Chapter 8
Desalination in the Pacific

Yingfei Huang, Conna Leslie-Keefe, and Greg Leslie

Abstract Desalination has traditionally underpinned public water infrastructure in the Middle East and is now an important component of urban water supplies for communities in Asia, Southern Europe, the Americas, and Australia. However, the deployment of this technology in the Pacific at scale has mostly been used to support defense installations, mining operations, and tourist resorts. Drawing on data from more than 60 facilities, this chapter charts the use of seawater desalination as a source of freshwater in the Pacific. Beginning with the first installation of a multi-stage flash distillation system in 1964 on Hao Atoll, French Polynesia, the chapter summarizes the features of the thermal distillation and reverse osmosis desalination systems deployed in Polynesia, Micronesia, and Melanesia, as well as the motivation for the projects, institutional arrangements, and current operational status. At present, the utilization of desalination in the Pacific per capita is lower than other countries of comparable gross domestic product (GDP) and water vulnerability as defined by the United Nations Environment Programme (UNEP). While non-government actors, including sovereign and international development banks have plans to develop desalination facilities, a variety of obstacles prevent the wider distribution of the benefits of this climate-resistant water source. The chapter examines the potential applications of desalination in enabling economic activity, reducing pressure on freshwater resources.

Keywords Desalination · Thermal desalination · Multi-stage flash distillation · Multi-effect distillation · Reverse osmosis · Mechanical vapour compression distillation · Potable water

---

Y. Huang · G. Leslie (✉)
School of Chemical Engineering, UNSW, Sydney, Australia
e-mail: g.leslie@unsw.edu.au

C. Leslie-Keefe
School of Law, Society and Criminology, UNSW, Sydney, Australia

G. Leslie
Global Water Institute, UNSW, Sydney, Australia

A. Dansie et al. (eds.), *The Water, Energy, and Food Security Nexus in Asia and the Pacific*, Water Security in a New World,
https://doi.org/10.1007/978-3-031-25463-5_8

8.1 Introduction

Desalination describes a variety of mechanisms used to produce potable water by removing dissolved solids and salts from raw water sources, which may include river water, seawater, brackish water, and wastewater (Australia National Water Commission 2008). Desalination plants are used to supply potable water to coastal communities and urban areas in over 40 countries and are the main source of potable for countries in the Arabian Gulf (Australia National Water Commission 2008). While the Pacific differs significantly in climate and weather patterns from the Arabian Gulf, limitations and obstacles to the reliable collection and distribution of potable water has necessitated the use of seawater desalination systems for defense, industrial, and commercial developments across Pacific Island Countries and Territories (PICT). The following chapter describes the technology used in desalination plants, the history of deployment in PICTs, features of selected applications across the three regional areas, and challenges in the use of desalination to enable economic activity and reduce pressure on freshwater resources.

8.2 Overview of Desalination Technology

8.2.1 Description

The objective of the desalination process is to remove salts and other molecules that form the Total Dissolved Solids (TDS) content in untreated water sources to an upper limit of 1000 mg/L, which is the World Health Organization's (WHO) acceptable limit for potable water (World Health Organization 2011). In seawater desalination plants, the TDS of the feedwater ranges from 33,000 to 45,000 mg/L depending on the location and is typically reduced to less than 500 mg/L for municipal water applications and less than 20 mg/L for industrial applications (Australia National Water Commission 2008). In municipal applications, the desalination process is followed by additional treatment, including chemical stabilization to adjust the TDS to match the local drinking water supply and prevent corrosion or damage to the distribution system and disinfection for pathogen control in the potable supply.

The two main desalination processes used in PICTs include thermal distillation systems and the pressure driven reverse osmosis membrane systems (Australia National Water Commission 2008). Both processes are energy intensive and offer direct water-energy nexus interaction and trade-offs to be managed according to energy requirements and cost per liter of production considerations for water use. The following section describes the technical features of these systems, beginning with the thermal process which was first used in the Pacific prior to the widespread use of membrane systems in the 1970s.

