AQUARIUS CONSULT CC

Reg. No.: CC/2010/3052

TSUMEB MUNICIPALITY

POTABLE WATER TREATMENT PLANT

PRELIMINARY DESIGN REPORT

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Written & Compiled by: T. Seifart

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SECTION 1: BACKGROUND

1. INTRODUCTION

Aquarius Consult was appointed by Tsumeb Municipality to prepare bidding documents for a new 400 m^3/h potable water treatment plant (PWTP) for the town of Tsumeb, with specific emphasis on cryptosporidium contamination and hardness removal. Cryptosporidium contamination was measured at several of the raw water (borehole) sources and presents a serious health concern. Hardness removal is to be incorporated to alleviate scale precipitation problems in the water supply network.

This Preliminary Design Report summarises the treatment plant design and shows capacity and technology to be provided for the plant. Power requirements, capital and operating cost estimates and footprint requirements are also given.

2. LOCATION AND SETUP

The new PWTP will be installed adjacent to the existing Tupper Dam Reservoir on the southern outskirts of Tsumeb as per Figure 1 below. This location was chosen as it is a central point to which water from all raw water sources is pumped before being fed into the town's potable water network. Therefore, treating water at this location immediately upstream of the Tupper Dam reservoir ensures that the entire town's water supply can be treated with one central plant.

Figure 1: Plant location

3. BASIC DESIGN PHILOSOPHY

The following general design criteria shall be applied:

- A new WTP with 400 m^3/h feed water capacity shall be provided.
- Final, treated water will conform to the Namibian Water Quality Guidelines acceptable quality for all parameters, as well as the NamWater Group A specification for potable water.
- Special attention must be given to complete cryptosporidium contamination removal. Final water quality must achieve a 0 oocysts per 100 litre requirement as per the Water Quality Guidelines.
- In addition, the treatment works shall make provision for the reduction of calcium and magnesium carbonate hardness to alleviate scale precipitation problems in the water supply network.

4. RAW WATER QUALITY PARAMETERS

Water from various boreholes is currently pumped to the Tupper Dam before distribution to the town's reticulation network. The water quality will therefore vary slightly depending on the blend of boreholes in operation at any given time. Unfortunately, accurate total volumes or proportions of each borehole feeding the Tupper Dam were not available at the time.

However, the water quality parameter concentrations do not differ more than 15% between individual boreholes and therefore a more or less constant feed quality can be expected.

Table 1 below shows a typical average feed water quality to be expected and to be used for design purposes. The table also shows the final water NamWater Group A qualities that need to be achieved by the PWTP. This will by default also ensure that the more lenient Namibian Water Quality Guidelines Acceptable Standard is also adhered to (attached in Appendix A for reference).

Table 1: Typical raw water quality

Parameter	Unit	Raw Water	NamWater Group A
Flow	m^3/h	300	
pH		7.5	6-9
Electrical Conductivity	mS/m	84.8	150
Turbidity		< 1	< 1
Total dissolved solids	mg/l	825	
P-Alkalinity as $CaCO_3$	mg/l	<10	
Total Alkalinity as $CaCO_3$	mg/l	455	
Total Hardness as $CaCO_3$	mg/l	505	300*
Ca-Hardness as $CaCO_3$	mg/l	262	375
Mg-Hardness as $CaCO_3$	mg/l	243	290
Chloride as Cl^-	mg/l	10	250

Fluoride as F^-	mg/l	0.1	1.5
Sulphate as SO_4^{2-}	mg/l	17	200
Nitrate as N	mg/l	2	10
Sodium as Na	mg/l	5.8	100
Potassium as K	mg/l	0.9	200
Magnesium as Mg	mg/l	59	70
Calcium as Ca	mg/l	105	150
Manganese as Mn	mg/l	0.01	0.05
Iron as Fe	mg/l	0.05	0.1

*The requirement for this plant will be 120 mg/l or less total hardness in the final water

The only inorganic parameter of major concern is therefore total hardness, which needs to be reduced to below 300 mg/l. However, in order to prevent scaling of any downstream equipment in the distribution network, **the design requirement for this plant is to reduce total hardness to below 120 mg/l.**

In addition, cryptosporidium oocyst contamination was detected at various sources in the network feeding the Tupper Dam, which presents a serious health hazard. Therefore, one critical requirement of this plant is the complete removal of cryptosporidium contamination from the water.

5. DESIGN CAPACITY AND TECHNOLOGY OF CHOICE

5.1 Capacity Requirements

According to the Client requirements the PWTP is to be designed to be able to handle peak inflows of up to 400 m^3/h. Currently, the measured peak inflow rate into the Tupper Dam is approximately 320 – 350 m^3/h as per measurements taken by the Client. A further two boreholes are envisaged to be installed in the near future and it was therefore decided to allow for a design peak flow rate of 400 m^3/h. It should be noted that these peak flows are not pumped to the Tupper Dam continuously, they are only experienced for a few hours per day when most or all of the active boreholes are abstracting at any given time.

