WATER SUPPLY STUDY

WAGERUP REFINERY UNIT 3

for

Alcoa World Alumina Australia

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1. BACKGROUND

Prior to the commencement of construction of the Wagerup refinery in 1978 a study was conducted to examine water supply and drainage issues with the proposed refinery (Alcoa, 1977). Due to the well established drainage and irrigation network in the area and the opportunity provided by the refinery development to divert and store surface runoff water, a supply scheme was proposed which relied primarily on a number of surface catchments to supply the make-up water requirements for the initial refinery development. At the time it was suggested that a groundwater supply be developed to supplement surface sources.

In 1978 Alcoa established a network of hydrometric stations on a range of possible surface water sources to provide ongoing data such that annual yields could be established. This was done with the support of the then Public Works Department (now Department of Environment) and data were gathered for varying periods. Some of these data were used in the current assessment.

The availability of groundwater was examined and the advice of the Western Australian Government's Geological Survey at the time was that sizable high quality groundwater supplies (such as had been developed for the Pinjarra refinery) were unlikely in the Wagerup area. This was confirmed by some preliminary investigations commissioned by Alcoa (Layton Groundwater Consultants, 1980)

Apart from a small quantity of surficial groundwater extracted to manage hydrostatic pressures beneath some of the residue facilities, surface water sources have provided for the refinery's water needs over the past 20 years. Over this period the refinery has expanded from an initial alumina production level of 0.5 million tonnes per annum (Mtpa) to the current 2.4 Mtpa.

Expansion of the refinery and variable surface runoff has required Alcoa to develop a range of surface sources to meet the operational water requirements. The most recent development was a pumping station and pipeline to harvest winter runoff from the Harvey River Main Drain (called the Harvey Pumpback), which was commissioned in 2003. Short term water deficiencies, due to delays in commissioning the Harvey Pumpback and lack of fresh water storage capacity required for residue dust control sprinklers have also been met by the purchase of water from the irrigation cooperative, Harvey Water.

In 1998 the Water & Rivers Commission (DoE) prepared the Proposed Harvey Basin Water Allocation Plan to determine water availability and help manage water allocation including consideration of Ecological Water Requirements (EWRs) in the catchment.

2. STAKEHOLDER ENGAGEMENT

An intensive stakeholder engagement process has been established to facilitate the review of the Wagerup Unit Three Project. The process encourages the involvement of all key stakeholders, including the local community, Government decision makers and Alcoa. A number of focus groups have been established to address key areas of concern. One of these groups addresses issues associated with residue management and water supply. This group has provided input to and has reviewed this report.

3. PHYSICAL SETTING AND HYDROLOGY OF THE WAGERUP AREA

3.1 Location

Alcoa's Wagerup refinery and residue storage areas are located near to the eastern edge of the Swan Coastal Plain, 110 km south of Perth, Western Australia (Refer to Figure 1 – Locality Plan). The refinery facilities are located on the Ridge Hill Shelf Formation at the foot of the Darling Escarpment at a ground elevation of around 30 m AHD, while the residue areas are located some 2 km to the west on the much flatter Pinjarra Plain which has an elevation between 14 – 20 m AHD. The land to the east of the refinery is predominantly uncleared State Forest with some cleared privately owned farming blocks. To the west of the refinery the land has been almost totally cleared for agriculture.

Alcoa has acquired a land holding of around 5,000 ha to accommodate the refinery, residue areas and associated land management zones. The land which is not currently utilised for industrial purposes is utilised for beef farming, landscaping and ecosystem protection.

3.2 Climate

The Mediterranean climate of the region is characterised hot, dry summers and cool, wet winters. Rainfall data for Wagerup, outlined below is compiled from incomplete records at Waroona Post Office, Wagerup Refinery and an automated pluviograph at North Yalup Brook gauging station.
In 1977 estimated rainfall for the refinery and residue storage area was estimated to be between 1020 mm to the west to 1270 mm on the escarpment (Alcoa, 1977). More recent estimates indicate that average rainfall for the refinery site was 938 mm over the period 1977 - 2002 and that the 10 year moving average has declined from 975 mm in 1987 to 852 mm in 2003 (Nield, 2003). Rainfall in 2001 was only 587 mm, which is the lowest on record for the Wagerup area.

3.3 Soils

The surficial soils in the region are very variable from freely draining sand to very low permeability clay. The soils of the Yoganup Formation beneath the refinery are sandy and include the mineral sand deposits that are being progressively mined to the north and south of the refinery site. The soils of the Guildford Formation that underlie the residue areas are lower permeability clays and sandy clays.

3.4 Surface Hydrology

The Wagerup refinery area is within the lower reaches of the Harvey River catchment. The section of the Harvey River as well as its feeder streams that traverse the Pinjarra Plain have generally been highly modified into trapezoidal drains. The Harvey River Main Drain lies approximately 4 km to the west of the current residue areas and flows in a north-westerly direction to discharges into the Harvey Estuary. The natural hydrology of the lower Harvey River catchment was comprised of streams draining relatively small catchments from the escarpment onto the plain and thence to the Harvey River. The natural hydrology of the area was highly altered in the early 1900's due to the development of the irrigation and drainage systems servicing agricultural developments around the towns of Harvey and Waroona. A number of dams have been constructed within the larger Darling Range catchments to retain winter runoff for summer irrigation use and the watercourses on the Plain have been modified or replaced by constructed channels to distribute irrigation water and improve winter drainage.

Even though the Harvey catchment has been highly altered by the construction of irrigation water dams and irrigation and drainage systems it is estimated that the current runoff into the Harvey Estuary is 25 – 50% higher than it would have been under pre-European conditions. Runoff from the Plain is estimated to be about 300% greater reflecting the extensive clearing of native vegetation that took place for agriculture (Water and Rivers Commission, 1998).

In more recent times, declining trends in rainfall have been accompanied by a reduction in surface runoff, especially from the Darling Range sections of the catchment. Water and Rivers Commission (WRC, now part of Department of Environment; DoE) suggest that a decline of 10% in average annual rainfall over the last 20 years has resulted in a 20 -40% decline in surface runoff (WRC, 1998).

3.5 Groundwater Hydrology

The superficial soils beneath the refinery and residue areas contain groundwater which flows generally in a westerly direction. Groundwater flow velocities in the Yoganup Formation are higher due to higher permeability and steeper gradients, water quality is good due to local recharge. The Guildford Formation soils underlying the residue areas also contain groundwater of limited quantity and variable quality. Deeper sediments of the Leederville formation underlie the Guildford Formation beneath the residue areas and the groundwater may be artesian or subartesian. However bores into these strata are likely to be low yielding and brackish (Layton Groundwater Consultants, 1980).

Surface and subsurface hydrology of the area is illustrated in Figure 2.

4. EXISTING DEVELOPMENT OF WATER RESOURCES

The water resources within the region are utilised for irrigated agriculture, public water supply and industrial use. The construction of the new Harvey River Dam in 1998 resulted in a detailed review of water resource utilisation and the development of the Harvey Basin Surface Water Allocation Plan by the WRC (DoE) who recognise that there is potential for 'strong resource competition' within the Harvey River Basin (WRC, 1998).

The primary water use in this area is for irrigated agriculture. There is a bulk water allocation from dams within the Harvey Basin of around 80 GL for agriculture. There is also an increasing use for public water supply with the extension of the Water Corporation's Perth water supply network to the new Harvey Dam. The current bulk water allocation for public water supplies is around 40 GL. Licensed allocation for industrial use is currently around 10 GLpa.

Local community water supplies are typically sourced from relatively small catchment dams located on perennial streams in the Darling Scarp close to the communities. These schemes are operated by Water Corporation.

5. WATER RESOURCE MANAGEMENT FRAMEWORK AND POLICIES

The WRC (DoE) is the custodian and regulator of the State's water resources. WRC operates under *The Water and Rivers Commission Act* (1995). In the past water allocation has been dealt with under the *Rights in Water and Irrigation Act (1914)* however in recent years water resource regulation has been influenced by reforms proposed by the Council of Australian Governments (COAG). Western Australian water regulations and management plans are being amended to meet the COAG agenda including most notably the recognition of the need to provide for ecological water requirements (EWRs). This subject is dealt with in detail in CENRM, 2005 (Appendix A).

6. EXISTING REFINERY WATER SUPPLY ARRANGEMENTS

Wagerup refinery is almost totally dependent on surface water sources to provide for process make-up water. This contrasts with the Kwinana and Pinjarra refineries which rely heavily on groundwater supplies. The recent approved expansion at Pinjarra has resulted in in-principle agreement between Alcoa and the Water Corporation to use treated sewage effluent from Mandurah to fulfil the expansion water requirements. This will be delivered via a 25 km long pipeline.

The catchments that provide water for Wagerup refinery include the refinery and residue storage areas and surrounding land including Darling Range and agricultural catchments. These sources are shown schematically on Figure 3 and can be identified in Figure 1.

Rainfall runoff primarily occurs during the months of April – September so storage facilities are provided to store the runoff for year round use by the refinery. Surface runoff is highly dependent on weather conditions and may vary by orders of magnitude depending upon the intensity, frequency, duration and pattern of rainfall. As the refinery has expanded surface water harvesting and storage facilities have been constructed to meet the water supply needs.

Apart from rainfall and runoff from the fully controlled catchments of the refinery and residue areas, Wagerup Refinery's current water needs are provided from the following licensed sources.

Table 6.1 Licensed Water Sources

SOURCE	Licensed Amount (MLpa)
North & South Yalup Brooks	1,600
South Samson Diversion Drain (includes Black Tom Brook	2,500
Harvey River Main Drain	4,400
Surficial Groundwater	550

7. WAGERUP REFINERY WATER CONSUMPTION AND SUPPLY

Alumina refining is a hydro-thermal process in which an alkaline solution (referred to as process liquor) is used to transport bauxite as a slurry, extract alumina into solution (digestion) and then crystallise it out as hydrated alumina (precipitation), and transport bauxite residue to long term storage areas. The hydrated alumina is subsequently calcined in a high temperature thermal process following the removal of most of the liquor. Temperature of the solution is the main controlling mechanism in the extraction and crystallisation processes and the energy efficiency of the process is determined by the transfer of heat from the crystallisation (and calcination) processes to the extraction circuit. The water requirements of the refinery are dictated by the configuration of these processes and in particular the energy management practices.

Alcoa's refineries in Western Australia were designed to maximise the recycling of process and other water collected within the refinery and residue areas to the extent that process and cooling effluent discharge is not required. This water conservation philosophy was adopted in recognition of the prevailing climate, which results in a relatively high net evaporation, limited availability of fresh water resources and the environmental issues raised by effluent discharge.

It is hard to compare alumina refineries in different parts of the world due to the range of process conditions that apply to different bauxites, differing fuel sources and climatic factors. However, Alcoa's Wagerup refinery is the most energy and water efficient in the Alcoa system and possibly in the world.

Water consumption in the refining process is dominated by evaporation losses associated with the:

- final cooling of process liquor to enable the crystallisation of alumina to be optimised;
- evaporation of stored fresh water;
- evaporation of process liquor storages and tanks;
- vapour released during the drying and calcination of alumina;
- moisture retained in the residue; and
- water used for dust control within the residue storage areas.

Annual water consumption is primarily determined by the process conditions and is largely independent of prevailing weather conditions. Summer conditions that dictate the amount of water used for residue dust control for instance are reasonably predictable. (Annual gross evaporation rates only vary by around 10% whereas annual rainfall may vary by up to 50% and runoff by several hundred percent).

Alcoa has developed a water balance model for each refinery which allows prediction of water consumption and supply requirements under varying process and weather conditions. These balances are actively used by refinery staff in decision making regarding water supply and storage requirements. The refinery water circuit is shown schematically in Figure 3.

The Wagerup Water Balance Model has been used to predict water consumption and supply for the existing refinery and for the expanded refinery for a range of weather conditions.

Case A below summarises refinery consumption and supply in average rainfall and runoff years.

Table 7.1 Refinery Water Consumption and Supply
CASE A – Average Rainfall/Runoff Conditions

Refinery Water Consumption

	Current Refinery (2.35 Mtpa) (MLpa)	**Future Refinery (4.7 Mtpa) (MLpa)**
Evaporation Losses from Fresh Water Surfaces	1,400	2,000
Evaporation Losses from Liquor Surfaces	1,000	1,300
Moisture lost with Stored Residue	2,400	4,500
Cooling Evaporation from Liquor Ponds	730	900
Vapour losses from in- plant processes & vessels (including cooling towers)	1,730	2,700
Residue Dust Control Sprinklers	2,200	3,500
Total Consumed	**9,460**	**14,900**

Refinery Water Supply

	Current Refinery (2.35 Mtpa)	**Future Refinery (4.7 Mtpa)**
Moisture with Bauxite & Reagents	1,000	1,890
Rainfall collected in Fresh Water Reservoirs	700	1,000
Rainfall Runoff from Plant Area	270	270
Rainfall Runoff & Drainage from Residue & Liquor Pond Areas	2,390	3,330
Surface Water Sources (Licence)		
- Nth & Sth Yalup Br (1,600 MLpa)	1,200	1,200
- Black Tom Br (2,500 MLpa)	1,500	1,500
- Harvey R Main Drain (4,400 MLpa)	2,100	4,300
Groundwater (550 MLpa)	300	300
Additional Sources (as identified in this study)		**1,110**
Total Supplied	**9,460**	**14,900**

Case B below summarises refinery consumption and supply during dry rainfall and runoff years (based upon 2001 which was the lowest rainfall (and runoff) year in 25 years of records for the Wagerup locality)

Table 7.2 Refinery Water Consumption and Supply
CASE B – Dry Rainfall/Runoff Conditions (Based on driest year on record - 2001)

Refinery Water Consumption

	Current Refinery (2.35 Mtpa) (MLpa)	**Future Refinery (4.7 Mtpa) (MLpa)**
Evaporation Losses from Fresh Water Surfaces	1,400	2,000
Evaporation Losses from Liquor Surfaces	1,000	1,300
Moisture lost with Stored Residue	2,400	4,500
Cooling Evaporation from Liquor Ponds	730	900
Vapour losses from in- plant processes & vessels (including cooling towers)	1,730	2,700
Residue Dust Control Sprinklers	2,200	3,500
Total Consumed	**9,460**	**14,900**

Refinery Water Supply

	Current Refinery (2.4 Mtpa)	**Future Refinery (4.5 Mtpa)**
Moisture with Bauxite & Reagents	1,000	1,890
Rainfall collected in Fresh Water Reservoirs	500	680
Rainfall Runoff from Plant Area	180	180
Rainfall Runoff & Drainage from Residue & Liquor Pond Areas	1,420	1,980
Surface Water Sources (Licence)		
- Nth & Sth Yalup Br (1,600 MLpa)	200	200
- Black Tom Br (2,500 MLpa)	800	800
- Harvey R Main Drain (4,400 MLpa)	4,400	4,400
Groundwater (550 MLpa)	300	300
Additional Sources (as identified within this study)	**660**	**4,770**
Total Supplied	**9,460**	**14,900**

8. IDENTIFICATION AND PRELIMINARY ANALYSIS OF WAGERUP UNIT THREE WATER SUPPLY OPTIONS

A range of options for additional water supplies for the expanded Wagerup Refinery have been identified through consultation with a range of stakeholders, including Alcoa staff, local community representatives consulted during the Pinjarra Optimisation consultation and more recently the Wagerup Expansion Stakeholder Consultation Process, Harvey Water, WRC (DoE) and Department of Agriculture.

The water supply options identified include groundwater, surface water and recycled water sources as described below and as summarised in Table 8.1.

8.1 Shallow Groundwater

The hydrogeology of the Wagerup area has been well characterised through the numerous investigations that have been carried out since before the refinery was built . Shallow groundwater flows in a westerly direction and is good quality. The estimated throughflow of the more permeable superficial formations has been estimated at around 400 MLpa per km width in a North South direction (Alcoa, *pers. comm*.). This means that a dispersed well network would be required to harness a large water supply. Alcoa currently holds an extraction licence for up to 550 MLpa to allow the operation of depressurising bores around some of its residue facilities. The use of these bores is minimised in line with their depressurising role and a water volume of 250 MLpa is more representative of their operation. Alcoa consider it undesirable to expand pumping of shallow groundwater in the area as the associated decline in water levels could accelerate seepage from residue areas and impact on other nearby users (Alcoa, *pers. comm*.).

8.2 Deep Groundwater

The region along the Darling Range has complex deep hydrogeology due to faulting. At Pinjarra, Alcoa established a major groundwater supply from the Cattamarra Formation at a depth of around 100 – 200 m which has served the refinery well. In the hope that a similar resource might exist at Wagerup, Alcoa undertook a preliminary investigation of groundwater potential in 1979-80 which included the drilling of two exploratory wells to depths of 300 - 400 m. Low permeability strata and brackish groundwater were encountered and it was concluded that a suitable groundwater resource was not likely to exist in the area (Layton Groundwater Consultants, 1980).

8.3 Harvey Main Drain – Increased Pumping from Existing Pump Station

Alcoa currently has a licence to draw up to 4.4 GLpa from the Harvey River Main drain during the winter period of May to October. The existing pump station and pipeline has the capacity to recover this amount of water so long as the flow in the drain exceeds 100 MLpd for at least 100 days per year.

A study by CENRM suggests that up to 28 GLpa of additional water may be available at the Pump Station location which is well in excess of the Wagerup Unit Three requirement of 4.7 GLpa.

8.4 Winter Flow Harvesting from Other Agricultural Drains

The WRC (1998) recommend that local runoff and drainage water be utilised and that the creation of in-stream and wetland habitat be encouraged.

The harvesting of winter runoff is further supported by work conducted by the Western Australian Department of Agriculture on behalf of the Harvey Water Cooperative which shows that almost 90% of the nutrient flow into the Harvey Estuary occurs with winter runoff. (Rivers, Clarke and Calder, 2003).

There are a number of drains in the area which transmit enough flow during the winter months to provide Alcoa’s additional water needs. These include Samson North Drain and Samson South Drain (CENRM, 2005). It is possible that one or more of these sources could be developed in a way that meets both of the above WRC objectives.

8.5 Other Darling Range Catchments

While there are several sources of high quality water from Hills catchments such as Bancell, Clarke and McKnoe Brooks that could be developed to meet the refinery’s additional water needs, it is unlikely that the WRC would support the development of these sources due to ecological considerations (WRC, 1998; CENRM, 2005).