8.2.2 *Thermal Desalination*

Thermal processes are the oldest form of desalination technology which separates based on differences in vapor pressure between water molecules and the dissolved salts (Australia National Water Commission 2008). Thermal energy is used to break hydrogen bonds between water molecules and effect a change of phase from the liquid to vapor state. Dissolved salts are retained in solution while the vapor is removed and then condensed with negligible levels of TDS (Australia National Water Commission 2008). Thermal desalination plants are typically co-located with power generation facilities and utilize the waste heat from the turbines (Australia National Water Commission 2008). However, in smaller application, diesel engines or mechanical compressors are used to generate the thermal energy. Consequently, the technology has been deployed at scales ranging from less than a megalitre per day (ML/d) to over 400 ML/d. Thermal desalination facilities were first utilized to deliver drinking water to metropolitan centers in the 1950s, and by the turn of the twenty-first century, they had processed 70% of worldwide desalted water capacity (Australia National Water Commission 2008).

Thermal desalination systems used in PICTs include Multi-Stage Flash (MSF), distillation Multiple Effect Distillation (MED) and Mechanical Vapor Compression MVC.

8.2.2.1 Multi-Stage Flash Desalination System

Multi-Stage Flash (MSF) distillation uses a series of chambers operating at progressively lower temperatures and pressures (Australia National Water Commission 2008). Each chamber has three sections (Fig. 8.1a): a bottom where seawater is heated and forced to flash into steam; a top section containing a bundle of the tube heat exchangers where the vapor collects and condenses; and a middle a distillate collection chamber, located directly below the heat exchangers (Australia National Water Commission 2008).

Seawater enters the system through the heat exchangers in the last chamber and is progressively heated by the hot vapor before the temperature is boosted by the external source to achieve the final top brine temperature (TBT), typically 90 °C to 115 °C. High temperature and low-pressure force the brine water to boil violently and is instantly vaporized into steam, which rises rapidly to the top of the chamber. It passes through demister pads to remove entrained brine, and then is condensed on the outer surface of the tube heat exchanger and flows in the opposite direction via the collection trough (Australia National Water Commission 2008).

The first desalination systems installed in the Pacific in the 1960s used MSF technology. The equipment was supplied as skid-mounted, self-contained systems that were easily transported, and installed on concrete pads or plinths to minimize construction costs (Fig. 8.2). MSF can operate as a “once-through” process which discharges brine directly into the ocean, or include additional recirculation pumps,

