Funded by the Centre for Sustainable Research Processing (CSRP)

# Towards Achieving Zero Liquid Discharge in Process Industry

Honours Thesis

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# Declaration

This thesis is presented to fulfil the requirements of a Bachelor of Science (Environmental Science) with Honours.

I, Alison Deanne Prior, declare that the information contained in this thesis is the result of my own research unless otherwise cited.

Signed

…………………………………………………….

A. Prior

10 November 2008

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# Abstract

Fresh water is invaluable in supporting life on Earth. It is scarce, cheap, and exploited. A number of initiatives have been taken to reduce the consumption of fresh water, particularly in agricultural and residential situations. In industry, much focus has been placed on pollution control and wastewater minimisation, however attention to source protection and water minimisation is nominal. The ultimate goal of any water management program is achieving Zero Liquid Discharge (ZLD). This research argues that with a current focus on pollution control and wastewater minimisation, ZLD is not attainable. Protection of water sources has recently been identified as the most critical issue preventing sustainability of industrial water management. It is also given the least attention. This thesis argues that incorporating water auditing and water conservation programs into industrial water management programs is a crucial step towards achieving water source protection and ultimately in achieving zero liquid discharge. A water audit of key water using operations at the BP Refinery in Kwinana has been undertaken to test this hypothesis.

The BP Oil Refinery in Kwinana is an example of an industry which has received much attention for its excellent practice in water management. BP has almost halved its total water consumption from 7ML/day in 1996 to 4ML/day in 2007. It has developed employee awareness-raising programs, on-site recycling and reuse of wastewater and is now in the final stages of using recycled domestic wastewater as a key water source, expected to minimise fresh water consumption even further.

Despite this, detailed analysis of the major water uses at the refinery show a number of poor management practices and severe wastages of water. In assessing the whole of refinery water use in Chapter 2, we see that poor record keeping and meter reading is commonplace. Major leaks are left unattended and information about major water-loss incidents is often unavailable. In Chapters 3-5 we look more closely at specific water using operations within the refinery. The refinery steam system is one of the largest fresh water users on site and has been commended for its steam trap survey program and the development of condensate return infrastructure, increasing the percentage of condensate returned from 32% in 1998 to a condensate return target of 50% in 2007. Despite this, major losses still occur in the steam system and turnaround time for fixing major leaks can take years. Simple measures can improve the condensate return rate from 50%-75% quite easily, but there are few incentives for the refinery to invest in such a program which offers diminishing returns. The use of water in process units is enormous, particularly the use of

scheme water in the Residue Cracking Unit. A number of available tools and techniques, particularly water pinch and water optimisation tools, are widely recognised to reduce water use on such units but have not been investigated at BP. Many water losses on process units occur because of poor operator management and a focus on increasing efficiency of feed throughput which offers the refinery the greatest financial return. Another inefficient water user in the process category is the Waste Management Area Land Farm. The land farm is irrigated to keep the moisture content of waste high. The exceptionally large volumes of water used in this area can be easily reduced, however costs are considered too high. Finally we assess other uses of water at the refinery. Other uses include commercial and domestic uses, safety showers and the staff carwash. Because of the extraordinary volumes of water used in the refining process, these other uses are considered comparatively insignificant. Practically no water efficiency measures have been taken at this level, and enormous wastages of high quality water are witnessed through our case study of the staff carwash. The carwash is an enormous water waste which uses scheme water once before it is discharged to the sewer.

Each of these case studies shows major inefficiencies in current water management at a number of levels at the BP Refinery in Kwinana. It is important not to forget that this refinery has been recognised for its excellence as a leader in water management not only in the Kwinana Industrial Area but also in the global oil refining industry. This reflects the inherent flaws in water management throughout industry. Chapter 6 assesses management implications associated with reducing water use on site and applies these principles and concepts to industry in general. The most significant barriers to closing industrial water loops were found to be neglect of protection of water sources and larger focus on pollution prevention and wastewater minimisation; misconceptions about the true value of water; and poor regulatory drivers to reduce water use. A paradigm shift in industrial water management to incorporate a more holistic approach is required if water scarcity is to be seriously addressed by industry.

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# Acronyms

| | |
|---|---|
| **ALKY** | Alkylation Unit |
| **AWWA** | American Water Works Association |
| **BAT** | Best Available Techniques (or Best Available Technology) |
| **BBN** | Boiler Blowdown |
| **BPRK** | BP Oil Refinery, Kwinana |
| **BREF** | BAT Reference Documents |
| **COC** | Cycles of Concentration |
| **CDU** | Crude Distillation Unit |
| **Cogen** | Kwinana Cogeneration Plant |
| **CR3** | Catalytic Reformer |
| **CSBP** | CSBP Limited (CSBP), part of the Wesfarmers Limited Group |
| **CSRP** | Cooperative Research Centre for Sustainable Resource Processing |
| **DEC** | Department of Environment and Conservation |
| **DM** | BPRK Internal Data Management System |
| **DW** | Drinking Water (also known as scheme water, or town water): describes water of a potable quality, is commonly used to describe water supplied by water utilities (e.g. the Water Corporation in Western Australia) |
| **IE** | Industrial Ecology |
| **IPPC** | Integrated Pollution Prevention & Control |
| **IWA** | International Water Association |
| **KIA** | Kwinana Industrial Area |
| **KIC** | Kwinana Industries Council |
| **KLPD** | Kilolitres Per Day |
| **KWRP** | Kwinana Wastewater Reclamation Plant |
| **P&ID** | Process and Identification Diagram |
| **PW** | Process Water |
| **MLPD** | Megalitres Per Day |
| **MLPY** | Megaliters Per Year |
| **NABERS** | National Australian Built Environment Rating System |
| **NAICS** | National American Industrial Classification System |
| **RCU** | Residue Cracking Unit |
| **SCW** | Salt Cooling Water |
| **SIC** | Standard Industrial Classification |
| **SGA** | Steam Generation Area |
| **SDOOL** | Sepia Depression Ocean Outfall Landline |
| **TPD** | (Metric) Tonnes Per Day |
| **WA** | Western Australia |
| **WHB** | Waste Heat Boilers |
| **WMA** | Waste Management Area |
| **WWTP** | Waste Water Treatment Plant |
| **ZLD** | Zero Liquid Discharge |

# Chapter 1: Industrial Water Conservation

The protection and provision of clean water has never been as challenging as it is today. Expanding and shifting populations, climate uncertainties and greater environmental regulations place demands at every point in the water cycle (Bailey and Searle, 2008). In industry, pollution control has been on the agenda since environmental management gained popularity in the 1970s. However it has now been widely recognised that pollution control alone is not enough. Source water supply and protection has recently been identified by as the primary concern facing the global water industry both in the short and long term (American Water Works Association, 2008). Source protection is an area which is poorly researched and often neglected by industry. Instead, focus has been placed on issues such as pollution control and wastewater minimisation, also known as 'end-of-pipe' solutions. The ultimate goal of any water and wastewater management program is closing the industrial water loop or attaining Zero Liquid Discharge (ZLD). ZLD is defined and discussed in detail in section 1.3.

In order to set the context for this research, the current situation in Perth, Western Australia is assessed (Section 1.1). The need for appropriate water management in industry, including current practice and understanding of industrial water management, is identified in section 1.2.  In order to assess current industry practice in water management a case study has been selected in the Kwinana Industrial Area (KIA). An introduction to the KIA is given section 1.4, and our case study, the BP Refinery in Kwinana (BPRK) identified in section 1.5. The need for this study, the study period, scope, aims and objectives are set out in Sections 1.6; 1.7; 1.8 and 1.9 respectively. The thesis statement is defined in section 1.10 and the structure of the thesis detailed in section 1.11.

## 1.1 Perth Environment

In Perth, repeated episodes of below average rainfall[1] have been experienced since the 1980s (Water Corporation, 2007). This has resulted in diminishing potable water resources and increased pressures on other water sources including groundwater which is drawn to supplement lower dam levels in water catchment areas. With few options for supplementary water supply, urban water users have had to seriously reassess their current levels of consumption and establish new and innovative methods for minimising demand for potable water (Water Corporation, 2007). To combat water scarcity in Perth, a number of initiatives have been taken by the Water Corporation, the state water utility. Emphasis is now being placed on using water from a range of sources, ensuring security through diversity[2], a practice which encourages using water that is 'fit-for-purpose[3]' (Water Corporation, 2007). Another major initiative being taken by the Water Corporation is the Waterwise Business Program[4]. This program legally requires all businesses using more than 20 megalitres of scheme water per year[5] to undertake a Water Management Assessment and to develop a Water Efficiency Management Plan (WEMP) identifying major scheme water uses and developing water minimisation projects subject to annual review (Water Corporation, 2007).

## 1.2 Industrial Water Use

The high standards of living experienced in Perth are supported by the processing and manufacturing of raw resources and materials in the process industries[6] (Verstegen, 2003). These industries represent a major portion of the world economy, with annual productions exceeding US$5trillion (Mann and Liu, 1999). Wastewater reduction and water conservation are increasingly

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[1] Refers to both frequency and intensity of rainfall.

[2] In planning for the State's water future, the Water Corporation has adopted a *Security through Diversity* approach that is now a strategic priority.

[3] 'Fit-for-purpose' refers to water that is of a quality appropriate for its intended use.

[4] These requirements have been legislated under the *Water Agencies (Water Use) Bylaws 2007* and are mandatory.

[5] 1 megalitre per year is equal to 1 million litres per year, known from here on as MLPY.

[6] Process industries include chemicals, petrochemicals, petroleum refining, pharmaceuticals, pulp and papers, metals and minerals, steam electric power and certain food and consumer products (Mann and Liu, 1999).

important issues in process industry, being driven by factors such as stricter environmental regulations, concerns about human and environmental health, and availability of “clean” water resources (Abu-Zeid, 1998; Dunn and Wenzel, 2001; Lambert and Boons, 2002). As a result of these changes, industry has made extensive progress in the development of systematic techniques for water reduction, reuse and recycling, with the ultimate goal of ZLD and the closing of industrial water cycles (Foo et al., 2006).

The concept of water conservation has been around since the 1950s but only started to gain serious attention in the 1970s when pressures mounted for industry to operate in a more environmentally friendly manner. Water conservation, as it is understood today, emphasises the long term focus on reducing water consumption and improving water use efficiency while maintaining quality of life standards (American Water Works Association, 2006). There are many ways to reduce water use on industrial sites. Water can perform a number of functions in production processes; a resource, means of heat transfer, or a medium for waste transportation (Liaw *et al.*, 2006).

The annual water volume used by industry globally is expected to rise from 752 km$^3$/year in 1995 to an estimated 1,170 km$^3$/year in 2025. Industry is therefore recognized as a major water user, with the United Nations Educational and Scientific Cultural Organisation (UNESCO) citing 59% of total water consumption in industrialised countries being withdrawn by industry (United Nations Educational Scientific and Cultural Organisation, 2008). Water has been a target for significant reform throughout process industry worldwide. As a consequence, water management is undergoing dramatic changes. In Australia, a National Water Initiative requires the establishment of clear pathways to return all systems to environmentally sustainable levels of extraction (Committee for Economic Development of Australia, 2007). In Perth however, only 3% of the city’s total scheme water is used by industry (Water Corporation, 2007). As a result industry has been neglected from many water conservation initiatives despite using significant volumes of water in the areas in which they operate. Industry can often be the single largest user of water in their local catchments

(Victorian Women's Trust, 2007; Pigram, 2006; ACIL Tasman, 2007). This is particularly true in the Kwinana Industrial Area, which is discussed in greater detail in section 1.4.

Over the last two to three decades, process industry in Australia and other industrialised countries has progressed from resistant adaptation to environmental standards, through compliance and beyond-compliance initiatives, where such offer competitive advantage (van Beers *et al.*, 2007). This creates exceptional opportunities for successful water auditing and conservation programs to be implemented in the Perth region.

Industrial water use is dependent on a number of variables, depending on the type of industry, its location and surrounding physical, legal and economic environment.  Different industries require water for specific purposes, and it can be difficult to adequately establish a water auditing technique that applies to all industries. Flow diagrams are recommended as the primary method of visual representation of water streams  (European Commission, 2003; Sturman et al., 2004). Figure 1 is laid out with water sources on the left hand side (pink); water-users in the centre; and water sinks on the right hand side (purple). While each industry has its own specialist requirements for water, there are generally thought to be three broad categories of water use: utilities (blue); process uses (green); and other (yellow) as shown in Figure 1 (Mann and Liu, 1999).This format will be followed throughout the remainder of the thesis.

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Figure 1: Three categories of industrial water consumption (Mann and Liu, 1999).

This division of industrial water use defines the structure of this paper, and is discussed in detail in Section 1.11: Structure. Today, industrial water consumption and disposal have become widely recognised as key environmental issues (van Beers *et al.*, 2006).

## 1.3 Zero Liquid Discharge

The ultimate goal of any water minimisation program is Zero Liquid Discharge (ZLD), or closing the loop on water use (Byers, 1995). Although the meaning of the term varies, ZLD has most commonly referred to a facility that discharges no wastewater to surface water. ZLD applies to the concept of a closed circuit of water, such that water disposal is eliminated altogether, that is zero 'liquid' discharge (Bagajewicz, 2000). In Europe, zero discharge is defined as being "…no continuous discharge during dry weather, allowing intermittent discharges, but rainfall run-off is allowed to occur…", whilst in Australia and the USA no discharge at all is permitted until after a storm of prescribed intensity and duration (Sturman et al., 2004). The defined intensity and duration of such a storm is dependent on the particular site and its operations (Byers, 1995). When discussing ZLD, three main options can be considered:

1. Reduce the volume of water used by each process;
2. Pollution control (contaminant removal from wastewater);
3. Reducing the volume of wastewater output (e.g. through increased reuse of water).

Each of these options results in water savings and reduces water pollution, leading industry closer to the ultimate goal of ZLD. This definition of ZLD is central to the hypothesis of this research, as described in Section 1.10.

A Water Minimisation Hierarchy (WMH) has been derived from the well-known waste management principles: “reduce, reuse, recycle” (Seneviratne, 2007). The WMH underlies the approach taken to testing the hypothesis, as it identifies avoidance of water usage and improvements in water efficiency and water minimisation as low risk and low cost approaches to water management. It encourages the principles of waste minimisation - avoid, reduce, reuse and recycle – to be applied to water management (Seneviratne, 2007). For clarification of terms, reuse water is defined as water discharged from one operation to be used as input to another operation, while recycling is defined as the reuse of water as input for the same operation that it was discharged from (Brouckaert and Buckley, 2000).

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**Figure 2. Water minimisation hierarchy (WMH) (Seneviratne 2007).**

Water conservation implies minimisation of water loss and improved water efficiency (Butler and Memon, undated). When properly planned and implemented, conservation programs can benefit industry greatly through more efficient utilisation of available water sources, public recognition and participation, and improved support for water pricing adjustments (American Water Works Association, 2006; Piet et al., 2002). This research focuses on the first two principles of the WMH which do not require water quality assessments, but rather focus on avoidance and minimisation of water use. This will be done through a series of water audits focusing on key processes within the BP Oil Refinery in Kwinana, as discussed in Chapter 2: Industrial Water Conservation.

## 1.4 Kwinana Industrial Area (KIA)

The Kwinana Industrial Area (KIA) is a cornerstone of the Western Australian economy. The KIA is located approximately 35 km south of Perth city and represents one of the largest concentrations of heavy process industries in Australia[7] (Kwinana Industries Council, 2006). Kwinana industries generate a significant percentage of Perth's annual output, employee earnings and total direct and indirect employment in the economy (Jones *et al.*, 2008). The KIA today consists of a diverse range of industries, from smaller service industries (e.g. fabrication and construction facilities) through to large heavy process industries such as the chemical and fertiliser manufacturers, and alumina, nickel and oil refineries (Jones *et al.*, 2008). Due to the historic isolation of Perth from major industrial centres, as well as the vast mineral and resource wealth of Western Australia, the KIA has grown significantly. The KIA today is a closely integrated industrial area with many industries sourcing products, materials and services from other KIA industries (Jones *et al.*, 2008). A graphical representation of the co-location of industries in the KIA is shown in Figure 3 (van Beers, 2007).

---

[7] Note that the Kwinana Industrial Area includes not only a variety of industrial operations, but also a residential area, parks and reserves, and a sensitive marine environment.

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Figure 3: Map of the KIA showing the close proximity of diverse industries (van Beers, 2007).

Kwinana industries consume vast quantities of water. The majority of water consumed by industry is groundwater, followed by water from a variety of other sources (rainfall, recycled water, storage ponds etc) (van Beers, 2007). It is estimated that the members of the Kwinana Industries Council (KIC) use approximately 18.7ML of scheme water per day, making close to 20% of the KIC's total water consumption (Figure 4).

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Figure 4: Major Sources and Sinks for KIC Member Industries in kilolitres per day (van Beers, 2007).

Figure 4 shows the total input and output water quantities of the Kwinana Industries Council (KIC) member companies as documented in the CSRP Kwinana Input and Output Database (van Beers, 2007). The 30 companies included in this study consume more than 35 gigalitres of fresh water per year. Scheme (potable) and bore water represent about 18% and 39%, respectively, of the fresh water input. About 24% of the outputs are evaporative losses, and an additional 23% of total water output is unaccounted for due to evaporation, lack of monitoring and data inaccuracy. These values indicate that there might be significant scope for condensate recovery and other measures to reduce water losses to the environment and also to enhance water monitoring (van Beers, 2007). Of the area's total water use, BPRK consumes a total of 1.5GL/year[8], making up approximately 4% of total KIC water use. When considering scheme water use on its own, BPRK uses 32% of the KIC total scheme water consumption. BPRK also discharges 29% of the KIC's total disposed process water into the Cockburn Sound as will be shown in Chapter 2:.

Limited access to water resources in the KIA is has been identified as a key issue restricting industry growth requires urgent attention if industry is to continue to operate and grow in a sustainable manner (Kwinana Industries Council, 2006). The groundwater in Kwinana has also reached its sustainable allocation limits for 2008. These limits must be strictly adhered to in order to prevent saltwater intrusion into the Tamala and Yarragadee aquifers (Kwinana Industries Council, 2006). To prevent such water crises from occurring, new and innovative ways to reduce freshwater consumption and protect available sources are required in the KIA to secure its water supplies for the future (Manan *et al.*, 2004; Kwinana Industries Council, 2006). Water consumption and effluent disposal by Kwinana businesses are key environmental issues addressed by the KIC. Over the past years, significant progress has been made towards the improvement of water consumption and disposal in the Kwinana region, both at the company level (eg on-site water efficiency assessments at various KIC member companies) and at the regional level (eg Kwinana Water Reclamation Plant). As such, protection of water resources and further development of the KIA is critical to the future of the Western Australian economy.

## 1.5 Research Case Study: BP Oil Refinery, Kwinana (BPRK)

The BP Refinery in Kwinana is the largest oil refinery in Australia, with a capacity of 6million tones of crude oil per year (BP, 2006). BP's production at Kwinana commenced in 1955 after the Anglo-Iranian Oil Company (later to become BP) acquired land at Kwinana (BP, 2006). The location and aerial plot of the refinery, as it is today, can be seen in Figure 5.

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[8] Excluding salt cooling water.

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**Figure 5: Map and Aerial photograph of the BP Refinery Kwinana (Google Earth, 2008).**

At present BP operates at capacity due to the large resources boom occurring in Western Australia. BPRK processes crude oil to manufacture products including petrol, diesel, liquefied petroleum gas (LPG), aviation gasoline, jet fuel and bitumen. 70% of the refinery's products are distributed locally and 30% exported (Kwinana Industries Council, 2005). The products supplied by the Refinery are essential to Western Australian transportation and industrial needs (BP, 2006). The refinery employs around 340 people directly, and approximately 200 others by contract. The number of staff on site varies greatly depending on current site activities and is discussed further in 5.1.2.2.

The BP Refinery is a major user of both scheme water and groundwater, and makes up a large proportion of the Kwinana Area's total water use. In 1996, BPRK was the largest single water user in Perth, consuming approximately 7,000kL of water per day. Water is extremely important in the refining process, with major uses being for heating and cooling, steam generation, cleaning of process equipment and removing impurities from product streams. Water is also necessary to provide facilities for employees such as bathrooms, showers, a laundry and a canteen. Water use by the refinery has major impacts on the wider Kwinana region which is facing large water restrictions due to growing demand for water by nearby industrial operations and a growing residential population. The refinery also has a significant impact on the nearby Cockburn Sound, a sensitive marine environment which receives the treated wastewater from BPRK as well as being the major source and sink for the refinery's salt water cooling system. The Cockburn Sound is the most intensively used marine environment in Western Australia (Cockburn Sound Management Council, 2008). Further details on BPRK's current and historical use of water are given in Chapter 2: BP Refinery Integrated Water Management.

## 1.6 Need for the Study

The need for a baseline assessment of water use at the BP Oil Refinery was identified by Professor Goen Ho in association with Dr Rod Lukatelich, the BP Environment Manager and Mr Chris Oughton from the Kwinana Industries Council (KIC). The Centre for Sustainable Resource Processing (CSRP) has supported this project and recognised the need for collating information about current water management practice of industry members of the KIC. The information will contribute towards a wider project funded by CSRP to identify opportunities for developing water synergies in the KIA using the Water Tool developed for the Kwinana Synergies Project (van Beers *et al.*, 2006). Despite the fact that BPRK is a major water user within this area, little is known about the refinery's internal water using processes.

## 1.7 Study Period

The audit examines water use at BPRK for the period 01/01/2007 – 31/12/2007.

Assessing water use over a one year period allows effective analysis and evaluation of the total system. One month or even six months is too short a time to give an overall picture of water flow through the system (American Water Works Association, 2006). By evaluating water use during a calendar year, the effects of lag time in meter readings are reduced and seasonal variations and unit shutdowns can be accounted for (American Water Works Association, 1999). Fieldwork for the water balance took place from March to September 2008. Direct measurements were assumed to be representative of 2007 flows unless otherwise stated.

## 1.8 The Water Audit: Scope and level of analysis

The water use at BPRK will be audited at a number of levels as shown in Table 1. The boundary levels are related to the structure of the thesis which will be detailed in Section 1.11. The levels are identified here to present scope limitations only.

**Table 1: Hierarchical Conceptual Systems Model applied to water auditing boundaries that can be applied to the BP Refinery Kwinana (*adapted from* Cote *et al*. 2007).**

| **Level** | **Scope** | **Details** | **Example** | **Chapter** |
|---|---|---|---|---|
| **Level 5** (regional) | Linked operations | Industrial ecology and regional synergy: interactions between geographically close entities. | Kwinana Industrial Area (KIA). | 6 |
| **Level 4** (primary) | Whole site as a single unit | Considered from the point of view of the overall inputs to and outputs from the site. | Primary audit of BP Refinery Kwinana (BPRK). | 2 (2.6) |
| **Level 3** (secondary) | Interactions between major site processes | System-level description of the whole site or operation. | BPRK integrated water system. | 2 (2.7) |
| **Level 2** (tertiary) | Interactions between unit operations | Unit operations are combined to form a process chain. This level considers interactions of water between unit operations within a given process chain or processing plant. | BPRK steam system. | 3 |
| **Level 1a** (unit) | (Process) Unit operations | Water consumption within an operation in the manufacturing process. | BPRK Residue Cracking Unit (RCU);<br>BPRK WMA land farm. | 4 |
| **Level 1b** (unit) | Non-process operations | Water consumption within non-process operations on an industrial site. | BPRK staff car wash. | 5 |

The scope of this project is limited because of the time constraints placed on an Honours year. Many issues were encountered with the study, including high levels of security at BPRK requiring a number of safety inductions to be completed before having entrance granted to the site[9] . Some time was also taken to secure access to the site, the internal data management system and to obtain a computer and desk space. The complexity of the refinery's water system and the process interactions on site have also meant that the water audit can focus on water volumes and flowrates only and not water quality. Time required to familiarise with refinery process operations and to organise meetings with engineers, operators and other site staff was significant. As a result, a case study approach has been used and set examples of each water use category as represented in Figure 1 has been used rather than analysing all refinery water uses. These units are representative of key water uses on site. The audit method can easily be transferred to a more detailed study in the future.

## 1.9 Aims and Objectives

The primary aim of this research is to determine whether water auditing and conservation programs can make a significant contribution to water source protection and assist industry in achieving ZLD. To achieve this aim, the following objectives have been set:

1. Complete a water audit of major water users at the BP Oil Refinery and update the 1997 flow diagram using 2007 data.
2. Present examples of process water uses, utility water uses and other water uses to show the complexity of water requirements within an oil refinery.
3. Identify issues in water management and conservation at BPRK and compare with barriers to current approaches to industrial water conservation.
4. Identify significant knowledge gaps in industrial water conservation in Perth and develop priority areas for research.
5. Determine limitations to achieving ZLD in industry.

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[9] Two safety inductions were completed by the author. Security passes and safety briefing sessions were organised by the author for the Murdoch University ENV206 student audit team who conducted minor audits at the refinery in May 2008.

A number of underlying research questions arise from this study:

1 Is water auditing the most effective tool for attainment of a closed industrial water cycle?

2 Is the assessment of water volume and understanding of baseline water use effective without concurrent studies on water quality?

3 Are the boundaries of a water audit confined to a single industrial site? Where and how are boundaries defined?

## 1.10 Thesis Statement

*Zero Liquid Discharge (ZLD) has traditionally focused on wastewater minimisation and pollution control. By incorporating source protection into water management regimes, ZLD becomes a more realistic goal for industries in Kwinana.*

## 1.11 Structure

The thesis determines whether water auditing can assist industry to achieve ZLD. Due to the complex nature of water use in oil and gas refineries, this thesis has been structured around a subset of the refinery's water-use data. The structure of the thesis demonstrates how auditing of industrial water uses can form a crucial step towards achieving ZLD. By assessing the refinery water use as a whole in Chapter 2, we can see the major water use and management issues at BPRK. More specific individual water uses are then audited in Chapters 3-5 to show how opportunities for water minimisation and efficiency improvements are easily achievable by conducting a water audit and identifying appropriate efficiency measures. Finally Chapter 6 discusses the management issues associated with water auditing and draws the whole audit together showing how water auditing is a crucial step towards achieving source protection and ultimately ZLD. A detailed breakdown of the structure of this thesis is given in Table 2.

