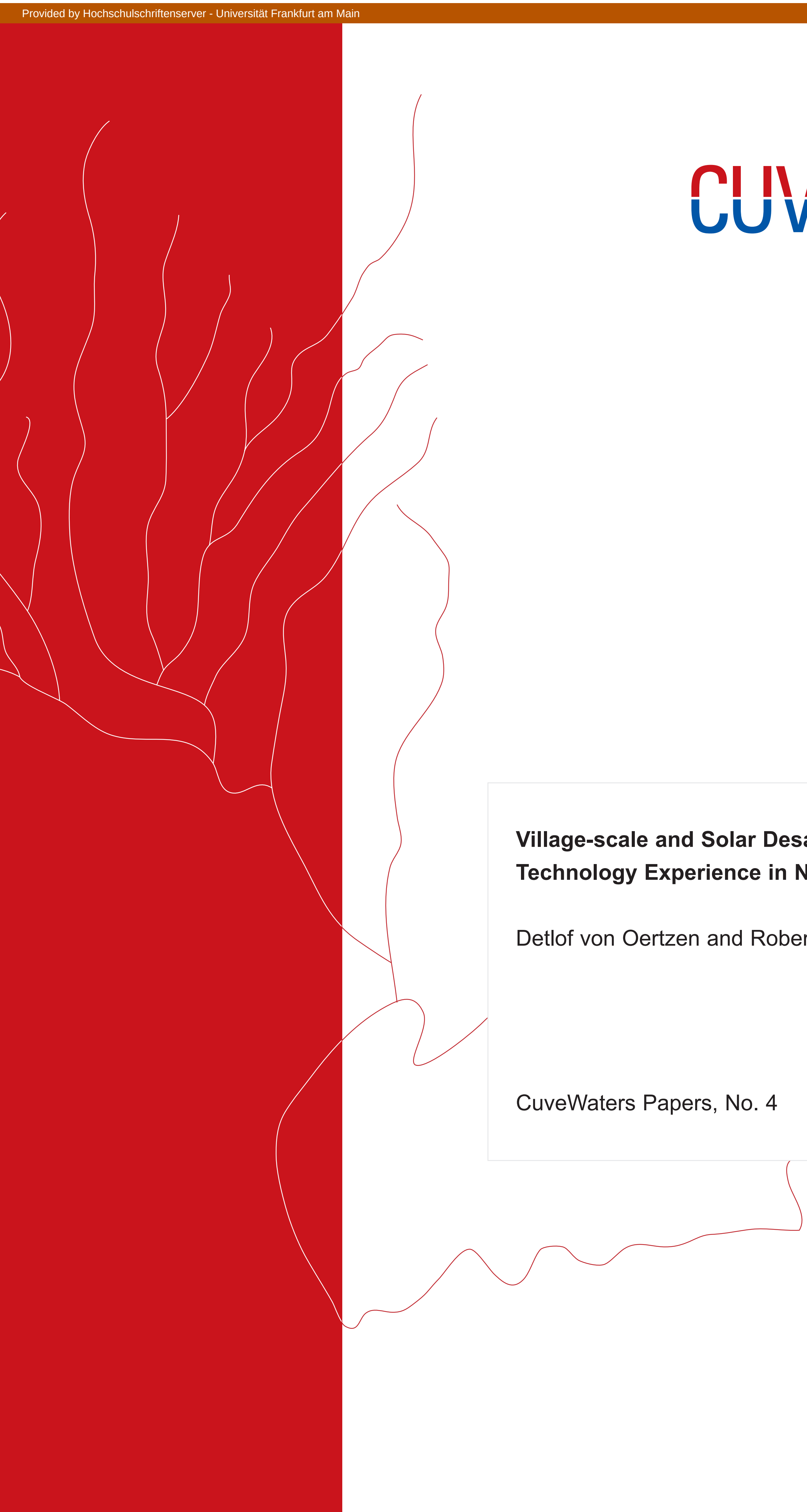

Village-scale and Solar Desalination Technology Experience in Namibia

Detlof von Oertzen and Robert Schultz

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1 Background

Access to sufficient quantities of affordable and safe drinking water is a key to the long-term sustainable development of Namibia. In northern Namibia in particular, where potable water resources are scarce and population densities are high, there is a considerable need to increase and diversify the supply of water sources supplying drinking water for human and animal consumption at different levels of appropriate quality. Here, desalination of groundwater with high total dissolved solids content offers some opportunities to use local water resources. This in turn may lead to a greater independence from the water of the Kunene (and possible future importation of Okavango river water via pipelines) into the Cuvelai basin and the extensive piped water systems currently used there.

Current desalination technologies range from those found in survival kits for yachts, producing from a few hundred millilitres to a few litres per day, to large-scale treatment facilities that serve the needs of entire cities. This briefing paper only focuses on small desalination plants that have been or are used for village-scale water provision in Namibia. The paper’s main purpose is to highlight the challenges that need to be addressed before village-scale desalination technologies can be introduced on a larger scale in rural Namibia. The integration into national policies, pricing of water infrastructure and associated water tariffs are however not discussed here.

The paper is structured as follows: the introduction provides some notes on the most common desalination technologies suitable for small to medium-scale desalination which could be of interest to future village-level desalination plants. Then, some past and present Namibian desalination examples are discussed, focusing on the actual experiences in small-scale desalination in Namibia. The paper furthermore identifies the critical issues and aspects that need to be considered for the further introduction and dissemination of desalination systems in rural Namibia. The paper concludes with a summary of the critical issues and some suggestions to be considered when planning for the introduction of such plant in Namibia.

2 Introduction

The process of desalination involves the use of energy to separate pure water from the total dissolved solids (chemical constituents) of brackish or saline feed water. The wastewater output of a desalination process, i.e. the brine, is characterised by a high concentration of total dissolved solids, and has to be properly disposed of in order not to contaminate the feed water source or the environment. In northern Namibia, where considerable quantities of brackish or saline groundwater resources exist, various options for the disposal of brine are available, including the storage in evaporation ponds, and the re-injection into shallow underground water-bearing layers, provided that source water will not be contaminated with the brine. Disposal methods are often site-specific and every disposal method has its unique requirements and associated costs.