8.6 Murray River

The Murray River represents a major potential water source in the Pinjarra/Waroona area. Unfortunately agricultural land development in the catchment has resulted in a deterioration of water quality. If Murray River water was to be utilised by the refinery it would require desalination to reduce dissolved salts to an acceptable level. A 16 km long pipeline would be required to deliver treated (or untreated) water to the refinery, and a 17 km long pipeline for the discharge of more saline blowdown water to the Murray River below Pinjarra or to the Harvey Estuary. Based upon studies that were completed for the Pinjarra Optimisation project a preliminary cost estimate of $60M was established for this scheme, this capital cost is prohibitive for the amount of water involved.

Approval of pipelines and effluent discharge could also be problematic.

8.7 Use of Excess Alcoa Farmlands Irrigation Water Entitlement

Alcoa Farmlands has an irrigation water entitlement of > 6 GLpa and in recent years have utilised around 2.5 GLpa.

A temporary trade of 2 GL is being explored by Alcoa through Harvey Water and Water Corporation for use by Pinjarra refinery while a treated effluent pipeline from Mandurah is constructed.

The WRC (1998) supported the trading of surplus irrigation water to industrial use. Considering that the water should be available without threat to existing irrigation, it would be within Alcoa's overall entitlement, the water would be used to create value in the local area and would generate additional income for the water service providers then it may be worth pursuing. There may be resistance from the farming community (and Harvey Water Cooperative) as transfer of irrigation water to other uses is seen as a threat to the future of irrigated agriculture in the area.

8.8 Irrigation Efficiency Water

It has been estimated that improvements to Harvey Water's water distribution system as well as on-farm improvements to irrigation water application practices could result in water savings of more than 45 GLpa. It is unlikely that the capital required to effect these improvements will be funded through agricultural tariffs but rather through Government grants and commercial arrangements whereby the water savings are made available to other higher value uses such as public water supplies or industry. It is understood that negotiations are taking place between Harvey Water and Water Corporation to take advantage of the efficiency savings that have already been made.

There may be an opportunity for Alcoa to gain access to some of this efficiency water through a commercial arrangement with Harvey Water.

8.9 Seawater

A stand-alone 5 GLpa desalination plant located near to the ocean at Lake Clifton would require a 28 km long pipeline to transmit desalinated water to the refinery . Estimated capital cost would be around $70M and operating costs could be expected to exceed $1.50 per KL. This cost is considered prohibitive for the amount of water involved.

8.10 Wellington Dam Saline Water

A company called Agritec have developed a proposal to treat around 40 GL of brackish water that is released from Wellington Dam each year and sell it for public water supply purposes. A supply cost of less than $1/KL has been quoted. In addition to a smaller scale treatment plant which would incur operating costs above $1/KLpa pipeline to deliver this water to Wagerup would be 45 km long. Total estimated capital cost would be around $70M. This cost is considered prohibitive for the amount of water involved.

It is understood that there is uncertainty regarding the future release of water from Wellington Dam.

8.11 Treated Sewage Effluent from Local Communities

It is possible that treated sewage effluent from nearby communities such as Waroona or Harvey could be pumped to the refinery and utilised in the process water circuit. A precedent for this exists at Pinjarra, however the close location of Water Corporation's Pinjarra Wastewater Treatment Plant to Alcoa's Pinjarra refinery makes this feasible. At Wagerup an 8 km long pipeline with an estimated cost of $2M would be required to deliver the water to the refinery from Waroona and a 18 km long pipeline with an estimated cost of $3.5M for Harvey. Considering that the amount of water available pumping the water over such long distances is not considered practicable.

8.12 Treated Sewage Effluent from Mandurah

Alcoa is negotiating with Water Corporation over the construction of a pipeline to transmit up to 2 GLpa of treated wastewater from Mandurah's Gordon Road treatment plant to the Pinjarra refinery. The current water availability from Gordon Road is just over 2 GLpa and this is expected to grow at a rate of 6% pa (Kellogg Brown Root P/L, 2004). In the event that Pinjarra doesn't require all of the water in future, the excess could be pumped to Wagerup. A 36 km pipeline and possibly two pump stations would be required at an estimated capital cost of $36M. This cost is considered prohibitive for the amount of water involved.

8.13 Water Corporation

Water Corporation's Perth integrated supply network was extended in 1999 to connect to the new Harvey Dam. A 5 km long spur line could be constructed to allow Water Corporation to supply water to the Wagerup refinery. The water would be treated and presumably would attract a cost similar to other users of around \$0.70 - \$1.00 /KL.

During periods of drought, conflict between supplying Alcoa or the public could arise.

Each of these sources has been evaluated from an environmental, social and economic standpoint. Table 8.1 summarises the findings relating to these sources.

Table 8.1 Preliminary Water Supply Options Analysis

OPTION	SOURCE	Quantity (GL) *(Note 1)*	Quality *(Note 2)*	ENVIRONMENTAL ASPECTS		SOCIAL ASPECTS		ECONOMIC ASPECTS				
				Environmental Impacts	**Env. Approval/Licensing**	**Possible Impacts on Other Water Users**	**Community Acceptance** *(Note 3)*	**Capital Cost ($M)** *(Note 4)*	**Operating Cost ($/KL)** *(Note 4)*	**Impact on Alumina Production**	**Specific Source Issues**	**Recommended for Further Consideration**
1	Groundwater from local superficial aquifers	>1	Good	Possible drawdown of local water table, limited availability	Difficult as current allocation near to sustainable yield.	Could result in lowering of GWT – may have positive benefits to irrigation, or negative impacts on other users of shallow groundwater.	Unknown	Bores & Piping - $2M	$0.20	Nil	Resource largely allocated. Drawdown beneath residue areas undesirable. Could improve irrigation waterlogging problem	No
2	Groundwater from deep aquifers	Unknown	Marginal	Low	Will require major investigation	None if allocation is below sustainable yield	Low	Bores & Piping - $5M, Treatment (if req'd) - $20M	$0.20 - $1.50	Nil if treated	High uncertainty until investigated. Public acceptance of groundwater use is low (e.g. Yarragadee)	No unless other options unacceptable
3	Increased winter runoff harvesting from existing Harvey Main Drain pumping station	A further 5 GL	Good	Low, so long as total abstraction is less than sustainable yield. Reduced nutrient runoff into Harvey Estuary.	Increase in licence can be justified. Proposed Harvey Basin Surface Water Allocation Plan supports use of this source.	None if increased allocation is below sustainable yield	Moderate	Pumping Upgrade - $2M, Storage - $25M	$0.20	Minor if quality maintained	May not yield adequate water during droughts	Yes
4	Winter runoff harvesting from other agricultural drains in the area	5	Good	Low, so long as total abstraction is less than sustainable yield	Additional licence required. Proposed Harvey Basin Surface Water Allocation Plan supports use of this source.	None if increased allocation is below sustainable yield	Moderate	Pumping & Pipework - $5M, Storage - $10 - 20M	$0.20	Minor if quality maintained	A number of other drains to the north of the current Harvey Main Drain Pump Station could be harnessed such as Samson South Drain, Samson North Drain or Waroona Main Drain	Yes
5	Increased winter runoff harvesting from local Darling Range systems	5	Good	Ecological Water Requirements of streams may exclude use.	Difficult. Proposed Harvey Basin Surface Water Allocation Plan does not support further allocation.	Reduced higher quality environmental flow in streams and drains.	Low	Minor upgrade to diversion structures & Pumps <$2M, Storage $10 - $20M	$0.20	Nil	Unlikely to get increased allocation	No
6	Murray River	5	Poor	Treatment required. Pipelines and discharge of higher salinity blowdown are issues	Allocation shouldn't be an issue, but permits for pipeline and effluent discharge will be difficult.	Nil	Unknown	Pumping, pipelines & desalination plant - $60M	$1.50	Nil if treated	Very expensive, effluent discharge a problem	No
7	Utilising Surplus Alcoa Farmlands Irrigation Water Entitlement	2	Good	Low	Supported by Harvey Basin Surface Water Allocation Plan however Harvey Water Co-op may oppose transfer of water from agricultural to industrial use.	Irrigation community may not support transfers away from agricultural use	Low - Unknown	Minor modifications to supply system to allow release of water during irrigation season to refinery system. Cost $0.5M.	Industrial water charge	Nil	Probably consistent with future water trading objectives (trade to higher use) but resistance likely from irrigated farming community. In long term may compete with public water supply demand.	Yes
8	Irrigation water gained through efficiency measures	5	Good	Reduced losses from irrigation system.	Should have strong Gov't and Harvey Water Coop support. Special agreement would be required to secure allocation.	May end up competing with Water Corp for Perth supply	High	Investment in efficiency measures. Say $3M/Gl	Discounted industrial water charge	Nil	Strong water conservation case in the broad sense. May be difficult securing guaranteed allocation. In long term may compete with public water supply demand.	Yes
9	Seawater	5	Poor	Pipeline impact. Energy/Greenhouse	Long pipelines & issues associated with saline effluent discharge.	Nil	Unknown	Alcoa owned and operated desalination plant. Pumping, pipelines & plant $70M	>$1.50	Nil if treated	Assumes desalination plant near to intake, with direct return of effluent water. Treatment plant & pipeline site selection & environmental approval may be difficult.	No
10	Wellington Dam saline water	5	Poor	Greenhouse emissions	Long pipelines & issues associated with saline effluent discharge.	Nil	Unknown	Alcoa owned and operated desalination plant. Pumping, pipelines & plant $70M	>$1.50	Nil if treated	Assumes treatment plant at Collie River, SW Highway X'ing with direct return of effluent water to river. Treatment plant, pipeline route & effluent discharge approval may be difficult. Source depends upon future operating strategy & condition of Wellington Dam.	No
11	Treated effluent from Waroona/ Hamel Harvey/ Yarloop townsites.	<0.3	Good	Positive impact – reduced nutrients in catchment	Supply agreements with Water Corp. Long pipelines. Disinfection would be required for use in dust control sprinklers.	Nil	High	Pumps, pipelines & disinfection $6M	$0.40	Negligible if treated	Minor source. Expensive due to pipelines. Other community benefits need to be considered. Timeframe	No.
12	Treated effluent from Mandurah (via Pinjarra)	>1	Good	Help achieve recycle goals & reduce impacts of current effluent discharge	Should have strong Gov't support. Pipeline access may be simplified by co-location with water Corp Harvey Dam pipeline.	May create competition for available water. Need to overcome negatives associated with using treated effluent.	High	Pumping, pipelines $36M	$0.50 Not including capital amort.	Disinfection may be required if used for dust control.	Very expensive water. Possible supply conflicts between PJ & WG and other users. Timeframes and water availability.	No
13	Scheme water	5	Good	Low	Would require supply agreement with water provider	Public acceptance of scheme water for industrial use would be low. Exasperated during periods of drought	Low	Pipeline $5M	Industrial water charge	Nil	Could be in direct competition with public water supply during drought periods.	No

NOTES:

Note 1 - WG 3 will require an additional 4 - 5 GLpa of makeup water based upon current estimates

Note 2 - Water quality is in respect of use for the alumina refining process and refers primarily to total dissolved salt content (<1000 ppm - good, >3000ppm - poor)

Note 3 - Expected community acceptance based upon past feedback from members of the Wagerup and Pinjarra communities.

Note 4 - Capital and operating cost estimates are indicative only and are based upon past work.

9. WATER CONSERVATION OPPORTUNITIES

Alcoa developed a Water Conservation strategy in 2001 in recognition of the growing concerns about water in the community (Alcoa, 2001). This strategy was shared with external stakeholders including key Government personnel and community consultative networks. The strategy recognises that with the current refinery configuration and without major capital investment there are no opportunities to significantly reduce total water consumption. The strategy calls for a reduction in the use of high quality (potable) water supplies in competition with other users. Initiatives such as the recycle water pipeline for Pinjarra and the Harvey Drain Pumpback at Wagerup are believed to be consistent with this strategy.

As mentioned in Section 7 the Wagerup refinery was designed to recycle process and runoff water in recognition of the climate, fresh water availability and environmental factors associated with effluent discharge. This means that opportunities to reduce water consumption without major process and equipment modifications are limited. Never the less a range of water conservation opportunities that involve Alcoa's presence in the Wagerup area have been identified.

9.1 Process Options

Increase Vapour Recovery :

Vapour discharges from refinery processes form visual plumes during cold weather and may contain traces of organic compounds that result in odour impacts within the refinery and also within the surrounding community. Over the last few years the refinery has embarked on an odour reduction program that has included facilities for capturing vapour and condensing it. So long as the heat in the condensate is utilised by the process as against discharge to other evaporative cooling circuits then the condensate represents a net saving of water. In 2002 a condenser was added to capture vapour released from the digestion process which is estimated to save 250 ML of water per annum.

The largest source of vapour discharged by the refinery is from the calcination process. Studies have been conducted on condensing this vapour mainly for odour control reasons however the huge flow volumes, unfavourable process conditions due to the presence of combustion products, difficulty in identifying a practical alternative heat sink (e.g. ocean, or air), as well as the high capital and operating cost of condensing and heat transfer equipment currently renders this option unfeasible.

Alternative Cooling Equipment:

Another large source of vapour emissions are the cooling towers which are used to cool process liquor within the precipitation stage. Alternative equipment to cooling towers are being assessed for the Wagerup Unit Three Expansion. The equipment is called a Fin Fan cooler and utilises air as a sink for reject heat in a similar way to an automobile's cooling system. It has been estimated that if this technology is incorporated into the Wagerup Unit Three Expansion it will save around 300 MLpa of water.

Reducing Residue Dust Control Irrigation Water:

Sprinkler irrigation is the method used to control dust emissions from residue areas during dry, windy conditions. Neighbour concerns at Wagerup have resulted in a more conservative approach to sprinkler system use which has increased water consumption in recent years. A project is underway at Wagerup to progressively improve the coverage of sprinklers under all wind conditions and also to increase control system flexibility. It is expected that this project will result in more efficient use of the available water and possibly an overall reduction in the amount required.

Covers on Water Storage Facilities:

Net evaporation losses from fresh water storage facilities such as dams, amount to around 1m over the whole surface area each year. Alcoa currently operates two such facilities, Upper Yalup Dam and the Samson South Drain Detention Pond with a combined total area of 50 ha, so the net annual loss from these facilities amounts to 500 MLpa. Residue area expansions and the Wagerup Unit Three Expansion will require additional fresh water storages of a similar surface area which will double the water storage evaporation loss.

There are relatively new high density polyethylene products that are being used to construct floating reservoir covers. These and earlier geomembrane floating covers have been installed on ponds and dams with surface areas up to a few hectares, but their performance on larger water bodies is unknown. Of particular concern is the potential for damage caused by strong winds that are common in the Pinjarra and Wagerup areas.

9.2 Non-Process Options

Alcoa Farmlands On-farm Irrigation Efficiency Water

Alcoa Farmlands has an irrigation allocation of around 6 GLpa. Current utilisation is around 2.5 GLpa. It is estimated that improvements to the on-farm water distribution and control systems could improve water use efficiency by around 20-30%. A recent study (Alcoa, 2004b) estimated that improvements to the existing flood irrigation system could cost >$5,000/ha while more efficient water application techniques such as centre pivot irrigators could add a further $300,000/ha. Assuming a water saving of 2.5 ML/ha (30% of a typical water application rate for dairying), a capital cost for on-farm irrigation efficiency improvements of around $2M/GL is estimated.

It is unlikely that these costs could be justified for the current extensive beef farming operation, however higher return farming options could be considered or the water saved traded to another user. This option is covered in greater detail in Section 10.

Harvey Water Off-farm Irrigation Efficiency Water

Losses from the irrigation water distribution system between the storage dams and the farm have been estimated to be as high as 30% (AgWA, *pers. comm*.). Therefore the 6 GL that is allocated to Alcoa Farmlands may have a corresponding 3 GL of transmission losses associated with it. From studies and recent improvement projects undertaken by Harvey Water it is estimated that distribution system improvements cost on the order of $2M - $4M/GL.

The water saved could be traded to another user to recovery the investment. This option is covered in greater detail in Section 10.

Community Water Use

Local Governments within the Peel Region have initiated a Water Campaign aimed at reducing community water consumption. Alcoa could actively support this campaign particularly through its workforce and contractors who represent a significant sample of the community.

Table 9.1 provides a summary of these opportunities as well as their environmental, social and economic aspects.

Table 9.1 Wagerup Refinery Future Expansion - Water Conservation Opportunities

Option	Outcome	Approx Water Saving (MLpa)	Environmental Aspects	Social Aspects	Economic Aspects	Main Issues	Recommendations
Process Related							
Vapour Condensation Recovery	Reduced Refinery Cooling Evaporation Losses	500 – 2,000	Reduce visible plumes. Alternative heat sink may have impacts eg pipelines Air cooling requires higher electricity consumption with corresponding energy/greenhouse impacts. Potential for increased noise emissions from fans.	Positive	Large scale vapour capture on calciners prohibitively expensive (>$50M per calciner)	Digestion vapour condenser saved 250 MLpa. Air cooling instead of cooling towers for WG3 will save 300 MLpa. Large scale vapour capture from calcination not practicable at present.	Assess air cooling option for broader application. Carry out periodic refinery water audits with an emphasis on vapour loss and opportunities for heat recovery & water savings.
Non-evaporative Cooling eg: Fin fan coolers	Reduced Refinery Cooling Evaporation Losses	300	Reduced visible plumes and other emissions from cooling towers.	Positive	Under examination for WG3		Include in WG3 if practicable.
Upgraded Sprinkler and Met system	Reduce Residue Dust Control Water Consumption	1000 – 2,000	Experience at Pinjarra suggests dust control should be achieved with lower water application.	Concern about greater risk of dust emissions	Depends upon capital investment in sprinkler systems improvements over several years.	Greatest potential to reduce fresh water consumption.	Implement planned project to improve dust control system to practically minimise fresh water consumption.
Covers on water storage areas	Reduce Evaporation loss from fresh water storage reservoirs (WG3 total 100Ha)	500 – 1,000	Negative impact on wildlife use due to loss of surface area and oxygen depletion. Aesthetic considerations	Unknown	Capital expenditure $10 -20M Maintenance Costs Unknown	Large scale floating covers unproven in strong winds. Possible water quality issues due to oxygen depletion.	Consider for detention pond and any new water storages to more accurately assess ESE factors
Non-process Related							
Alcoa Farmlands On-farm Irrigation Efficiency Water	More efficient use of Irrigation Water	1,000 – 2,000	More efficient use of valuable high quality water resource. Reduced water logging and salinity.	Positive	On- farm Improvements $2M/GL Therefore Capital expenditure $2 - 4M	Based on Alcoa allocation 6 GLpa, current use 2.5GLpa. Capital return for beef production unlikely. Consider higher value adding land use options. More flexible licensing to allow transfer to refinery use if required.	Recommended for further consideration for future refinery water supply

Option	**Outcome**	**Approx Water Saving (MLpa)**	**Environmental Aspects**	**Social Aspects**	**Economic Aspects**	**Main Issues**	**Recommendations**
Harvey Water Off-farm Irrigation Efficiency Improvements	Reduce water losses from off-farm Irrigation distribution system (to Alcoa Farmlands & other users).	+2,000	More efficient use of valuable high quality water resource. Reduced water logging and salinity.	Positive	Off-farm Improvements $3 - 4M/GL	Investment would need to be justified in water supply concessions or long term contract to obtain water for refinery if required.	Recommended for further consideration for future refinery water supply
Community Water Consumption	Support Local Government Environmental Initiatives Water Campaign to reduce community water consumption.	100	Increase awareness of water related issues – resource use, recycling, ecological water requirements.	Positive	Publicity and possibly incentives related expenditure	Greatest potential for water conservation is private water use. Alcoa could offer incentives for employees /contractors to adopt Water-wise behaviour.	Alcoa (Western Australian Operations) should pursue opportunities to support the Water Campaign.