Table 2 below shows the monthly abstraction volumes of all currently operational boreholes, as obtained from the Client's log sheets over 8 months. This data was then used to determine how much flow would be obtained from all boreholes when averaged over 24 hours instead of pumped with peak flows. Some flowmeters are unfortunately faulty (highlighted in red font), but representative typical monthly abstraction volumes from each borehole could be obtained. Table 2 shows that, typically, approximately 242 m^3/h averaged over 24 hours is currently abstracted from the boreholes into the Tupper Dam. Therefore, the abstraction data from the boreholes definitively illustrates that average flow rates of approximately 240 m^3/h can be expected, even if peak flow rates of 350 m^3/h are observed currently.

It was therefore decided to base the plant treatment capacity on an average 300 m^3/h over 24 hours, with maximum peak inflows of 400 m^3/h to allow for the additional inflow from new boreholes. By providing adequate hydraulic buffer capacity at the inlet to the new PWTP, the remaining plant can then be sized for average inflows (300 m^3/h) instead of peak inflows (400 m^3/h) which drastically reduces capital and operating costs. In addition, this hydraulic buffering upstream of the treatment plant allows constant feed to the plant which is definitely preferred to stop/start scenarios if no flow balancing were to be done. Treatment processes require some time to reach steady state and as such frequent stops and starts to the plant should be avoided.

Borehole	Feb-23	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Total	Monthly
Icon 6	625 319	713 987	749 973	795 289	816 557	852 683	876 919	902 246	276 927	30 770
Icon 3	644 646	655 616	666 144	668 822	668 822	668 822	668 822	668 822	24 176	4 835
Nomtsoub 1	680 230	755 107	790 691	825 608	844 895	850 748	850 748	850 748	170 518	18 946
Nomtsoub 2	67 910	141 019	163 848	198 447	219 377	251 958	282 060	311 009	243 099	27 011
Wolf 1	783 377	845 128	868 573	893 122	906 929	927 133	947 511	966 503	183 126	20 347
Wolf 2	424 627	524 571	564 483	607 311	631 470	665 351	698 939	729 666	305 039	33 893
FP 15/3	274 287	319 705	345 476	378 605	389 108	400 077	404 434	404 434	130 147	16 268
FP 7/1	583 428	668 472	684 309	709 253	722 079	742 820	792 426	780 429	197 001	21 889
									Total Monthly (m^3)	**173 960**
									Total Daily (m^3)	**5 799**
									Total Hourly (m^3)	**242**

Table 2: Borehole abstraction volumes (m^3)

5.2 Recommended Technology

Various treatment technologies are available for the removal of cryptosporidium contamination and hardness reduction for potable water treatment plants. Each option was considered for this project to determine the optimum solution. The following criteria were considered:

- Capital cost requirements;
- Operational cost requirements;
- Minimal waste stream volumes;
- Ease of operation.

Treatment technologies that were considered with advantages and disadvantages on a qualitative basis are as follows:

1) Process Option 1: Sand filtration and UV disinfection for cryptosporidium removal, followed by ion exchange (IX) softening for hardness reduction, and chlorine gas disinfection for downstream residual disinfection.
2) Process Option 2: High-rate lime softening for hardness reduction, followed by sand filtration and UV disinfection for cryptosporidium removal, and chlorine gas disinfection for downstream residual disinfection.
3) Process Option 3: Reverse osmosis (RO) treatment for both cryptosporidium and hardness removal followed by chlorine gas disinfection for downstream residual disinfection.
4) Process Option 4: Nanofiltration (NF) treatment for both cryptosporidium and hardness removal followed by chlorine gas disinfection for downstream residual disinfection.
5) Process Option 5: Nanofiltration (NF) treatment for both cryptosporidium and hardness removal followed by RO treatment for brine reduction, and chlorine gas disinfection for downstream residual disinfection.

Comparative designs were performed for each of the above 5 options. The findings of each design are summarized below (chlorine disinfection is required for each option and is not discussed further in the comparative analysis).

Option 1: Sand filtration, ion exchange softening

This option is typically the easiest process solution for softening and cryptosporidium removal. However, on a large plant as this, there will be significant volumes of backwash wastewater generated from sandfilter backwash streams and softener regeneration. High salinity wastewater will be generated that will need to be discharged to the sewage treatment plant or treated elsewhere and volumes are estimated to be 225 m^3/day. Salt requirement for softener regeneration are approximately 8 tonnes dry salt per day, which needs to be made up into a brine solution for regeneration. Capital cost estimate depending on level of automation = N$ 30 - 35 million (excluding VAT).

Option 2: Sand filtration, lime softening

Approximately 50 kg/h of lime powder dosing would be required for this plant, which would mean that an operator has to make up 1.2 tonnes of dry lime a day. For a manual process this would become incredibly tedious, while an automatic process would be expensive for the available budget when considered with the sand filtration requirement as well. As for option 1 discussed above, sand filters would need to be backwashed regularly and approximately 700 – 1000 m^3/d of wastewater would need to be discharged to the sewage treatment plant or handled elsewhere. Capital cost estimate = N$ 40 – 50 million (excluding VAT) depending on level of automation.

Option 3: Reverse osmosis

Reverse osmosis is a very effective way of removing both pathogens such as cryptosporidium and softening the water in one process, as the membranes have very fine pore sizes. However, the process requires a lot of energy (electricity) and approximately 5-10% brine waste is produced, corresponding to 360 - 720 m^3/day of high salinity brine waste that would need to be handled. Capital cost estimate = N$ 20 – 25 million (excluding VAT) depending on level of automation.