Water in Namibia is classified according to the concentration of total dissolved solids (TDS) and the concentration of certain harmful chemical constituents (such as sulphate, fluoride and nitrate), measured in milligrams per litre, or abbreviated mg/ℓ, or grams per litre, g/ℓ. Due to the fact that 70% of the potable water used in Namibia comes from groundwater, the Namibian Government adopted water quality guidelines that take cognisance of the generally elevated levels of salinity experienced in arid climatic conditions, and classifies water into one of four classes. Water is considered fit for human consumption if it is either Class A or Class B water. Class C water will have certain health implications, and Class D water is considered unfit for human consumption. The TDS of the groundwater resources in central northern Namibia, and in particular in the Cuvelai Basin, have very high TDS values, and in some cases up to 95 g/ℓ (according to hydro-chemical analyses in Oponona and Uuvudhiya), while sea water used as feed water in coastal desalination plants has TDS values in the range of 30 to 36 g/ℓ [Sommer, 1997].

Desalination is an energy-dependent process, the overall efficiency being a function of the concentration of dissolved solids in the water, the technology employed, and the size and design of the plant. Different energy sources and combinations thereof can be used to drive a desalination process, and are chosen depending on the availability and affordability of heat and electricity sources. The natural presence of heat, e.g. as in the case when solar technologies are used, or when waste heat is available from industrial processes, can hold considerable cost and input advantages in a desalination process.

As can be expected in Namibia, which has an excellent solar regime, the use of the free solar resource to drive a desalination process is of great interest. This is particularly so as the use of renewable energy sources in general, and specifically the use of solar energy, holds few environmental risks and is abundantly available throughout rural Namibia. However, although the resource is for free, the technologies that utilise solar energy are not. Also, many renewable energy technology-powered desalination devices are less efficient than those powered otherwise. Presently, in the absence of targeted capital cost subsidies supporting the use of renewable energy technologies for desalination, the high upfront capital costs of such technologies and resultant high unit costs are a main barrier limiting the larger-scale rollout of such plant in many rural areas throughout the developing world.

2.1 Overview of Desalination Technologies

The following short summaries present an overview of some of the more common desalination technologies considered suitable for village-scale application [Leitner, 1992; Green, 2001; Commonwealth Science Council, 1999; Kennedy et al., 2001]. A recent overview of desalination technologies suitable for the desalination of sea and brackish water, also presenting some of the newer developments in solar desalination technologies, has been brought to the attention of the authors following the drafting of this paper [Sturm, undated].

Distillation is the boiling of saline water and condensing the vapour to produce potable water [Buros, 2000]. The process requires thermal energy to generate steam, which is then condensed into pure water. Efficient distillation processes use parts of the heat recovered in the condensation of steam to pre-heat and produce more steam. Of note is the scaling up (i.e. the formation of deposits of calcium carbonate and magnesium hydroxide) occurring in distillation processes, which can severely limit the efficiency of distillation technologies [Teplitz-Sembitzky, 2000].

Many desalination processes using porous membranes rely on the physical properties of specific membranes that permit some substances to pass freely through them while blocking the path of others. A particular and well-used process using membranes is **reverse osmosis** [Buros, 2000], which is based on reversing the principle of osmosis, whereby water diffuses through the membrane to dilute the salty feed water as if under a pressure. This is the osmotic pressure, which is a function of the temperature and the concentration of the salt content. By applying pressure on the feed water the process is reversed, and benefits from having large surface areas of membranes and sustaining a large pressure on the feed water side. Figure 1 shows a schematic of a reverse osmosis process.

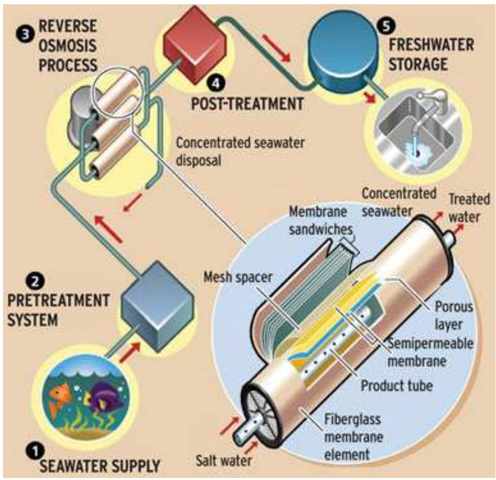


Figure 1: Schematic of a reverse osmosis process [Australian Water Association, 2008]

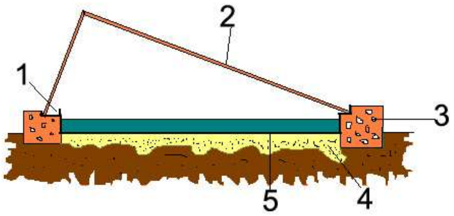
Membranes are *the* critical component in reverse osmosis desalination, and have to be kept clean. This procedure often requires the pre-treatment of feed water, e.g. by way of water softening, the removal of substances that may clog the membranes using filtration, and the regular use of chemicals to clean the membranes.

Reverse osmosis requires electrical energy, which can be provided by fossil fuels or renewable energy sources, depending on the cost and supply characteristics at the site. Figure 2 shows an example of a solar photovoltaic operated reverse osmosis plant in Tunisia.

Figure 2: 10.5 kWp solar electricity-operated reverse osmosis of brackish water in Tunisia with a fresh water output of 15 m³/day [WISIONS, 2008]

As the energy required to obtain desalted water is in parts dependent on the quantity of solids that need to be removed from the saline water, reverse osmosis is often considered to be more efficient in moderately contaminated brackish water.

Solar stills use solar radiation to heat the saline water, mostly in a bath or basin covered with a transparent glass or plastic top [see for example Scharl and Haars, 1993; Heber, 1985; McCracken et al., 1985]. The heat of the sun produces water vapour in the still, which condenses on the underside of the glass or perspex cover, and is channelled into a fresh water collection area. The evaporation temperature is dependent on the water temperature and the relative humidity of the space above the water. A great variety of solar stills have been designed and tested, the most common and economical is the single-basin single-stage design depicted in Figure 3 below.