10. FURTHER DISCUSSION OF PREFERRED WATER SUPPLY OPTIONS

10.1 Harvey River Main Drain

Alcoa has a licence to extract up to 4.4 GLpa from the Harvey Main Drain using a pumping station located at the confluence with Logue Brook Drain. Water is pumped from the Drain to off-stream storage reservoirs located within the residue complex (refer Figure 1). The infrastructure was established in 2003 and water harvesting commenced in 2003 when 900 ML of water was recovered and continued during winter 2004 when 1,500 ML was recovered.

These volumes are less than the licensed amount due to delays in commissioning the pump station in 2003 and relatively good runoff from other sources during winter 2004.

The pumping station draws directly from the drainage channel when flow exceeds a defined minimum. There is no detention storage provision which means that the amount of water harvested is determined by the pumping rate and the time interval that the flow exceeds the minimum. Historical flow data for the period 1978 - 86 from a gauging station on the Harvey River Main Drain at the Bristol Road crossing was used to estimate the days when flow was above the minimum and to calculate the required capacity of the pumps.

The available data suggests that there should be ample flow in the Harvey River Main Drain at the pump station to sustain a higher rate of harvesting. However, the amount of water that can be intercepted by a certain sized pumping station over a specific period can only be estimated with up to date continuous flow data. Additional monitoring will therefore be required to provide data for expansion of the pumping station. It is understood that Alcoa has installed a stage height recorder downstream of the pump station which will provide the required information.

10.2 Other Local Drains

There are other drains in the area which could be utilised to harvest winter flow to supplement the Harvey Drain source. These include South Samson Drain, North Samson Drain, and Waroona Main Drain.

The Proposed Harvey Basin water Allocation Plan supports the development of water supplies that utilise agricultural drainage water rather than Hill's runoff. Most of the larger drains in the area carry a combination of Hill's runoff and agricultural land drainage water. A harvesting system that intercepts one or more of these drains during the high rainfall period, such that the flow can be pumped to storage is feasible. Figure 1 shows a number of the drains that could provide additional water.

By way of example, Samson North Drain, where it intersects Somers Road drains a solely agricultural catchment of 17.5 km^2 in size. This was recognised as a possible future water source by Alcoa in 1978 and a gauging station was constructed to provide data on the hydrology of this relatively flat agricultural catchment. The station operated until 1998 and the 21 years of data indicates that on average 7 GL of flow passes the gauging site each year of which 5 GL occurs during the May to September period. Steamtec's analysis of Samson North Drain suggests a maximum yield from this source of 5 GLpa is possible. This estimate includes an allowance of one-third for Ecological Water requirements.

The 'peaky' nature of the flow indicates that a detention pond would be necessary to maximise water recovery from this site. An excavated detention pond with a working capacity of around 300-500 ML would allow the required water to be recovered. Such a facility could be located on Alcoa owned land, provide construction materials for residue area construction and double as a constructed wetland to partially replace some of the wetlands that have been drained in the area. Such a development would seem to be consistent with the objectives of the Harvey River Restoration Trust for the Lower Harvey River (WRC, 1998).

10.3 Transfer of Part of Alcoa Farmlands Irrigation Water Entitlement

The Proposed Harvey Basin Surface Water Allocation Plan (WRC, 1998) supports the trading of surplus irrigation water to industrial use.

Alcoa Farmlands has an irrigation water allocation of around 6 GLpa. The current beef farming operation typically utilises around 2.5 GLpa of this allocation. It is understood that Alcoa have examined opportunities to increase irrigated agriculture on its land however that the cost of reinstating the distribution system is not justified with the current land management practices (Alcoa, 2004b).

Alcoa is negotiating a temporary trade of up to 2 GLpa of its allocation to obtain the water necessary to operate the expanded Pinjarra refinery (under construction) until a recycle water (treated sewage effluent) pipeline from Gordon Road wastewater treatment plant to the Pinjarra refinery is completed. The physical transfer of water from dams in the Wagerup region to the Pinjarra refinery can be accomplished through the Water Corporation's existing pipeline network.

A permanent arrangement to enable use of the Alcoa Farmlands irrigation water entitlement for either agriculture or industry may be possible, however this would be dependent on gaining the agreement of WRC (DoE) and Harvey Water as well as the support of the general agricultural community

10.4 Irrigation System Efficiency Water

Most of the irrigation distribution system was constructed more than 60 years ago. Losses are high and controls are inefficient by modern standards. On-farm distribution systems and practises are also relatively inefficient. It has been estimated that the overall efficiency of irrigation water use within the area may be as low as 50%.

Harvey Water Cooperative has embarked on a program of irrigation infrastructure improvements and along with the WA Department of Agriculture are promoting improved on-farm irrigation practises. If efficiency gains can be demonstrated then the water so gained could be diverted for higher value uses such as public potable supplies or industrial supplies, without impacting on the extent of current irrigated agricultural use. As a result of distribution system improvements already completed in the Harvey and Waroona irrigation districts, Harvey Water believe that more than 6 GL of water has been saved. It is estimated that these improvements have cost around $2 - $3M per GL (Harvey Water *pers. comm*.).

The Board of Harvey Water have agreed that water gained through efficiency improvements should be available to trade for non-agricultural use, with the higher price achieved helping to fund further improvements to the irrigation system, benefiting further users.

If Alcoa was to invest in off-farm and possibly on-farm water distribution improvements it should be able to secure the efficiency water for industrial use as well as gain the benefit of improvements in irrigation practices.

The financial trade off for Alcoa lies in the ability to utilise existing irrigation storage dams rather than investing in new fresh water storage facilities. The reduced water surfaces subject to evaporation loss which would result would be a net water saving.

Although this option seems to be positive in many respects it will require a long term contractual agreement between WA Government, Harvey Water and Alcoa to ensure that any investment secures the required water. While this might seem complex most of the issues have already been addressed as a result of negotiations between Harvey Water and the Water Corporation which should result in efficiency water being made available for Water Corporation’s integrated water supply system.

The required irrigation system improvements and commercial agreement should be able to be implemented within the timeframe of the Wagerup Unit Three Expansion, however if delayed other temporary sources of water such as transfer of part of the Alcoa Farmlands irrigation entitlement or an expansion of pumpback facilities on local drains could provide the required water in the interim.

Table 10.1 Detailed Comparison of Water Supply Options for the Wagerup Refinery Expansion

				ENVIRONMENTAL		SOCIAL		ECONOMIC		
OPTION	**SOURCE OF WATER**	**Quantity Available (Glpa)**	**WG3 Quantity Required (Glpa)**	**Environmental Impacts**	**Env Approval/ Licensing**	**Possible Impacts on Other Water Users**	**Community Acceptance**	**Capital Cost ($M)**	**Operational Cost($/Kl)**	**Other Business Risk Issues**
1	**Harvey River Main Drain winter flow via existing pumping station**	28	5	***Drain/Stream Ecology -*** Low impact as planned total abstraction (4.4 +5 = 9.4 Glpa) is well below estimated sustainable yield (28 Glpa) and limited to winter months. Monitoring is established to ensure ecological water requirements are met. ***Water Conservation -*** Net evaporation loss from additional storage facility (say 0.5 Glpa) represents additional loss from the system. ***Footprint -*** Increased footprint for water storage facility (say 50 Ha)	***Surface Water Licence -*** Should be straight forward as proposal is supported by Proposed Harvey Basin Surface Water Allocation Plan. ***Works Approval -*** may be required for upgrade of pump station/pipelines and water storage facility.	***Downstream Users -*** No known licenced or unlicenced users will be affected.	***Water Quality Concerns -*** There is a perception with some community members that the current pump station may be preferentially harvesting higher quality water from Logues Brook Drain which includes Hills runoff. Modifications to the intake and more intensive monitoring should overcome this issue.	Upgrade Harvey Pumpback pumps, intake and delivery piping to new storage facility. Capital Est. - $2M Construct new 5 Gl water storage facility. Capital Est. - $XXM	Power, maintenance, monitoring etc - Est. $0.20/Kl	***Droughts -*** Agricultural land runoff is more predictable than Hills runoff therefore there should be adequate water even during droughts
2	**Samson Sth and Samson Nth Drain winter runoff via new detention pond and pumping station**	11	5	***Drain/Stream Ecology-*** Low impact as planned total abstraction (5 Glpa) is well below estimated sustainable yield (11Glpa). Monitoring is established to ensure ecological water requirements are met. ***Wetland Creation -*** Will require new detention pond and pumping station. Detention pond could provide perrennial wetland in support of Harvey River Restoration Trust objectives. ***Water Conservation -*** Net evaporation loss from additional storage facility (say 0.5 Glpa) represents additional loss from the system. ***Footprint -*** Increased footprint for water storage facility (say 50 Ha)	***Surface Water Licence -*** Should be straight forward as proposal is supported by Proposed Harvey Basin Surface Water Allocation Plan. ***Works Approval -*** will be required for new detention pond & pumping station and water storage facility.	***Downstream Users -*** No known licenced or unlicenced users will be affected.	***Water Quality Concerns -*** These drain catchments are purely agricultural and therefore concerns about use of higher grade Hills runoff water should be avoided. ***Wetland & Riparian Improvements -*** the detention pond could be designed as a perrennial wetland and create a valuable ecological, community & tourist resource. It could readily be integrated into Alcoa's Land Management Programme.	Construct detention pond/wetland, pump station and delivery pipeline to new storage facility. Capital Est. - $5M Construct new 5 Gl water storage facility. Capital Est. - $XXM	Power, maintenance, monitoring etc - Est. $0.20/Kl	***Droughts -*** Agricultural land runoff more predictable than Hills runopff therefore should be adequate water even during droughts
3	**Utilise currently unused Farmlands Irrigation Water Entitlement (IWE) for refinery**	3 (Assumes 50% of IWE preserved for farm use)	5	***Water Conservation -*** Avoids evaporation loss associated with new storage facilities. Use of water to create greatest overall value is consistent with National Water Reform Agenda	***Harvey Water Bulk Water Licence -*** Would require increase in the industrial use component of Harvey Water's bulk licence however Proposed Harvey Basin Surface Water Allocation Plan supports transfer of unused irrigation water to other uses. ***Harvey Water Cooperative -*** may be philosophically opposed to alternative use of Alcoa's IWE however not prohibited by their legislation or charter.	***Irrigation Farmers -*** greater use of Alcoa's IWE may decrease water available to other users especially under drought conditions. ***Water Corporation/City -*** Water Corporation's supply network can now access irrigation water in Waroona & Harvey area. WC are keen to gain access to unused irrigation water. Desalination plant may reduce demand for this water in short term.	***Farming Community -*** may be opposed to greater industrial use of water currently allocated for irrigation however not technically a trade away from an existing agricultural user. ***Local Community -*** there should be support for retaining the water for value adding use within the local area rather than transferring it to the city. Refinery's demand for water should decrease over time as residue catchment increases, water use could then revert to agriculture.	Water can be released by gravity from irrigation system to detention pond. Samson South Drain channel capacity and diversion structures may require upgrading. Capital Estimate - $1M.	Industrial Water Charge ($0.30)	***Droughts -*** Water availability could reduce during drought periods resulting in water shortages and priority issues between the refinery & farmlands. Farming viability could be affected as a result. ***Competition -*** as city water supply demand increases Alcoa could end up competing with the Water Corporation for high quality water. ***Price -*** Industrial Water Rates are likely to increase in line with demand and more expensive options such as desalination. ***Water Conservation Strategy -*** The use of this high grade source is not aligned with Alcoa's current strategy which emphasizes use of lower grade water.
4	**Irrigation water gained through efficiency measures**	>5	5	***Water Conservation -*** Avoids evaporation loss associated with new storage facilities. Use of water to create greatest overall value is consistent with National Water Reform Agenda. ***Irrigation System Water Inefficiency Issues -*** distribution system losses and over irrigation may result in waterlogging and salinity and sustain non-representative riparian ecology. Efficiency improvements will impact on these aspects.	***Harvey Water Bulk Water Licence -*** Would require increase in the industrial use component of Harvey Water's bulk licence. Proposed Harvey Basin Surface Water Allocation Plan & Water & Rivers Commission supports transfer of unused irrigation water to other uses. ***Supply Contract -*** Special agreement would be required to secure allocation for long term.	***Irrigation Farmers -*** support trading of efficiency water to other users to help underpin Harvey Water's financial position ***Water Corporation/City -*** Water Corporation's supply network can now access irrigation water in Waroona & Harvey area. WC are keen to gain access to irrigation efficiency water although some issues with funding of efficiency measures. Desalination plant may reduce WC demand for this water in short term.	***Farming Community -*** support trading of efficiency water to other users to help underpin Harvey Water's financial position. ***Local Community -*** there should be support for retaining the efficiency water for value adding use within the local area rather than transferring it to the city. Refinery's demand for water should decrease over time as residue catchment increases, water use could then revert to agriculture.	Based upon recent Harvey Water project costs to achieve water distribution efficiencies a cost of $2M/Gl is suggested.(pers. comm.) Capital Est. - $10M	Discounted Industrial Water Charge (<$0.30/Kl)	***Droughts -*** Water availability could reduce during drought periods resulting in water shortages and priority issues between the refinery & farmlands. Alcoa Farmlands operations could be affected as a result. ***Competition -*** as city water supply demand increases Alcoa could end up competing with the Water Corporation for high quality water. ***Price -*** Industrial Water Rates are likely to increase in line with demand and more expensive options such as desalination.

11. WATER SUPPLY RECOMMENDATIONS

1. It is recommended that Harvey Drain be the preferred source of water for the future expansion of the Wagerup refinery. Analysis by CENRM suggest that a further 28 GLpa of water should be available from this source which is well above Alcoa's additional water requirement of around 5 GLpa.

   Continuous flow monitoring that has been installed and additional water quality and ecological monitoring as recommended by CENRM, will allow pumping configurations and operating rules to be established. In addition to duplication of the pumping station and delivery pipeline, development of this source will require construction of additional water storage facilities by Alcoa.

2. Use of part of the existing Alcoa Farmlands irrigation water entitlement for the refinery is the lowest capital cost option and should be further investigated. It avoids the need for additional pumping and storage facilities, and is in line with the Harvey Basin Surface Water Allocation Plan and the broader Water Law Reform Agenda. While it may be resisted by the local irrigated agricultural industry it does represent a higher valued use of water for the overall benefit of the region and may be more attractive than transfer of the water to the Water Corporation for the Perth market.

   The feasibility of this option should be discussed with the WRC and Harvey Water.

3. If there is resistance to using water allocated to agriculture for industry then Alcoa may be able to gain access to water saved through efficiency measures by helping to finance these measures.

   This should be included in discussions with Harvey Water over use of irrigation water by the refinery.

4. Other local drains and in particular Samson North Drain could provide the additional water required for Wagerup Unit Three, however this option is unlikely to be viable for the next stage of development when compared to the Harvey Drain Pumpback or irrigation water options.

5. Alcoa should continue to incorporate water saving measures into plant modifications and expansions such as non-evaporative cooling planned for Wagerup Unit Three in line with sustainability principles and cleaner production goals.

6. The community a large has the biggest opportunity to reduce water consumption through modification of landscaping and house construction practices. Through its workforce and contractors Alcoa has considerable influence in the Peel Region to support the Local Governments' ICLE Water Campaign. Engagement in this initiative will help to strengthen awareness of water conservation and also Alcoa's reputation in this area.

