PACKAGE PLANTS FOR DRINKING WATER TREATMENT

Technology survey, operation and maintenance aspects

Report to the
Water Research Commission

by

S Korlam, P Thompson, R Rajagopaul
Umgeni Water

WRC Report No. TT 665/16

June 2016

Obtainable from
Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

This publication of this report emanates from a project entitled *Package Water Treatment Plants: Lessons and Experiences in South Africa* (WRC Report No. K8/1091/3).

ISBN 978-1-4312-0795-4
Printed in the Republic of South Africa

EXECUTIVE SUMMARY

BACKGROUND

In efforts to make package plants more compact, affordable and easier to operate and maintain, it has been noted that the design and performance of some of these plants containing conventional treatment processes is sometimes compromised if technical expertise in this regard is lacking. Generally, there are several risks associated with poorly designed treatment systems, including loss of production, poor safety and compromised equipment and process unit efficiency with associated higher operating and maintenance costs. These risks have more severe consequences in the case of desalination (including water reclamation and water re-use) package plants. The objective of this project is to develop a set of guidelines to assist municipalities, water treatment practitioners, designers and package plant manufacturers in the specification and design of appropriate unit processes and operating parameters to fit the influent water quality, operating environment and other special treatment requirements.

AIMS

The following were the aims of the project:

1. Establish trends on the use of package plants in South Africa including:
   - Trends on the use of water treatment package plants in South Africa
   - Types of application
   - Raw water types
   - Challenges in operation and maintenance
   - Special raw water types and technology employed.
2. Compile considerations for package treatment plants including selection of appropriate technologies for treatment of specific pollutants.

METHODOLOGY

The first part of this project entailed conducting a desktop market survey to identify package water treatment plants installed across South Africa. The scope of the study was limited to treatment processes for drining water production. Information was sourced from the suppliers or owners of these plants. The following information was requested: capacity of the treatment process; raw water source (river, dam, groundwater, sea water); technology employed (treatment processes); clarifier and filter dimensions and summary of operations and maintenance (O&M) aspects. The populated data was then analysed in terms of the market trends, treatment technologies employed and challenges faced. A review of literature on previous work done on package water treatment plants was conducted, and was used for interpretation and comment on the survey data.

SUMMARY OF FINDINSG

- Package water treatment plants are widely used in South Africa, with the majority of these plants located in rural areas.
- Some of the main challenges experienced with package plants include:
  - Lack of technical skills in the design of package plants: this can in part be due to contractors being consulted directly, in order to save costs, instead of obtaining technical assistance with the design of package plants. In addition, the design engineers of package plants would require sufficient experience to identify and design around challenges, some of which are generic and others which are specific for each package plant application
  - Lack of skills in managing cash flows during O&M
  - Lack of operator training and skill.
- Sophisticated control strategies and instrumentation can assist in the automation of processes, so that full time operator presence may not be required. However, the limitations of automation must be taken into account when designing processes. The maintenance of instrumentation and equipment used is essential for the success of automation. The decision on whether or not to automate processes must be made based on cost, risk and benefits.
- Reliability, by making allowance for stand-by equipment must be built into the design. Rural plants, which are far from maintenance workshops, face the challenge of having to wait long for maintenance personnel to repair equipment, but also due to theft are unable to keep shelf stand-by equipment on site.
- Remote monitoring technologies are readily available and offer solutions for easier process monitoring for rural sites. The potential of this technology was not extensively exploited in the package plants surveyed.
- Renewable energy can assist with limiting the extent of process disruptions due to power failures. These technologies also offer operational cost savings.

CONCLUSIONS AND RECOMMENDATIONS

In this project a representative inventory of package water treatment plants in South Africa was compiled. In addition, the challenges experienced were identified and guidelines/considerations on the selection of processes for the removal of contaminants and when designing package water treatment plants are discussed. This report will assist water treatment designers and water treatment practitioners particularly in South Africa to make informed decisions on the appropriateness of high rate clarification processes under local conditions. It is essential that the circumstances under which package plants utilising nonconventional water sources are carefully assessed, since the investment in the full time presence of skilled operators and technical support services is necessary given the nature of the risks. Water quality challenges associated with unconventional raw water sources require to be dealt with appropriate treatment technologies in order to minimise risks associated with emerging contaminants. A continual review in this regard is recommended in order to update the sector on emerging treatment technologies, and to identify the challenges experienced as well as emerging solutions.

CONTENTS

ACKNOWLEDGEMENTS

The cooperation of the suppliers and owners of package water treatment plants is acknowledged. The support from the WRC and Umgeni Water for allowing this research work to be conducted is gratefully acknowledged.

LIST OF FIGURES

LIST OF TABLES

ACRONYMS & ABBREVIATIONS

AVGF	Auto Valveless Gravity Filter
DPR	Direct Potable Re-use
GAC	Granular Activated Carbon
GSM	Groupe Spécial Mobile (Global system for Mobile Communications)
IPR	Indirect Potable Re-use
MLD	Megalitres per day (i.e. 1 ML/day = 1000 m^3/day)
O&M	Operation and Maintenance
PAC	Powdered Activated Carbon
RO	Reverse Osmosis
SANS	South African National Standards
SLA	Service Level Agreement
UF	Ultra-filtration
UV	Ultra-violet
VOC	Volatile Organic Compound
WW	Waterworks

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Water treatment package plants have become an increasingly popular option in South Africa, especially in smaller remote areas. Not only can package plants be used as a short term solution to augment water supply during plant upgrades and unexpected increases in water demand, but also to enable steadfast service delivery to meet backlogs in un-serviced areas where it may not be economically viable to install large municipal plants. In addition, due to rivers and groundwater becoming depleted, coupled with the increase in water use and prolonged periods of drought, alternative water sources are being investigated. In particular, desalination and water reclamation and re-use technologies are being investigated and used in South Africa for both industrial use as well as potable water use. Desalination and water re-use technology have been employed as emergency drought relief solutions in the southern Cape region.

In recent years, negative perceptions around package plants have been reported, and this has been attributed to various design, operational and maintenance shortcomings, which resulted in these treatment processes taken offline after a short period of operation and a consequent poor return on investment on these installations (Thompson *et al*., 2015). Some of the shortcomings noted by Thompson *et al*. (2015) include incorrect process design philosophy, overly optimistic design fluxes, lack of redundancy, complex operation and poor mechanical and maintenance specifications.

This report documents and evaluates the information obtained from the market survey on the use of potable water treatment package plants in South Africa.

1.2 PROJECT AIMS

The following were the aims of the project:

1. Establish trends on the use of package plants in South Africa including:
    a. Trends on the use of water treatment package plants in South Africa
    b. Types of application
    c. Raw water types
    d. Challenges in operation and maintenance
    e. Special raw water types and technology employed

2. Compile considerations for package treatment plants including selection of appropriate technologies for treatment of specific pollutants

1.3 APPROACH

The first part of the market survey consisted of sourcing the needed information. This was done through a desktop study and comprised the following activities:

a. Identification of consulting firms, suppliers, manufacturers and owners of water treatment package plants, achieved via an internet search and verbal communication. Adverts were also placed in the local newspaper requesting suppliers of package plants to provide information on the package plants which have been supplied

b. A survey form was developed and sent via email to the stakeholders identified in step (a) above, where the following information was requested:
    - Capacity of the treatment process
    - Raw water source (river, dam, groundwater, sea water)
    - Technology employed (treatment processes)
    - Clarifier and filter dimensions
    - Summary of O&M challenges

The populated data was then analysed in terms of the market trends, treatment technologies employed and challenges faced. A review of literature on previous work done on package water treatment plants was conducted, and was used for interpretation and comment on the survey data.

1.4 SCOPE AND LIMITATIONS

Package plants were defined in this study to be processes of capacity less than 5 MLD (5 000 m^3/day or 208 m^3/h) and which require minimal civil construction work to install. Package plants were not limited to treatment systems sold as integrated units by manufacturers. Advantages of package plants are well documented in literature (Voortman and Reddy, 1997; Clark *et al.*, 1994; Alagarsamy, 1981), and include the following aspects;

- Compact and rapidly deployable processes
- Simplified operation, which enables less operator intervention in applications where technical skill and support is not readily available
- Suitable for meeting the small demands in sparsely populated areas

The scope of the study was limited to treatment processes for drinking water production. Smaller plant capacities for supplying water at a household level were not considered.

CHAPTER 2: TRENDS ON THE USE OF DRINKING WATER TREATMENT PACKAGE PLANTS IN SOUTH AFRICA

2.1 INTRODUCTION

Package plants are generally used in areas not served by larger centralized water treatment plants. Some of the negative perceptions developed over the years about package plants being more problematic and having a high cost to benefit ratio are in part due to shortcomings in a number of factors, including planning and specifications, equipment selection and process design and operation and maintenance. This resulted in unnecessarily high capital investments in package plants which were sometimes abandoned after being unsuccessfully operated for a short period of time (Thompson *et al.,* 2015).

Often when package plant solutions are used in situations where there are constraints in terms of budget and time, the pressure on design engineers to find economic and practical solutions with short lead times can result in inappropriate technology selection and attempts to extract beyond recommended design capacity out of equipment so as to maintain minimal capital investment. This result in over-optimistic designs and aspects such as reliability and matching technologies selected with available operational support structures being ignored. This eventually results in high post-construction modification costs and sometimes failure of the infrastructure.

Package water treatment plants however have great potential, when well designed and supported by appropriate operation and maintenance structures. Some of the advantages offered by package water treatment plants include:

- Suitable for decentralised rural water supply
- Compact, and in some instances modular units
- Suitable for emergency or unplanned water demand, especially mobile type of units
- Temporary supply while a fixed structure plant is being designed and built

This section presents:

- A description of the package plants surveyed
- Trends observed, including
    - Rationale for selecting a package plant solution
    - Market trends, where cost data is given
    - A description of the technologies employed in package plants
    - The operations and maintenance (O&M) challenges which were reported in the package plants surveyed

2.2 AN INVENTORY OF DRINKING WATER TREATMENT PACKAGE PLANTS IN SOUTH AFRICA

A total of 69 drinking water package plants were identified throughout South Africa, mostly at rural sites. Table 2-1 shows the data obtained for the plants and is also discussed below. Details of suppliers and owners of package plants who provided information can be found in Appendix A.

2.2.1 Location

The location of package plants at remotely located sites would be expected since the limited availability of operational capability and maintenance support, and the lack of economies of scale available to larger systems, makes package plants an attractive choice. In addition, due to rapid deployment, package water treatment plants enable steadfast delivery to meet backlogs in these areas.

2.2.2 Size

The capacities of the plants in the survey varied between 1 m^3/h and 250 m^3/h, with more than 90% of the plants in the survey having a capacity < 150 m^3/h. Figure 2-1 shows the relative proportions of the number of plants in various capacity ranges.

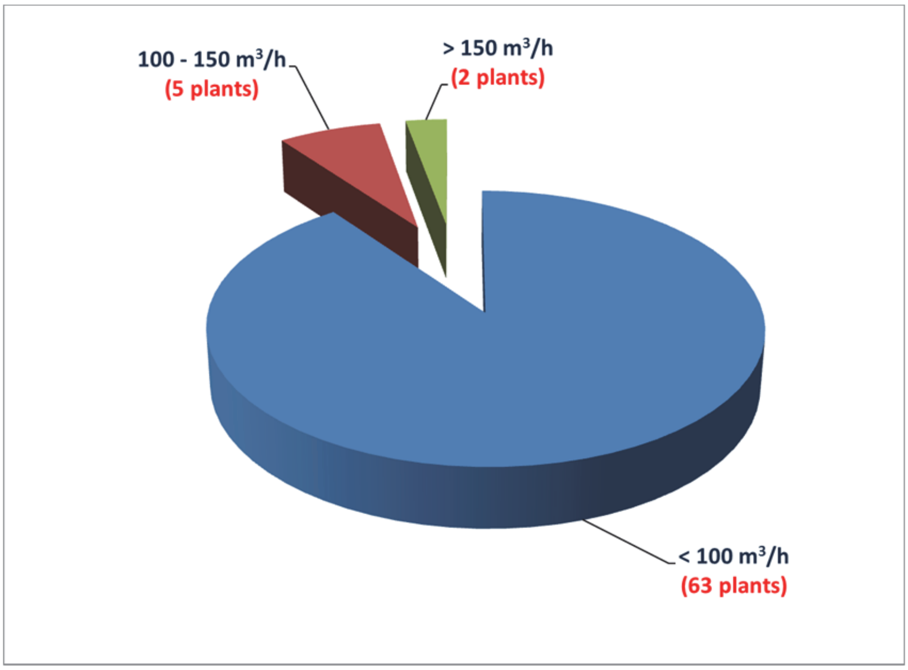

Figure 2-1: Proportion and capacities of the plants surveyed

Table 2-1: An inventory of drinking water treatment package plants (less than 5 ML/day)

No.	Package plant	Capacity		Raw water type	Treatment process description	Operation and Maintenance challenges/comments
		Mℓ/day	m^3/h			
1	Dennedal Garcia, Riversdale	0.16	6.7	River	Ultrafiltration	Remote location
2	Tshaanda, Limpopo	0.05	2.1	River	Ultrafiltration	Remote location
3	DWS, Clanwilliam dam	0.15	6.3	Dam	Ultrafiltration	Electricity supply
4	Sandriver Package Plant	1	41.7	River	Abstraction, filtration & disinfection	The plant uses 6 JoJo tanks as sedimentation tanks. The JoJo tanks are flat bottomed and pose a challenge for de-sludging. The package plant requires an upgrade
5	Marite Package Plant	4	166.7	Small dam or weir	Abstraction, filtration & disinfection	The package plant requires a mixing channel and sedimentation tanks. The quality of the treated water is compromised due to inadequate treatment processes.
6	Edinburg Package Plant	3	125.0	Canal	Abstraction, flocculation, sedimentation, filtration & disinfection	No challenges
7	Dwaleni Package Plant	2	83.3	River	Abstraction, filtration & disinfection	The package plant requires a mixing channel and sedimentation tanks. The quality of the treated water is compromised due to inadequate treatment processes. The raw water abstraction point is a small stream-quantity & quality of water affected
8	Mshadza Package Plant	2	83.3	River	Abstraction, filtration & disinfection	The package plant requires a mixing channel and sedimentation tanks. The quality of the treated water is compromised due to inadequate treatment processes. The raw water abstraction point is a small stream-quantity & quality of water affected
9	Mganduzweni Package Plant	2	83.3	Agricultural Dam	Abstraction, filtration & disinfection	The package plant requires a mixing channel and sedimentation tanks. The quality of the treated water is compromised due to inadequate treatment processes
10	Sterkstroom – Eastern Cape	1.92	80.0	Dam	Iron Removal (aeration towerx2), sedimentation tank - lamella clarifier and pressure dual media filtration - modular plug and play	Fully automated (PLC, SCADA, with remote monitoring via the internet)

No.	Package plant	Capacity		Raw water type	Treatment process description	Operation and Maintenance challenges/comments
11	Riemvasmaak Northern Cape	0.96	40.0	River	Abstraction Flocculation Pressure Filtration - modular plug and play	Fully automated (PLC, SCADA, with remote monitoring via the internet)
12	Molteno Eastern Cape	0.12	5.0	Borehole	Membrane plant and conditioning of hard water	Fully automated (PLC, SCADA, with remote monitoring via the internet)
13	Modikwe Platinum Mine Potable Water Plant, Limpopo	0.24	10.0	Borehole	Floc dosing, chlorine dosing, inline mixer, filtration, storage	Under construction
14	Twickenham Mine Hackney Shaft Potable Water Plant, Limpopo	1.2	50.0	Dam	Floc dosing, chlorine dosing, inline mixer, filtration, storage	Under construction
15	Schmidtsdrift Potable Water Treatment Plant, Northern Cape	0.36	15.0	-	Floc dosing, chlorine dosing, clarification, inline mixer, filtration	Under construction
16	Kuruman Orphanage, Northern Cape	0.034	1.4	Borehole	RO	Backwash and brine handling
17	Zinkwazi Water, KZN	0.6	25.0	Borehole	Clarification, UF, RO	Sludge, retentate and brine disposal
18	Kwanyuswa Package WTW	0.72	30.0	River	Floc Conditioning using a flocculation column, Sedimentation using 2 x Upflow sludge blanket settlers. Filtration & Disinfection and Sludge drying beds	Issue with the backwash effectiveness on the Auto Backwash Filter
19	Umkamyakude DM - Containerised Package plant	0.576	24.0	River	Floc Conditioning using a flocculation column, Sedimentation using 2 x Upflow sludge blanket settlers. Filtration & Disinfection and Sludge drying beds	River abstraction was a challenge
20	Umgeni Water - New package WTW for Mhlabatshane	2	83.3	Dam	Flocculation, Flocc Conditioning using a flocc conditioning tank with 4 x Mixtec stirrer, Sedimentation using 4 x DW 50 Lamella settlers. Filtration using 4 x DW 50 pressure filters	Plant worked exceptionally well overall. The flocculation tank proved itself. Weak point in this installation was the compressed air supply - client will use electrical actuators for future plants
21	Umgeni Water - Mtwalume	2	83.3	River	Flocculation, Flocc Conditioning using a flocc conditioning tank with 4 x Mixtec stirrer, Sedimentation using 4 x DW 50 Lamella settlers. Filtration using 4 x DW 50 pressure filters	Still due for installation
22	Tumela Mine, Limpopo, Anglo American Platinum Mines	0.36	15.0	Borehole	Reverse osmosis (containerised)	-
23	Tumela Mine, Limpopo, Anglo American Platinum Mines	0.36	15.0	Borehole	Reverse osmosis (containerised)	-