Table 2

**Table 2: Thesis Structure**

| | |
|---|---|
| **Chapter 1:** Industrial Water Conservation | The need for water auditing and conservation in large industrial operations is introduced. The aims, objectives and research question of the study are defined and the structure for the remainder of the thesis set out. |
| **Chapter 2:** Integrated Refinery Water Management | The case study, BPRK, is introduced and trends in water management at the refinery are evaluated. Major water sources and sinks are identified through primary and secondary level water audits. Issues in integrated refinery water management are highlighted. Through a whole of refinery assessment, sustainability of water resource management at the refinery is assessed on a large scale. |
| **Chapter 3:** Utility Water Uses | Utilities include the cooling system and the steam system and are by far the largest water users in an oil refinery. The focus of this chapter is on the steam system at BPRK and identifies major steam uses throughout the site, discusses current management of the steam system and identifies management implications and minimisation opportunities. |
| **Chapter 4:** Process Water Uses. | Process units are unique at each refinery, and can consume large volumes of water. There are approximately 100 water using process units at BPRK, so our attention will be on the Residue Cracking Unit which is the largest water using process on site (and also the most complex). The methods used for quantification of water on the Residue Cracking Unit may also be applied to other water using process units at BPRK. |
| **Chapter 5:** Other Water Uses. | "Other" water uses include commercial and domestic (office amenities) usage, safety showers and the staff car wash. These processes use comparatively low volumes of high quality (potable) water. The staff car wash has been selected to demonstrate the inefficiency of water use within this category. |
| **Chapter 6:** Management Implications. | This chapter brings the audit into perspective by assessing overarching management structures and identifies common issues and implications affecting water conservation in large industrial operations such as oil refineries. This chapter determines feasibility of water auditing as a tool for water minimisation in oil refineries and concludes the study. Recommendations for further research and future work are given here. |

A common internal structure has been used for chapters 2, 3, 4 and 5 in order to facilitate the reading and understanding of the document. This was necessary as each of the three major water using categories requires a specialised approach. The structure has been set within these chapters as follows:

1 Introduction/background:
   a. Water use category (i.e. Whole Refinery, Utility, Process, Other);
   b. Identification of units that fit within the category;
   c. Water using process "case-study" chosen to represent the category.
2 Body:
   a. Method used for category/case study water audit
   b. Development of water flow diagram;
   c. Water input and output flowrates;
   d. Water balance where applicable;
   e. Discussion of issues and trends.
3 Concluding thoughts and analysis of system as a whole.

This structure is the most appropriate way to demonstrate the wide variety of processes within each category and to accurately portray the relevant methods used for water auditing of a large industrial site which has a wide range of water using processes and operations, particularly as each of these requires a unique approach to quantification of water volume.

# Chapter 2: BP Refinery Integrated Water Management

The oil refining industry is the cornerstone of a modern economy. Oil prices have significant influences on local and national economies throughout the world. Current global oil refining capacity is in excess of 11million TPD (82.5 million barrels/day) (European Commission, 2003). Refineries manage huge amounts of raw materials and products and are intensive consumers of water, particularly for refinery-specific processes and for cooling and heating purposes. In their storage and refining processes, refineries emit pollutants to nearby water sources, with major contaminants including oil products such as hydrocarbons, sulphides, ammonia and some metals (European Commission, 2003). The industry is unique in that both the processes used to refine petroleum and the products generated are subject to government regulation. Increasing regulation on environmental performance has encouraged inefficient refineries to be closed down, and remaining refineries to invest in new environmentally benign processes (Seneviratne, 2007). Refinery waste water treatment techniques are mature techniques, and emphasis is now shifting towards preventative approaches. Reduction of water use and/or the concentration of pollutants in the water can have effects in reducing the final emission of pollutants (European Commission, 2003). BP Limited is one the world's major oil companies and owns a number of refineries around the world and is an industry leader in environmental management as will be discussed in Section 2.1 (BP, 2004).

## 2.1 Case Study: BP Oil Refinery, Kwinana

The BP Refinery in Kwinana (BPRK) refines crude oil into a variety of end products including aviation gas, diesel, motor spirits, hydrogen and LPG. This occurs through a number of processes including separation (physical distillation and vacuum distillation); conversion (catalytic reforming, isomerisation, catalytic cracking and alkylation); purification (hydrotreating and sulphur plants); and blending of products to achieve various grades (BP Refinery, 2000). These processes will not be discussed in detail, but to assist in understanding of the refining process, a summary flowchart of crude processing at BPRK is shown in Figure 6.

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Figure 6: Simplified flowchart of crude processing at the BP Kwinana Refinery (BP, 2006).

Each of these units has varying requirements for water, and may include water for steam generation, wash water, fire water and other process-specific water needs. These uses are all classed as process uses. The refinery also requires large volumes of water for heating (i.e. steam generation) and cooling, otherwise known as utility uses. Water is also required to support staff on site, and is used in office buildings for domestic purposes, in the site laundry and canteen, for the staff carwash and for safety showers located near the refinery's process units. Typical major users of water in the refining process are shown in Figure 7, with all flowrates given in KLPD (Seneviratne, 2007).

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Figure 7: Typical water flows at a refinery in KLPD (Seneviratne 2007).

Figure 7 will not be discussed in detail here but instead is presented to give an idea of the typical flows of water found in an oil refinery. The major water users at BPRK are discussed in greater detail in section 2.1.1 below.

### 2.1.1 Water Sources

BPRK has five major water supply sources. The volumes of each of these water sources used at BPRK will be assessed in detail in the section indicated in brackets.

**Scheme water** (2.7.1) is supplied by the Water Corporation and is used within the Refinery where high quality water is required. The major uses of potable water within the Refinery cooling towers (that require water to replace what is lost through evaporation), boiler feed water (to generate steam) and office use for domestic purposes (BP, 2006).

**Bore water** (2.7.2) is ground water extracted onsite from the Yarragadee subartesian Aquifer and the Tamala Aquifer. Bore water is used as process water which may be topped-up with scheme water if necessary. Process water is used throughout the Refinery for uses that do not require high quality water such as sample cooling, pump jacket cooling, pump water seals, closed loop cooling circuits, process wash waters and fire water (BP, 2006).

**Salt cooling water** (n/a) is sea water extracted from Cockburn Sound and is used in a once through cooling system (BP, 2006). Salt cooling water will not be covered in this research. Some brief information about the system can be found in Chapter 3:Utility Water Uses.

**Cogen** (2.7.3) refers to the steam supplied from the neighbouring Kwinana Cogeneration Plant. The Cogeneration Plant produces steam as a by-product of electricity generation. BPRK purchases the steam and feeds it directly into its steam system[10].

**Rain and storm water** (2.7.4) is not harvested at BPRK, but is discussed as a potential source.

A proposed water source to be fully implemented by 2009 is **recycled domestic wastewater** from the Kwinana Wastewater Reclamation Plant (KWRP). This will not be assessed in this study as it was not in use during the audit year 2007.

### 2.1.2 Water Sinks

The majority of wastewater generated at BPRK is discharged to the refinery's Oily Water Sewer (OWS) system. The OWS collects process water, storm water run off and tank drainings and takes it to the refinery's centralised  Waste Water Treatment Plant (WWTP) (BP, 2006). Water from the WWTP is treated to a minimum standard determined by the Department of Environment and Conservation (DEC) license and discharged to the Cockburn Sound. Common sources of wastewater at BPRK include process waste such as condensate losses, boiler blowdown, cooling-tower

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[10] The Plant is a gas turbine Combined Cycle-Cogeneration plant capable of producing 2300 tonnes per day of process steam. Using waste steam from electricity production is a significant step towards the refinery's water use minimisation program as it not only reduces the need for high quality water, but also saves treatment costs, energy requirements and makes use of another industry's waste product (Bax, 1999).

blowdown, and wastewater from other uses such as housekeeping and stormwater runoff (Mann and Liu, 1999). Salt cooling water operates as part of a once-through system and does not require any treatment in the WWTP, though is held in tanks for temperature control before discharge back to the Cockburn Sound. The closed nature of the cooling system generally prevents contamination. Domestic wastewater at BPRK is collected in a number of septic tanks see Appendix 1: BP Septic System. No water from site is discharged to mains sewers.

## 2.2 BP Water Management: Pre-2007 Water Management

The water supply for the Refinery was potable water supplied directly by pipeline from Serpentine Dam (Hill's Water). BPRK conducted a water balance study in 1997/1998 to identify major water users and shortly after implemented a number of water minimisation programs. The water minimisation programme has a unique 'whole of refinery' approach to water conservation and has resulted in dramatic reductions in water use on site. The first step towards the implementation of the program was to conduct a water audit. The audit was completed in 1998 and forms the basis of BPRKs steps towards water minimisation (unknown author, 1998b). As a result BPRK received several awards and international recognition for its leading practice in water conservation. Awards received include the BP Downstream Innovation Award, the Water Industry Award in 2000, Minister's Award for Excellence and an Award for Water Treatment/Reuse. The water balance as at 1998 can be seen in Figure 8.

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Figure 8: BPRK Water Flow Diagram as at 1998 in kilolitres per day (unknown author, 1998a).

The diagram represents major water supplies at the top (black), major users in the row directly beneath (dark blue). Process uses and wastewater are both shown in blue, with losses in red and the steam system in green. Boiler blowdown and salt cooling water are shown in yellow. The diagram has major flaws, and takes a good understanding of the system in order for accurate interpretation. The distinction between estimated and measured flows is not clear, and the time period for flow measurements not defined. Rather than going into detail on the water using processes in this diagram, the diagram will be redeveloped using flow information from 2007 and presented in the latter half of this chapter (Figure 12). The essence of the field work for this research has been spent in updating and evaluating this diagram. The water-using processes identified in Figure 8 are discussed throughout the thesis.

## 2.3 Oil Refinery Benchmarks and International Water Management Practice

The Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques (BREF) for Mineral Oil and Gas Refineries was developed in 2003 and identifies environmental practice and benchmarks for petroleum refineries in Europe[11] (European Commission, 2003). BPRK currently assesses its fresh water use as a function of crude throughput against the performance of other BP refineries across the world. This information is compared with benchmarks given by the BREF to establish whether it fits within current guidelines (Figure 9). There has been an overall improvement in water use efficiency at BPRK in the past 15 years, with 0.62kL/tonne used in 1992 compared to 0.25kL/tonne in 2007 (BP Refinery, 2008a).

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Figure 9: Freshwater Efficiency of all BP Refineries (BP Refinery, 2008a).

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[11] The document will be referred to from here on simply as “the BREF”.

BP's Kwinana Refinery has the highest freshwater efficiency of all BP Limited's refining sites. This is largely due to the refinery's cooling system being a once-through salt water cooling system while other refineries are dependent on fresh water for cooling. When comparing freshwater use less cooling tower make-up, the refinery still performs well, but is not as efficient as the Nerelco site and is almost on par with the Bulwer, Castellon and Toledo refineries. Due to individual nature of refineries and varying techniques, processes and scale variations from refinery to refinery, the benchmarks are extremely broad and do not give adequate incentive for improving water conservation. The focus on freshwater reduction reduces incentive to minimise water consumed from other sources such as groundwater which is also important to conserve.

Similarly, BPRK's wastewater output is compared to other BP refineries as a function of crude throughput. BPRK has excelled in reducing its wastewater output, reducing volumes from

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Figure 10: Wastewater Efficiency of all BP Refineries worldwide (BP Refinery, 2008a).

The major water initiatives taken by BPRK to achieve such water savings are summarised in Table 3.

**Table 3: BP Refinery Kwinana water minimisation initiatives (Seneviratne 2007)**

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To assess the volume of water used at BPRK in 2007, and compare it to the 1997/1998 water audit, the methods discussed Section 2.4 were employed. These will assist in evaluating the success of the water minimisation initiatives in Table 3.

## 2.4 Methods

A water audit of BPRK water use was completed using data from the study period 1/1/2007-31/12/2007. These methods apply to the evaluation of water use for primary and secondary water audits, as identified in Table 1. The approaches to water auditing are standardised. Approaches for this water audit were in line with the methods used by four central authors Vickers; Sturman; Seneviratne; and the American Water Works Association (AWWA) (American Water Works Association, 2006; Seneviratne, 2007; Sturman *et al.*, 2004; Vickers, 2002). The methods used to assess flow rates for the construction of the updated flow diagram are presented in Table 3 -

Table 8. However general auditing principals used are summaries in Sections 2.4.1-2.4.7.

### 2.4.1 The Water Audit: Data Collection

The field component of the water audit can be divided into five major tasks:

1. Liaison and site familiarization;
2. Quantifying water supply;
3. Quantifying metered water uses;
4. Quantifying unmetered water uses; and
5. Quantifying losses.

Each of these tasks described briefly in Sections (2.4.2-2.4.7). Specific methods used to audit utility, process, and other water uses are given in Chapter 3: Chapter 4: and Chapter 5: respectively.

### 2.4.2 Liaison and Site Familiarisation

The information from previous water studies has been used at each case study and compared with current flow data. Implementation of previous water saving measures will be evaluated where appropriate. Knowledge of the water-using process and its water distribution network is important to gain a baseline understanding of water use in an industrial site and must be obtained before field work and flow measurements can commence. Process and Identification Diagrams (P&IDs) and Computer Aided Design (CAD) engineering diagrams were assessed in detail to establish flow networks for various water sources. Information was discussed with process engineers and operators for context and accuracy. On-site inspections and observation of water using processes and leaks were frequently carried out.

### 2.4.3 Quantifying water supply

Water sources were identified through discussions with environmental team and review of water monitoring records. Primary metered water uses at BPRK are scheme water and cogen. Flow to the refinery was recorded through meter checks in an intensive audit period from 8-14 September 2008 to determine baseline[12] water use. Meter readings were also taken on a monthly basis in order to update BPRK's water use records. The bore water supply is monitored continuously through BPRK's online Data Management system (DM system) discussed in Section 2.4.4.

### 2.4.4 Quantifying metered water uses

Authorised metered uses are those uses on site which are known (i.e. authorised) and metered. These are primarily identified using BPRK's internal Data Management (DM) system. All new pipelines at BPRK have orifice plate flow meters installed to ensure accurate and continuous measurements of water use through each pipe. The DM system records information sent from the flow meters and associates it with a tag. The information can then be pulled from the tag into excel spreadsheets. This was the main approach used for obtaining information about metered water uses at BPRK. Flow meter errors are common and often are not easily detectable. Due to the nature of the refinery's operations, it is difficult to conduct operation and maintenance on process units and therefore replacement/maintenance of orifice plates cannot be carried out regularly. As a result many flow meters at the refinery are faulty and reliability of some data is questionable. For information on flow meters used at the refinery, refer to Appendix 2: Flow Meters. Because of the time limitation of this study it is assumed that all flow meters are accurate. When information from flow meters is unavailable, the procedures outlined in Appendix 8: Data Management Errors are followed.

### 2.4.5 Quantifying unmetered uses

Many industries have good records of water supply to site. However, once the water passes through the boundary, its uses are often not metered unless there is a special need (American Water Works

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[12] Baseline water use assesses consumption during on and off-peak hours. The idea of a baseline assessment is that no water should be used at night time, and the resulting night-time flows could be mainly attributed to leaks.

Association, 1999). Examples of authorized, unmetered uses include irrigation, canteen use, laundry, and internal flows in process units, to name a few. Quantifying these flows depends largely on the end use. These will be discussed in association with unmetered processes such as the land farm and domestic water uses. Identification of such flows at the case study sites can be complex, particularly for the smaller flows. Unmetered uses were also assessed through discussions with relevant operators or managers, to find out type and frequency of use, and to determine the volumes used with each operation (e.g. sprinkler type and application rate for irrigation, washing machine brand and water efficiency in laundry's, dishwasher brand and efficiency in canteens etc).

### 2.4.6 Quantify water losses

Potential water losses at case study sites are identified and estimated depending on the type of loss. Most water losses can be attributed to the following causes:

- Malfunctioning distribution-system controls;
- Seepage and leakage;
- Unauthorised water use;
- Discovered leaks;
- Other leaks.

The total volume of water lost to unknown leaks can be determined by first of all accounting for all other losses and then subtracting them from total water loss. Assessment of losses is beyond the scope of this study.

### 2.4.7 Obtaining Closure

The quantitative heart of a water audit is to measure the quantity and quality of water outputs from within the boundary. The water outputs are compared with the water inputs to match within a pre-determined tolerance to regard the quantitative audit as satisfactory. Sturman et al. prioritise obtaining ‘closure’ as a key component of the audit (2004). This is calculated using Equation 1, derived from Figure 11.

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Figure 11: The form of the quantitative heart of a water audit (Sturman *et al.*, 2004)

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Equation 1: Obtaining closure (Sturman *et al.*, 2004)

The standard acceptable predetermined tolerance is usually set at 10%. This figure has therefore been used as a basis for obtaining closure in this project (Sturman *et al.*, 2004).

A water audit process review is attached in Appendix 9.

## 2.5 Results

The results are split into secondary and primary level audits. The secondary level audit is presented first as it is the major result of the water audit completed at the refinery this year. The limited scope of this thesis does not allow a full discussion on each of these flows to be entered into, so only select processes will be discussed in detail. In this chapter the flow diagram presented for the secondary level audit is broken down into a primary level audit showing the refinery water sources and sinks. These are each discussed in detail in Sections 2.7.1 - 2.7.5.

## 2.6 BPRK Secondary Level Water Audit

A flow diagram of major water uses at BPRK has been developed to represent data collected in the water audit. The flow diagram gives an "average" daily flowrate for each water-using process for the year 2007 as determined by the audit. A number of factors impact each flowrate and the variability and error associated with each are summarised in Tables 3-8. The processes, or water-using operations, in the centre of the flow diagram are colour coded by water-use category. Process uses are green, other uses are yellow, and utility uses are blue. The flow diagram does not represent all water flows on site, but accounts for all major flows. It is expected that all processes using more than 1% of the refinery's total water are represented. A more detailed audit would require further assessment and analysis.

The flow diagram in Figure 12 represents the average daily flows occurring at BPRK. The level of accuracy and variability of each flowrate (shown on the lines connecting boxes) is dependent on a multitude of factors. Each flow rate is shown in Table 4 (rain water); Table 5 (bore water); Table 6 (discharges to OWS and WWTP); Table 7 (Scheme Water) and Table 8 (Cogen and Salt Cooling Water). with the method of measurement and a reliability indicator given in adjacent columns. Reliability is based on the following confidence grading descriptors (*Performance Indicators for Water Supply Services*, 2000):

A – Highly reliable (based upon sound records of high quality data);

B – Reliable (good data but with minor shortcomings – some missing, old or dated data);

C – Unreliable (data based on extrapolation from a limited sample of actual data);

D – Highly unreliable (data based on unconfirmed verbal reports and/or cursory inspections or analysis).

Further discussion on flowrate variability and accuracy can be found in latter sections where indicated.

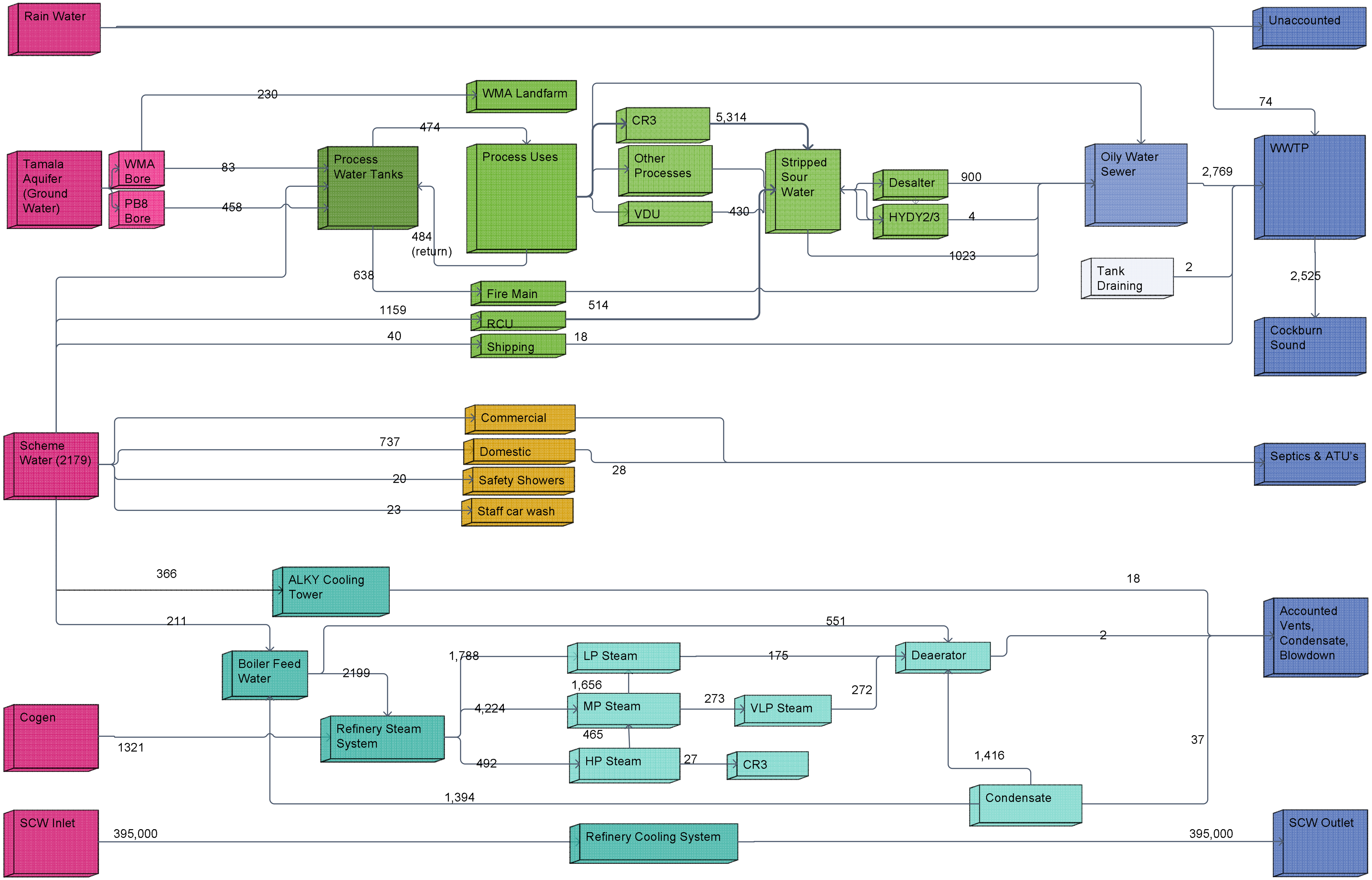

Figure 12: Snapshot of "typical" daily water use at BPRK during 2007 Flow Diagram for BPRK (all units in KLPD or TPD for steam system)

Table 4: Accompaniment to BPRK flow diagram (Figure 12): audit methods, flow rate reliability and accuracy for rain water.

| Source | Sinks | Reliability | Method | Variability |
|---|---|---|---|---|
| **Rainwater** | Unaccounted | C | Catchment area estimated on approximate land area (m$^2$). See Appendix 3: Storm and Rainwater. | Annual variations<br>Seasonal variations |
| | OWS | B | DM | Water from rainwater storage at WWTP recorded.<br>Stormwater runoff entering OWS not recorded. |

Table 5: Accompaniment to BPRK flow diagram (Figure 12): audit methods, flow rate reliability and accuracy for bore water.

| Source | Sinks | Reliability Indicator | Method | Variability |
|---|---|---|---|---|
| **WMA Bore** | Process Water Tanks | D | DM system.<br>Flow meter recording flows to process water tanks - excludes land farm irrigation.<br>Pipe breakage in 2007 (Section 2.7.2). | Scheme water make-up (emergency only);<br>Leaks (sporadic);<br>Use of bore-water pre-tank fill (subject to seasonality);<br>Bore closure. |
| **PBA Bore** | Process Water Tanks | D | DM system.<br>Water used for emergency/fire system prior to tank-fill. | As above. |
| **WMA Bore** | WMA Landfarm | C | Experiment: sprinkler catchment area and uniformity distributions (Appendix 6: WMA Landfarm). Sprinkler flowrates obtained from manufacturer. Application rates obtained via discussion with operator. | Application rates dependent on perceived soil moisture.<br>Seasonal variability.<br>Frequent pipe bursts.<br>Leaks common. |
| **Process Tanks** | Process Uses | A | DM system. Water leaving process water tanks datalogged. | Dependent on water use on process units.<br>Shutdown & maintenance |

| | | | | |
|---|---|---|---|---|
| | | | | of units have large impact. |
| **Process Uses** | Process water return | A | DM system. All process water returned through single pipe re-entering process water tanks. | Unknown. Further investigation needed. |
| **Process Water Tanks** | Fire main | D | Minor hydrant leaks estimated using direct measurement (stopwatch and bucket).<br>Major losses unmeasured. | Leaks and pipe bursts sporadic. Minor leaks have been audited in the past and quantified. |
| **Process uses** | Oily Water Sewer (OWS) | D | Unknown. | All units discharge an unknown quantity and quality of wastewater to OWS. |
| **CR3** | Stripped Sour Water | A | DM system | n/a[13]. |
| **VDU** | Stripped Sour Water | A | DM system | n/a. |

**Table 6: Accompaniment to BPRK flow diagram (Figure 12): audit methods, flow rate reliability and accuracy for wastewater discharge.**

| Source | Sinks | Reliability Indicator | Method | Variability |
|---|---|---|---|---|
| **Stripped Sour Water** | OWS | A | DM system | n/a. |
| **Desalter** | OWS | A | DM system | n/a. |
| **HYDY2/3** | OWS | A | DM system | n/a. |
| **Tank draining** | WWTP | A | DM system | n/a. |
| **OWS** | WWTP | A | DM system | n/a. |
| **WWTP** | Cockburn Sound | A | DM system (used for licensing purposes). | n/a. |

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[13] n/a: there may be variations associated with the data management system associated with error meter, daily variations, process unit shutdowns etc. Full assessment of process unit water use is beyond the scope of this thesis. Where data for certain periods was missing or unavailable, the methods described in Section 2.4 were employed.