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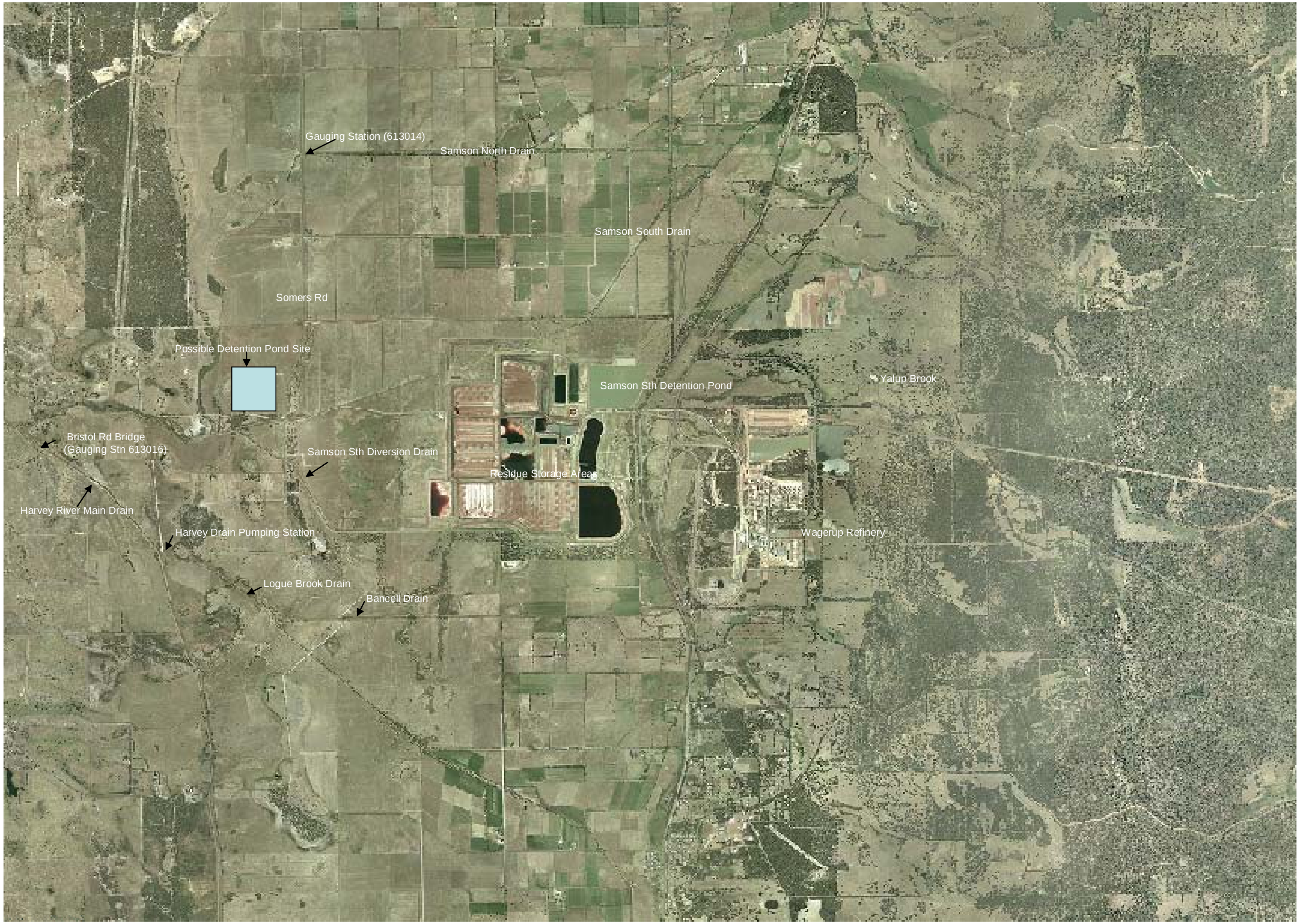

Figure 1

Locality Plan

Client: Alcoa World Alumina	ENVIRON	
Project: ERMP: Wagerup Refinery Unit 3	Drawing Ref: DG 1	Date: 17 Jan 2005

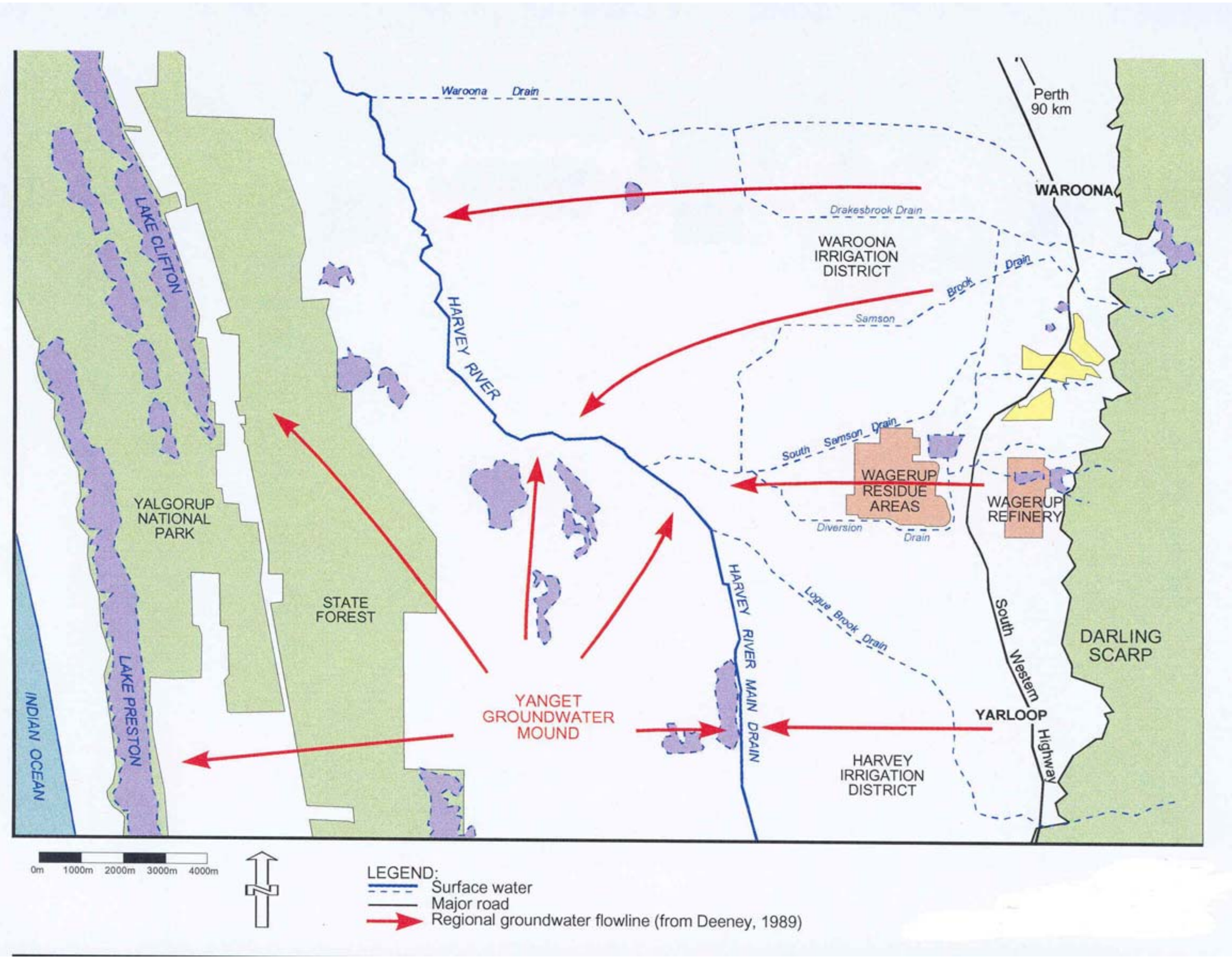

Figure 2

Hydrology

Client: Alcoa World Alumina	ENVIRON	
Project: ERMP: Wagerup Refinery Unit 3	Drawing Ref: DG 2	Date: 17 Jan 2005

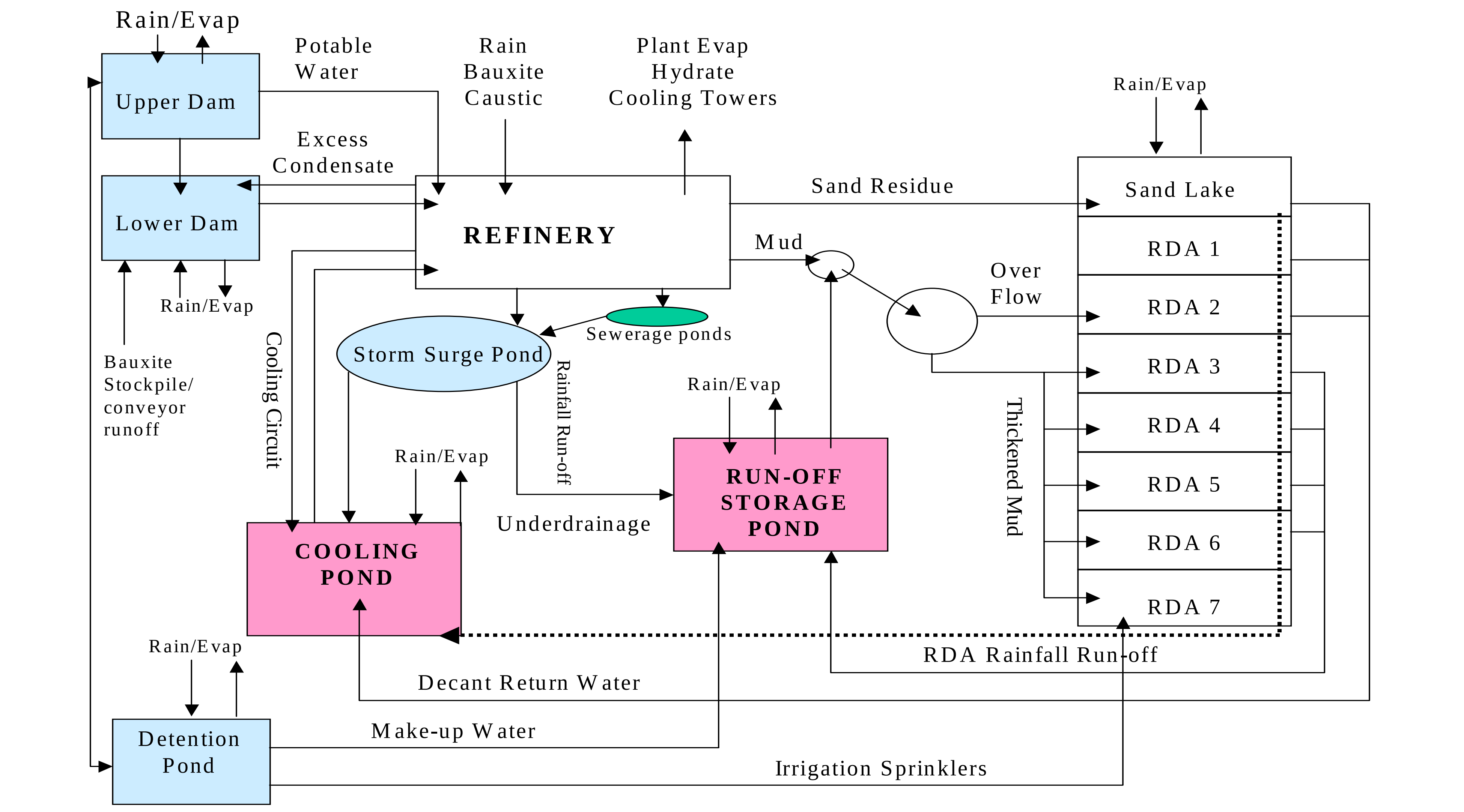

Figure 3

Wagerup Refinery Water Circuit

Client: Alcoa World Alumina	ENVIRON	
Project: ERMP: Wagerup Refinery Unit 3	Drawing Ref: DG 3	Date: 17 Jan 2005

Appendix A

Ecological Water Requirements and Water Availability in the Lower Harvey River Catchment Associated with the Proposed Wagerup Unit Three Expansion (CENRM, 2005)

ALCOA WORLD ALUMINA – AUSTRALIA

Ecological Water Requirements and water availability in the lower Harvey River (Main Drain) catchment associated with the proposed Wagerup 3 Expansion.

CENRM Report 02/05
February 2005

TITLE Ecological Water Requirements and water availability in the Lower Harvey River catchment associated with the proposed Wagerup 3 Expansion

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Cover photograph: The Harvey Main Drain near the Logue Brook confluence.

EXECUTIVE SUMMARY

The proposed expansion of Alcoa World Alumina Australia Wagerup operations (WG3) will require an additional water source of about 4GL/annum. The refinery is currently supplied from surface water sources whereby winter/spring runoff is pumped into storage reservoirs for year-round supply. It is anticipated that the additional water, required for WG3, could be gained in a similar way.

The Wagerup operations are located in the lower reaches of the Harvey River catchment. In the greater catchment, existing flows are regulated for irrigation, domestic water supply and industry. Despite this, flow into Harvey Estuary, due to catchment clearing, is about 50% greater than the pre-European condition. Existing models of climate change predict a reduction of winter rainfall in the southwest and an associated increase in summer storms. Over the past 20 years, rainfall in the Harvey catchment has significantly reduced leading to almost a 40% reduction in Hills catchment runoff. Consequently, the impact of climate change on runoff needs to be built-into any longer-term water resource planning.

Most water in lower river systems is now from both groundwater and runoff from agricultural areas, therefore water quality is considerably lower than water sourced from the Hills (particularly nutrients). This, and the more intact nature of the stream network and riparian systems in the Hills, leads to substantially elevated ecological values compared to lower river and drain systems. At present, ecological values of drains are predominantly only their capacity to maintain hydrological connectivity (for downstream carbon flow and upstream fish migration) between upland and lower river/estuarine systems.

In order to assess the availability of additional surface water from drains and streams in the vicinity of the Wagerup refinery, a "rule of thumb" for Ecological Water Requirements (EWRs) was derived which was based on previous work in the greater Harvey catchment. This rule is based on a "one-third, two-thirds" guideline; that is for lower river systems and drains, one-third of flows (based on the normal seasonal pattern) are required for EWRs and for Hills streams, due to increased ecological values, about two-thirds of flows are required. For the WG3 proposal, surface water sources that have been assessed included:

- *Harvey River main drain (at the location of Alcoa's pumpback facility)*
- *Other Harvey River main drain locations*
- *South and North Samson drain*
- *Logue Brook*
- *Black Tom Brook*
- *McKnoes Brook*
- *Bancell Brook*

Based on the above rule of thumb and previous detailed EWR analysis, the preferred surface water supply option is the use agriculture run-off and return waters from drains in the lower catchment, for example:

- *Harvey River main drain*
- *North and South Samson drain*

This option is supported by the (then Water and Rivers Commission) Harvey Basin Water Allocation Plan. To gain increased understanding of water availability at these sites, a monitoring program is recommended. This would require measuring daily flows in the Harvey River main drain downstream of the Alcoa pumpback facility.

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1. INTRODUCTION

Alcoa World Alumina - Australia (Alcoa) has proposed expansion of the operations at Wagerup (WG3) in southwestern Australia. As part of the assessment process, studies were initiated to:

- *Assess catchment-scale (Harvey) water allocation.*
- *Provide a historic context to Harvey catchment flows.*
- *Construct a water flow model for operations located at WG3.*
- *Briefly describe flow management within the Harvey catchment.*
- *Make recommendations on potential water supply sources for WG3.*
- *Recommend a monitoring program to assess impacts of flow regulation on aquatic ecological condition.*

2. SITE DESCRIPTION

The proposed WG3 operations are located within the Harvey Drainage Catchment, which has an area of 2055km^2 of which approximately 29% (605km^2) is State Forest and 45% (925km^2) is cleared land. The area is the largest of the catchments draining into the Harvey estuary. Historically the largest drainage line within the catchment was the Harvey River, now referred to as the Harvey Main Drain.

The Harvey River was dammed in 1916 with the construction of Harvey Weir and in 1930 the River was diverted west to the ocean along the Harvey Diversion Drain. In 1948 a second impoundment, Stirling Dam, was constructed upstream of Harvey Reservoir. In 1998 the New Harvey Dam was constructed immediately downstream from the existing Harvey Weir.

The Harvey Main Drain catchment contains a series of small rivers and brooks that originate on the Darling Scarp and drain onto the Swan Coastal Plain (Figure 1). Almost all streams on the Coastal Plain have been extensively modified by artificial drainage, irrigation, channelization and clearing of native vegetation. The Harvey River is the main river in the catchment and may be considered as consisting of five major components:

- *Harvey River / Harvey River Main Drain.*

- *Harvey Diversion Drain, diverting overflow from the Harvey and Wokalup rivers (including Wellesley Creek) to the Indian Ocean at Myalup.*

- *Weekes, Clarke, Logue, Bancell and Yalup brooks, which discharge into the Harvey Main Drain.*

- *Samson-Waroona-Drakesbrook drainage system, which includes Black Tom and McKnoe brooks and discharges into the Harvey Main Drain via both Samson River Main Drain and Drakesbrook Drain.*

- *Mayfield Drain, which discharges into the Harvey River Main Drain, close to Harvey Delta.*

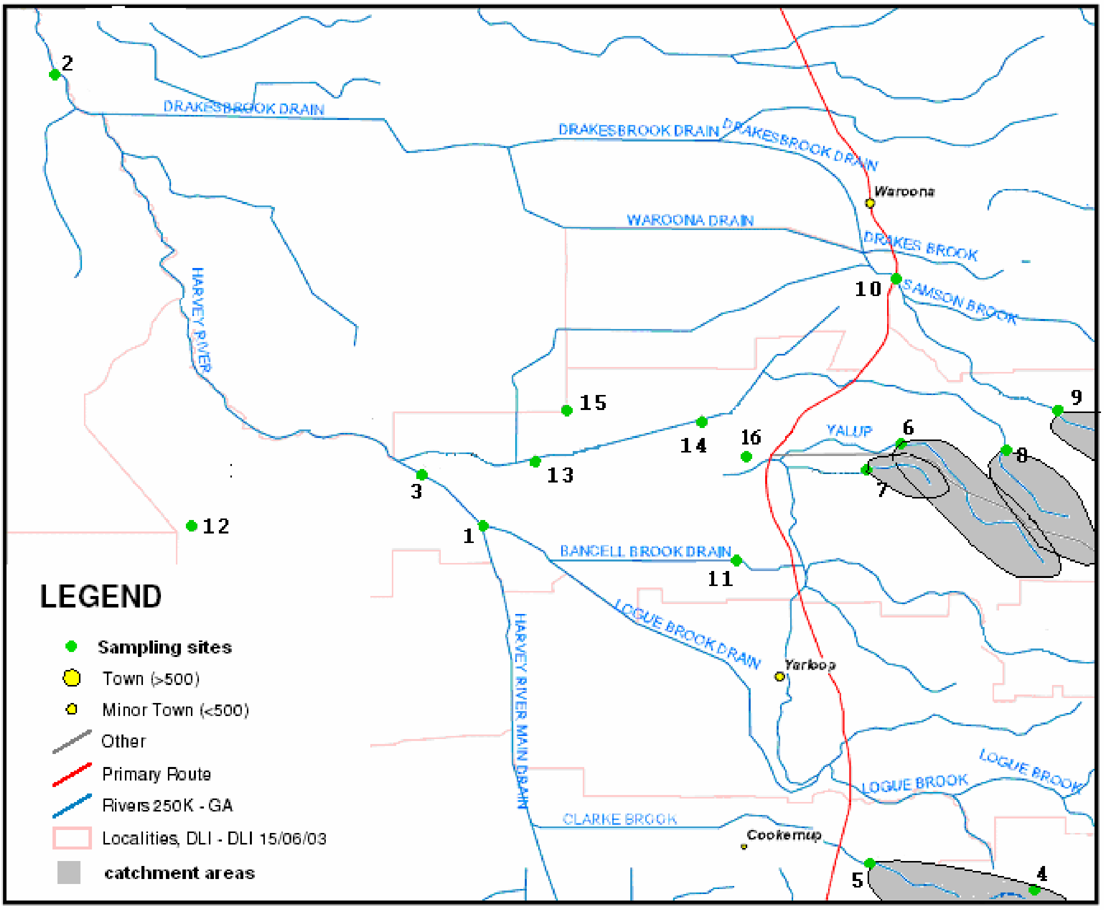


Figure 1. The area adjacent to Wagerup operations showing all monitoring stations (shaded areas are catchment boundaries). See Section 3.1 for site codes.

2.1 Climate

The climate of the area is Mediterranean, characterised by cool, wet winters and hot, dry summers (Seddon 1972). The annual rainfall of wetter regions of the northern jarrah forest is approximately 1250mm (Gardner 1942) which is both seasonal (predominantly May – September) and highly predictable (Bunn *et al.* 1986).

The long-term average annual rainfalls for the towns of Harvey and Waroona are 1012 and 1053mm respectively. Average monthly evaporation varies from about 50mm in June to 300mm in January; the Harvey region has received below average rainfall for the last 20 years (Welker 1999).