Option 4: Nanofiltration

Nanofiltration is similar to reverse osmosis discussed above, except that the pore size of membranes is slightly larger, thereby allowing more calcium and magnesium hardness to pass through and requiring less energy (electricity) than reverse osmosis. Approximately 90% recovery can be achieved, which would mean that 720 m^3/day of high salinity waste brine needs to be handled. Capital cost estimate = N$ 20 – 25 million (excluding VAT) depending on level of automation.

Option 5: Nanofiltration and reverse osmosis

This option is a combination of options 3 and 4 above. The water is first treated using nanofiltration, which requires less energy than reverse osmosis. Only the resulting 10% brine stream is then further treated using reverse osmosis, so that only approximately 180 m^3/day of final brine effluent is produced. This combination of processes produces the optimal balance between low power consumption while producing as little as possible final brine. Capital cost estimate = N$ 22 – 27 million (excluding VAT) depending on level of automation.

Table 3: High level process technology comparisons summary

Operational Parameter	**Option 1 SF + IX**	**Option 2 SF + Lime Soft.**	**Option 3 RO**	**Option 4 NF**	**Option 5 NF + RO**
Ease of operation	Low	Medium	Medium	Medium	Medium
Power requirement	Low	High	High	Medium	Med-High
Operation and maintenance cost	Low-medium	High	High	Medium	High
Waste/brine stream volume (m^3/day)	250	700 – 1 000	360 - 720	720	180
Capital cost (million N$)	30 - 40	40 - 50	20 - 25	20 - 25	22 - 27

A previous bidding process using the Option 5 process technology revealed that operational costs would be excessive, in the order of N$ 10 million per annum, mostly attributable to high power consumption (225 kW) and chemicals consumption. It was therefore decided to pursue Option 1, which may have a higher capital cost and produce more waste streams, but will be cheaper to operate.

This is the option that uses the lowest amount of electricity and chemicals, with estimated capital costs of N$ 30 – 35 million (excluding VAT). Final pricing will depend on contractor's choice of equipment as well as their availability and risk appetite (i.e. mark-up) for the project.

The chosen process was then designed in more detail for incorporation into the bidding documents, including process description, process and instrumentation drawings and Bill of Quantities.

5.3 Process Description

For the below description also refer to P&ID Nr 2301.001.TSU-201 Rev 1.

Borehole water from various sources is currently pumped into the existing 15 000 m^3 Tupper Dam reservoir in a 315 mm HDPE pipe. The scope of works for this contract will start with installation of a tee-off and manual isolation valves from this rising main pipe, so that water can either be directed to the new WTP or can still be pumped to the Tupper Dam reservoir as is currently done.

From the tee-off, water will be directed to a new 2 100 m^3 zincalume raw water reservoir (T-100) which will be used for hydraulic and quality balancing of the raw water. Depending on the number of boreholes in operation at any given time, the peak flow rate entering the reservoir can be up to 400 m^3/h and the quality may also vary slightly. The WTP downstream of this raw water reservoir is to be sized for 300 m^3/h only. Instantaneous demand peaks on the supply to the town will be balanced by the 15 000 m^3 Tupper Dam reservoir.

After blending and equalization in the raw water reservoir water must be abstracted by two off pumps (P102, Q= 300 m³/h, H= 30 mWH) and pumped through the sand filters and through the softener (ion exchange vessels). After the softeners, water is additionally treated with UV to ensure complete destruction of any cryptosporidium or other cysts.

Water from the raw water tank is pumped through 8 off pressure sand filters (FV01) in parallel. Two off (1 duty/1 standby) filter feed pumps will be provided as follows:

Tag Number	-	PC01 A/B
Type	-	Centrifugal, end-suction
Capacity	-	300 m³/h
Filtration rates		
Normal	-	9.9 m/h
Maximum	-	11.3 m/h (when backwashing 1 filter)
Head	-	30 mWC
Motor	-	55 kW, 380 V

8 off pressure sand filter, 2 200 mm diameter and sized for a flow of 37.5 m³/h will be provided. The filters will be packed with 1 000 mm silica sand with an effective size of 0.8 mm and uniformity coefficient less than 1.4. The plant automation will be such that the filters will be automatically backwashed on a timer, or when the pressure drop (detected by pressure transducers) has reached a certain high value. Backwash water will be directed to the waste discharge channel. All electrically actuated valves will be provided to achieve this.

Each filter must be backwashed at least every second day or when the filter become blocked, considered to be when the pressure difference over the filter is 0.3 bar or more as measured between the inlet and outlet pressure transducers. The backwashing procedure will commence with a combined air and water scour for 5 minutes followed by a water only rinse for a further 5 minutes. Backwash water is to be discharged to a manhole not further than 200 m away from the plant. Pipework and connection onto the manhole is to be included under this contract.

Backwashing of thesfilters is carried out automatically. Because the filters share a common in- and outlet header, they clog at the same time and all filters have to be backwashed when a backwash is required. The filters are individually backwashed, one after the other.

The filters are backwashed utilizing water and air (combined). The backwash cycle is performed automatically in two stages:

- Simultaneous air (at 55 m/h) and water (at 33.8 m/h) wash (scouring)
- Water (only) rinse (at 33.8 m/h)

The filter system is provided with a side channel blower to provide compressed air the air scour cycle during initial backwash operation of the sand filter.