No.	Package plant	Capacity		Raw water type	Treatment process description	Operation and Maintenance challenges/comments
24	Mtulwa	0.35	14.6	Borehole	Oxidation, coagulation, flocculation, clarification, pressure filtration, disinfection	Poor chemical dose control and chemical dose optimisation, no sparing of pumps on disinfection system
25	Ngungu	0.36	15.0	River	Flocculation, clarifier, pressure filter	Plant operating above design capacity of 0.36 Ml/day. Backwash regime requires optimisation. No O&M manuals available
26	Makeni	0.32	13.3	River	Coagulation, flocculation, clarifier, pressure filter, disinfection	Poor chemical dose control and chemical dose optimisation, no sparing of pumps on disinfection system
27	Nagle Package Plant	0.14	5.8	Dam	Conventional: Coagulation, flocculation, clarification, filtration.	Only notable challenge is the manual operation.
28	Rosedale; Umtata	3	125.0	Dam	Coagulation, flocculation, sedimentation, filtration, disinfection	Lack of skilled operators & maintenance personnel
29	Nokweja WTP, Umzimkulu	1.8	75.0	River	Coagulation, flocculation, sedimentation, filtration, disinfection	Lack of maintenance
30	Umzimkulu WTP, Umzimkulu	3	125.0	River	Coagulation, flocculation, sedimentation, filtration, disinfection	Lack of skilled operators & maintenance personnel
31	Nzinga WTP, Impendle	1	41.7	River	Coagulation, flocculation, sedimentation, filtration, disinfection	-
32	Airfield, Manguzi	1.9	79.2	Borehole	Iron removal - pH correction, oxidation, coagulation, filtration	Borehole pump maintenance – affects raw water supply
33	Thengani, Manguzi	2.6	108.3	Borehole	Iron removal - pH correction, oxidation, coagulation, filtration	Borehole pump maintenance – affects raw water supply
34	Manguzi WTP, Manguzi	0.7	29.2	River	Coagulation, flocculation, sedimentation, filtration, disinfection	-
35	Bergville	1	41.7	River	Coagulation, flocculation, sedimentation, filtration, disinfection	-
36	Machunwini, Kokstad	0.5	20.8	River	Coagulation, flocculation, sedimentation, filtration, disinfection	Lack of skilled operators & maintenance personnel
37	Kwanovuka PH A	0.5	20.8	Borehole	Coagulation, filtration, disinfection	-
38	Kwanovuka PH B	0.6	25.0	River	Coagulation, flocculation, sedimentation, filtration, disinfection	-
39	Nondweni WTP, Nondweni	2	83.3	River	Coagulation, flocculation, sedimentation, filtration, disinfection	-
40	Mpendle (Gomane borehole)	0.6	25.0	Ground water	Arsenic removal system	In progress not yet completed
41	Lion River	0.36	15.0	Ground water	Defluoridation System	In progress not yet completed

No.	Package plant	Capacity		Raw water type	Treatment process description	Operation and Maintenance challenges/comments
42	Hazelmere WTW	6	250.0	Dam	Conventional treatment	
43	Zinkwazi WTW	1	41.7	Ground water	Reverse Osmosis	
44	Komati WTW	1.0	41.7	River	Auto back wash sand filter	
45	Paris Dam WTW	1.0	41.7	dam	Auto backwash sand filter	
46	Giant Castle Game Reserve Ukhahlamba (Maloti - Drakensberg)	0.075	3.1	Spring	Inline mixer,Floc-column, Clarifier, two filters	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
47	Didima Game Reserve Ukhahlamba (Maloti - Drakensberg)	0.075	3.1	River(Spring source)	Inline mixer,Floc-column, 2 X Clarifiers, three filters	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
48	Midmar (Munro Bay) Nature Reserve - Howick	0.144	6.0	Dam source	Polyelectrolyte dosing, inline mixer, floc-column, clarifier, sodium hypochlorite disinfection and one filter	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
49	Midmar Training centre	0.034	1.4	Dam source	Polyelectrolyte dosing, inline mixer, clarifier, sodium hypochlorite disinfection and one filter	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
50	Midmar (Power boat) Nature Reserve - Howick	0.181	7.5	Dam source	Polyelectrolyte dosing, inline mixer, retention pipes, sodium hypochlorite disinfection and three filters	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
51	Midmar (Workshop) Nature Reserve - Howick	0.024	1.0	Dam source	Polyelectrolyte dosing, sedimentation in 10 m^3 Jo-Jo, sodium hypochlorite disinfection and one filter	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
52	Chelmsford Nature Reserve	0.144	6.0	Dam source	Polyelectrolyte dosing, flocculation channels, steel clarifier, floc-column, sodium hypochlorite dosing, two filters	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
53	Ndumo Game Reserve	0.147	6.1	River source	Polyelectrolyte dosing, inline mixer, floc-column, two clarifiers, sodium hypochlorite disinfection and one filter	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
54	Sodwana Bay Nature Reserve	0.508	21.2	River source	Polyelectrolyte dosing, inline mixer, retention pipes, three clarifiers, sodium hypochlorite disinfection and eleven filters,	SCD unable to handle changes in turbidity
55	Hluhluwe(Hilltop) Game Reserve	0.204	8.5	River/Spring source	Polyelectrolyte dosing, inline mixer, retention pipes, two clarifiers, sodium. hypochlorite disinfection and six filters,	SCD unable to handle changes in turbidity
56	Imfolosi(Mpila) Game Reserve	0.12	5.0	River source	Polyelectrolyte dosing, clarifier, two filters, bromochlor disinfection	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity

No.	Package plant	Capacity		Raw water type	Treatment process description	Operation and Maintenance challenges/comments
57	Imfolosi (Umganu) Game Reserve	0.18	7.5	River source	Polyelectrolyte dosing, inline mixer, retention pipes, two clarifiers, sodium hypochlorite disinfection and three filters,	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
58	Ithala(Ntshondwe) Game Reserve	0.06	2.5	Spring source	Filter only, poly electrolyte and sodium hypochlorite dosing	
59	Kamberg Nature Reserve	0.06	2.5	Spring source	Flocculant dosing(mechanical), in-line mixer, retention pipes filter, chlorine dosing {no centrifugal pumps, i.e. gravity system}	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
60	Rugged Glen	0.144	6.0	Dam source	Steel clarifier, floc-column, filter	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
61	Culfargie Nature Reserve			River source		-
62	Royal Natal National Park(Mahai)	0.181	7.5	Spring/river source	Flocculant dosing (mechanical), in-line mixer, retention pipes, three filters, chlorine dosing {gravity system}	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
63	Royal Natal national Park(Thendele)	0.06	2.5	Spring source	Flocculant dosing (mechanical), in-line mixer, retention pipes, three filters, chlorine dosing {gravity system}	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
64	Spioenkop Nature Reserve	0.144	6.0	Dam source	Polyelectrolyte dosing, flocculation channels, steel clarifier, floc-column, sodium hypochlorite dosing, two filters	Plant operation problems during or a few hours after rainy weather conditions because of high raw water turbidity
65	Pearly Beach - Cape Town	2.2	91.7	Dam source	Coagulation, Memcor UF, carbon filters	
66	Beaufort West direct reclamation plant	2	83.3	WWW effluent	Phosphate removal, settling, sand filtration, Memcor UF to remove TSS, 2-stage RO, advanced oxidation (UV+hydrogen peroxide), chlorination	Beaufort West has shortage of potable water. After managing water losses and imposing water restrictions and exploring groundwater sources, WW reclamation was next sustainable and affordable solution (inline equipment measure real time performance)
67	Mama Lumka, Cape Town	0.024	1	High saline borehole water	gravity fed UF, RO, carbon filters	
68	De Kelders	1.6	66.7	Ground water	Aeration (Fe oxidation), UF, 2-stage brackish water RO, partial blending of RO permeate with UF permeate	
69	Sedgefield	1.5	62.5		Desalination	Used for emergency drought relief - now offline.

2.2.3 Water treatment technologies

The majority of the plants used river, dam or groundwater water sources, with the Beaufort West reclamation plant using effluent from a wastewater works and the Sedgefield plant using seawater. There were 14 plants surveyed consisting of membrane type of treatment processes (i.e. ultrafiltration and reverse osmosis). The largest membrane package plant process identified was of 92 m^3/h capacity at Pearly Beach, Cape Town, which used a dam water source. Conventional types of treatment processes used in the plants surveyed included flocculation, coagulation, sedimentation, filtration and disinfection. Applications for treatment of borehole water to potable water standards were also noted in the mining sector, in particular to provide drinking water to employees working at mine shafts. Water re-use plants, used for the provision of water for industrial processes were also noted.

It is worthy of mention that the application of water treatment package plants extends beyond that of producing potable water. During the survey, several applications in other industries including the Fast Moving Consumer Goods (FMCG) and mining sectors were noted[1], where package plants were used to treat influent water to recycled process water standards. There were three plants noted which were monitored and controlled remotely. Remote monitoring techniques are innovative opportunities to ease the logistical challenge of providing safe drinking water to customers especially in rural stand-alone schemes.

2.3 TRENDS ON THE US E OF DRINKING WATER TREATMENT PACKAGE PLANTS IN SOUTH AFRICA – CASE STUDIES

Further information was sourced regarding the capital and operating and maintenance costs for the package plants, as well as the reasons for selecting a package plant solution. The information obtained is presented in Table 2-2.

2.3.1 Rationale for package plant solution

The main reason provided for the reason for selecting a package plant solution was due to the capacity of the plants being small. Since the unit processes used in package plants are commonly pre-fabricated, package plants offered shorter lead times, require less civil works, occupy a smaller footprint compared to fixed structures and has the option to be designed to be movable if required.

[1] Note that plants being used for these applications were not included in the survey

Table 2-2: Trends on selected drinking water treatment package plants

Package plant location	Capacity (Mℓ/day)	Date of installation	Capital cost[2]	Reason for selecting a package plant solution	Raw water type	Technology process description	Other notes
Tumela Mine, Limpopo, Anglo American Platinum Mines	0.36	2015		Little civil works required. Quicker solution - Factory tested before shipping, shorter commissioning times. Modular design	Borehole	Pre-treatment: sodium hypochlorite, flocculation, sodium metabisulfite and antiscalant -> multi-media filtration -> reverse osmosis (containerised) - > sodium hypochlorite	Redundancy: 2 units for: multimedia filters, cartridge filter, high pressure pump. Local equipment used if compatible. Electricity consumption for RO process: 0,60. kWh/m^3 22 KVA generator supplied as standby power for each plant. No calibration needed for chemical dosing, only manual replenishment of chemicals. - Flow control: provided, filter backwash: automatic operation (time) - Routine monitoring: - pH, residual chlorine & conductivity of treated water. Alarm if outside of required range - operators check: delta/P of: multimedia filters, cartridge filters, R.O. unit. No laboratory on site
Tumela Mine, Limpopo, Anglo American Platinum Mines	0.36	2015			Borehole		
Paris Dam WTW	1.0	1996	R 4 043 120.31	Small size plant was required	Dam	Polyelectrolyte (controlled using SCD), Dortmund type clarifier, auto backwash sand filter, disinfection using chlorine	Access to the Dam was a challenge. Filter system sourced locally. Chlorine and poly dosing: off-the-shelf items. Fixed influent flowrate. Laboratory available on site with water quality testing instruments, including jar testing equipment

[2]Capital cost (escalated at 5% p.a., compounded annually, to PV)

Package plant location	Capacity (Mℓ/day)	Date of installation	Capital cost[2]	Reason for selecting a package plant solution	Raw water type	Technology process description	Other notes
Komati Mill WTW	1.0	1993	R 5 265 469.30	Small plant capacity was required	River	Polyelectrolyte (controlled using SCD), Dortmund type clarifier, auto backwash sand filter, disinfection using chlorine	
Kuruman Orphanage, Northern Cape	0.048	2012	R 405 168.75		Borehole	Pre-treatment, sand filters, RO, chlorine	R50 000 installation and commissioning cost. Chemical cost: R1000 per month. Raw water quality not variable, fully automated processes (PID control + alarms). Waste disposed of into municipal sewer.
Zinkwazi Water, KZN	0.6	2013	R 2 425 500.00	Temporary plant needed in a short lead time (plant no longer operational)	Beach wells	Pre-treatment, lamella plate settler, UF, RO, chlorine	R100 000 for installation and commissioning. R 3000 per month for chemicals. Sludge, retentate and brine disposal. No laboratory on site.
Schmidtsdrift Potable Water Treatment Plant, Northern Cape	0.36	2014	R 1 774 500.00	A plant with a small footprint was required	Wells in river	Chemical dosing, lamella clarification, filtration, chlorine	R 70 000 for installation and commissioning. R 1000 per month is expected chemical cost. Fully automated process with alarms, sludge treated using drying beds
Nagle Package Plant	0.14	1996		Small plant capacity required	Dam	Coagulation, flocculation, clarification, filtration, sodium hypochlorite	Chemical costs: R15000 per year. Redundancy provided for filters and dosing pumps. Interlocks available to protect equipment. Waste discharged to forest

Package plant location	Capacity (Mℓ/day)	Date of installation	Capital cost[2]	Reason for selecting a package plant solution	Raw water type	Technology process description	Other notes
Sterkstroom Eastern Cape	1.92	2010	R 2 169 678.66	Cheaper capital outlay, and movable if required	Dam	Iron Removal (aeration towerx2), sedimentation tank - lamella clarifier and Pressure dual media filtration, chlorine or UV - modular plug and play	R 120 000 installation and commissioning cost. Yearly service and media change if required, 6 monthly adjustments for seasonal variations, monthly functional adjustments, local equipment used, solar driven pumps, no laboratory, sludge disposed of to drying bed
Riemvasmaak Northern Cape	1.0				River	Abstraction Flocculation Pressure Filtration - modular plug and play	Fully automated PLC SCADA with remote monitoring by supplier, yearly service and media change if required, monthly functional adjustments, solar driven pumps
Molteno Eastern Cape	0.1				Borehole	Membrane plant and conditioning of hard water	Fully automated PLC SCADA with remote monitoring by supplier, yearly service and media change if required, monthly functional adjustments
Rosedale; Umtata	3.0	2010	R 4 594 613.63		Dam	Coagulation, flocculation, sedimentation, filtration, disinfection	
Nokweja WTP, Umzimkulu	1.8	2008	R 1 371 922.91		River	Coagulation, flocculation, sedimentation, filtration, disinfection	
Umzimkulu WTP, Umzimkulu	3.0	2009	R 4 288 306.05		River	Coagulation, flocculation, sedimentation, filtration, disinfection	
Nzinga WTP, Impendle	1.0	2010	R 976 355.40		River	Coagulation, flocculation, sedimentation, filtration, disinfection	
Airfield, Manguzi	1.9	2012	R 818 440.88		Borehole	Iron removal - pH correction, oxidation, coagulation, filtration	
Thengani, Manguzi	2.6	2012	R 933 045.75		Borehole	Iron removal - pH correction, oxidation, coagulation, filtration	

Package plant location	Capacity (Mℓ/day)	Date of installation	Capital cost[2]	Reason for selecting a package plant solution	Raw water type	Technology process description	Other notes
Manguzi WTP, Manguzi	0.7	2011	R 617 477.18		River	Coagulation, flocculation, sedimentation, filtration, disinfection	
Bergville	1.0	2011	R 1 146 222.39		River	Coagulation, flocculation, sedimentation, filtration, disinfection	
Machunwini, Kokstad	0.5	2012	R 857 800.13		River	Coagulation, flocculation, sedimentation, filtration, disinfection	
Kwanovuka PH A	0.5	2012	R 456 104.25		Borehole	Coagulation, filtration, disinfection	
Kwanovuka PH B	0.6	2015	R 220 000.00		River	Coagulation, flocculation, sedimentation, filtration, disinfection	
Nondweni WTP, Nondweni	2.0	2014	R 252 000.00		River	Coagulation, flocculation, sedimentation, filtration, disinfection	
Midmar Training centre	0.0	2003	R 62 854.97		Dam source	Polyelectrolyte dosing, inline mixer, clarifier, sodium hypochlorite disinfection and one filter	
Kamberg Nature Reserve	0.1	2008	R 70 355.02		Spring source	Flocculant dosing(mechanical), in-line mixer, retention pipes filter, chlorine dosing {no centrifugal pumps, i.e. gravity system}	
Royal Natal national Park(Mahai)	0.2	2008	R 70 355.02		Spring/river source	Flocculant dosing (mechanical), in-line mixer, retention pipes, three filters, chlorine dosing {gravity system}	
Royal Natal national Park(Thendele)	0.1	2008	R 70 355.02		Spring source	Flocculant dosing (mechanical), in-line mixer, retention pipes, three filters, chlorine dosing {gravity system}	

2.3.2 Market trends

Capital cost data was obtained for some of the plants surveyed. Since the operation and maintenance of many of the plants surveyed may not be in line with best practice, with less being invested in O&M in some plants compared to others, the O&M cost data would therefore not be a true reflection of the actual costs incurred when following best practice. The integrity of O&M cost trends developed would then be questionable. In addition, it is noted that specific aspects such as the site location, degree of automation and technology choices influence both the capital cost and the O&M cost. The O&M, cost data for plants which were known to have satisfactory O&M support structures in place is presented.