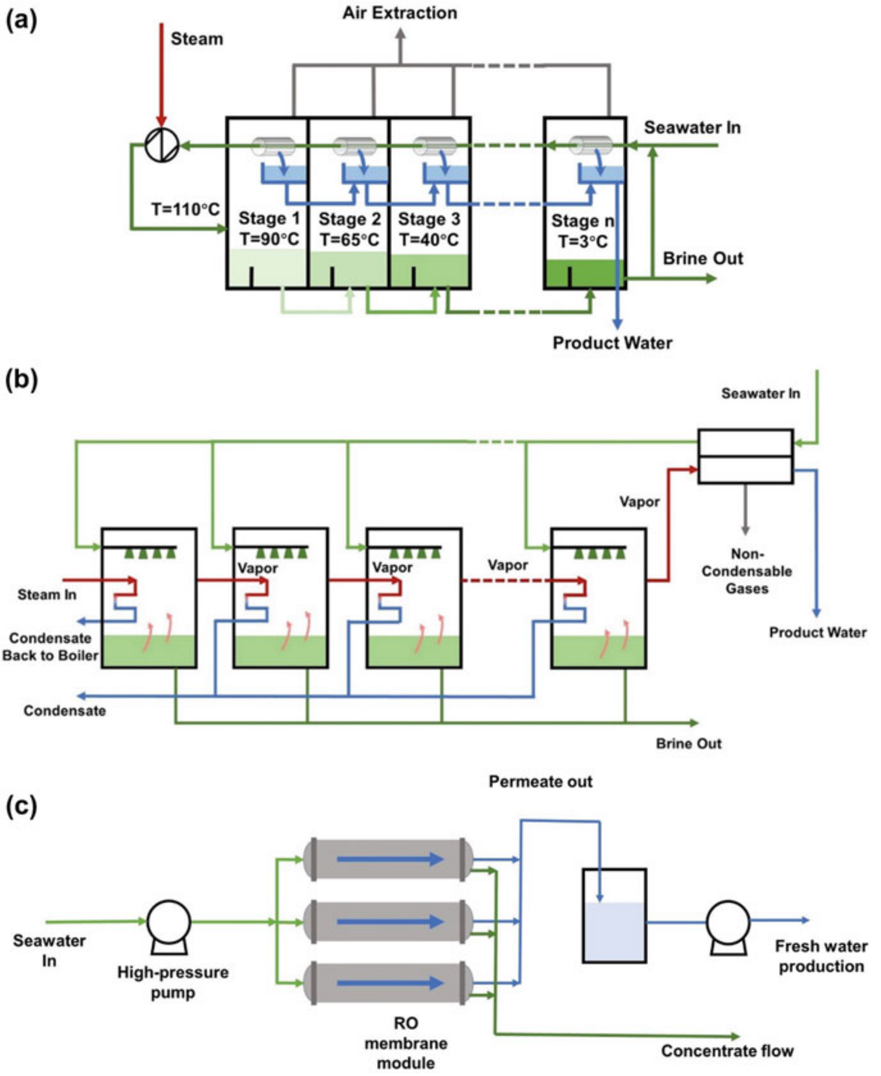


Fig. 8.1 (a) Multi-stage flash distillation, (b) multi-effect distillation and (c) reverse osmosis membrane system

to recycle and reprocess the brine which reduces consumption of antiscalant and anti-foaming agents, thereby reducing operational costs (Australia National Water Commission 2008).

Fig. 8.2 An 817 m^3/d flash evaporator c.1970 (© Tom Pankratz)

8.2.2.2 Multiple Effect Distillation Desalination System

Multiple effect distillation (MED) also use a series of chambers divided into three sections, however, unlike MSF, evaporation occurs when a seawater film meets the heat transfer surface, and "flashes" in each chamber to form the vapor (Australia National Water Commission 2008; Nannarone et al. 2017) (Fig. 8.1b). The objective of having several chambers at lower pressures is to enhance energy recovery in the vaporization condensation cycle and take advantage of the decreased heat needs for vaporization. The use of Thermal Vapor Compression (TVC) can increase the velocity of the steam flowing on the interior of the tube, as an alternative to increasing the surface area of the heat exchanger to improve the heat transfer efficiency (Nannarone et al. 2017). The inclusion of TVC increases the mechanical complexity of the distillation plant but decreases the size and improves efficiency. Like MSF, MED systems are modular and have been installed in offshore operations (Fig. 8.3) and were widely used in the Caribbean in applications similar to those in PICTs (Figs. 8.4, 8.5, 8.6, 8.7 and 8.8).

8.2.2.3 Mechanical Vapour Compression Desalination Systems

Mechanical Vapour Compression (MVC) distillation is a technique using mechanical energy as the main driving force instead of steam as the primary source of thermal energy (Tleimat 2010).