**Table 7: Accompaniment to BPRK flow diagram (Figure 12): audit methods, flow rate reliability and accuracy for Scheme Water.**

| Source | Sinks | Reliability Indicator | Method | Variability |
|---|---|---|---|---|
| **Scheme water** | Process water tanks | D | Estimated by frequency of emergency scheme water supply to process water tanks. | Emergency only. One major incident in May 2007 when process water supply pipes burst. |
| | RCU | A | DM system | n/a. |
| | Shipping | A | WaterCorp records. | Dependent on jetty/shipping requirements. Sub-metered by BPRK. |
| | Domestic | D | NABERS Office Buildings Water Consumption Framework | Not applicable to industrial offices. |
| | Safety showers | D | Estimated | Affected by number of staff onsite.<br>Testing of safety showers increases with safety education. |
| | Staff car wash | B | Car wash metered.<br>Number and volume of washes estimated.<br>Leaks and post-wash drizzle estimated. See Chapter 5:Other Water Uses | Seasonal variation.<br>Changes with number of staff onsite.<br>Frequently broken down. Wind/rain triggers automatic sensor. |
| | ALKY cooling tower | A | DM system. | n/a. |
| | Boiler feed water | A | DM system. | n/a. |

**Table 8: Accompaniment to BPRK flow diagram (Figure 12): audit methods, flow rate reliability and accuracy for Cogen and Salt Cooling Water.**

| Source | Sinks | Reliability Indicator | Method | Variability |
|---|---|---|---|---|
| **Cogen** | Boiler Feed Water | A | Kwinana Cogeneration Plant Records | Dependent on refinery steam make, cogen supply and refinery demand.<br>2007 BP waste heat boiler went off line in October, so almost all steam was imported into refinery. See Section 2.7.3 |
| **SCW Inlet** | Cooling system & SCW Outlet | C | Dye test (2002). | Varies significantly according to refinery needs but not considered environmentally damaging therefore volumes based on estimates alone. |

A comparison of water use based on the water audit completed in 1998 and the current (2007) water audit is presented in Table 9.

**Table 9: Comparison of 1998 and 2007 main water uses at BPRK (KLPD).**

| Source | Sink | 1998 | 2007 | Change |
|---|---|---|---|---|
| Rain | WWTP | Unknown | 74 | n/a. |
| WWTP | Cockburn Sound | 5,200 | 2,500 | -52% |
| Bore water | Process Tanks | 1,600 | 541 | -66% |
| Bore water | WMA | 230 | 200 | -13% |
| Bore water | Process Uses | 2,840 | 474 | -83% |
| Scheme water | Refinery | 3,550 | 2,179 | -39% |
| Cogen | Refinery Steam System | 1,700 | 1,321 | -22% |
| Scheme water | ALKY Cooling Tower | 500 | 366 | -27% |
| Scheme water | Boiler Feed Water | 1,500 | 211 | -86% |
| Bore water | Fire main | 300 | 638 | 213% |
| Scheme water | Shipping | 70 | 40 | -43% |

The enormous reductions in water use over this period can be clearly seen in almost all aspects of the refinery's water use. The greatest reductions can be seen in the volume of bore water used in process units, the reduction of scheme water to boiler feed water supply and the volume of bore water to process tanks. Only one increase in water consumption was reported, which was the water to the fire system. It is expected that the reasons for such dramatic increase is not due to changes in use on the fire main, but rather in differences in auditing approach, particularly as the methods of the previous fire main audit are not known. However leaks in the fire system may have also been a significant contributor. The key water sources and water sinks will be considered in depth throughout the remainder of this chapter.

## 2.7 Primary Water Audit

To summarise the main sources and sinks, a primary audit of the refinery's water use for the 2007 calendar year has been completed (Figure 13).

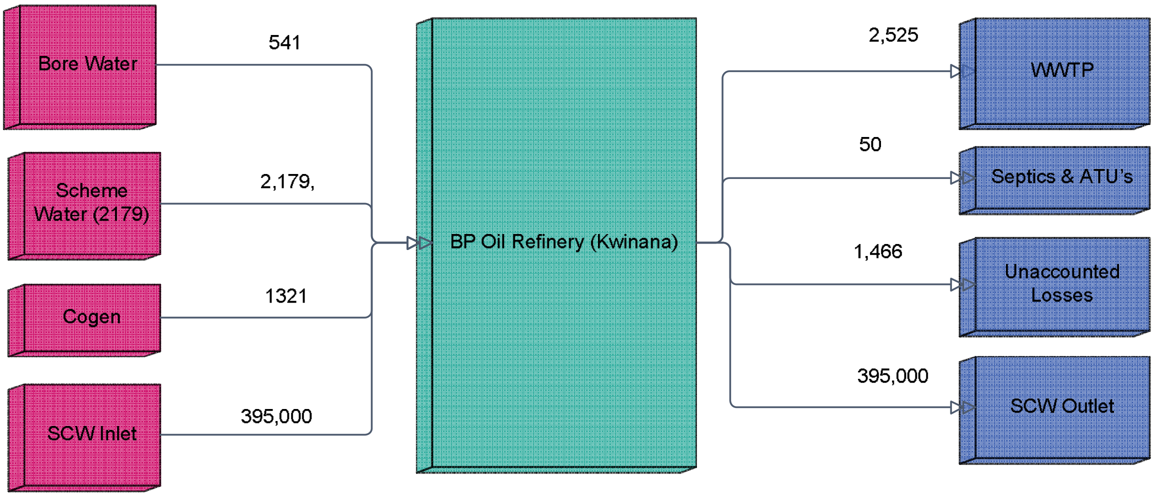

Figure 13: 2007 major water sources and sinks for BPRK.

Estimated inputs to the refinery are approximately 4.041MLPD, with outputs estimated at 2.575MLPD, excluding Salt Cooling Water (SCW). This means that approximately 1.5MLPD of water is unaccounted for, giving us closure of 36%. Usually closure should be within a predetermined tolerance, typically around 10%. A number of factors could be responsible for this apparent “loss” of water within the refinery. Internal recycling, reuse and regeneration reuse can significantly reduce wastewater output. Losses to evaporation, grade (i.e. groundwater, runoff etc), leaks and atmospheric vents are also major factors. The fluctuations in source water supply throughout 2007 are shown in Figure 14.

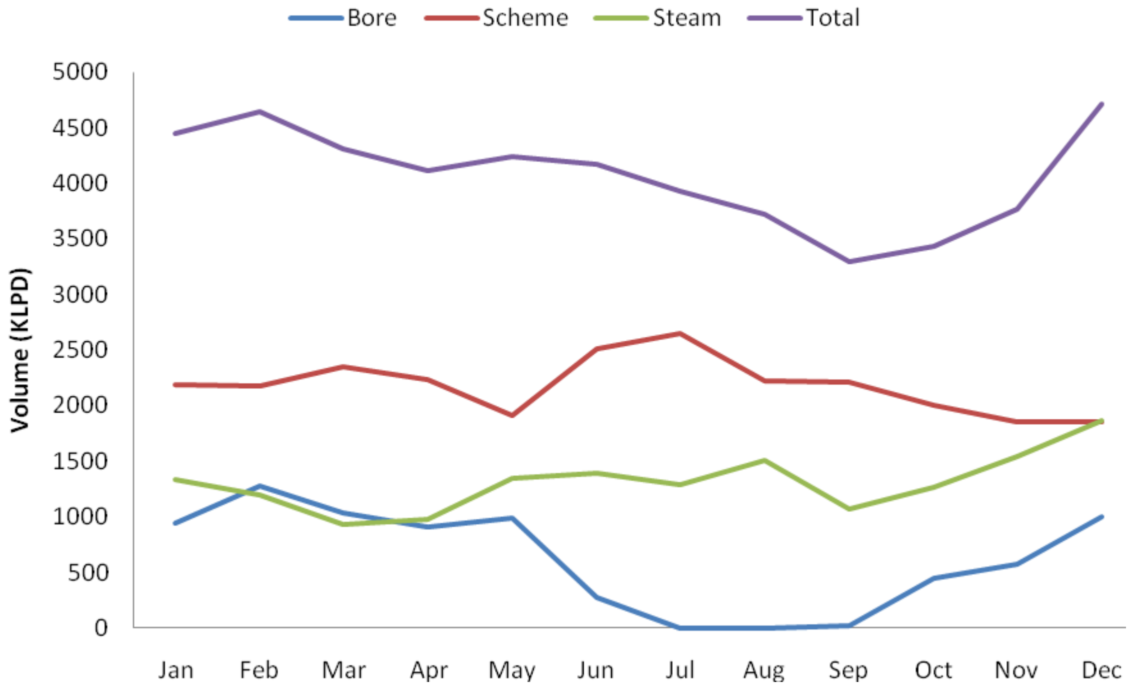

**Figure 14: BPRK Water consumption by source (excluding Salt Cooling Water).**

Analysis of each major source can be seen in Sections 2.7.4 - 2.7.6.

### 2.7.1 Scheme Results

Scheme water use is monitored by two 300mm positive displacement meters at the BPRK boundary. It is the largest water supply to BPRK with approximately 2-2.5MLPD being used on site. Figure 14 shows the volume of scheme water used at the refinery significantly increasing in May 2007. This was due to an emergency scheme water fill of the process water tanks after a truck crashed into the main bore water inlet. This is discussed further in Section 2.7.2. Scheme water use then returns to normal levels in August before slowly dropping for the remainder of the year. The decrease in scheme water use from October is related to the reduced requirement for scheme water for steam generation on the Carbon Monoxide Burner on the Residue Cracking Unit. More information about this is given in Section 2.7.3.

Meter readings are taken irregularly due to confusion about whose role it is to read the meter. This has resulted in poor recording of monthly water use. The water conservation team do not access the Water Corporation bills which detail monthly water use as determined by meter readings by Water Corporation staff. Instead the meter readings taken by BP staff are irregularly updated and information usually extrapolated to estimate average daily water use. The information recorded by BP staff was used for this audit. An intensive scheme water audit was also completed between 8-14 September to establish baseline water use.

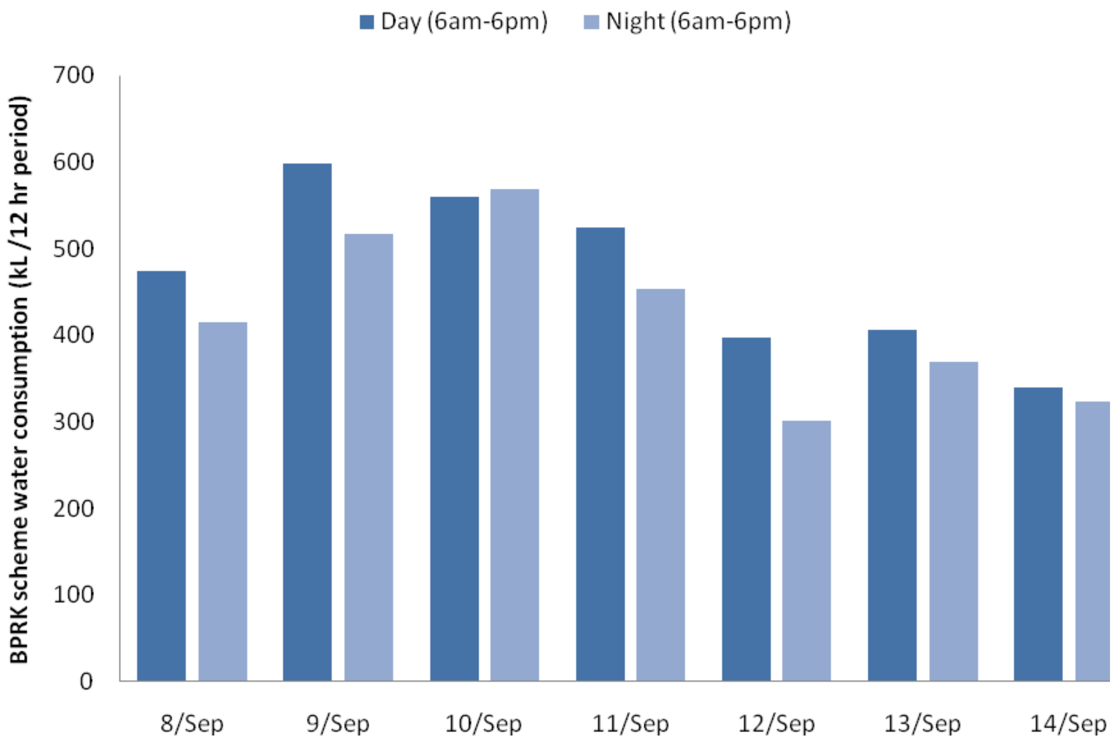

Figure 15: Scheme water audit results for BPRK as recorded on the 8-14 September 2008.

Major uses of scheme water at BPRK include office and hygiene uses including bathrooms, laundry, and lunchrooms. It is expected that as these are generally not in use during night-time periods when numbers of staff onsite are low, that scheme water use would be significantly lower at night reflecting the reduction in domestic and commercial uses. This is what is known as a baseline assessment, usually used to assess building leakage during off-peak hours. In order to effectively determine whether

It was also important to assess the number of staff on site over the period of a working day to establish whether scheme water use increases dramatically with increased staff population at the refinery. The number of staff at the refinery throughout the work week 8-12 September 2008 is displayed in Figure 16.

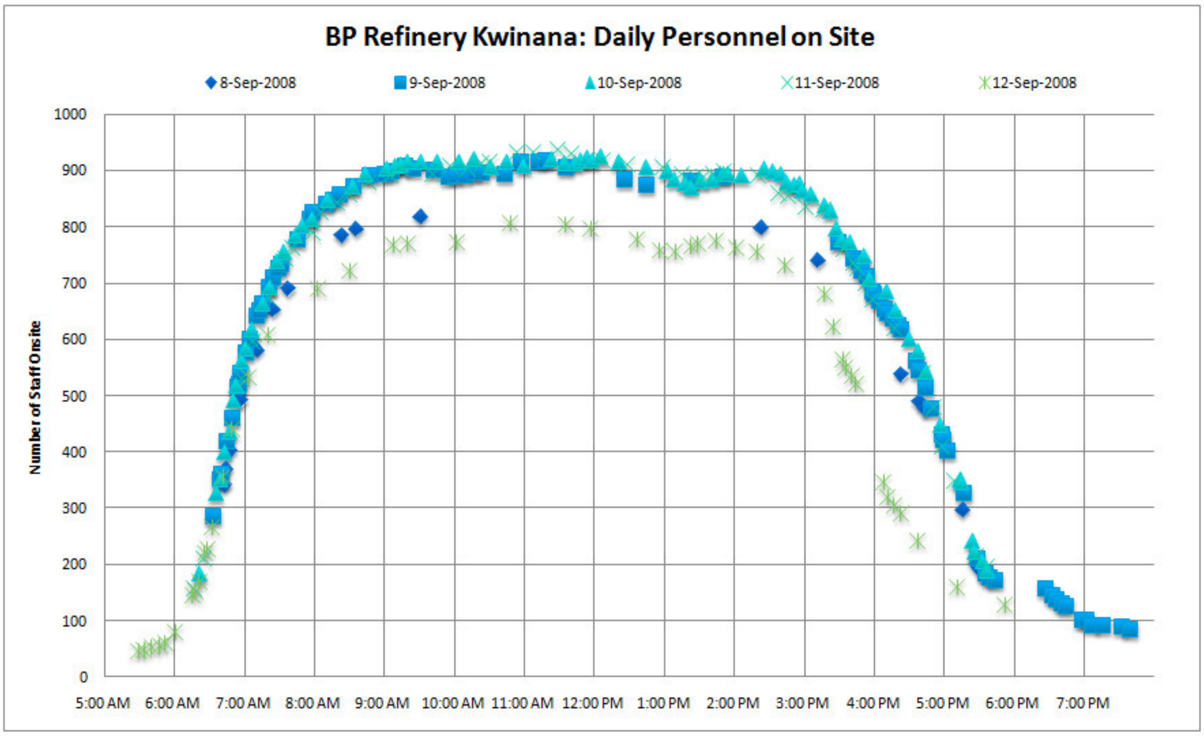

Figure 16: Number of staff at BPRK for the audit period 8 Sep-12 Sep 2008.

The number of staff present at the refinery during work hours was plotted by regularly checking the online system which records current numbers of staff at the refinery. The system is able to report current staff numbers but does not log this information over time. The process of recording staff numbers against time of day was tedious but shows a clear trend throughout the week of an 8am-3pm peak period and a minimal number of staff on site between 7pm-6am. This information can be used to compare with the audit meter readings.

In general daytime scheme water consumption is higher than night time, with the exception of 10/Sep. The additional use of scheme water during the day ranges from 16-100KLPD. The variability in scheme water flow required on process units and for cooling tower make-up makes it difficult to relate scheme water use directly to domestic water consumption without conducting a detailed assessment of all other scheme water uses on the same day to determine how much water is used for other processes and how much is for domestic purposes. Without sub-metering of domestic and commercial scheme water on site it is difficult to assess the flowrates accurately. Domestic water uses are typically neglected from water conservation studies within industry, and BPRK is no exception to this. When looking at the daily increases in scheme water when compared to night it is obvious that domestic uses are comparatively low when scheme water is also used for cooling tower make-up and other process uses.

### 2.7.2 Bore Water

The Refinery uses 3.5 - 5 kL/day of process water. Variations in flow are a function of Refinery operations (operational and maintenance) and weather conditions. Process water is used in Refinery services that create intimate contact between the water and hydrocarbon or other process streams. For example, process water is used to strip contaminants from some process streams, used to clean vessels, or can be generated from stormwater that has fallen on process areas (BP Refinery, 1992). Other uses of process water include water in sample coolers, cooling water for pumps, general cooling water, wash water, seal water and as a water source for hoses (unknown author, 1998b). Process water is a combination of bore water, scheme water and steam condensate, and usually has a low dissolved salt content. Raw process water is collected in the Refinery's water feed tanks[14] and is treated with sodium hypochlorite. Where possible, uncontaminated water and steam condensate are recycled in process water tanks (BP Refinery, 1992). 2007 flows into the process water tanks are summarised in Figure 17.

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**Figure 17: 2007 BPRK average daily flows to process water tanks (BP Refinery, 2008a).**

There are some fundamental issues in BPRK's 2007 bore water flow data. Metering of bore water flows into the process tanks is limited. BPRK usually operates four bores, of which one is metered[15], and the others which are monitored as a sum of total bore water input into the process water tanks. As only two bores were working during 2007, the input volume of the other working bore (the WMA bore) was calculated by subtracting the flow from PB8 from total bore water input to the process water tanks. The process water return metered and results imported from the BPRK DM system. Data can be viewed in Appendix 5: Process Uses.

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[14] The refinery feed water tanks, numbered Tank 24 and Tank 25 are known from here on as "process water tanks".

[15] Process Bore number 8 (PB8) is metered as it is a new bore.

In June 2008 there was a major incident with a truck crashing into the main bore water supply line to the process water tanks. As a result much water was lost and the bores were not used again until August. Process water tanks were filled with scheme water while the pipe was repaired, but the bore water supply to tanks was not fully reinstated until 2008. A large volume of process water is recycled to the tanks and combined with process water for reuse.

### 2.7.3 Cogen

The steam system is not considered in detail here as a Chapter 3:Utility Water Uses assesses the use of steam within the refinery. However, the volume of steam imported from the Kwinana Cogeneration Plant[16] imported in 2007 is assessed here briefly.

A noticeable increase in the volume of Cogen imported in the period 22/10/07 to 18/12/07 is seen as import increases from 1259TPD on average in October to 1861TPD average in December. This occurred because of a failure with one of the refinery's Waste Heat Boilers (WHB); the carbon monoxide boiler (COB). As a result on-site steam production decreased and import of steam from cogen increased.

### 2.7.4 Rain and Storm Water

Stormwater management can be a difficult issue to deal with on large industrial sites, and contamination with process water and other chemicals on site is common. Rain water is a clean water source available to industry, however costs associated with harvesting and storage are often large and outweigh perceived benefit of collecting rainwater. At BPRK, rainwater falls on to three main areas:

1. Process Areas (tanks and process units);
2. Offices and car parks;
3. Impervious surfaces comprising the remaining land area of the refinery.

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[16] Known from here on as "cogen".

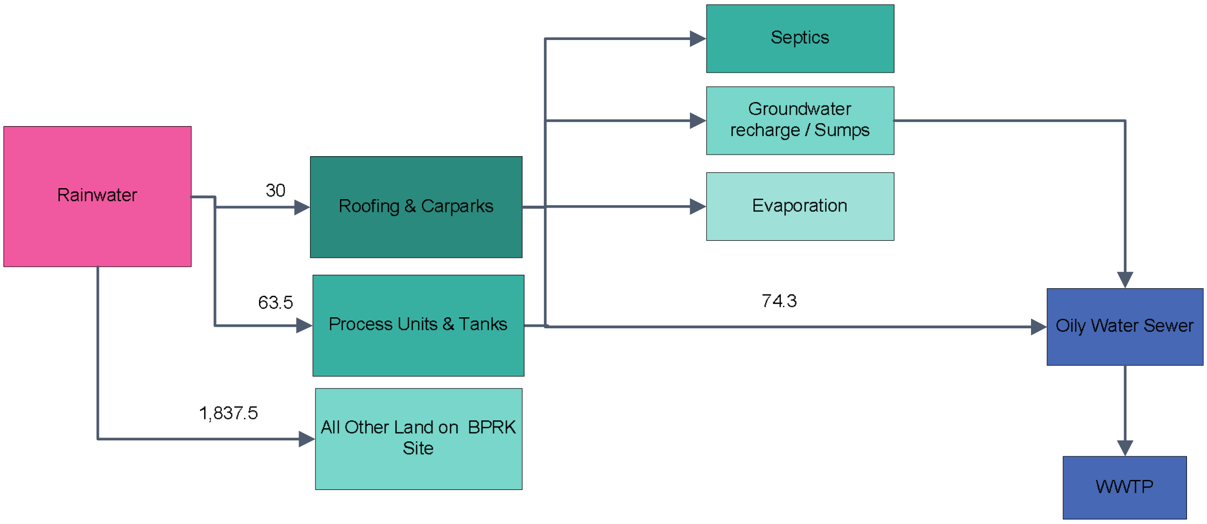

**Figure 18: Annual Rainfall and Stormwater Runoff Available at BPRK in 2007 (KL/year).**

The area of each of these zones has been calculated depending on level of permeability. Realistically, the rainfall available for harvest is estimated at 93.5kL/year using rainfall data from 2007. If rainfall availability was calculated using the area of the whole refinery then almost 2,000kL of rainwater was available to the refinery for 2007. Creating a rainfall catchment for the entire area is not viable with present technology and is therefore not considered as 'available' to the refinery. Of this total rainfall available to the refinery, approximately 74kL was recorded as a metered flow to the refinery's WWTP (from refinery stormwater tank 806). For more detailed information about rain and storm water view Appendix 3: Storm and Rain Water.

### 2.7.5 WWTP

Wastewater generated per ton of crude ranges from 0.01 to 0.62 $m^3$/ton of crude (0.36-22.3 U.S. gal/barrel). The Oily Water Sewer (OWS) collects water from all process operations including sour water, water from desalters and contaminated oily water. The OWS does not collect sanitary waste or storm water collected in bunded areas, tank farm floating roofs and roofs of buildings in the green zone. Rainfall collected on the Refinery units paved areas drains into the oily water sewer by gravity with the process effluents. It is essential that sources of wastewater discharged to the OWS are understood, to assist trouble shooting in the event of a significant increase in the hydrocarbon flow or a potential contaminant to downstream operations of the WWTP. Refinery procedure includes details of the contaminant load of each unit. The storm water surge system is to be used to store unusual flows and contaminant loads to prevent shock loading of the WWTP.

Wastewater is generated from a number of process units. The process units that contribute the most wastewater are crude distillation[17], the RCU (discussed in detail in Chapter 4:) and catalytic reforming[18]. A well designed and operated refinery could generate only 0.4m$^3$/ton (Seneviratne, 2007). Refineries produce four types of wastewater. These are:

1. Process water (desalter wash water, sour water);
2. Surface water runoff (storm water);
3. Cooling water, boiler water blowdown and pre-treatment of ion exchange units; and
4. Sanitary wastewater.

Reuse potential of wastewater should be thoroughly assessed by competent staff to determine opportunities for reuse either within the refinery or by nearby organizations. Unit operators and engineers generally know the volumes and quality of water discharged from their unit to the Oily Water Sewer (OWS) system. This information is generally not shared with others on site and is only investigated if problems occur within the WWTP and the source of an specific contaminant or increased flow needs to be sought. Currently sour water, oily water and stormwater are being mixed with other wastewaters of varying quality before treatment. Understanding of wastewater qualities is required for maximum effectiveness, and knowledge about minimum input requirements for process operations is crucial for improvement of BPRK’s water management. A previous internal study at BPRK estimated a composite of flows to the OWS. By applying these figures to the total volume received from the OWS, wastewater flows at BPRK for 2007 have been estimated (Table 10).

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[17] Crude Distillation Units (CDU1 and CDU2), particularly the desalter, a process within the CDUs which requires a lot of washwater for removing solids and contaminants from crude oil.

[18] The catalytic reformer at BPRK is known locally as the CR3.

Table 10: Estimated Wastewater Volumes

| Wastewater Source (by unit) | 2007 (KLPD) | |
|---|---|---|
| Desalter | 267 | 10.66% |
| Hoses | 332 | 13.27% |
| Boiler Blowdown | 430 | 17.21% |
| Other | 313 | 12.52% |
| Condensate | 119 | 4.77% |
| Floor Drainings | 84 | 3.37% |
| Boiler & Pump Seals | 216 | 8.63% |
| Washwater, Backwash & Scrubbers | 124 | 4.95% |
| Tanks | 112 | 4.48% |
| Sour Water | 277 | 11.08% |
| Vac Tankers, HYDY, Bitumen | 50 | 2.01% |
| Ship Slops | 176 | 7.06% |
| | **2500** | **100.00%** |

The wastewater sources identified in this table are by no means comprehensive as significant wastewater produces such as the RCU and CR3 have not been estimated as part of this study. However it gives some idea of the volumes of various wastewater sources that are being discharged to the OWS. Once treated at the WWTP, the water is discharged to the Cockburn Sound. Contaminant levels are monitored closely and are regulated by the Environmental Protection Authority (EPA).