Capital cost data provided was escalated to present value by compounding annually at 5% per annum. The cost was then determined per unit of water produced, for comparison purposes. This data is given in Figure 2-2 and Figure 2-3. Note that the capital cost for plants using desalination technology is not included in these graphs.

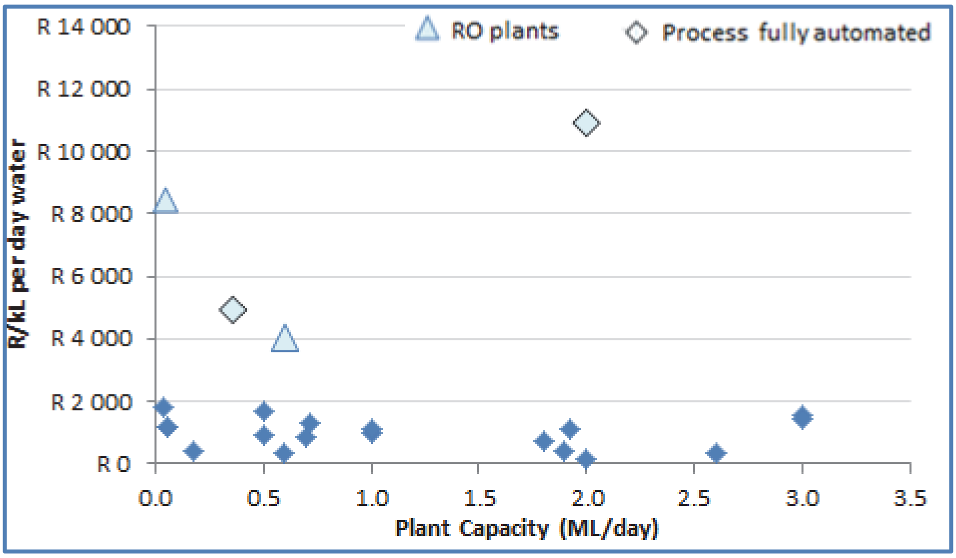

Figure 2-2: Production costs for package plants of various capacities

The capital cost of the package plants per unit of water produced is noted to be below R 2 000 per kL of water produced. The two RO plants, which consisted of conventional treatment of the influent water which then fed the RO process, ranged between R 4 000 to R 8 000 per kL of water produced. In addition to the more complex treatment technologies employed, a higher level of automation would also contribute to the higher capital cost of these plants. The capital costs data for the technology used at Beaufort West water reclamation plant (Turner *et al*., 2015) was calculated to be R 16 000 per kL of water produced. It is noted that the capital cost of package plants depends on a number of factors other than the capacity of the plant. These include, but are not limited to, the degree of automation, a containerized plant vs. a plant with fixed structures, the types of technology employed, the type of raw water abstraction and distance of the plant from the abstraction point.

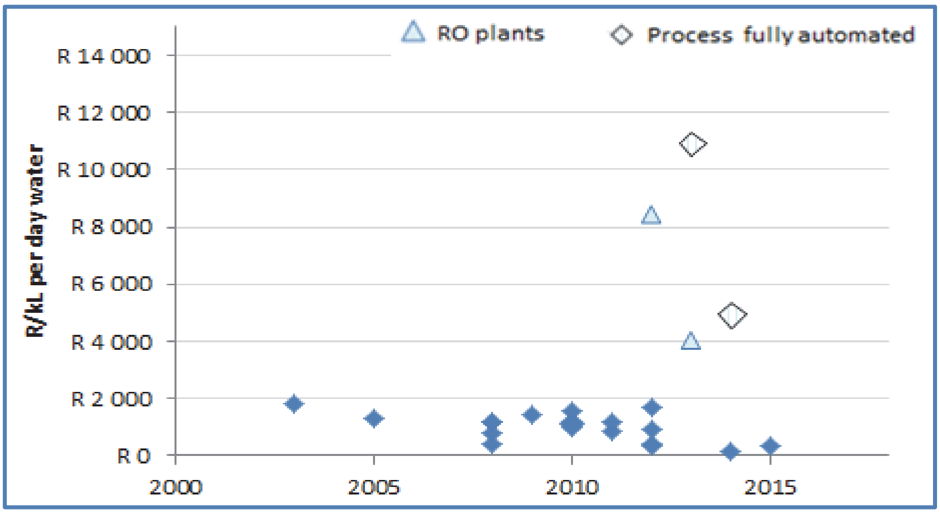

Figure 2-3: Unit costs of production of package plants over the past 15 years

For larger capacity plants, general rules of thumb can be obtained in terms of relating the cost to the volume of water produced. For smaller plants this is not so since the capital cost is more sensitive to variations in the design, such as the degree of automation chosen or the type of process selected. Package water treatment plants are small in capacity, and therefore lack the benefits of economies of scale available to larger plants. When the cost to operate and maintain a treatment plant is ignored during the planning and budgeting phase, the adoption of crisis maintenance practices or poor O&M of the treatment plant in efforts to reduce the O&M costs can be observed. Therefore, the O&M costs for those package plants which are known to have O&M support structures in place is presented in Figure 2-4.

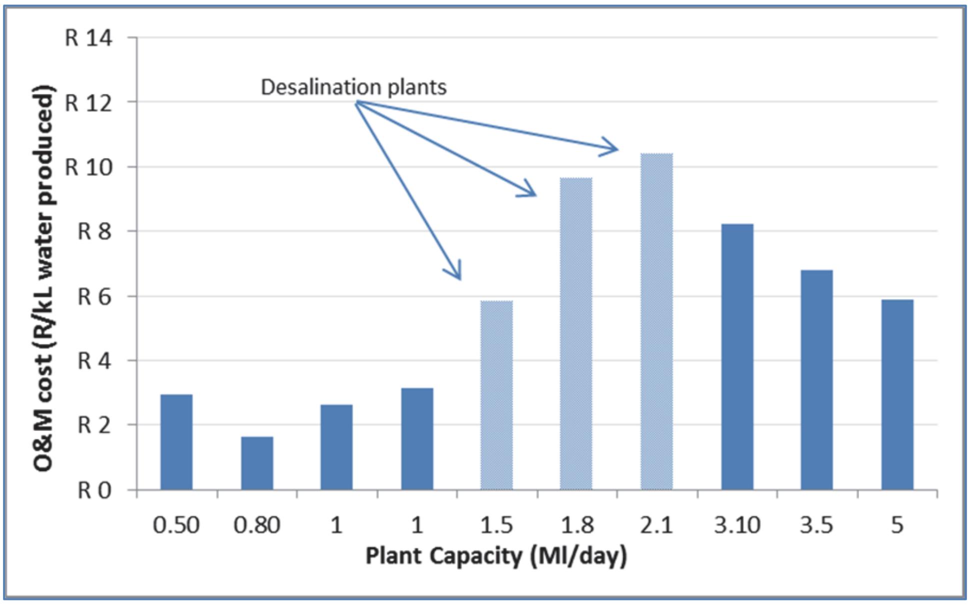

Figure 2-4: O&M costs for package plants

Electricity costs are one of the main factors influencing the choice of desalination technology. In addition, the frequent starting and stopping the plant to minimize running costs, is not optimal for membrane life (Turner *et al*., 2015). Electricity costs in the South African context are on the rise and electricity supply interruptions are becoming increasingly common, and must therefore be given due attention when selecting processes. The running of a treatment works on generators results in high diesel usage, and should be considered for short duration of power outages. The use of sustainable energy solutions are worthy of consideration. Also, running the plant at full capacity during off-peak periods, when electricity tariffs are lower, then during peak hours can lead to a reduction in power costs. Turner *et al* (2015) reports that the energy consumption of desalination plants has a major impact on the overall O&M cost, with electricity consumption typically in excess of 50% of the total O&M costs.

Labour costs can be a significant contributor to the operating cost, especially when the complexity of processes selected warrants the presence of full-time operators. Where the required level of process supervision cannot be afforded, the additional capital investment in automation of processes and automatic cut-off systems is justifiable (Voortman and Reddy, 1997). However, this increases the maintenance cost, as the success of automation relies on effective maintenance of equipment and processes.

Preventative maintenance practices will reduce plant downtime and additional maintenance costs associated with crisis maintenance practices. Also, ensuring that the UF/RO membrane integrity is maintained by proper pre-treatment and following the required preventative maintenance practices, will extend the periods between replacement of the membranes

2.3.3 Technologies employed

This section describes the technologies typically employed in package water treatment plants. Details on the design of these processes are widely available in literature, and are not included in the scope of this report. The purpose of this section is to provide a description of the types of unit processes which are recommended be used in package water treatment plants, and general information to assist the reader select suitable technologies for specific applications. The scope includes conventional treatment processes and membrane treatment processes. Guidelines in the selection of technologies for the treatment of special contaminants, such as iron, manganese, fluoride, arsenic and nitrate, are described in the next chapter.

When selecting a treatment technology, apart from the reported efficiency of the treatment process, it is vital that the required operating and technical support which is required for the selected system is available. For instance, technologies which are maintenance intensive may be unsuccessful in rural applications which lack the necessary O&M support required by the technology. Therefore, attention must be given to O&M during the design stage, to ensure that the systems do not fail or become very costly to operate and maintain once installed.

Most package plants consist of a series of conventional treatment processes, similar to those used in larger capacity plants. Conventional water treatment processes are typically configured as follows:
Raw water abstraction → pre-treatment (e.g. oxidation, pH correction) → coagulation → flocculation → sedimentation → filtration → disinfection

Desalination processes are considered to be non-conventional processes, and are considered separately below.

2.3.3.1 Conventional treatment processes

Pre-treatment
Pre-treatment typically consist of conditioning the influent water, to enable solid liquid separation in the clarification and filtration processes. Pre-treatment typically consists of:

- pH adjustment processes: lime, sodium chloride (caustic soda) or sodium carbonate (soda ash) are chemicals generally used for pH correction. Lime is least costly and is suitable to use when the water being treated is very soft. The dosage of caustic or soda ash required is less than that for lime and less sludge is generated when using these chemicals. It is important to know the optimal pH range for each of the chemicals used in the treatment process, which will assist in deciding on the correct dosing point for the pH adjustment chemical, as well as the typical dosages which would be required.

- Pre-oxidation: This can be accomplished by aeration, where oxygen is added to the water for the oxidation of typically iron and manganese. Examples of aeration processes include diffused mechanical nozzle spraying, multiple tray cascading and packed tower type. There are also chemical oxidative processes, which use chemicals such as potassium permanganate, chlorine or sodium hypochlorite to oxidise reduced forms of iron and manganese.

- Taste and odour removal: This is typically achieved by adsorption using activated carbon.

- Flocculation aids: In some instances, where the turbidity of the influent water is very low (< 5 NTU), the dosing of bentonite as a flocculation aid is used. Bentonite slurry (concentration typically 3% m/v) is dosed at the Head of Works of a treatment plant.

Coagulation and flocculation processes
Coagulation is achieved using organic polyelectrolytes and/or inorganic coagulants (aluminium sulphate, ferric chloride, etc.). Coagulants are generally dosed using variable speed diaphragm dosing pumps. Treatability studies, consisting of jar tests using various types of coagulants and other chemicals, can be used in the selection of the most suitable chemicals to employ; in terms of ability to economically and effectively meet the regulatory drinking water quality requirements; and to estimate expected chemical dosages.

- Rapid mixing of chemicals: It is essential that chemicals be rapidly and evenly distributed into the water at the point of dosing. Typically, the product of the G value for the flash mixing step and the flash mixing time lies in the range of 500-1600 (Kawamura, 2000). An inexpensive way to achieve rapid mixing is to use components of the process, such as pumps, in which turbulence occurs and energy is imparted to the water. An in-line static mixer can also be used to achieve rapid mixing. These offer the advantage of having no moving parts and requiring no electricity, but must be designed to impart sufficient mixing energy even at low throughputs.

- Flocculation: It was found in the survey that pre-fabricated flocculation columns are generally used in package water treatment plants. These are referred to as heliocoidal flocculators, where water enters tangentially into the base of a column, and the energy required for flocculation is provided by the inlet jet and side wall friction as water travels spirally up to the outlet. It is essential that these be correctly sized to ensure adequate flocculation energy and mixing time is provided. Mixing is an integral part of the water treatment process, and imparting the correct amount of energy is critical to the success of the flocculation process. Other common types of flocculation technologies include baffled tanks, and tanks in series fitted with mechanical mixers. Flocculation devices must be carefully designed to provide sufficient energy to increase the number of inter-particle collisions that result in agglomeration of flocs, but also not too high velocity gradient which will shear the developing agglomerates. Kawamura (2000) recommends G-values between 10 and 70 s^{-1}. In any of the flocculation mixing methods, it is essential to have the ability to vary the mixing energy in accordance with fluctuations in the influent water flowrate.

Sedimentation processes

The sedimentation processes used in the package plants surveyed were sedimentation tanks and upflow sludge blanket clarifiers. In some of the plants surveyed, sludge blanket clarifiers were fitted with inclined plates or tubes, to enhance the solid liquid separation process at higher upflow rates. The surface overflow rate (surface loading rate), which is used in the design of sedimentation processes, represents the operating envelope of the process, and must be adhered to during operation to ensure effective solid liquid separation.

It was noted in the survey that difficulties in desludging were experienced, in an application where a Jo-Jo tank was used as a sedimentation tank, due to no floor slope. The sedimentation tank should be designed to accommodate sludge removal. Inadequate sludge removal results in poor solid liquid separation and anaerobic conditions potentially developing due to sludge not being removed.

Filtration processes

Locally manufactured pressure sand filters were found to be commonly used. Pressure filters are able to operate at higher filtration rates compared to conventional rapid gravity filters or slow sand filters. Pressure sand filters offer the further advantage of being compact. These units require minimal civil construction work during installation, which enables easy mobility. The process control can also be automated, so that the full-time operator supervision is not essential for the reliable operation of the process.

The Auto Valveless Gravity Filter (AVGF), which backwashes automatically through siphoning, was also used at certain plants surveyed. This type of technology, together with slow sand filter technology, is particularly suitable to rural applications, since these processes are relatively self-regulating. The AVGF requires minimal operator intervention, mainly in instances where there are pre-treatment processes. Raw water turbidity of > 15 NTU may require a roughing filter or clarifier to lower the solids content of the influent to the AVGF. A shortcoming is that, due to backwashing consisting of using water only to rinse, as opposed to combined air and water, mudballs can form in the filter media. The process would therefore need to be monitored for declined performance.