Legend:

1 – lip channel
2 – glass / perspex cover
3 – containment
4 – foundation
5 – feed water reservoir

Figure 3: Simple single-basin single-stage solar still

Figure 4 shows the expected fresh water yield in litres per day per square metre of solar still area exposed to the sun, and indicates that most localities in Namibia can expect to harvest approximately 1.3 m^3/m^2/year. Regarding design and maintenance, solar stills are generally simple to operate and can be automated to some degree. An additional strength of solar stills is their simple design and the low technical skills level required to operate them, which make them suitable for decentralized applications provided their generally low yields satisfy the local fresh water requirements.

Solar stills can be operated in a hybrid mode, whereby solar radiation and energy provided by fossil or other fuels can be used in combination to achieve the evaporation of saline water, which would render them suitable for operations beyond the daily sun shine periods. Sommer [1997] finds that the cost of water from stills producing 3m^3/day or less is typically in the range of US$ 5/m^3 to US$ 25/m^3 (N$ 38/m^3 to N$ 190/m^3, [1]) when averaged over the life of the still, which is substantially more than what is currently paid by most Namibians for water (about N$ 6.25/m^3 in 2007/08).

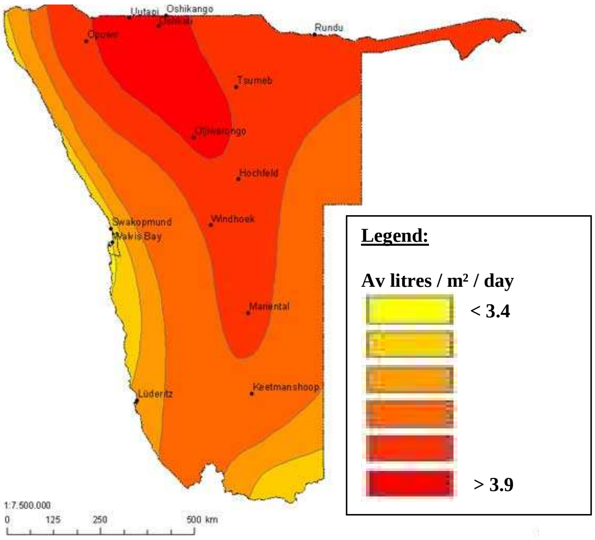


Figure 4: Daily average per square meter yield of a single-stage solar still, in litres/m²/day, assuming a still efficiency of 40%, based on average Namibian insolation data [von Oertzen, 1999]

Multistage flash (MSF) [Acwa Sasakura, 2002] distillation is a process in which heated feed water is turned into vapour (i.e. flashed) in a series of separate stages (refer to Figure 5). While the vapour is condensed and channelled into a fresh water containment, the heat generated during the condensing process is used to pre-heat additional feed water. Excess feed water that has

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[1] Using an exchange rate of 1 US$ = N$ 7.60 as at May 2008

not flashed in one stage is channelled to the next stage, at increased total dissolved solids content. The particular design of an MSF plant will determine the number of stages that are used, and determine the overall efficiency of the process. Generally, a large number of stages will enhance the overall process efficiency, but is more capital and maintenance intensive. The formation of residues, i.e. the formation of scale, is a particular challenge for MSF plants, and requires the careful pretreatment of feed water as well as regular plant maintenance. MSF plants can be considered complex, and require skilled operators. Similar to solar stills, MSF plants require a source of dependable heat, which can be provided by solar and/or fossil fuels, and/or the use of industrial waste heat.

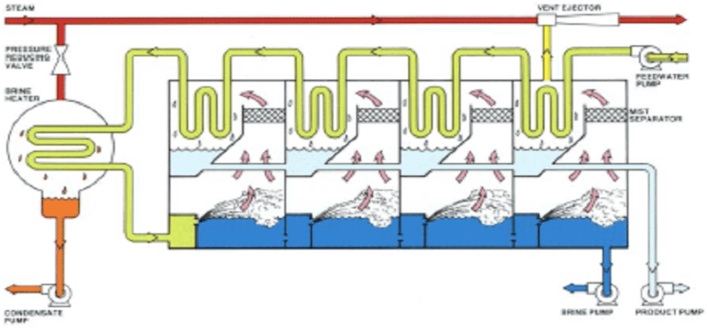

Figure 5: Schematic of a multistage flash distillation process [Acwa Sasakura, 2002]

Multiple effect distillation (MED) uses the steam produced by a boiler to successively heat feed water in a series of steps, which are called 'effects' [Halcrow Water Services]. Similar to the MSF process described above, each successive effect operates at a lower temperature and pressure to cause further vaporisation, and a portion of the feed water vaporises in each effect while the remainder goes to the next effect. The formation of process residues is, just as in the MSF case, an issue to be avoided or minimised, and the operation of MED plants require ongoing technical and operational capacity. MED plants also require a source of dependable heat, which can be provided by solar and/or fossil fuels, or the use of industrial waste heat.

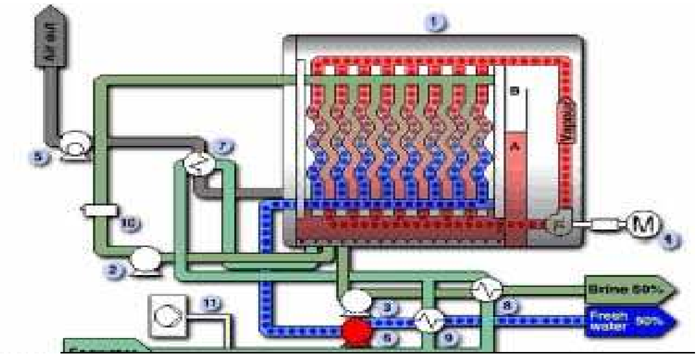

Figure 6: Mechanical Vapour Compression Multi-effects System [Thrane, 2002]

Vapour compression (VC) [Thrane, 2002] distillation uses one or several compressors to compress water vapour, as depicted in Figure 6. The high-pressure vapour is then condensed to produce drinking water, while the heat released is used to further vaporise feed water. Unlike the other desalination processes described above, vapour compression does not require the presence of a heat source, and can be operated using only electrical or mechanical energy, which can be provided by using fossil fuel based generators or renewable energy sources. VC is considered a simple process, and has low operating and maintenance requirements, which makes it suitable for some rural applications.