Tag Number	-	BB01 A/B
Type	-	Side channel
Capacity	-	210 m^3/h FAD
dP	-	35 kPa
Motor	-	5.5 kW, 380 V

After the sand filtration to remove fine particles the raw water needs to be softened. For this, a softener plant to treat 250 m^3/h of filtered water has been provided, while 50 m^3/h of filtered water will bypass the softeners and is blended back afterwards (to reduce softening plant capacity requirements while ensuring that the final Ca and Mg hardness < 120 mg/l). The plant is of the 2 duty 1 standby type, i.e. three softener vessels are provided, each for a duty of 6 hours at 125 m^3/h. Thus, while two vessels are on-line, one is regenerated.

Ion exchange resin. The softeners are filled with Rohm & Haas Amberlite IR 120 Na, a strong acidic cationic exchange resin chosen specifically for the required application.

Supply. The plant as designed consists of 3 off mild steel (rubber coated inside) vessels, each 2 200 mm dia and 2 300 mm high (FV01 A/B/C) that will each be filled with 7 700 L of strongl acidic cation (SAC) resin, such as Amberlite HPR 1100 Na or equivalent.

For regeneration, a complete brine solution make-up station is provided. This consists of a 100 m^3 concrete sump fitted with a mechanical mixer (MM01) and an ultrasonic level sensor to signal to the PLC that high/low levels in the tank have been reached. Two off (duty/standby) brine transfer pumps (PC02 A&B) are supplied for regenerating the softeners as follows:

Tag Number	-	PC02 A&B (duty/standby)
Make and Model	-	Grundfos/KSB or similar
Type	-	Centrifugal
Capacity	-	15.4 m^3/h
Head	-	30 mWC
Motor	-	1.1 kW; 380 V; 3 000 rpm

In-line electrically actuated valves are provided to switch and control the regeneration flows ().

Process and automation. The plant is designed to deliver 250 m^3/h of softened water using filtered raw water with a quality as described above, plus 50 m3/h of bypass water. The plant operates for approximately 6 hours on one vessel to produce 750 m^3 of softened water, after which it automatically switches over to the standby vessel and regenerates the first vessel. Switching is controlled via PLC once the totalizing flowmeter has registered 750 m^3 of soft water delivered to the Tupper Dam.

After switching over to the standby vessel, the first vessel is regenerated in co-flow mode while the standby vessel then continues to produce softened water. The full regeneration cycle will be done automatically via the PLC and takes approximately 2 hours.

Brine make-up. A manual brine make-up as station will be provided. Brine is made up as a 10% solution. The operator will add the required amount of salt to the brine sump when empty, fill up the sump with water and switch the mixer on for ca 30 min to dissolve the salt. A fork lift will be provided as part of this contract to transfer bulk (1 ton) salt bags from the storage area inside the building to the brine sump chute.

The entire 300 m^3/h blended stream is then disinfected using ultraviolet (UV) point disinfection in combination with hydrogen peroxide dosing, before discharge into the Tupper Dam reservoir. This combination achieves an advanced oxidation step to ensure that any remaining cryptosporidium cysts and other microbiological contaminants cysts are eliminated.

Chlorination

Chlorine will be dosed at the overflow from the flush tank to the Tupper Dam reservoir. The existing chlorination building is to be used for this purpose, with all necessary modifications required at this building included under this contract. The current building consists of a single room where bottles and dosing equipment are housed. This is to be split into two rooms for separation of bottles and remaining equipment and structural alterations for sealing of the bottle room and installing doors etc. are included under this scope.

The chlorine dosing rate at the dosing point will vary proportionally to the inflow to the reservoir. The dosing set points will be determined from the measured reservoir inlet flow rate and outlet chlorine residual value. The dosing set point will then adjust in order to maintain a free chlorine level of 0.8 ppm.

The system shall be designed to disinfect water at the plant capacity of 300 m^3/h. The design shall also make specific provision for shock dosing ability.

Brine/ Backwash Disposal

Approximately 140 m^3/d of brine and 85 m^3/d of filter backwash water will be produced by the plant, which needs to be discharged to the sewage treatment plant, or otherwise handled appropriately. The backwash water will be relatively clean as it is pure raw water that has just been filtered for removal of fine particles. It is therefore assumed that the filter backwash water can be spilled below ground to recharge the groundwater supply while only the softener brine (140 m^3/d) needs to handled further. Options for brine handling include discharge to the sewage treatment plant, groundwater recharge or evaporation ponds.

1) Discharge to the sewage treatment plant: This is the easiest option since an existing sewage treatment manhole is relatively close to the envisaged PWTP site and brine can easily be discharged into the sewage system. This stream will contain high concentrations of sodium (5 500 mg/l), magnesium (2 650 mg/l), calcium (5 300 mg/l) and chlorides (25 000 mg/l) with a total suspended solids concentration of 40 000 mg/l and conductivity of 56 500 microS/cm.

- Evaporation ponds: to fully evaporate the entire brine stream would require an area of approximately 31 200 m^2 (or 177 m x 177 m). This pond has to be lined with a plastic liner. Besides the massive area required for evaporation, the costs to construct such a pond are not feasible.
- Groundwater recharge: Another option would be to discharge the brine stream into a new borehole adjacent to the envisaged new potable water treatment plant. This would result in the water and minerals into the soil and groundwater in the area and forming natural deposits in the surrounding soil and groundwater. This option is subject to environmental approvals.