The slow sand filter requires influent turbidity of < 5 NTU, occupies wide areas of land due to low filtration rates and require scraping of the top layer of sand from the filter bed once in several months. Other advantages that favour its use in rural applications are that these types of filters can be built and operated using local labour and materials. Slow sand filter technology is less maintenance intensive compared to other filter technologies. In addition, slow sand filters do not require complex mechanical and electrical equipment and instrumentation to enable the process to be automated.

It was observed that difficulties associated with the automation of processes; such as breakdown of equipment and malfunctioning of automated valves; are very common and can increase maintenance costs. It is therefore important to outsource the maintenance function, if these skills or support services are not available.

Membrane filtration processes identified in the survey included ultrafiltration (UF) and reverse osmosis (RO). Membrane processes usually consist of standard unit ‘plug-and-play’ modules of fixed capacity. It was found in the survey that the membrane modules are not sourced locally. These processes rely on electricity and can be easily automated. RO is suitable for the removal of ions such as calcium and magnesium, which impart hardness to water. Water produced from RO processes is aggressive to piping, and the treated water may therefore require to be blended with a side stream of untreated water. Pre-treatment of water may be necessary to prevent fouling of membranes.

Disinfection processes

Disinfection is typically achieved using chlorine or sodium hypochlorite in package plant applications. While chlorine offers advantages over sodium hypochlorite of a longer shelf life due to its stability, sodium or calcium hypochlorite is safer to handle and requires less skills since it is easier to dose. Chlorine also offers the advantage of maintaining a disinfectant residual in the treated water. However, due to the safety requirements associated with chlorine dosing systems, the capital cost of such systems may be higher than other types of disinfectant dosing systems.

Even though UV systems are easy to operate and use no chemicals, some of the shortcomings of this technology, which may render it unsuitable for rural applications, include it being expensive compared to other disinfection methods and its disinfection effectiveness depends on the turbidity of the water being treated. It is also noted that no disinfectant residual is maintained in the final water of UV disinfected processes.

For package plant applications, where there is a need for processes which require less operator and maintenance input, are safe and easy to operate and are more forgiving to turbidity spikes which may occasionally occur in the treated water quality, it is recommended that preference be given to the use of sodium hypochlorite or chlorine as disinfectants.

Waste disposal

The use of sludge lagoons for the disposal of water treatment wastes were noted at some of the plants surveyed. Other plants indicated that effluent was directed to the municipal sewer. The sludge emanating from the sedimentation processes is typically 3% solids by mass, from which the supernatant water can be recovered and recycled and the remaining sludge dried in sludge settling ponds or drying beds.

Spent backwash water, from the filter backwashing process, can be recycled where water supply issues exist. This results in less water losses from the process. It is essential that when *Cryptosporidum* or *Giardia* is present in the influent, the spent backwash water not be recycled but instead be disposed to sludge lagoons until these parasites are removed. The disposal of membrane concentrate and effluent containing cleaning chemicals can be disposed in lined evaporation ponds.

2.3.3.2 Desalination and water reclamation

As the supply of water from rivers and groundwater become further depleted, and once unaccounted for water losses have been addressed, alternative water sources are needed to meet the increasing potable water demand. Desalination technologies and water reclamation and reuse are two options.

Desalination

Desalination technology includes pressure driven membrane processes, in particular the use of reverse osmosis (RO) technology, for the desalination of seawater. This type of technology is suitable in instances where adequate budget is available for both the capital cost and the operating and maintenance costs, and a reliable supply of electricity is available, as these plants are energy intensive. It was noted in the study by Turner *et al* (2015) that the electricity consumption in the desalination of seawater is typically in excess of 50% of the total O&M costs. Therefore, energy consumption is one the major contributors in the process selection and operation of seawater desalination plants (Voutchkov, 2013).

In terms of abstraction, the use of beach wells (vertical bores or seabed infiltration) can be considered for package plant installations, which due to offering natural filtration, reduces the amount of pre-treatment required. This also avoids the costly associated with construction of intake structures. Adequate pre-treatment of the influent water is required to avoid fouling or scaling of the RO membrane.

Generally, the output from an ultra-filtration process, which can be used to pre-treat the sea water, would provide feed to the RO membrane. Where there is oil in the influent water, the use of dissolved air flotation technology can be considered. It is recommended that investigations be conducted at feasibility stage to determine the appropriate pre-treatment processes required.

Since the desalinated water (RO permeate) has an acidic pH which makes the water corrosive and aggressive to metal pipework, blending with other water supplies and careful selection of the pipe material of construction for conveying RO permeate must be considered (Voutchkov, 2013)

An acceptable and cost effective way to dispose of the wastes from the membrane concentrate and membrane flush water from chemical cleaning must be considered. Commonly used concentrate management alternatives which would be suitable for package plants include (Voutchkov, 2013):

- Sewer disposal: common method at small desalination plants used for disposal of small volumes of concentrate. The impact of this on the wastewater treatment plants biological treatment systems should be investigated
- Deep-well injection: commonly used for medium to large sized inland brackish water desalination plants. This is a costly option
- Land application: used in small to medium sized plants where soil conditions provide year round growth and harvesting of halophytic vegetation
- Evaporation ponds: used in small to medium sized plants where the climate provides high evaporation rate

Water re-use

There are two types of water re-use options which can be considered, viz. direct potable reuse (DPR) and indirect potable reuse (IPR). In IPR, treated wastewater is released into groundwater or surface water, with the intent of reclaiming it for treatment to potable water standards. In DPR, treated wastewater is treated to potable water standards without prior release to the environment.

Droughts in the southern Cape in 2009 resulted in the construction of seawater desalination plants in order to meet water demand. In addition, the first South African direct potable water reuse plant was constructed in Beaufort West and an indirect potable water reuse plant in George. For direct potable reuse, it is critical that there is no compromise on the water quality. Therefore, in the interest of public health protection, attempts to extract additional capacity out of treatment processes at the expense of water quality, in order to minimize the capital investment or running costs, should not be considered an option.

Reuse systems typically consist of membrane separation processes, advanced oxidation, adsorptive processes and various disinfection techniques, all aimed at reducing the risk associated with water reuse. It is expected that technology advancements in the future will improve the effectiveness of contaminant removal and will reduce energy costs, making this also a favoured water source option.

The processes used at the Beaufort West reclamation plant include (Swartz *et al*., 2014b):

- Ferric chloride dosing at the inlet to the secondary settling process at the wastewater treatment works
- Pre-chlorination
- Sedimentation
- Post-chlorination
- Rapid sand filtration
- Ultrafiltration
- Reverse osmosis
- UV-hydrogen peroxide
- Chlorination

The contractor is responsible for operating the plant for 20 years (Swartz *et al*., 2014b). Both membrane processes are fully automated. Alarms are triggered when parameters monitored on-line deviate from specified set-points, and the plant is able to automatically shut down. Where skills are lacking on the O&M of complex technologies, this function is best outsourced.

2.3.4 Operating and Maintenance challenges

The challenges faced, which were given in the survey data, are discussed in the following sections. The second part of this project will look in more detail into the challenges faced, and this report will be updated to include that information.

The O&M challenges identified which are discussed include:

- Remote location of package plants
- Electricity supply issues
- Plant design and process optimization issues
- Operating and maintenance support issues
- Waste disposal issues

2.3.4.1 Remote location

Long travel distances and poor road infrastructure creates logistical challenges and increased operating cost. The transport of chemicals, employees and maintenance personnel to and from the treatment plant becomes difficult and costly. Therefore, it is not uncommon that procurement challenges and chemical inventory management issues can be found at the remote stand-alone plants, with resultant adverse effects on the treatment process efficiency and water quality.

Processes that require daily operator input can be a challenge where full-time operator presence may not be possible or very costly. Therefore, investment in the automation of processes is preferred. Process automation is usually also accompanied by the need for increased maintenance, in order to be successful. The maintenance function can be outsourced through maintenance contracts.

The use of technological solutions, such as remote monitoring techniques for process monitoring and control, can also be employed to ease the logistical challenge. The use of GSM or satellite technology is an attractive option for the remote monitoring of process parameters such as tank levels, water quality at various points in the treatment process and equipment operational status. Three of the plants surveyed used remote monitoring techniques.

2.3.4.2 Electricity Supply

Unreliability of power supply coupled with rising electricity costs makes processes which require minimal energy input preferable. Unreliable power supply, which was reported for one of the plants in the survey, results in process failure and associated non-compliance with regulatory standards for the drinking water supplied. It is general practice that a diesel generator is available to provide standby power to critical equipment in the event of a power failure. The use of renewable energy sources can assist in limiting the extent of process interruptions associated with power failures, and also offer cost savings. Even if key equipment can be kept online using renewable energy sources, this would help mitigate the operational strain.

2.3.4.3 Process design issues

Process design deficiencies can in part be due to inexperienced designers of package plant systems, as well as attempts to save on capital costs due to the limited budgets of smaller schemes. Approaching contractors directly to save costs, instead of making use of process engineers or scientists who are experienced in the design of these systems, have in part contributed to poorly designed systems. Inexperience on the part of the clients who prepare technical specifications and approve the designs of these plants, also plays a role in the installation of package water treatment plants which operate inefficiently and are costly to operate and maintain. Process design deficiencies, among other things, limit the performance of plants. Some of the design deficiencies recorded in the survey data included:

- Lack of adequate redundancy being built into processes: Sparing of key equipment enables the treatment process to continue uninterrupted while the non-working equipment is repaired or replaced. For instance, when a chemical dosing system is taken off-line and there is no standby pump available, it is necessary to halt the entire treatment process so as to not compromise final water quality. However, this would result in interrupted water supply. It is therefore prudent to install standby capacity for key equipment and processes. Another example is the filtration unit process. It was noted that pressure filter systems were designed to operate at the recommended design filtration rate of approximately 10 m/h, however no standby capacity was available, in the event the plant would be required to run at full capacity with one filter taken offline. In the case where there are only 2 filters, the filtration rate would double to 20 m/h when one filter is taken off line for backwashing or maintenance. This filtration rate is well above the recommended design filtration rates and the water quality produced would definitely exceed the SANS 241 water quality standards. In some instances, budgetary constraints inhibit the building in of redundancy into designs. If this is the case, then the raw water inflow would have to be reduced to maintain the filtration rate within design guidelines. The operating manual must take this into consideration and appropriate instructions for operating in this mode must be included in the Operating Manual.

- Inadequate mixing: Flash mixing is typically achieved using an inline mixer or using the mixing energy available in pump volutes. For slow mixing required for the flocculation process, flocculation towers were noted in several of the plants surveyed. These towers however have limited input flocculation energy and residence time, and are unable to vary the flocculation energy to meet mixing energy requirements with changes in water flowrate. Other flocculation technologies include pre-fabricated baffled flocculation channels and also flocculation tanks fitted with mechanical mixers that have variable speed drives to enable the varying of mixing energy imparted to the water. It is important for effective pre-treatment that variations in throughput are taken into account in the design of flocculation systems. The package plants surveyed which utilized variable speed mechanical mixers were able to adjust the mixing energy according to the raw water flowrate.

- Difficulty in removing sludge from sedimentation tanks: A shortcoming noted in the survey was that in some instances Jo-Jo tanks were used as sedimentation tanks, and desludging was difficult since the floors were not sloped towards the drain to facilitate extraction of accumulated sludge. Desludging is essential to avoid floc carryover to filters, which increases the solids loading on the filters; and to prevent anaerobic conditions developing due to insufficient sludge removal. Anaerobic conditions have several negative impacts, including the lowering of the pH of water, reducing oxidised compounds such as iron and manganese (hence inhibiting their removal) and imparting taste and odour to water. Sludge with high solids content can be expected at many package plants, due to infrequent desludging, therefore pipes carrying sludge must be large enough to prevent blockages and large radius bends must be used. Rodding points or pipe flushing facilities may also be required. The design of this process must take this into consideration.

- Process inflexibility: Thompson *et al* (2015) reported that deficiencies in the process design and control philosophy of package plants resulted in the treatment process being inflexible to respond to fluctuations in influent water flowrate and quality. Some of the challenges noted in the survey data, which are associated with the variable influent water quality, relate to increased turbidity after rainy weather. Several plants in the survey noted inability to deal with fluctuating influent water quality, with some of these plants being placed offline when the influent water turbidity fell outside the design range. No or ineffective automatic regulation of the coagulant dose in response to flowrate or water quality fluctuations, and the inability of the flocculation process to adjust the mixing energy, were two common limiting factors in the treatment of variable quality or flowrates of influent water in these instances. In addition, keeping the plant operational when conducting maintenance of key equipment must be taken into account in the design of package plants.

- Overly optimistic design fluxes: The clarification and filtration processes are designed according to prescribed design fluxes. A short-sight during design is in overlooking the situation when a clarifier or filter is taken offline for maintenance or to be backwashed. The result of this is that the units which are operational receive a higher load, which can result in operation beyond the recommended design fluxes. This results in poor solid liquid separation and the final water quality not meeting regulatory standards. A second reason for suppliers using high flux rates is to minimise the size of flocculators, clarifiers and filters; and thus minimise capital costs in their tender submissions. This can be mitigated by ensuring that municipalities have a detailed specification which includes redundancy, filtration/flux rates, upflow rates, flocculation energy and mixing times. Conducting Hazard and Operability Studies (HAZOP) is an important step in the design process.

2.3.4.4 Operator skill and maintenance issues

The lack of skilled operating and maintenance personnel was reported in the survey data. It is essential that the selection and design of suitable water treatment processes is accompanied by the correct operating and maintenance procedures and adequate training of operating and maintenance personnel. Complex processes, which require skilled operators and have complicated maintenance requirements, are best automated where the required skill is not available. This however becomes a problem when it the plant has to be operated in manual mode (as indicated by one plant in the survey), and many of the parameters that are managed by a PLC now have to be controlled manually by the operator. The problem is compounded by the lack of detailed operating procedures for operating the plant in manual mode, lack of operator training or no full-time operators.

In the survey, the following operating and maintenance challenges were noted:

- Raw water supply was interrupted due the borehole pumps requiring maintenance. This was reported at 2 plants. The breakdown of critical equipment results in water supply interruptions and inability to meet water demand. It is essential to build in reliability into the design of water treatment systems. A shelf standby of a borehole pump, which can be shared among a few boreholes, can avoid delays associated with sourcing a new pump. Thompson *et al.* (2015) reported that the O&M challenges typically faced in package plants included spares not being available and the maintenance requirements not being clearly defined. The identification of critical spare equipment during the design phase can assist reduce the lead times for the procurement of these equipment. The use of locally available equipment and standardization can assist maintenance staff to respond more effectively, and standardization also enables easier training of maintenance personnel. In addition, outsourcing the maintenance function can reduce operational downtime due to delays in attending to maintenance related issues.

- A lack of skilled operators and maintenance support were reported on four plants. Training of operators is essential prior to handover of a new treatment process. Also, entering into long term service level agreements or contracts can alleviate some of the load of calibrations, repairs and renewals on owners of the treatment systems. In small systems, it may become too costly to employ full-time personnel. These treatment systems must be designed to take this into account. During the technology selection and design phase of projects, consideration must also be given to the recurring maintenance costs, which must be built into the project cost. When these costs are not factored into the operating costs, equipment is run to breakdown instead of recommended preventative maintenance practices being followed.

- One of the challenges recorded in the survey related to the inefficiency in the use of the streaming current detector to automatically regulate the coagulant dose in response to changes in influent water turbidity. Common causes for this are:
  - Incorrect installation of the SCD
  - Poor response times to turbidity fluctuations
  - Over reliance on the SCD
  - Operators not capable of doing jar tests
  - Not adjusting the set point when the raw water turbidity changes more than 20% compared to the turbidity when the set point was previously adjusted

  It is essential that operators be trained to respond to these situations, especially in instances where technical support services are lacking. The Operating Manual should contain step by step instructions on how to optimize chemical dose manually.

- The backwash regime not being optimized was noted on two plants. These plants used pressure sand filters. The backwash regime is typically optimized during the commissioning of a plant. Where a permanent change in the filter influent water characteristics takes place, compared to the filter influent water quality at the time of commissioning (e.g. turbidity increases), it is essential that the backwash regime be again optimized. This would require specialized technical services, which is seldom available at remote schemes. The operating manual must include clear instructions on the procedure for optimizing the backwashing regime. Similarly, the de-sludge regime for clarifiers must also be optimised and adjustment of the time and frequency of sludge removal from clarifiers must be included in the operating manual.

