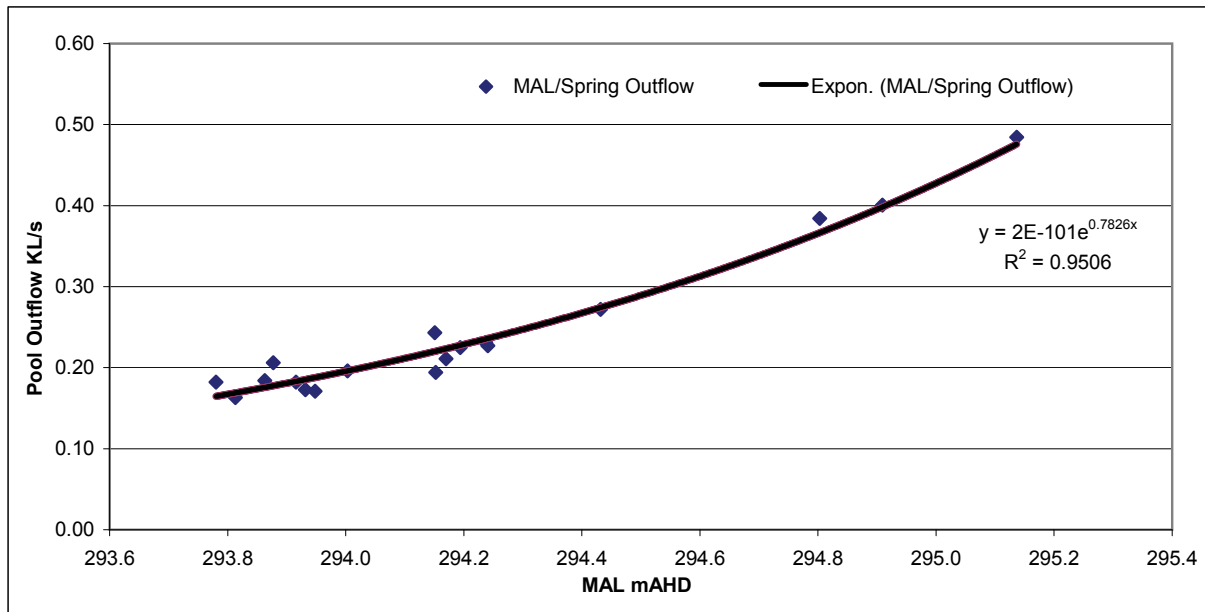


Figure 19: MAL/Chinderwarriner Pool outflow relationship

Anecdotal evidence suggests that pool water-level and outflow also respond to abstraction from production bores at the upstream end of the pool (Welker Environmental Consultancy 1995)<sup>4</sup>

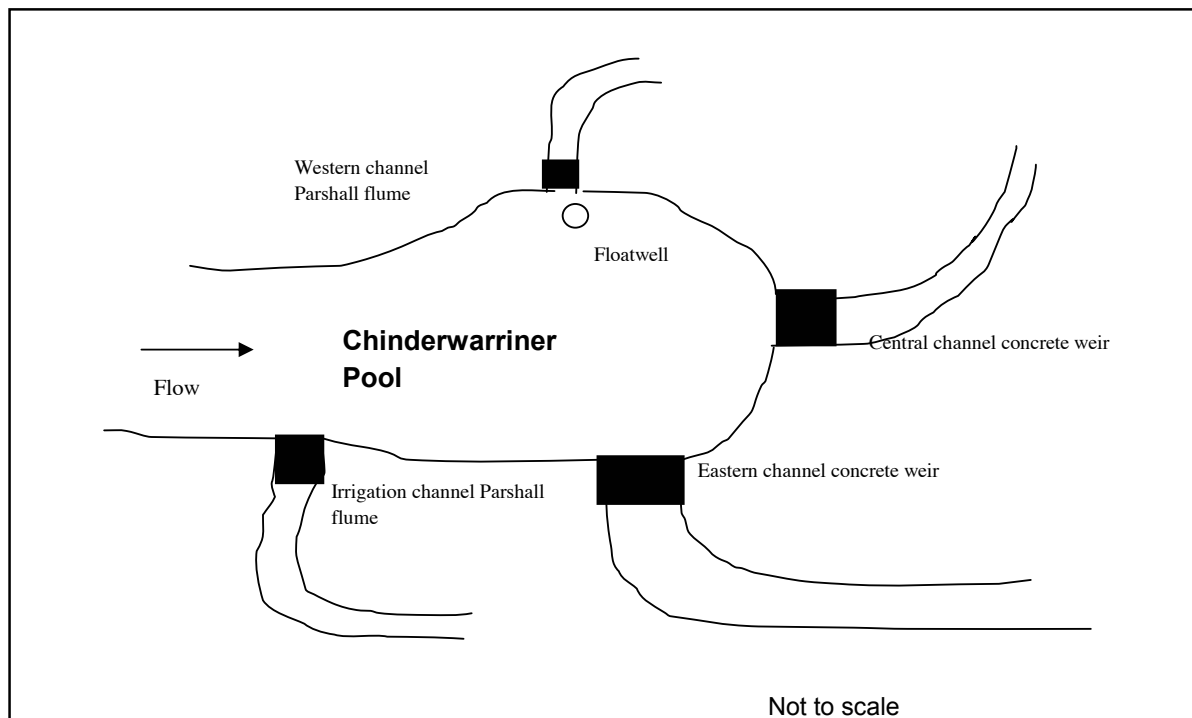
#### Discharges from Chinderwarriner Pool

Spring discharge that is not lost through evapotranspiration leaves the pool either as infiltration to the local watertable surrounding the pool or as surface flow to the downstream delta environment.

While there are no monitoring bores adjacent to Chinderwarriner Pool, it is assumed that watertable levels supporting the surrounding vegetation are responsive to water levels in Chinderwarriner Pool – rather than being directly linked to the MAL (Welker Environmental Consultancy 1995).

Surface flow from Chinderwarriner Pool occurs by four separate channels; each controlled by either a broadcrest concrete weir or a parshall flume (Figure 20). The majority of flow occurs from the central and eastern channels while the western and irrigation channels combined account for less than 10 per cent of the total outflow.

<sup>4</sup> More accurate and continuous stage-level monitoring is necessary to investigate this relationship. The Water Corporation currently estimates that the production bores will be switched on during October 2008. This will provide an opportunity to gather the relevant monitoring data to further investigate this relationship.



*Figure 20: Conceptual diagram of Chinderwarriner Pool showing outflow channels and stream-flow measuring points*

#### *Management criteria*

#### Outflow criteria

Discharge rates into Chinderwarriner Pool are secondary, in terms of volume, to Deep Reach Pool, but are significant in relation to the ecosystems they support. As discussed in Section 4.1, the Millstream Delta and, to a lesser degree, the Woodley Delta significantly depend on spring flows from Chinderwarriner Pool.

Management criteria, as detailed in Table 6, were designed to ensure that outflow rates were sufficient to meet the Millstream Delta's ED. Monthly monitoring and reporting of outflow rates are in place to ensure imminent breaches are identified.

**Table 6: Management criteria for Chinderwarriner Pool outflow rates**

Chinderwarriner Pool outflow	Original criteria (MMP, Dames & Moore 1984)	Revised criteria (MWMP, Welker 1998)	Current criteria
Criteria	Target outflow from Chinderwarriner Pool: ranging from 0.061 kL/s to 0.112 kL/s. Total 2.71 GL/a (see Table 7)	Minimum Average Annual Discharge (MAAD): 4.7 GL. Instantaneous outflow rate of 0.15 kL/s increasing in Nov and Dec to 0.20 kL/s	Minimum Average Annual Discharge (MAAD): 4.7 GL*. Instantaneous outflow rate of 0.15 kL/s increasing in Nov and Dec to 0.20 kL/s.
Flow monitoring	Flow: two weekly	Level: continuous Outflow: calculated monthly	Level: continuous Outflow: calculated monthly
Groundwater monitoring			No monitoring bores are located adjacent to this pool
Management	The Chinderwarriner Pool supplementation scheme is available to ensure that flows to the downstream environment are maintained if flow criteria are in danger of being breached.		
<b>Objectives</b> <i>Maintain environmental flows into Millstream Delta</i> (Welker Environmental Consultancy 1998). – Maintain the marshy woodlands of Cajeput over sedges in the central eastern portion of the Millstream Delta. – Improve the environmental value of the Millstream Delta by increasing channel flow into the lower western and central eastern parts of the delta to restore wetland areas.			

\* The calculated MAAD for Chinderwarriner Pool does not include the seasonal increase. If the seasonal increase is included the correct MAAD is 4.99 GL/a.

1. Original criteria (Dames & Moore 1984): ED for Chinderwarriner Pool and Millstream Delta was estimated by defining subareas based on vegetation density and then calculating the vegetation's water use based on the following:

ED (subarea) = potential evapotranspiration x vegetation coefficient x area m<sup>2</sup>

Where: potential evapotranspiration = a rate based on consideration of literature available at the time (2587 mm/a).

vegetation coefficient = a classification between 1.0 (very dense forest) to 0.1 depending on the density and height of the vegetation as determined from aerial photography and ground surveys.

This methodology was developed by SMEC (1975) during consideration of the Fortescue River dam proposal. The figures were redeveloped to help calculate ED during design of the conjunctive-use scheme (SMEC 1982) and subsequently adopted in the 1984 *MMP*.

Based on this approach total annual ED was estimated to be 2.71 GL/a, with monthly ED determined by consideration of monthly evapotranspiration rates (Table 7).

*Table 7: Targeted outflow required from Chinderwarriner Pool to meet the ED of the Millstream Delta as calculated in Dames and Moore (1984)*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
GL/m	0.27	0.29	0.30	0.27	0.24	0.24	0.21	0.18	0.15	0.16	0.18	0.22	2.71
kL/s	0.10	0.11	0.11	0.10	0.10	0.09	0.08	0.07	0.06	0.06	0.07	0.08	

These monthly minimum discharge rates were the criteria against which flows were monitored and managed. The Chinderwarriner Pool supplementation system was commissioned in 1984 to enable natural spring flows to be supplemented by pumping additional water from the aquifer into the pool.

*Monitoring:* Chinderwarriner Pool outflow was monitored every two weeks. As discussed in the MHCC minutes of meeting (April 1992), quantitative flow measurement of Chinderwarriner Pool outflow was not considered to be critical. Monitoring whether flow was occurring in predetermined areas of the delta was considered the best way to ensure ED was being met (see Section 4.1-Millstream Delta).

*Non-compliance with original criteria:* The 1984 monthly criterion was breached in 1985, resulting in an increase in supplementation rates. In 1988, the monthly criterion was breached again but this was not identified until after the event. From 1989 to 1998 the monthly criterion was periodically breached during the months of November and December. Available records from the Water Corporation are unclear about the actions taken in response to these breaches. When in breach in November 1998, local Department of Water staff decided that no action would be taken to supplement the Millstream Delta as there had recently been a wet winter, the vegetation was healthy and the Bureau of Meteorology predicted a good wet season (WC 1999).

**Box 4: Assumptions and limitations with original outflow criteria for Chinderwarriner Pool**

- Does not include consideration of precipitation inputs.
- Assumes no subsurface or alternative input to water balance in the delta.
- Based on the limited knowledge of evapotranspiration and plant physiology available at the time.
- Does not consider general water status: i.e. period since flood or recharge event, period since rainfall event and local groundwater levels.

2. Revised criteria (Welker Environmental Consultancy 1998): For the *MWMP*, ED was recalculated based on a water balance approach that assumed the loss of flow between gauging points was equal to ED for vegetation between the two points. This methodology can be approximated by the following:

Environmental demand (ED) = (annual flow loss between pools) + rainfall

Minimum Average Annual Discharge (MAAD) from Chinderwarriner Pool was calculated as follows;

MAAD for Chinderwarriner Pool =  $\frac{\text{annual flow loss between pools}}{\text{total area}}$  x subarea

This method resulted in a recommended outflow criterion for Chinderwarriner Pool of 0.11 kL/s.

However, modelling from the Water Corporation's Millstream aquifer Model indicated that due to weed infestation and blockages within the channels, outflow would need to be about 0.15 kL/s (Welker Environmental Consultancy 1998) with a view to potentially reduced to 0.12 kL/s once clearing has been undertaken by CALM. The derivation of this revised estimate of 0.15 kL/s is unclear.

Based on this calculation the MAAD for Chinderwarriner Pool was estimated at 4.7 GL/a. Minimum required instantaneous discharge rates from Chinderwarriner Pool were estimated to be 0.15 kL/s for January to October and 0.20 kL/s for November and December.

The seasonal adjustment to 0.20 kL/s included for November and December was based on the assumption that a 40 per cent increase in potential evapotranspiration during these hotter months would result in a proportional increase in ED.

*Monitoring:* A stable stage/discharge rating was made possible by use of artificial control structures that allow accurate measurement of outflow, and a gauging station which continuously measures Chinderwarriner Pool stage height. The Department of Water maintains the rating curve that defines the stage/discharge relationship

and calculates pool outflow on a monthly basis when stage data is received from the Water Corporation.

DEC is responsible for maintaining the channels and controls so that the weirs and flumes operate correctly. After major flood events or on a six-monthly basis, the Department of Water carries out manual gauging at each of the four Chinderwarriner outflows to verify the rating. Any change in rating is reported to the Water Corporation and a new rating curve provided.

**Box 5: Assumptions and limitations with revised outflow criteria for Chinderwarriner Pool**

- Modelling of pool outflows was based on flow data from only two years: 1977 and 1983. This presents two possible sources of error:
  - the representative years may not adequately cover the natural variability of the groundwater-derived flows into the system and
  - the assumption that ED was adequately met during these two representative years may not be correct.
- Changes in soil- and tree-moisture storage were not taken into account. As the watertable was declining during the modelled period, changes in water storage may have been significant.
- Contributions of throughflow and bank storage into the system were not considered.
- Management measures did not allow for consideration of general water status: i.e. period since flood or recharge event, period since rainfall event and local groundwater levels.
- Assumption that ED trends mimicked inter-annual evaporation trends.
- MAAD of 4.7 GL/a has not been adjusted to incorporate the increased ED predicted for November and December, i.e. recalculated MAAD = 4.99 GL/a.

*Non-compliance with revised criteria:* The instantaneous flow rate was breached during November 2002. This breach did not trigger supplementation because outflow was measured and reported against the MAAD, rather than being reported and measured against the instantaneous flow rate.