The **freezing method** uses the process of crystallisation, which occurs when feed water is cooled to its freezing point (a process mostly achieved through inducing evaporation by lowering atmospheric pressure to a near vacuum) and allowed to form crystallites of pure water surrounded by brine [Wipplinger, 1963]. An advantage of this method is that there is no scaling. However, a part of the fresh water produced is used to “wash” the brine off the fresh water crystals, which impacts negatively on the overall efficiency of a freezing desalination plant. The freezing process has a smaller energy requirement per unit volume of water produced than the heating process required in other desalination processes. A number of technical challenges remain, particularly ensuring that a 99.5% vacuum can be maintained in the vacuum chamber.

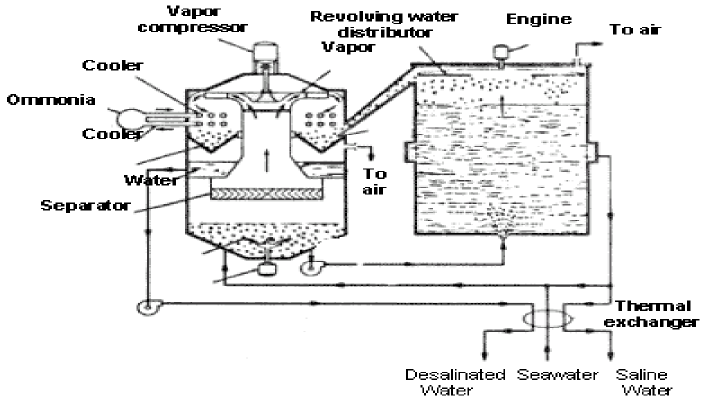

Figure 7: Schematic of freeze-desalination unit [UNEP, 2000]

Submerged tube evaporators are an old technology that was deployed mostly during the late 19th to early 20th century [Wipplinger, 1963]. Sea water was boiled by steam heated tubes in successive boiling chambers, while condensation was achieved with the aid of sea water which entered the condenser at a high flow rate. This system also used multiple stages (usually a standard 6 stages) or effects, where each effect comprised a chamber at successively reduced atmospheric pressure. Pressure reduction was achieved by air ejector pumps. Scale formation was significant, and apparently resulted in high maintenance costs and complex operational requirements.

Chemical desalination is accomplished by mixing chemical reagents which interact with the salts in the feed water to form compounds which can be readily separated [Berg, 1997]. An example is an ion exchanger, which is a porous bed of resin materials that have the ability to exchange ions in the resins with the solution which is in contact with the resin.

A host of other desalination and distillation technologies exist; many however have not been trialled under field conditions and/or have not yet found a commercially viable applications or markets. These technologies include photovoltaic-powered reverse osmosis, electro dialysis, membrane distillation and microwave distillation. For the purposes of this paper, these technologies are not considered in any further detail. The authors also do not discuss other methods to collect water for domestic use, although relevant [Hasse, 1989].

In conclusion to this section, it is emphasised that site-specific considerations, including the availability of skilled labour, the availability and cost of land, the cost of feed water, the cost and long-term environmental suitability of disposing brine, the availability of one or several inexpensive sources of heat, the availability of cheap power sources, the reliability of fuel supplies, and logistical considerations for operations and regular maintenance are among a host of factors that have a considerable influence on the eventual choice of a desalination technology. Section 3 below raises these and similar considerations that need to be taken into account before a particular technology choice should be made.

3 Namibian Village-scale Desalination Systems

3.1 Historical Plants

3.1.1 Lüderitz

Sea water desalination was introduced in Lüderitz in 1897, using a submerged tube evaporator condensing plant [Wipplinger, 1963]. Prior to this the reception of this plant, fresh water had been imported, mostly by ship from Cape Town. Since coal was the thermal energy source, the tube evaporator plant and subsequent plants built in 1906 and 1912, were closely integrated with the operation of the railway system, and were managed by the railway authorities.

In 1914, the South African military authorities established a 6-effect submerged tube evaporator with a capacity of about 150 m³/day, coupled to 600 m³ storage reservoirs for distilled water. The South African Railways took over the plant and operated it until the 1941, when it was replaced by a similar plant. In 1954, the Lüderitz Municipality completed a coal-fired power station with an adjoining 200 m³/day tubular evaporator plant. Water supply to the town was thus no longer the responsibility of the railway administration, and by 1962, diesel fuel had replaced coal as transportation fuel [Wipplinger, 1963].

In 1962, the Municipality added a 24-stage multistage flash plant with a capacity to produce some 550 m³/day. Unlike the earlier plants, the latter two were not independent units, but worked in conjunction with the Lüderitz power station. Water consumption in Lüderitz in 1962 was 70,000 m³, and both plants jointly had a capacity of 225,000 m³ (300 days per annum). The excess fresh water supply meant that the 1962 plant operated below capacity, and thus below cost effectiveness, which prompted the Municipality to put measures in place to increase the water consumption of residents and industry. Today, Lüderitz drinking water is supplied from an aquifer, piped from the Koichab Pan some 120 km inland.

3.1.2 Walvis Bay

The municipality of Walvis Bay initiated an investigation into the desalination of sea and brackish aquifer water in the early 1990s [Botha, 1991]. The investigation only considered a reverse osmosis plant with a capacity of 5,000 m³/day, and focused primarily on the financial feasibility of the approach. The study sites included brackish water with a TDS content of about 1.4 g/ℓ from the Kuiseb aquifer, as well as sea water from Walvis Bay. The different TDS concentrations resulted in conversion factors of 75% and 40% respectively, which had a significant impact on the cost per unit of fresh water produced. In the case of brackish water, the unit fresh water cost was N$ 1.46/m³, while for sea water the 1990 cost would have been N$ 4.48/m³ [Botha, 1991]. The feasibility assessment revealed that labour costs for the operations of the plants were considerable, and it was recommended that automation be considered to improve the prospects of operating the plants on a more sustainable basis.

Both plants were envisaged to be operated using grid electricity, and given the low electricity tariffs at the time, no concerns were raised regarding the cost of energy. The investigation estimated an electricity consumption of 1.5 kWh/m³ of fresh water produced. At a plant capacity of 5,000 m³/day, this would have resulted in a daily electricity consumption of 7.5 MWh, which is the equivalent daily consumption of over 260 average high-income urban households or over 500 average low-income households in Namibia in the late 1990s [MME, 1999]. Both plants were regarded as financially unfeasible, and the investigation concluded that “serious attention should be given to the possibility of delaying the introduction of desalination for as long as possible" [Botha, 1991].