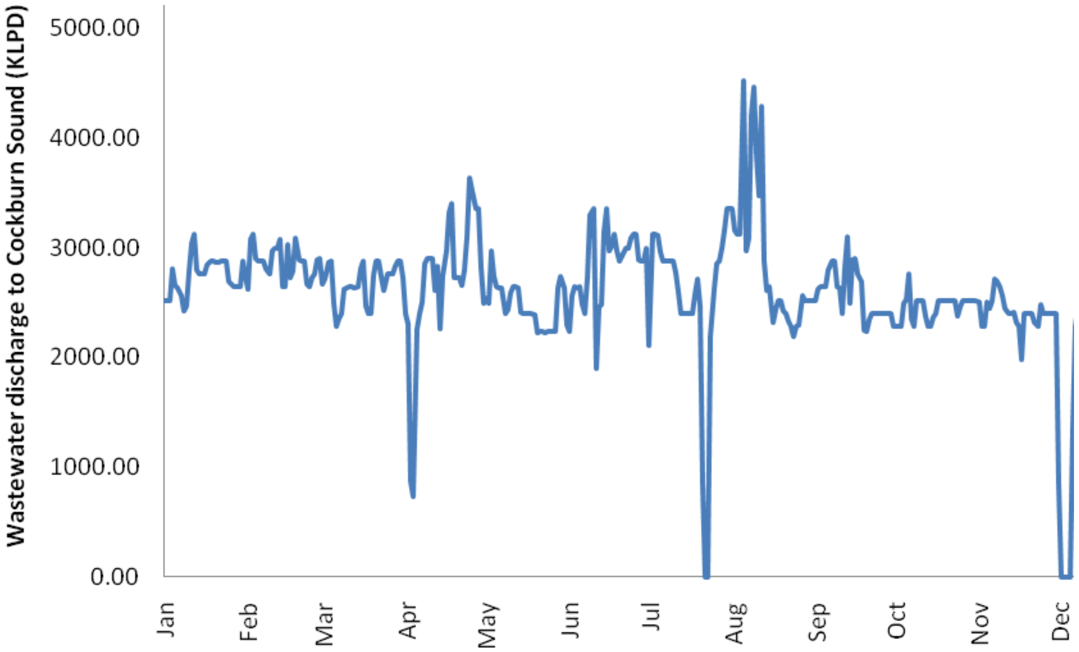

Figure 19: BPRK WWTP 2007 daily average discharge to Cockburn Sound.

The WWTP now discharges an average of 2.5MLPD of treated wastewater to the Cockburn Sound.

### 2.7.6 Other Sinks

Septics are the primary receiver of wastewater from office buildings at BPRK. Daily sanitary wastewater production per person estimated at 120L/day (European Commission, 2003). Average number of people on site in 2007 is 230 (BP Refinery, 2008a).

There are three separate outfalls at BPRK for the discharge of cooling water.

## 2.8 Evaluation of BPRK Water Management

Despite marked improvements in BPRKs water use from 1996 to 2003, changes in water consumption between 2003 and 2008 have been negligible if not slightly negative.

Table 11: water reuse and minimisation programme results (Seneviratne, 2007).

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Table 11 shows reductions made in total water use, scheme water use and wastewater flow at the refinery between 1996 and 2003. This period was the major period of implementation of the water minimisation programme. Since 2003 water use has generally been steady. Minor increases in water consumption are consistent with increased crude throughput. Total water use on site has decreased by 12% since 2003. However we can also see that scheme water use as a proportion of total water has increased from 42.8% in 2003 up to 50% in 2008.  This offsets the benefits of overall reductions in water use as it is important to reduce the proportions of scheme water being used in preference for ‘fit-for-purpose’ water where possible.

In assessing water use at BPRK for the 2007 calendar year, many issues were presented. A generally poor understanding of water use was encountered. Scheme meter readings were taken irregularly because of internal disagreements over whose role it should be to read the water meter. When investigating why the bore water meter had gone offline for the majority of the 2007 calendar year, little was known about where water was sourced from during this period and losses for this period were not evaluated or accounted for. Generally water conservation was found to be low in priority. Only one person in the environmental team is aware of the refinery’s water use and the associated record keeping system. When that person is away there is no-one with adequate understanding of the refinery’s water use. The water conservation team in general is made up of two people, both with primary responsibilities in other areas of the refinery's environmental management. Water conservation therefore takes a backseat to other environmental issues, typically those driven by environmental regulations. Each of these issues is discussed in detail in Chapter 6:Management Implications.

The water use profile at the BP Refinery will change significantly from 2008 onwards as recycled domestic wastewater from the Kwinana Water Reclamation Plant (KWRP) is to be used as a substitute for existing scheme and groundwater uses. The initial phase will involve substituting KWRP water for the two largest scheme water uses at the Refinery, the alkylation unit cooling tower and make-up for boiler feed water. The second phase will involve substituting KWRP water for process water use, which is currently supplied by groundwater (BP Refinery, 2008c).

# Chapter 3: Utility Water Uses

The utility water uses at BPRK are made up of two major systems:

1. The refinery cooling system;
2. The refinery steam system.

In oil refineries, cooling water is responsible for up to 90% of water requirements (Asano *et al.*, 2006; Lens *et al.*, 2002). At BPRK, a study showed that the refinery's once-through cooling system uses approximately 395MLPD of ocean water from the nearby Cockburn Sound. This volume represents around 99% of the refinery's total water use. Once-through cooling has many negative environmental implications. However because of the complex nature of cooling circuits at the refinery they will not be included in this study and may justify a separate study in the future. An exception to the once-through nature of the refinery's cooling system is the Alkylation Unit (ALKY) Cooling Tower which is supplied with scheme water. The refinery cooling system will not be covered in detail here as it would justify an entirely separate study in itself. The main purpose of water use in refineries is to transfer heat. Boiler feed water makeup and cooling water typically account for 40-45% of water usage in refineries (Seneviratne, 2007). In a refinery a number of clean condensate streams are generated from condensed steam that has not been in contact with product. These condensate streams are suitable for direct re-use as Boiler Feed Water (BFW), leading to cost savings (European Commission, 2003).

A detailed analysis of the steam system is given in the following section.

## 3.1 BPRK Steam System

Oil and Gas refineries are amongst the most steam-intensive industries in the world (Seneviratne, 2007). The steam system at BPRK is an extremely complex system and is the largest water user on site[19]. The primary source of steam in the oil refining industry is utility boilers and WHBs and, more recently, cogeneration plants.

Boilers work using the same principle as a kettle, in which Boiler Feed Water (BFW) enters the boilers, then is heated either by gas firing or by using the waste heat from a process. As a result, of the heat, the water is vaporised and turned into steam. Because boilers operate at certain heat loads, temperatures and pressures, the water entering the boilers must be treated to remove impurities to ensure that the materials from which the boilers are made are not adversely affected (BP Refinery, 2002). The water present within the boiler faces continual build-up of impurities. Contaminants must be kept below specified concentrations to avoid risk of legionnaire's disease which can be brought about by improperly managed boiler systems. BPRK currently discharges approximately 450KLPD of boiler blowdown to the refinery's Oily Water Sewer (OWS) (BP Refinery, 2002). To account for the water losses, the volume of make-up water must be sufficient to replace both vaporisation and blowdown from boilers. Approximately 2.2 MLPD of BFW enters the refinery steam system, down from 3.2 MLPD recorded in 1998.

Out of a refinery's total steam use about 40-60% is used directly in the refining process and therefore not available as returned condensate. Steam condensate recovery varies from 30% in older refineries to 70% in well maintained and newer refineries (Seneviratne, 2007). Condensate recovery can save the refinery a considerable amount through:

- Reduced volumes of softened water required;
- Reduced costs in heating softened water;

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[19] Excludes the refinery cooling system which uses salt water from the Cockburn Sound in a once-through system.

- Reduced WWTP requirements for condensate treatment;
- Reduced need to deal with hot condensate discharges which can release hydrocarbons into the atmosphere when discharged into the oily water sewer.

BPRK has numerous boilers throughout the site, which generate steam for a variety of purposes (BP Refinery, 2002; Seneviratne, 2007). The bulk of the steam is used in processes such as the RCU (discussed in Chapter 4:); the Vacuum Distillation Unit (VDU); Alkylation (ALKY); atmospheric distillation; catalytic hydrotreating and in driving steam turbines. In the process, large amounts of steam condensate is generated. Out of a refinery's total steam use about 40-60% is used directly in the refining process and therefore not available as returned condensate. Steam condensate recovery varies from 30% in older refineries to 70% in well maintained and in newer refineries (United States Department of Energy, 2002). Water is lost through:

- Steam and condensate leakage;
- Dumping of oil-contaminated steam condensate;
- Non-recovery of condensate from tank farm areas due to low flows and long distances;
- Poor steam trap maintenance;
- Poor blowdown control;
- Venting to remove non-condensable gases from steam systems.

The use of steam at BPRK is discussed in detail in throughout the remainder of this chapter.

## 3.2 Methods

Because of the complexity and technical nature of steam systems, the first step in the steam audit was discussions with the environmental team, energy and process engineers with specialist knowledge of the system. Detailed information on the steam system has been compiled by the energy specialists on site[20] and is collated in a number of spreadsheets which can be regularly updated to establish balance of flows throughout the refinery steam system. Likewise, results from

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[20] The majority of information was sourced from BPRK steam system expert Brian King.

current and previous steam trap audits were regularly monitored and updated. These records were easily accessible and were the primary source of data for the steam system flowrate results shown in Figure 12. As boiler blowdown is intermittent in nature (water is only discharged to the oily water sewer as solids and other contaminants build up to specified levels), the annual total has been calculated for 2007 and averaged over 365 days to get a flowrate in tonnes per day. A simplified steam balance was developed in conjunction with steam engineers to ensure accuracy and completeness. A flow diagram was developed and checked with energy efficiency staff.

A tour of the site steam system was also taken to view steam trap leaks, as well as major steam and condensate leaks in various sections of the refinery. The utilities audit focuses on the boiler system and steam use throughout the refinery. This information is regularly monitored and updated by process engineers at the refinery and is kept in a number of spreadsheets and databases available for staff access. Information has been drawn from these sources and process engineers have taken me on a tour of the refinery steam system and pointed-out major issues (steam trap leaks, burst pipes and management issues) in order to assist in a complete understanding of the system. Additional information on the steam system was imported from the BPRK DM system and analysis of NALCO[21] reports on boiler blowdown and steam quality indicators were analysed.

A baseline audit was conducted on cogen use in the refinery from the period 8-14 September 2008, while the results are not included here they can be accessed in Appendix 4: Steam System. Instead, data from the DM system was imported into a spreadsheet to determine average production and consumption of steam on each unit as daily averages for each day in 2007, and then summarised into monthly and finally annual data for the balance calculations. This information can be found on the CD at the back of the thesis as a supplement to Appendix 4.

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[21] NALCO are an American Organisation specialising in cooling and heating systems, particularly maintenance and operations of cooling tower and boiler systems and associated chemical control, blowdown and venting rates etc.

# Steam System Results

Figure 20 shows the utility section of the 2007 BPRK flow diagram presented in Chapter 2: Figure 12.

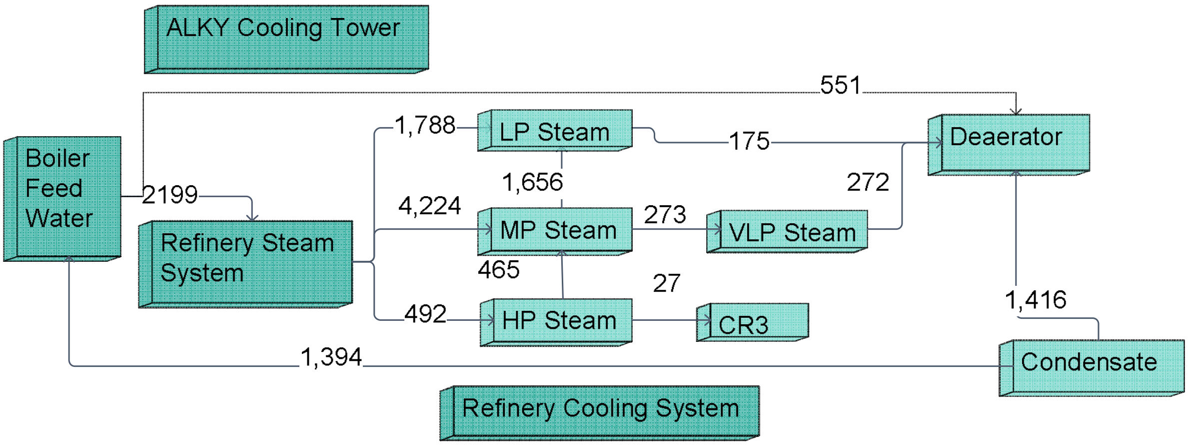

Figure 20: BPRK Steam System

Before analysing Figure 20, it is important to first show the way steam flows through the refinery. A process flow diagram[22] was developed in order to gain an understanding of where steam is formed on site and how it flows through the refinery. A simplified process diagram was developed to assist the author in gaining understanding and is shown in Figure 21.

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[22] NB a process diagram differs from a water flow diagram in that it represents logical flow order from the time the input (i.e. the water supply) enters site, undergoes treatment, and flows through the refinery. And eventually is discharged or lost at the end. This is not necessarily the best way to present water flows but is important to demonstrate how a complex system such as the refinery steam system works.

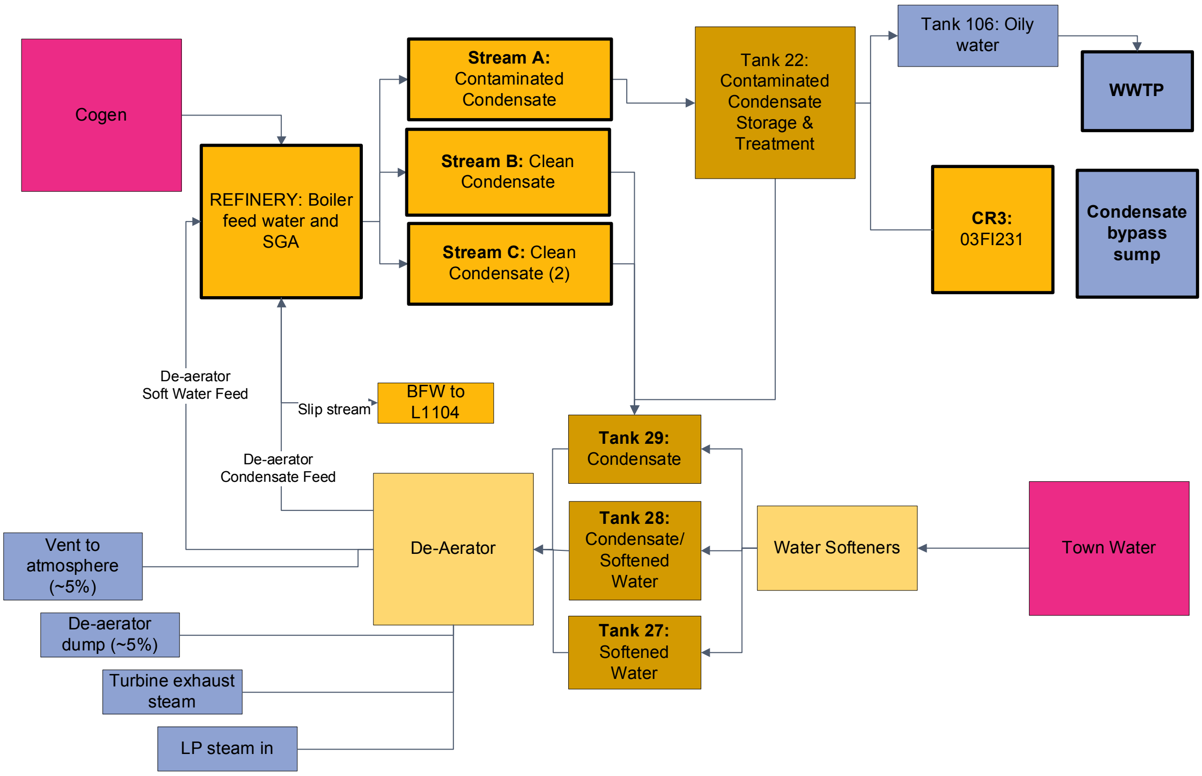
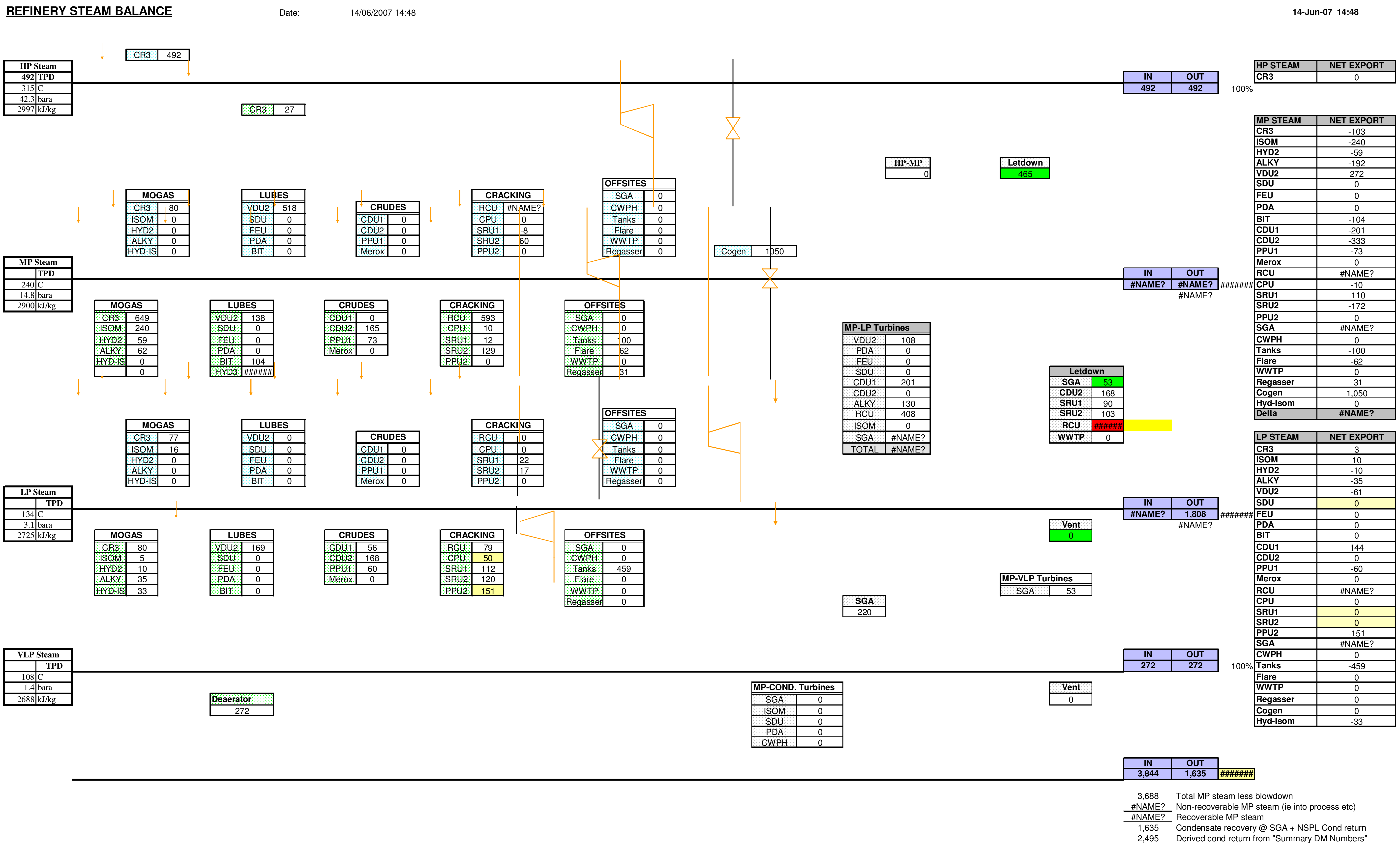


Figure 21: BPRK Steam System

At BPRK, steam is imported from the neighbouring Kwinana Cogeneration Plant (cogen), and scheme water which supplies the boiler feed system for on-site steam generation. The majority of onsite steam generation is done in the Steam Generation Area (SGA), though steam is also generated from heat recovery steam generators or Waste Heat Boilers (WHBs). Some examples of WHBs are located within the Residue Cracking Unit (RCU) and are discussed in Section 4.1. The steam system at BPRK can be separated into 3 major streams:

1. **Stream A:** Contaminated condensate
   *(PDA, Bitumen, SDU, VDU2, PPU1, RCU, CPU, PPU2, ISOM, Tankfarm);*
2. **Stream B:** Clean Condensate
   *(SRU1, SRU2, Bitumen [900-901], LPG Regasser);*
3. **Stream C:** Clean Condensate (2)
   *(ISOM, CWPH, CR3).*

The refinery operates two separate condensate return systems for returning clean condensate and contaminated condensate. A loop system returns condensate with little chance of contamination to the SGA without any treatment. Condensate with the potential of being contaminated with oil is returned to the tank 22 in the SGA , where oil water separation is achieved, before the resultant clean condensate is return to the steam cycle (Bax, 1999). There are process water and condensate return systems established within the refinery but are not connected to all units. In the past, increased refinery throughputs and additional processing units, together with minimal changes to the offsite piping resulted in problems returning condensate to the SGA (Bax, 1999). Increasing emphasis on good condensate return levels was the driving force for the Condensate Loss Minimisation Project in 1995. Currently, only the waste water treatment plant does not return condensate to the SGA (Bax, 1999). In 2000 BPRK implemented an energy efficiency program which involved converting waste heat to steam. Raising steam means using water and has resulted in an increase in scheme water use in order to minimise the need for raising steam using electricity driven by fossil fuels (BP, 2006). A snapshot of the steam system as at 14 June 2007 is shown in Figure 22.



**REFINERY STEAM BALANCE** Date: 14/06/2007 14:48

14-Jun-07 14:48

| HP Steam | |
|---|---|
| 492 | TPD |
| 315 | C |
| 42.3 | bara |
| 2997 | kJ/kg |

| CR3 | 492 |
|---|---|

| CR3 | 27 |
|---|---|

| MOGAS | |
|---|---|
| CR3 | 80 |
| ISOM | 0 |
| HYD2 | 0 |
| ALKY | 0 |
| HYD-IS | 0 |

| LUBES | |
|---|---|
| VDU2 | 518 |
| SDU | 0 |
| FEU | 0 |
| PDA | 0 |
| BIT | 0 |

| CRUDES | |
|---|---|
| CDU1 | 0 |
| CDU2 | 0 |
| PPU1 | 0 |
| Merox | 0 |

| CRACKING | |
|---|---|
| RCU | #NAME? |
| CPU | 0 |
| SRU1 | -8 |
| SRU2 | 60 |
| PPU2 | 0 |

| OFFSITES | |
|---|---|
| SGA | 0 |
| CWPH | 0 |
| Tanks | 0 |
| Flare | 0 |
| WWTP | 0 |
| Regasser | 0 |

| HP-MP |
|---|
| 0 |

| Letdown |
|---|
| 465 |

| Cogen | 1050 |
|---|---|

| IN | OUT |
|---|---|
| 492 | 492 |

100%

| HP STEAM | NET EXPORT |
|---|---|
| CR3 | 0 |

| MP Steam | |
|---|---|
| | TPD |
| 240 | C |
| 14.8 | bara |
| 2900 | kJ/kg |

| MOGAS | |
|---|---|
| CR3 | 649 |
| ISOM | 240 |
| HYD2 | 59 |
| ALKY | 62 |
| HYD-IS | 0 |
| | 0 |

| LUBES | |
|---|---|
| VDU2 | 138 |
| SDU | 0 |
| FEU | 0 |
| PDA | 0 |
| BIT | 104 |
| HYD3 | ###### |

| CRUDES | |
|---|---|
| CDU1 | 0 |
| CDU2 | 165 |
| PPU1 | 73 |
| Merox | 0 |

| CRACKING | |
|---|---|
| RCU | 593 |
| CPU | 10 |
| SRU1 | 12 |
| SRU2 | 129 |
| PPU2 | 0 |

| OFFSITES | |
|---|---|
| SGA | 0 |
| CWPH | 0 |
| Tanks | 100 |
| Flare | 62 |
| WWTP | 0 |
| Regasser | 31 |

| IN | OUT |
|---|---|
| #NAME? | #NAME? |

####### #NAME?

| MP STEAM | NET EXPORT |
|---|---|
| CR3 | -103 |
| ISOM | -240 |
| HYD2 | -59 |
| ALKY | -192 |
| VDU2 | 272 |
| SDU | 0 |
| FEU | 0 |
| PDA | 0 |
| BIT | -104 |
| CDU1 | -201 |
| CDU2 | -333 |
| PPU1 | -73 |
| Merox | 0 |
| RCU | #NAME? |
| CPU | -10 |
| SRU1 | -110 |
| SRU2 | -172 |
| PPU2 | 0 |
| SGA | #NAME? |
| CWPH | 0 |
| Tanks | -100 |
| Flare | -62 |
| WWTP | 0 |
| Regasser | -31 |
| Cogen | 1,050 |
| Hyd-Isom | 0 |
| Delta | #NAME? |

| MP-LP Turbines | |
|---|---|
| VDU2 | 108 |
| PDA | 0 |
| FEU | 0 |
| SDU | 0 |
| CDU1 | 201 |
| CDU2 | 0 |
| ALKY | 130 |
| RCU | 408 |
| ISOM | 0 |
| SGA | #NAME? |
| TOTAL | #NAME? |

| Letdown | |
|---|---|
| SGA | 53 |
| CDU2 | 168 |
| SRU1 | 90 |
| SRU2 | 103 |
| RCU | ###### |
| WWTP | 0 |

| MOGAS | |
|---|---|
| CR3 | 77 |
| ISOM | 16 |
| HYD2 | 0 |
| ALKY | 0 |
| HYD-IS | 0 |

| LUBES | |
|---|---|
| VDU2 | 0 |
| SDU | 0 |
| FEU | 0 |
| PDA | 0 |
| BIT | 0 |

| CRUDES | |
|---|---|
| CDU1 | 0 |
| CDU2 | 0 |
| PPU1 | 0 |
| Merox | 0 |

| CRACKING | |
|---|---|
| RCU | 0 |
| CPU | 0 |
| SRU1 | 22 |
| SRU2 | 17 |
| PPU2 | 0 |

| OFFSITES | |
|---|---|
| SGA | 0 |
| CWPH | 0 |
| Tanks | 0 |
| Flare | 0 |
| WWTP | 0 |
| Regasser | 0 |

| LP Steam | |
|---|---|
| | TPD |
| 134 | C |
| 3.1 | bara |
| 2725 | kJ/kg |

| MOGAS | |
|---|---|
| CR3 | 80 |
| ISOM | 5 |
| HYD2 | 10 |
| ALKY | 35 |
| HYD-IS | 33 |

| LUBES | |
|---|---|
| VDU2 | 169 |
| SDU | 0 |
| FEU | 0 |
| PDA | 0 |
| BIT | 0 |

| CRUDES | |
|---|---|
| CDU1 | 56 |
| CDU2 | 168 |
| PPU1 | 60 |
| Merox | 0 |

| CRACKING | |
|---|---|
| RCU | 79 |
| CPU | 50 |
| SRU1 | 112 |
| SRU2 | 120 |
| PPU2 | 151 |

| OFFSITES | |
|---|---|
| SGA | 0 |
| CWPH | 0 |
| Tanks | 459 |
| Flare | 0 |
| WWTP | 0 |
| Regasser | 0 |

| IN | OUT |
|---|---|
| #NAME? | 1,808 |

####### #NAME?

| Vent |
|---|
| 0 |

| MP-VLP Turbines | |
|---|---|
| SGA | 53 |

| SGA |
|---|
| 220 |

| LP STEAM | NET EXPORT |
|---|---|
| CR3 | 3 |
| ISOM | 10 |
| HYD2 | -10 |
| ALKY | -35 |
| VDU2 | -61 |
| SDU | 0 |
| FEU | 0 |
| PDA | 0 |
| BIT | 0 |
| CDU1 | 144 |
| CDU2 | 0 |
| PPU1 | -60 |
| Merox | 0 |
| RCU | #NAME? |
| CPU | 0 |
| SRU1 | 0 |
| SRU2 | 0 |
| PPU2 | -151 |
| SGA | #NAME? |
| CWPH | 0 |
| Tanks | -459 |
| Flare | 0 |
| WWTP | 0 |
| Regasser | 0 |
| Cogen | 0 |
| Hyd-Isom | -33 |

| VLP Steam | |
|---|---|
| | TPD |
| 108 | C |
| 1.4 | bara |
| 2688 | kJ/kg |

| Deaerator |
|---|
| 272 |

| IN | OUT |
|---|---|
| 272 | 272 |

100%

| MP-COND. Turbines | |
|---|---|
| SGA | 0 |
| ISOM | 0 |
| SDU | 0 |
| PDA | 0 |
| CWPH | 0 |

| Vent |
|---|
| 0 |

| IN | OUT | |
|---|---|---|
| 3,844 | 1,635 | ####### |

| | |
|---|---|
| 3,688 | Total MP steam less blowdown |
| #NAME? | Non-recoverable MP steam (ie into process etc) |
| #NAME? | Recoverable MP steam |
| 1,635 | Condensate recovery @ SGA + NSPL Cond return |
| 2,495 | Derived cond return from "Summary DM Numbers" |

Figure 22: Refinery Steam Balance

Figure 22 divides the refinery steam system into four major lines based on pressure:

1. HP Steam (High Pressure);
2. MP Steam (Medium Pressure);
3. LP Steam (Low Pressure); and
4. VLP Steam (Very Low Pressure).