3. *Current criteria:* After the instantaneous flow criterion was breached in November 2002, the criteria and method of reporting against the criteria were altered at the 2003 MHCC meeting. As such, monitoring and reporting against the MAAD criterion was replaced by the instantaneous flow-rate criterion (MHCC, 2003). It should be noted however, that the MAAD criterion has been retained in the latest operating strategy (WC 2008). The status of this criterion needs to be resolved.

*Monitoring:* Monitoring is carried out on a bi-monthly basis as detailed under “revised criteria”.

**Non-compliance with current criteria:** The instantaneous flow criterion was breached throughout November and December 2003, which resulted in the supplementation scheme being activated in early December 2003 (WC 2004).

The time delay before supplementation began was raised as a concern in the following MHCC meeting of September 2004 (MHCC 2004). Negotiations with the Traditional Owners were cited as the cause of the delay. As a result, the technical working group (TWG) designed a 'supplementation implementation flow chart' (Appendix 2) to ensure supplementation was triggered before breaches occurred. There is no record of the flow chart being adopted and it still remains in draft form.

#### **Outstanding issues**

2. Determine the relationship between operation of production bores and the observed drop in Chinderwarriner Pool and associated outflow rates.
3. Supplementation implementation flow chart remains in draft format and there is no record of it being formally adopted. There is an urgent need to finalise this draft plan, as abstraction from the aquifer is likely to begin late 2008 and it is estimated that flow criteria may breach within 12 months if a recharge event does not occur.
4. Develop MAL/pool outflow relationship to aid in pre-emptive management of potential breaches of pool outflow criteria.

#### Cease-to-flow criteria

Chinderwarriner Pool and the surrounding riparian vegetation have high aesthetic and cultural values that rely on surface-water levels in the pool being maintained, which in turn maintain local watertables. Erosion and flooding events have the potential to lower the pool's CTF level, resulting in a drop in pool level. Consequently, management criteria have been developed and implemented to ensure the CTF level at Chinderwarriner Pool is maintained at appropriate levels (Table 8).

**Table 8: Management criteria for Chinderwarriner Pool – cease-to-flow level**

<b>Chinderwarriner – cease to flow</b>	<b>Original criteria (MMP, Dames &amp; Moore 1984)</b>	<b>Revised criteria (MWMP, Welker 1998)</b>	<b>Current criteria</b>
	Maintain at about 293 mAHD	Not to fall > 0.3m below the present cease-to-flow level (currently about 293.15 mAHD). Install equip to allow adjustments of outlet height	Obsolete: fixed at 292.959 mAHD by artificial structures
<b>Monitoring</b>	Bi-monthly		N/A: cease-to-flow level is fixed by artificial structures
<b>Objectives</b> <ul style="list-style-type: none"> <li>• To maintain the aesthetic values of Chinderwarriner Pool (Welker Environmental Consultancy 1998).</li> </ul>			

1. Original criteria (Dames & Moore 1984): The 1984 *MMP* determined that the pool's CTF level should be maintained at its then current level of 293 mAHD. The primary reason was to maintain the pool's aesthetic values, as it is one of the region's main tourist destinations.

*Monitoring:* Chinderwarriner Pool outlets were monitored every two months.

*Non-compliance with original criteria:* There is no record of non-compliance.

2. Revised criteria (Welker Environmental Consultancy 1998): In 1998, the *MWMP* recommended that mechanisms be put in place to allow lowering of the cease-to-flow level by 0.3 m to 292.6 mAHD. This was to be for two years to maintain outflow onto the delta. It was argued that no detrimental effect to the pool or surrounding vegetation would occur. The recommendation was implemented in the 2001 *WRMOS*. Through its *Detailed annual statements* (WC 1999; WC 2007), the Water Corporation indicates that the current CTF is 292.959 mAHD and has not been lower.

*Monitoring:* There is no specific requirement to monitor against these criteria.

*Non-compliance with revised criteria:* There is no record of non-compliance.

3. Current criteria: The installation of fixed pool outlets has put the CTF at 292.959 mAHD and has since rendered this criterion obsolete.

### Pool salinity criteria

#### *Trends in salinity levels and relationship with abstraction*

From 1968 to 1987 the electrical conductivity (EC) levels of Chinderwarriner Pool increased substantially (Muir 1995). Welker Environmental Consultancy (1998) analysed these trends toward increasing EC in groundwater near Chinderwarriner Pool and within the pool itself. While not conclusive the analysis suggested that 'high abstraction rates from production bores near Chinderwarriner Pool similar to those experienced in late 1970 and early 1980 may result in increased salinity in this pool' (Welker Environmental Consultancy 1998).

It was concluded that the effect of abstraction on salinity may be two-fold: firstly, reduced pool outflows resulting in decreased flushing of salts out of the delta system; and secondly, increased pool salinity directly resulting in increased surface water and soil salinity levels within the delta.

**Box 6: Assumptions and limitations on determining the relationship between abstraction and salinity levels.**

- The analysis did not consider the effects of drought, which may also increase salinity by concentrating salts within the system through evapotranspiration and reduced flushing and dilution effects.
- The transport of salts into the aquifer (and subsequently Chinderwarriner Pool) due to the effects of recharge of high-salinity surface water was not considered.

*Implications of increasing salinity in Chinderwarriner Pool and the Millstream Delta*

It was considered likely that increasing salinity in Chinderwarriner Pool and its outflows could affect the distribution and composition of vegetation surrounding the pool and in the delta. Specifically it was thought that increasing salinity could favour the successful germination and establishment of date palm (*Phoenix dactylifera*) over the Millstream fan palm (*Livistona alfredii*).

In addition, anecdotal evidence suggesting an increase in the distribution of the salt water wattle (*Acacia ampliceps*) in response to increasing salinity was confirmed by Welker Environmental Consultancy (1995), who demonstrated that the distribution of *A. ampliceps* was increasing and corresponded to areas of higher soil salinities.

These concerns about the implications of increasing salinity levels on the composition and distribution of vegetation within the delta resulted in the implementation of a criterion to manage Chinderwarriner Pool's salinity (Table 9).

This criterion was first developed in 1998 and subsequently revised during implementation of the 2001 *WRMOS*.

**Table 9: Management criterion to maintain salinity levels in Chinderwarriner Pool within acceptable levels**

Chinderwarriner – salinity	Original criteria (MMP, Dames & Moore 1984)	Revised criteria (MWMP, Welker 1998)	Current criteria
<b>Criteria</b>		Average annual salinity not > than 10 per cent above existing levels (currently at 960 mg/L TDS i.e. 1056 mg/L)	WRMOS, 2001: Not > than 10 per cent above average (988 mg/L TDS i.e. 1086 mg/L)  WRMOS, 2008: not included
<b>Monitoring</b>		Chemical: monthly (pool)	Chemical: bi-monthly (pool)
<b>Objectives:</b> <i>Maintain the quality of environmental flows into Millstream Delta and protect from increases in salinity</i> (Welker Environmental Consultancy 1998).			

1. Original criteria (Dames & Moore 1984): No criteria for salinity.

2. Revised criteria (Welker Environmental Consultancy 1998): There was limited data on salinity levels in the pool before abstraction from the aquifer began. In the absence of this information, the criterion was set at TDS 1056 mg/L based on an average salinity of 960 mg/L. This was the mean salinity recorded between 1988 and 1996 when abstraction rates were relatively low and salinity rates steady (Welker Environmental Consultancy 1998).

*Monitoring:* pool salinity is measured on a monthly basis. The measure of TDS is derived from raw groundwater EC readings measured in the field. Before 2007, the Water Corporation converted EC readings to TDS using the following relationship (URS 2007):

$$\text{TDS (mg/L)} = \text{EC (mS/m)} * 6.4053 + 0.1006$$

*Non-compliance with revised criteria:* There is no record of non-compliance with this criterion.

3. Current criteria: In the 2001 WRMOS (WC, 2001), the criterion was changed to 1086 mg/L based on an average salinity of 988 mg/L. It is not clear why this figure was recalculated.

*Monitoring:* Pool salinity is measured on a bi-monthly basis. TDS is derived by a contracted lab that calculates TDS by summation of ions and not by applying a conversion factor to the conductivity (J. Bellhouse, Water Corporation, personnel communication, February 2009).

*Non-compliance with current criteria:* This criterion was breached consistently throughout 2002 and 2003, with average salinities of 1147 mg/L being recorded.

Since 2004 the average annual salinity level in Chinderwarriner Pool has remained below the criterion (Figure 21).

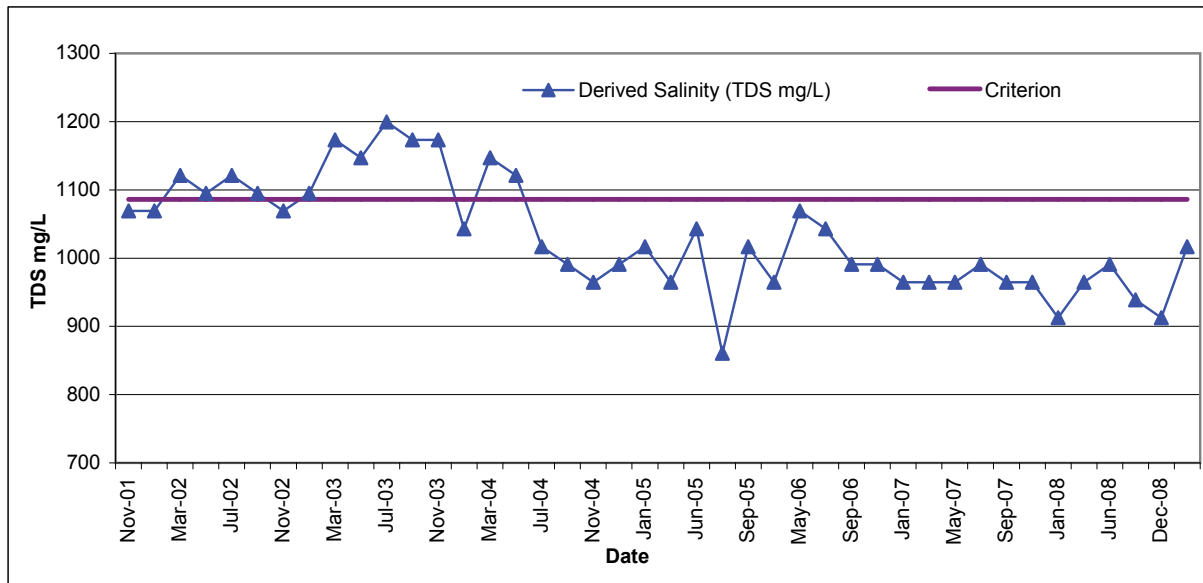


Figure 21: Chinderwarriner Pool salinity against salinity criterion

Breaches of the criterion were reported in the 2001–02 and 2002–03 *Detailed annual statements* (WC 2002; WC 2003). In the annual compliance presentation to the MHCC (MHCC minutes of meeting, 2003), the Water Corporation explained increasing salinity levels as being consistent with a regional increase in salinity after flood events in 1999 and 2000.

Water Corporation management actions in response to these breaches have been minimal. In the 2003–04 *Detailed annual statement* the Water Corporation stated that the *WRMOS* (2001) did not indicate any course of action in response to salinity criterion breaches. Contrary to this, the *WRMOS* (2001) did state that management measures were to include consideration of relocation of abstraction bores or adjustments of pumping strategies to prevent salinisation of the pool.

Discussions at the September 2004 MHCC meeting resulted in an action item for the Water Corporation to review salinity data and then determine management objectives and responses for pool salinity. Consequently, the Water Corporation (2005) stated it was developing management objectives and associated responses for pool salinity that would be presented to the then Department of Environment in due course. There is no indication that these actions were carried out and the issue of pool salinity remains unresolved.

The salinity criterion has been removed in the latest *WRMOS* (WC, 2008) but pool salinity is still monitored.

**Outstanding issues**

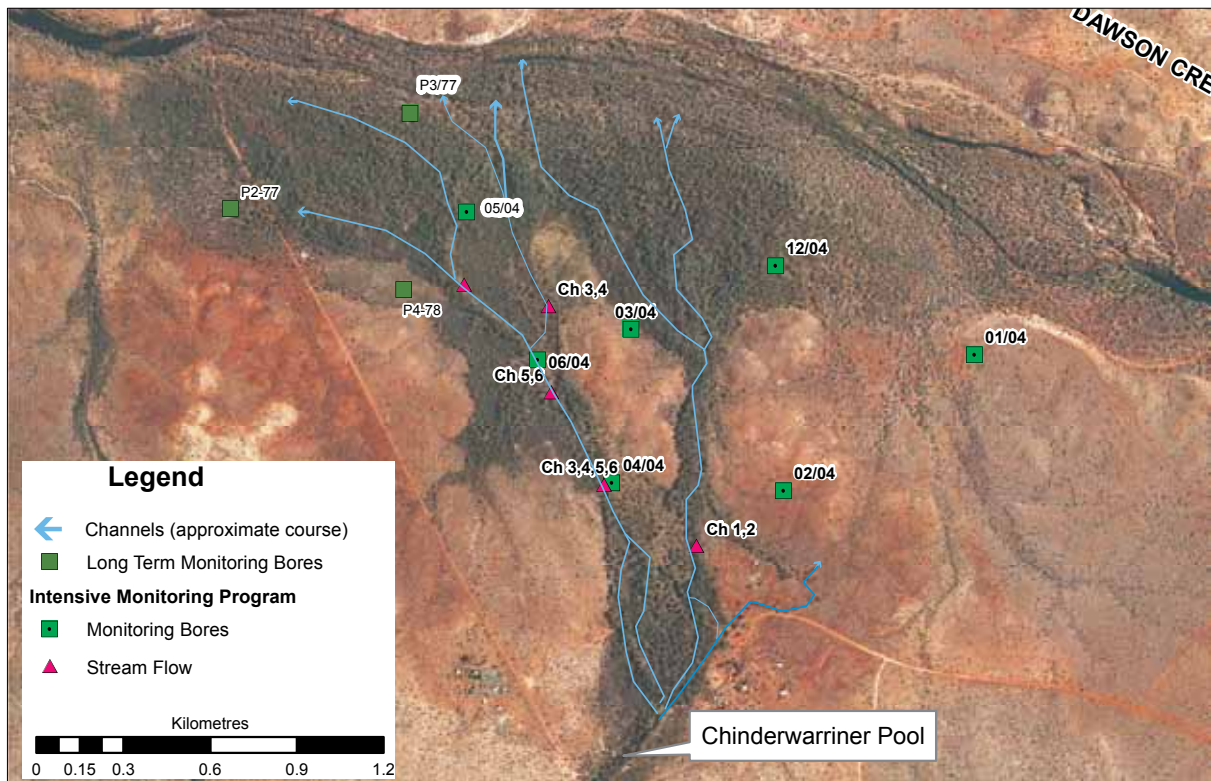
5. Although salinity is not considered a high-priority issue, a general small increase in salinity in Chinderwarriner Pool and the increasing abundance of the salt-tolerant *Acacia ampliceps* indicates the need to investigate the cause and possible effect of higher-salinity trends. One of the aims should be to better understand groundwater salinity distribution and the salinity of recharge from Fortescue River to the aquifer.
6. Clarify management actions in response to breaches of this criterion.