- <u>Process monitoring and optimization</u>:
  It was noted in the survey that since the raw water quality from boreholes was not expected to fluctuate, no jar tests were conducted on site. Jar tests were only conducted during commissioning. Jar tests are an important process optimization tool, which offers an indication of the optimal chemical dosages. Inefficient chemical dose control compromises final water quality. Over-dosing of chemical also results in wasteful chemical expenditure. Where the influent water turbidity is not expected to fluctuate, it is recommended that the influent water quality monitoring data be checked daily to determine whether jar tests are required to optimize chemical dosages. Therefore, it is essential that an on-site laboratory be available, or a mobile laboratory which can service a number of plants. Jar tests would typically by conducted when the raw water turbidity changes by more than 20% of the turbidity recorded the previous time a jar test was conducted.

2.3.4.5 Waste disposal issues

Waste from treatment plants mainly originate from spent filter backwash water, sludge from clarifiers and brine concentrate and chemically contaminated water from chemical cleaning of membrane filters. Some of the plants surveyed reported waste being discharged to sludge lagoons.

Backwash water can be recycled, but this process must be controlled so when Cryptosporidium or Giardia are present in the influent water, the backwash water is not recycled but routed to sludge lagoons. The waste from membrane processes can be disposed in lined evaporation ponds.

2.3.4.6 Summary

Common reasons that challenges were experienced with package plants include:

- Time constraints: lack of time to plan adequately and develop a suitable design, resulting in short cuts being taken
- Lack of skills: this refers to technical skill to develop tender specifications and appoint suitably qualified contractors, plan and manage cash flows during O&M, operational skill, technical and maintenance skill during O&M phase
- Lack of information regarding technologies available
- Budgetary constraints

Some of the aspects in the design of these treatment systems which are necessary for sustainable efficiency, operation and maintenance include:

- Allowing flexibility in operating parameters for changes in raw water quality
- Allowing flexibility for changes in water demand
- Ensuring reliability by making allowance for stand-by equipment
- Selection of appropriate unit processes and equipment in the process train
- Appropriate waste disposal facilities

CHAPTER 3: PACKAGE PLANT SELECTION FOR CONTAMINANT REMOVAL AND GOOD PRACTICES

3.1 INTRODUCTION

When contaminants are present in the source water, the removal of the source of contamination, location of an alternate source or blending is favoured over installing contaminant removal processes, especially in rural settings or unmanned plants. If this is not feasible, then prior to designing any treatment system, the raw water quality and the required final water quality must be known. Treatability studies must be conducted to determine the effectiveness of chemicals or treatment processes, the typical chemical dosages which would be required and other data needed for design.

Consideration must also be given to the logistical challenges which exist that influence the mode of delivery as well as disposal, level of operator skill and maintenance support available, availability of chemicals, capital and operating budgets and procedures for handling and storage of chemicals. Other considerations include the stability (shelf life) of chemicals and safety, flammability or explosive nature of substances.

3.2 GENERAL CONSIDERATIONS DURING PACKAGE PLANT PRE-DESIGN STAGE

This section provides guidance on the typical aspects to consider from the conceptual design stage to construction, operation and maintenance.

- **Budgetary allocations**
  - Capital budget (initial technical investigations or specialist studies, treatment processes, electricity supply and installation, abstraction works, distribution network)
  - Pre-investment and turn down considerations: pre-investment relates to future development (how much is catered for in the present design) and turn down is the normal operating range for which the plant will be designed
  - Operation and maintenance budget

- **Raw water source**
  - Available and sustainable
  - Treatability studies, including highlighting special pollutants present, variable water quality warranting process adjustments and projected future water quality
  - Abstraction method

- **Location of the package plant**
  - Logistics (accessibility for chemical transport to site, O&M support services, waste disposal issues)
  - Security/Vandalism issues

- Availability of staff to operate the plant

- **Waste treatment and disposal method**

- **Statutory requirements and approvals**
    - Environmental considerations such as EIA requirement, MHI studies and other health, safety and environment studies and approvals

- **Design considerations**
    - Space requirements
    - Electricity availability
    - Process treatment alternatives (some of the factors to take into account include ease of waste treatment and disposal, level of operator skill available, ease of automation, proven dependable technology, public perception on the technology, safety requirements, considerations for compatibility of equipment coatings with chemicals and chemicals stored next to each other, etc.)
    - Utility Summary (electricity, water, compressed air, standby power, firefighting water, etc.): details can be summarised for each unit process into a table giving the voltage, power, pressure, flows, etc. as relevant
    - Reliability, accessibility and maintainability
    - Operating philosophy
    - Sparing philosophy and list of critical spares
    - Process flexibility required: ability to treat water of variable influent characteristics and flows
    - Noise level limitations, fire-proofing, area classifications
    - Time available: Lead times for equipment
    - Design redundancy requirements
    - Power requirements and standby capacity
    - Control philosophy and safe guarding narratives: control refers to the equipment and logic by which data from instruments is used to control the process (including set-points, alarms, interlocks, switching values, etc.). Safe guarding refers to the pressure and thermal relief systems and the emergency shut-down of equipment. Alarm and trip conditions must be rated according to how critical each is, and the extent to which these require to be backed up or supported by automated diagnostics and standby power.
    - Drawings (including Process and Instrumentation Drawings, Layout Drawings, Equipment Drawings)
    - Compilation of post audit criteria, i.e. how performance will be measured/assessed
    - Hazard and Operability study (HAZOP)

- **Compilation of functionality criteria for tendering purposes**

- **O&M plan**

3.3 PRACTICAL CONSIDERATIONS FOR PACKAGE PLANT TREATMENT PROCESS SELECTION FOR CONTAMINANT REMOVAL

Treatment technologies which are recommended for use in package plants for the removal of the following contaminants are presented:

- Iron and manganese
- Fluoride and arsenic
- Calcium and magnesium (source of hardness in water)
- Nitrates
- Taste and odour causing compounds

Detailed design calculations, which are readily available in literature and from suppliers, are not given in this report. Instead a description of the available treatment technologies and other practical considerations are given, with the aim to assist in the selection of a suitable technology for package plant applications.

Especially in rural applications or unmanned plants, removal of the source of contamination, location of an alternate source or blending are favoured over installing contaminant removal processes. Prior to designing any contaminant removal system, the raw water quality and the required final water quality must be known. Treatability studies must also be conducted to determine the effectiveness of chemicals or treatment processes, the require dosages and other data needed for design. Consideration must be given to the logistical challenges which exist that influence the mode of delivery and disposal, level of operator skill and maintenance support available, availability of chemicals, capital and operating budgets and procedures for handling and storage of chemicals. Other considerations include the stability (shelf life) of chemicals and safety, flammability or explosive nature of substances. It is noted that the powdered form of all substances is potentially hazardous.

Sophisticated control strategies and instrumentation can assist in the automation of processes, so that full time operator presence may not be required. However, the limitations of automation must be taken into account when designing processes. The maintenance of instrumentation and equipment used is essential for the success of automation. The decision on whether or not to automate these processes must be made based cost, risk and benefits.

3.3.1 Treatment processes for the removal of iron and manganese

Soluble iron and manganese usually exists in their divalent form. When oxidized to convert them to trivalent iron and quadrivalent manganese, precipitates form which can be removed by sedimentation and filtration. There are no known harmful effects of iron and manganese in drinking water (Wong,

1984) but these are removed for aesthetic reasons. The SANS 241:2015 aesthetic limit for iron and manganese in drinking water is < 0.3 mg/L for iron and < 0.1 mg/L for manganese.

There are several technologies available for the removal of iron and manganese. To remove soluble iron and manganese, an oxidation process followed by a suspended solids removal process is generally used (Wong, 1984). Manganese is more difficult to remove compared to iron, due to its slower oxidation rate, and is typically removed by oxidation via the use of potassium permanganate. Oxidants used for iron removal are typically chlorine or sodium hypochlorite.

In order to calculate chemical dosages to apply at the plant, it is imperative to know with accuracy the inflow rate as well as the influent soluble iron and manganese content. The installation and calibration of inflow meters is essential to optimizing chemical dosage. Tests kits for quickly measuring total iron and manganese (colorimetric methods) are available; however speciation of reduced and oxidised iron/manganese may be required, since it is only the reduced species that consume the oxidant.

Aeration is not an effective oxidant for manganese and is ineffective in oxidizing organically bound manganese or iron. Further oxidation may be required. The coke tray type of aerator consists of a series of coke (crushed stone, limestone or plastic medium) filled trays that are 0.3 to 0.45 m deep, which are perforated at the bottom. The rate of oxidation is a function of pH, with higher pH producing better results (see recommended pH in Table 3-1).

Table 3-1: Amount of oxidising agents required for the oxidation of iron and manganese (Kawamura, 2000)

Oxidising agent (mg)	Amount of contaminant oxidized (mg)	pH requirement for effective oxidation
Air: 1 mg	7 mg divalent iron (organically bound iron is not oxidized)	> 7.5 (preferably 8), oxidized within 15 min
	3.4 mg divalent manganese (organically bound manganese is not oxidized)	> 9.5, oxidation time more than 1 hour
Chlorine: 1 mg	1.58 mg iron	8 – 8.5, oxidized within 15 to 30 min
	0.78 mg manganese	Preferably 8.5, oxidized within 2 to 3 hours
Potassium permanganate: 1 mg	1.06 mg iron	> 7, oxidized within 5 min
	0.52 mg manganese	> 7, oxidized within 5 min

The very high pH of > 9.5 required for the oxidation of manganese is noted. pH correction following aeration may be required to obtain the optimum pH for subsequent treatment processes. Forced/induced draft aeration is similar to natural draft aeration, but is equipped with a blower. The blower forces air from the bottom of the aerator out the top. This counter-current flow allows for better transfer compared to natural draft systems. The column can be filled with packing material (plastic or ceramic typically) to form a packed tower aerator or air stripper to enable better mixing and transfer, and would typically be used for the removal of VOC's. It is noted that a reliable source of power is required for the blower in this type of technology.

It is recommended that when both iron and manganese is present in the water to be treated, that chlorine be used to oxidise iron, followed by the dosing of more expensive potassium permanganate to oxidise manganese. Sodium hypochlorite can also be used, which is more costly than chlorine, but which is easier and safer to handle. Sodium hypochlorite is dosed as a solution, and the regular cleaning of precipitate in pipes to avoid blockages is necessary (Swartz *et al*., 2009).

Where there is a high concentration of organic compounds in the feed water, which have the potential to form THMs when chlorine is used as a pre-oxidant; potassium permanganate can instead be used. Potassium permanganate is a stronger oxidant than chlorine or sodium hypochlorite, and offers the advantage of not producing THMs, but is a more expensive chemical. Potassium permanganate is usually dosed close to the intake in the treatment process, which allows time for the oxidative process to take place prior to filtration. The dose of potassium permanganate must be carefully controlled, since excess chemical dosed applied imparts a pink colour to the water. The manganese dioxide produced in the oxidation process is a black precipitate, which if not properly removed by suitable solid-liquid processes, will create black particulate deposits in the distribution system and household plumbing fixtures.

The various oxidation processes can be automated based on flow proportional dosing, but where the influent iron and manganese content is not fixed, daily monitoring of the iron and manganese content in the influent water and adjustment of chlorine or potassium permanganate dose set point is required. The part time presence of an operator is also required for the preparation of the potassium permanganate solution or changing of chlorine cylinders. The use of remote monitoring and notification systems would help to enable a plant to operate without the need for full-time operator presence.

3.3.2 Treatment processes for the removal of arsenic and fluoride

Elevated arsenic and fluoride levels in drinking water pose health risks at levels above 10µg/L for arsenic and above 1.5 mg/l for fluoride. Commonly used methods for the removal of arsenic and fluoride include adsorptive methods (e.g. use of activated alumina in adsorption columns), ion exchange processes and membrane processes such as reverse osmosis.

Precipitation processes, which entail the addition of lime and aluminium sulphate to precipitate these compounds, were not considered suitable for package water treatment plants for the following reasons:

- This process raises the pH of the treated water, and therefore re-carbonation is required after treatment for pH adjustment.
- When aluminium sulphate is used, caution must be exercised in the operation of the process to prevent aluminium in the treated water, which has adverse health implications.
- The process is maintenance intensive, especially the lime dosing system, which is known to have operational challenges in terms of caking of lime in the hopper and screw feeder.
- Lime softening processes for metal removal generate large amounts of sludge waste, have complex process control requirements and even if automated, would require a skilled operator for chemical make-up, process monitoring and chemical dose regulation.
- The large chemical dosages required results in these processes being costly. Precipitation processes are therefore not recommended for package plants where the construction of a precipitation plant would be solely for arsenic or fluoride removal. This method would be more suitable for industrial effluents containing large amounts of arsenic or fluoride.

Arsenic occurs in different forms in water, depending on the pH and oxidation potential of the water. Arsenite (As-III; H_3AsO_3) is more toxic and more difficult to remove compared to arsenate (As-V; $H_2AsO_4^-$ or $HAsO_4^{2-}$) using commonly used separation technologies. Therefore, to improve removal efficiencies, an oxidative step to convert As-III to As-V will be required to precede many of the separation processes, where As-III is the predominant species.

The US-EPA has recommended the following processes as Best Available Technology (BAT) for the removal of fluoride from drinking water:

- Membrane process: Reverse osmosis
- Adsorptive process: Activated alumina

In all processes, it is necessary to monitor the performance of the process by monitoring the quality of the treated water. Regeneration of media is usually triggered on the basis of the volume of water which has been treated, but monitoring of arsenic or fluoride concentrations in the effluent from the columns is also necessary. Any change in the influent water quality, or a reduction in the adsorptive capacity of the activated alumina or ion exchange resin, would require the run length until regeneration is required to be modified (Chwirka *et al*., 2000). The use of an external contractor for the regeneration of the activated alumina or ion exchange resin is preferred. This transfers the responsibility for the safe and complaint disposal of the waste to the contractor. If the onsite disposal of the waste is preferred, then the use of lined evaporation ponds is required.

3.3.2.1 Adsorptive processes

In the use of activated alumina [dehydrated $Al(OH)_3$] for the adsorptive removal of arsenic or fluoride, arsenic or fluoride is exchanged with surface hydroxides on the alumina. When adsorptive sites on the activated alumina surface become filled, the bed must be renewed or regenerated. Failure to regenerate can result in the captured arsenic or fluoride in the bed being released at once, which would cause a large concentration of these compounds in the treated water. Operating beds in series would help to minimise this, by providing an early warning system for when the media requires regeneration or to be renewed (see Figure 3-1).

Regeneration is accomplished through rinsing with regenerant (a strong base such as 4% sodium hydroxide), flushing with water and neutralising with a strong acid (such as 2% sulphuric acid). After 3 to 4 regenerations, the media would need to be discarded and replaced. For on-site regeneration, the storage of the acid and base would be necessary. In terms of operating the process safely and efficiently, operators would need to be trained on handling these hazardous chemicals and the regeneration of the resin. Selection of a suitable method for disposal of regeneration waste and spent alumina is also required. To avoid these complications, off-site regeneration can be considered by entering into a contract with a service provider, which eliminates the hazard of on-site storage and handling of acid and base as well as waste disposal.

Low pH is favourable for arsenic removal (pH of 5.5 – 6), with studies producing conflicting results on the exact optimum pH range for arsenic removal. Laboratory scale tests to determine the arsenic removal efficiencies would be required, and would also indicate whether pH correction is required. The oxidation state of arsenic plays an important role in its removal efficiency, and therefore pre-oxidation of the raw water would be required. The effect of competing ions (selectivity sequence) is shown below (US-EPA, 2000):

$OH^- > \mathbf{H_2AsO_4^-} > Si(OH)_3O^- > F^- > SO_4^{2-} > \mathbf{H_3AsO_3}$

The effect of competing ions (selectivity sequence) for the use of activated alumina for fluoride removal is shown below:

$OH^- > H_2AsO_4^- > Si(OH)_3O^- > \mathbf{F^-} > HSeO_3^- > TOC > SO_4^{2-} > H_3AsO_3$

3.3.2.2 Membrane processes

The reverse osmosis (RO) process is a high pressure process which requires relatively high quality influent water, with the presence of colloids, organics, iron and manganese increasing the fouling rate. An analysis of the raw water quality, for the presence of these substances as well as silica, turbidity, sodium ions, chlorine ions and TDS, is required to determine pre-treatment requirements. The RO process is able to remove both arsenite and arsenate, therefore eliminating the need for raw water pre-oxidation. The main advantage of this process is that no large quantity of sludge is produced and the process is not pH sensitive. For small rural applications, the RO brine concentrate can be used for purposes such as flushing toilets. Alternatively, lined evaporation ponds can also be used to hold the effluent requiring disposal from the RO unit. Corrosion control would need to be considered, if blending of treated and untreated water does not take place.