The discharge to the sewage treatment plant was chosen as the easiest and cheapest solution. Should additional funding be made available, then the ponds or groundwater recharge option could be considered.

5.4 Power Supply, Electrical Board, Control and Monitoring

Total, continuous power consumption for the treatment plant will be approximately 70 kW (absorbed power), 380 V, 3-phase power. The current Cenored supply infrastructure will need to be upgraded for this plant (by Cenored after application from Tsumeb Municipality) and an allowance of N$ 250 000 has been included for this purpose.

NOTE: The exact power requirements will only be finalized at detail design stage once all equipment choices and control requirements are finalized by the contractor.

The plant will be fitted with very basic control:

- Automatic duty/standby rotation every 12 h of all pumps sets;
- Two indication lights (running/trip) for every pump are required;
- An alarm signal light (similar to a break-down truck) on top of the control board will be provided. Latter will be activated if any pump trips and will be switched off when all signals are healthy again. Thus, an operator will be able to already see from a considerable distance from the plant, if any motor has tripped.

Data logging/monitoring will include:

- Raw water inflow;
- Brine wastage;
- Final treated water discharge.

6 OPERATION AND MAINTENANCE

We recommend that a semi-skilled person is employed to oversee proper operation at the site and to do all necessary routine service and maintenance functions. Theoretically, only one person would suffice, but for health and safety reasons, a minimum of two people should ideally be present at any industrial site.

6.1 Operation and Maintenance Manual

The PWTP will have a proper operating manual containing all the details necessary to successfully operate and understand processes and procedures of the plant. The manual will be properly bound and be available in the English language. The following information will be included in the manual, as a minimum:

- The commissioning procedure and plant settings after successful commissioning;
- All plant-related drawings and diagrams. This includes layout, mechanical, and piping and instrumentation drawings as well as electrical wiring diagrams and any other drawings which may be useful for plant operation and maintenance;
- Complete functional description of the process including the control philosophy;
- Illustrated operating instructions including start-up, shut-down, backwashing, regeneration and/or cleaning procedures and emergency actions to be taken in the case of possible equipment failures;
- Maintenance instructions to include the descriptions and required frequency of all maintenance tasks;
- Equipment data sheets and manufacturer's operation and maintenance instructions;
- Procedures for chemicals preparation with cautionary notes and clearly visible signage for hazardous chemicals. Clear instructions for emergency procedures to be followed in case of an accident involving chemicals must be easily visible and available;

- Chemicals suppliers contact details;
- Trouble shooting notes with contact details for emergency action;
- Suggested typical plant operating parameters, such as chlorine dosing, flow rates and head losses. After commissioning, such values that are fine-tuned during the commissioning process should be included in the commissioning report and included in the operation and maintenance manual;
- Sample calculations where applicable.

6.2 Routine Operation

4.2.1 Spares and Consumables. In addition to the regular checks and procedures to be followed, it is very important to keep stock of critical spares and consumables on the plant. In the event of failure of equipment that is crucial to the successful operation of the plant, a technician should be able to replace or repair such equipment with minimal or no plant shutdown. Stock levels of consumables and chemicals (e.g. chlorine) should also be managed carefully in order to ensure that sufficient time is allowed for re-ordering and delivering new supplies. Typical spares to be kept on site include pumps, valves, pipes and fittings, instrumentation and service kits for major equipment.

4.2.2 Asset inventory. An asset inventory helps plant managers to identify what assets they own, where these assets are located or stored and what their condition and service history is. This data needs to be catalogued in a logical, readable format such as a handwritten list, spreadsheet software, database software or even commercially available asset management database software for very large plants. These lists can be drawn up for installed equipment, chemical supplies as well as for general stock available at the plant.

4.2.3 Safe Operation. The main health and safety concern is that the PWTP produces a final water that complies with the prescribed quality standards at all times. Failure to comply with the required final water quality must result in immediate remedial action or even complete plant shut-down to rectify the factor(s) causing the non-compliance. During shut-down raw water will be diverted to the Tupper Dam reservoir, as is currently done. The PWTP needs to monitor its final water quality in order to ensure that the consumer receives a safe drinking water supply at all times. This is done with regular sampling and testing in either on-site or an independent laboratory.

The PWTP will need to keep records of plant performance regarding final water quality achieved, with minimum sampling frequencies as set out in the applicable quality standards. The results of these analyses must be available at any time for auditing by the Department of Water Affairs in order to ensure the safe supply of treated water. The following records need to be available and may be requested by DWA during a plant audit:

- Logs of final water quality, with minimum sampling frequencies as prescribed;
- Proof of operator and process controller qualifications and attendance registers, as proof that the minimum operator and process control qualification requirements have been met.

6.3 Environmental, Safety and Health Aspects

Every PWTP needs to adhere to all relevant local Acts regarding the operation and environmental impacts of the plant. The plant must provide treated water safe for human consumption and conforming to the required quality standards at all times while having a minimum impact on the environment.