**Millstream Delta****Overview**

The Millstream Delta is a roughly triangular area of wetlands that lies between Chinderwarriner Pool and the Fortescue River. The delta consists of a braided network of dynamic channels that emerge from the pool and radiate towards the river 2 km away (Figure 22). Outflow leaves Chinderwarriner Pool from four outlets that separate into seven main channels. These channels, numbered from 1 to 6b and 6a (east to west) distribute water across the delta.

These wetlands support several significant ecological communities consisting of aquatic macrophytes, sedges and dense forests of *Melaleuca argentea* and *Eucalyptus camaldulensis*. These vegetation assemblages are considered to be unique to the Pilbara and provide a variety of habitats of restricted distribution in a regional context. Of particular conservation significance is the occurrence of the marshy woodland of *M. argentea* over sedges (Welker Environmental Consultancy 1998).

The distribution of water between the channels and the course of the channels across the delta is considered to be particularly important to ensure the sedgeland and marshes in the lower reaches of the delta receive appropriate amounts of water. As such, management criteria have been implemented to ensure adequate distribution of water across the delta to sustain these important ecosystems.



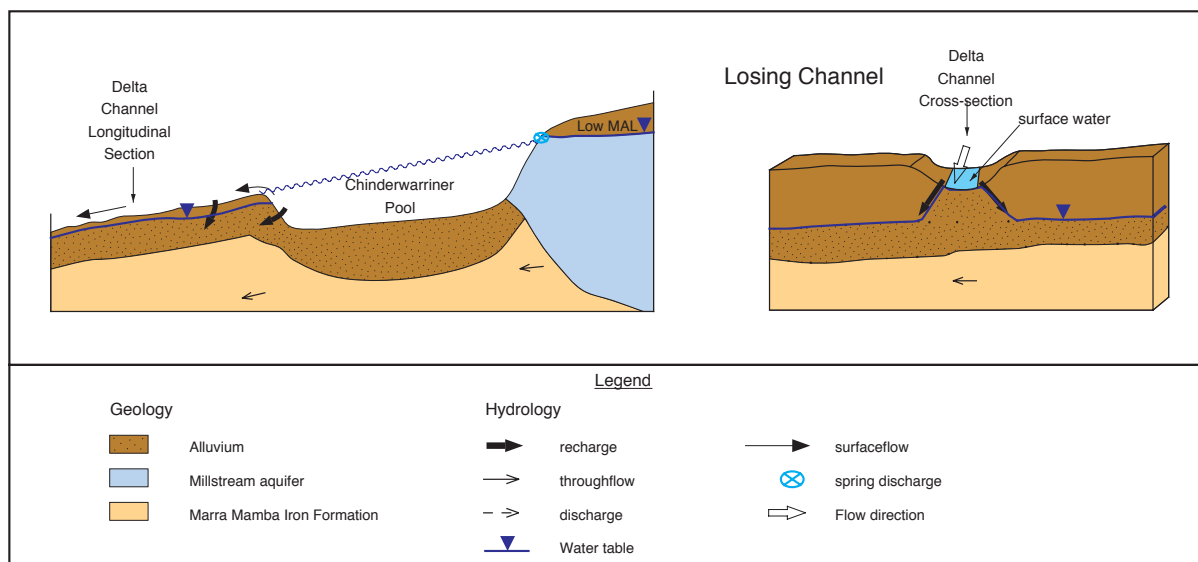
*Figure 22: Map of the Millstream Delta showing the approximate course of the channels across the delta and the location of the monitoring bores (taken from Welker Environmental Consultancy 1998)*

### Recharge of the Millstream Delta alluvium

Although the delta's hydrogeology is not fully understood, results of a study by Welker Environmental Consultancy (1995) suggest it is underlain by shallow alluvial sediments, with a shallow watertable responsive to the flow of water in the channels that cross the delta. This study concluded that the alluvial sediments could be both recharged from and discharged to the delta channels, with the normal condition being that of recharge.

Recharge to the alluvial sediments in response to channel flows was demonstrated during the early 1980s when flows were being maintained by supplementation into Chinderwarriner Pool. During this period, despite declining MAL, the alluvial sediment watertables increased by 2 m, supporting the premise that the local watertable is recharged by channel flows.

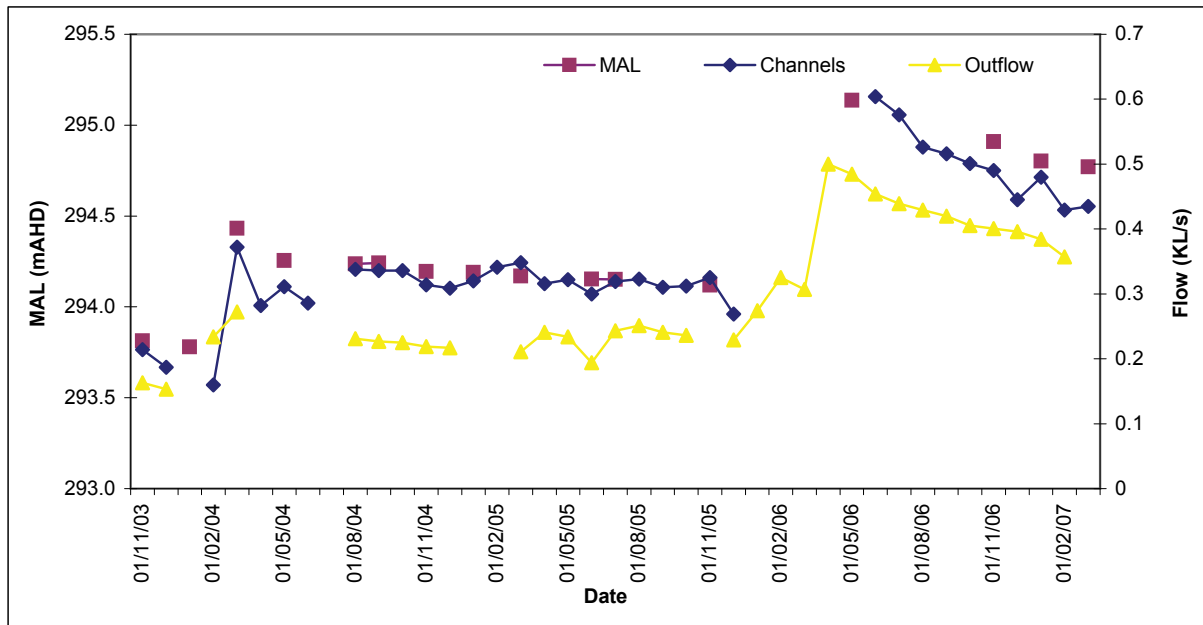
Although the delta's major source of recharge is likely to be the channels, it may also receive throughflow or subsurface flow from the Millstream aquifer. Investigations carried out by Welker Environmental Consultancy (1998) suggest that regional throughflow maintains general water levels several metres below ground level, while recharge from the channels results in localised mounding (Figure 23).



**Figure 23: Conceptual diagram of Chinderwarriner Pool's hydrogeology and the channels across Millstream Delta**

As suggested previously, channels across the delta may also gain water from alluvial sediments in certain scenarios. To examine this relationship, in November 2003 an intensive monitoring program was implemented that included channel gauging and installation and monitoring of an additional seven bores across the delta (see section 5.2).

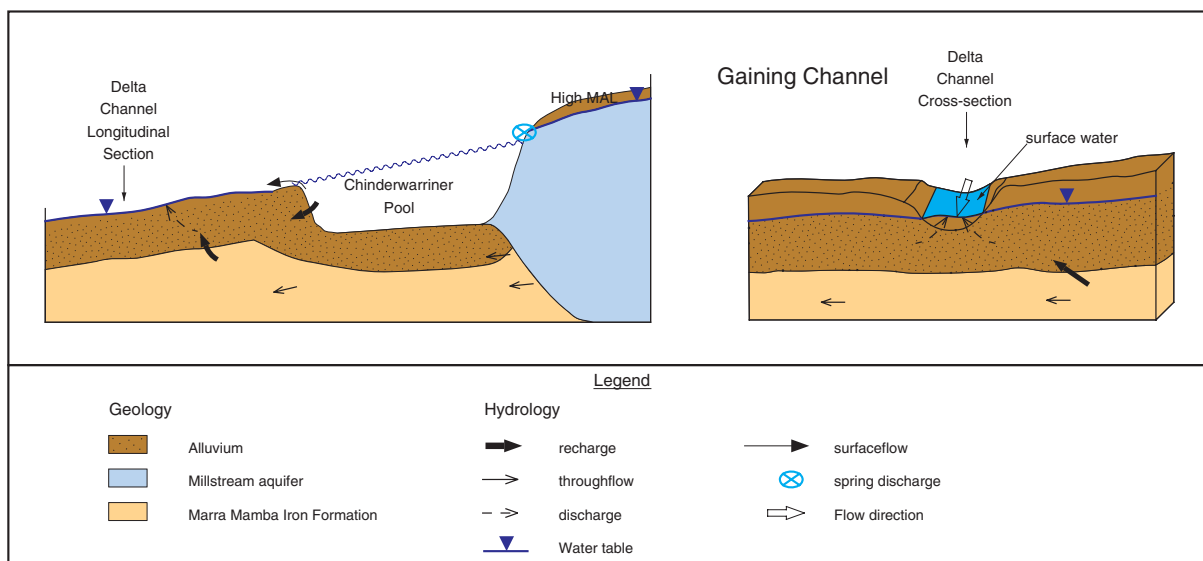
The monitoring results show the measured discharge within the delta's channels downstream of Chinderwarriner Pool is – for most of the measurement period – more than the measured discharge from Chinderwarriner Pool (Figure 24). This strongly suggests there are inputs into the delta's channels in addition to surface-water flows from Chinderwarriner Pool.



**Figure 24** Chinderwarriner Pool outflow rates compared with combined channel flow rates and MAL

Assuming the data's accuracy and the absence of other surface-water inputs, this indicates that during periods of high MAL, the channels are gaining water from the alluvial sediments – which in turn may be receiving inputs from subsurface flows (Figure 25).

It is intended that the intensive monitoring program's data be further examined to better quantify the relationship between MAL and channel dynamics. An estimation of throughflow contributions into the alluvial sediments is also sought.



**Figure 25:** Conceptual diagram of hydrogeology of Chinderwarriner Pool and the channels across the Millstream Delta during periods of high MAL.

## Management criteria

### Millstream Delta channel criteria

Water distribution is the target of monitoring and management of water across the delta. Management criteria are in place to ensure flow-distribution targets across the delta are met (Table 10). Because it is difficult to maintain fixed gauging points to consistently and accurately measure flow, criteria were established in terms of the extent of flow down the various channels and not in terms of quantity.

Short-term monitoring of stream-flow volume across the delta was undertaken as part of the intensive monitoring program, the results of which have been summarised above. This monitoring ceased in June 2008 and no quantitative monitoring of channel flow across the delta has been included as a management criterion.

*Table 10: Management criteria to maintain distribution of flows down channels of the Millstream Delta*

Millstream Delta channels	Original criteria (MMP, Dames & Moore 1984)	Revised criteria (MWMP, Welker 1998)	Current criteria
<b>Criteria</b>	Maintain flow into the west and north-west channels to maintain P3/79 at or above RL274, flow down north channel to reach river and down east channel past ref point	No reduction in flow down channels 1 & 2, target for flow down 2 to reach river, flow down channel 6a to at least 250 m past ref point	WRMOS, 2001: No reduction in flows down 1 & 2, target for flow down 2 to reach river, flow down 6a to at least 250 m past ref point (DEC responsibility). WRMOS, 2008: not included
<b>Flow monitoring</b>	Determine presence of water at specific points along each channel: weekly	Flow distance down channels and estimate of flow into Fortescue: fortnightly	Monitoring is no longer being undertaken.
<b>Groundwater monitoring</b>	P2/77, P3/77, P4/78, P3/79 monthly	P2/77, P3/77, P4/78 plus additional bores under investigation for the intensive monitoring program	P2/77, P3/77, P4/78 plus intensive monitoring bores 1/04, 2/04, 3/04, 4/04, 5/04, 6/04, 12/04 (currently under review)
<b>Objectives</b> <i>Maintain environmental flows into Millstream Delta</i> (Welker Environmental Consultancy 1998). <ul style="list-style-type: none"> <li>• To maintain the marshy woodlands of Cajeput over sedges in the central eastern portion of the Millstream Delta.</li> <li>• To improve the environmental value of the Millstream Delta by increasing channel flow into the lower western and central eastern parts of the delta to restore wetland areas.</li> </ul>			

1. Original criteria (Dames & Moore 1984): Criteria were designed to maintain the marshlands and flow channels and ensure the values of key ecosystems were maintained or restored.

*Monitoring:* Qualitative monitoring to be carried out on a weekly basis.

*Non-compliance with original criteria:* Monitoring records were not available to determine compliance.

2. *Revised criteria* (Welker Environmental Consultancy 1998) and *current criteria*: These criteria aim to ensure that Chinderwarriner Pool outflow leads to channel flow down the lower western and central eastern parts of the delta to restore wetland areas that dried during the early 1980s (Figure 22). These channel flows are also required to maintain local alluvial watertable levels. Specific criteria for flow down channel 6a ensure that the local Woodley aquifer, situated adjacent to the delta, is also recharged by channel flows (Welker Environmental Consultancy 1998).

*Monitoring:* Qualitative monitoring to be carried out on a weekly basis.

*Non-compliance with revised criteria:* Monitoring against these criteria, and ensuring distribution of flow across the delta, is the DEC's responsibility under the *MWMP*. There is no formal reporting against these criteria and as such it is difficult to determine whether monitoring has been undertaken or if any breaches have occurred. It is understood that due to resource constraints DEC no longer undertake this monitoring.

#### ***Outstanding issues***

7. DEC's role and reporting responsibilities need to be confirmed and formalised or alternative arrangements implemented for surface-flow monitoring across the delta.