The drawback is the larger capital investment and that a reliable power supply is required for the process to operate. Water recovery rates are typically 70-85%.

3.3.2.3 Ion exchange for arsenic removal

Anionic exchange systems use a physical/chemical process to exchange ions between a resin bed and water passing through. A strong base resin is usually used for arsenic removal, which is pre-treated using sodium chloride. An oxidative step is needed as a precursor to the ion exchange process, since As-III is not removed. The US-EPA recommendation is that the influent water should contain < 500 mg/L TDS and < 25 mg/L sulphate. Ion exchange removals with strong base resins are not sensitive to pH in the range 6.5 – 9, with arsenic removals quickly decreasing outside this range. The ion exchange option will require the raw water to be analysed, since iron complexes which form between iron and arsenic cannot be easily removed using an ion exchange resin. The arsenic removals using this method are in practice variable, therefore laboratory scale tests before design are recommended.

Competition from background ions for ion exchange sites can affect the efficiency of the system. The adsorption preference is shown below:

$HCrO_4^- > CrO_4^{2-} > ClO_4^- > SeO_4^{2-} > SO_4^{2-} > NO_3^- > Br^- > (HPO_4^{2-}, \mathbf{HAsO_4^{2-}}, SeO_3^{2-}, CO_3^{2-}) > CN^- > NO^{2-} > Cl^- > (H_2PO_4^-, \mathbf{H_2AsO_4^-}, HCO_3^-) > OH^- > CH_3COO^- > F^-$

The main advantage of the use of this process is that it is not energy intensive and is easy to operate. Disadvantages are that maintenance, in terms of backwashing and recharging the resin with salt after every few weeks, when the resin becomes exhausted, is required. In addition, large amounts of salt are required during frequent regeneration of the resin (Chwirka *et al*., 2000). Also, if the system fails, all the arsenic captured in the resin at that time can be released at once causing a large concentration of arsenic in the treated water, with can have serious health implications. Columns used to hold the resin which are operated in series, can be used to provide an early warning system for the regeneration of resin (see Figure 3-1). In a configuration of two columns, only the upstream columns would be regenerated when SO_4^{2-} breakthrough is detected from that column. The columns would then switch positions, with the column containing newly regenerated resin occupying the final position in the treatment series. Monitoring of the effluent from the first and last column would be required.

The poisoning of anion exchange resins must be considered, with anion exchange resins designed to resist poisoning being employed or the removal of the fouling substance ahead of the ion exchange process. Silica is a common substance which fouls ion exchange resins.

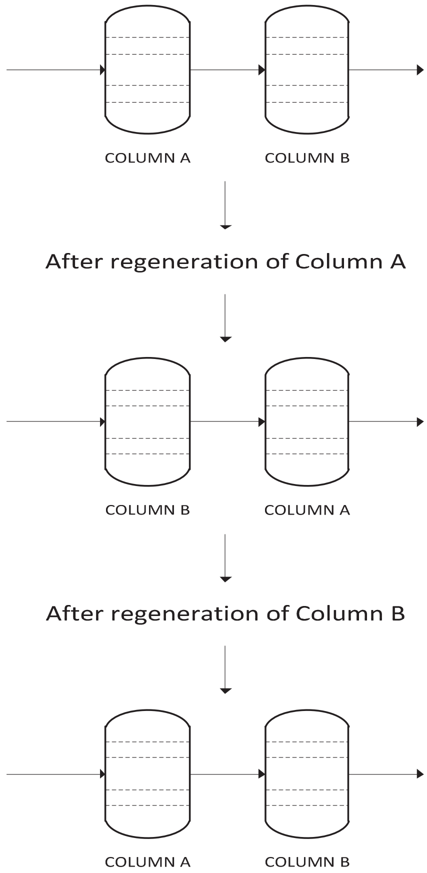

Figure 3-1: Schematic showing rotation of columns in series when using activated alumina or ion exchange processes

3.3.3 Softening processes

Hardness is caused by a high concentration of divalent metallic ions, primarily calcium and magnesium. Softening is usually achieved using one of the following methods:

- Chemical precipitation with lime or with lime and soda ash. The water then requires clarification and filtering to remove the precipitate
- Sodium cycle ion exchange process
- Membrane process such as reverse osmosis or nano-filtration, often applied to a portion of the flow which is then blended with untreated water

In the chemical precipitation process, large volumes of sludge which requires treatment and disposal are generated. Caustic soda can be used instead of lime, since it is easier to handle and generates less sludge compared to lime. The drawback is the higher price of caustic soda. In addition, in precipitation processes, pH correction following the softening process is required. Given this and that the process monitoring and control requirements for chemical precipitation processes can be more complex than other processes which can be used; this type of softening process is not preferred for package water treatment plants.

Membrane processes are favoured due to low capital and operational costs and small space requirements. A reverse osmosis process is recommended where water is not very hard. This is since very hard water will rapidly foul the reverse osmosis membrane. It is recommended that a portion of the water be treated using reverse osmosis and the treated water blended with untreated water, in order to avoid producing corrosive treated water. Nano-filtration membranes are also suitable for hardness removal, which are coarser and less expensive. Pre-treatment of the influent water to the membrane may be required, to prevent fouling of the membrane.

In the sodium cycle ion exchange process, calcium and magnesium are exchanged for sodium ions. In a weak acid hydrogen cation exchange process, hydrogen instead of sodium is exchanged for calcium and magnesium. Traditionally, zeolites have been used, although modern ion exchange processes consist of a matrix or hydrocarbon network such as polystyrene which is co-polymerized with divinyl benzene. Ionisable groups are attached to the network. Ion exchange processes are recommended to treat very hard water, where there is a high concentration of calcium and magnesium ions which require removal. Because of the high sodium content of softened water, individuals who have heart or circulatory problems or who are on low-sodium diets must be considered. Potassium chloride can be substituted for sodium chloride, especially when the sodium levels in the influent water is already elevated, however the cost of potassium chloride is much higher than sodium chloride.

3.3.4 Treatment processes for the removal of nitrate

The SANS 241:2015 limit for nitrate is 11 mg/L as N (equivalent to 50 mg NO_3^- per L). Nitrate is an acute contaminant, and therefore the reliability of the treatment system is critical. The major health concern of nitrate exposure through drinking water is the risk of methemoglobinemia or ‘blue baby syndrome’ in babies and pregnant women. Nitrate is especially prevalent in groundwater that has been impacted by pollution. The US-EPA lists anion exchange, reverse osmosis and electrodialysis reversal (EDR) as acceptable methods for nitrate removal in potable water (Seidel *et al*., 2011). For package water treatment systems, ion exchange and reverse osmosis processes are recommended.

ED works by passing an electric current through a series of anion and cation exchange membranes that trap nitrate and other ions in a concentrated waste stream. The polarity of the system (and the solution flow direction) can be reversed with electrodialysis reversal, which serves to minimize fouling. The main advantages of this technology include higher water recovery compared to RO and that the process is unaffected by the presence of silica. The main disadvantages include the energy demand, operational complexity and waste disposal. It is more suited to nitrate removal in high TDS water. This method is not recommended for the South African context at present, mainly due to a reliable electricity supply being required and due to the operational complexity of the system.

There exists biological denitrification processes as well, in which bacteria transform nitrate to nitrogen gas through a reduction process. Substrate and nutrient addition is necessary, as well as post-treatment of the water (Seidel *et al.*, 2011). The advantage offered in a biological process is the avoidance of having to dispose of a brine waste. However, the requirements for the process to operate well, including the maintenance of anoxic conditions, pre-treatment of water to the required pH, the addition of nutrient and substrate, potential for nitrite formation due to incomplete denitrification and high monitoring needs; makes it less suitable for package plant application where the level of skills of operators is low and full time operator presence for monitoring and control may not be available. Therefore, this type of nitrate removal process is not considered further.

The choice of treatment option cannot be generalized. The guidelines are meant to assist one in the choice of a suitable treatment option for the specific application. More details on ion exchange and reverse osmosis processes are given.

3.3.4.1 Ion exchange

The main advantages of ion exchange are that there are nitrate selective resins available and that it is a commonly used technology. The disadvantages include the potential for nitrate peaking, the high use of chemical (salt) and disposal of the brine. Nitrate is removed by displacing chloride on an anion exchange resin (Seidel *et al.,* 2011). Regeneration of the resin is achieved by using a concentrated salt solution resulting in the displacement of nitrate by chloride. The waste brine, concentrated with nitrate, is costly to treat and dispose of. The use of lined evaporation ponds is an inexpensive option.

The relative affinity of conventional anion exchange resins is: $SO_4^{2-} > NO_3^- > Cl^- > HCO_3^-$

Nitrate selective resins are typically used when the raw water has high sulphate content. Nitrate selective resins are more expensive than generic or conventional resins and have been developed to avoid nitrate dumping by increasing the selectivity of the NO_3^- ion as follows (Seidel et al., 2011):
$NO_3^- > SO_4^{2-} > Cl^- > HCO_3^-$

Sediel *et al* (2011) reports that where the disposal of waste brine is not limiting, ion exchange is the best option for low to moderate nitrate concentration, and also for the simultaneous removal of other contaminants such as arsenic and chromium. For very high nitrate concentrations, the high amount of salt required and the amount of waste generated makes this option less favoured. Seidel e*t al* (2011) reports that an emerging technology is weak base ion exchange, which is operationally more complex than conventional ion exchange processes, but could potentially, offer the recycling of waste as a fertilizer.

Important factors in the specification and selection of an anion exchange resin include (Seidel *et al*., 2011):

- The exchange capacity: a measure of the number of ions the resin can capture per unit volume
- The selectivity coefficient of the resin: the relative affinity of resin surface sites for the nitrate ion
- The rate of ion transfer (kinetics or rate of reaction): the rate that nitrate displaces chloride on the resin

Depending on the source water quality, ion exchange applications would require pre-treatment to remove iron, manganese, TSS and organic matter to prevent resin fouling, water softening to prevent scaling and dechlorination to prevent resin oxidation. Post treatment may also be required to avoid dezincification, by restoring alkalinity in the treated water, and to avoid galvanic corrosion which is associated with a high ratio of chloride to sulphate (Seidel *et al*., 2011).

Important considerations when using this process include the presence of competing ions (predominantly sulphate), organic matter, salts, alkalinity, hardness and metals in particular iron and manganese (Seidel *et al*., 2011). Where high levels of contaminants are present, nitrate selective resins may be necessary rather than generic resins. A difficulty experienced with nitrate selective resins is that regeneration efficiency decreases, with the resultant increase in chemical use, since nitrate is more strongly bound (Seidel *et al*., 2011). Regeneration frequency depends on the degree of pre-treatment, water quality and the type of resin used. As already mentioned, the poisoning of anion exchange resins must be considered, with anion exchange resins designed to resist poisoning being employed or the removal of the fouling substance ahead of the ion exchange process. Silica is a common substance which fouls ion exchange resins.

The ion exchange treatment system would need to be equipped with online nitrate analysers for monitoring and control purposes, and which would signal the shutdown of the treatment system when the nitrate level in the effluent reaches 50 mg NO_3^- per L. Figure 3-1 gives an example of a type of system which can be employed to determine when regeneration is required.

Where the nitrate concentration is only slightly above the SANS 241 limit, the approach which can be employed is the treatment of a portion of the flow (a side stream) and then blending the treated water with the water that by-passed the treatment process, so that the combined stream meets regulatory requirements. This approach offers capital and operational cost savings.

Sound O&M practices are essential for the success of this technology. One of the plants surveyed by Seidel *et al* (2011) showed design and operational shortcomings. The brine tank developed algal growth, and was then replaced with an opaque UV resistant tank. In addition, due to the online nitrate analyser not being calibrated, it was not known when the nitrate concentration in the treated water having exceeded the regulatory limit. Also, the brine saturator having low salt concentration resulted in incomplete regeneration of the resin.

3.3.4.2 Reverse Osmosis

The main advantages with reverse osmosis processes are that multiple contaminants can be removed and that it is a commonly used technology. The disadvantages include the potential for membrane fouling, low water recovery (Seidel *et al*., 2011 reported 85% recovery), complexity of operation, waste disposal and energy demand.

Pre-treatment to prevent membrane fouling is generally required. One of the key factors to consider is the trade-off between water recovery and power consumption. Recent developments in membrane technologies (e.g. ultra-low pressure RO membranes) have resulted in lower power consumption, resulting in this treatment option gaining favour.

RO can address multiple contaminants simultaneously, such as ionic (arsenic, fluoride nitrate, chloride, etc.) and organic constituents such as pesticides, etc. The waste stream can be disposed to a wastewater treatment plant, if the increased salt concentration can be accommodated. Other options include lined drying beds or evaporation ponds, deep well injection or discharge to nearby surface salt-waters. Seidel *et al* (2011) reports that for small capacity systems, RO can be cost effective if there are multiple contaminants requiring removal.

3.3.5 Treatment processes for the removal of taste and odour

There are a number of sources of taste and odour. For instance the presence of iron and manganese in water can impart a metallic or bitter taste to water, the extra-cellular products of algae or algae themselves give odour problems to water or sloughing off of colonies of dissolved iron consuming bacteria in distribution pipes can also cause odour problems. Causes of taste and odour from microbial activity in the distribution system, mixing of waters using chlorine and chloramination for disinfection and the release of aromatic compounds from material linings; are not considered.

The common causes for taste and odour in water supplies include the presence of algae and actinomycetes and decaying vegetation (Kawamura, 2000). Taste and odour can also be caused by hydrogen sulphide, chemical run-off and spills and pollution. Metals such as iron and manganese and phenolic compounds also impart taste and odour. It is important during the design of processes to provide flexibility in operation to enable the treatment of seasonally occurring or intermittent taste and odour issues.

The options for prevention of contamination at source include:

- Installation of reservoir mixing devices to assist when stratification of dams occur, resulting in an oxygen deficit bottom layer; or the ability to abstract at various levels in a dam
- The control of aquatic plant growth, such as the use of copper sulphate to control algal growth. The dosages applied must take into account not exceeding the lethal dosage for fish
- Groundwater source management, by prevention of groundwater contamination

Where prevention at the source is not practical or not feasible, treatment of taste and odours at the plant is required. There are many treatment methods available. Common practices which are suitable for package water treatment plants include oxidation by aeration or potassium permanganate and adsorption on activated carbon. Chlorine is not considered suitable for package plants where minimal operator intervention is available, due to the potential to create chlorinated by-products which pose a health risk and also due to changes in the odour type if the process is not well monitored. In addition, chlorine does not react with actinomycetes, geosmin and 2-methyl isoborneol, which are common sources of taste and odour (Monteil, 1983). Biological treatment is also not considered, due to complex operation and process control requirements for the successful removal of taste and odour compounds.

Oxidation using potassium permanganate is a practical and effective method to control taste and odour. Potassium permanganate is able to remove taste and odour, oxidise iron and manganese and remove hydrogen sulphide. It should be added prior to the coagulant so that manganese dioxide formed can be coagulated (Gauntlett and Packham, 1972).

Aeration can be used to fulfil two purposes viz. transfer of oxygen to the water and the removal of volatile gases. Aeration can be used to remove small quantities of hydrogen sulphide. For higher concentrations, aeration must accompanied by the use of chlorine. Aeration reduces tastes and odours from water that are dissolved in it as gases or that are otherwise sufficiently volatile to escape rapidly at an air-water interface, such as sulphide; but has no effect on geosmin and 2-methyl isoborneol; which are frequently occurring taste and odour compounds (Lin, 1977).

For sulphides, additional treatment following the aeration process; using chlorination and activated carbon adsorption or conventional coagulation and sedimentation processes; may also be required. When the level of sulphides (H_2S) is less than 3 to 4 mg/L, aeration devices can be used with pH adjustment to below 6 prior to aeration (Kawamura, 2000). Aeration devices which can be considered for package plant application include forced draft packed towers, diffused mechanical spraying and multiple tray cascading. Design fluxes for these systems are given in Kawamura (2000).

Activated carbon is a widely used and effective treatment option, and is recommended for use in package plants for the treatment of taste and odour. Activated carbon has a very large adsorptive capacity for both organic and inorganic molecules. Unlike oxidation which transforms the odourous compounds, adsorption removed the substances from water. In addition, activated carbon improves the quality of water by removing other substances such as colour and organic matter.