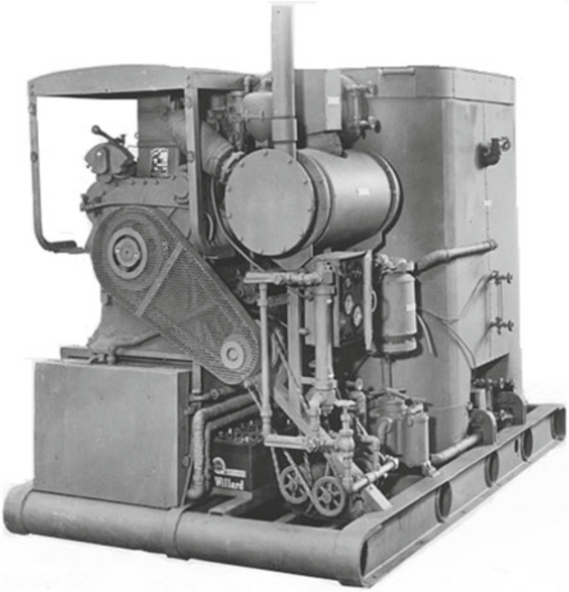
Fig. 8.3 A 768 m^3/d offshore MED-TVC c.2000s (© Tom Pankratz)

Fig. 8.4 A Caribbean MED (no TVC) c.1986 (© Tom Pankratz)

MVC evaporator-condensers progressively increase the temperature of seawater through a series of tubular heat exchangers until water vapor condenses on the upper surface of the tube which cause seawater on the other side of the tube to evaporate which allows water vapor in the tube to condense as permeate. The smallest MVC systems are generally single effect units that operate at a temperature of 102 °C and pressure slightly above the atmospheric pressure (Australia National Water Commission 2008).

Fig. 8.5 A Caribbean MED-TVC c.1971 (© Tom Pankratz)

Fig. 8.6 A Caribbean MVC in 1960s–1990s (© Tom Pankratz)



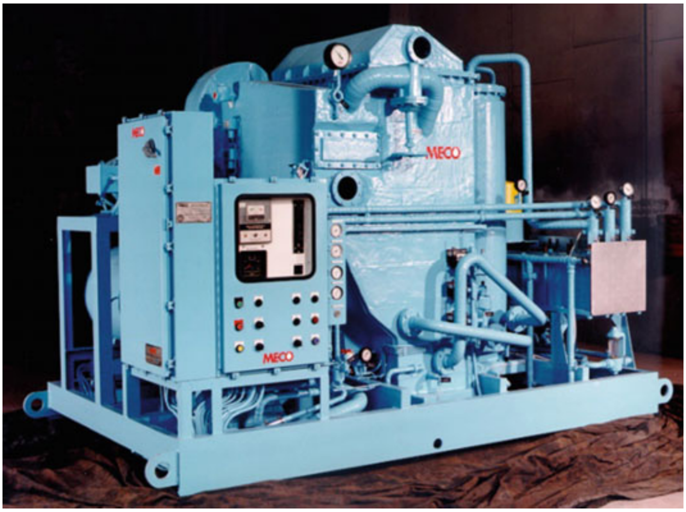


Fig. 8.7 An island/offshore MVC c.1985 (© Tom Pankratz)

Fig. 8.8 A larger Caribbean MVC c.1985 (© Tom Pankratz)

8.2.2.4 Reverse Osmosis

Reverse osmosis (RO) is a member of the family of pressure driven, liquid phase membrane separation processes. Mechanical energy supplied by a pump raises the feed pressure above the osmotic pressure of the seawater which moves water molecules across a semipermeable polymeric membrane at a faster rate than the dissolved salts (Truby 2008). In a RO system, the flow of feedwater across the membrane surface is tangential to the flow of product water (permeate) which passes across the membrane (Fig. 8.1c). Unlike thermal processes that produce near distilled quality water, the separation efficiency and product water quality of the RO process depends on the type of membrane, the concentration of salts in the feedwater, and the permeate flow rate. The ratio of the feedwater flow to the permeate flow is referred to as the process recovery. Increasing the recovery increases the concentration in the feedwater and the osmotic pressure, which decreases the net pressure driving and decreases permeate flowrate. The optimum recovery rate for RO in seawater desalination applications ranges from 40 to 50%. RO membranes are cast as flat sheets that are sandwiched between a mesh feed spacer on the top and a woven permeate spacer on the bottom. The membrane sheets are assembled into a spiral wound configuration with sealed edges to separate the feed and permeate channels. Spiral wound elements are arranged in series inside pressure vessels. The inlet of the pressure vessel is connected to the discharge of the high-pressure pump, with two outlets at the end of the pressure vessel to collect concentrate salt stream (brine) and the permeate stream. Pressure vessels used in seawater desalination applications typically contain between six and eight elements.