8. Develop a better understanding of the contributions made by throughflow or subsurface flow into the delta.

## **Crossing Pool**

### ***Overview***

Crossing Pool is a permanent pool situated on the Fortescue River approximately 1 km downstream from Deep Reach Pool. Crossing Pool and the surrounding environment is one of Millstream's main tourist destinations and has high aesthetic value.

The permanence of Crossing Pool is the result of a constant supply of surface water from Deep Reach Pool (Figure 15). Outflows from Crossing Pool, combined with any surplus flows from Chinderwarriner Pool, are the primary input into the downstream environment through to at least Gregory Gorge.

As such, management criteria have been implemented to protect the pool's *in situ* values and ensure its outflows are sufficient to maintain the downstream environment.

### Recharge to the riverine alluvium from Crossing Pool

Crossing Pool receives surface water from Deep Reach Pool, which in turn leaves the pool as outflow, evapotranspiration or recharge to the riverine alluvium.

Recharge of surface flow is thought to be the main input into the riverine alluvium with little or no input from groundwater throughflow (Welker Environmental Consultancy 1998). As such, local watertables rely on sufficient outflow from Deep Reach Pool to maintain water levels, recharge the local watertable and meet the ED of the downstream environment.

### *Management criteria*

#### Outflow criteria

Management criteria are in place to ensure riverine flows are sufficient to maintain the local and downstream environments (Table 11). In 1984, a criterion based on maintaining pool levels was developed for Crossing Pool to protect the broadly identified aesthetic values in and around the pool. This criterion was based on maintenance of a minimum pool CTF level of 282.5 mAHD.

When the management criteria were revised in 1998, it was not deemed necessary to implement any criteria for this pool; however, it later became necessary when the monitoring points could no longer be maintained at Deep Reach Pool. These criteria were first included in the 2001 *WRMOS* (WC 2001).

*Table 11: Management criteria to ensure Crossing Pool outflow rates are maintained*

Crossing Pool – outflow	Original criteria (MMP, Dames & Moore 1984,)	Revised criteria (MWMP, Welker 1998)	Current criteria
Criteria	Maintain the pool level above its cease-to-flow level (currently 282.5 mAHD)		Instantaneous flow rates: 0.08 kL/s, Nov/Dec 0.11 kL/s,
Flow monitoring	Pool level: weekly	Pool level: monthly	Outflow: bi-monthly
Groundwater monitoring			None
	The Deep Reach supplementation scheme is available to ensure that flows to downstream pools are maintained if monthly monitoring indicates the criteria are in danger of being breached.		
<b>Objectives</b>			
To ensure no significant adverse impacts of water abstraction on the environment and cultural values of riverine vegetation from Deep Reach Pool to Gregory Gorge.			

1. Original criteria (Dames & Moore 1984): Pool-level criteria were based on the understanding that the aesthetic values around Crossing Pool and adequate outflow rely on the maintenance of adequate pool levels. A minimum pool CTF level of 282.5 mAHD was to be maintained.

*Monitoring:* Crossing Pool's level was monitored on an opportunistic basis, usually several times a month.

*Non-compliance with revised criteria:* Monitoring against the criteria was a DEC responsibility. Because no formal reporting occurred, it is difficult to determine whether monitoring was undertaken or if any breaches occurred.

2. Revised criteria (Welker Environmental Consultancy 1998): The 1998 *MWMP* did not specify any management criteria for Crossing Pool.

3. Current criteria: Because monitoring at Deep Reach Pool is difficult and inaccurate, the WRC recommended the discharge monitoring point be moved to Crossing Pool. The July 1999 MHCC meeting agreed on the new monitoring point and adopted an interim measure for streamflow of 0.08 kL/s. This was implemented as part of the 2001 *WRMOS* (WC 2001).

This figure was based on Welker Environmental Consultancy (1998) ED estimates for the riverine environment downstream of Crossing Pool – using the same methodology detailed previously for Deep Reach Pool 'revised criteria'. It assumes that meeting this figure will also ensure the ED upstream to Deep Reach Pool has been met.

It was intended that the TWG review the figure and then present its findings to the Department of Water and the MHCC for approval. There is no record of this happening.

*Monitoring:* General practice is for the Water Corporation to contract the Department of Water to carry out manual flow monitoring at Crossing Pool on a monthly basis. This information is provided to the Water Corporation monthly. This contract has not been renewed and it is understood that flow monitoring is currently being undertaken by WC.

*Non-compliance with revised criteria:* Outflow monitoring that was undertaken in December 2002 is missing off WC reporting. Whilst measured instantaneous flow was below the December criterion, this would not have been considered a breach as outflow was reported against MAAD prior to 2003 (as discussed in Chinderwarriner Pool – Management criteria).

Outflow from Crossing Pool dropped below the instantaneous flow criterion for supplementation in November 2003. In response to this breach the supplementation scheme was activated in early December 2003 and ceased in January 2004.

### Outstanding issues

9. The WC should update its dataset to include missing data from December 2002 indicating a breach of the monthly outflow criterion.

10. Consideration of Chester (2001) criteria, as discussed below, remains outstanding.

At the 2001 MHCC meeting alternative criteria for Crossing Pool were presented (Chester 2001). The report was forwarded to attendees, who were asked to make a decision about which criteria to adopt at the next MHCC meeting. This action was not followed up at any of the subsequent MHCC meetings. The suggested criteria will be considered during the revision of EWR that the Department of Water is undertaking.

Figure 26 compares the outflow criteria recommended in Chester (2001) with the implemented Welker Environmental Consultancy (1998) criteria and actual measured outflow rates at Crossing Pool. The Chester flow criteria mimics the inter-annual trends in pool outflow rates, while the current criteria is designed to mimic inter-annual evaporation trends.

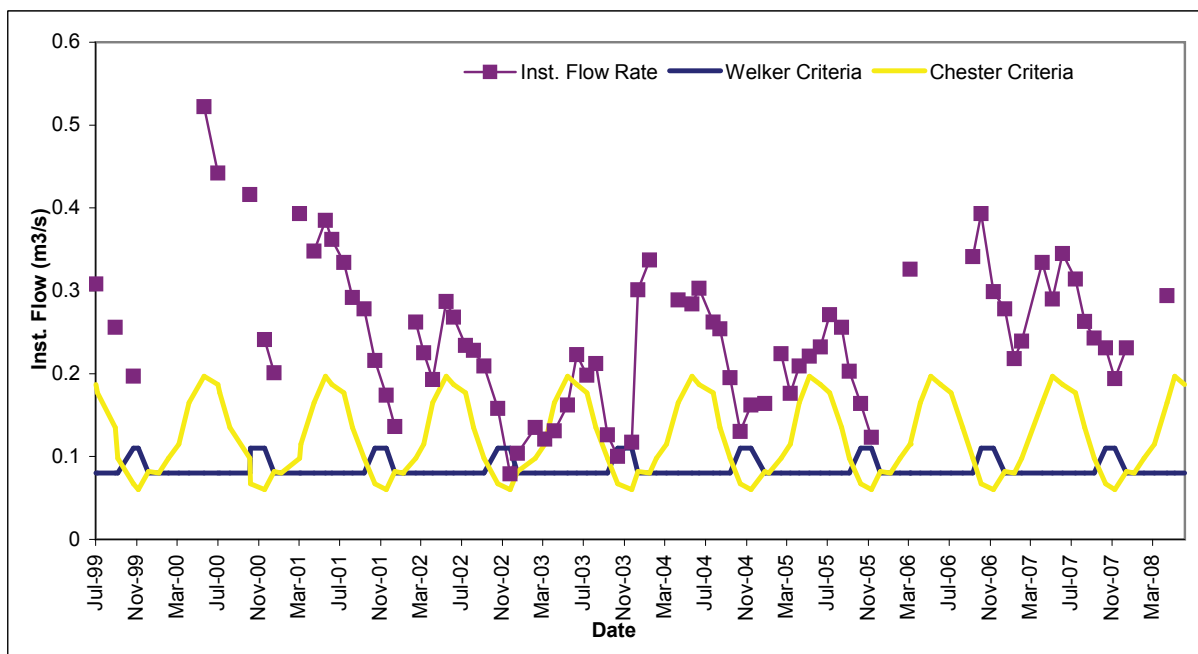


Figure 26: Recorded instantaneous outflow from Crossing Pool compared with Welker Environmental Consultancy (1998) criteria and proposed Chester (2001) criteria

## Gregory Gorge

### Overview

Gregory Gorge contains a series of semi-permanent riverine pools located on the Fortescue River approximately 20 km downstream from Deep Reach Pool. This area's ecological, cultural and aesthetic values are maintained by surface-water flows provided in part by groundwater discharge from the Millstream aquifer.

## Hydrology

Pool water levels and flows as well as adjacent riparian ecosystems are likely to be maintained by rainfall-derived surface-water flows from the Fortescue River catchment, along with surface-water flows derived from Millstream aquifer discharge to Deep Reach and Crossing pools.

Analyses of surface-flow trends to determine pool permanency indicate that flows are usually continuous from February to September, remain close to nil throughout November and December, and in October and/or January experience low or no flow in one out of every three years.<sup>5</sup>

## Management criteria

### Riverine flow criteria

Gregory Gorge is reliant on outflows from upstream to ensure the environmental flows are maintained at the required levels. A stream gauging station has been in place since 1968. This station is used to assess whether criteria (as detailed in Table 12) have been met.

*Table 12: Management criteria to ensure riverine flows at Gregory Gorge are maintained*

Riverine flow	Original criteria (MMP, Dames & Moore 1984)	Revised criteria (MWMP, Welker 1998)	Current criteria
Criteria	Maintain discharge to Livistona Pool between April–Oct, allow to decline 0.5 below CTF (269.83) Nov–March	Maintain historical flow at Gregory Gorge	Two consecutive years should not have > 4 months each of no flow at Gregory Gorge
Flow monitoring	Outlet: weekly Pool levels: weekly	Flow: continuous	Flow: continuous
Management	If the current criterion is breached, a review of flow and rainfall patterns will be undertaken with consideration given to supplementation or an increase in outflow requirements from upstream pools.		
<b>Objective</b> <i>To ensure no significant adverse impacts of water abstraction on the environmental and cultural values of riverine vegetation from Deep Reach Pool to Gregory Gorge (Welker Environmental Consultancy 1998).</i>			

<sup>5</sup> There are no stream gauging records before abstraction began; as such, these figures are influenced by abstraction.

1. Original criteria (Dames and Moore 1984): This criterion was designed to ensure flow occurred to an appropriate distance down Fortescue River. The criterion only extended to Livistona Pool, as it was determined that ecosystems downstream of Livistona were only dependent on aquifer-derived water for a small portion of their needs (Dames & Moore 1984).

*Monitoring:* Livistona Pool stage monitoring was carried out opportunistically (usually several times a month).

*Non-compliance with original criteria:* The *MMP* criterion was breached in the summer of 1985–86 and again in May to August 1986. Management actions resulted in direct augmentation into Palm Pool with subsequent inflows into Livistona Pool.

2. Revised criteria (Welker Environmental Consultancy 1998): In the 1998 *MWMP* this criterion was extended to include flow down to Gregory Gorge, with the recommendation that ‘historical river flow should be maintained at Gregory Gorge’. At the time historical river flow was not actually defined, which left the meaning of ‘historical flows’ open to interpretation.

*Monitoring:* A gauging station is in place at Gregory Gorge to record continuous stage level data.

*Non-compliance with revised criteria:* This criterion was not reported against before it was revised in 1999 (see below – current criterion).

3. Current criterion: In its annual report to the WRC (now Department of Water), the Water Corporation (1999) reviewed the 30 years of available flow and rainfall data and recommended a suitable and achievable historical flow criterion of: ‘two consecutive years should not experience more than four months each of no flow’. The department endorsed this criterion at the December 1999 MHCC meeting and it was subsequently implemented into the 2001 *WRMOS*.

*Monitoring:* The Department of Water operates a telemetered gauging station at Gregory Gorge with continuous data available from 1968. Real-time level and discharge data is available on the Department of Water website. WC is only required to report on the absence or occurrence of flow.

*Non-compliance with current criteria:* The current criterion has not been breached since it was implemented.

## Other minor spring-fed creeks

### *Overview*

Woodley Creek, Peters Creek and Palm Creek are semi-permanent creeks with flows maintained by spring discharge from the aquifer. Each creek is a tributary of the Fortescue River and enters the river downstream of Millstream Creek.

The springs are located down gradient from the known boundary of the aquifer and are thought to derive their spring flows through subsurface flow from the aquifer rather than direct discharge (Figure 2). Palm Creek is of particular conservation significance, mainly due to the large Millstream fan palm community in the area.

### Spring discharge into minor creeks

Surface flow largely depends on small discharges of aquifer water occurring along the creeks (Dames & Moore 1984). Previous analyses of groundwater monitoring data suggest that discharges in areas surrounding Palm Creek respond to changes in MAL on a magnified basis. Therefore, small changes in MAL may cause nearly triple the amplitude fluctuations in groundwater level and subsequent spring flow (WC 1999).

Although data on Peters and Woodley creeks is limited, it is likely the area surrounding these creeks will also respond to changes in MAL in a similar fashion to areas surrounding Palm Creek (Welker Environmental Consultancy 1995).

The relationship between aquifer level and spring discharge along the minor creeks is less well known than for Deep Reach and Chinderwarriner pools. It has been estimated that at MAL 293.2–293.3 mAHD, flow would be negligible, increasing to approximately 1.5 GL/a when at 293.6 mAHD (Welker Environmental Consultancy 1998).

In 2006, small-volume Parshall flumes were installed at Palm Creek, Peter Creek and Woodley Creek to enable accurate flow recording. The Water Corporation has since carried out monthly manual flow monitoring. Through negotiation between the Water Corporation and the Department of Water, monitoring frequency increased to every two months in the 2008 *WRMOS* (WC 2008)

Monitoring data is also available for the period 1999–2006; however, this data is based on estimates of flow.

Based on the available dataset, Palm Creek appears to have the most permanent flow, with flow being recorded for 100 per cent of the 55 monitoring occasions since 1999. Woodley Creek recorded flow on 80 per cent of occasions, while Peters Creek recorded flow on 95 per cent of occasions.

## Management criteria

### Minor creeks outflow criteria

Because the understanding of the hydrogeology around these minor creeks is generally lacking, no criteria have been developed specific to Peters Creek, Woodley Creek or Palm Creek. The *MWMP* (Welker Environmental Consultancy 1998) proposed that general watertable-decline criteria be used as interim management criteria for these areas (see Section 4.1 – Management of aquifer level).