A number of boxes are located directly above and below each line. The boxes above the line are the systems that are producing steam and feeding it into the system. The boxes directly below the line are those importing or consuming steam from the system. All units are in tonnes per day (TPD). For example, in the HP Steam line, the CR3 is shown to produce 492TPD steam. Concurrently, the CR3 is also consuming 27TPD of HP Steam to meet its operational needs. By following the same line over to the right, the letdown steam from HP to MP is shown as 465TPD. This volume of steam is then available in the MP Steam line. The far right hand side of the HP Steam line shows a balance of 482TPD in and 482TPD out. Each steam line after this is divided into region of the refinery: Mogas; Lubes; Crudes; Cracking and Offsites. Within each of these divisions, the abbreviation of the steam producing or consuming unit can be seen.

The information in Table 12 is supplementary to that given in Figure 22. These figures are those forming part of the steam system but are not included in the more specialised steam flow balance as used by the energy efficiency team.

Table 12: Deaerator feed, boiler feed water and condensate utilisation for 2007.

| | Soft water to deaerator (KLPD) | Condensate to deaerator (TPD) | % Condensate used | Total BFW (KLPD) |
|---|---|---|---|---|
| Average | 540.49 | 1407.85 | 0.73 | 1284.50 |
| Standard Deviation | 180.69 | 134.43 | 0.07 | 959.55 |
| Standard Error | 26.36 | 19.61 | 0.01 | 113.08 |

The data in Table 12 shows the variability associated with de-aerator feed and boiler feed water to the refinery. Because of the variability of the daily steam requirements at BPRK, a single day snapshot was used to represent the steam system rather than using annual averages. This better accounts for variations in boiler blowdown, and keeps the proportion of steam consumption and production of various units in check. The information from 14 July 2007 was used as this was felt to be representative of typical daily steam use in 2007.

Losses from the steam system were based on steam trap audit data. The steam trap monitoring program at BPRK was implemented as part of the BPRK water minimisation program. Because of the complexity of the system, the entire steam system cannot be audited within a one year period. Instead, the information collected in each year is extrapolated out to the 2,600 steam traps on the refinery to give 'representative' data. For this study, the data from 2007 and 2008 is combined and extrapolated to the whole site to be more representative of the whole refinery.

Table 13: Steam traps survey 2008

| | UNIT | No. traps tested | Correct | Failed open | Failed closed | % failed open | % failed closed | % Failed | Losses (TPD) |
|---|---|---|---|---|---|---|---|---|---|
| **2008** | **HYDY2** | 37 | 31 | 2 | 4 | 5 % | 11 % | 16 % | **0.72** |
| | **ISOM** | 10 | 7 | 1 | 2 | 10 % | 20 % | 30 % | **0.36** |
| | **WWTP** | 11 | 8 | 2 | 1 | 18 % | 9 % | 27 % | **0.72** |
| | **JET MEROX** | 7 | 5 | 1 | 1 | 14 % | 14 % | 29 % | **0.36** |
| | **PIPELINES (13)** | 155 | 99 | 20 | 36 | 13 % | 23 % | 36 % | **7.2** |
| | **SGA** | 42 | 38 | 1 | 3 | 2 % | 7 % | 10 % | **0.36** |
| **2007** | **ALKY** | 80 | 67 | 11 | 2 | 14 % | 3 % | 16 % | **3.96** |
| | **PPU1** | 39 | 32 | 2 | 5 | 5 % | 13 % | 18 % | **0.72** |
| | **CDU2** | 93 | 84 | 7 | 2 | 8 % | 2 % | 10 % | **2.52** |
| | **BIT** | 305 | 271 | 29 | 5 | 10 % | 2 % | 11 % | **10.44** |
| | **RCU** | 251 | 197 | 11 | 43 | 4 % | 17 % | 22 % | **3.96** |
| | **PPU2** | 19 | 10 | 1 | 9 | 5 % | 47 % | 53 % | **0.36** |
| | **CPU** | 44 | 27 | 11 | 6 | 25 % | 14 % | 39 % | **3.96** |
| | **SRU1** | 71 | 65 | 4 | 2 | 6 % | 3 % | 8 % | **1.44** |
| **TOTALS** | | **1,127** | **910** | **101** | **117** | | | | **37.08** |

When the steam audit data is extrapolated to whole site, approximately 85.5TPD is lost through steam traps. This is the equivalent of 31MLPY of water lost.

## 3.3 BPRK Steam System Discussion

There are no records of where steam traps are directed to (i.e. condensate return, OWS or grade) resulting in inefficient management of leaks. This information is not currently recorded, reducing the validity of the steam trap audit for water minimisation purposes. Without knowing whether the steam is returned for condensate reuse or lost to grade we are not able to surmise an appropriate solution to for the leaks. Ideally all steam should be reused in the condensate return loop. The losses recorded in steam traps returning to the system should be repaired accordingly, however those that are usually discharged to grade or to the sewer should have return pipelines fitted to ensure that maximum condensate return is achieved throughout the refinery.

The procedure for reporting steam leaks at the refinery is inefficient. Some leaks in the steam system have been reported to have been left as long as 3 years without being tended to. This is even the case when leaks are estimated to be losing 10 or more TPD of water equivalent. Such large losses should not be allowed to escape the system without any attempts to quantify or value losses. Losses through the steam system are unknown and difficult to calculate, and quite often shutdown of the process in question is required to accurately assess the size of the hole through which steam is leaking. Because losses are not quantified, the cost to the refinery and the volume of steam losses is generally unknown. These are discovered through the steam trap audit however only a small section of the refinery is covered by the audit each year and those leaks that are not part of the study area are left neglected. Water in the refinery’s steam system can typically be lost through:

- Steam and condensate leakage;
- Dumping of oil-contaminated steam condensate;
- Non-recovery of condensate from tank farm areas due to low flows and long distances;
- Poor steam trap maintenance;

- Poor blowdown control;
- Venting to remote non-condensable gases from steam systems.

Steam trap discharges are easy to minimise and are often caused by human error or even operator laziness. Unit operators are able to set the temperature on the steam system which controls steam pressure. When pressure is set too low, a large volume of condensate is formed. There are a number of steam traps which still discharge this condensate to the OWS or to grade. This waste of clean condensate could be minimised if the operator were to set the steam at the appropriate temperature for the pressure needed within the system. However this is a common issue at the refinery as setting lower-than-required steam temperatures requires less monitoring on the operators behalf and is therefore commonly set at low temperatures to reduce maintenance requirements. Leak reporting must be given higher priority, mainly through changes in employee culture and reporting. This issue is not specific to the steam system and employee education about water conservation is required throughout industry. This issue is addressed in more detail in Chapter 6: Management Implications.

The steam system requires high maintenance throughout all areas of the refinery. Much attention is paid to the energy consumption of the steam system, but due to the low cost and low priority of water use on site, not as much attention to water inputs and outputs is given. If operators become complacent it is easy to set the steam system of each process unit to a low temperature which requires less attention but creates higher volumes of water waste. This is an issue which is often let slide at BPRK but a crucial one to be paid attention to if water conservation is to be taken seriously. Also leak identification and management is a crucial issue in the steam system as leaks can be left unattended for years. This is something that has been observed throughout the site, and not necessarily just low volume leaks. Leaks are not quantified and costs of leaks are not measured.

Currently the goal of the refinery’s condensate return system is 50% return on volume of condensate. According to energy efficiency engineers on site, condensate return could easily be increased to 75% if the refinery were to a) have an accurate understanding of which steam traps are returned to the clean condensate system, b) which are lost to grade/evaporation and c) which are lost to the oily water sewer. This seems like a straight forward measure but has not yet been completed at BPRK. By identifying those steam traps that are currently discharged to grade and implementing a condensate return system on those traps, up to 25% more of the condensate losses can be recovered.

There are no technical /technological barriers to improving efficiency on the refinery, but with no economic, political or social pressure to reduce steam use there is no incentive for implementing additional conservation measures. The measures taken by BPRK in the late 1990's are considered sufficient for current practice in industrial water management. A number of potential conservation measures exist for steam systems.

Table 14: Potential Conservation Measures for Steam System

| Area | Action |
|---|---|
| Maintenance | Repair steam leaks<br>Maximize condensate recovery<br>Install continuous blow down heat recovery |
| Operating practices | Minimize vented steam<br>Reduce steam system operating pressure<br>Improve blowdown practices<br>Isolate steam from unused lines<br>Reduce excess boilers on standby or install smaller boiler<br>Use high-pressure condensate to make low pressure steam<br>Reduce de-aerator vent steam rate. |
| Water treatment | Maintain clean boiler heat transfer services<br>Minimize blowdown<br>Reduce boiler water dissolved solids<br>Improve condensate recovery by improving condensate chemistry and preventative maintenance of steam traps |

Some of these have been implemented at BPRK but require ongoing attention and continual improvement of the steam system efficiency. A future measure for efficiency improvements in the steam system is a total energy balance using energy pinch analysis to identify and rationalise energy and steam demands. Known as Pinch Analysis these are now used by oil refineries to optimise water and energy demands (Seneviratne, 2007). Water-pinch technology is the best known graphical approach to water conservation and is the most significant tool in the area today (Foo et al., 2006; Mann and Liu, 1999; Piet et al., 2002; Wenzel et al., 2002). The water pinch is now an established concept in the literature, with modifications being made by various researchers, including the concept of mass integration (Hallale and Fraser, 1998; Alva-Argáez et al., 2007; Hallale, 2002; Wang and Smith, 1994). The water pinch can obtain a minimum freshwater flowrate using advanced algorithms (Ng et al., 2007; Tan et al., 2007).The water pinch allows the analysis of water-using processes both before design and operation and/or retrofitting of existing systems to minimize freshwater consumption and wastewater generation, giving it an advantage over other tools which require pre-development planning (Dunn and Wenzel, 2001; Hallale, 2002; Lens et al., 2002; Wang and Smith, 1994).

The future refinery steam system will have lower use of scheme water when the Kwinana Wastewater Reclamation Plant (KWRP) is commissioned it is the intention of the refinery to use recycled water in place of scheme water as boiler feed water. The impact of connection to KWRP should be investigated when the system is fully operational.

The record-keeping associated with the steam system in general demonstrates excellent practice in data management. Flow diagrams that are easily understandable for both process engineers and unit operators are readily available and can be updated to instantly provide information about the steam system balance for any time period just by entering in the date in question and the time period under examination (i.e. hourly or daily use). The key point to be taken from the steam audit is that there are specialists at the BP Refinery that have a thorough understanding of the steam system and its operations. This knowledge is generally focused on energy efficiency improvements, a priority focus for all BP refineries. Many suggestions for water efficiency improvements were raised whilst I was inquiring about water use efficiency within the steam system. The general sentiment amongst staff was that a lack of priority on water conservation was the key barrier to implementing efficiency programs rather than any technological barriers to water use reduction or recycling. Without better communication between steam specialists and the water minimisation team, improvements in efficiency will likely continue to focus on the energy efficiency of the system rather than on water minimisation. It is important for specialists to communicate regularly with the water conservation taskforce in order to have their ideas incorporated into future water conservation projects.

# Chapter 4: Audit of Process Water

The Audit of "Process" water uses at BPRK focuses on the assessment of water used for processes unique to the petroleum refining industry. Major process uses at BPRK were described in the primary-level BPRK flow diagram developed in section 2.6 (as shown in Figure 12) are summarised in Figure 23 below.

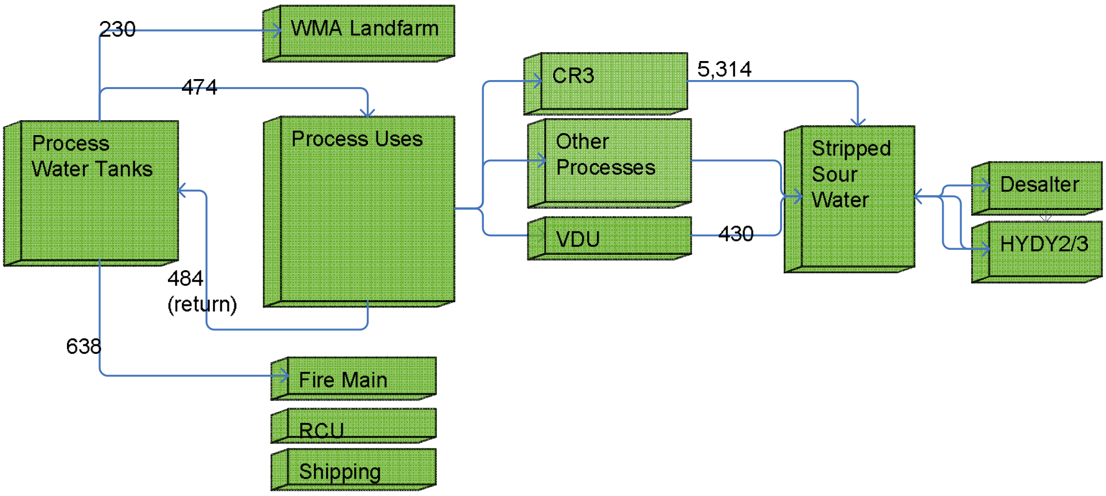


Figure 23: Simplified representation of refinery process uses.

This is not an exhaustive list of process activities at BPRK. The diagram represents the main known uses of water serving refinery-specific processes, which include:

1. The Waste Management Area (WMA) Landfarm;
2. Process Uses;
3. Fire Main;
4. Residue Cracking Unit (RCU);
5. Shipping.

Due to the limited timeframe of this research it is not possible to analyse all process uses. The complexity of process uses at BPRK is indicated in Figure 24 which shows all water uses occurring within the "process uses" box in Figure 23. More detailed information about the process units and other water balances completed on process units are included in Appendix 5: Process Uses.

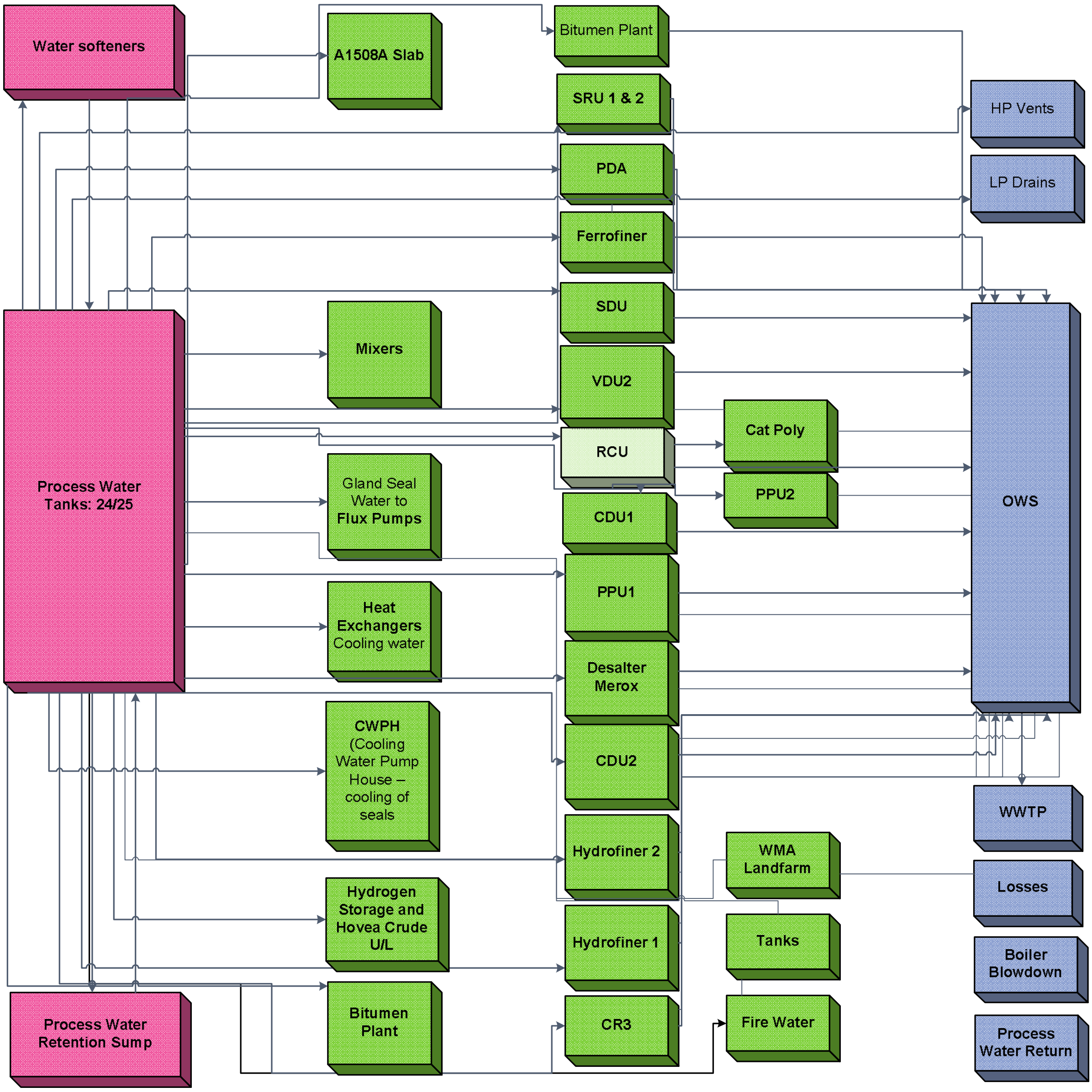


Figure 24: Process Unit Water Flow Diagram

To demonstrate the diversity of process water uses at BPRK, the Residue Cracking Unit (RCU) has been selected as a case study.

## 4.1 Residue Cracking Unit

Catalytic cracking is one of the most widely used refining processes. The Residue Cracking Unit[23] (RCU) is one of the largest water using units at BPRK. It uses a combination of fresh water, steam and

---

[23] The Residue Cracking Unit (RCU) is the name used at BPRK for the sites Fluidised Catalytic Cracker (FCC).

salt water for cooling purposes. The use of steam throughout the refinery is covered in more detail in Chapter 3: Utility Water Uses. This chapter will assess only the volumes of steam consumed and produced directly by the RCU. This enables us to analyse the RCUs water use as a whole system. A process diagram of a typical catalytic cracker can be seen in Figure 25. The main water inputs are circled in blue, and wastewater in yellow and steam production in red.

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**Figure 25: Simplified process flow scheme for a FCC (European Commission, 2003).**

It is well known in petroleum refineries that catalytic crackers such as the RCU are amongst the most significant producers of refinery wastewater (European Commission, 2003). The typical volume of wastewater generated by a catalytic cracking process is around 60-90L per tonne of feedstock treated, or around 5-10% on feed (European Commission, 2003). Generated wastewater is typically from sour water drains and spillages from the fractionator containing some hydrocarbons (high levels of oil BOD, COD), suspended solids, sulphur compounds ($H_2S$), phenols, cyanides, ammonia and high pH as in Table 15 (European Commission, 2003).

**Table 15: Quality parameters of wastewater from RCU (European Commission, 2003).**

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Catalytic cracking produces large amounts of sour water which contains BOD, ammonia, phenols, cyanides and sulphides. Steam is injected with feed to ensure good atomization. Condensed steam is collected in the accumulator water boots downstream of the main fractionator. The water then goes to the sour water stripper as it is now contaminated with hydrocarbons, sulphur compounds and $NH_3$. Wash water is injected upstream of the main fractionator overhead condensers and compressor intercoolers to help protect the from process-side corrosion. That water also accumulates in the accumulator water boots. Boiler feed water and condensate are used (Eble and Feathers, 1992a).

### 4.1.1 Methods: RCU

Information about the RCU was collected from BPRK's internal data management system. The major flow meters were identified and then constructed into a flow diagram by separating them into inputs and outputs. The tags for each flow meter were imported into an excel spreadsheet which provided daily average flows, and accounted for the whole years water use, wastewater and steam production on the unit. Balance was calculated and losses determined on a daily basis, and averaged to get a representative figure for the RCU's daily flowrates. Boiler blowdown was estimated at 5% to determine boiler blowdown adjusted losses. Process and Instrumentation Diagrams (P&IDs) analysed to determine major steam and water supply lines to unit. These assisted in the identification of water supply lines to the unit and to determine the location of flow meters on the supply and discharge pipes. The refinery intranet also utilises a babelfish server which displays live information about current flows through the process. This system was used to integrate water use information about the RCU. All information was discussed with process engineers and operators to confirm accuracy and incorporate on-ground experiences and management issues into the assessment. Water conservation strategies determined through literature search and best available techniques discussed in the IPPC EU BREF or Oil and Gas Refining.

### 4.1.2 Results: RCU

The internal water using processes are not considered in this assessment, but rather the major inputs into and out of the system are recorded. On a unit such as the RCU this can become complex as steam is not only consumed by the unit but is also produced by the unit. This can create issues when trying to obtain balance.  To gain an understanding of the major water users and producers on the RCU, benchmarks from the BREF are useful for comparison.

**Table 16: Residue Cracking BPRK current practice compared with international benchmarks (KLPD and TPD).**

| | Water | Meyers | BREF | BPRK |
|---|---|---|---|---|
| Inputs | Cooling water | 20,808 | 10-20m3/t | 30,000 |
| | Boiler feed water[24] | 984 | | 1,158.8 |
| | MP Steam (TPD) | 292.8 | 50-300kg/t | 157.4<br>112.8<br>189.2<br>108.1<br>224.7 |
| | | | | |
| Outputs | MP Steam produced (TPD) | 55.2 | 100-170kg/t | 209.2<br>993.9 |
| | HP Steam produced (TPD) | 849.6 | | 515.5 |

The BREF shows that there is a large margin of acceptability of water use by fluid catalytic crackers and steam requirements can range from 50-300kg/tonne of feed. This wide range makes it difficult to assess whether the refinery's RCU is operating at maximum efficiency because it easily fits within the given range. However when compared with a study done by Meyers it seems that the refinery is using a larger volume of water than standard. Without assessing this against feed throughput though it is not appropriate to surmise that the unit is operating inefficiently as it may just be that the unit at BPRK is producing at a greater rate than the one in Meyers' study.

**The monthly inputs and outputs for the RCU are displayed in**

Table 17. Import from slurry boilers represents steam import to the unit. These boilers are all metered and are referred to as Boilers 1 – 4 for ease of interpretation and discussion. The Carbon Monoxide Boiler (COB) and the Waste Heat Boiler (WHB) are major steam producers within the refinery. Much of this steam is used within the unit, however the remainder of steam is sent to other processes on site.