The following aspects are especially important for the environmental analysis:

- Quantities and nature of chemicals used at the PWTP. Emergency preparedness plans, safety equipment and emergency clean-up procedures need to be in place in case of a spillage. Chlorine gas that is used for disinfection is a particular concern, as this is a highly toxic gas and can have severe health and environmental impacts if leakages occur. The chlorination equipment including the chlorine cylinders will be contained within a separate building, away from any other chemicals. All relevant safety notices and safety equipment will be available at this building.

- Construction. The construction process for the treatment plant will take the best part of 4 – 6 months. During this time, care must be taken to ensure minimal impact on the environment and to ensure that all construction works comply with the relevant Acts regarding health and safety.

APPENDIX A: WATER QUALITY STANDARDS AND GUIDELINES FOR POTABLE WATER

Table 1: CHEMICAL AND BIOLOGICAL REQUIREMENTS

Specifications for water quality intended for human consumption from the source and piped water supply					
Status				**Ranges and upper limits**	
Interpretation				**(Ideal guideline)**	**(Acceptable Standard)**
DETERMINANTS	**Unit**	**Format**	**Concern**	**95 Percentile Requirement**	
PHYSICAL AND ORGANOLEPTIC REQUIREMENTS					
Temperature	° C		E	Ambient temperature	
Colour	PTU	or mg/litre	E	10	<15
Taste			O,E	No objectionable taste	
Odour			O,E	No objectionable odour	
Turbidity (treated surface water)	NTU	or TU	H,I	< 0.3	< 0.5
Turbidity (groundwater)	NTU	or TU	H,I	< 0,5	<2
pH @ 20 °C	pH		I	6.0 to 8.5	6 to 9
Electric Conductivity @ 25 °C	mS/m***	E.C.	H,I	< 80	< 300
Total Dissolved Solids (treated surface water)	mg/litre		H,I	< 500	< 2 000
Total Dissolved Solids (groundwater)	mg/litre		H,I	< 1000	< 2 000
INORGANIC MACRO DETERMINANTS					
Ammonia	mg/litre	N	H	< 0.2	< 0.5
Barium	mg/litre	Ba	H	0.5	< 2
Calcium	mg/litre	Ca	I	< 80	< 150
Chloride	mg/litre	Cl	H,I	< 100	< 300
Fluoride	mg/litre	F	H	< 0.7	< 1.5
Magnesium	mg/litre	Mg	H	< 30	< 70
Nitrate	mg/litre	N	H	< 6	< 11
Nitrite	mg/litre	N	H	< 0.1	< 0.15
Potassium	mg/litre	K	H	< 25	< 100
Sodium	mg/litre	Na	H.I	< 100	< 300
Sulphate	mg/litre	SO_4	H,O	100	< 300
Asbestos (fibres longer than 10 µm)	Fibres/litre		H	<500 000	< 1000 000
INORGANIC MICRO DETERMINANTS					
Aluminium	µg/litre	Al	H	< 25	< 100

Specifications for water quality intended for human consumption from the source and piped water supply					
Status				Ranges and upper limits	
Interpretation				(Ideal guideline)	(Acceptable Standard)
DETERMINANTS	Unit	Format	Concern	95 Percentile Requirement	
Antimony	µg/litre	Sb	H	< 5	< 50
Arsenic	µg/litre	As	H	<10	< 50
Beryllium	µg/litre	Be	H	< 2	< 5
Bismuth	µg/litre	Bi	H	< 250	< 500
Boron	µg/litre	B	H	< 300	< 500
Bromide	µg/litre	Br	H	< 500	< 1 000
Cadmium	µg/litre	Cd	H	< 5	< 10
Cerium	µg/litre	Ce	H	<1 000	<2 000
Cesium	µg/litre	Cs	H	< 1 000	< 2 000
Chromium Total	µg/litre	Cr	H	< 50	< 100
Cobalt	µg/litre	Co	H	< 250	< 500
Copper	µg/litre	Cu	H	< 500	< 2 000
Radon	Bq/L	Ra		< 200	< 1 000

Specifications for water quality intended for human consumption from the source and piped water supply					
Status				Ranges and upper limits	
Interpretation				(Ideal guideline)	(Acceptable Standard)
DETERMINANTS	Unit	Format	Concern	95 Percentile Requirement	
INORGANIC MICRO DETERMINANTS					
Cyanide (free)	µg/litre	CN^-	H	< 20	< 50
Cyanide (recoverable)	µg/litre	CN^-	H	< 70	< 200
Iron	µg/litre	Fe	H,E	< 200	< 300
Lead	µg/litre	Pb	H	<10	< 50
Manganese	µg/litre	Mn	H	< 50	< 100
Mercury	µg/litre	Hg	H	< 1	<2
Nickel	µg/litre	Ni	H	< 50	< 150
Selenium	µg/litre	Se	H	< 10	< 50
Thallium	µg/litre	Ti	H	< 5	< 10
Tin	µg/litre	Sn	H	<100	<200
Titanium	µg/litre	Ti	H	< 100	< 300