### Management of aquifer level

#### Absolute aquifer decline criteria

Aquifer level is considered to be the primary ‘driver’ for the spring flows that support key environmental values. Declining aquifer level results in declining spring discharge – in turn reducing pool outflows and recharge of the alluvial watertables.

The subsequent impact of declining watertables on key vegetation species will primarily depend on the tree roots’ ability to adapt to the changing hydrology. To protect tree species from water stress owing to abstraction of groundwater, a criterion was implemented to limit the extent of aquifer decline based on tolerances of key vegetation species (Table 13).

*Table 13: Management criteria to manage extent of aquifer decline*

Aquifer decline limit	Original criteria (MMP, Dames & Moore 1984)	Revised criteria (MWMP, Welker 1998)	Current criteria
<b>Criteria</b>	N/A	MAL shall not fall > 0.5m over the long term (5 years).	WRMOS, 2001: MAL shall not fall > 0.5 m from the long-term average currently at 293.6 mAHD. WRMOS, 2008: MAL not to fall below what is considered to be the historical minimum MAL of 293.10 mAHD
<b>Monitoring</b>	Levels: MAL 19 bores monitored bi-monthly	Levels: MAL bores monitored bi-monthly	Levels: MAL bores monitored bi-monthly

1. Original criteria (Dames & Moore 1984): No criterion for an aquifer decline limit was specified.

2. Revised criteria (Welker Environmental Consultancy 1998): This criterion has been implemented to ensure the MAL does not decline by > 0.5 m over the long term (five years).

The reason for the measure of 0.5 m is not specified in the *MWMP*, but is likely to be linked back to the EWR study carried out by Muir (1995). Muir states that reductions of greater than 0.5 m may stress *M. argentea* in the most sensitive situations.

*Monitoring:* Bi-monthly monitoring of the MAL bores.

*Non-compliance with revised criteria:* This criterion was not reported against.

**Box 7: Assumptions and limitations for determining absolute aquifer decline criterion.**

- Criterion was developed with limited knowledge of the physiology of targeted tree species.
- Does not consider other sources of water used by the vegetation such as soil and surface water.
- Does not consider the importance of other components of the hydrological regime required by the plants, such as flooding to promote *E. camaldulensis* seedling establishment.
- Does not take into account natural seasonal fluctuations in local watertables.

3. *Current criteria* (WC 2001): This criterion ensures the MAL does not decline by > 0.5 m from the long-term average of 293.6 mAHD. It sets the drawdown limit on the aquifer to 293.1 mAHD.

The criterion recommended previously in Welker Environmental Consultancy (1998) did not specify a reference level to measure watertable decline against. Subsequently, when it was implemented into the 2001 *WRMOS*, a measure of 293.6 mAHD was adopted. This measure originated from early works by SMEC (1982) that determined an historical long-term average aquifer level as 293.6 mAHD, a commonly referenced figure throughout the literature (Barnett & Commander 1986, p60; WAWA 1992, p25).

*Monitoring:* Bi-monthly monitoring of the MAL bores.

*Non-compliance with current criteria:* This criterion has not been breached since it was implemented in 1998.

**Outstanding issues**

11. Reference to MAL 293.6 mAHD as the long-term average needs to be reviewed. The *MWMP* cites a more recent investigation by Welker Environmental Consultancy (1995) on the simulated MAL from 1908 onwards. This investigation indicates that without abstraction, the MAL is unlikely to have ever been as low as 293.6 mAHD and is likely to have had a historical long-term average of 293.75 mAHD. This figure is likely to be considerably higher now after several years of record high MAL.

Rate of aquifer decline criteria

As well as setting limits on the acceptable magnitude of aquifer decline, the *MWMP* also recommends criteria to limit the rate of aquifer decline (Welker Environmental Consultancy 1998) (Table 14). These criteria are designed to ensure the rate of watertable decline does not exceed the estimated root-growth capacity of the key tree species.

Table 14: Management criteria to manage rate of watertable decline

Watertable rate of decline – general	Original criteria (MMP, Dames & Moore 1984)	Revised criteria (MWMP, Welker 1998) Recommendation only, not implemented as a criteria	Current criteria
Short term		Where the watertable is within 4 m of the surface, watertable should not fall greater than 20 cm over 12 months	MAL decline of no more than 20 cm over 12 months
Medium term		Where the watertable is within 4 m of the surface, watertable should not fall greater than 28 cm over 18 months	MAL decline of no more than 28 cm over 18 months
Long term		Where the watertable is within 4 m of the surface, watertable not to exceed a total of 0.5 m and 7–10 cm/a on a 3-monthly rolling average, or; where the watertable > 4 m from the surface not to exceed 1.5 m and 20 cm/a on a 3-monthly rolling average, away from creeks	MAL decline of no more than 0.5 m over 5 years
Watertable rate of decline – creeks		Short and medium term as above. Long term: not to exceed 1.0 m (average trend of 20 cm/a)	
Monitoring		Levels: MAL bores monitored bi-monthly	Levels: MAL bores monitored bi-monthly

1. Original criteria (Dames & Moore 1984): No criterion to limit the rate of aquifer decline was specified in this management plan.

2. Revised criteria (Welker Environmental Consultancy 1998): Based on the water requirements study by Welker Environmental Consultancy (1995), recommendations as detailed below were proposed to control watertable-decline rates in areas where environmental flows were not supported by a supplementation program.

For the area immediately upstream from Deep Reach Pool where watertables are less than four metres, the short-term (12-month) decline should not exceed 20 cm. The medium-term (18-month) decline should not exceed 28 cm and the long-term (5–7–year) decline should not exceed 1.5 m over 5–7 years. If the watertable is greater than four metres, the long-term decline should not exceed 1.5 m.

In minor creek beds the long-term decline should not exceed 1.0 m; while away from the creek beds where the watertable is greater than 4 m, the long-term decline should not exceed 1.5 m.

The long-term MAL decline recommendation was based on observed trends at Palm Creek and upstream from Deep Reach Pool from 1977–84. During this period MAL decreased approximately 0.5 m over seven years with no obvious impact on the vegetation in those areas (Muir 1995).

A recommendation allowing for larger decline rates away from creeks was also established. This was based on a decrease in the likelihood of vegetation being groundwater dependent where depth to groundwater was greater, and where there was no groundwater discharge (Muir 1995).

These recommendations were not considered applicable to the Millstream Delta or riverine areas downstream of Deep Reach Pool. The assumption is that these are protected by the supplementation programs established to maintain pool outflow rates.

These recommendations were not assigned as criteria. In 2001 they were implemented in a revised form as detailed under current criteria.

*Monitoring:* It was expected that a general understanding of the relationship between changes in MAL and corresponding changes in local watertables would have enabled these criteria to be monitored through changes in MAL.

3. Current criteria: These criteria were implemented into the 2001 *WRMOS*. They were specified in relation to the MAL rather than local watertables. This was done on the understanding that changes in local watertables could not be directly assumed from changes in MAL. As such the following relationships between MAL and local watertables were concluded after investigations into historical groundwater levels (Welker Environmental Consultancy 1995):

$$\Delta \text{MAL} = \Delta \text{Deep Reach water level}$$

$$\Delta \text{MAL} = 0.50 \times \Delta \text{creek-bed water level}$$

$$\Delta \text{MAL} = 0.33 \times \Delta \text{water level away from creek beds}$$

However, the reference to ‘local water tables’ was overlooked during implementations of the criteria and as such the decline criteria incorrectly apply to MAL.

*Monitoring:* MAL was monitored and reported to determine compliance against these criteria.

*Non-compliance with current criteria:* MAL exceeded the 12-month drawdown

criterion from March 2002 until late 2003 and again in March 2005. The first of these triggered a residential demand-management campaign throughout 2003 and into 2004.

The 18-month drawdown criterion was breached during December 2002 and January 2004. After the decline rate was breached the Water Corporation initiated an investigative drilling program to determine contingency options (WC 2004).

The short-term criterion was also breached during periods of high MAL and low or no abstraction rates. This was likely to be due to natural aquifer decline rates exceeding the criterion during periods of high MAL. As such, no management actions have been required on these occasions.

#### ***Outstanding issues***

12. During high MAL periods, natural aquifer decline rates have been shown to exceed the short- and medium-term criteria during periods of low or no abstraction. Natural decline rates and decline rates under abstraction regimes need to be identified.

13. Given these criteria were originally developed to apply to local watertables rather than MAL, which they are not applied against, there is a need to review the criteria and their application.

### **General criteria**

#### **Scheme annual abstraction limit**

Abstraction limits for the aquifer are implemented to ensure sustainable use of the resource whilst meeting environmental demand. Table 15 details abstraction limits for the West Pilbara water-supply scheme (WPWSS), the conjunctive use scheme which includes supply from the Harding Dam.

*Table 15: Management criteria to manage abstraction rates for the WPWSS.*

<b>Combined annual abstraction (licence)</b>	<b>Original criteria (MMP, Dames &amp; Moore 1984)</b>	<b>Revised criteria (MWMP, Welker 1998)</b>	<b>Current criteria</b>
<b>Criteria</b>	20.4 GL/a	15 GL/a (can be Millstream as long as aquifer decline limits are not breached, and after testing <sup>1</sup> )	WRMOS, 2001: 15 GL/a (can be Millstream as long as aquifer decline limits are not breached, and after testing)

1. Original criteria (Dames & Moore 1984): This figure was determined by SMEC

(1982) with a conjunctive-use model. A number of simulation studies were conducted using historical data. It was determined that the WPWSS could supply 20.4 GL/a using a full supply level of 60.0 mAHD for Harding Dam while ensuring 100 per cent of Millstream environmental demand was being met.

2. Revised criteria (Welker Environmental Consultancy 1998): The Department of Water reduced the conjunctive scheme licence allocation to 15 GL/a as a result of environmental investigations undertaken by Welker Environmental Consultancy (1995) and a Water Corporation scheme-reliability assessment undertaken in 1997.

*Non-compliance with revised criteria:* No breaches have been recorded.

3. Current criteria: Remains the same as the *revised criteria*.

#### Long-term rate of abstraction

A criterion to manage long-term abstraction from the aquifer was determined based on the calculated sustainable yield of the aquifer. Details are limited on how these figures were derived but they appear to be loosely based on annual recharge being 18 GL/a and environmental demand being 12 GL/a (SMEC 1982; WAWA, 1992).

*Table 16: Management criteria to manage long-term abstraction rates from the aquifer*

Long-term abstraction of Millstream	Original criteria (MMP, Dames & Moore, 1984)	Revised criteria (MWMP, Welker 1998)	Current criteria
Criteria		6.4 GL/a	WRMOS, 2001: 6 GL/a
<b>Objectives</b> <i>To ensure abstraction from the aquifer is managed within ecologically sustainable limits.</i>			

1. Original criteria (Dames & Moore 1984): No criterion was developed to limit the long-term rate of abstraction from the aquifer for the MMP.

2. Revised criteria (Welker Environmental Consultancy 1998): The source of this figure is unclear, however it is likely to have originated from SMEC (1982). There investigation determined a system yield for Millstream of 6.4 GL/a whilst allowing for 100 per cent of ED to be met. The detail in the report is limited but it appears that the figure was determined with the understanding that the yield exceeded the aquifer's sustainable yield and a method of artificially recharging the Millstream aquifer before the end of 100 years would be necessary.

This figure was referenced to as the system yield in the *Millstream groundwater scheme review* carried out by WAWA (1992), which in turn was referenced as the sustainable yield in the *MWMP* (Welker Environmental Consultancy 1998).

*Monitoring:* Not applicable, see *current criteria* below.

*Non-compliance with revised criteria:* No assessment of criterion between 1998 and 2001, see *current criteria* discussed below

3. *Current criteria:* The 2001 *WRMOS* put in place a figure of 6 GL/a as the long-term average draw. Again the detail on how this figure was derived is limited.

*Monitoring:* Production rates are monitored continuously during periods of abstraction and are reported by the Water Corporation annually.

*Non-compliance with current criteria:* The reporting periods 2000–01, 2001–02, 2002–03 and 2003–04 each recorded abstraction rates above 6 GL/a. The long-term-average abstraction rate (five years) between 1999–2000 and 2003–04 was 7.86 GL/a. During this period Harding Dam was offline due to water quality issues and the figure being exceeded was not highlighted as a criterion breach.

Since abstraction began in 1968, average abstraction (including supplementation) has been 6.41 GL/a. Abstraction rates have been well below this criterion since Harding Dam was brought back online in 2004.

It should be noted that this criteria was removed from the 2008 *WRMOS*. The Department of Water is currently developing an estimate of the long term sustainable yield for the aquifer.

## 5 Monitoring program

### 5.1 Long-term monitoring program

Since 1984 Millstream and the aquifer have been the subject of a long-term monitoring program that consists of three components: groundwater monitoring, surface-water monitoring and biological monitoring. The objective of the program is:

To provide information which will be used in the day-to-day management of groundwater abstraction and the management of water-dependent environmental values of key areas of environmental significance (Welker Environmental Consulting 1998).

The key components of the monitoring programs are shown in Figure 8.

#### Groundwater monitoring program

As discussed throughout this report, aquifer level as represented by MAL is the key management indicator for the system. Aquifer level relates directly to rates of discharge from the aquifer and subsequently the supply of water to dependent ecosystems. Aquifer level also relates directly to total aquifer storage.

Considerable time and effort is spent on the groundwater monitoring program, which involves the collection of data from nine monitoring bores to determine MAL and monitor water quality. Groundwater and water quality data is also obtained from production and monitoring bores located in key environmental areas to enable trends in groundwater characteristics to be observed. The current groundwater monitoring program is detailed in Table 17.

*Table 17: Current groundwater monitoring program*

Criteria	Attribute	Current program	Agency responsible
<b>Production bores</b>	<b>Levels</b>	10 x monthly (PB 1–10), 2 x 2 monthly (unequip PB 11–12)	WC
	<b>Quality</b>	Monthly	WC
<b>Deep Reach supplementary Bores</b>	<b>Levels</b>	3 x monthly (when operating, otherwise annually) (DR1 DR2 DR3)	WC
<b>Chinderwarriner supplementation bores</b>	<b>Levels</b>	3 x monthly (when operating, otherwise annually) (CP1 CP2 CP3)	WC
<b>MAL monitoring bores</b>	<b>Levels</b>	9 x 2 monthly	WC
	<b>Water quality</b>	Annual	WC

Criteria	Attribute	Current program	Agency responsible
Riverine monitor bores	Levels	4 x 2 monthly (P9/78, P7/78 or P7/77 when dry, P8/77, P9A/78 which replaced P9/77 when it could not be located), 5 x monthly (intensive monitoring bores 07/04, 08/04, 09/04, 10/04, 11/04)	WC
	Water quality	4 x 2 monthly	WC
Chinderwarriner monitor bores	Levels	3 x 2 monthly (P2/77, P3/77, P4/78), 7 x monthly (intensive monitoring bores 01/04, 02/04, 03/04, 04/04, 05/04, 06/04, 12/04)	WC
	Water quality	3 x 2 monthly, 10 x monthly	WC
Palm springs monitor bores	Levels	4x2 monthly (P2, P4, P5, P8)	WC

In general the Water Corporation has fulfilled its responsibilities under the monitoring program. The main exception has occurred during periods when the bores could not be reached due to weather or site conditions.