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[24] Includes 10% blowdown

Table 17: RCU Water Balance Calculations.

| | Boiler 1 (C410) | Boiler 2 (C401W) | Boiler 3 (C401E) | Boiler 4 (C407) | COB | WHB | LP steam import | High Pressure steam export | Sour water to SRU2 | Scheme water makeup | Total in | Total out | Losses | % Closure | Total steam flows (TPD) | Blowdown (BBD) loss | | BBD adjusted loss | BBD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tag no.** | 04FI290. pv | 04fi338. pv | 04fi339. pv | 04fi340. pv | 04fi269. pv | 04fi379 | 04fi285a. pv | 04fi284a. pv | 04fi264. pv | 04fi275. pv | | | Total in - Total out | (Total in - Total out) / Total in (%) | 04fc1458. pv | total steam flows (TPD) x 5% blowdown | Total steam flows (TPD) x 10% blowdown | Losses - bbd loss (assumed 5%) | Losses – bbd loss (10%) |
| **Jan 2007** | 143 | 114 | 142 | 150 | 1094 | 237 | 132 | 604 | 509 | 1303 | 1984 | 1350 | 634 | 31.95% | 1879.991 | 94.00 | 188.00 | 540 | 446 |
| **Feb 2007** | 123 | 225 | 157 | 212 | 1165 | 204 | 114 | 634 | 509 | 1316 | 2146 | 1347 | 799 | 37.22% | 2085.339 | 104.27 | 208.53 | -1391 | 590 |
| **Mar 2007** | 118 | 166 | 161 | 214 | 1144 | 184 | 319 | 550 | 522 | 1502 | 2480 | 1256 | 1224 | 49.36% | 1987.235 | 99.36 | 198.72 | -2849 | 1026 |
| **Apr 2007** | 115 | 198 | 158 | 215 | 1045 | -32 | 105 | 591 | 526 | 1466 | 2256 | 1085 | 1172 | 51.90% | 1699.317 | 84.97 | 169.93 | -4012 | 1001 |
| **May 2007** | 106 | 201 | 157 | 228 | 999 | 232 | 173 | 524 | 521 | 1433 | 2299 | 1278 | 1020 | 44.40% | 1923.069 | 96.15 | 192.31 | -6768 | 828 |
| **Jun 2007** | 110 | 213 | 32 | 233 | 1001 | 261 | 143 | 490 | 519 | 1112 | 1843 | 1269 | 573 | 31.11% | 1849.94 | 92.50 | 184.99 | -8769 | 388 |
| **Jul 2007** | 108 | 146 | 141 | 231 | 1103 | 251 | 309 | 471 | 508 | 1132 | 2066 | 1230 | 836 | 40.46% | 1979.22 | 98.96 | 197.92 | -11138 | 638 |
| **Aug 2007** | 114 | 224 | 61 | 249 | 814 | 253 | 256 | 329 | 530 | 854 | 1758 | 1113 | 646 | 36.71% | 1714.93 | 85.75 | 171.49 | -11445 | 474 |
| **Sep 2007** | 120 | 245 | 81 | 256 | 1217 | 249 | 292 | 642 | 513 | 1392 | 2385 | 1405 | 980 | 41.09% | 2167.23 | 108.36 | 216.72 | -16466 | 763 |
| **Oct 2007** | 105 | 191 | 77 | 249 | 1274 | 226 | 46 | 819 | 512 | 1344 | 2012 | 1557 | 455 | 22.61% | 2122.36 | 106.12 | 212.24 | -18753 | 243 |
| **Nov 2007** | 89 | 244 | 97 | 228 | 665 | 218 | 30 | 349 | 552 | 683 | 1370 | 1119 | 251 | 18.35% | 1541.49 | 77.07 | 154.15 | -15240 | 97 |
| **Dec 2007** | 102 | 105 | 35 | 231 | 406 | 226 | -28 | 182 | 442 | 369 | 813 | 850 | -37 | -4.55% | 1104.67 | 55.23 | 110.47 | -12244 | -147 |
| **ANNUAL AVERAGE** | **113** | **189** | **108** | **225** | **994** | **209** | **157** | **515** | **514** | **1159** | **1951** | **1238** | **713** | **33%** | **1838** | **92** | **184** | **9045** | **529** |

Flow meters on slurry boilers 2 and 4 are unreliable; however no plans to replace these meters are in place. The effect of this on the closure calculations is unknown. For the purpose of this study we assume that all flow meters are accurate. The information from Table 17 is graphically represented in a flow diagram to show the major inputs and outputs for the RCU (Figure 26).

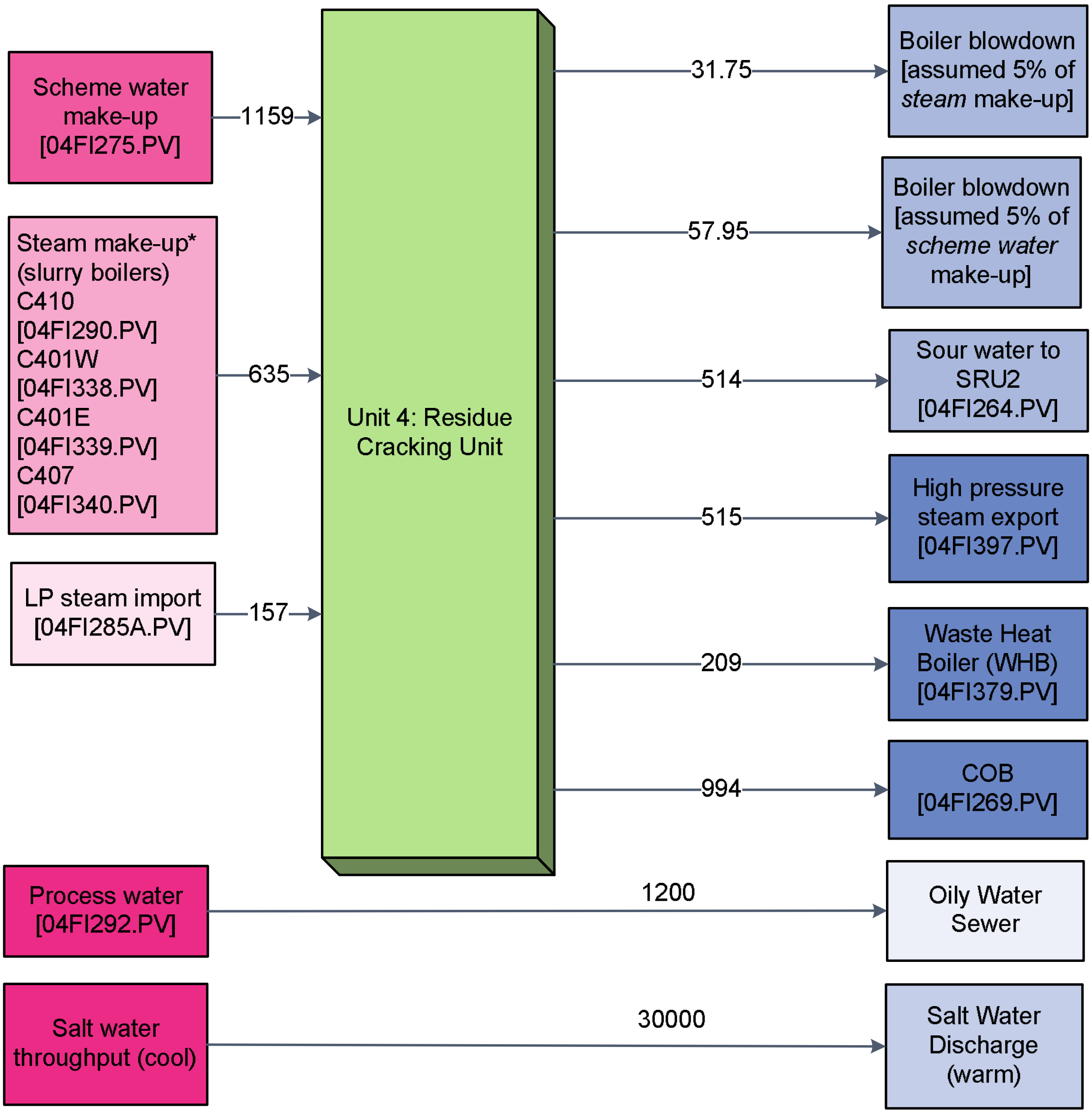

Figure 26: BPRK RCU 2007 Average Daily Water Use

The major water users on the RCU are the make-up of water from the slurry boilers and scheme water supply for steam generation on the RCU. The process water used on the RCU is used for hoses and emergency only and was therefore shown as a throughput instead of a water source that could be consumed within the unit. The total volume flowing in to the RCU is 1200KLPD and it is assumed that this is discharged directly to the OWS. Similarly, Salt Cooling Water (SCW) is once-through and is returned to the Cockburn Sound after use. It is worth noting that the volume of SCW used on the unit is more than 10 times the amount of all other water sources combined. The total inputs excluding process and salt cooling water are equivalent 1,951KLPD.

The discharges from the RCU include boiler blowdown, wastewater being sent to the Sour Water Stripper (SWS) and steam export. Wastewater discharge to the OWS is not measured despite the RCU being one of the biggest wastewater producers at the refinery. Boiler blowdown has been estimated for the purposes of the RCU flow diagram as 5%. However this figure varies markedly depending on the system requirements and the build-up of contaminants in boilers. The average boiler blowdown for the year 2007 is shown for each of the RCU's waste heat boilers in Table 18.

**Table 18: Average boiler blowdown on each of the waste heat boilers on the RCU (NALCO, 2008).**

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The four WHBs on the RCU vary in the percentage of feed water that is discharged as boiler blow down. The information has been obtained from reports by NALCO, the contractors in charge of the cooling system and steam system at BPRK. The boiler blow down rate varies markedly with Boiler 2 discharging an average of 2.56% of feed with a low error margin, and Boiler 3 discharging around 23% of feed on average.

Total discharges from the RCU equate to 2322 KLPD.

Closure can be obtained on the RCU by using Equation 1. Closure can calculated for the RCU on two different levels. Firstly, we can include assumed boiler blowdown, or alternatively boiler blowdown can be excluded from the calculation. By incorporating boiler blowdown from the calculation we obtain an annual average closure of 33%. When the assumed volume of boiler blowdown is increased to 10% or even 20%, the closure becomes 24% and 14% respectively. This gets us closer to the desired level of closure of <10% and more accurately reflects the blowdown rates on Boilers 1 and 3. However other losses within the system or consumption of water within the process may also be responsible and a further investigation of this is required. It should also be noted that the RCU does not record its wastewater discharges to the OWS and that not all flows are included in the balance calculations, only major streams and monitored streams are included. By incorporating minor streams and unmetered streams it is more likely that closure will be representative of the whole system water use. Gaps in information such as unmetered streams make obtaining closure near impossible.

Variability of each flowrate is dependent on the requirements of the RCU processes itself, as well as the ability to generate steam from waste heat boilers. The variability in total imports and exports from the RCU in 2007 are shown in Figure 27.

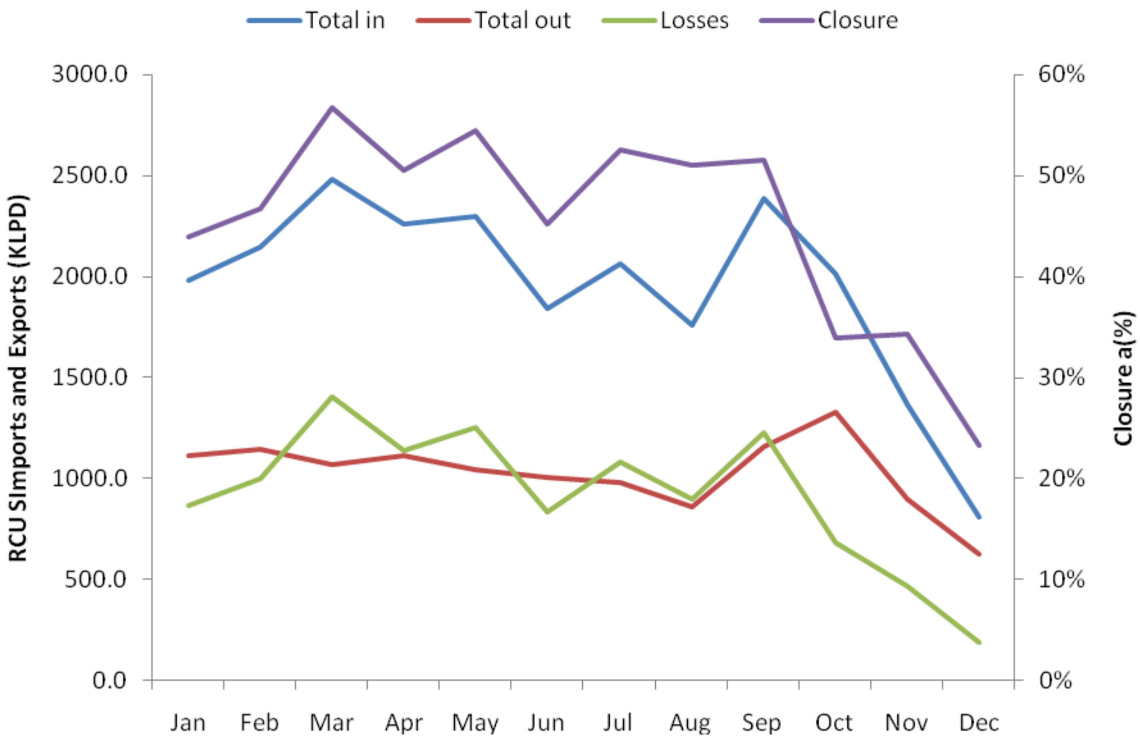

**Figure 27: RCU monthly water balance, assesses major inputs, outputs and losses for the RCU in 2007.**

In 2007 the carbon monoxide boiler (COB), a waste heat boiler, went offline from 22 October-18 December 2007. This had significant impact on the volume of scheme water make-up imported to the unit which declined dramatically as steam was no longer being generated. As a result, cogen import to the refinery also increased for this period. This was highlighted in Chapter 2: through discussions of variability in scheme water and cogen imports to the refinery. Scheme water input decreases dramatically

Losses may reflect the amount of water that is consumed within the process. The RCU is a special case as much of the water imported into the unit is used to generate steam on waste heat boilers. It is therefore expected that much of the water entering the RCU would be consumed within the unit. Wash water from the RCU is discharged to the SWS for treatment and regeneration reuse, most likely in the Crude Distillation Units (CDUs) desalter. The large drop in water use from October is due to the COB going offline for this period, therefore water imports for steam generation were reduced dramatically.

### 4.1.3 Residue Cracking Unit (RCU) Efficiency Measures

The RCU is one of the most complex water-using units on site. The ability to obtain closure on the unit is largely variable depending of the requirements of the cracking process and the rate of crude throughput. As we observed in the previous section, the volume of water being imported into the unit declined significantly when the waste heat boiler went offline. It is theoretically possible for stripped sour water to be used as wash water on the RCU (European Commission, 2003). This is dependent on a number of local factors and should be investigated at BPRK.

Flow meters on the slurry boilers on the RCU are unreliable. No substitute information about flow rates is available so for the purpose of this assessment they are assumed to be accurate. However it is important for these flow meters to be regularly maintained and/or replaced if suspected to be inaccurate or unreliable, and should be reported and replaced as soon as possible. This should be done routinely during unit shutdowns[25].

Operational boiler blowdown is assumed to be approximately 5% of steam make-up. Boiler blowdown on the RCU can be as high as 10% of steam make-up[26]. The accuracy of this figure is expected to be low as it does not include the make-up sent to the debutaniser, a section of the unit which is currently unmetered. Because scheme water is used as steam make-up, the estimated cycles of concentration are high, resulting in minimal blowdown requirement. With low quality input streams, larger concentrations of ions and solids are present in the water which build up and require a more frequent blowdown rate. In 2008/2009 when BPRK replaces scheme water make-up with KWRP water the cycles of concentration will increase and blowdown is expected to reduce to 2% of make-up (BP Refinery, 2002).

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[25] The RCU was one of the units closed for maintenance during the October-December 2008 shutdown.

[26] Figures for RCU boiler blowdown were estimated by the process engineer for the RCU (at the time of study was Mr M. Northcott).

Minimisation of the use of aeration and purge steam can decrease particulate emissions significantly. Aeration/steam rates are based on achieving a stable catalyst circulation in the catalyst lines (European Commission, 2003). A lot is known about minimisation and control of emissions to atmosphere generated by the RCU, however there is little known of water efficiency and minimisation in catalytic crackers. Hydrotreatment of feed to the RCU can reduce sulphur emissions by up to 90% and eliminates the need for hydrotreated mercaptane oxidation, a wastewater generating process. Many studies have been done on improving efficiency of process unit water use. The residue cracking unit is a good example of units on the refinery and demonstrates the complexity of process unit water requirements and variation in water use. The RCU requires steam for its operations, and  also generates steam from WHBs on the unit. The steam generated often supplies its own requirements so much internal reuse of generated steam occurs. This internal recycling makes it difficult to obtain closure but is an excellent example of making use of waste heat. The sour water is sent off for reuse to the nearby hydrofiners where it is used as wash water before being sent to the sour water stripper for regeneration. Assuming a low ammonia content, sour water stripper bottoms can be considered as a makeup source for this system it may be possible to eliminate water entirely with the use of process-side additives. Contaminants found in the produced water include cyanides, sulfides, ammonium chlorides and phenolic compounds (phenols, creasols xylenols etc). Because the hydrocarbon becomes cleaner as it progresses downstream, it is sometimes possible to cascade wash water. Wash water injected at the wet gas compressor intercoolers will accumulate downstream. This water could be pumped to the overhead water wash system upstream of the main fractionator overhead condensers (Eble and Feathers, 1992a).

A number of technical approaches to water minimisation on process units are available and should be investigated by relevant staff at the refinery. The layout of industrial water using networks can be maximised through effective pre-development design. For existing networks methods have also been established to retrofit to improve water use efficiency. For this reason it is more effective to establish efficiency measures with the development of new buildings rather than trying to redevelop the unit latter on. Engineering approaches are usually much more expensive than the conceptual approaches discussed previously as they may require changes to entire processes or building of relatively large infrastructure. Previously two approaches have been used to obtain good designs of water using systems (Bagajewicz, 2000):

- Graphical approaches; and
- Numerical approaches.

These are discussed here briefly to recognise that there are a number of tools available for process water use minimisation, but as a whole are beyond the scope of this research.

### *Water Cascade*

Water cascading is the sequential reuse of water from one unit operation to the next, without treatment (or with limited treatment). In this process, water is used first in processes with strict purity requirements and is cascaded to processes that can use the wastewater of the previous process without further treatment (Mann and Liu, 1999). A water cascade can provide opportunities for several cycles of re-use before it becomes too dirty and must be discharged. An example of this is the use of storm-water runoff for makeup water to cooling towers (Mann and Liu, 1999). Cascade analysis tools have been developed by El-Halwagi and colleagues to identify opportunities for cascade reuse within or between industrial processes (Foo et al., 2006; El-Halwagi, 1997; Shoaib et al., 2008). The volume of wastewater produced by the RCU at BPRK can be reduced to 2-4% on feed if cascading of wash water is accomplished.

### *Graphical Approaches*

Graphical insights are of importance in practice because they allow the engineer to incorporate many factors that mathematical programming does not consider (Bagajewicz, 2000). The water pinch is the best known graphical approach (discussed in Section 3.3).

### *Numerical Approaches*

Numerical tools are preferred when rapid and accurate answers, or repeated calculations, are needed (Foo et al., 2006). Mathematical optimisation is an efficient tool for handling problems that involve multiple contaminants and specialised models of water-using operations. It provides the user with a minimum freshwater flowrate and water-using network design, although it gives little insight to understanding how the network is constructed (Mann and Liu, 1999). Mathematical programming is a tool used to target maximum water reuse in processing industries (Brouckaert and Buckley, 2000; Doyle and Smith, 1997). Mathematical optimisation provides a choice of models for each water-using operation, making it more flexible than other approaches (Mann and Liu, 1999). Other tools such as sensitivity analysis can be combined with mathematical optimisation to identify effective process changes for complex systems of water-using operations and identify the most efficient process changes for industrial operations that are not readily modelled by water-pinch analysis (Bishop et al., 1971; Liaw and Chen, 2004; Mann and Liu, 1999).

### *Combination of Mathematical & Conceptual Approaches*

Current research is showing that a combination of both mathematical models and conceptual insights can result in greater water conservation (Bagajewicz, 2000). Numerous other techniques have been proposed for the design of water networks, each with the ability to improve water conservation opportunities, either in their own right or in combination with other tools. Examples include the water grid diagram (Mann and Liu, 1999; Wang and Smith, 1994), the load table (Aly et al., 2005; Olesen and Polley, 1996), the water main method (Castro et al., 1999; Feng and Chu, 2004), mass transfer-based process (Gouws et al., ; Castro et al., 1999; Hallale and Fraser, 1998); and the source-sink mapping diagram (Dunn and Wenzel, 2001; El-Halwagi, 1997). Some of these tools are most effective for single-contaminant or single-stream operations while others have the ability to deal with complex processes. In many cases, various tools have been shown to obtain identical results (Mann and Liu, 1999).

### 4.1.4 Integrated Assessment of the RCU

Specialist knowledge of each process unit is required. It is difficult to obtain balance on the RCU because of the internal processes, some of which are water consuming, some of which treat water and others yet which produce steam and essentially export water. Amongst these internal operations, we must also determine how to identify and measure losses on the unit. Some of the major unit flows are not measured, which again makes obtaining closure difficult if not impossible. For example, the wastewater discharge to the oily water sewer is not measured, despite being a one of the most significant wastewater producers on site.

There are many opportunities for water conservation through mathematical optimisation, water pinch studies, network optimisation and water cascading. Each of these requires an in-depth study of both quality and quantity of water use by the process and surrounding processes to determine opportunities for recycle, regeneration, reuse and minimisation of water and wastewater.

Process engineers tend to focus more on maximising production and minimising costs and water is not a primary consideration.

Many engineers tend not to understand the broader picture of their units water use and how it relates to the rest of site, and while some were interested and willing to spend time and give attention to water minimisation, others were not interested and felt it was not part of their job requirement.

Units are generally designed to maximum efficiency and reduced environmental impact (particularly with respect to reduced atmospheric emissions), much of the real inefficient water use and waste occurs with human error and mismanagement such as operator laziness, use of hoses on the unit for cooling and washing and being left on during breaks, and poor setting of steam temperature. This can result in increased losses through traps because of larger volumes of condensate being produced (see Chapter 3:Utility Water Uses). The barriers to implementation of water conservation programs therefore seem to be through variables such as operator incompetence or carelessness, lack of funding or interest from higher levels of management, or lack of incentive from overarching policy or government structures rather than through unavailability of appropriate technologies.

Process water uses that are not metered can be difficult to measure, particularly in a high security site such as BP where processes operate 24 hours a day, 365 days a year. The majority of maintenance must be completed within a shutdown period, and these are infrequent (perhaps once every five years). This makes it difficult to measure things such as steam losses which must be estimated based on hole size which can only be seen when the process is shut down. This is not possible in an oil refinery where shutting down of processes is such an infrequent and major event. It is hoped that methods used to quantify water uses for the RCU will assist in future attempts to quantify other refinery water uses.

# Chapter 5: Other Water Uses

The final category of water use is simply defined as “other”. “Other” water uses at BPRK are varied and many. The flow diagram has divided “other water uses” into four categories:

1. Domestic;
2. Safety showers;
3. Staff car wash;
4. Commercial.

Domestic water uses include all office uses including toilets, urinals, basins, kitchenette sinks and hot water, air conditioning and losses through various kinds of leaks typically associated with office buildings. Safety showers can be a significant water user at the refinery as they are required in large numbers throughout the refinery and must use water of a potable quality. The staff carwash is a service available to refinery staff to rinse their cars of any catalyst that has fallen on the car park during the day, or salt from the nearby ocean that may affect cars in the car park. Finally, commercial use includes the staff canteen and the laundry for washing of protective clothing required for wear in the refinery red zone27. This category of water use appears simplistic at first with only four boxes representing a small volume of water use when compared with utility and process uses. The water used within this category however is all high quality scheme water supplied by the Water Corporation. Whilst volumes used in this category are small compared to other refinery water uses, BPRK still consumes approximately 30% of the KIA’s total annual scheme water use and has a significant impact on availability of scheme water to other nearby residential, industrial and agricultural users (Kwinana Industries Council, 2006; van Beers, 2007). The main water users in the “other” category are shown in yellow in
Figure 28, with a breakdown of commercial and domestic uses shown in pink and green respectively.

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[27] The red zone at BPRK is an area which includes all of the process units and the tank farm. Protective equipment must be worn at all times when in the red zone.

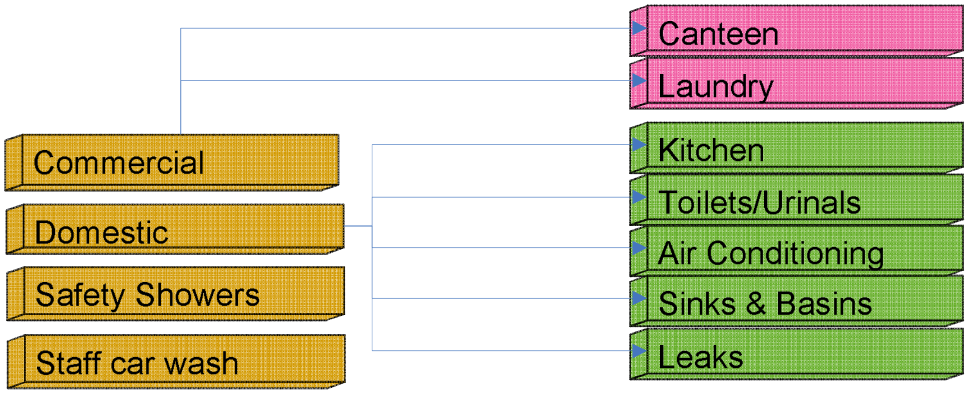

Figure 28: "Other" water uses at BPRK.

A break down of the methods used to calculate the average daily flowrate for the carwash are examined throughout this section.

## 5.1 Carwash

The car wash is not the largest water user in the category of “other” water using-processes, but it is an extremely inefficient user of scheme water on site. The car wash was established in the 1970’s when employees were complaining of their cars were being covered in catalyst and other particulate matter from refinery operations. The carwash is a simple structure with four major pipelines running across the sides and top of an open-ended aluminium shed. There are approximately 40 working nozzles in the car wash (10 on each pipe). The pipelines are connected to the refinery’s scheme water network. The BPRK staff carwash is a touchless carwash – an automatic car wash in which a series of water jets pass over a stationary vehicle (Water Corporation, 2008). The water from the carwash is discharged to septic tanks immediately after use. A small percentage of water is lost to the environment through evaporation or lost to vehicle carry out. (Water Corporation, 2008). Typical wastewater contaminants and concentrations associated with touchless carwashes are highlighted in Table 19.

Table 19: Water Corporation estimate of wastewater quality for touchless car washes (Water Corporation, 2008).