Specifications for water quality intended for human consumption from the source and piped water supply					
Status				**Ranges and upper limits**	
Interpretation				**(Ideal guideline)**	**(Acceptable Standard)**
DETERMINANTS	**Unit**	**Format**	**Concern**	**95 Percentile Requirement**	
Uranium	µg/litre	U	H	< 3	< 15
Vanadium	µg/litre	V	H	< 100	< 500
Zinc	µg/litre	Zn	H	< 1 000	< 5 000
Organo-metallic compounds (as organo or industrial chemicals or others)	µg/litre	Polymer	H	below detection limit (in accordance with WHO and EPA requirements)	below detection limit (in accordance with WHO and EPA requirements)
ORGANIC DETERMINANTS					
Dissolved Organic Carbon	mg/litre	DOC-C	H	< 5	<10
Phenol compounds	µg/litre	phenol	H	< 5	< 10
DISINFECTION AND DISINFECTION BY-PRODUCTS					
Bromodichloromethane (Part of THM)	µg/litre		H	< 20	< 50
Bromoform (Part of THM)	µg/litre		H	< 40	< 40
Chloroform (Part of THM)	µg/litre		H	< 20	< 100
Dibromomonochloro-methane (Part of THM)	µg/litre		H	< 20	< 100
Trihalomethanes (Total)	µg/litre	THM	H	< 100	< 150
Bromate	µg/litre		H	< 5	< 10
Chloramines	mg/litre	Cl_2	H	< 2	< 4
Chlorine dioxide after 30 min. GENERAL	µg/litre		H	200 - 500	< 800
Chlorine dioxide after 30 min. SPECIFIC	µg/litre		Turbidity > 0.3 NTU	200	200 - 400
Chlorine dioxide after 60 min. SPECIFIC	µg/litre		Turbidity > 1.0 NTU	< 200	200 - 500
Chlorite	µg/litre		H	< 400	< 800
Chlorate	µg/litre		H	< 200	< 700
Haloacetic acids	µg/litre		H	not detected	< 60
Chlorine, free, after 30 min; GENERAL	mg/litre	Cl_2	H,I	0.3 – 0.5	0.1 – 1.5
Chlorine, free, after 30 min; SPECIFIC	mg/litre	Cl_2	Turbidity: < 0.3 NTU	0.3	0.1 – 1.5
Chlorine, free, after 30 min; SPECIFIC	mg/litre	Cl_2	Turbidity: > 0.3 NTU	0.5	0.1 – 1.5
Chlorine, free, after 60 min; SPECIFIC	mg/litre	Cl_2	Turbidity: >1.0 NTU	1.0	0.1 – 1.5

Specifications for water quality intended for human consumption from the source and piped water supply					
Status				**Ranges and upper limits**	
Interpretation				**(Ideal guideline)**	**(Acceptable Standard)**
DETERMINANTS	**Unit**	**Format**	**Concern**	**95 Percentile Requirement**	
BIOLOGICAL REQUIREMENTS					
Algae					
Chlorophyll α	µg/litre		E,O	< 1	< 2
Total algae cell count		/ml	H,O	< 200	<5 000
Blue-green algae	cells	/ml	H,O	< 200	<2 000
Mycrocystin	µg/litre		H	< 0.1	< 1
Geosmin	ηg/litre		E, H	< 15	< 30
2-Methyl Iso Borneal (2 MIB)	ηg/litre		E, H	< 15	< 30
OTHER DETERMINANTS					
Agricultural chemical compounds			H	Any organic compound recognized as an agro-chemical shall be in accordance with the WHO and EPA requirements.	
Industrial chemical compounds			H	Any organic compound recognized as an industrial chemical shall be in accordance with the WHO and EPA requirements.	
Endocrine disruptive chemicals			H	Any chemical compound that is suspected of having endocrine disruptive effects shall be in accordance with the WHO and EPA requirements.	
RADIOACTIVITY				**95 Percentile Requirement**	
Gross alpha activity	Bq/litre		H	< 0.2	< 0.5
Gross beta activity	Bq/litre		H	< 0.4	< 1.0
If Gross alpha and beta is above specification calculate Dose based on individual radionuclide concentrations	mSv/a		H	≤ 0.04	≤ 0.1

"Concern" refers to impact if the limit is transgressed: H = health concern; O = organoleptic effect;
I = effect on infrastructure, structural; E = aesthetic effect
* Based on a viral cell culture-dependent method and not on cell culture-independent methods (e.g. PCR)
** Indicative of faecal pollution having occurred, even when the residual disinfectant levels are safe.
*** Comply with SANAS Guidelines

Table 2: Standards for Microbiological and Biological Requirements

MICROBIOLOGICAL REQUIREMENTS APPLICABLE TO ALL POTABLE WATER					
Microbiology	**cfu**			**95 percentile**	**1 of samples maximum**
Heterotrophic bacteria HPC or TCC	counts	/ml		100	1 000
Total Coliform	counts	/100 ml	H	0	5

E.Coli	counts	/100 ml	H	0	1
Entrerococci	counts	/100 ml	H	0	1
Somatic Coliphage	counts	/100 ml	H	0	1
Clostridium perfrigens inclusive spores	counts	/100 ml	H	0	1
Enteric viruses	viral count*	/10 L	H	0	1
Parasites (Protozoa) applicable to all potable water				95 percentile	99 percentile
Giardia lamblia	cysts	/100 litre	H	0	1
Cryptosporidium	oocysts	/100 litre	H	0	1
Giardia lamblia and Giardia lamblia (Grab sample)	cysts or oocysts	/10 L	H	0	0