3.1.3 Okashana Trials

In 1998, the Center for Solar Energy and Hydrogen Research (ZSW) assisted the Department of Water Affairs with the installation, operation and performance evaluation of two solar thermal desalination systems using brackish water, with a TDS of 14 g/ℓ, in trials that took place at Okashana in northern Namibia [ZSW, 1998; Stöck, 2004].

One system was a TAS GOR/ME 30 solar plant from the Munich-based company TAS, while the other was an Aquasolar LTD-17 from the Bremerhaven-based company Aquasolar. Both systems used the process of distillation by evaporation and condensation. The Aquasolar system (see Figure 8 and Figure 9) used flat plate collectors and a single pass flow of brine through the system, while the TAS system used vacuum tubes, and re-circulated the brine (see Figure 10). Both systems were operated from March until November 1998, and the ZSW report states that the trials recorded some 90 days of actual performance for each system using only solar radiation as energy source as well as for a few days on 24-hour cycles with heat recovery from a generator set.

Figure 8: Aquasolar Flat Solar Collector Panels [Stöck, 2004]

For the Aquasolar, the ZSW report concludes that

- the desalination process is expected to perform satisfactorily if the brine flow is properly controlled
- the system is suitable for 24-hour operations from a constant heat source
- all system components could be designed and manufactured in Namibia
- the thermal performance and distillate production did not reach the manufacturer's predictions
- the control of brine circulation and process temperature did not work as envisaged
- the quality of the collectors was insufficient for harsh field operating conditions, and
- that the investment cost for the system was considered high.

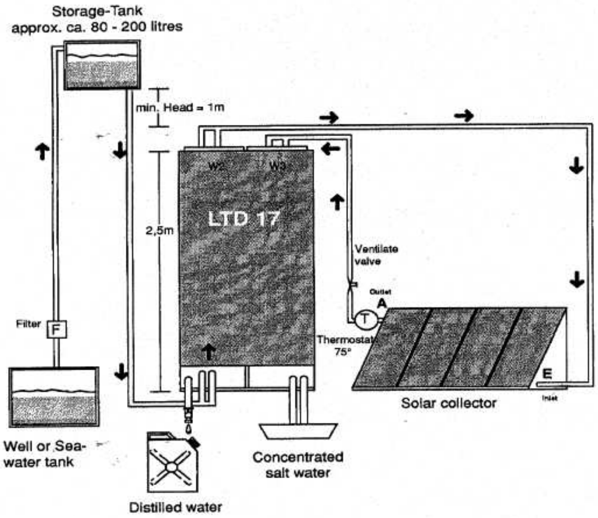

Figure 9: Schematic of the Aquasolar LTD-17 system [Stöck, 2004]

For the TAS, the ZSW report concludes that

- the thermal performance of the distillation process was found to be good, while that of the vacuum tube collector was acceptable
- the system was suitable for stationery 24-hour operations from a constant heat source
- the system components, with the exception of the vacuum tube collectors and pumps, could be designed and constructed in Namibia
- the electronic brine circulation control was unreliable
- the quality of the vacuum tubes was unsatisfactory for harsh field operating conditions, and
- that the investment cost for the system was too high.

Figure 10: Broken vacuum tubes of TAS solar panel after a hail storm [Stöck, 2004]

Overall, the ZSW report concludes that

- the levelised water cost[2] (LWC) [Fane, 2003] for the TAS and Aquasolar operating on a 24-hour basis are at N$ 270/m³ and N$ 283/m³ respectively[3]
- on a solar-only operation, the LWC is N$ 1,144/m³ (89€/m³) for the Aquasolar and N$ 964/m³ (75€/m³) for the TAS[4]
- the costs of the solar-only option are too high to be charged to customers in rural areas, and
- that considerable cost savings would be achieved if components of the stills would be produced in Namibia.

Figure 11 below displays the various LWCs, and compares this to that of a solar still.

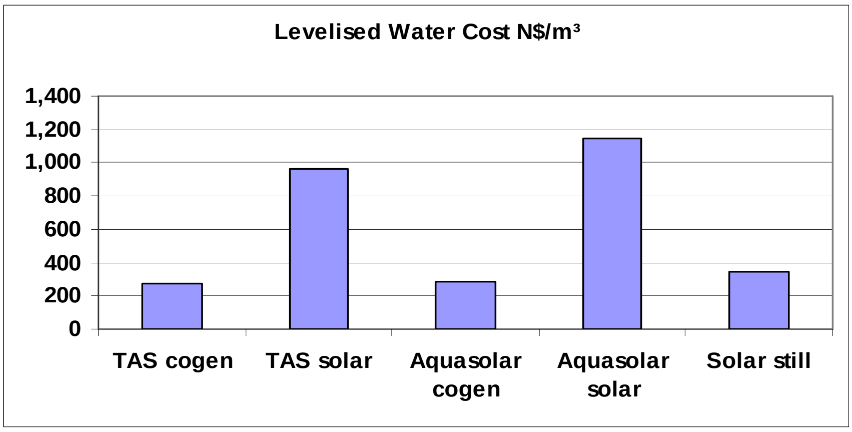

Figure 11: Levelised water cost in the Okashana trials

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[2] The levelised water cost is based on the life cycle cost of procuring, operating and maintaining the system divided by the total quantity of distillate produced over the system's life.

[3] The report states a cost of 21€/m³ and 22€/m³, at an exchange rate of 1 € = N$ 12.85 in April 2008.

[4] Using an exchange rate of 1 € = N$ 12.85 as at April 2008.

Both systems produced good quality water, at a rate of between 30 (Aquasolar) and about 100 litres (TAS) per day, using only solar radiation. A combination of both systems, particularly the distillation system of the TAS and improved flat plate collectors of the Aquasol, could improve the cost effectiveness and reliability, while local manufacture could reduce cost by as much as 40% of the imported product [Stöck, 2004]. Ultimately though, the successful implementation of any treatment system in remote areas will depend greatly on the careful and responsible operation and monitoring of these systems by the local community, which will be discussed in further details in section 4 below.

3.2 Desalination Plants Currently in Operation

This section provides a brief overview of some of the desalination plants currently in operation in Namibia. Some plants, such as the one at Spitzkoppe run by NamWater, and the Nauchab plant run by the Directorate of Rural Water Supply have not been described here because of a scarcity of reliable performance records and related information.