In addition, bore P9A/78 become inaccessible due to dense vegetation and has not been monitored since mid-2006. This bore replaced bore P9/77 in 1997 when the bore could not be located. Bore P9/77 has since been replaced by bore 7/04 (E. Hambleton *pers. comm.*).

The data collected is appropriate for determining compliance against the current management criteria. However, it has been suggested the program should incorporate:

- additional monitoring bores along the river
- opportunistic monitoring of extreme events
- better analyses of water quality data.

(P. Commander, personnel communication, March 2009).

If management criteria are revised, this program may need to be reviewed.

#### **Outstanding issues**

14. Monitoring of additional bores along the Fortescue River recharge zone will allow for better aquifer recharge estimates.

### **Surface-water monitoring program**

Maintaining the environmental values of the primary management area is largely related to the magnitude and quality of the surface-water flows that emerge from the pools in the river (Deep Reach Pool) or from springs adjacent to the river (Chinderwarriner Pool, Woodley Creek, Palm Creek and Peters Creek).

The surface-water monitoring program involves the collection of data to determine outflow rates, water distribution across the delta and water quality data. The current surface-water monitoring program is presented in Table 18.

*Table 18: Current surface-water monitoring program*

Criteria	Attribute	Current program	Agency responsible
Chinderwarriner Pool	Level	Continuous	WC
	Outflow	Calculated monthly	DoW calc. monthly
	Water quality	Monthly	WC
Delta channel 1 & 2	Outflow	Fortnightly flow distance and east of flow into Fortescue	DEC
	Water quality	Monthly	
Delta channel 3&4	Outflow	Fortnightly flow distance and east of flow into Fortescue	DEC
	Water quality	TBA	
Delta channel 5&6	Outflow	Fortnightly flow distance and east of flow into Fortescue (5, 6a/b)	DEC
	Water quality	TBA	
Deep Reach Pool	Level	Continuous	DoW
Woodley Creek	Outflow	Monthly	WC
Peters Creek	Flow	Monthly	WC
Palm Creek	Flow	Monthly	WC
Crossing Pool	Outflow	Monthly	WC
	Level	Monthly	DEC
Palm Pool	Level	Monthly	DEC
Livistona	Level	Monthly	DEC
Gregory Gorge	Flow	Continuous	DoW

Management of these outflows is central to compliance with environmental water provisions for the area. The Department of Water and Water Corporation have met their responsibilities in regard to monitoring these components and the data provided has been adequate to determine compliance against spring discharge criteria.

Monitoring to determine compliance against criteria for distribution of flow across the delta does not appear to have been carried out methodically. The reason for this was not determined during this review.

## Biological monitoring program

### *Current biological monitoring program*

As discussed previously, Millstream's ecological values are intrinsically linked to the abundance and permanence of groundwater-derived spring flows. As such, these values are likely to be adversely affected by abstraction from the aquifer and subsequent decreases in spring flows.

Since formal management of Millstream began, various biological monitoring programs have been implemented to help identify any adverse effects of abstraction on these environmental values (Table 19). The original program developed for the 1984 *MMP* (Dames & Moore 1984) included direct surveys of vegetation and fauna combined with aerial photography to detect change. The 1998 *MWMP* (Welker Environmental Consultancy 1998) excluded these components in favour of remote survey techniques and fixed photographic points.

*Table 19: Biological monitoring program: The 'original program' was developed for the 1984 MMP (Dames & Moore 1984). This program was revised in the MWMP (Welker Environmental Consultancy 1998) and has subsequently been modified in the WRMOS (WC 2008)*

Component	Original program (MMP, Dames & Moore 1984)	Revised program (MWMP, Welker 1998)	Current program (WRMOS, WC 2008)
<b>Rainfall</b>	Read daily	Read daily	Read daily
<b>Pan evaporation</b>	Read daily	Read daily	Read daily
<b>Aerial photography – determine gross distribution and changes in vegetation units</b>	Annual (funded by WC, interpreted by DEC)	Annually	Annually
<b>Survey – transects A to H to detail floristic changes</b>	Annual – October		
<b>Visual assessment – transects A to H to assess veg. health</b>	Annual – in summer		
<b>Millstream palm – direct measure of growth rate</b>	Annual – in summer		
<b>Dragonflies and damselflies – sampling</b>	Annual – in summer		
<b>Baseline survey</b>		Initial baseline survey (DEC)	
<b>Photography points (36)</b>		Annually – August (DEC)	
<b>DMSV imagery – vegetation dynamics</b>		Annually (changed to satellite imagery, 2001)	

1. Original program (Dames & Moore 1984): The original program included aerial photography of Millstream and detailed vegetation surveys along eight transects to identify changes in vegetation distribution and health. This was complemented by direct measurement of Millstream fan palm growth rates and sampling of dragonflies and damselflies.

2. Revised program (Welker Environmental Consultancy 1998): The revised program featured an initial baseline survey including photography at prescribed points, ongoing aerial photography to be interpreted on an annual basis and daily meteorological readings.

The program aimed firstly to establish baseline information for significant areas of vegetation in the creek and riverine systems (particularly Palm Creek) and secondly, to provide the information needed to determine changes to the distribution, density and structure of vegetation communities in all key areas.

This program did not incorporate the Millstream fan palm, transect surveys and dragonfly/damselfly components because they were considered to be ineffective. This was due to difficulty in interpretation and the large lag time experienced in response to environmental change.

3. Current program (WC 2008): The current monitoring program – as outlined in the 2008 *WRMOS* (WC 2008) – has been simplified to include only daily meteorological readings and annual aerial photography.

#### ***Outstanding issues***

15. The biological monitoring program is funded by the Water Corporation and historically has been conducted by DEC. Little biological monitoring has been undertaken in recent years. A review of the program to ensure biological monitoring is informative, effective and adequately resourced is necessary.

#### ***Components removed from the biological monitoring program***

As discussed above, the biological monitoring program has undergone considerable modification and downgrading since it was initiated in 1984. Several components (Table 20) that were implemented in the *MMP* (Dames & Moore 1984) and the *MWMP* (Welker Environmental Consultancy 1998) have since been removed. These components – including direct survey and sampling of vegetation and biological components – were found to be overly intensive and limited in the information they provided to ongoing management.

Table 20: *Obsolete biological monitoring components*

Removed component	Initiating document and period of monitoring	Details
<b>Vegetation transect survey</b>	<i>MMP</i> , Dames & Moore 1984 Surveyed: 1978, 1991, 1993	Transects A to H Observations of height, understorey and density – yearly Visual assessment of health – yearly
<b>Millstream palm – direct measure of growth rate</b>	<i>MMP</i> , Dames & Moore 1984 Measured: 1975–85	Direct measure – yearly
<b>Dragonflies and damselflies – sampling</b>	<i>MMP</i> , Dames & Moore 1984 Sampled: 1985	Observations and yearly sampling to determine distribution and abundance
<b>Photography points (36)</b>	<i>MWMP</i> , Welker 1998 Taken: 1999–2001	Ground survey and photo annually (Aug) or more frequently if needed
<b>DMSV imagery – vegetation dynamics</b>	<i>MWMP</i> , Welker 1998 Taken: 1979–2005 Converted to PFC 1979–2005 (excluding 1980 & 1982)	2001 change to satellite imagery – cheaper with comparable result (MHCC 2001)

Although these parameters have been removed, the recorded information provides a useful set of baseline data and will allow a record of long-term trends in the biological composition to be made. Detailed below is an outline of the data that may be available through these monitoring programs.

### *Vegetation transects*

Seven vegetation transects were established in 1978 across the river valley between Deep Reach Pool and the downstream end of Palm Pool. Each of the transects has at least one piezometer located in the immediate vicinity. Records show that surveys were conducted in 1978, 1991, 1993 and 1994. The Department of Water re-surveyed transects A, F and G in 2008 and are using the complete dataset to analyse floristic changes.

WAWA's 1986 annual report noted that vegetation transect monitoring was not detecting obvious changes that had been identified by opportunistic sightings such as defoliating trees. As such, it was recommended that monitoring be reduced from 'yearly' to 'as required' monitoring. The program was downgraded in the 1992 *MEMP* (WAWA 1992) because the procedure was considered to be excessively detailed and time consuming.

In the 1998 *MWMP* (Welker Environmental Consultancy 1998) it was recommended that vegetation transect monitoring be discontinued because it provided inadequate representation of vegetation dynamics and had limited value for management. However, there was still a requirement for DEC to carry out annual observations through aerial photographs and triennial surveys, with the results to go to the MHCC.

### *Monitoring of Millstream fan palms*

Monitoring the growth rates of individual Millstream fan palms began in 1975 to determine whether these could be used as a potential indicator of water stress. This continued on an annual basis until at least 1985, allowing for a comparison between rate of growth and depth to groundwater. The data collected to this date was reported in WAWA's 1986 annual report.

The results suggest there is no statistical relationship between groundwater fluctuations and rate of tree growth. A relationship between depth to groundwater and mean growth rate was also not established, with healthy trees growing at sites with depths to groundwater ranging from 2 m to 7 m.

### *Monitoring of Odonata*

A survey of the Odonata was carried out during April 1985, the results of which are appended in WAWA (1985).

WAWA (1992) considered the Odonata/macroinvertebrate sampling program to be of limited value and recommended that a regular monitoring program be determined. The monitoring program was deferred until it could be finalised at the 1994 MMC meeting. Minutes from this meeting could not be located to determine whether an actual decision was made; however, the monitoring program was not re-established.

### *Photography points*

There are records of photos being taken at these photography points in 1999, 2000 and 2001.

### *Satellite imagery*

DEC has developed a method for reliably converting Landsat imagery into percentage foliage cover (PFC) as an indicator of vegetation vigour. This technique allows changes in vegetation vigour over time to be assessed. Using information on past management (including weed removal), fire history and hydrological data it is possible to relate changes in vegetation vigour to other factors. In recent years DEC has not been able to complete the processing and analysis of imagery due to a lack of resources.

As part of the current investigations, the Department of Water is completing a review of the available data. In particular, the possible link between vegetation vigour and aquifer level is being investigated to determine if the imagery analysis can be used to inform management of the Millstream system.

## 5.2 Intensive groundwater monitoring program

In addition to the long-term monitoring program detailed above, an intensive monitoring program (as discussed in Section 1.9.4) was implemented in 2003–04. This program was originally proposed by Welker Environmental Consultancy (1998) to enable better characterisation of the hydrological and environmental demand of key areas within Millstream.

The program is based on monthly observations of water level and the basic water-quality-indicator parameters of electrical conductivity (EC) and pH. In the delta the program also included surface-flow monitoring. It was originally intended that this program be carried out over a 12-month period, after which the program was to be reviewed.

The Welker Environmental Consultancy (2003) *Millstream water management implementation plan* outlined the program which included:

- establishment of five new monitoring bores in the riverine area adjacent to Deep Reach Pool
- establishment of seven new monitoring bores in the Millstream Delta and intensive surface-flow monitoring of channels
- re-invigoration of four monitoring bores adjacent to Palm Creek.

The objectives and details of the program as they relate to each subarea are detailed below.

### Deep Reach Pool

With only one monitoring bore collecting groundwater data in the riverine area upstream of Deep Reach Pool, this area was considered to be under-represented in the monitoring program. As such, an additional five monitoring bores were installed to:

- better characterise water levels and groundwater flow
- relate mean aquifer levels to the local watertable near Deep Reach Pool and ecological health
- better understand the stratigraphy of the alluvial sediments and Millstream aquifer in the vicinity of Deep Reach Pool.

*Table 21: Deep Reach intensive monitoring program*

Intensive monitoring	No. of sites	Period	Frequency
Groundwater, conductivity & pH	Five new monitoring bores	11/04 – ongoing	Monthly

## Millstream Delta

Sufficient water supply to the Millstream Delta to sustain dependent ecosystems is a key objective of the system's management. The monitoring network in this area was considered inadequate to evaluate the losses (or gains) from the channels into the sediments underlying the delta, seepage from the Millstream aquifer into the sediments and the relationship between MAL and delta groundwater levels. As detailed in the implementation plan (Welker Environmental Consultancy 2003), the seven additional wells and intensive stream gauging were needed to:

- better characterise water levels and variability of water levels within the delta
- evaluate the relationship of groundwater level with the delta and health of the dependent vegetation
- determine when and how much the channels are losing/gaining to the local alluvial sediments.

The seven additional monitoring bores were constructed in November 2004 and were monitored on a monthly basis. The monthly stream gauging began in November 2003 and ceased in August 2008 (Table 22). Figure 22 shows these monitoring locations.

*Table 22: Millstream Delta intensive monitoring program*

Intensive monitoring	No. of sites	Period	Frequency
Groundwater, Conductivity & pH	Seven new monitoring bores	11/04 – ongoing	Monthly
Channel flow monitoring	Channel 3,4,5,6	11/03 – 08/08	Monthly
	Channel 1,2	11/03 – 08/08	Monthly
	Channel 3,4	11/03 – 08/08	Monthly
	Channel 5,6	11/03 – 08/08	Monthly
	Channel 5	11/03 – 08/08	Monthly

## Palm Creek

Welker Environmental Consultancy (2003) recommended that 10 new monitoring bores be installed, and monitoring at an additional four bores be resumed. The TWG questioned the need to install 10 monitoring bores and works were apparently removed when previous drillers' logs were found to provide significant insight into the stratigraphy of the Palm Creek area.

Consequently the intensive monitoring program in this area consists of bi-monthly monitoring of four re-established bores within Palm Creek in conjunction with streamflow monitoring (Table 23). This program has the following objectives:

- develop an understanding of the apparently anomalous relationship between MAL and the local watertable elevation
- better define flow patterns in the area

- understand the tolerance of vegetation in the creek areas to local watertable decline
- define the stratigraphy of the Palm Creek area.