Reverse osmosis plants, unlike thermal desalination plants, require a pretreatment step to remove material from the feedwater that can block the feedwater channels and foul the membrane surface. The feedwater channels in spiral wound membranes range from 0.07 to 0.08 mm, therefore a filtration step using granular media or membrane filtration is required to remove fine particles. Chemical addition is also required to prevent inorganic scale formation on the membrane and periodic chemical cleaning is required to restore membrane permeability. Consequently, while RO is at least four times more energy efficient than thermal processes, the processes have higher consumable costs (membranes and chemicals) (Australia National Water Commission 2008). Notwithstanding this, RO has replaced thermal processes as the preferred technology for seawater desalination in PICTs due to the simplicity of design and operation and the lower capital costs.

8.3 History of Desalination in the Pacific

The following section was based on analysis of a database of desalination plants produced by global water intelligence. The database was accessed with license in 2020 and contained information of the year of construction, location, capacity, and technology of the desalination plants in the Pacific (Global Water Intelligence Desalination Database 2020). The information was analyzed by geographic regions and communities.

8.3.1 Polynesia

Modern desalination plants were first deployed in Polynesian countries with use in military, industrial, and commercial applications. Deployment of the technology can be divided into three waves: 1966–1968, 1983–1998, and 2016–2017 (Global Water Intelligence Desalination Database 2020). In 1965 the first MSF plant was installed on Hao Atoll by the French military, followed by the installation of an additional 15 thermal desalination plants on Hao and Mururoa Atolls. Overall, the cumulative thermal desalination capacity installed in Polynesia was approximately 8600 m^3/day with plant capacities ranged from 121 m^3/day to 1200 m^3/day (Table 8.1; Fig. 8.9). Commencing in 1968, 13 MSF facilities were constructed over seven years to produce industrial grade (TSD $<$ 10 ppm) water (Global Water Intelligence Desalination Database 2020). These facilities were built to support the French military base on Hao Atoll, housing personnel working on the nuclear test program on Mururoa Atoll. When atomic testing ceased in 1996, and French military activity in the area came to an end in 1998, the region saw a new wave of RO desalination projects to supply drinking water to tourist facilities (Global Water Intelligence Desalination Database 2020). By 2020 the total cumulative capacity of RO plants was 650 m^3/day and ranged from 0.65 m^3/day and 200 m^3/day respectively. A municipal level drinking water facility was built in Rangiroa, French Polynesia in 1998, and was able to conveniently supply the nearby Hotel Kia Ora Resort. The first desalination facility exclusively supplying tourist facilities in Polynesia was operational in Tahiti in 2008 (Global Water Intelligence Desalination Database 2020).

8.3.2 Micronesia

The first Micronesian desalination facility was a 114 m^3/day MED plant built in 1973 on Saipan, Northern Mariana Islands for a resort (Table 8.1; Fig. 8.9).