Activated carbon is available in powdered or granular form. The powder is usually dry-fed or slurry-fed (Gauntlett and Packham, 1972). Granular activated carbon (GAC) is usually applied to filtered water, in purpose built adsorption beds. If carbon treatment is required intermittently to remove seasonally occurring odours, or if the dose of carbon required is very low, the cost of installing granular carbon may not be justified, and the dosing of powdered carbon (PAC) is preferred. Granular carbon eliminates the need to dose, store and dispose of powdered carbon, eliminating handling and dust problems; and can be regenerated and reused. However, the use of powdered carbon is more economical than granular carbon at plants feeding low dosages of powdered carbon (Lin, 1977). This report discusses PAC only, since taste and odour problems are more known to occur seasonally.

PAC is best added early in the treatment process, to improve effectiveness by enabling longer contact time (Gauntlett and Packham, 1972). It is important that activated carbon not be applied with chlorine, since activated carbon essentially dechlorinates the water. It is usually applied to the raw water, mixing tank, clarifiers or to filters. It is worth noting that 2-MIB is less readily adsorbed that geosmin, therefore when both compounds are present, the PAC dose applied should be based on the removal of 2-MIB instead of geosmin. A general rule of thumb is that is the PAC dosing system is less than 70 kg/h, and a PAC dry feeder should be used in combination with a solution mixing tank or vortex mixer. At higher flowrates and more frequent PAC addition, slurry systems can be considered (Kawamura, 2000). Therefore, the package plant systems, a dry feeder with a mixing tank must be considered.

3.4 CONTENT CONSIDERATIONS FOR AN O&M MANUALS

This section provides information which would typically be contained in an O&M manual, and can be used as a guide when specifying the content of an O&M manual.

3.4.1 Operations manual

The operations manual would typically contain the following information:

- General process safety instructions including PPE requirements, identified hazards, references to emergency measures and hazardous materials data sheets (MSDS) and chemical handling information, etc.

- Operating instructions including:
    - Start-up
    - Shut-down
    - Normal Operational Procedures: step by step instructions for automatic and manual operations (including sample calculations, chemical make-up, backwashing, emergency

response and troubleshooting), including operation of the plant during maintenance activities. The design capacity of the plant must be given.
    - Commissioning of the plant (this must include procedures for determining the optimal backwash regime as well as the guidelines on when and how to adjust the sludge removal duration and frequency from the clarification process)
    - Operating envelopes/windows
    - Sampling, calibration and process monitoring and record keeping requirements
    - Troubleshooting guides listing probably causes and solutions for process problems

- Process engineering and control data :
    - Functional Design Specification (FDS) or a detailed control narrative
    - SCADA mimics
    - Process Flow Diagram, including a mass balance
    - Process and Instrumentation Diagrams (P&IDs)
    - Commissioning data

- Emergency Measures
    - Evacuation plan
    - Hazardous material info
    - Alarms, trips and interlocks

- A directory of contacts containing the following information: Names, physical address, email and telephone numbers of all keys suppliers, designers/contractors involved in the design and installation of the plant and who would be of assistance in future spares sourcing, modification or troubleshooting.

- An asset register, including equipment listing, manufacturer equipment brochures and technical data sheets.

3.4.2 Maintenance Manual

The Maintenance Manual would typically contain the following information:

- A listing of common failure modes of the equipment, with relevant remedial actions
- Manufacturers recommendations for service intervals
- A listing of all routine and preventative maintenance tasks with their individual timings
- Procedures for safe disassembly, reassembly, cleaning, inspection and adjustment
- List of tools required to maintain in the equipment and instruments

- Spares and consumables: a list of all critical spares which are deemed necessary to keep a shelf standby available, and a list of spares and consumables which will be utilized in routine or preventative maintenance tasks
- Drawings of equipment contained in the system, including the hydraulic gradient line at average and full capacity, layout drawings, civil structures, electrical circuit and panel layout diagrams, PLC program code, mechanical diagrams of equipment and communication network drawings
- Certificates, guarantees and warrantees for each piece of equipment: to contain all certificates relating to the systems equipment, electrical compliance certificates, calibration certificates, factory acceptance tests (FATs), site acceptance tests (SATs), copies of manufacturers guarantees as well as a statement of warrantee period in which exclusions are expressly notes and any other certificates relating to the equipment. Any statutory certificates must clearly indicate the validity date/period
- Application specific calibrations and settings for each piece of equipment
- Commissioning data
    - Date, place, scope of commissioning, attendance register and hand-over documentation relating to the system
    - Signed pre-commissioning records of all FATs, SATs, calibration certificates, etc. for all mechanical and electrical equipment and instrumentation
    - Expected and actual recorded parameters of the installation
- The manufacturer's maintenance manual must contain:
    - Maintenance instructions
    - Assembly diagrams
    - Parts list
    - Contact details of local supplier
    - Scheduled maintenance requirements

3.5 GOOD PRACTICES AND RULES OF THUMB

Good practice guidelines, some of which are developed taking into account the challenges identified in the survey of package plants, are presented in this section. Small water treatment schemes sometimes experience difficulty in complying with best available technologies, mainly due to poor financial management or financial constraints and a lack of technical capacity. This section provides guidance only, and it must be noted that it does not provide exhaustive design calculations and methodologies, for which literature is readily available or which specialized suppliers can provide. Instead the aim is to:

- Provide guidance on the factors to consider when deciding on whether to use a package water treatment plant
- Assist in formulating a technical specification for tender purposes, so as to ensure long term sustainability of the water treatment package plant system

Both conventional treatment processes and membrane technology processes are included in the scope. The guidelines encompasses both technical and management issues.

A negative perception about package plants has developed in the past, especially due to process design and operational shortcomings and mechanical failures. The cause of this may in part be due to the intention of wanting to extract beyond recommended design capacity out of equipment and processes in efforts to minimize the capital investment; time constraints as well as poor planning in terms of supporting package plants with a suitable operating structure to ensure the sustainability of these processes. It is essential to understand that despite package plants having smaller treatment capacity, it does not exclude it from the general O&M support systems which would be required from larger capacity treatment plants. In addition, inexperienced persons approaching contractors directly, instead of seeking guidance from engineers, has in part contributed to poorly designed package plants in the past.

Where time and budget permits, value engineering is useful even on these small capacity processes, since it improves reliability, performance and offers potential for cost savings. This assists on optimising the design, ensuring all aspects of operating the facility are considered and ensuring the appropriate treatment processes are used; which play an essential role in the successful operation and sustainability of package water treatment plants.

3.5.1 Package plants – mobile vs. non-mobile

Mobile package plants offer the advantage of flexibility and have value in roles such as in emergency or short term situations to provide treatment capacity to augment water supply. Where water supply is required as a long term service, investment is fixed structures is prudent.

The treatment processes, design fluxes and process control are similar for both mobile and non-mobile package plants. The poor process flexibility to handle variable quality influent water, which was noted in the package plants surveyed, was as a result of the absence of automated chemical dose control and skilled operators to respond the changes in influent water quality. Any type of treatment process, forming part of either mobile or non-mobile package plants, would be expected to respond similarly under these circumstances if adequate process monitoring and control is lacking.

The formulation of pre-built plug-and-play mobile type of package plants, which can be used for short-term or emergency potable water supply, offer quick solutions but also require caution when used. The suitability of the process design for each new application the package plant is used in, and the process optimization once installed, should ideally be carried out by technically skilled individuals. This is since site specific factors may require modifications in the treatment process or the operation of the process.

3.5.2 Chemical dosing systems

It is essential that treatability studies be conducted prior to installation of a package plant. Treatability studies are typically jar tests conducted, using the raw water source, which assists in the selection of suitable chemicals to achieve treatment targets. Apart from the chemical type selection, it also serves as a guide on the chemical dosage ranges which would typically be required. This information is useful for sizing of the chemical dosing system and estimating chemical running costs for budgeting purposes.

It is important that jar testing apparatus be available, should raw water fluctuations warrant conducting a jar test to optimise the chemical dosages. Where raw water is sourced from river, where variable water quality can be expected, jar testing equipment available on site would be required for chemical dose adjustment, despite an SCD is being used for chemical dose control. Procedures for conducting jar tests and calculation of chemical dosages must be available and operators trained in this regard. This will avoid chemical wastage and water quality not being compliant with regulatory standards.

Apart from adjustment of chemical dosages, fluctuations in raw water turbidity may require other adjustment to be made, including changing coagulants, adjusting flash mixing and/or flocculator mixing intensity, adding a coagulant aid or adjusting the pH. Operators must be trained to respond to these changes in influent water quality, and step by step instructions must be included in the O&M manual in this regard.

The shelf life of chemicals must be taken into account when designing and managing storage tanks for chemical dosing systems. Chemicals such as sodium hypochlorite solutions will last longer if the tanks are painted in a dark colour to screen the contents from sunlight and are also sheltered from heat sources.

Correctly sized dosing pumps with variable speed drives are essential to ensuring that chemical dosages can be adjusted. It is also essential that redundancy is built into the design of the chemical dosing systems, by either having duty-standby, or a shelf standby, dosing pumps. For chemicals which are dry solids, which are less effective when dosed in powder form into a pressurised line, it is best that these chemicals be dissolved in a saturator device and then dosed as a liquid solution into a side stream (Voortman and Reddy, 1997). Hygroscopic powders coalesce under humid conditions. Liquid coagulants, on the other hand, can be administered using diaphragm dosing pumps. The dilution of chemicals supplied in concentrated form may be required to enable sourcing a suitable small enough dosing pump enabling more accurate chemical dosing. Facility for flushing of pumps and pipework must be taken into account.

For the pre-treatment processes, drop test devices which can be used to confirm the chemical dosages being administered are recommended. Operators would need to be trained on the use of these devices. It is also recommended that self-priming pumps be used where systems are automated.

To achieve rapid mixing of coagulants into water, passive devices (such as valves, rotameters and orifices) where momentum changes results in turbulence and energy dissipation, can also be used but with caution since the G-value will be a strong function of flowrate in such devices (Voortman and Reddy, 1997). In-line static mixers or mechanical mixers are also typically used to achieve rapid mixing of chemicals into water.

In terms of disinfection chemicals, the type of disinfectant selected must take into account which chemical is locally readily available, so that the logistical challenges associated with rural locations can be minimised. Operators must receive adequate training on dosing procedures and monitoring and control of the disinfectant dose.

3.5.3 Flocculation and sedimentation processes

The flocculation process must take into account whether the raw water flowrate will be variable; to ensure that the correct flocculation energy is imparted for various throughputs.

It was noted in the plants surveyed, that flocculation was achieved mostly using a flocculation tower type of technology. This type of design is suitable for situations where the influent water flowrate is not variable. There exist other types of flocculation systems, which allow for more process flexibility in terms of being able to vary the mixing energy as required when the influent water flowrate varies.

The use of mechanical mixers fitted with variable speed drives in flocculation mixing tanks can be employed to enable flexibility in varying the mixing energy. In addition, the use of hydraulic flocculators such as multiple baffled tanks in parallel, with the option to isolate sections of the tank to impart the flocculation energy required by the influent water flowrate, would also enable the mixing energy to be varied.

Sedimentation tanks should be designed on the basis of surface overflow rates (surface loading rates). It was noted in some of the plants surveyed that clarification systems were designed at upflow rates beyond design recommendations. Design guidelines can be found in books such as Kawamura (2000), and must be adhered to, so as to ensure efficient solid liquid separation. In addition, some systems reported difficulty with desludging due to the use of JoJo tanks as sedimentation tanks, which do not have a sloped floor. It is essential when designing settling tanks that the ease of desludging is taken into account.

3.5.4 Filtration

The survey indicated that there are two types of filtration systems most widely used in package plant technologies. These are pressure filters and membrane filtration processes. The recommended filtration rates for these types of processes are available from suppliers of these technologies and are available in books and literature such as Kawamura (2000).

It is important to build in redundancy in filter systems. This includes designing systems which can operate within the recommended filtration range even when one filter is taken off-line (e.g. for backwashing, maintenance, etc.). For pressure filters, it is important that the backwash regime be optimized as part of the commissioning process. Backwash water can be recycled, which offers cost savings. However, the option to stop the recycle of backwash water must also be incorporated into the design, since when Giardia or Cryptosporidium is present in the influent water, these would typically be removed by the filtration process and then concentrate in the backwash water when the filter is cleaned.

Scaling and/or fouling can be one of the most crippling effects of inadequate pre-treatment for membrane processes. Well-designed membrane type of processes will incorporate appropriate pre-treatment to minimize fouling. The disposal of membrane concentrates and spent membrane chemical cleaning chemicals must be done appropriately, and must be factored into the overall project cost. Disposal is usually into lined evaporation ponds.

3.5.5 Desalination

For desalination processes, it is noted that variations in seawater salinity and temperature play an important role in the selection of membranes, recovery, treatment process configuration and the required operating pressure to meet product water quality (Turner et al., 2015). In terms of abstraction, for package desalination plants, beach wells are generally considered. The characterization of the seawater quality with respect to parameters that can cause fouling, such as turbidity, organic carbon, hydrocarbons, picophytoplanton, metals, nutrients, as well as sulphur, algae, jellyfish and seaweed blooms, is generally conducted which provides guidance on the pre-treatment processes required to provide the required quality of influent to the RO process.

Swartz *et al* (2014b) noted that the energy use and cost for desalination technology has decreased over the years and is now more affordable. However, the use of energy recovery devices to reduce energy consumption, especially on the RO process, should be considered.

Since these are specialised processes, which require more careful monitoring and control compared to conventional treatment processes using river or groundwater sources, it is recommended that where technical and O&M support services are not available, the O&M component be outsourced.

For water reclamation and reuse applications, it is preferred that the source water quality does not vary significantly. Therefore, where the influent is obtained directly from a wastewater treatment works, it is essential for the process to be optimized to ensure a steady quality of effluent feed to the reuse process. The investment in full time presence of skilled operators and adequate technical support services is necessary for water reuse processes given the risks.

3.5.6 Process Control

Package water treatment plants are small water treatment systems with small budgets, and therefore cannot take advantage of economies of scale available to larger systems. In these instances, only part-time operator presence and minimal management supervision can be afforded, with very little budget available for training (Swartz *et al.*, 2009). Therefore, processes which are inherently self-regulating and less reliant on technical expertise and maintenance are preferred. It is worthy of mention that automated equipment and instrumentation such as flow meters and valves require regular cleaning, calibration and maintenance, which is essential for the success of the automated systems.

The investment in automatic chemical dose control in rural applications of package water treatment plants, where minimal skill or process supervision is available and often not affordable, is recommended. This however does not eliminate the need for process monitoring. A feedback control loop that continuously monitors flowrate or streaming current is commonly used to control coagulant dose. This is recommended to adjust chemical dose for changes in influent water flowrate, and for small changes in water quality are compensated for using a streaming current detector. Other chemicals, including the disinfectant dosage, would typically be regulated using flow proportional dosing to match the dose set-point.

Where there are no skilled operators available, and when a reliable supply of electricity or a reliable backup power supply is available, then the flow proportioned adjustment of chemicals dosed is recommended. Where a fixed influent flow is being used, flow proportional dose control is not required. Chemical dosage adjustments based on the influent water quality is typically achieved using a streaming current detector (SCD). In some of the package plants surveyed, no chemical dose adjustment took place subsequent to commissioning, since the influent water quality was assumed not to be variable. Where water is sourced from dams or boreholes, sudden large fluctuations in water quality; as would be expected from river abstraction after periods of rainfall; is not expected. It is however prudent to still ensure that raw water quality monitoring data is examined to establish the need for manual chemical dose optimization.

Controls and alarms can consist of flow switches, pressure switches, and automatic shutdown of pumps when tank levels are low. Tank level sensors can also be used to control automatic tank filling operations. This type of control on chemical dosing systems can also be used to shut down the plant when chemical levels are very low. This will prevent damage to the pump caused by dry operation, and also avoid final water quality not meeting regulatory requirements. Additional alarms include tank high level alarms, smoke, illegal entry alarms, flooding, electrical power failure and the tripped condition of equipment.

When systems are automated, investment in alarms and automatic cut-off to prevent damage, clogging, loss or treated water contamination is recommended. Fail safe design so as to not compromise product quality during power failures, chemical depletion or component failure is critical to providing water of acceptable quality and in ensuring operating costs do not escalate. Therefore, in these smaller plants, additional capital expenditure on alarms and automatic cut-off systems may be justified.

3.6 GENERAL

It is important to ensure that critical spares be identified and be readily available, to reduce plant downtime. In instances where equipment cannot be repaired or replaced promptly, it is good design practice to ensure there is a shelf standby, or a standby installed on the process.

Many package systems have a poor reputation because of the corrosion associated with the metal tanks (DeMers *et al*., 1998). Materials selection must be considered.