*Table 23: Palm Creek intensive monitoring program*

Monitoring	No. of sites	Starting date	Frequency
Monitoring recommenced	Four re-established monitoring bores	08/04 – ongoing Data is also available for these bores for 1976–92	Bi-monthly
Flow	1	2006 – ongoing	Monthly

### *Outcomes*

To date this monitoring program's dataset has yet to be fully analysed. As discussed in Section 4.1, evaluation of the dataset as it applies to the delta has demonstrated the complex relationship between groundwater and surface-water flow.

#### ***Outstanding issues***

16. Stratigraphy reports for the three subareas remain outstanding.
17. Analysis of the intensive monitoring program dataset has not been undertaken.

## 6 Evaluation and recommendations on management criteria

In commenting on historic and current criteria and management of Millstream, it is recognised that decisions were made within the bounds of the available hydrological data and scientific understanding at the time. This review, and subsequent additional investigative work being done as part of the 'Stage 2' review, provides an opportunity to address a number of the assumptions made in developing previous and current criteria and to resolve outstanding issues that have been highlighted.

Based on the outcomes of this review, it is anticipated that the current management framework will be largely retained. Additional Department of Water investigations now underway are aimed at refining and improving the current criteria and management framework. The proposed way to address the assumptions and outstanding issues highlighted as part of this review is summarised in Figure 27 and detailed below.

### Estimation of environmental demand

A number of the assumptions and limitations of criteria developed to manage water abstraction from Millstream relate to the estimation of environmental demand (ED). ED was originally determined by estimating total evapotranspiration for stands of vegetation (Dames & Moore 1984). The assumptions and limitations of this approach are detailed below.

***Box 2 & 4: Assumptions and limitations with original outflow criteria for Deep Reach and Chinderwarriner pools (Dames & Moore 1984)***

- Does not include consideration of precipitation inputs.
- Assumes throughflow inputs are insignificant i.e. no additional inputs of groundwater downstream of Deep Reach Pool.
- Based on the limited knowledge of evapotranspiration and plant physiology available at the time.
- Does not consider general water status: i.e. period since flood or local recharge event, period since rainfall event and local groundwater levels.

Revised criteria (Welker Environmental Consultancy 1998), which were based on estimates of ED using a water balance approach, included a number of additional assumptions (Box 3 & 5). These included using a very limited dataset to estimate ED (flow records for two years) and an assumption that ED was met during the representative years selected.

**Box 3 & 5: Assumptions and limitations with revised outflow criteria for Deep Reach Pool and Chinderwarriner Pool**

- Estimates of ED were based on flow data from only two years, 1977 and 1983. This presents two possible sources of error:
  - the representative years may not adequately cover the natural variability of the groundwater-derived flows into the system and
  - the assumption that ED was adequately met during these two representative years may not be correct.
- Changes in soil- and tree-moisture storage were not taken into account. As the watertable was declining during this period, changes in water storage may have been significant.
- Contributions of throughflow and bank storage into the system were not considered.
- Management measures did not allow for consideration of general water status: i.e. period since flood or recharge event, period since rainfall event and local groundwater levels.
- Inflows from tributaries into the system, such as Dawson Creek, were assumed to be insignificant. This assumption is likely to be acceptable due to the low surface flows experienced at the time.
- Assumption that a 40 per cent increase in evaporation during November and December is mimicked by ED.
- MAAD has not been adjusted to incorporate the increased ED predicted for November and December.

The following outstanding issue has also been highlighted for consideration when estimation of ED is refined.

**Outstanding issues**

10. Consideration of Chester (2001) criteria remains outstanding.

The Chester flow criteria mimics the inter-annual trends in pool outflow rates, while the current criteria is designed to mimic inter-annual evaporation trends.

**Actions**

Improved estimates of ED or ecological water requirements (EWRs) are currently being developed. The approach being taken involves a combination of:

- revision of the current water balance approach by including, where possible, additional and more recent data and evidence of ecosystem response to water availability
- improved estimates of evapotranspiration through the quantification of tree water use.

The results of both techniques will be compared and used to calculate a revised ED. The final EWRs for Millstream will also include EWRs for aquatic ecosystems.

## Estimation of spring discharge and pool outflow

In the absence of additional rainfall-derived surface-water flows, the provision of water to meet estimated ED relies on sufficient discharge from the Millstream aquifer. The quantification of discharge from the aquifer has most often been based on equations characterising the relationship between MAL and discharge. The assumptions and limitations of these relationships are summarised in Box 1.

### **Box 1: Assumptions and limitations with Deep Reach Pool spring discharge equation**

- The model used to determine this relationship assumes that there is no barrier between the aquifer and Deep Reach Pool (SMEC 1975). However, a 1.5–2 m drop in water level between the Deep Reach Pool water level and aquifer level adjacent to the pool indicates that transmissivity is low and groundwater throughflow, while apparent, is likely to be constrained (Welker Environmental Consultancy 1998).
- The equation also assumes the rate of spring discharge is independent of the actual pool water levels. This is a limitation as the water level of Deep Reach Pool is often 0.5 m or more above the CTF, a factor which should be taken into account in spring discharge calculations.
- The equation relies on a stable cease to flow, however, due to ongoing erosion being experienced at the toe of Deep Reach Pool the cease to flow is likely to be highly variable.

The following outstanding issue has also been highlighted for consideration during development of spring discharge and pool outflow rates.

### **Outstanding issue**

1. Need to resolve cause of difference in water level between Deep Reach Pool and adjacent aquifer level (illustrated in figure 16).
4. *Develop MAL/pool outflow relationship to aid the instigation of management actions for potential breaches of pool outflow criteria.*

## Actions

The Department of Water is in the process of obtaining a more refined digital elevation model for the Millstream area. This should help resolve the apparent discrepancy between aquifer level and pool elevation. If required, additional survey points will be collected. The results of this work may lead to revision of the conceptual model of the Deep Reach Pool area's hydrogeology.

Implications of the altered cease-to-flow (CTF) level for Deep Reach Pool on spring discharge and MAL need to be considered. Previous work by Welker Environmental Consultancy (1995) will be reviewed in combination with numerical model outputs, if possible, to assess the implications of altered CTF on spring discharge.

## Provision of water to the delta

The distribution of water across the delta supports the health of the wetlands and vegetation of the area. No recent monitoring has been undertaken, so the effectiveness of criteria relating to water-flow management through the delta cannot be established. Current responsibilities and management criteria are unclear.

### ***Outstanding issues***

7. DEC's role and reporting responsibilities need to be confirmed and formalised or alternative arrangements implemented.

The contribution of subsurface flow to the delta in addition to the surface flow from Chinderwarriner Pool is poorly understood. Preliminary analyses indicate that subsurface-flow contributions could be as much as 20 per cent.

### ***Outstanding issues***

8. Develop a better understanding of the contributions made by throughflow or subsurface flow into the delta.

Anecdotal evidence suggests that pool water level and outflow also respond to abstraction from production bores at the upstream end of the pool.

### ***Outstanding issues***

2. Determine the relationship between operation of production bores and the observed drop in Chinderwarriner Pool and associated outflow rates.

## *Actions*

The following actions are required to resolve issues relating to surface-water flows within the delta:

- Review targets, monitoring and reporting arrangements for distribution of water across the Millstream Delta. DEC's involvement in the monitoring, management and reporting should be part of the review.
- Investigate further the relationship between MAL and throughflow and the contribution of throughflow to local watertables such as those in the delta. This would include looking at how the operation of production bores affects pool outflow rates.

## Salinity criteria

The interrelationships between recharge, pool and aquifer salinities for the Millstream system appear complex and poorly understood conceptually. In the past, attempts were made to examine available monitoring data and criteria were established. However, these were subject to significant debate and then dropped (although monitoring continues).

**Box 6: Assumptions and limitation on determining relationship between abstraction and salinity levels.**

- The analysis did not consider the effects of drought, which may also increase salinity by concentrating salts within the system through evapotranspiration and reduced flushing and dilution effects.
- The transport of salts into the aquifer (and subsequently Chinderwarriner Pool) due to the effects of recharge of high-salinity surface water was not considered.

**Outstanding issues**

5. Although salinity is not considered to be a high-priority issue, a general small increase in salinity in Chinderwarriner Pool and the increasing abundance of the salt-tolerant *Acacia ampliceps* indicates the need to investigate the cause and possible effect of higher-salinity trends.
6. Clarify management actions in response to breaches of this criterion.

## Actions

A review of water quality monitoring and hydrological data is required to revise our conceptual understanding of solute transport in the Millstream aquifer system. The hydrogeological model currently under construction includes a solute transport module. This should help clarify salinity trends and aid in refining salinity criteria and management.

## Aquifer decline criteria

Deriving the rate of aquifer decline and absolute aquifer decline criteria included a number of assumptions. These criteria have been subject to considerable debate. The absolute aquifer decline criterion, in particular, is a key component of the management framework for the resource, providing an absolute limit on abstraction.

**Box 7: Assumptions and limitation on determining absolute aquifer decline criteria.**

- Criterion was developed with limited knowledge of the physiology of targeted tree species.
- Does not consider other sources of water used by the vegetation such as soil and surface water.
- Does not consider the importance of other components of the hydrological regime required by the plants; such as flooding to promote *E. camaldulensis* seedling establishment.
- Does not take into account natural seasonal fluctuations in local watertable.

**Outstanding issues**

11. Reference to MAL 293.6m AHD as the long-term average needs to be reviewed. The MWMP cites a more recent investigation by Welker Environmental Consultancy (1995) on the simulated MAL from 1908 onwards. This investigation indicates that without abstraction, the MAL is unlikely to have ever been as low as 293.6 mAHD and is likely to have had a historical long-term average of 293.75 mAHD.

12. During high MAL periods, natural aquifer decline rates have been shown to exceed the short- and medium-term criteria rates during periods of low or no abstraction. Natural decline rates and decline rates under abstraction regimes need to be identified.

13. Given these criteria were originally developed to apply to local watertables rather than MAL, which they are not applied against, there is a need to review the criteria and their application.

**Actions**

A number of actions are required to revise and possibly improve the aquifer decline criteria and their application. The following actions have been identified as possible approaches:

- Outputs from the numerical model of the Millstream aquifer as well as the existing monitoring dataset will be used to revise the estimate of long-term average MAL. The applicability of these criteria in their current form will also be reviewed.
- A review of natural aquifer rate of decline data will be used to revise these criteria. This will also be aided by an improved understanding of the physiology of key vegetation and ED estimates.
- A review of decline criteria and how they relate to local watertables will be completed. The application of these criteria against MAL versus local watertable – as represented by selected reference bores – will be considered.

**Long-term monitoring program**

The current monitoring program is a result of the decisions and agreements between the lead agencies represented in the MHCC. The review has identified relative continuity in the surface-water and groundwater programs, while the biological monitoring program has changed repeatedly. The biological monitoring program is largely non-existent at present.

### ***Outstanding issues***

15. The biological monitoring program is funded by the Water Corporation and historically has been conducted by DEC. Little biological monitoring has been undertaken in recent years. A review of the program to ensure biological monitoring is informative, effective and adequately resourced is required and will be completed as part of the Department of Water's current investigations.

### ***Actions***

Changes to criteria and the management framework may require the surface-water and groundwater monitoring programs to be altered. An example of a possible change might be the return of the pool outflow point to Deep Reach Pool. The current arrangements for monitoring of surface-water flows, particularly at Chinderwarriner Pool, may also be reviewed. At present, however, the review does not recommend any immediate changes to these programs.

The long-term biological monitoring program needs to be reviewed. Indications are that the current program is insufficient to identify vegetation stress and its consequences. This is of particular concern, as the primary objective of the monitoring program relates back to protecting the environment from the adverse effects of abstraction.

### **Reporting and review**

Development of revised criteria will include revision of reporting frameworks and responsibilities.

### ***Actions***

- It is suggested that: Table 2 be included in future management plans to help formalise the reporting and reviewing responsibilities of the various agencies.
- Since the EPA has highlighted public review as a requirement, this should be included as a Department of Water or MHCC reporting responsibility.

In addition, a process to make transparent the ongoing review of management criteria needs developing. It is recommended that:

- Changes to management practices are highlighted and presented to the MHCC for discussion during the subsequent annual meeting. Any resolution that will result in changes to management should be recorded in the minutes of meeting and assigned a resolution number. At this time management practices can be formally modified and implemented.

## Outstanding management issues

This review has also highlighted the following additional outstanding issues, as detailed below.

### **Outstanding issues**

- 3. Supplementation plan remains in draft format and there is no record of it being formally adopted.
- 9. The Water Corporation should update its dataset to include missing data from December 2002, which indicates a breach of the monthly outflow criteria (for Chinderwarriner and Crossing Pool outflows).
- 14. Monitoring of additional bores along the Fortescue River recharge zone will allow for better aquifer recharge estimates.
- 16. Stratigraphy reports for the three intensive monitoring subareas remains outstanding.
- 17. Analysis of the intensive monitoring program dataset has not been undertaken.

### **Actions**

These outstanding issues will be addressed by consultation with the MHCC and the TWG.

### **Conclusions**

The current review represents completion of Stage 1 in revising the management of water abstraction from the Millstream aquifer. The review has summarised the development of previous and current ecological water requirements and other management measures.

The main purpose of the review has been to consolidate our current knowledge of the system and improve our understanding of how past management has impacted on the aquifer and the ecosystems it supports. It also serves to highlight areas where additional work is necessary to close information gaps.

Each of the information gaps or outstanding issues presented in the previous section can be broadly grouped into the following categories:

- revise ED estimates: address assumptions and information gaps to determine better ED estimates
- determine how ED is met or provided: improve our conceptual understanding of the link between the area's hydrology and the environment and how the aquifer provides ED
- review monitoring and management.

These provide the focus for Stage 2, the investigative part of the review, which aims to close the information gaps identified (Figure 27).

The output from Stage 2 will be the development of revised EWRs and a revised management framework for Millstream. This will ensure ED is met and abstraction is managed within defined environmental limits.

Stage 2, in part funded by the Australian Government's Water Smart Australia program, is to be completed by mid 2010.

The final output will be development of allocation limits and revised rules to manage abstraction, as well as revised monitoring. The allocation limit and management plan is to be completed by 2011.

As an interim measure we are also working to determine an estimate of the long term sustainable yield for Millstream. This will use the current management criteria and outputs from a numerical model of the aquifer currently being constructed. The establishment of an interim estimate of sustainable yield will provide certainty for water resource management planning whilst Stage 2 is completed.