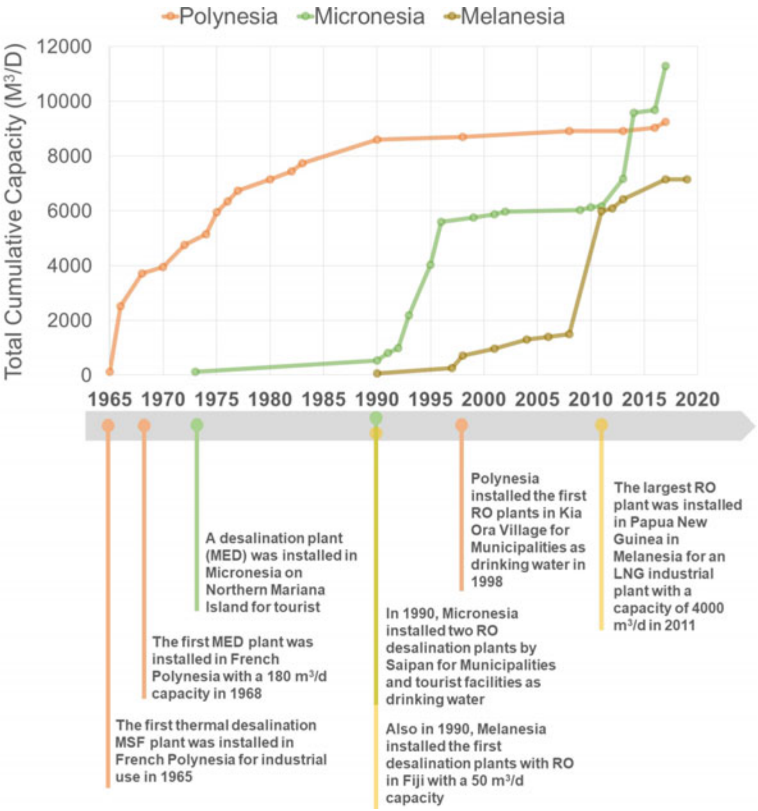
Additional plants were installed in two waves between 1990 to 2017. A total of 32 RO desalination plants were established, mainly in Northern Mariana Island and Tuvalu, with a total aggregated capacity of 9970 m^3/day. Plants ranged in size from 10 m^3/day to 1600 m^3/day (Global Water Intelligence Desalination Database 2020). The market for desalination in Micronesia has been driven by the tourism sector, including several championship golf courses, with the exception of a 1200 m^3/day MED plant installed in 1993 for industrial applications. Facilities on the island used predominantly seawater as their feedwater, though some facilities made use of brackish and inland water sources. Municipal drinking water facilities were also installed in 1995 and 2001 on Saipan, and on Rota Island in 1995, but the tourism industry remains the dominant consumer of desalinated water in the Northern Mariana Islands where the largest plant has three times the capacity of the municipal plant. In addition to plants in the Northern Mariana Islands, a dedicated membrane

Table 8.1 Summary of desalination plant installation history in Polynesia, Micronesia, and Melanesia located in Pacific Region with data accessed from DesalData

Region	Polynesia	Micronesia	Melanesia
First plant			
Year of installation	1965	1973	1990
Location	Hao, Tuamotu Archipelago	Saipan, Northern Mariana Islands	Mamanuca Island, Fiji
Application	Military support	Tourism	Tourism
Technology	MSF	MED	RO
Capacity (m^3/d)	165	114	50
Total plants			
Installations—Total	22	34	21
Applications—Total	Municipal drinking water (11) Industry (9) Tourism (1)	Municipal drinking water (15) Tourism (14) Emergency (3)	Tourism (10) Municipal (8) Industry (3)
Thermal desalination			
Installations	16	2	0
Total capacity (m^3/d)	8600	1314	-
Max. Capacity (m^3/d)	1200	1200	-
Min. Capacity (m^3/d)	121	114	-
Active Plants	0	0	-
RO			
Installations	6	32	21
Total capacity (m^3/d)	5500	9970	7150
Max. capacity (m^3/d)	200	1600	100
Min. capacity (m^3/d)	0.65	10	2.5
Active plants	6	28	19
Database with license (Global Water Intelligence Desalination Database 2020)			

desalination facility supplying drinking water to tourist facilities was installed in 1999 in Kiribati (Fraser Thomas Partners 2012).