Table 3: Special Requirements for the Protection of Infrastructure

Specifications for water quality intended for human consumption from the source and piped water supply for the protection of infrastructure against corrosion					
Status				Ranges and upper limits	
Interpretation				(Ideal guideline)	(Acceptable Standard)
DETERMINANTS	Unit	Format	Concern	95 Percentile requirement	
CORROSIVE AND SCALING PROPERTIES (treated surface water)					
Calcium Carbonate Precipitation Potential	mg/litre	CCPP	I	4 - 5	1 - 6
Alkalinity/Sulphate/ Chloride Ratio	Equi-valents	Corrosivety Ratio	I	With SO_4 and Cl above 50 mg/litre Ratio=(Alk/50)/(SO_4/48+Cl/35.5) > 5.0 Water is Stable Ratio= (SO_4/48+Cl/35.5)/(Alk/50) > 0.2 Water is Corrosive	
Total Hardness (Ca & Mg)	mg/litre	$CaCO_3$	I	<200	< 400
CORROSIVE AND SCALING PROPERTIES (ground water)					
Calcium Carbonate Precipitation Potential	mg/litre	CCPP	I	4 - 5	3 - 15
Alkalinity/Sulphate/ Chloride Ratio	Equi-valents	Corrosivety Ratio	I	With SO_4 and Cl above 50 mg/litre Ratio=(Alk/50)/(SO_4/48+Cl/35.5) > 5.0 Water is Stable Ratio= (SO_4/48+Cl/35.5)/(Alk/50) > 0.2 Water is Corrosive	
Total Hardness (Ca & Mg)	mg/litre	$CaCO_3$	I	<400	< 1000

Table 4: Frequency of Microbiological Monitoring (including Turbidity values) for Water Supply and Distribution

Size of population served	Turbidity 95%**	Frequency of sampling
> 250 000	< 0,5 NTU	**Thrice weekly *** **
100 001 – 250 000	< 1,0 NTU	**Twice weekly**
50 001 – 100 000	< 1,0 NTU	**Once weekly**
10 001 – 50 000	< 1,0 NTU	**Three times every month**
< 10 000 reticulated	< 1,0 NTU	**Once every 1 month***
< 10 000 non-reticulated	**1 – 2 NTU**	**Once every 1 month***

* Upon complaints by the consumers or of medical practitioners and after incidents such as pipe breaks, the frequency should be increased until the situation has returned to original counts and been declared safe;
** Average or 95 percentile turbidity of the water supplied
*** The frequency should be stepped up by one extra sampling per week for every 100 000 residents (including the estimated number of visitors residing within

General Information

1. The area being monitored shall be defined by the Minister in consultation with the Minister responsible for health and, where applicable, relevant officials from the Regional and Local Authorities;
2. At the time of sampling the operator shall also take a "free chlorine" reading of the same water under examination but prior to sampling for microbiological sampling, whilst using a portable device designed for that purpose and accepted by the Minister; this 'reading' is to be recorded and reported together with the results from the microbiological analyses;
3. As for field 'screening' of water supplies for microbiological contamination there exist portable devices designed for that purpose and accepted by the Minister; these 'readings' are to be recorded and reported together with the results from the microbiological analyses;
4. The results of the microbiological monitoring together with the free chlorine readings is to be reported as per mutual agreement to the ultimate supplier (bulk water supplier, Local Authority, or any other supplier) for remedial action where required, and to the Minister for record and monitoring purposes and follow up actions;
5. The costs of routine monitoring shall be borne by the authority commissioning the monitoring;
6. The US-EPA 2012 (update) Drinking Water Standards and Health Advisories shall be used to prescribe the maximum disinfection dosages when deemed necessary by the Minister.
7. Biological monitoring of invertebrates shall be conducted using the NASS method as prescribed in the guidelines by the Minister.

Methodology for Sampling and Analyses

The methodologies followed for sampling and during transit and storage of samples prior to analysis shall be as prescribed.
1. Preferably samples are to be taken in borosilicate glass bottles with a glass or polypropylene screw-cap lid;
2. Where this is not feasible or practical polyethylene bottles with internal seal and with screw-lid can be used;
3. Samples shall, as far as practical, be analysed within 24 hours of sampling;
4. Where there are special requirements for the period between sampling and analysis to be less than 24 hours, such requirement should be attended to as far as is practical;
5. Samples are to be kept and stored, even during transit, at as low a temperature as is practically manageable, whilst preventing the risk of the sample freezing;

6. The sample shall be kept away from light and shielded from sunlight, to reduce chances of micro-/biological growth to a minimum;
7. The use of preservation chemicals should be considered, planned and executed with extreme care;
8. Where sample preservation is appropriate or required an extra smaller volume sample should be taken so as to not upset any other analyses that are affected by the preservation chemical(s);
9. Certain determinants may be monitored 'in the field' at the time of sampling; such field-data are to be measured in a receptacle or container different from the sample container; data so obtained shall be recorded as "field measurement" and cannot replace laboratory analysis for the parameters concerned;
10. The methodologies followed for physical, chemical and microbiological analysis shall be in agreement with the specifications listed in the latest edition of the SANS 241, Drinking Water Standards, published by the SABS.
11. The cost of routine, regulatory inspections and monitoring, for the purpose of fulfilling the provisions of this regulation shall borne by the service provider.