The effect of lower rainfall is amplified in streamflow records. A decline in annual rainfall of 10% has been shown to reduce streamflow in jarrah forest catchments by about 20–40%. There has been a statistically significant reduction in streamflow for the period from 1975 to present (WRC 1996).

2.2 Climate change

Based on current models for global warming, CSIRO (1996, 2000) has predicted an increase in temperature for the south-west, and rainfall is predicted to increase during summer and decrease during winter/spring. While the intensity of rainfall events may increase, their duration is expected to decrease. Correspondingly, the duration of drought events is also predicted to increase. Climate change from global warming has been examined by the Climate Impact Group in the CSIRO Division of Atmospheric Research (CSIRO 1996, 2000). The latest scenarios for the year 2030 for the south-west of Western Australia are:

- *temperature increase of between 0.3 and 1.3o C; and*
- *rainfall increases in the November to April period of -4% to +12%, and rainfall changes for May to October period of -8% to +2%.*

The predicted reduced winter rainfall is likely to lead to lower runoff from catchments.
Inter-annual and decade scale climate variability will continue in the future and will remain a source of uncertainty in projecting the impacts of future climate change on resource yields.

2.3 Landforms

The Darling Scarp is the most prominent physiographic feature of the south-western region of Australia, rising steeply to 300m above sea-level. The Scarp is an ancient erosional feature, presently lying 1-2 km east of the Darling Fault. The Darling Fault separates the Archaean Yilgarn Block from the Phanerozoic sedimentary deposits that underlie the Swan Coastal Plain to the west. The Darling Range is the uplifted edge of the Yilgarn Block, which forms part of the Pre-Cambrian Western Plateau (Great Plateau) which extends to the Goldfields.

The Darling Range as part of the Great Plateau, is an area of ancient weathered rock (Bettenay & Mulcahy 1972) which results in the very low nutrient status of upland streams (Bunn & Davies 1990). In contrast, the mean concentration of total phosphorus and total nitrogen in lowland rivers is about 30 times greater than upland streams, primarily due to clearing, cultivation and drain construction on the Coastal Plain (WAWA 1990).

2.4 Geomorphology

The geomorphology of the upper reaches of the Harvey catchment is typified by moderate relief and dissection of lateritic soils which overly ancient Archaean granites. The Harvey River system has headwaters in the jarrah forest on the south-western edge of the Great Plateau (Jutson 1950). The streams arise from the western edge of the Range, at about 250 to 300m above sea level. Streams of this area flow westward through incised valleys and across the lowly-elevated Swan Coastal Plain (Bettenay & Mulcahy 1972).

2.5 Vegetation

Clearing for agriculture and construction of drains for flood control has resulted in the loss of 60 - 100% of native vegetation in the lower Harvey catchment. Darling Scarp catchments are mainly composed of State Forest with extensive areas of relatively undisturbed riparian vegetation. Jarrah-marri (*Eucalyptus marginata-Corymbia calophylla*) forest dominates, with open woodlands of moonah (*Melaleuca preissiana*) and swamp peppermints (*Agonis linearifolia*). Understorey vegetation comprises bull banksia (*Banksia grandis*) and sheoaks (*Allocasuarina fraseriana*) nestled over water tolerant and dense sclerophyllous shrubs and sedges. Some forested areas are severely affected by dieback (*Phytophthora* spp.).

On the Coastal Plain, the composition of natural vegetation is determined to a large extent by height above the water table (Wells 1989). At the highest elevations low banksia woodlands occur on sandy soils, grading into jarrah-marri associations on wetter (lower elevation) soils. In uncleared regions this overstorey is sometimes replaced by other eucalypt species, including blackbutt (*Eucalyptus patens*), bullich (*E. megacarpa*) and flooded gum (*Eucalyptus rudis*).

2.6 Water quality

As part of the Great Plateau, the Darling Range is an area of ancient and weathered rock (Bettenay & Mulcahy 1972), which results in the very low nutrient status of forested upland streams in the Harvey catchment (Bunn & Davies 1990). The pervasive water quality issue for the lower Harvey catchment however is high nutrient status (Rivers & Clarke 2003). Harvey River and associated drains discharge a total annual volume of 221 $\pm$ 58 $m^3 \times 10^6$ with a mean total P load of 171 tonnes (1977-86) (Kinhill 1988) (Table 1) and a mean total N load of approximately 300 tonnes (Hodge *et al.* 1980) to the Harvey Estuary.

Up to 50% of total annual flow to the Estuary can occur during July - August, while almost no flow occurs during December - April. Stream flow from uncleared lands on the coastal plain is approximately 0.1×10^6 $m^3/a/km^2$ and up to 2x for cleared land.

In contrast, construction of water supply and drainage developments (*e.g.* the Harvey River diversion drain in the 1930's) has reduced streamflow by about 130×10^6 m^3/a (Kinhill 1988) (Table 1). Approximately 36% of total streamflow to the Peel-Harvey system is derived from the Harvey Main Drain and drains, though in dry years this contribution may be more than 50% (Hodge *et al.* 1980). Regulation of some rivers and drainage schemes has reduced the natural flow variability and seasonally reversed some of the wetting and drying cycles. Dams on hills catchments have also greatly reduced the input of nutrient-poor water, while clearing, cultivation and drainage on the Coastal Plain have increased the input of nutrient-rich water to the Peel-Harvey Estuary (Black & Rosher 1980). River flow and consequent the total nutrient input to the estuary is strongly seasonal; approximately 85% of nitrogen and phosphorous loadings during winter (Black & Rosher 1980).

Assessment of the Harvey Irrigation Area (HIA) showed the recommended guideline for nitrogen in water of 0.75 mg/L (ANZECC, 1992) was typically equalled or exceeded in most samples (Rivers & Clarke 2003). Harvey drains were, similarly, at this guideline level, but exhibited some high-frequency peaks of nitrogen levels up to 3.0mg/L.

Channel associated wetlands in areas of high phosphorus export (*e.g.* the Meredith Drain sub-catchment) act as nutrient sinks, collecting phosphorus from agricultural runoff (Chambers *et al.* 1993). These wetlands, dominated by paperbark woodlands (*Melaleuca*) with sedge (*Lepidosperma longitudinale*) understoreys, occur in seasonally flooded basins, isolated from drainage channels for most of the year.

2.7 Nutrient Management

Any further reduction in river flow from the hills catchments would reduce any beneficial flushing action to the Harvey Estuary. River flow and consequent nutrient input to the estuary is strongly seasonal; approximately 85 % of nitrogen and phosphorous loadings occur during winter. More than 50% of phosphorus loadings to the Peel/Harvey system come from the catchments of the Harvey River and Mayfields Drain (~ 32 % from the Harvey River, ~ 52% from Mayfields drain and ~ 16 % from other drains).

In the estuary, massive blooms of nitrogen-fixing blue-green algae, *Nodularia spumigena*, develop in response to relatively high phosphorus levels, low N:P ratio and water temperatures greater than 18°C (Hodgkin *et al.* 1980). The construction of the Dawesville channel in January 1995 has increased flushing of the Harvey Estuary in particular, with a resultant reduction in weed and algae growth. Urban, special rural and more intensive agricultural development within the catchment however, has the potential to increase nutrient inputs and result in a recurrence of earlier problems.

Reduced fresh water inputs (flushing) resulting from further diversion of winter runoff to alternative uses, may have localised ecological impacts however, as this runoff contains the majority of nutrients, the effect of reduced fresher water inputs to the estuary is likely to be neutral. Many of the natural seasonal and perennial wetlands within the catchment have been drained in the past for agriculture. This draining has resulted in more rapid movement of runoff and associated nutrients into the Estuary. Wetlands can act as nutrient traps, particularly of nutrients associated with sediment. Total clearing of native vegetation, especially along drainage lines, has reduced the retention of nutrients on the land. The creation of wetlands and riparian vegetation within the Harvey catchment has been identified as a priority by the Department of Environment (previous Water and Rivers Commission).

Table 1. Estimated phosphorus inputs to the Peel-Harvey Estuary (after Kinhill 1988).

Harvey	**Phosphorus (mg/L)**		**Streamflow ($m^3 x10^6/a$)**		**P Load (t/a)**	
Catchment	***circa 1930***	***1977-86***	***circa 1930***	***1977-86***	***circa 1930***	***1977-86***
Hills	0.01	0.01	195	65	2	1
Coastal Plain	0.09	0.46	180	370	16	170
Total	0.10	0.47	375	435	18	171

2.8 Hydrology

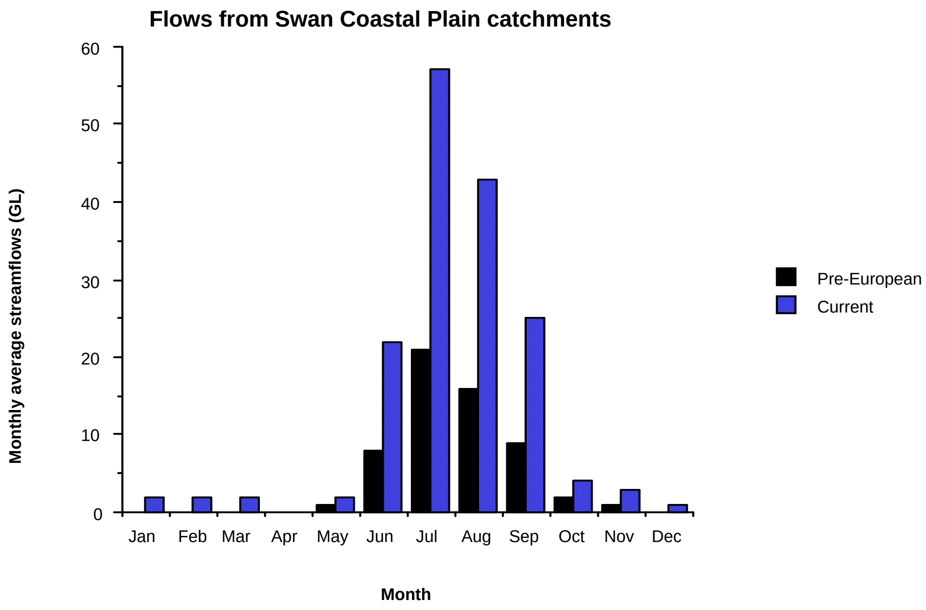
Monthly average streamflows vary predictably according to season with the highest flows being in July and August (Table 2). Since European settlement, winter streamflow has increased even though there has been a high degree of regulation on the Harvey Main Drain and some tributary streams such as Samson, Drakes, Yalup and Black Tom brooks. Several tributary streams, particularly in the mid-reaches of the system, are currently unregulated (*e.g.* Clarke and McKnoe brooks) or have minimal regulation (*e.g.* Bancell Brook). Summer flows on the coastal plain are similar to the historic regime and are now almost entirely derived from irrigation and groundwater discharge (WRC 1998).

Table 2. Monthly average streamflows (GL) to Peel–Harvey Estuary from Darling Range and Swan Coastal Plain catchments in the Harvey Basin.

Catchment	Situation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Darling Range	Pre-European	2.7	1.7	1.5	1.9	3.9	9.5	15.2	16.7	12.9	9.8	5.8	3.4	85
Swan Coastal Plain	Pre-European	0.1	0	0	0.1	0.7	8.0	21.1	15.9	9.1	1.5	0.5	0.1	57
Total	Pre-European	2.8	1.7	1.5	2.0	4.6	17.5	36.3	32.6	22.0	11.3	6.3	3.5	142
Darling Range	Current	0.6	0.4	0.4	0.5	1.0	2.3	4.7	6.2	5.3	4.0	1.4	0.8	32
Swan Coastal Plain	Current	1.3	1.4	1.4	1.4	2.0	22.1	57.3	42.7	24.7	4.3	2.9	1.7	170
Total	Current	1.9	1.8	1.8	1.9	3.0	24.4	63.0	48.9	30.0	8.3	4.3	2.5	202

Source: WRC 1998a

Approximately 53GL (51%) of the current total mean annual streamflow is diverted from the upper Harvey River for irrigation and town water supplies (WRC 1996). Since completion of the New Harvey Dam in 2000, most of the upper Harvey River flow is retained in the Harvey River/Main Drain rather than directed down the Diversion Drain.



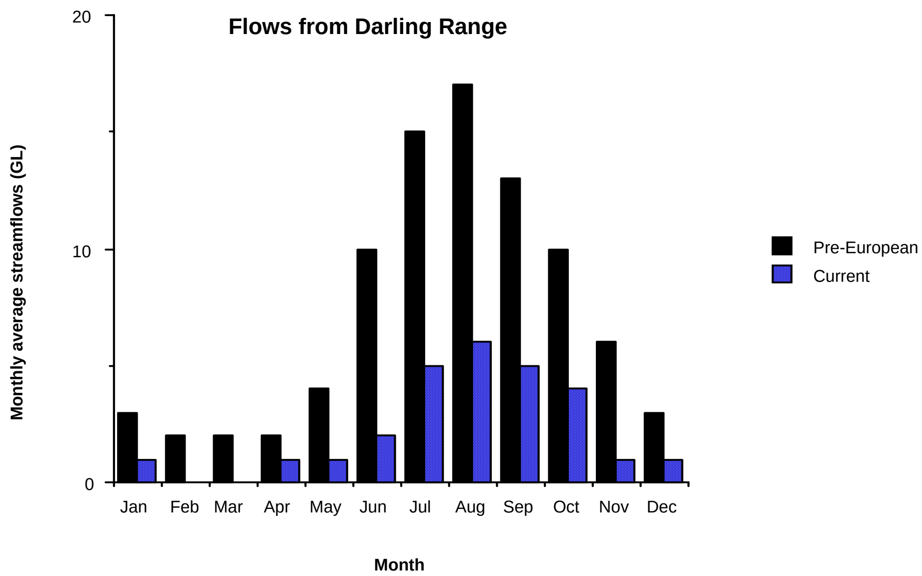


Figure 2. Current and pre-European monthly average flows (GL) from Coastal Plain (top) and upland catchment (bottom).

While there has been a substantial development of the Harvey River and its tributaries, the shape of hydrographs of monthly annual streamflows into the Peel–Harvey Estuary currently and prior to European settlement are similar.

2.8.1 Lower Harvey River

Regulation has substantially reduced flows from the forested upland (Darling Range) sub-catchments, while clearing has substantially increased flows from the Swan Coastal Plain (Streamtec 1998, WRC 1998). This has resulted in an overall increase in flows in the lower rivers compared to the historic (pre-European) conditions (Figure 4, Tables 2 & 3). Streamflow from other Darling Range streams constitutes about 20% of the flow into the Harvey Estuary from the Lower Harvey River.

The total annual flow to the Harvey Estuary from the Harvey River is now approximately 25-50% greater than it would have been under pre-European conditions (WRC 1998). The change post-European settlement is however, patchy throughout the catchment (Table 3). This increase is due to increased coastal plain runoff from irrigation and groundwater discharge. Current runoff from the plain is estimated to be about 300% greater (about 141GL/yr) than it was before European settlement (about 46 GL/yr) reflecting the extensive clearing of native vegetation that has occurred. By contrast, upland sub-catchments now only contribute about 16% of total flows to the Harvey Estuary, compared with 60% under pre-European conditions (WRC 1998).

Table 3. Percentage differences in flow volumes between existing (using average climatic conditions) and simulated pre-European flows.

Site	Station Code	Change from Pre-European conditions
Estuary Inflow	No weir	25-50% Increase
Harvey River Main Drain	613 016	1% Decrease
Harvey River Clifton Park	613 052	20% Increase
Harvey Diversion Drain	613 019	600% Increase
Clarke Brook	613 146	100% Increase
McKnoes Brook	613 018	90% Increase
Upper Harvey River	613 050	11% Decrease
Bancell's Brook	613 007	108% Increase

2.8.2 River regulation

Recently, the Stirling–Harvey Redevelopment Scheme involved diverting water (34GL/yr) from the Harvey River Hills Resource and storing water from the Harris Reservoir in the Stirling Reservoir for public water supply.

There is substantial regulation of the upland systems in the Harvey catchment (Table 4). Some systems (*e.g.* Logue, upper Harvey) are considered highly regulated. Table 5 shows the potential yields of systems adjacent to Wagerup operations.

2.8.3 Surface Waters at Wagerup

For the period following construction of the Alcoa Dam on South Yalup Brook (1978 – 1999), average annual rainfall recorded at Wagerup was 953 mm (Nield 2000) with stream discharge highly correlated with total rainfall. This correlation is probably explained by the nature of the Yalup catchment which is largely located on the escarpment. More generally the declining trend in annual rainfall (10% over the last 20 years) has been shown to reduce streamflow in jarrah forest catchments by about 20–40%. (WRC 1996).

Surface water flows into the refinery area from the east, via North and South Yalup Brooks, and from the north via the Wagerup Diversion Drain (Samson South Diversion Drain) (Figure 2). The Diversion Drain diverts water from South Samson Drain through Alcoa's Detention Pond, before reconnecting with South Samson Drain downstream from Alcoa's residue areas. The refinery and residue area catchments are totally controlled but runoff from Alcoa owned surrounding land enters the Wagerup Diversion Drain or other agricultural drains. The upper reaches of South Yalup Brook were dammed in 1978 to supply industrial and domestic water for the refinery. Under conditions of the refinery lease, run-off from residue areas and the refinery is strictly controlled to prevent contamination of adjacent streams and downstream receiving systems.

Alcoa has been licensed under the *Rights in Water and Irrigation Act (1914)*, to divert water from the Yalup, Black Tom and Harvey Main Drain for storage and use by the Wagerup Refinery. The pertaining licences set conditions under which Alcoa may divert surface waters and require adherence to an agreed Operational Strategy that is amended from time to time. Water diverted by Wagerup Refinery is stored in the existing Upper Yalup Dam, Samson South Diversion Drain Detention Pond, or a Runoff Water Storage Pond. The latter pond also collects alkaline runoff from residue areas, and as such, is used solely for process-makeup, while freshwater stored in the other dams is used for potable supplies and/or residue area dust-suppression.