3.2.1 Namdeb Reverse Osmosis Plant

The Namdeb plant [Lempert, 2008] at Bogenfels is an electrically powered reverse osmosis desalination plant using sea water; it has a design capacity of 25m³/day, and is in daily operation. Table 1 and Table 2 below summarise other technical details, while operating experiences are discussed in greater detail in Section 4.

3.2.2 Valencia Reverse Osmosis Plant

An electrical reverse osmosis plant using brackish borehole water with a design capacity of 5m³/day on 12 hours/day is installed at the Valencia mine exploration site [Lempert, 2008], and is in daily operation. Table 1 and Table 2 below summarise other technical details.

3.2.3 Reverse Osmosis Farm Plants

Two reverse osmosis plants for farmers are located in the vicinity of Aranos, using brackish ground water as feed water. One of which is powered by electricity from the national grid, while the other is powered from on-site diesel generators. They operate for 10–12 hours/day to produce fresh water for 8–10 hours/day [Lempert, 2008]. Table 1 and Table 2 below summarise other technical details.

3.2.4 Toscanini Mine

The reverse osmosis desalination plant at the Toscanini mine on the coast of north-western Namibia supplies water for some limited mining operations, using sea water as feed water [Lempert, 2008]. At an output capacity of 120 ℓ/h, this is a very small plant, and the water is only used to provide drinking water to mine personnel. Due to the non-continuous operation of the plant, and infrequent maintenance, the plant scaled up easily, a problem that was overcome when a service provider made some anti-scaling dosing and adjusted the operating pH, after which the plant operated fine. It was noticed that basic maintenance routines, e.g. flushing the membranes with fresh water before the plant is switched off, were previously not followed, leading to membrane failures.

This plant illustrates the importance of having reliable backup and service arrangements in place to ensure the plant's continuous operation. This is particular true for far-away plants in rural areas, where little or no local know-how and spare parts are available. Here, a service contract ensuring that regular maintenance is undertaken is essential, and should – in case of a reverse osmosis plant – include the regular chemical cleaning of the membranes. To be effective, the interval of such maintenance needs to be adjusted with the salinity of the feed water. Here, as a rule of thumb, using brackish feed water necessitates the cleaning of membranes every 3 to 6 months, while using sea water as feed water necessitates that membranes be cleaned every 3 to 4 weeks.

Table 1: Summary of technical specifications of some small-scale desalination plants currently operating in Namibia

	Namdeb Bogenfels	*Valencia exploration*	*Farm Rykerhof*	*Farm Steenkamp*	*Toscanini mine*
Capacity in [ℓ/h]	4,100	1,500	1,000	2,200	500
Capacity out [ℓ/h]	1,200	750	600	1,400	120
Feed water	Sea	Brackish	Brackish	Brackish	Sea
Salinity range [g/ℓ]	35–38	12–22	8–12	10–14	35–38
Power source	Genset	Genset	Diesel pump	NamPower	Genset
Power requ. [kW]	15	5.5	2.2	4.5	2.2
Capital cost [x 1000 N$]	800	340	180	320	85
Operation (24/7 = continuous; d/w = days per week)	24/7	2–4 d/w	1 d/w	2 d/w	2 d/w
Operating pressure [bar]	60	40	35	35	60
Operating cost[5] [N$/m³]	11.70	6.80	4.85	3.90	18.40

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[5] Operating costs: these costs only include power and chemicals for maintenance, while capital recovery and labour are not included.

Table 2: Summary of issues of some small-scale desalination plants currently operating in Namibia

	Namdeb Bogenfels	*Valencia exploration*	*Farm Rykerhof*	*Farm Steenkamp*	*Toscanini mine*
Ownership	Mining company	Mining company	Private	Private	Mining company
User needs and expectations	Sized to technical specs of engineers	Sized to momentary requirement as interim solution	Satisfies needs of owner	Satisfies needs of owner	Sized to momentary requirement as interim solution
Technical capacity	Substantial in-house engineering and technical capacity	Some in-house engineering and technical capacity	Some technical capacity	Some technical capacity	Some in-house engineering and technical capacity
Maintenance	In principle good, in practise (staff retention) unsatisfactory	Good, with dedicated operator and service contract with specialist supplier	Good, with dedicated manager and service contract with specialist supplier	Good, with dedicated manager and service contract with specialist supplier	Improved once a service contract with specialist supplier was entered into
Energy requirements	Genset	Genset	Diesel pump	NamPower	Genset
Ease of relocation	Possible: minor civil works and plumbing required	Possible: minor civil works and plumbing required	Possible: minor civil works and plumbing required	Possible: minor civil works and plumbing required	Possible: minor civil works and plumbing required
Institutional arrangement	Operated by owner	Operated by owner	Operated by owner	Operated by owner	Operated by owner
Security	Good, and part of wider security arrangements at the mine	Good, and part of wider security arrangements at the mine	Good, as part of farm security arrangements	Good, as part of farm security arrangements	Good, and part of wider security arrangements at the mine
Costs	Borne by owner and competitive with alternative on-site arrangements	Borne by owner and competitive with alternative on-site arrangements	Borne by owner and competitive with alternative on-site arrangements	Borne by owner and competitive with alternative on-site arrangements	Borne by owner and competitive with alternative on-site arrangements

4 Critical Village-scale Implementation Issues

The assessment of the experiences with small-scale desalination plants in Namibia, and the operation of similar stand-alone technologies in rural Namibia and in other developing countries allows the identification of critical pre-implementation issues. Such issues, when adequately addressed, will pave the way for the smooth operation of such plant, and can potentially save considerable funds and reduce the frustration of users, operators, owners and suppliers.

4.1 Ownership

As future village-scale plants are most likely sited in remote areas, the question of who owns the plant and is, by implication, responsible for its operation and upkeep, needs to be addressed well before the plant is commissioned. While this aspect may appear straightforward, in practice it is not. Ambiguities can easily arise, and non-specific arrangements regarding the ownership and responsibility for maintenance have caused numerous stand-alone plants to cease operating.

Of interest could be recent trends followed in large-scale desalination facilities, that have seen developers become the “build, operate, and own” agents [Buros, 2000]. The advantage of such arrangements is that it shifts the responsibility for choosing particular desalination technologies to the developer/owner, since they are responsible for plant design and subsequent operation, and their profitability.