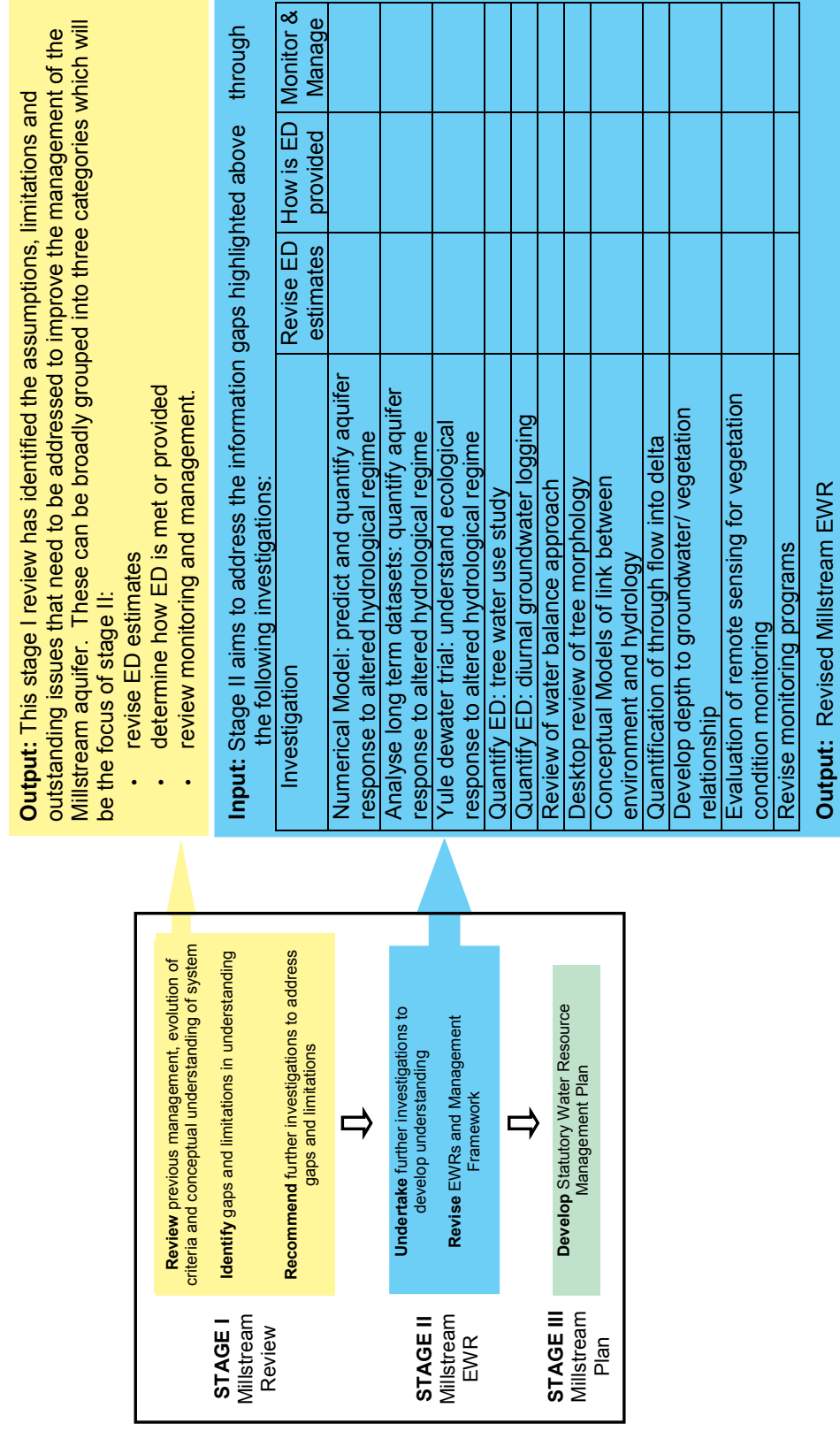


Figure 27: Outputs from the Stage 1 review will direct the Stage 2 investigations. Outputs from Stage 2 will address the information gaps, and determine a revised EWR for Millstream



# Appendices

## Appendix A. Role and terms of reference for the Millstream Harding consultative committee – under review

These terms of reference are based on documents tabled and discussed at MHCC meetings of July 1999, December 1999, with final comments incorporated from the meeting of August 2001.

1. The MHCC's role is to provide for consultation and coordination of agency activities to ensure that water abstraction for the West Pilbara water-supply scheme meets agreed environmental impact criterion and is in accordance with relevant policies, plans and legislation.
2. The committee is an advisory and coordinating committee, and is not delegated any of the statutory responsibilities of the individual agencies. The statutory relationship between the Commission and the Corporation is maintained outside the committee. The technical working group (TWG) is the operational arm of the MHCC and the committee delegates authority for collaborative decision making on operational matters to the TWG.
3. The committee's functions are to:
  - Consult and collaborate on actions required to meet the obligations under the current *Operation strategy, Environmental/water management plan, National Park management plan, Water source protection plans* and any other relevant plans.
  - Receive and review reports from the Water Corporation, WRC and CALM on the monitoring programs for Millstream and the Harding River and provide advice to the relevant decision-making authorities.
  - Provide a forum for consultation with the Aboriginal community and the wider community.
  - Following each meeting, provide a short statement to the Conservation Commission and the EPA reviewing the previous year, outlining actions planned for the forthcoming year, raising awareness of any potentially significant environmental issues, and providing recommendations.
4. The committee will **provide advice** to the Water and Rivers Commission, the Department of Environmental Protection, the Department of Conservation and Land Management and the Water Corporation (as appropriate) on:
  - The Commission's response to the Corporation's WPWSS annual statement.
  - Management of the environmental impacts of the WPWSS.
  - The implementation and review of management plans and policies relevant to the WPWSS.
  - Future development proposals and their impact on the WPWSS.
5. The committee is chaired by the Water and Rivers Commission and meets on an annual cycle one month after the Water Corporation's WPWSS annual statement is due to the Commission (31 May). TWG meetings are held monthly.
6. The committee will have a core membership, and will offer observer status to members of the public and representatives from member and other agencies. Membership comprises:
  - Conservation and Land Management Regional Ecologist
  - Conservation and Land Management Regional Manager
  - Conservation and Land Management Ranger in Charge of Millstream Chichester National Park
  - Water Corporation Infrastructure Planning Branch Manager
  - Water Corporation Operations Manager
  - Water Corporation Environmental Engineer
  - Water Corporation Water Resource Officer
  - Water and Rivers Commission Policy and Planning Divisional Manager
  - Water and Rivers Commission Regional Manager
  - Water and Rivers Commission District Manager, Pilbara
  - Water and Rivers Commission Environmental Officer
  - Pilbara Native Title Service Representative

## Appendix B. Terms of Reference for the technical working group – under review

The technical working group (TWG) evolved from the Millstream Harding water management committee meeting of November 1997. It resulted from the need to address the continuing indecision and inaction over several technical issues. Without the need for formal endorsement by the whole committee, local MHWMC members could have adequately managed these issues. The TWG would therefore provide a means to more effectively address technical issues, and have devolved responsibility for operational decision-making.

The TWG meets regularly at two-monthly intervals. Chairman duties are rotated and minutes are recorded and distributed. Composition of the TWG is as follows:

### **Water Corporation**

Service Delivery Manager, West Pilbara  
Environmental Officer, NWR  
Engineering Assistant

### **Department of Environment**

Regional Ecologist, Pilbara  
Ranger in Charge, Millstream

### **Department of Water**

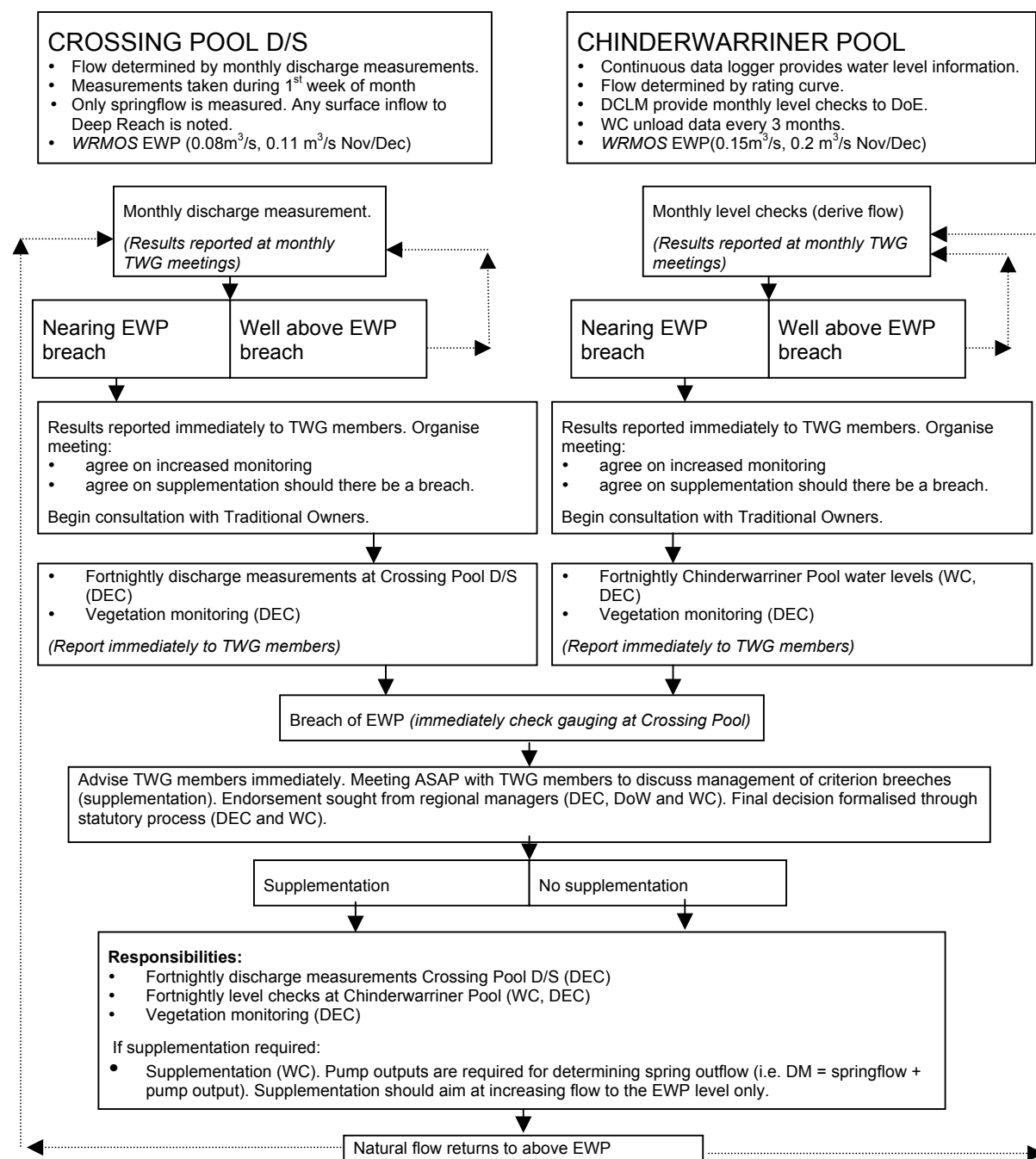
District Manager, Pilbara  
Senior Water Resources Officer

The role of the TWG is to;

- conduct environmental monitoring according to accepted monitoring programs as defined in current management plans
- decide methodology and technology required to achieve management measures to ensure management criterion is met
- implement practical solutions to technical problems and operational barriers
- recommend modification of monitoring programs due to operational constraints and/or improved knowledge of processes
- decide ideal flow distribution in Millstream and Deep Reach deltas, in accordance with management objectives, and implement mechanisms to achieve this (with ongoing monitoring of effectiveness)
- implement a program to assess the potential of, and monitor the progress of, active erosion channels.
- monitor environmental changes at agreed locations via a six-monthly photography program
- report TWG activities and progress to MHWMC at six-monthly meetings
- maintain links with Indigenous groups and the wider community by progress reporting via an agreed communication plan.

## Appendix C. Draft plan for supplementation implementation – under review

This supplementation plan outlines agency responsibilities, dissemination of information to key stakeholders (DEC, WC and the Department of Water) and provides a clearly defined process to be followed before, during and after supplementation:



## Shortened forms

CALM	Department of Conservation and Land Management
CTF	cease to flow
DEC	Department of Environment and Conservation
DEP	Department of Environmental Protection
DoW	Department of Water
EC	electrical conductivity
ED	environmental demand
PFC	percentage foliage cover
EPA	Environmental Protection Authority
ET	evapotranspiration
EWR	environmental water requirement
MAAD	minimum average annual discharge
mAHD	metres Australian height datum
MAL	meal aquifer level
MEMP	<i>Millstream environmental management program (1992)</i>
MHCC	Millstream Harding consultative committee
MMC	Millstream management committee
MMP	<i>Millstream water management program (1984)</i>
MWMP	<i>Millstream water management plan (1998)</i>
WRMOS	<i>Water resource management operation strategy</i>
TWG	technical working group
WAWA	Water Authority of Western Australia
WC	Water Corporation
WRC	Water and Rivers Commission
WPWSS	West Pilbara water-supply scheme

# Glossary

<b>Abstraction</b>	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.
<b>Aquifer</b>	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock.
<b>Cultural significance</b>	In accordance with the meaning in the Burra Charter, cultural significance means aesthetic, historic, scientific or social value for past, present or future generations.
<b>Ecological water requirement</b>	The water regime needed to maintain the ecological values (including assets, functions and processes) of water-dependent ecosystems at a low level of risk.
<b>Hydrogeology</b>	The hydrological and geological science concerned with the occurrence, distribution, quality and movement of groundwater, especially relating to the distribution of aquifers, groundwater flow and groundwater quality.
<b>Hydrograph</b>	A graph showing the height of a water surface above an established datum plane for level, flow, velocity or other property of water with respect to time.
<b>Hydrology</b>	The study of water, its properties, movement, distribution and utilisation above, on and below the Earth's surface.
<b>Karst</b>	Term used to describe landscapes that are commonly characterised by closed depressions, subterranean drainage and caves. Karst landscapes are formed principally by solution of the rock, most commonly limestone.
<b>Licence</b>	A formal permit that entitles the holder to 'take' water from a watercourse, wetland or underground source.

<b>Sustainable yield</b>	The sustainable yield is the level of water extraction from a particular system that, if exceeded, would compromise key environmental assets or ecosystem functions and the productive base of the resource.
<b>Tributary</b>	A stream, creek or small river which flows into a larger stream, river or lake.
<b>Water balance</b>	The relationship between input, storage and output within a hydrological system.
<b>Water regime</b>	A description of the variation of flow rate or water level over time.

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