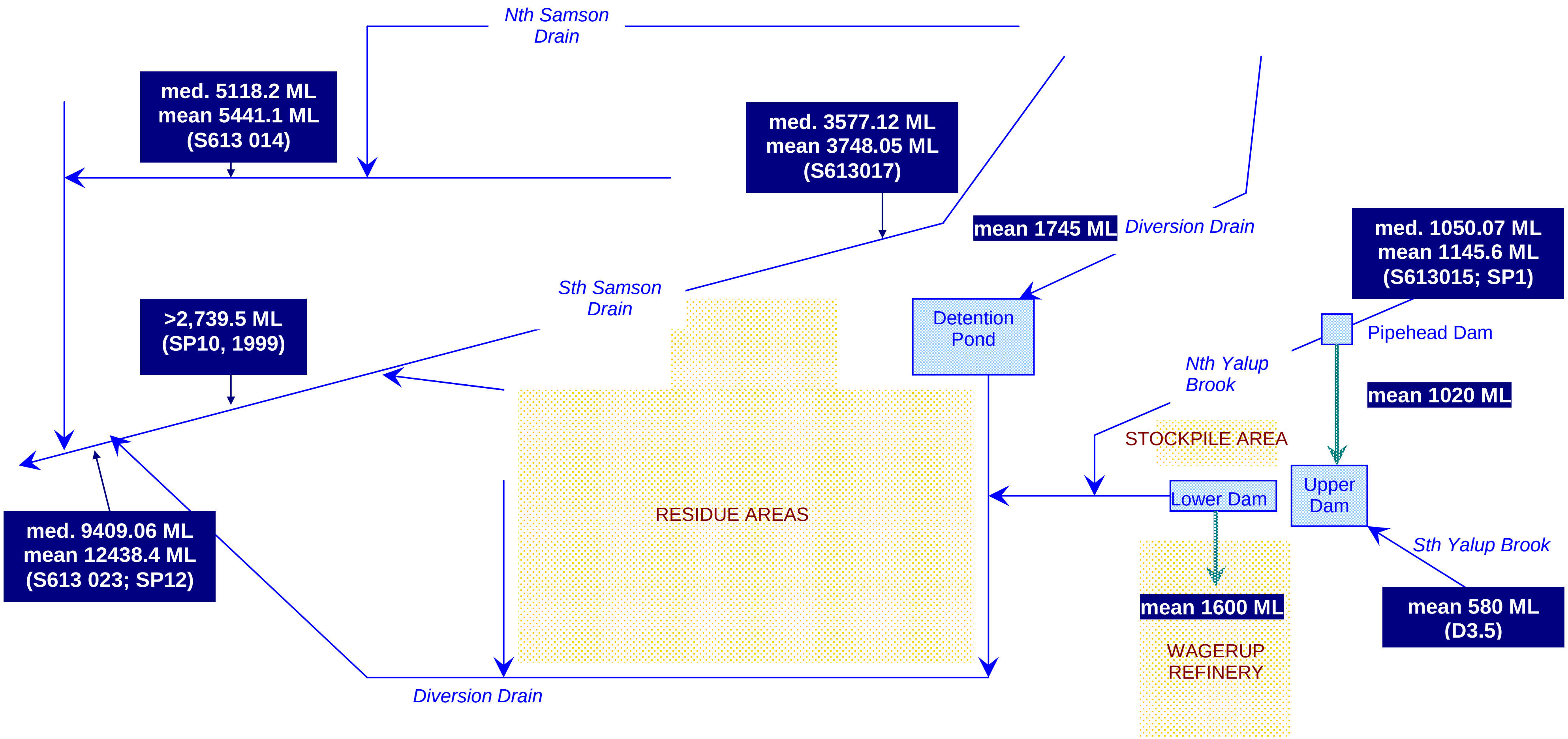


Figure 3. Existing annual water balance model for Wagerup.

3. ECOLOGICAL WATER REQUIREMENTS - RULES OF THUMB

A "rule of thumb" for EWRs based on previous work in the Harvey catchment was determined as a "one-third, two-thirds" guideline. That is, for "working" rivers and streams (those with existing multiple uses), one-third of the flows are required for EWRs and for more pristine rivers, two-thirds of flows are required. This rule of thumb was applied to streams where no formal EWR assessment had been conducted. This was applied to the broader Harvey catchment by using the "two-thirds" rule in the higher quality upland streams (Hills) and the "one-third" rule on the lower rivers systems and drains. The application of this rule however, must be consistent with the "historic flow paradigm"; that is, the modified flows have to mimic the historic regime. Operationally this may mean not over-allocating during seasonal low-flows.

Specific important dependent ecosystems requiring water allocation for the "two-thirds" systems includes; channel maintenance[1], riparian vegetation, aquatic macroinvertebrates, inundation of habitat, reproductive migration of fish, pool water quality and carbon/energy linkages.

The design of the drains and decreasing water quality has led to their current degraded ecological condition. Flows in drains are required for upstream connection (for migratory fish and downstream energy flows of detritus from forested reaches to subsidise downstream food webs) within little in-site ecological values.

3.1 Potential water sources

To assess potential water sources, the following surface-water systems adjacent to Wagerup were examined and will be discussed below:

1. *Harvey River at the Logue confluence (Alcoa pumpback location)*
2. *Harvey at Clifton Park (S613052)*
3. *Harvey at Bristol Road (S613016)*
4. *Logue Brook at outflow (S613175)*
5. *Clarke Brook at S613146*
6. *North Yalup Brook at SP1*
7. *South Yalup Brook*
8. *Black Tom Brook at DS 5*
9. *McKnoes Brook at DS 2*
10. *Samson Brook at Southwest Highway*
11. *Bancell Brook at DS 10*
12. *Meredith Drain at 613053*
13. *South Samson Drain at Cooyah (S613023, SP12)*
14. *South Samson Drain at Deleos Farm (S613017)*
15. *North Samson Drain at S613014*
16. *Detention Pond at S613024, SP5*

1. Channel maintenance flows are in-stream flows that maintain existing (or active) channel dimensions (*e.g.* through the physical process of erosion), and prevent the accumulation of sediment and organic debris.

1. Harvey River at the Logue Brook confluence.

There are no gauging stations at either Logue Brook or the Harvey River at this site. Currently, an Alcoa pumping station is operated from this confluence. The closest gauging station site to the pump station is at Bristol Rd Bridge, around 4km downstream. This station was only operated from 1977 to 1986 (Figure 6) and as there has been considerable changes to flow regulation since that period, the flow record may not be representative of current conditions and should therefore be treated with caution. During the gauging period, about 80GL/annum were recorded with approximately 59GL over the 'winter' period (Figure 6).

From 1984-1986, two gauging stations were operational; Bristol Rd near the proposed abstraction point and Clifton Park, downstream of the lower Harvey River. Regression analysis showed a significant relationship in the flows from these sites, with Bristol Road about 40% of the flows of Clifton Park (Streamtec 2002). This analysis (and assuming minimal influence due to the New Harvey Dam) showed about 75.2GL/a flow past the abstraction point, suggesting that there is approximately 28GL available per winter.

There is no recent accurate flow data available at this stage, however flow estimations of around 13ML/day in spring 2003 were substantially lower than expected suggesting that earlier estimates of available water at this location might be too high. The low flow readings might however be a reflection of dry conditions during September/October 2003 or reflect unlicensed users upstream rather than typical of winter or spring flows.

To consider this site as a potential water source, the difference between the gauged flows at Bristol Rd (1977-1986) and the present flows needs to be reconciled.

The Alcoa Pump Station on the confluence of Logue Brook and the Harvey River Main Drain.	*The Alcoa Pump Station abstraction point.*

Figure 3. Alcoa's pumping station on the confluence of Logue Brook and the Harvey River Main Drain.

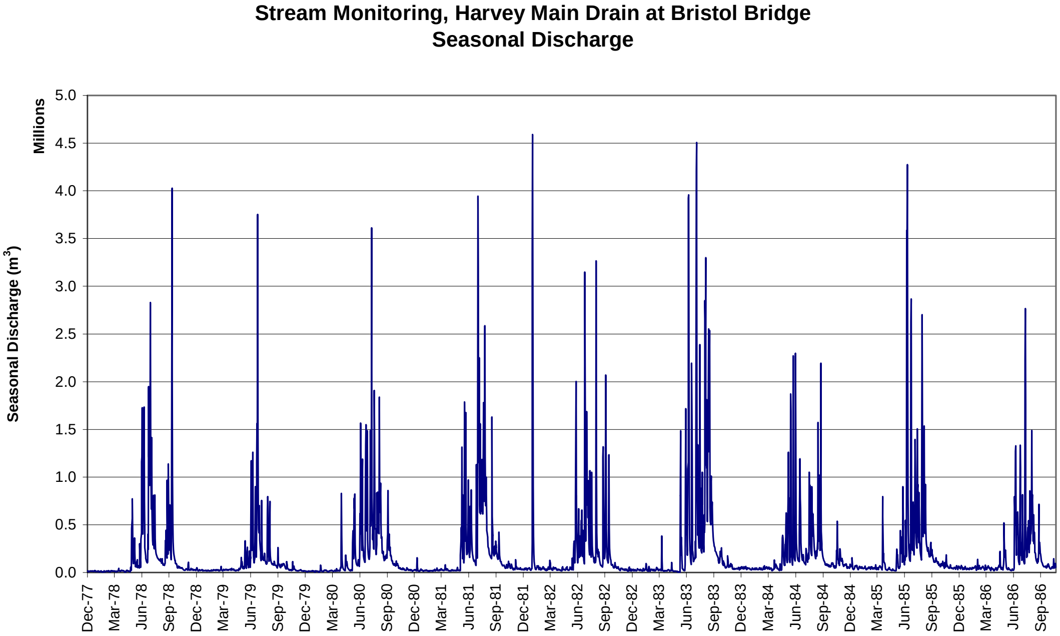


Figure 4. Flow records from Bristol Rd on the Harvey River from 1977-1986.

Table 4. Annual winter flows from Bristol Rd on the Harvey River 1977-1986. SEM= standard error of the mean; a measure of variance year-year.

Period	**Flow (GL)**
May – Sept 1978	59
May – Sept 1979	37
May – Sept 1980	63
May – Sept 1981	75
May – Sept 1982	56
May – Sept 1983	97
May – Sept 1984	55
May – Sept 1985	68
May – Sept 1986	45
Mean (SEM)	**62 (12)**

Harvey River at the Pumpback Station. Historic Bristol Rd data suggests ample water should be available. Additional monitoring required to adequately confirm availability.

2. Harvey at Clifton Park (S613052)

This site is well-downstream from the Alcoa pump station, as consequently there would be considerable transmission gains over the reach. A flow record immediately prior to the construction of the New Harvey Dam is shown in Figure 7 and after in Table 4; showing little change (approximately 15% reduction) as a consequence of the Dam. About 160GL of flows occur over the 'winter' months.

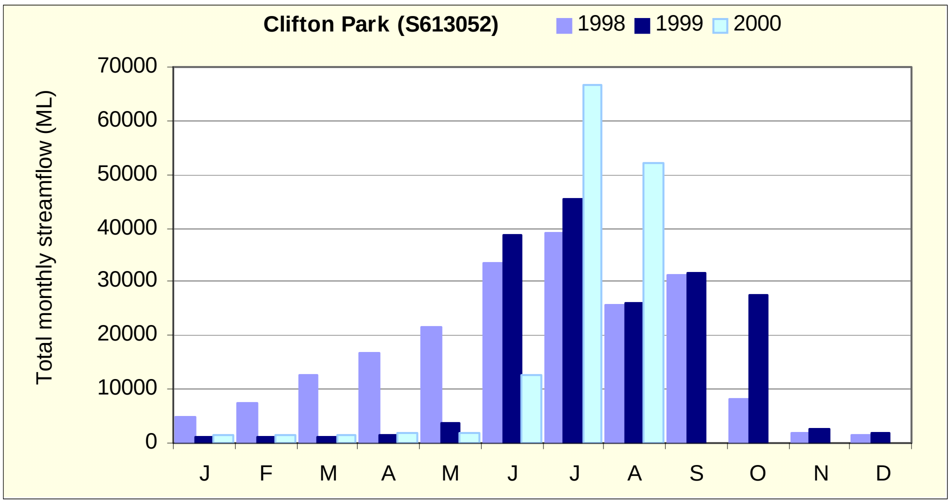


Figure 5. A recent (1998-2000; immediately pre- Harvey New Dam) flow record at Clifton Park.

Table 5. Monthly flows (in ML) in the Harvey River Main Drain at Clifton Park (S613052) pre- and post-New Harvey Dam (commissioned in late 2001, listed in red).

Month	Monthly Flows at Clifton Park (ML)					
	1998	1999	2000	2001	2002	2003
January	5,013	1,198	1,603	2,113	1,986	1,120
February	7,485	1,001	1,574	2,785	1,769	1,005
March	12,574	1,178	1,469	3,176	2,756	1,673
April	16,733	1,525	1,822	2,498	2,065	1,996
May	21,486	3,629	1,677	9,761	3,092	3,158
June	33,616	38,656	12,562	19,750	17,650	18,679
July	39,123	45,327	66,541	43,357	22,164	28,785
August	25,809	25,983	52,051	44,563	37,479	27,680
September	31,356	31,678	32,989	32,117	28,754	31,452
October	8,010	27,407	17,432	19,653	22,376	19,763
November	1,793	2,592	2,096	3,156	5,432	3,458
December	1,337	1,880	1,264	1,875	2,654	1,987
Annual Total	204335	182054	193068	184844	148187	140530

Harvey River at the Clifton Park. Considerable winter flows at this site. Water quality can be poor (predominantly N & P). Data suggests adequate water should be available at Pumpback location. Or at other locations on the Harvey River Main Drain closer to the Wagerup Refinery.

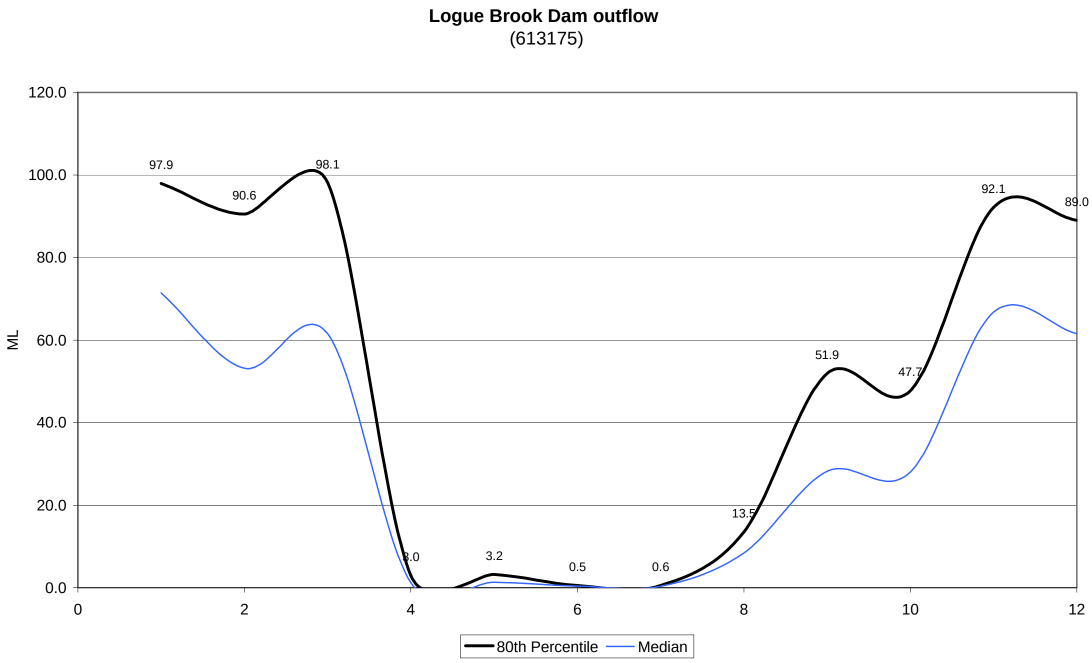
3. Harvey at Bristol Road

See Figure 6 (above).

Harvey River at the Bristol Road. Gauging information considered out-of-date; no post New Harvey Dam information.

4. Logue Brook at outflow (S613175)

Flows from Logue Brook (outflow) are shown in Figure 8. As water is used for irrigation, flows at this site occur predominantly during summer. Winter flows are about 20ML and the long-term (inter-annual) pattern is reasonably consistent (Figure 8). (This site is located in the Hills catchment just below the dam and is therefore not a potential source).



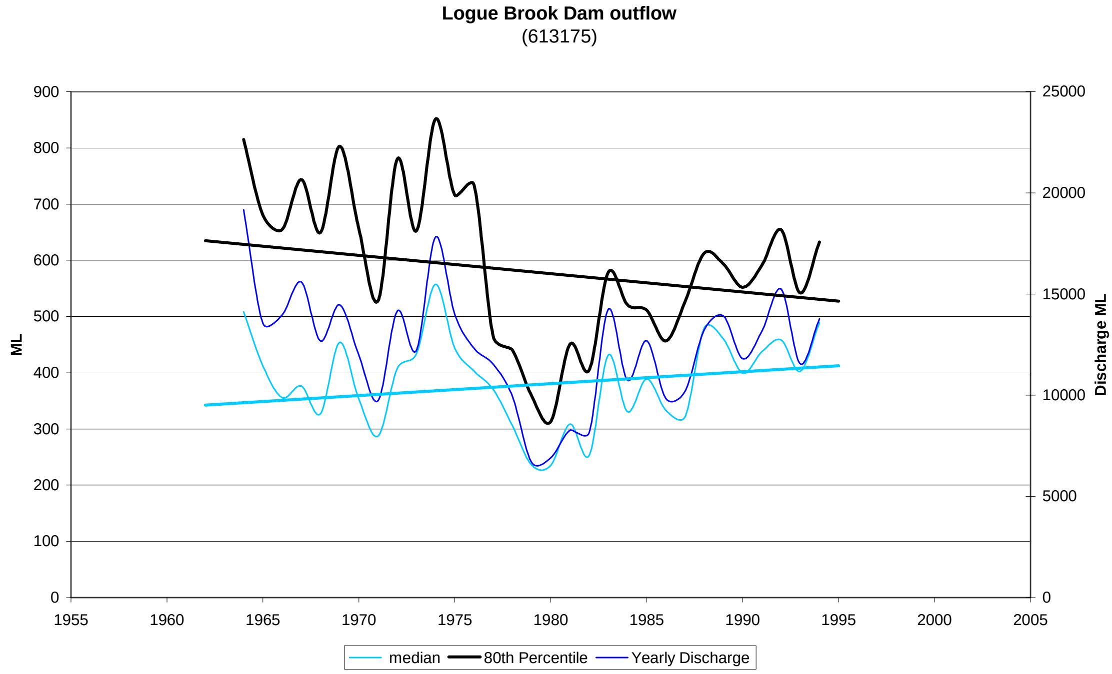


Figure 6. Analysis of the flow record in Logue Brook Dam outflow (S613175). The top plot is seasonal flows (month is represented by 1=January and 12=December *etc*). The lower plot, shows the annual trends (as median, 80th percentile) in discharge (ML).

Logue Brook outflow. Major flows during summer (irrigation), little winter flows. Not suitable as a source.

5. Clarke Brook at S613146

The gauging information a S613146 shows mean annual flows are about 0.8GL with only about 0.2GL over 'winter' (see Figure 9). The trend is for reduced median flows at this site (Figure 9).