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Usually all wastewater is discharged to an approved pre-treatment fixture to remove hydrocarbons and settleable solids that may otherwise enter the sewerage system (Water Corporation, 2008). At BPRK however the water is drained immediately to septic tanks without treatment. No reuse occurs in the carwash.

### 5.1.1 Methods: Carwash

The carwash audit was completed in three stages:

1. Desktop study;
2. Discussions with relevant personnel at BP;
3. Two-phase audit (May and September 2008).

The desktop study involved an assessment of results from a previous water audit completed in 2002 by BPRK environmental engineer Janelle Shackley. The audit comprised a series of meter readings from December 2001-January 2002. The meter readings were recorded on an irregular basis and were therefore converted averaged out to 24 hour periods in order to be useful for comparison to 2008 data. An assessment of post-carwash leaks/drizzle from nozzles was also completed in 2002 which was found useful in determining losses from the carwash, presuming that no major changes in post-wash leakage have occurred since the previous study. Also as part of the desktop study, Process and Identification Diagrams (P&IDs) were analysed to determine the water source supplying the carwash.

Discussions with a number of BPRK staff were required to understand the reasons for constructing the carwash, problems experienced with the carwash and to rectify major leaks and malfunctions which were occurring at the carwash during the first audit period. These will be discussed further in Section 5.1.2.

The audit period for this study was completed in two stages:

1. May 2008 (ENV206 student Salah Ibrahim, supervised by Alison Prior);
2. September 2008 (Independent audit completed by Alison Prior).

These audits used different methods to assess the carwash water use. The core method used for each audit involved meter readings from the sub-meter installed on the scheme water supply pipes to the carwash. The differences in each audit are described here briefly.

The audit completed by Salah Ibrahim in May 2008 formed part of a group water audit of water using processes at BPRK. Salah was monitoring the car wash water use, and elected to do so by measuring the flow of water from various nozzles in the car wash. The flowrate for each nozzle was extrapolated out to the 40 nozzles within the carwash to determine variations in nozzle efficiency, duration of the carwash and assessed in conjunction with infrequent water meter readings. For much of the audit period however, the carwash was not working and therefore data collected in this study was limited. We also attempted to obtain video footage of the carwash to study the frequency of washes to assist in identification of peak wash times as well as to determine the frequency of “ghost washes”, when the sensor was falsely triggered by wind or rain.

The second water audit, completed in September 2008 involved meter readings at 6am and 6pm for 7 consecutive days. This assisted in determining peak wash periods and in identifying leaks through the baseline audit approach described in Section 2.4: Methods.

### 5.1.2 Results: Carwash

The audit of the carwash showed a number of key trends. The information needed to appropriately assess the car wash water use includes duration of carwash, number of staff on site, wash characteristics including volume of post-carwash leakage. Each of these will be assessed here before comparing to benchmarks of carwash water efficiency.

#### 5.1.2.1 *Audit results*

The 2008 water audit took meter readings at 6am and 6pm every day for a 7 day period between 8-14 September. The volume of water used in each period is graphed in Figure 29.

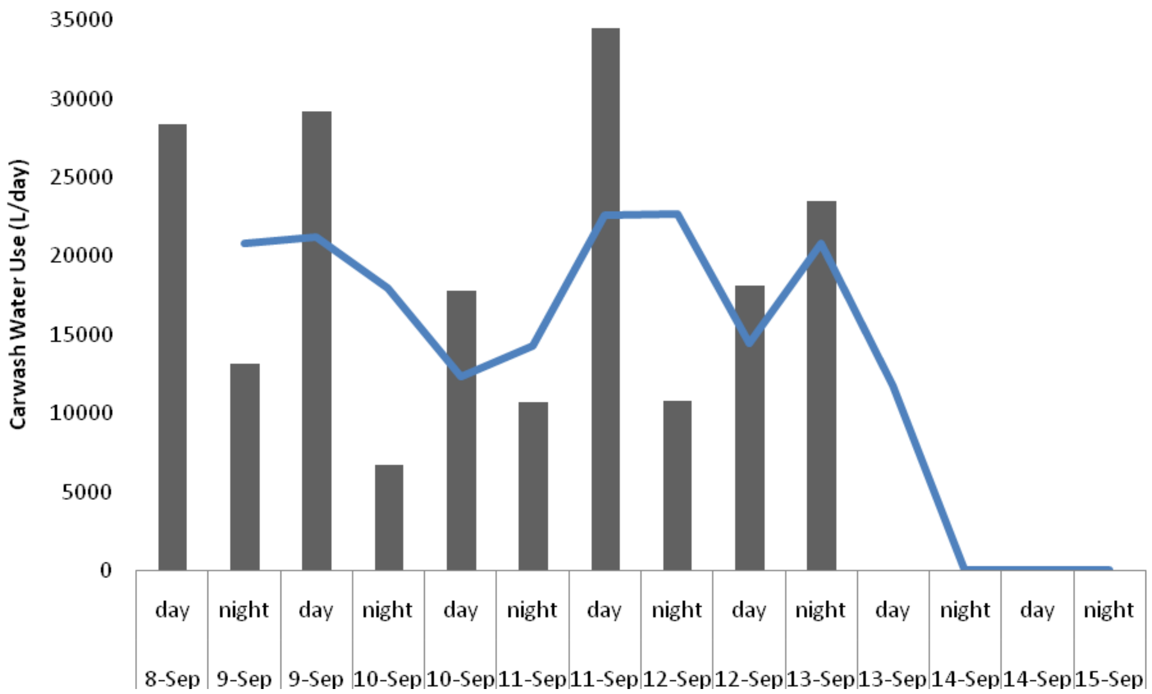

**Figure 29: BPRK audit of car wash water use by 12hrly period (8-14 Sep 2008)**

The trend of higher use during daylight hours (6am-6pm) is apparent, excluding Friday afternoon when wash frequency is much higher than other weeknights. This has been observed at the refinery on a regular basis as employees like to wash their cars before the weekend. On the weekend of the audit the carwash was not used, and the meter showed that no water was leaking over this period.

In order to determine the frequency of car washes it is important to assess the characteristics of the car wash, including the duration and volume of water used in each wash. First, however I will assess the number of people on site for the audit period.

### *5.1.2.2 Numbers of Staff on Site*

As frequency of car washes are related to the number of people on site it is important to present data on employee numbers both over the audit period (years) and over time during any given day. The number of staff on site was provided by BPRK administration for the years 2007 and 2008. The current numbers of staff on site are particularly important as the water audit took place in 2008 despite our intention to represent 2007 data. The numbers of staff on site for these two years is presented in Figure 30.

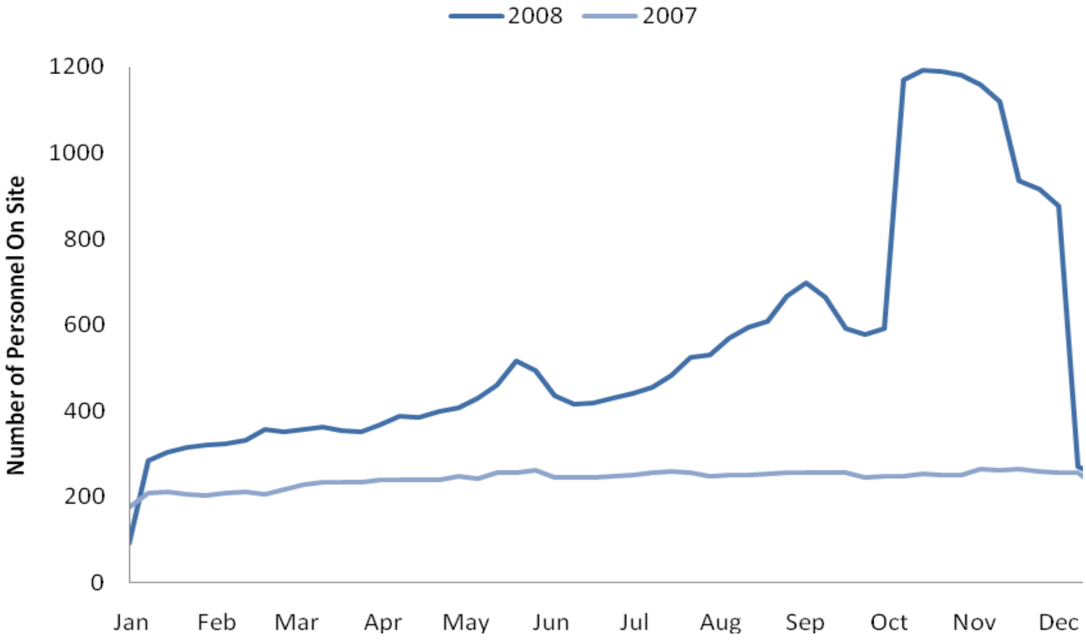

**Figure 30: Number of Staff on-site (2007 and 2008)**

The stark difference in the number of staff on site for the two years is obvious. In 2008 one of the major units at BPRK was closed down for maintenance. The actual maintenance period was during October and November 2008, and required a large number of external contractors for the maintenance period and in the months leading up to it. At its peak, 1200 people were working at the refinery. Extra employees were on site in 2008 because of the construction of a new administration building. This explains the slight increase in employee numbers from January 2008. The number of employees on site in 2007 remains consistent at 200-250. This is representative of a regular year at BPRK and data must therefore be adjusted to account for variations in employee numbers between the field assessments of water use (i.e. 2008) and the audit period (2007). The number of staff on site during a working week also strongly correlates to the frequency of carwashes. Staff working hours can clearly be seen in Figure 16.

#### *5.1.2.3 Duration of car wash*

The car wash operates at an average of 27 seconds per wash, though this time was found to vary quite significantly each wash. Using information from the May audit, we found that the duration of a car wash lasted for between 23 and 35 seconds. Quite often the post-wash leakage would last for up to 10 seconds after the wash had finished.

#### *5.1.2.4 Wash Characteristics*

The carwash audits completed in 2002 and 2008 revealed that the volume of the average wash is 201.7L. This varied significantly however, with a standard deviation of 76L per wash. Some washes recorded less than 100L per wash whilst others were using more than 300L for a single wash. In order to gain an understanding of how much water was used in a standard wash the volume recorded for a single wash in the 2008 audits was plotted into a histogram (Figure 31).

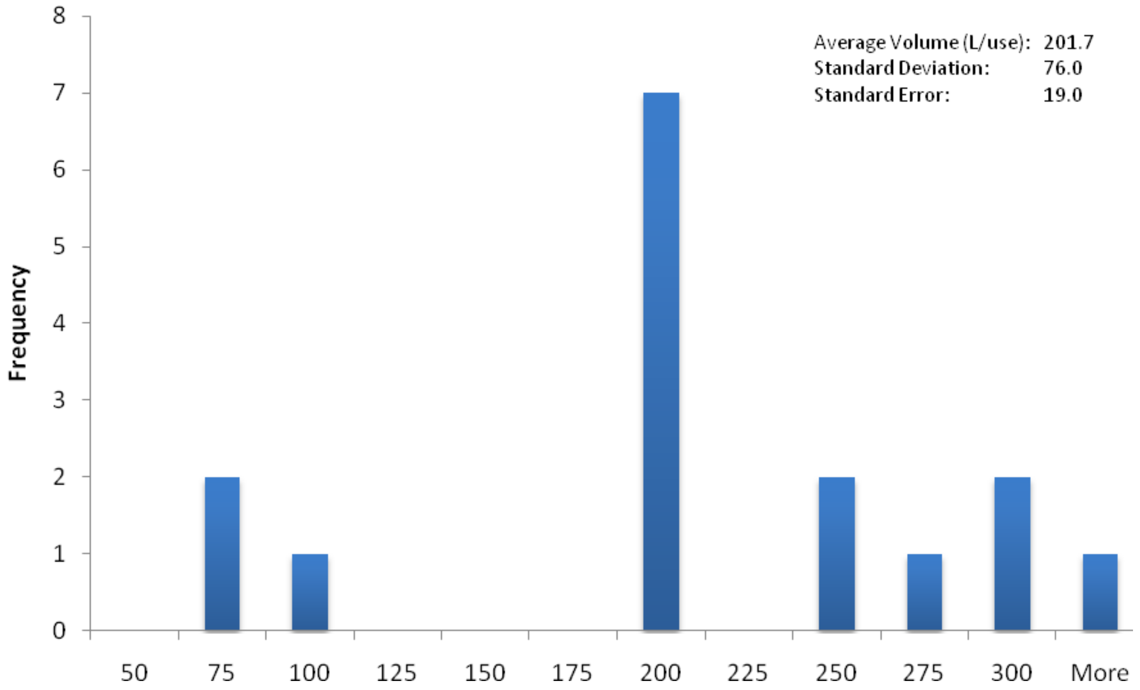

**Figure 31: BPRK car wash histogram showing volume of water per car wash.**

Of the 16 car washes audited, 7 washes used 200L per wash and washes consuming 75<L<300+ were less frequent, occurring only once or twice each. We therefore assume a volume of 200L/wash for the assessment of wash frequency in a 24hr period. When the results of all three audits were extrapolated to represent a 24hr period, there were vast variations between the three. This is expected to be related to numbers of staff on site, particularly as the 2002 audit was conducted over the Christmas-New Year period from December 2002 - January 2003, when the number of staff on site was significantly lower. The 2008 audit on the other hand represents a much higher than usual employee rate with more than 600 people on site at the time of the audit (Figure 30). In order to get a more accurate idea of the volume of water used in a typical 24hr period, a histogram was constructed (Figure 32).

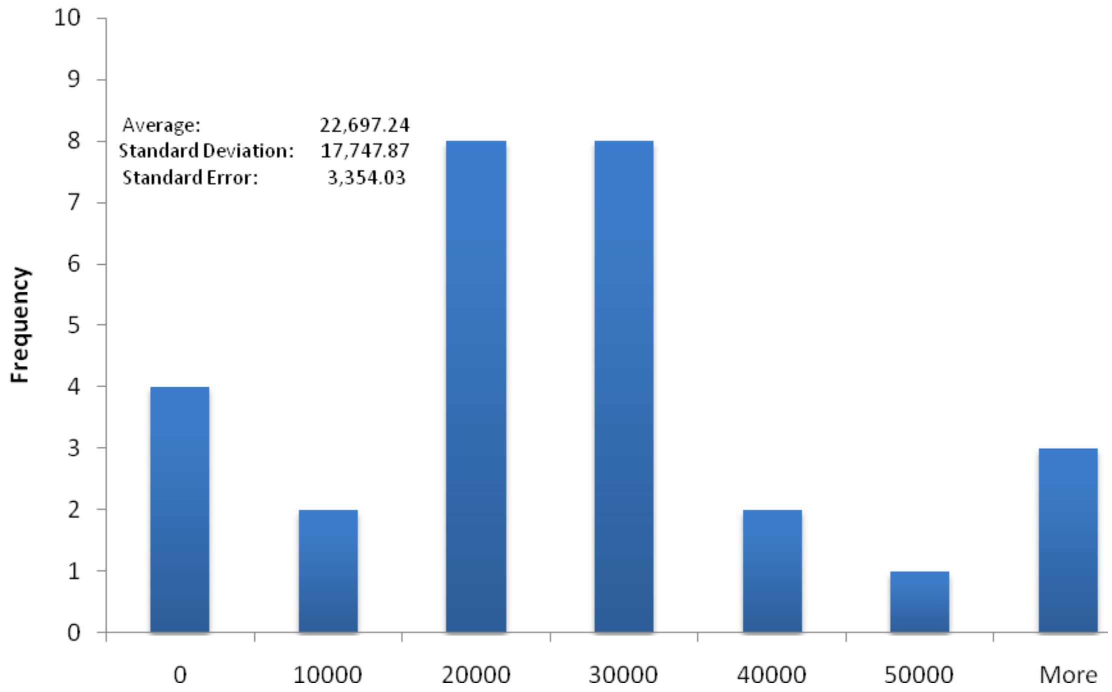

Figure 32: Histogram of average daily use of the carwash (L/24hr period).

The average daily car wash volume was found to be 22.7kL. This varied significantly with some 24hr periods showing 0L/day being used by the carwash and others showing more than 50KLPD. As a general rule however, the carwash would use between 20-30kL of water. Applying the information previously gathered, we assume a single carwash uses 200L per wash. This infers that on average the carwash is used 100-150 times per day. As yet there appears to be no way to verify this figure at the refinery as the frequency of carwash use is not monitored and there are no easy assumptions about how many employees wash their cars and at what frequency. Using the information presented here, total water use in the carwash for 2007 can be estimated at 8.3MLPY. However range indicates that the actual water use be as low as 1.8MLPY or as high as 14.8MLPY.

### 5.1.2.5 *Volume of post-wash leakage*

The 2002 water audit examined the volume of the carwash compared with the volume of post-wash leakage. By testing a representative sample of nozzles, the information in Table 20 was compiled.

**Table 20: Post-wash leakage observed on car wash (Shackley, 2003).**

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With 12.2% losses on average, we can extrapolate this to the carwash and discover leaks in the order of 2,769.4L/day when applied to the average consumption of 22.7KLPD as calculated in Section 5.1.2.4.

### 5.1.2.6 *Benchmarking of Carwash Water Efficiency*

A start rating system is identified for commercial carwashes and shows that the lowest star rating is for carwashes using 151-210L/wash (Figure 33). This is the category in which the BPRK staff carwash fits, indicating the lowest level of efficiency.

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Figure 33: Water efficiency ratings for car wash (Brown, 2000).

Based on this information, BPRK needs to seriously reassess the current practice of its staff carwash. With deteriorating infrastructure, the carwash is already leaking excessive amounts of high quality water which are immediately lost to the septic tanks. The condition of the infrastructure is only likely to deteriorate more over the coming years creating a greater chance of ongoing leaks and maintenance requirements. While construction of a new carwash may be expensive, it could save water in the order of 6-7MLPY if the current carwash is replaced with a carwash with a 5 star rating.

## 5.2 Carwash

The car wash has been shown to be an inefficient user of high quality water. The water is not reused or recycled but is discharged immediately to septics. The volume of water used for each carwash in general is deserving of a one-star water efficiency rating (Brown, 2000). The sub-meter on the carwash has been useful for water auditing purposes. However with no one being solely responsible for the car wash operations and its water use, the meter is very rarely read. Inefficient use of the carwash by employees was observed on numerous occasions at BPRK, particularly during summer when the carwash is used by staff to cool down their cars before driving home. The car wash is also generally ineffective at washing any real grit or grime from cars and as a result employees drive through multiple times in an attempt to get their cars cleaner. The carwash infrastructure itself is very old and leaks are common, with approximately 11% of the total volume of each wash being lost to leakage. Car wash nozzles should be replaced regularly to avoid leakage (Queensland Water Commission, 2008; Seneviratne, 2007). Finally, the carwash has been observed to have a faulty sensor, which is triggered falsely. Discussions with employees have revealed that this occurs more during stormy weather, with wind and rain triggering the sensor.

The operating costs of the carwash are relatively low and replacing or improving current carwash infrastructure is a low priority. Staff now expect they should be able to access a car wash (due to the refinery's proximity to the ocean and also to wash off catalyst and airborne solids from refinery processes). It is therefore not appropriate to remove the carwash completely; however it may be worth investing in a modern water efficient car wash to reduce water consumption and waste. While this would require significant capital outlay, installing a water efficient carwash could save the refinery as much as 6-7megalitres of potable water each year.

# Chapter 6: Management Implications

Chapters 2-5 have given a detailed overview of how water auditing at BPRK can provide information on current water consumption on site. This has been shown to provide opportunities for water minimisation and comparison with international benchmarks. This chapter will now bring the specific water auditing information discussed in the previous chapters to a broader level to discuss the management implications of water auditing, water conservation and ultimately ZLD. The importance of water auditing and conservation is applied to industry in general, to identify generic issues faced across a wide range of industries and the need for improved and more integrated approaches to water management.

## 6.1 Industrial Water Conservation Review

The three major focal points of ZLD were identified in Chapter 1. These were wastewater minimisation, pollution control and source protection. To demonstrate the importance of all three aspects of ZLD, a Venn diagram has been developed showing the equal importance of each of these aspects (Figure 34). When any one of the approaches shown in Figure 34 is neglected, the possibility of achieving ZLD diminishes. This research has shown that current water management approaches, both theoretical and practical, have an overwhelming focus on wastewater treatment and minimisation. A key approach to source protection is the avoidance of water use in the first place. It is clear that without a good understanding of where water is used within industry, opportunities for water efficiency improvements and minimisation cannot easily be identified. This makes the case for the importance of water auditing in the greater scheme of industrial water management and ultimately ZLD.

Overlapping areas:

1) Minimisation of wastewater volumes;

2) Protection of nearby water sources through contaminant removal; and

3) Preventing pollution of wastewater discharge area by wastewater treatment and volume reduction.

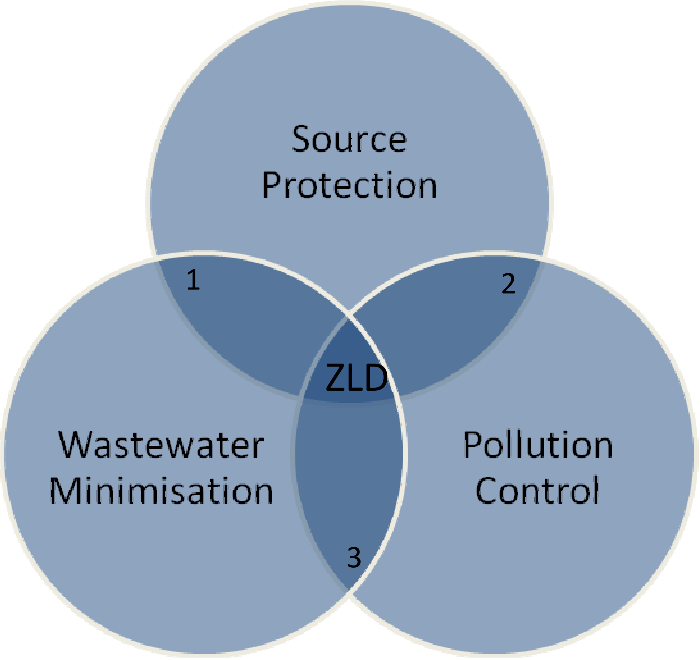

Figure 34: Venn diagram displaying major interventions required to achieve Zero Liquid Discharge (ZLD).

While some literature sources stress that initial source protection and minimisation of water use is important, there are few sources which attempt to demonstrate how to minimise water use. This is easily seen in Table 21.

Table 21: Authors advocating wastewater treatment and minimisation versus authors advocating source protection through water auditing and conservation.

| **Authors advocating wastewater treatment focus.** | **Authors advocating source protection through water auditing and conservation.** |
|---|---|
| (ACIL Tasman, 2007; Al-Redhwan *et al.*, 2005; Alves *et al.*, 2006; Asano *et al.*, 2006; BP Refinery, 2008b; Byers, 1995; Castro *et al.*, 1999; Das, 2005; Doyle and Smith, 1997; Dunn and Wenzel, 2001; Dunn *et al.*, 2001; Eble and Feathers, 1992b, 1992a; Eckenfelder, 2000; El-Halwagi, 1997; European Commission, 2003; Foo, 2007; Foo *et al.*, 2005; Koppola and Bagajewicz, 2004; Lavric *et al.*, 2007; Lens *et al.*, 2002; Liaw and Chen, 2004; Liaw *et al.*, 2006; Majozi, 2005; Majozi *et al.*, 2006; Mann and Liu, 1999; Tebbutt, 1998; United Nations Industrial Development Organisation, 2002; Wang and Smith, 1994; Zbontar and Glavic, 2000; Zbontar Zver and Glavic, 2005). | (American Water Works Association, 2006; Gleick *et al.*, 2004; Nabers Office, 2008; Seneviratne, 2007; Sturman *et al.*, 2004; Victorian Women's Trust, 2007) |

The focus on contaminant removal from wastewater and wastewater minimisation has predominantly been driven by regulatory measures which set guidelines for maximum allowable concentrations of a number of wastewater contaminants[28]. The impacts of discharging poor quality wastewater to an open water source can be seen almost immediately. On the other hand, the impact of withdrawing large volumes of water from a given water source has severe long term impacts, but these are often not apparent immediately. Wastewater minimisation and pollution control are critical to any good water management program, however to achieve a more integrated and holistic approach to industrial water management, a paradigm shift is needed to balance current approaches through the incorporation of source protection.

## 6.2 Water Auditing as a Key Step to Source Protection

Water conservation is characterised by the limitation or modification of water use by human beings, so that our use of water does not cause fluctuations of water quantity and quality within any cycle beyond those fluctuations caused by natural events (Sturman et al., 2004). To achieve water conservation, it is crucial to quantify internal water uses in industry to gain an understanding of where water is used and in what quantities. Most companies and organisations know how much water they use, but may not know where the water is used within the industrial site and may not use this knowledge to help them reduce the amount of water consumed (American Water Works Association, 2006; Piet et al., 2002). Conducting regular water audits and updating water efficiency management plans are effective ways to identify areas to improve water use efficiency and minimise water use. Without basic knowledge of water flows through site, this is a much more difficult task to achieve. The water source is therefore protected by the elimination of unnecessary wastage of water of all qualities, but in particular reduces unnecessary waste of potable water such as scheme

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[28] In Western Australia allowable contaminant concentrations in wastewater discharge are regulated by the Department of Environment in the *1986 Environmental Protection Act*. BPRK is regulated under Licence 5938/8 of the EP Act.

water. Thus it is clear that in order to truly work towards ZLD, water auditing needs to be incorporated into all water management programs.

The issues that have been outlined in this thesis are not unique to BPRK. Instead they reflect management flaws inherent in industries throughout the world. BPRK demonstrates international best case practice in refinery water management, however many inefficiencies and poor management practices are still prevalent within the refinery. It is hoped that by highlighting these management and operational deficiencies, industry can take steps to improve conservation in the future and enhance management strategies to ensure continuous improvement and focus on environmental and social impacts as an additional driver to reducing water consumption, rather than purely focusing on cost. It is well known that water is an underpriced and scarce resource (Gleick *et al.*, 2004; Pigram, 2006). The true value of water is often neglected by industry, and is instead viewed as a cheap and easily accessible resource. Leaks need to be treated seriously and dealt with immediately rather than being left for days, weeks, months and even years before being resolved.