Similar arrangements may, in future, be possible between local or regional authorities, and contractors. Alternatively, arrangements similar to those used in Namibian water point committees could be explored, but will hinge on the ability of such joint ownership arrangements to mobilise sufficient capital, meeting operating costs (through payment of water tariffs) and staff to operate and maintain the plant when it is required.

4.2 User needs and expectations

Although not an exact science, understanding and incorporating the user needs and expectations into the design of a desalination system is essential. Key activities, to be undertaken during the scoping and pre-design phase of the plant, should include

- Understanding user needs and water use priorities
- Ensuring that the solution/design, as well as the upfront and ongoing system costs are understood, affordable and accepted by the beneficiaries
- Communicating and having regular exchanges with system users and beneficiaries
- Building the required local organisational and managerial capacity

A participative process, initiated early on during the pre-design phase, can ensure community buy-in, which is essential to the successful operation of the plant. The capacity of the local communities to understand the technology and the implications should also be taken into consideration when the technology is discussed with the community. This is best understood as an ongoing commitment to communicate with users, to ensure that buy-in and the resulting “ownership” remains in place over the life of the plant. In particular, sufficient local knowledge and understanding of the capabilities and limitations of the plant needs to be built. In rural Namibia, expectations with regard to water provision for cattle and other livestock, and the cost associated with the provision of water remain critical, and need ongoing moderation.

Many of these issues that may arise during user consultations may neither be formal nor predictable – they require some flexibility and time in order to consolidate the buy-in of the community into the new water provision service arrangement. Here, the presence of a local champion that is recognised and respected by the user group could be important. If community trust is to be maintained, clear and appropriate feedback mechanisms need to be in place, ensuring that all stakeholders are informed of the status of the plant, understand their responsibilities and rights, system limitations and costs, and other non-water related implications that arise when a water provision system is introduced.

4.3 Technical capacity – training and staff retention

The availability of reliable technical capacity to support the implemented technology, at the managerial, operational and service provider level, is mission critical, as recurring maintenance and occasional system failures are likely. If this capacity is not present, it needs to be built during the implementation. Experience in small-scale desalination plants in Namibia however indicates that the retention of suitably qualified staff, especially those that have acquired new skills, remains a major challenge.

Poor local technical capacity results in the long-term dependence on service providers, or regional/international experts, which in turn results in high costs and potentially long plant downtimes. This time can be bridged by providing reservoirs to store water, but small-scale plants may not have the capacity to keep a reservoir full to bridge a 24 to 48 hour period of downtime while help is on its way. Experience shows that even if competent staff is at hand to run and maintain the equipment, training and ongoing performance management of the staff remains a major shortcoming in many desalination plants currently in operation in Namibia. Lempert [2008] cites the example of a plant that had a contract with his company, including an operator for 4 months. Training was then given to a staff member at the site, who went through the complete training, operation and maintenance cycle in 4 months. Shortly after the finalisation of this training and hand-over process, the newly empowered operator left the company. This incident took place twice in a row. The Client then appointed the service company for regular troubleshooting, and to assist them to operate the plant on their own. Later, the service company was asked to supply an operator, and they now have an operation and maintenance contract with the Client, which has resulted in smooth operations for the past nine months.

The above highlights a broader Namibian problem, namely that of retaining qualified staff. Even within well-established and well-resourced organisations there are often more pressing needs than looking after the ongoing maintenance of specific machinery that is often not viewed as mission critical before it eventually breaks down. Even at sites where operators remain in place for some time, continued service excellence is rare, and operators often neglect to carry out basic maintenance tasks, such as backwashing of filters, chemical clean up and others, which is mostly attributed to an absence of procedural and monitoring guidelines on the one hand, and a missing dedication to good maintenance and service on the other.

4.4 Ongoing maintenance

Most technical plant, irrespective of whether it is a diesel generator or a desalination plant, requires regular maintenance. Such maintenance can be costly, especially when it has to be undertaken by service providers operating far away from the site. This necessitates good planning, careful costing and the technical ability of locals to render at least some first-line services.

An interesting experience, shared by Lempert [2008], highlights the importance of proper technical understanding and related procedures: a client had purchased membranes for a reverse osmosis plant, but did not acquire the right kind of membranes designed for the desired feed water quality and plant throughput. The service company was then called in to rectify the problem, which showed that those in charge of maintenance did not have the required skills to undertake the job, and did not understand that membrane cleaning and/or replacement specifications have to be matched to the feed water quality, and fitted to plant specifications.

For rural communities to benefit from a desalination plant, the requirements imposed by technical complexities of the plant will have to be considered before a plant is finally designed. Proper maintenance training, and ongoing supervision on the one hand, and a reliable service partner that can render more complicated maintenance services on demand on the other, would have to be put in place. Here, the issue of access to the required spare parts, chemicals, tools and know-how in rural areas could favour a longer-term service agreement with a reputable supplier, and ensure that the community's expectations continue to be met. In some cases, the bundling of service activities rendered to several sites in a larger geographic area by an experience service agent may bring about considerable cost benefits as the economies of scale of maintaining the equipment can be realised.

4.5 Energy requirements

The energy supply of a desalination plant merits careful attention. Several energy technologies would be combined when operating such a plant and may include solar, wind or diesel electricity generation for water pumping, solar thermal or cogeneration for evaporation, and possibly electricity-based cooling for condensation. This implies that the plant operator needs a diverse range of technical skills. Maintaining batteries, repairing pump rotors, cleaning pump seals, replacing carbon brushes on electric motors, cleaning and replacing membranes and many more essential tasks might be included in the routine maintenance activities, in addition to maintaining the desalination unit itself. The current care takers of rural water points, as established by the Directorate of Rural Water Supply, do not receive this level of technical training.

Certain energy technologies, particularly solar photovoltaic modules and smaller diesel-powered generators and associated equipment, are vulnerable to theft, and special security precautions need to be in place. In addition, these technologies as well as glassed solar thermal collectors can also be subject to vandalism and occasional natural hazards such has hail storms. A plant operator would be required to take necessary precautions to avoid the loss or damage to these technologies.