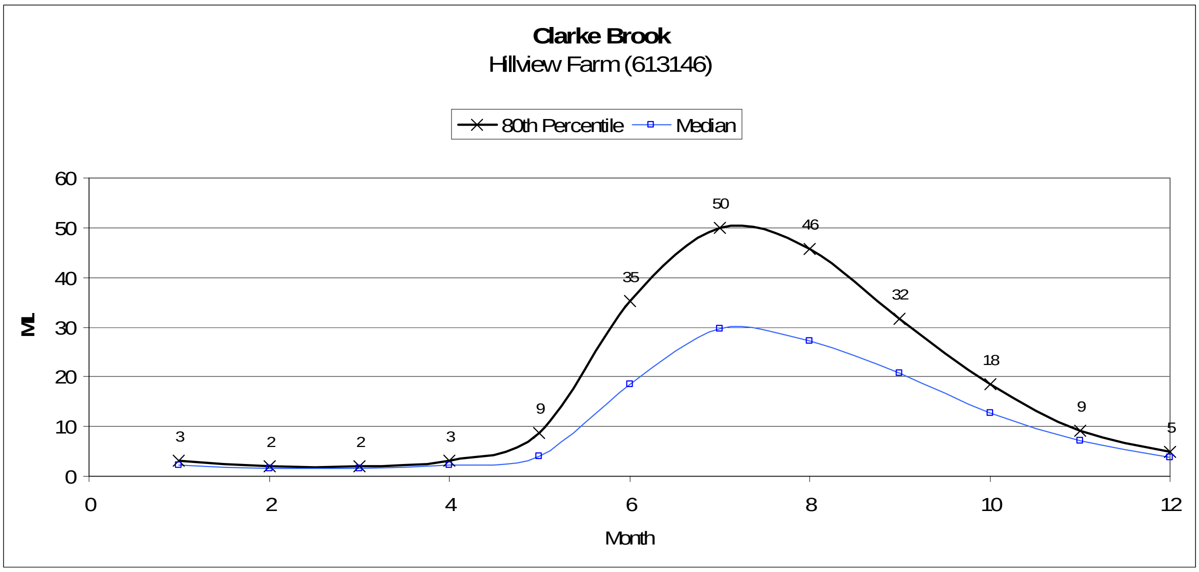


Figure 7. Analysis of the flow record in Clarke Brook (S613146). The top plot is seasonal flows (month is represented by 1=January and 12=December *etc*). The lower plot, shows the annual trends (as median, 80th percentile) in discharge (ML).

<u>Clarke Brook</u>. Low winter flows. Higher water quality from Hills catchment.

6. North Yalup Brook at SP1

The regulated section of North Yalup Brook extends for only 1.3 km downstream from the pipehead dam (SP1) above Wagerup Refinery before forming a confluence with the South Yalup Brook and flowing into the Diversion Drain. A total of 1,600ML/a is abstracted from the North and South Yalup system. All flows are intercepted from the South Yalup with the remainder (~1,020ML/a) supplemented from the North Yalup. In most years this leaves only 30ML/a for downstream environmental flows (based on median flows 1977 – 2003). In 2000 however, only a few pools were located in the downstream reaches of the North Yalup. Existing flows were, however, considered adequate for the maintenance of these pools. Additional flows, although unmeasured, from a major tributary to the north of SP1 and localised catchment run-off also add to the maintenance of these pools and play an increasingly important role during dry years. Table 5 shows the formal EWR assessment for North Yalup Brook.

Table 6. Summary sheet of environmental parameters and recommended flow regime for North Yalup Brook, based on estimated EWRs in unregulated, upstream forested reaches (table after Streamtec 2000) (see Appendix 1).

North Yalup Brook, upstream of S613015 (SP1)		Flow (ML) to maintain:					
Month	**Median flows '77-'99 (ML)**	**Channel form**	**Macro-invertebrates**	**Fish passage**	**Riparian vegetation**	**Seasonal adjustment**	**Flow (ML)**
January	**18.7**		**11.4**				**11.4**
February	**11.5**		**9.9**				**9.9**
March	**12.3**		**11.4**				**11.4**
April	**21.1**		**11.0**				**11.4**
May	**45.5**		**11.4**				**11.4**
June	**170.5**		**11.0**			**22.1**	**22.1**
July	**308.7**	**126.1**	**11.4**		**137.4**		**137.4**
August	**260.6**		**11.4**	**106.2**		**55.4**	**106.2**
September	**194.3**		**11.4**	**109.3**			**109.3**
October	**98.3**		**11.4**				**11.4**
November	**57.8**		**11.0**				**11.0**
December	**32.2**		**11.4**				**11.4**

TOTAL ESTIMATED EWR = 464.3 ML/ANNUM TOTAL MEDIAN FLOW '77-'99 = 1,145.61* ML/ANNUM

North Yalup at SP1. No "excess" water available. All existing flows required for environmental purposes.

7. South Yalup Brook

All flows (about 580ML/a) from the upper reaches of South Yalup Brook have been impounded by the Alcoa Upper Dam. Again, the regulated reach (below the Alcoa Lower Dam and above the confluence with the North Yalup) is extremely short; only about 600m in length. Typically, surface water of South Yalup Brook is limited to a few isolated pools, maintained by local catchment. The catchment below the Lower Dam is highly-degraded with extensive clearing/channel modification.

South Yalup Brook. No "excess" water available. All existing flows required for environmental purposes.

8. Black Tom Brook at DS 5

Black Tom contributes the majority of flow to the detention pond and Alcoa is licensed to use up to 2.5Glpa.

Black Tom at DS 5. No water available

9. McKnoes Brook at DS 2

About 5GL/a is the long-term median annual flows at McKnoes Brook at DS 2. This source was highlighted in the Harvey Basin Water Allocation Plan as a potential site to be "quarantined" from further water development. This was designed to maintain some stream systems in the Harvey catchment with links from the forested, upland reaches through to the Estuary. McKnoe and Bancell brooks have also been recommended to be "quarantined" from further major water resource developments.

McKnoes Brook at DS 2. About 3.5GL/a available after application of the two-thirds rule, however note site was nominated to be "quarantined" for further water resource development.

10. Samson Brook

Samson Brook Dam was constructed in 1941 to supply water for the Waroona Irrigation Scheme. The reservoir, Lake Kabbamup, is used extensively for public recreation (Crisp & Coleman 1996). Current irrigation utilisation is 7,600ML (45.7%) of the estimated average annual inflow to the lake of 16,600ML. In 1962, a small pipehead dam (Lower Samson Pipehead) was constructed downstream of Samson Dam to provide a water supply for the township of Hamel. The Water Corporation have recently constructed a pipeline from this dam to the New Harvey Truck Main in order to capture excess winter flow for Perth water supply.

Samson Dam overflow and winter flow from the downstream Samson Brook catchment including McKnoe Brook enters the constructed drainage/irrigation system at the Southwest Highway where it may be diverted into Samson South Drain or into the Waroona Main Drain.

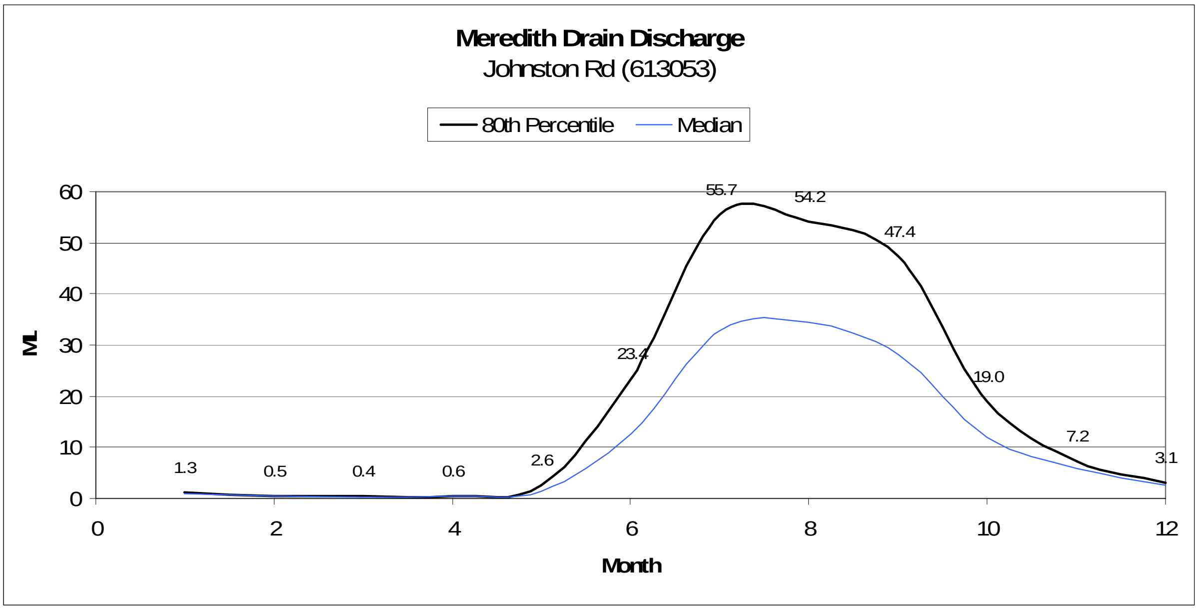
It has been assumed that this water will be allocated to Water Corporation for Perth's water supply or quarantined from use.

11. Bancell Brook at DS 10

Bancell Brook at DS 10. About 1.3GL/a available after application of the one-third rule.

12. Meredith Drain at 613053

Flows in Meredith Drain as highly seasonal with median annual flows of about 0.01GL (Figure 10) with a trend of decreasing median and 'high' flows (Figure 10).



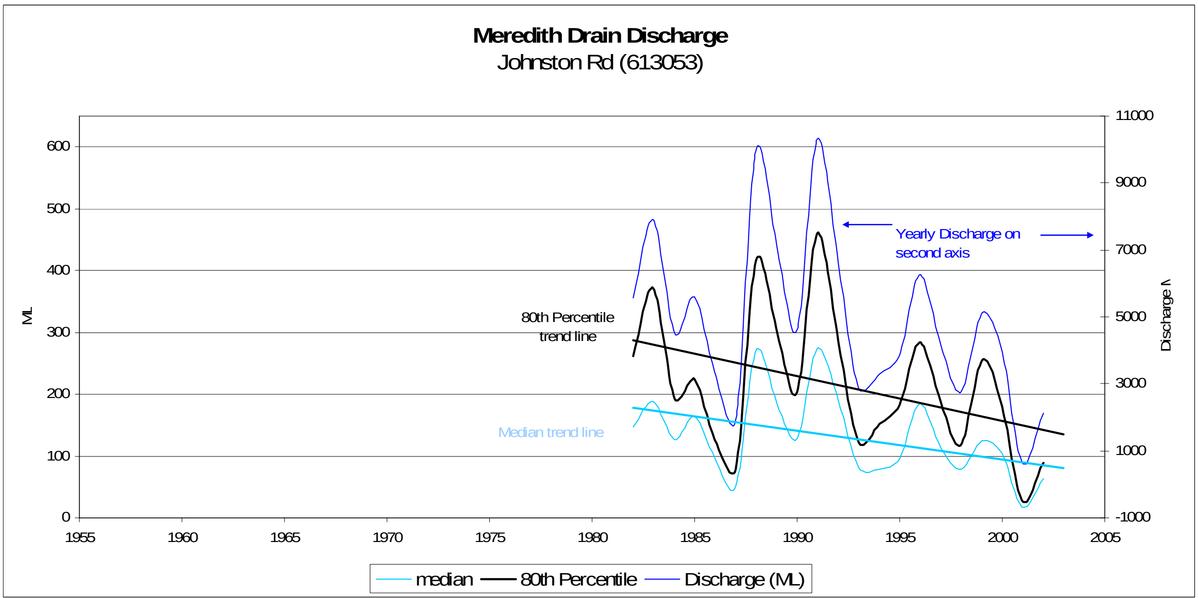


Figure 8. Analysis of the flow record in Meredith Drain (S613053). The top plot is seasonal flows (month is represented by 1=January and 12=December etc). The lower plot, shows the annual trends (as median, 80th percentile) in discharge (ML).

<u>Meredith Drain at S 613053</u>. Very little water available, even after application of the one-third rule. Not recommended as a reliable source.

13. South Samson Drain at Cooyah (S613023, SP12)

Table 6 shows the formal EWR assessment for the south Samson Drain. After this assessment, there is approximately 6.2GL available for abstraction.

Table 7. Summary sheet of environmental parameters and recommended flow regime for South Samson Drain, based on estimated EWRs after Streamtec (2000).

Cooyah, South Samson Drain, S613023 (SP12)		**Flow (ML) to maintain:**					
Month	Median flows '82-'99 (ML)	Channel form	River pools	Macro-invertebrates	Fish passage	Seasonal adjustment	Maximum
January	**108.3**		**11.2**	**15.0**			**15.0**
February	**92.9**		**10.1**	**13.5**			**13.5**
March	**108.6**		**11.2**	**11.2**			**11.2**
April	**157.6**		**10.8**	**14.5**			**14.5**
May	**259.7**		**11.2**	**15.0**			**15.0**
June	**1403.8**		**10.8**	**14.5**			**14.5**
July	**3022.0**		**11.2**	**15.0**		**156.8**	**156.8**
August	**2342.4**	**1,296**	**11.2**	**15.0**	**1,268**		**1,268.5**
September	**1303.0**		**10.8**	**14.5**	**1,310**		**1,310.8**
October	**463.3**		**11.2**	**15.0**		**161.3**	**161.3**
November	**257.0**		**10.8**	**14.5**			**14.5**
December	**137.8**		**11.2**	**15.0**			**15.0**

TOTAL ESTIMATED EWR = 3,010 ML/ANNUM TOTAL MEDIAN FLOW '82-'99 = 9,409.06ML/ANNUM

<u>South Samson Drain at SP 12</u>. Considerable water available. Site of limited ecological significance. About 6.2GL/a available. Recommended as a potential abstraction site.

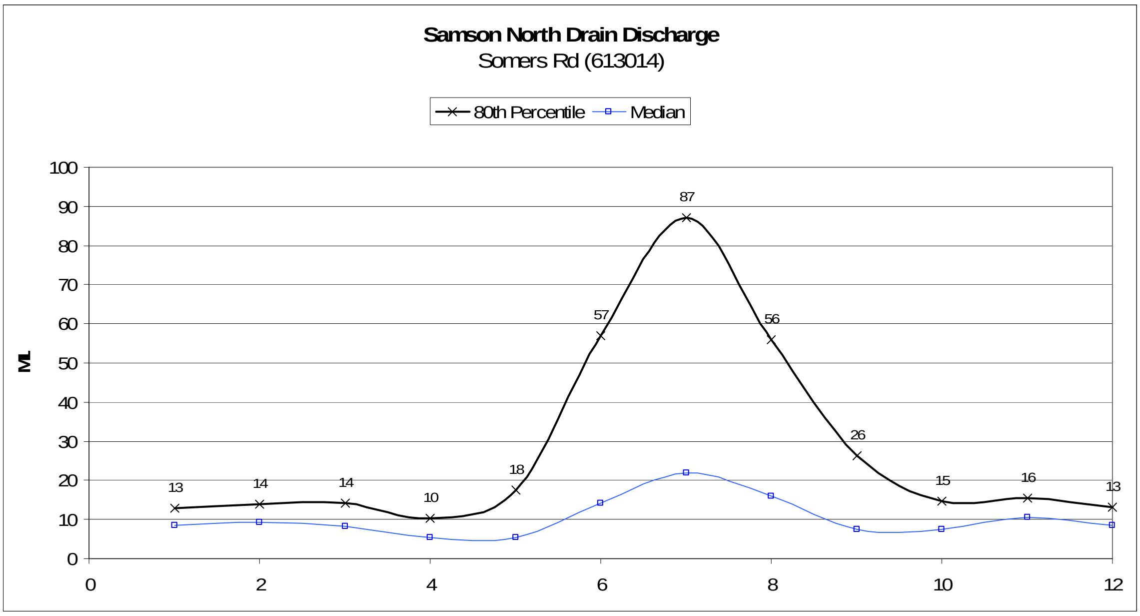
14. South Samson Drain at Deleos Farm (S613017)

Median flows in the South Samson Drain Deleos Farm, are about 0.015GL/a.

<u>South Samson Drain at Deleos Rd</u>. Limited water availability.

15. Samson North Drain at Somers Rd (S613014)

Median flows over winter in Samson North Drain (at Somers Rd) are approximately 7 GL. The trend at this site is for increasing inter-annual flows (Figure 10).



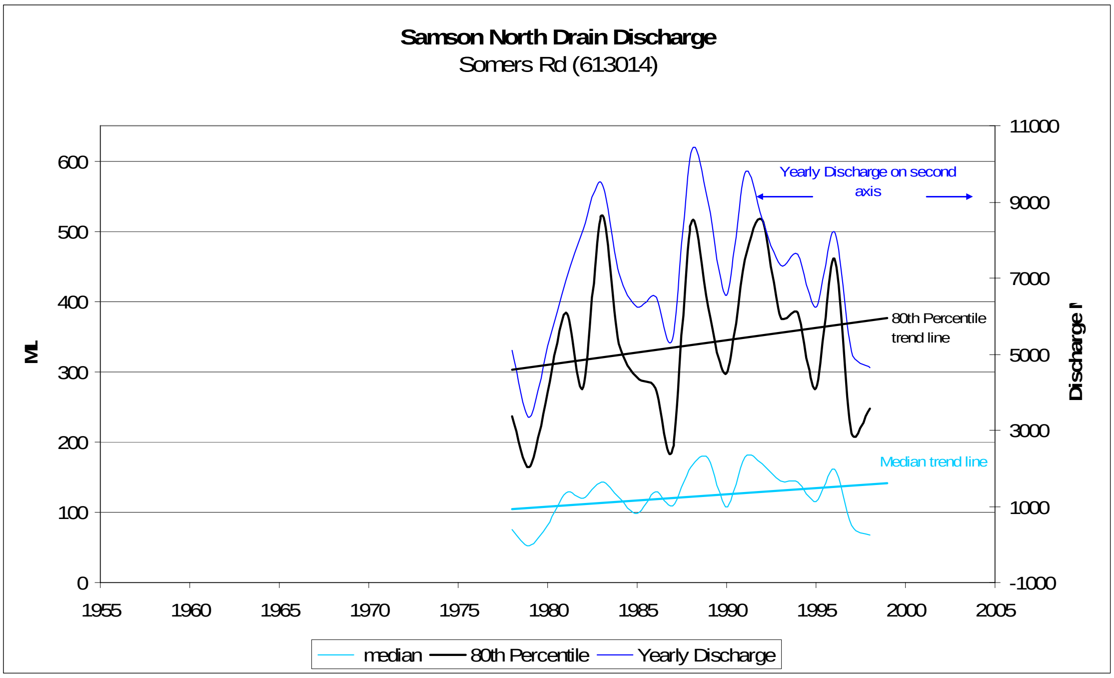


Figure 9. Analysis of the flow record in Samson North Drain (S613014). The top plot is seasonal flows (month is represented by 1=January and 12=December etc). The lower plot, shows the annual trends (as median, 80th percentile) in discharge (ML).