The American Water Works Association's State of the Industry 2008 report identifies source protection and water conservation both in the short and long term as the most crucial issue facing industry (American Water Works Association, 2008). The water minimisation hierarchy (WMH) identified by Seneviratne is shown in Figure 35.

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Figure 35. WMH (as presented in Figure 2) has been adapted to show water quality and water quality assessments as required for improved water management and attainment of ZLD (Seneviratne 2007).

The figure has been revised to show the appropriate method required for each step in the hierarchy. In this research water auditing has been used as a tool to assess the volume of water used in various processes at BPRK. This has assisted in identifying areas where water is wasted and in recognising areas in need of water efficiency improvements. This demonstrates how water auditing can assist in the first two steps on the WMH; avoiding water usage and thus improving water efficiency. In turn, these will reduce the volume of water within the refinery available for wastewater discharge, having the combined effect of wastewater minimisation and source protection. The latter two steps on the WMH are water reuse and water recycling. These are not possible without completing a water quality assessment, including identification of maximum contaminant load receivable on water using processes and assessing the wastewater discharge parameters of each unit to identify opportunities for reuse and recycle. Without knowledge of water quality, identification of reuse and recycle is not possible. Reuse and recycle of water results in reduced wastewater discharge and pollution control, linking back in with Figure 34 and showing how the combination of water quality assessments and water audits can be used in conjunction with one another to develop a water management plan which addresses all aspects of the WMH. The first step in this should always be the water audit, in order to determine areas where water efficiency can be improved and thus achieves the lowest risk and lowest cost target of avoiding water use in an increasingly dry climate and thereby protecting the water source.

## 6.3 Reporting

It is important to implement effective reporting strategies for those who identify water waste and/or leaks throughout the refinery. Currently no-one feels ownership for water conservation issues and it is assumed that someone else will take responsibility for reporting leaks and wastage. Water and steam leaks are not measured on site and costs of leaks have not been estimated, excluding steam trap losses. This system needs to change if water wastage is to be reduced.

## 6.4 Conceptual Approaches

Conceptual approaches often involve practical, common sense methods to help reduce the water consumption in a production plant. These methods are generally not based on a theoretical framework but are implemented in response to the audit findings. Ideas can be gathered on how to manage the water system more efficiently, and may include better housekeeping, opportunities for simple direct reuse or investment in reuse or water efficient technologies (Dunn and Wenzel, 2001; Dunn et al., 2001; Wenzel et al., 2002). Key conceptual tools include zero discharge, cleaner production and cascade analysis (Sturman et al., 2004).

A wide variety of technical approaches have also been developed to assist in industrial water conservation. These tools have proven particularly useful in industries with complex infrastructure and industries using large volumes of water. Each tool has its advantages, depending on the type of water-using operations encountered. Some tools present information graphically for ease of interpretation, whilst others are mathematically based (Wenzel et al., 2002). Water conservation tools can be selected depending on the number of contaminants in the system. If an operation is contaminated by a single pollutant, then tools such as the ‘water pinch’ can be applied and easily analysed (Shoaib et al., 2008; Wan Alwi et al., ; Tan et al., 2007). However when looking at processes with multiple contaminants, mathematical optimisation software should be used to deal with the complexity of the system (Foo, 2007). These are considered in further detail here.

#### 6.4.1.1 Cleaner Production

The concept of cleaner production was developed by the United Nations Environment Program (UNEP) in an effort to prevent pollution, reduce the use of water and material resources and minimise waste in the production process (Sturman et al., 2004). It is officially defined as '…the continuous application of an integrated preventative environmental strategy to processes and products so as to reduce the risks to humans and the environment…' (UNEP, 2001). It has gained world acclaim for its proven ability to reduce industry's environmental burden while simultaneously improving industry's bottom line (van Berkel, 1999).

#### 6.4.1.2 Fit-for-purpose

Much industrial water is used only once and then discharged to sewer or to an on-site treatment plant. This practice is inefficient and produces streams that are more difficult to treat and invariably incurs higher processing costs (Alva-Argáez et al., 2007). The hierarchy of water streams classifies water by its quality, ranging from contaminant-lean through to contaminant-rich streams (Sturman et al., 2004). The four quality levels are shown in Figure 36.

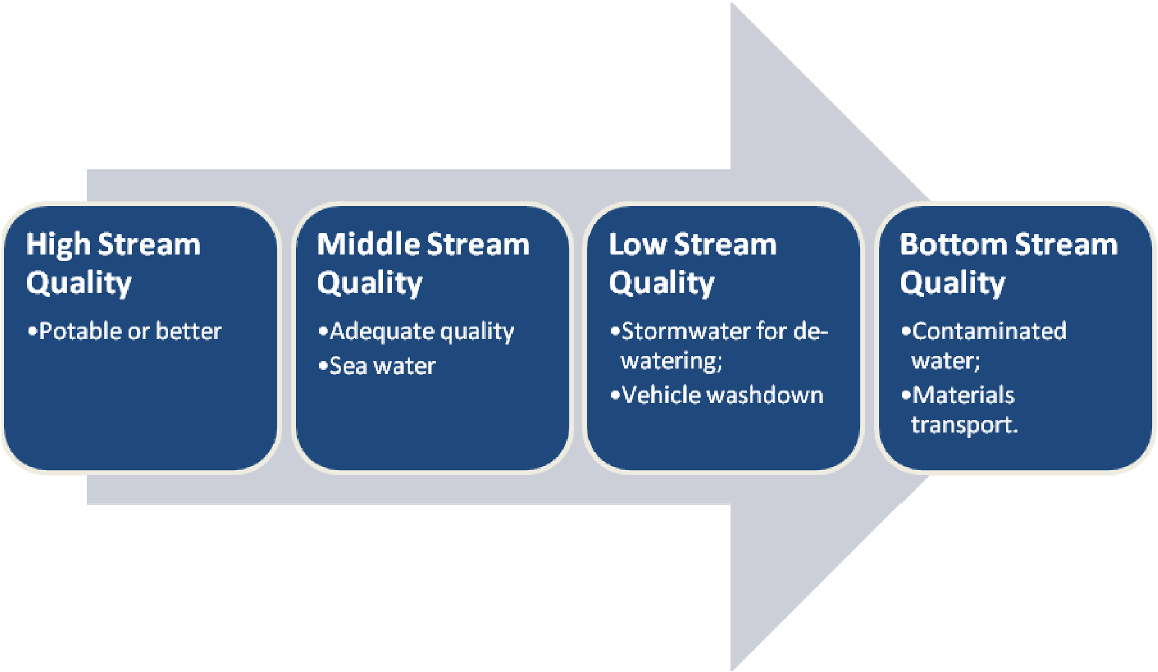

Figure 36: Hierarchy of streams (adapted from Sturman et al, 2004).

Discharged water from one unit operation is often suitable for input to processes where lower quality water supply is adequate (Cote et al., 2007; Eble and Feathers, 1992b). Reuse can occur either with treatment (decentralised treatment systems) or without treatment (water cascading).

## 6.5 Water Synergies

Water synergies combine the principles of both Cleaner Production and Fit-For-Purpose water use and provide opportunity for the reduction and reuse of water within a high density industrial area such as the KIA, home to a diverse range of industries (see Figure 3 in Chapter 1) (van Beers *et al.*, 2006). Currently there are 47 synergy projects in place in the KIA including 32 by-product synergies and 15 water and energy utility synergies. These include:

- Wesfarmers CSBP supplying bore water to TiWest pigment plant;
- Reuse of recycled effluent at alumina refinery;
- Artificial wetland treatment at Wesfarmers CSBP (soon to receive wastewater from BPRK);
- Demineralised water from coal-fired power station; and
- Kwinana water reclamation plant (KWRP).

BPRK was involved in a recent investigation of a water synergy opportunity which would involve the refinery supplying its treated wastewater to the Fremantle Shipping Authority for washing of ships. Unfortunately this synergy opportunity has been delayed because of concerns about environmental issues associated with using wastewater for ship washing in the Cockburn Sound. Potential for other industries to use BPRKs wastewater treatment plant are also currently being investigated.

Neighbouring CSBP[29] presents an opportunity for establishment of water synergies with BPRK because of their close proximity to one another and existing pipelines and other infrastructure between the two industries (particularly the old cooling pipelines which pumped salt water to CSBP via BPRK's saltwater inlet). Figure 37 shows the co-location of the two industries in the Kwinana Industrial Area. Their physical proximity and interaction allows trading of by-products for reuse and cooperative water recycling ventures, which would not be feasible if there were significant distances between facilities.

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**Figure 37: Co-location of BPRK and CSBP in the Kwinana Industrial Area (Google Earth, 2008).**

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[29] CSBP Limited (CSBP), part of the Wesfarmers Limited Group, is one of Australia's largest manufacturers and suppliers of industrial and mining chemical products and fertilisers. CSBP employs approximately 620 personnel at its Kwinana, Bunbury, Albany, Geraldton and Esperance facilities.

In order to determine whether opportunities exist for the development of water synergies between BPRK and CSBP, a primary water audit of CSBP was completed. Onsite investigations were conducted at CSBP in order to gain an understanding of its major water-using processes. CSBP manufactures and distributes more than 1,000,000 tonnes of fertiliser products and 800,000 tonnes of chemical products annually (CSBP Limited, 2008). The different nature of the two industries and unique process requirements of each industry provide scope for the development of water synergies. What is wastewater for one industry may be acceptable quality as an input water source for the other industries processes and vice versa.  A flow diagram of neighbouring CSBPs major water uses was constructed to determine whether it was feasible to create water synergies between BPRK and CSBP (Figure 38).

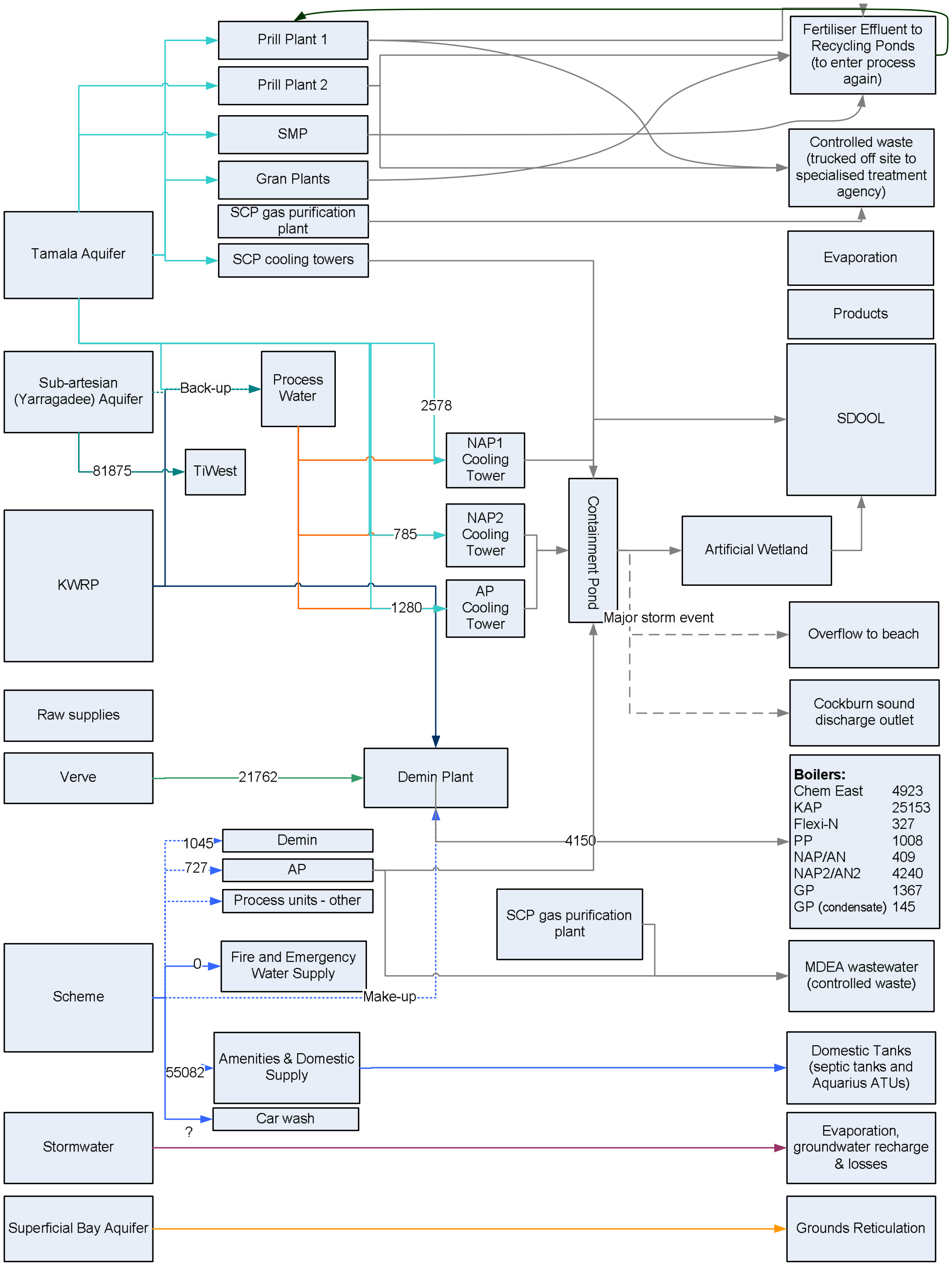

Figure 38: CSBP Primary Water Flows may assist in determining opportunities for water synergies

With water volume assessments alone it is not possible to identify opportunities for synergy. Further assessment is needed to establish water quality of each flow, and minimum quality input requirements (maximum receivable contaminant load) of major water users on each site. Without a complete dataset of major stream quality and flowrates it is not possible to accurately assess the feasibility of developing infrastructure and determining matches of wastewater streams to process inlet requirements. This is an area that would be very important for future research and synergy development. This information may be useful in a further investigation of water synergy development between the two industries.

Industries within the KIA understand the economic, social and environmental benefits that can be gained from industrial synergies and actively seek out new relationships with other industries with the support and guidance of the KIC (Jones *et al.*, 2008). This collaborative and proactive nature is highly developed within the KIA, setting the benchmark for other industrial precincts to emulate, both nationally and internationally (Jones *et al.*, 2008). The nature of water synergies in the KIA is complex and requires frequent meetings with company representatives, large investigations into infrastructure costs and development and most importantly financial, environmental and legal feasibility studies. Many theoretical opportunities for water synergies in the area have fallen due to legal difficulties, government regulations and lack of financial gain for one or more of the entities involved (Kwinana Industries Council, 2006). A major barrier to the implementation of water synergies in the KIC is the lack of knowledge about each industry's internal water flow volumes and qualities and the resulting lack of a market for industrial wastewater. With greater awareness of water use and water quality at each site, opportunities for new water synergies may arise. Water auditing is a key step towards making this knowledge available to nearby industries and to the KIC. This would assist in achieving a more sustainable approach to water management for individual industries, and guides the entire KIA region towards ZLD.

## 6.6 Corporate Culture

It is important in any environmental management program that the corporate culture promotes environmental advocacy and awareness (Baas, 1998). Employees at all levels should feel a sense of ownership or responsibility for the environmental performance of their workplace (Bixio *et al.*, 2008). This can improve employee motivation for reporting leaks, becoming involved in water minimisation programs and being proactive in identifying inefficient water use within industry. Currently at BPRK there is little incentive for employees to become involved in water minimisation activities at any scale. There was however, a strong interest shown when people were asked about potential water minimisation projects. Limitations in time, incentive and pressures in other aspects of work were found to be the key reasons employees were not able to follow up the areas of water management they had knowledge of, or expressed interest in. There also seemed to be some confusion at the refinery about whose responsibility it was to report leaks, resulting in a slow turnaround time for leak repair, regardless of scale. This is reaffirmed by the lack of importance placed on valuation of water loss through leaks.

An important step towards resolving this issue is the restricted involvement of the existing water conservation taskforce in water minimisation programs. This is due to the large work demands placed on the two members of the taskforce and a lack of time to focus on water conservation issues. The team is also limited as both members are located within the refinery's environmental program, meaning that sharing of knowledge amongst the wider refinery workforce and identification of current water minimisation issues is restricted.

Specialised process units have specific requirements for water. Often the process unit operators and process engineers are aware of these issues, but are not in a position to implement water efficiency projects because of other job demands. Lack of communication and information sharing between departments is a critical barrier to the implementation of effective water minimisation programs at

BPRK. This is an issue recognised throughout industry, particularly in large organisations where specialist roles are created, often restricting employees from becoming involved in projects outside the scope of their prescribed job descriptions.

## 6.7 Value of Water

The perceived value placed on water by industry is still very much based on the economic and immediate financial cost of water, as expressed per kilolitre in Table 22.

Table 22: Cost of major water sources and treatment at BP Refinery Kwinana (AUD/kL).

| Type of water | Base cost per kL (as at 2008) | Notes |
|---|---|---|
| **Scheme water** | $0.881/kL | Additional cost of 300mm water meter $122,513/year. |
| **Process water** | $0.82/kL | Includes pretreatment costs of water (mostly bore water) before being used on site. |
| **Boiler feed water** | $1.42/kL | Softened and de-aerated. |
| **Condensate** | $1.50/kL | After boiled and used as steam, loses latent heat. Clean condensate is essentially pure water and can be returned to steam system. |
| **Groundwater** | $0.05/kL | Straight from bore, cost of pumping only. |
| **Cost of wastewater treatment** | $2.34/kL | Can vary by 61c/kL depending on contaminant concentration and treatment requirements. |

When compared to other costs on the refinery, particularly that of product feed, water costs are extremely low. In financial terms, if the refinery loses 10TPD from the condensate systems (one of their highest quality water supply sources) as discussed in Chapter 3, it will only cost them $15 per day in initial outlay. This is affordable in the oil and gas industry which thrives in the oil-dependence of modern society. Pressure for short term profits in industry still takes priority over investment in longer term projects, particularly those which offer little to no financial return. Competing business priorities reduces the amount of time and money that can be invested in water minimisation programs and are major barriers to the implementation of effective water management strategies as a result (Baas, 1998). External barriers to the implementation of water minimisation programs may include perverse economic incentives, difficulty in accessing external finance, economic cycles and failure of current environmental regulations (Baas, 1998).

## 6.8 Continual Improvement

Despite the significant efforts of BPRK to minimise its water use there is a strong need for continual improvement in water management on the refinery. The continual improvement paradigm is identified by Standards Australia and New Zealand ISO14004. It shows the need for incorporation of environmental management into policy and planning before project implementation. When the project is in operation it is checked and undergoes management review to determine how the policy can be improved and updated and the cycle begins again (Standards Australia and Standards New Zealand, 2004). A similar approach is required for water management programs, to ensure that the audit is not a once-off event and ending up as a “shelf-document” as BPRK’s 1998 audit appeared to be. Instead there is a need for ongoing assessment and update of water minimisation and efficiency improvement opportunities and identification of projects before undergoing management review and continual improvement. Without such an approach the water audit will be next to useless and water management on the refinery is likely to remain stagnant.

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**Figure 39: Environmental Management System Model (Standards Australia and Standards New Zealand, 2004).**

The industries within the KIA need to seriously reassess current levels of water consumption, particularly with Kwinana's projected population increase over the next 23 years[30] (Australian Bureau of Statistics, 2000). Increasing demands on the area's water supply will force industry to reduce scheme water consumption and turn to other sources such as recycled wastewater.

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[30] The Australian Bureau of Statistics predicts that Kwinana's population will grow from 25,600 to 42,600 between 2006 and 2031.

# Chapter 7: Conclusion

A fundamental flaw in the way ZLD is assessed is in the exclusion of water source protection and water minimisation. This frequently occurs in text book assessments of ZLD but also in current industrial practice which tends to assume an infinite and cheap supply of fresh water. Instead, strong focus has been placed on pollution control and wastewater minimisation. These are fundamental aspects of any program which aims to achieve ZLD, however without source protection and focus on water minimisation ZLD does not represent a holistic approach to industrial water management. This research recommends that a paradigm shift is required in the way water management is approached and assessed in industry in order to include water conservation and source protection. This would then fully reflect all three key aspects of water management in order to move towards the ultimate goal of ZLD.

The assessment of water use at BPRK shows that while the refinery's water minimisation program is often cited as best case practice, there are many examples of inefficient water use and abhorrent losses of fresh water. This does not necessarily reflect badly on the BP refinery itself, as it has done an exceptional amount of work on water minimisation through employee education, improved water management and implementation of on-site water recycling and regeneration projects. What it does show is the inherent flaws in current approaches to water management and minimisation in industry. A company such as BP can afford to lose thousands of tonnes of steam and condensate per day because of unattended leaks, and choose not to implement water efficiency measures because of the perceived diminishing returns associated with expending on water minimisation programs and still be an industrial role model in water efficiency.

Australian industry has started to take proactive approaches to water management and there are many examples of companies, such as BPRK, which go beyond compliance in their water management programs. However the way in which water is overused and undervalued indicates that it is still seen as a low-cost resource which can be used at will in industrial processes, in volumes which are rarely questioned. It is now crucial for industry to re-assess the way it manages its local water sources, particularly as industries tend to be significant water users in their local catchment areas. We have seen that many industries are aware of how much water they use as a whole, but beyond entering the industrial site, insufficient knowledge about internal water flows is common. By conducting baseline assessments of water use through such methods as water auditing, industry are able to take a crucial first step in an effective water management program, which can then give them a greater understanding of where water can be minimised, reused, recycled or replaced with a more appropriate quality water input. This baseline assessment then allows the industry to move forward in their water management and lead on to true progress towards ZLD. Without this kind of baseline water assessment many industry water minimisation programs can be tokenistic and inefficient water users can go unnoticed or neglected for years.

Finally, it is shown that the value of water needs to be appreciated not only by financial outlay, but by its environmental, social and cultural value. Once water has been used by industry it is usually not returned to its natural state, and creates enormous interference with the Earth's natural hydrological cycles. While it is expected that the cost of water and wastewater treatment will continue to rise in coming years, we cannot rely on this alone to prevent major overconsumption and exploitation of our water resources. A change in attitude towards water management is desperately needed in industry. The true value of water needs to be fully appreciated and incorporated into all aspects of daily industrial operations. With over-allocated groundwater resources in Kwinana, lowering groundwater tables and declining water levels in dams in the Perth area, reassessment of industrial attitude and water management practice needs to start now.

# Chapter 8: Recommendations

## *Need for further minimisation of water at BPRK*

Despite enormous reductions in BPRKs water consumption since 2008, pressure to further reduce water uses is still high. BPRK has the opportunity to improve its water use efficiency and demonstrate world class water management and conservation practices.

## *Recognise water for its true value*

Currently water minimisation projects are not implemented in industry because of perceived diminishing returns. It is important for management and staff at all levels to recognise the value of water, not as a cheap resource, but as a limited and valuable resource with environmental, social and cultural importance. Until this occurs water will continue to be wasted in vast quantities in industry.

## *Sharing of knowledge across site*

Knowledge sharing is a crucial step in an effective and integrated water management program. Specialist knowledge of water efficiency in utility and process water consumption needs to be shared across the refinery so that people with knowledge of water inefficiencies can be linked up with those who have resources and funding for implementing water efficiency projects. This may be linked to the next recommendation, development of a multidisciplinary water conservation taskforce.

## *Establishment of multidisciplinary water conservation taskforce*

In order to approach water minimisation and management in a holistic manner across the refinery it is crucial to have a water conservation team with members from a number of key areas and either knowledge about water efficiency or regular communication with other staff in their department about water management issues on site. The team should be comprised of people from a range of disciplines including process engineers, operators, environmental staff, site workers and other disciplines as relevant. This will help knowledge sharing and improve employee attitudes and sense of ownership for water management on site.

### *2008/9 Water Audit*

With the implementation of the additional water sourced from the Kwinana Wastewater Reclamation Plant (KWRP), it is important to conduct another audit to establish changes in efficiency and water use minimisation (particularly scheme water) associated with recycled water use. This is predicted to contribute to large reductions in water use at the refinery.

### *Water Quality Audit*

A water quality audit is a crucial step if the refinery is to identify future opportunities for water reuse and recycling, particularly in the process units. This could lead on to water pinch and water optimisation studies which would push BPRK to cutting edge refinery water management at a global level. This would also increase potential for BPRK to be involved in water synergy projects in the KIA in the future.

### *Improve monitoring of wastewater discharges to the OWS*

Currently very few process units have metering on discharges to the OWS. In order to effectively manage the refinery’s water use, information about wastewater volume and quantity produced (at least by major units) should be known and easily available. This would also assist in obtaining closure for future process unit water studies and can form the basis for other recycling and reuse projects. It can also lead on to more opportunities for decentralised wastewater treatment, as recommended in the next paragraph.

### *Investigate opportunities for decentralised wastewater treatment*

Treating these waters before mixing may prove to be more efficient and even provide a viable business option for the refinery. It is especially worth assessing the viability of decentralised treatment options for the major wastewater producers: the desalter, the RCU and the CR3.

### *Sub-metering of Other Water Uses (Scheme Water)*

Sub-metering of scheme water used in office buildings, the laundry and the canteen at BPRK is non-existent. It is crucial for BPRK to place meters on these water uses if further reduction in scheme water use is to be achieved.

### *Improvement of Steam Trap Audit Method*

Currently the steam trap audits do not record whether condensate is usually returned to the steam system or discharged to grade or the sewer system. This information needs to be recorded for all future audits so that appropriate efficiency measures can be implemented and the refinery condensate return system can be improved.

### *Water Pinch for Process Units and Steam System*

A total energy balance using energy pinch analysis should be conducted to rationalise energy and steam demands. Likewise a water pinch analysis should be undertaken on process units to ensure maximum water efficiency is achieved. This would follow on from a complete water volume and water quality audit of the refinery.

### *Development of Water Conservation Campaigns*

All levels of staff should be involved in water minimisation projects to increase the sense of ownership and improve the level of environmental advocacy amongst employees at BPRK.

### *Redefine targets for water minimisation and reuse*

Targets for scheme, bore and total water consumption, condensate return and water to the WWTP at BPRK are outdated and in need of revision. These targets are outdated and do not challenge current refinery water use. Targets need to be redefined to ensure that the refinery is aiming for continuous improvement and that current water use levels are reduced even further.

### *Continual Improvement*

It is important for the refinery to pay close attention to its water use and to continually update and implement water minimisation projects. Future water minimisation, reuse and recycle projects may offer diminishing returns but are necessary if the refinery is to operate in an environmentally sound manner.

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