4.6 Ease of relocation

Groundwater supply in drylands can be highly erratic, and boreholes can dry up when over-utilised. In addition, even "strong" boreholes are known to fail. Underground water travels through seams and cracks in the bedrock, causing unnoticed erosion. At rapid flow rates, typically caused by excessive abstraction using borehole pumps, cavitation can result, which reduces the stability of the underground water way and borehole. A borehole collapses when the casing fails or if the borehole is not cased, and the geological formation in which it is drilled gives in.

The feed water requirement of a desalination plant should be compatible with the yield of the borehole or boreholes where the feed water is abstracted. If the general permeability of an aquifer is low, more boreholes may be required to extract the required quantity of water. Therefore, the safe yield of a borehole needs to be assessed, which in turn determines the number of boreholes that need to be drilled to supply the desired quantity of feed water.

4.7 Institutional arrangements

The good alignment of the roles and responsibilities between all involved institutions and users serves to ensure that the risks and benefits are allocated appropriately among the stakeholders. Here, broader institutional arrangements need to be harmonised with the wishes, roles and responsibilities of the users. Linkages with Government institutions, service providers and users need to be spelled out, and understood by all participating stakeholders. Feedback mechanisms in the agreements which regulate the relationships between the stakeholders are best implemented if they have self-correcting features, including regular meetings of decision-makers and consumers.

Decentralised structures with the necessary decision-making authority might also be more conducive than centralised structures with lengthy procedures. If water infrastructure fails, an immediate response is essential. This requires that critical services should be outsourced to agents as close to the water point in order to ensure that remedial action can be speedily taken.

4.8 Security

Security arrangements for the plant as a whole are vital. Not only the energy supply systems, but a wide range of other technologies and materials installed at the plant have potential uses elsewhere. In resource-scarce rural Namibia, plants that have inadequate security soon seize to exist, as equipment is quickly pilfered from site. Plants are especially vulnerable if there is no sense of ownership amongst the surrounding community. The rationale that the plant provides fresh water to the community, and the community therefore benefits directly and would take care of the installation, does not necessarily apply. Experience with communal solar water pumping infrastructure in Namibia, and decentralised electricity provision systems in South Africa [von Oertzen, 2007], has shown that these systems remain vulnerable, even from members of the community directly benefiting from such plant. Communal installations are often viewed as belonging to everyone, and no one, and are thus subject to the “tragedy of the commons”, whereby a small incident of theft can quickly escalate to large-scale theft and destruction.

Security risks usually increase if the installation remains defunct for a prolonged period, which in the case of a lack of access to water, can be as little as a few days. A community’s frustrations can then lead to theft, and/or vandalism, and so rapidly destroy the basis of the ongoing operations of such plant.

4.9 Upfront and long-term costs

In terms of upfront and long-term costs, a village-based desalination plant is similar to an electricity generation plant using a more expensive technology, such as solar or wind energy. Typically, the minimum cost that needs to be recovered per m³ of water produced at a desalination plant, is higher than the current water tariff to end-users. Introducing such a plant into a rural community and then attempting to charge cost-reflective tariffs from day one of operations, is not advisable as the increased water cost will be associated with the plant and result in animosity towards it.

In rural Namibia, cheap water at lesser quality is generally preferred to expensive water of high quality. In order to avoid outright rejection from the end-users towards the new technology, two main approaches should be considered [von Oertzen, 2007]:

1. Government should subsidise the capital cost to such levels that the LWC would be reduced to the current water tariff. Should a capital subsidy not suffice, operating and maintenance costs should also be borne by Government.
2. The current water tariff should be increased steadily over a longer time frame, prior to the installation of the plant. By the time the plant is installed, both tariffs should be equal. Communities would certainly object to increased tariffs, but a staggered approach could more easily be accommodated. By the time the desalination plant is installed and higher quality water is provided, the community is more likely to associate the plant with better water quality and not only higher water costs.

In practical terms it would be desirable if a combination of these two approaches could be implemented. A clear implementation strategy and time frame is vital and would improve the likelihood of success, despite increasing the lead time for a desalination plant's installation.

4.10 Critical issues compared to technologies

Table 3 below offers an overview on how critical issues relate to various desalination technologies.

Table 3: Overview of critical issues in relation to various desalination technologies

	Distillation	*Reverse osmosis*	*Solar stills*	*Multi-stage flash*	*Multiple effect distillation*	*Vapour compression*	*Crystallisation*	*Chemical desalination*
Scalability / modularity	High	High	Medium	Medium	Medium	Medium	Medium	High
Technical capacity requirements	Medium	High	Low	High	High	High	High	Medium
Energy requirements	Medium	High	Low	High	High	Medium	Medium	Medium
Ease of relocation	Low	Medium	High	Low	Low	Low	Medium	Medium
Security	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
Capital costs	Medium, dependent on energy source	High	Low	High	High	High	Medium	High
Operating costs	Medium	Medium	Low	High	High	High	Medium	Low
Maintenance requirements	Medium to high	High	Low	High	High	High	Medium	Medium
Local content possibility	High	Low	High	Low	Low	Low	Medium	Medium
Simplicity of operation	Medium	Medium	High	High	High	High	Medium	Medium
Physical area needed by the plant: installation footprint	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Availability of local spare parts	Medium	Low	High	Low	Low	Low	Medium	Medium

5 Conclusions

A number of key challenges have to be addressed to successfully introduce small-scale desalination plants in Namibia. These include:

- developing a shared vision for the long-term supply of potable water for human and animal consumption, particularly in and for rural Namibia
- payment/cost recovery for water services and supply
- subsidisation of water infrastructure and operational costs
- community participation through enhanced job creation prospects
- overcoming institutional hurdles with regard to the long-term sustainable provision of water to rural areas
- creating incentives for investments in rural water provision by private sector players
- ensuring eventual viability of rural water provision, and thereby enhancing prospects of a diversified supply arrangements
- service arrangements, and the possible coordination of preventative maintenance activities if several plants are established in one area
- availability of technical capacity and retention of qualified staff.
- energy sources, and their long-term technical and financial implications
- buy-in from high-level decision makers (e.g. Minister, governor) *and* local beneficiaries into more diversified water provision mechanisms, including desalination technologies, the blending of water to decrease unit costs, and an increase of water supply tariffs to allow better water provision service levels
- buy-in and support of local champions from mid-level decision makers (e.g. Regional Councillors) as well as service providers and/or the Directorate of Rural Water Supply
- sensitization and buy-in from communities from day one of the planning of the plant.

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