<u>Samson North Drain at Somers Road</u>. Approximately 5 GL/a available after application of the two-thirds rule.

16. Detention Pond

The Diversion Drain and Detention Pond were constructed in 1980, as part of the original long-term water supply strategy developed for the Alcoa Wagerup Refinery. Their design was based upon the anticipated closure of Samson South Drain, required to facilitate expansion of the residue storage areas. The water is used primarily as make-up water to the refining process, but also provides irrigation water for dust suppression on the residue drying-beds. The Detention Pond has a current storage capacity of 1,745 ML. The main source of water into the diversion drain above the detention pond is Black Tom Brook. At the junction with Samson South Drain an adjustable diversion structure (not Alcoa's) has been installed to prevent irrigation water that is released into Samson South Drain from entering the Diversion Drain. The same structures could be used to divert winter flow from Samson Brook including McKnoe Brook into the diversion drain and detention pond where the Diversion Drain joins the Samson South Drain.

<u>Detention Pond</u>. Limited water availability, about 0.6GL/a.

4. RECOMMENDED SURFACE WATER SOURCES.

Based on the assessment in Section 1, Table 7 summarises the estimated "extra" yield available (over the proposed "winter" months) and the basis for yield evaluation.

Table 8. A summary of the potential surface water sources. The shaded areas represent what could be priority areas for abstraction based on their (low) ecological values.

System	Sub-catchment	Estimated extra water availability	Basis of yield evaluation
Harvey River at Logue confl.	Scarp/Agricultural	24,800ML/a *	Spot measurements; Rule of Thumb (1/3 rule)
Harvey at Clifton Park 613052	Scarp/Ag	128,000ML/a	Formal EWR assessment
Harvey at Bristol Rd	Scarp/Ag	24,800ML/a	Rule of Thumb (1/3 rule)
Logue Brook at outflow (613175)	Scarp	7,500ML/a	Rule of Thumb (1/3 rule)
Clarke Brook at 613146	Scarp	260ML/a	Rule of Thumb (2/3 rule)
North Yalup Brook at SP1	Scarp	Nil	Formal EWR assessment
South Yalup Brook	Scarp	Nil	Formal EWR assessment
Black Tom Brook at DS 5	Scarp	1,800ML/a	Rule of Thumb (1/3 rule)
McKnoes Brook at DS 2	Scarp	3,500ML/a	Rule of Thumb (2/3 rule)
Samson Brook	Scarp	Nil	Formal EWR assessment
Bancell Brook at DS 10	Scarp	1,300ML/a	Rule of Thumb (2/3 rule)
Meredith Drain at 613053	Agricultural	~570ML/a	Rule of Thumb (1/3 rule)
South Samson Drain at Cooyah (613023, SP12)	Agricultural	~6200ML/a	Formal EWR assessment
South Samson Drain at Deleos Farm (613017)	Agricultural	Nil	Formal EWR assessment
North Samson Drain at 613014	Agricultural	5000ML/a	Rule of Thumb (2/3 rule)
Detention Pond at 613024, SP5	Scarp/Ag	~600ML/a	Rule of Thumb (1/3 rule)

∗ To consider this site as a potential water source, the difference between the gauged flows at Bristol Rd (1977-1986) and the present flows needs to be reconciled.

Based on Table 7, the preferred surface water supply option is the use agriculture run-off and return waters from drains in the lower catchment:

- *Harvey River main drain*
- *North and South Samson drain*

These sources are consistent with the recommendations of the "Proposed Harvey Basin Surface Water Allocation Plan" (Water and Rivers Commission 1998).

4.1 Long-term water sources

To source water for the Harvey catchment in the long-term, one option is for the use of efficiency gains of upgrades to the existing irrigation network. The Harvey Irrigation District is considered a region of considerable inefficiency of the irrigation distribution network. Any gains could be made available to downstream consumptive users. These gains make better-use of existing licences and, consequently, would have no impact on existing ecological condition. However it should be recognised that irrigation losses form a significant dry season base flow in some drains & streams. If the efficiency improvements mean that these losses no longer occur then some ecological changes are likely (*e.g.* some stream-zone vegetation loss). Therefore a long-term priority for increased water abstraction, based on environmental outcomes, of available water would be:

1. *Benefits from efficiency gains (fix the existing irrigation system)*
2. *Coastal Plain surface "drain" water (use lower quality water).*
3. *Scarp-derived water.*

The benefits of option (1) are difficult to assess and would be related to the extent and location of any restorative works. The high quality hill's water so gained may be utilised for public drinking water supplies in competition with industrial or further irrigation use (such as is proposed for efficiency gains already achieved). Depending upon growth in public demand and climate there may be a medium term opportunity for Alcoa to purchase efficiency irrigation water and in so doing underwrite the financial cost of the required improvements. To assess options (2) and (3), up-to-date hydrological data was analysed for a number of sites in the Harvey catchment.

4.2 Restoration planning

In many lower reaches, land clearing, intensive agriculture and uncontrolled livestock access to river channels has exacerbated erosion and nutrient enrichment. Therefore, EWRs should not be viewed in isolation from other river restoration issues, but should form part of an integrated catchment management (ICM) plan.

5. MONITORING PROGRAM

Comprehensive and scientifically sound in-stream flow recommendations can only be made where there is a sound knowledge of the river and its ecological systems, or where there is sufficient time to study and quantify responses to natural flow events before water developments are commenced. In the absence of sound ecological understanding (the usual case), the best available approximations of significant flow events and temporal patterns of flow must be used. Provision must be made within the budget of all water resource projects for these initial estimates to be refined and adjusted over time as the effects of the initial recommendations are monitored and/or special issues are researched in each river system (Arthington *et al.* 1992, 1993, 1994).

Therefore, the impact of flow regulation on the riverine ecosystem should be monitored in an adaptive management context (*e.g.* AEAM) as outlined below. A detailed monitoring program is recommended to assess the ecological adequacy of EWRs (see below) and should include hydrological, physical and biological parameters.

RECOMMENDED MONITORING REGIME FOR THE LOWER HARVEY		
Parameter	**Methodology**	**Sites/ Frequency**
Hydrology	Gauging station	Daily flows below the Alcoa pumping station at the Logue Brook/ Harvey River confluence[2]
Physical	Water quality sampling Pool aggradation Channel morphology	Every two months at four "nodes" Annually at areas within the four "nodes". Annually at areas within the four "nodes" (both banks).
Biological	Aquatic macroinvertebrates Fish recruitment Riparian assessment	Twice yearly ("wet" and "dry" seasons at the four "nodes"). Annually at the four "nodes" (coincide with breeding). Annually (summer) at the four "nodes".

[2] This recommendation is considered a priority.

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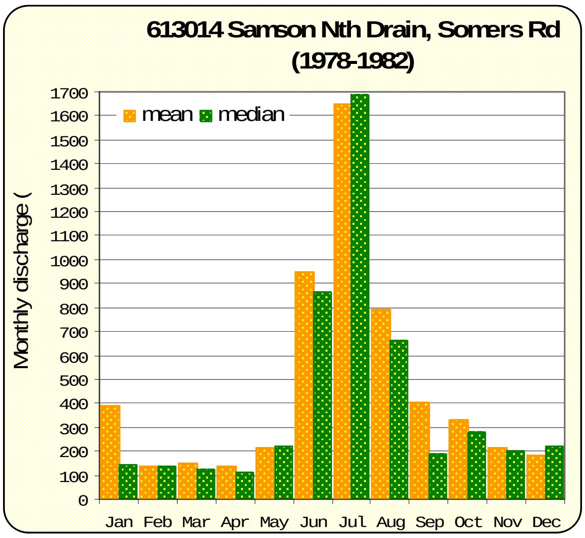
APPENDIX I. WRC gauging stations used: EWRs assessment for Wagerup.

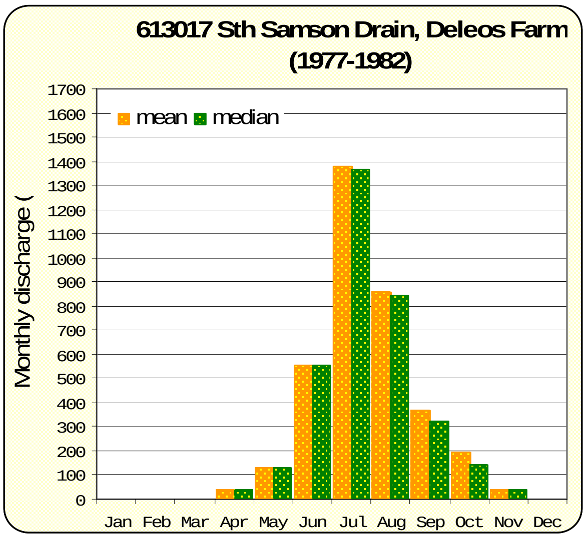
Gauging Station	*Brook*	*WRC Site name*	*Alcoa site name*	*Catchment*	*Catchment Area (km2)*	*Regulation*	*Clearing native veg.*	*Period of record*
613014	**Samson Brook**	**North Samson Drain, Somers Rd**	**-**	**North Samson Drain, north (upstream) of Wagerup.**	**17.5**	**Samson Dam, artificial drainage channels**	**~100%**	**1978 - 1982**
613015	**North Yalup**	**Yalup Brook, Springton North**	**SP1**	**Upper reaches of North Yalup Brook, upstream from Wagerup.**	**6.8**	**Pipehead Dam, Farm dams**	**~ 5% for orchards**	**1974 – 1982**
613017	**Samson**	**South Samson Drain, Deleo's Farm**	**SP7**	**South Samson Drain, north (upstream) from Wagerup.**	**17.3**	**Samson Dam**	**~100%**	**1977 – 1982**
613023	**Samson**	**Cooyah**	**SP12**	**South Samson Drain, west (downstream) of Wagerup; below junction with Diversion Drain but above junction with North Samson Drain.**	**48.5**	**Samson Dam**	**~100%**	**1977 - 1999**
613024	**Samson**	**Diversion Channel**	**SP5**	**Alcoa's detention pond & the Diversion Drain.**	**17.3**	**Detention Pond**	**~100%**	**1977 – 1999**

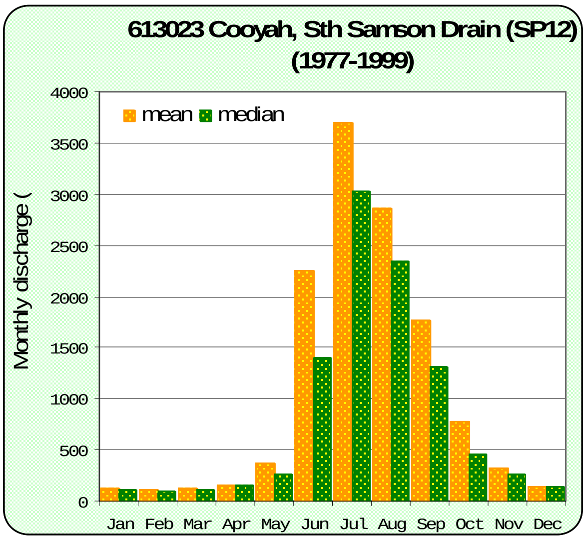
APPENDIX II. Summary of current and proposed surface water abstraction at Wagerup.

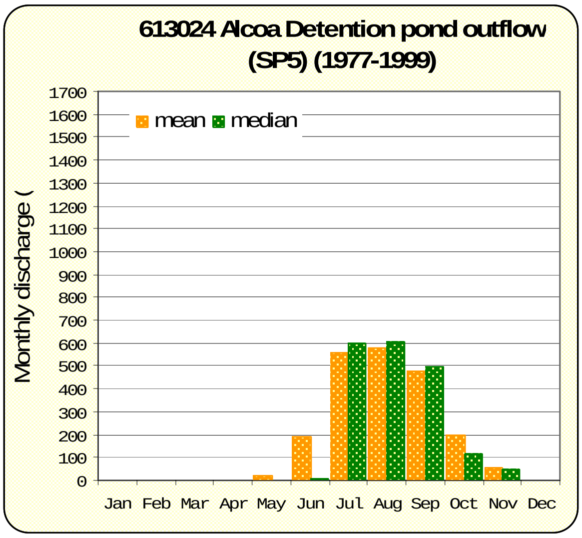
Dam	Catchment	Current storage capacity	Annual streamflow to dam	Annual outflow to South Samson Drain at Cooyah	Current average annual abstraction	Proposed average annual abstraction
Wagerup Dam	**South Yalup Brook**	**1,595 ML**	**Ave. 580 ML**	**-**	**580 ML (100%)**	**-**
Pipehead Dam	**North Yalup Brook**	**Not measured**	**Ave. 1,145.6 ML Median 1,050.07 ML**	**-**	**1,020 ML (89%)**	**-**
Detention Pond	**South Samson Drain**	**1,745 ML**	**Not measured**	**Ave. 12,438.4 ML Median 9,409.06 ML**	**1,745 ML (12.7%)**	**6,000 ML (48.2%)**

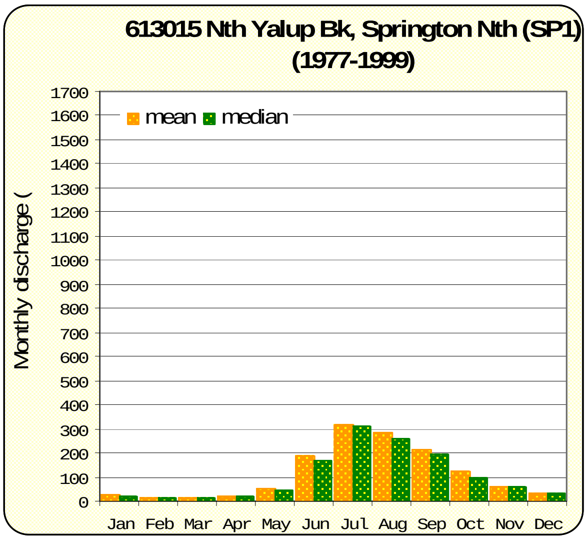
APPENDIX III. Hydrological analysis of key sites in the Wagerup region.









613015 Nth Yalup Bk, Springton Nth (SP1)
(1977-1999)
mean
median
Monthly discharge (
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

APPENDIX IV

Theoretical basis for the assessment of EWRs.

Initial assessments of EWRs for reaches in the lower Harvey River were set by *Streamtec* (1998). As part of this methodology, key components of the lower Harvey River ecosystem were first identified and their monthly water requirements then determined.

Water dependent ecosystems in the drain systems are more simplified. The drains have little ecological values due to a lack of in-stream habitat. However, drains are important as links between the lower reaches and the upstream, forested streams. This linkage is important for the upstream movement of migratory fish (*e.g. Galaxias occidentalis*) and for the downstream transport of carbon from forested zones to lowland food webs. This is described by the appropriate ecological model for the Harvey, the River Continuum Concept. Existing models of ecological processes differ in the interaction between a river and the catchment. The River Continuum Concept (RCC) (Vannote *et al.* 1980) emphasises an upstream-downstream linkage in energy flow, where material derived from forested regions "subsidises" downstream ecosystems. Reservoirs inhibit this upstream-downstream linkage in carbon flow. In these circumstances, the input from tributaries, below reservoirs is important to maintain the connectivity between forest and lower reaches.

Previous surveys of the lower Harvey have shown the system to be characterised by tolerant species of both fish and invertebrates which reflects the ambient environmental conditions. The lower Harvey River is a highly degraded system due to channelisation and straightening. The degradation of this system is due to an almost complete absence of both in-stream habitat and riparian vegetation.

Measurements of macroinvertebrate biodiversity in the Harvey system showed the catchment to be highly heterogeneous, with elevated biodiversity ("hot-spots") in the forested upland (first-order) streams (~ 70 "species"), moderately-low values in the lowland rivers (~20 "species") and extremely low values in drains and channelised regions of the Harvey River (<15 "species). The low values of biodiversity of the drains are a function of the lack of in-stream habitat and the absence of suitable riparian vegetation (Streamtec 1998).

No rare or restricted fauna were collected during a single-season sampling of the area. The aquatic fauna collected from the upland streams is well-represented in other systems in the northern jarrah forest (*i.e.* the North Dandalup and Serpentine catchments). In addition to catchment clearing, the hydrology is also highly-modified. Typically, the further a river system is removed from its historic hydrology, the more the ecological values are reduced. This has resulted in a reasonably degraded system typified by cosmopolitan, often generalist fauna.

Value/Feature	Qualitative EWR
Estuarine wetlands	Seasonal inundation (stimulus for seed-set and recruitment). Maintenance of existing salinity & water levels.
Riparian and floodplain vegetation	Seasonal inundation. Sufficient river flows for the maintenance & recruitment of vegetation intercepting river flows.
Estuarine fish	Sufficient water to maintain a diversity of habitats. River flows to stimulate recruitment. River flows transporting nutrients & other material from the catchment (see ecological processes).
Riverine fish	Sufficient water for reproductive migration. Water to inundate streamside vegetation during periods of spawning.
Aquatic macroinvertebrates	Flows that do not cause channel or bank erosion and pool aggradation. Flows that maintain a diversity of hydraulic habitats.
Ecological processes – energy/carbon linkages	An unregulated flow from forested regions to lower reaches (this maintains a downstream flow of carbon and other materials which subsidise the food webs of downstream ecosystems). Flows that do not result in river bed instability. With instability, primary production is low and nutrients are transported unprocessed into the estuary.
Channel maintenance	Flows that maintain the active channel morphology and scour aggraded material from pools without causing excessive erosion.

APPENDIX V. Plates of selected sites.

Samson Brook.
Active channel width = 5.9 m.
Discharge = 2.02 m^3/s.
Riparian assessment = B3 (weed dominated).
Q_{bf} = 53.3 m^3/s.
Slope = 0.0010. Manning's n = 0.056.
Fish=*Galaxias, Edelia, Tandanus.*

Harvey River upstream of the confluence with Samson Brook.
Active channel width = 8.9 m.
Riparian assessment = B3 (weed dominated).
Q_{bf} = 254.9 m^3/s.
Slope = 0.0011. Channelised.

Natural barriers to fish migration in the Yalup Brook system.

Artificial barriers to migration (Samson Brook).