It is essential that the provision of operating manuals form part of the contractors scope of work. Training of operators and maintenance personnel in the O&M of the package plant is also essential. A basic framework of the typical content of operations and maintenance manuals is given in Section 3.4. Preventative maintenance and predictive maintenance is best practices. Where the maintenance function is outsourced, it is essential to ensure that SLA’s are entered into with contractors who are skilled and equipped to carry out the required maintenance. The adequate supply of spare parts can be a problem, and so it is useful if parts which are off the shelf items and are interchangeable are used on package plants, and custom made items only be considered where this option is not available. Standardization can assist in stocking of spare parts, which is especially needed to avoid delays when non-local parts are used. Standardization also makes training in the maintenance of these parts easier.

Equipment reliability is dependent upon operation within the limits established by the designers. Equipment damage can occur when operating outside of these operating envelopes. Monitoring is therefore critical for the sustained reliability of process units. Risk based decision and undertaking cost-benefit analyses during the design phase, will point to either investing in the presence of an operator to monitor and control processes, or in automating processes. The use of remote monitoring technologies is recommended in instances where the full-time presence of an operator is not available. This can be achieved using satellite or GSM technology. In areas where the power supply is unreliable or no power supply exists, the use of solar powered equipment is recommended. However, the decision of where to apply renewable energy technology must take into account the risk of theft, and the necessary security features also budgeted for.

For renewable energy, matching demand with supply of energy, which is dependent on seasonal variations among other factors, would need to be considered. Solar systems sized for the month of least solar irradiance is recommended for applications where the system is the sole source of electricity for a small community.

In terms of tendering, the writing of specifications must be done by technically competent individuals. Tender evaluation should not be based on price only, but also take functionality issues into account to ensure suitable contractor with relevant experience is appointed.

CHAPTER 4: CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSIONS

- Package water treatment plants widely used in South Africa, with the majority of these plants located in rural areas

- Some of the main challenges experienced with package plants include:
  - Lack of technical skills in the design of package plants: this can in part be due to contractors being consulted directly, in order to save costs, instead of obtaining technical assistance with the design of package plants. In addition, the design engineers of package plants would require sufficient experience to identify and design around challenges, some of which are generic and others which are specific for each package plant application
  - Lack of skills in managing cash flows during O&M, otherwise budgetary constraints
  - Lack of operational training and skill

- Reliability, by making allowance for stand-by equipment must be built into the design. Rural plants, which are far from maintenance workshops, face the challenge of having to wait long for maintenance personnel to repair equipment, but also due to theft are unable to keep shelf stand-by equipment on site.

- Automation of processes offers the advantage that full time operator presence may not be required. However, the limitations of automation must be taken into account when designing processes. The maintenance of instrumentation and equipment used is essential for the success of automation.

- Remote monitoring technologies are readily available and offer solutions for easier process monitoring for rural sites

- Renewable energy can assist with limiting the extent of process disruptions due to power failures. These technologies also offer operational cost savings.

4.2 RECOMMENDATIONS

As water treatment technology advancements take place and new water sources are explored, new challenges associated with package plants emerge. It is recommended that this study be repeated in the future, in order to review the treatment technologies being employed and to identify the challenges experienced and provide new types of solutions.

It is essential that the circumstances under which package water reclamation and reuse plants are employed be carefully assessed, since the investment in the full time presence of skilled operators and technical support services is necessary given the nature of the risks.

REFERENCES

ALAGARSAMY S R and GANDHIRAJAN M (1981) Package Water Treatment Plants for Rural and Isolated Communities, Journal of the IWWA, **12**(4).

BUDHRAM S, NYUSWA M, RAJAGOPAUL R and THOMPSON P (2013) Operational and Design Considerations for High Rate Clarifiers in the South African Water Treatment Industry, *WRC Report No. K5/1942*

BROUCKAERT B M, PRYOR M J, PILLAY P, ZONDI T A and AMIRTHARAJAH A (2002). Assessing the use of Autonomous Valveless Filters for turbidity removal in rural applications
In: *Biennial Conference of the Water Institute of Southern Africa (WISA)*, Durban, 19 – 23 May 2002

CHWIRKA J D, THOMSON B M and STOMP III J M (2000) Removing arsenic from groundwater, Journal AWWA Vol 92 (3)

CLARK R M, GOODRICH J A and LYKINS Jr B W (1994) Package plants for small water supplies – the US experience, *Water SRT Aqua*, **43**(1)

DeMERS L D, HANZON B D, GLICK F L and SCHULTZ R M (1998) Design Considerations for Package Water Treatment Systems, Journal of the AWWA, **80**(8)

GAUNTLETT R B and PACKHAM RF (1972) The removal of organic compounds in the production of potable water, Presented at the symposium on “Removal of Residual non-biodegradable organic matter from notable and process waters” in London in October 1972

KAWAMURA S (2000) Integrated Design and Operation of Water Treatment Facilities. 2nd ed., John Wiley and Sons

LIN S D (1977) Taste and Odors in Water Supplies: A Review, ISWS/CIR-127/77

MONTEI A J (1983) Municipal drinking water treatment procedures for taste and odour abatement – A Review, Water Science Tech, Vol. 15, pp. 279-289

SEIDEL C, GORMAN C, DARBY J L and JENSEN V B (2011) An Assessment of the state of nitrate treatment alternatives, AWWA Journal

STOEBNER R A and ROLLAG D A (1981), Ozoonation of a municipal groundwater supply to reduce iron, manganese and trihalmethane formation
Paper presented at the 1981 AWWA conference at St Louis, Missouri

SWARTZ C D, MWIINGA G, MARLER M, MEYER V, HLOPHE M, RAJAGOPAUL R and CHARLES K (2009) Guidelines and training aids for the sustainable operation and maintenance of small water treatment plants, *WRC Report No. 1599/1/09*

SWARTZ (b) C D, COOMANS C J, MULLER H P, du PLESSIS J A and KAMISH W (2014) Decision-Support Model for the Selection and Costing of Direct Potable Reuse Systems from Municipal Wastewater, *WRC Report No. 2119/14*

THOMPSON P, MAHARAJ L, KORLAM S and SING N (2016) Process Design Guidelines for Package Water Treatment Plants
Presented at: *Biennial Conference of the Water Institute of Southern Africa (WISA)*, Durban 2016

TURNER J N, NAIDOO K, MATIMBA AT AND STROHWALD NKH (2015) Investigation into the cost and operation of South African desalination and water reuse plants, *WRC Project No. K5/2121*

US-EPA (2000) Technologies and Costs for Removal of Arsenic from Drinking Water, EPA 815-R-00-028

VOORTMAN W J and REDDY C D (1997) Package Water Treatment Plant Selection, *WRC Report No 450/1/97*

VOUTCHKOV N (2013) *Desalination Engineering: Planning and Design*, 1st ed., McGraw-Hill

WONG M J (1984) Chlorination-Filtration for Iron and Manganese Removal, AWWA Journal

APPENDIX A: INFORMATION FROM PACKAGE PLANTS SURVEYED

No.	Package plant location (Plant name, area)	Capacity (Mℓ/day)	Capacity (m^3/h)	Supplier		
				Name	Telephone	Email
1	Dennedal Garcia, Riversdale	0.16	6.7	Ikusasa Water	0218516700	info@ikusasawater.co.za
2	Tshaanda, Limpopo	0.05	2.1	Ikusasa Water	0218516700	info@ikusasawater.co.za
3	DWS, Clanwilliam dam	0.15	6.3	Ikusasa Water	0218516700	info@ikusasawater.co.za
4	Sandriver Package Plant	1	41.7	Aqua Centre Nelspruit	013 7457847/55	aquac@mweb.co.za
5	Marite Package Plant	4	166.7	Aqua Centre Nelspruit	014 7457847/55	aquac@mweb.co.za
6	Edinburg Package Plant	3	125.0	Aqua Centre Nelspruit	015 7457847/55	aquac@mweb.co.za
7	Dwaleni Package Plant	2	83.3	Aqua Centre Nelspruit	016 7457847/55	aquac@mweb.co.za
8	Mshadza Package Plant	2	83.3	Aqua Centre Nelspruit	017 7457847/55	aquac@mweb.co.za
9	Mganduzweni Package Plant	2	83.3	Aqua Centre Nelspruit	018 7457847/55	aquac@mweb.co.za
10	Sterkstroom Eastern Cape	1.92	80.0	TS Water Projects	0219 056 329	tom@tswaterprojects.co.za
11	Riemvasmaak Northern Cape	0.96	40.0	TS Water Projects	0219 056 329	tom@tswaterprojects.co.za
12	Molteno Eastern Cape	0.12	5.0	TS Water Projects	0219 056 329	tom@tswaterprojects.co.za
13	Modikwe Platinum Mine Potable Water Plant, Limpopo	0.24	10.0	WEC Projects	0117455500	info@wecprojects.co.za
14	Twickenham Mine Hackney Shaft Potable Water Plant, Limpopo	1.2	50.0	WEC Projects	0117455500	info@wecprojects.co.za
15	Schmidtsdrift Potable Water Treatment Plant, Northern Cape	0.36	15.0	WEC Projects	0117455500	info@wecprojects.co.za

No.	Package plant location (Plant name, area)	Capacity (Mℓ/day)	Capacity (m^3/h)	Supplier Name	Supplier Telephone	Supplier Email
16	Kuruman Orphanage, Northern Cape	0.034	1.4	WEC Projects	0117455500	info@wecprojects.co.za
17	Zinkwazi Water, KZN	0.6	25.0	WEC Projects	0117455500	info@wecprojects.co.za
18	Kwanyuswa Package WTW. For UGU DM	0.72	30.0	WPCP	027315023310	info@wpcp.co.za
19	Umkamyakude DM - Containerised Package plant	0.576	24.0	WPCP	027315023310	info@wpcp.co.za
20	Umgeni Water - New package WTW for Mhlabatshane	2	83.3	WPCP	027315023310	info@wpcp.co.za
21	Umgeni Water - Mtwalume	2	83.3	WPCP	027315023310	info@wpcp.co.za
22	Tumela Mine, Limpopo, Anglo American Platinum Mines	0.36	15.0	Befula Investments (Pty) Ltd	031-5027132/3/4	rob@rossieng.co.za
23	Tumela Mine, Limpopo, Anglo American Platinum Mines	0.36	15.0	Befula Investments (Pty) Ltd	031-5027132/3/4	rob@rossieng.co.za
24	Mtulwa	0.35	14.6	-	-	-
25	Ngungu	0.36	15.0	-	-	-
26	Makeni	0.32	13.3	-	-	-
27	Nagle Package Plant	0.14	5.8	-	-	-
28	Rosedale; Umtata	3	125.0	GR Solutions	0826 521 085	garthe@mweb.co.za

No.	Package plant location (Plant name, area)	Capacity (Mℓ/day)	Capacity (m^3/h)	Supplier		
				Name	Telephone	Email
29	Nokweja WTP, Umzimkulu	1.8	75.0	GR Solutions	0826521085	garthe@mweb.co.za
30	Umzimkulu WTP, Umzimkulu	3	125.0	GR Solutions	0826521085	garthe@mweb.co.za
31	Nzinga WTP, Impendle	1	41.7	GR Solutions	0826521085	garthe@mweb.co.za
32	Airfield, Manguzi	1.9	79.2	GR Solutions	0826521085	garthe@mweb.co.za
33	Thengani, Manguzi	2.6	108.3	GR Solutions	0826521085	garthe@mweb.co.za
34	Manguzi WTP, Manguzi	0.7	29.2	GR Solutions	0826521085	garthe@mweb.co.za
35	Bergville	1	41.7	GR Solutions	0826521085	garthe@mweb.co.za
36	Machunwini, Kokstad	0.5	20.8	GR Solutions	0826521085	garthe@mweb.co.za
37	Kwanovuka PH A	0.5	20.8	GR Solutions	0826521085	garthe@mweb.co.za
38	Kwanovuka PH B	0.6	25.0	GR Solutions	0826521085	garthe@mweb.co.za
39	Nondweni WTP, Nondweni	2	83.3	GR Solutions	0826521085	garthe@mweb.co.za
40	Mpendle (Gomane borehole)	0.6	25.0	Wetspec	(+27) 31 569 4184	info@wetspec.co.za
41	Lion River	0.36	15.0	Wetspec	(+27) 31 569 4185	info@wetspec.co.za
42	Hazelmere WTW	6	250.0	Wetspec	(+27) 31 569 4185	info@wetspec.co.za
43	Zinkwazi WTW	1	41.7	Wetspec	(+27) 31 569 4186	info@wetspec.co.za
44	Komati WTW	1.0	41.7	Water Engineering & Construction	-	-
45	Paris Dam WTW	1.0	41.7	Degremont	-	-
46	Giant Castle Game Reserve Ukhahlamba (Maloti - Drakensberg)	0.075	3.1	LPM Chemicals	(031) 764 7460 (082) 652 1085	garthe@mweb.com

No.	Package plant location	Capacity (Mℓ/day)	Capacity (m^3/h)	Supplier		
	(Plant name, area)			Name	Telephone	Email
47	Didima Game Reserve Ukhahlamba (Maloti - Drakensberg)	0.075	3.1	-	(031) 764 7460 (082) 652 1087	garthe@mweb.com
48	Midmar (Munro Bay) Nature Reserve - Howick	0.144	6.0	GR solutions	(082) 652 1088	garthe@mweb.com
49	Midmar Training centre	0.034	1.4	GR solutions	(082) 652 1089	garthe@mweb.com
50	Midmar (Power boat) Nature Reserve - Howick	0.181	7.5	GR solutions	(082) 652 1090	garthe@mweb.com
51	Midmar (Workshop) Nature Reserve - Howick	0.024	1.0	GR solutions	(082) 652 1091	garthe@mweb.com
52	Chelmsford Nature Reserve	0.144	6.0	Improchem (formerly Onduka)	(031) 949 8136/ (082) 560 4997	xolani.radebe@improchem.co.za
53	Ndumo Game Reserve	0.147	6.1	Improchem (formerly Onduka)	(031) 949 8136/ (082) 560 4997	xolani.radebe@improchem.co.za
54	Sodwana Bay Nature Reserve	0.508	21.2	LPM Chemicals	(031) 949 8136/ (082) 560 4998	xolani.radebe@improchem.co.za
55	Hluhluwe(Hilltop) Game Reserve	0.204	8.5	LPM Chemicals	(031) 949 8136/ (082) 560 4999	xolani.radebe@improchem.co.za
56	Imfolosi(Mpila) Game Reserve	0.12	5.0	WPCP	(031) 502 3310	dion@wpcp.co.za

No.	Package plant location	Capacity (Mℓ/day)	Capacity (m^3/h)	Supplier		
	(Plant name, area)			Name	Telephone	Email
57	Imfolosi(Umganu) Game Reserve	0.18	7.5	LPM Chemicals	(031) 502 3311	garthe@mweb.com
58	Ithala(Ntshondwe) Game Reserve	0.06	2.5	Klomac Engineering	(031) 579 1041 (031) 579 1041	-
59	Kamberg Nature Reserve	0.06	2.5	GR solutions	(031) 502 3312	garthe@mweb.com
60	Rugged Glen	0.144	6.0	Improchem (formerly Onduka)	(031) 949 8136/ (082) 560 4997	xolani.radebe@improchem.co.za
61	Culfargie Nature Reserve			LPM Chemicals	-	-
62	Royal Natal national Park(Mahai)	0.181	7.5	GR solutions	(031) 502 3311	garthe@mweb.com
63	Royal Natal national Park(Thendele)	0.06	2.5	GR solutions	(031) 502 3312	garthe@mweb.com
64	Spioenkop Nature Reserve	0.144	6.0	Improchem (formerly Onduka)	(031) 949 8136/ (082) 560 4997	xolani.radebe@improchem.co.za
65	Pearly Beach – Cape Town	2.2	91.6667	QFS Filtration Systems	-	herman@qualityfilters.co.za
66	Beaufort West water reclamation plant	2	83.3333	Water and Wastewater Engineering + QFS Filtration Systems	-	herman@qualityfilters.co.za

No.	Package plant location	Capacity (Mℓ/day)	Capacity (m^3/h)	Supplier		
	(Plant name, area)			Name	Telephone	Email
67	Mama Lumka, Cape Town	0.024	1	QFS Filtration Systems	-	herman@qualityfilters.co.za
68	De Kelders	1.6	66.67	QFS Filtration Systems	-	herman@qualityfilters.co.za
69	Sedgefield	1.5	62.5	-	-	herman@qualityfilters.co.za