Desalination projects at the municipal level outside the Northern Mariana Island can be found in Nauru and Palau. The Aiwo District of Nauru installed a MED thermal desalination facility in 1993, the largest plant ever installed in the region, to supply municipal drinking water, while in 2016 a municipal desalination facility was installed to supplement rainfall and groundwater, the island's other sources of drinking water (SOPAC Water and Sanitation Programme 2018).



The first thermal desalination MSF plant was installed in French Polynesia for industrial use in 1965

The first MED plant was installed in French Polynesia with a 180 m³/d capacity in 1968

A desalination plant (MED) was installed in Micronesia on Northern Mariana Island for tourist

In 1990, Micronesia installed two RO desalination plants by Saipan for Municipalities and tourist facilities as drinking water

Also in 1990, Melanesia installed the first desalination plants with RO in Fiji with a 50 m³/d capacity

Polynesia installed the first RO plants in Kia Ora Village for Municipalities as drinking water in 1998

The largest RO plant was installed in Papua New Guinea in Melanesia for an LNG industrial plant with a capacity of 4000 m³/d in 2011

Fig. 8.9 Total cumulative desalination plant capacity in Polynesia, Micronesia, and Melanesia with data accessed from DesalData Database with license (Global Water Intelligence Desalination Database 2020)

The Marshall Islands are located near the equator in the Pacific Ocean, part of a larger group of islands in Micronesia. It is the most densely populated island in the Pacific Ocean and is almost entirely dependent on desalinated seawater to meet its freshwater demands. Kili, Utrik, and Ebeye, located on Marshall Island, installed RO membrane desalination systems in 2014 and 2017, to provide residents with a stable and sufficient source of freshwater (SOPAC Water and Sanitation Programme 2018). Prior to the installation of the facility, residents of the site suffered not only from drought but also from groundwater contamination. The entire plant can be powered by wind and solar energy, saving tens of thousands of dollars in fuel costs each year (Fraser Thomas Partners 2012). In addition, with increasingly expensive fuel and unreliable supplies caused by seasonally choppy seas, the alternative energy power system ensures a continuous, affordable supply of water.

8.3.3 Melanesia

Installations of desalination facilities in Melanesia began relatively late compared to Polynesia or Micronesia. The region's facilities have exclusively employed RO. The first facility had a capacity of 50 m^3/day and was installed on Castaway Island in Fiji in the late 1980s. By 2020 the total capacity was estimated to be 7150 m^3/day. The largest installation is a RO plant with a capacity of 4000 m^3/day installed in an industrial application in Papua New Guinea (PNG), The plant was installed in 2011 following work by the Government of Papua New Guinea. Since the 1990s, several oil and gas companies have studied the feasibility of developing a natural gas plant in the country to commercialize natural gas resources for export as liquified natural gas (LNG) to customers around the world (Global Water Intelligence Desalination Database 2020). The RO desalination plants established at the site are for industrial use for the PNG LNG project awarded by the Chiyoda and JGC joint venture. The smallest desalination plant in the region is a plant with a capacity of 2.5 m^3/day in a hospital in the Solomon Islands. The plants were installed in 2017 and 2019 at the Youth With A Mission (YWAM) training center in Samarae Maternal Clinic and a hospital in Honiara. They use solar-powered desalination units, aiming to provide adequate freshwater resources for residents, patients, fishermen, staff, and clinical use (Pacific Island Forum Secretariat 2018).

Other facilities in Melanesia are in Fiji and Vanuatu. Fiji has established total 15 desalination plants, accounting for approximately 70% of all desalination plants in Melanesia. Tourism represents around 40% of Fiji's GDP in a given year. The nation's dependence on the industry is reflected in the number of desalination facilities dedicated to drinking water for tourist facilities (Weber 2007).

In Vanuatu, a 96 m^3/day desalination plant was installed on Ambae Island at the Lolowai Medical Center in 2013 to supplement the island's water supply (Global Water Intelligence Desalination Database 2020). The plant is also designed to provide water to more than 10,000 people on the island in case of an emergency. Due to the high cost of fuel and logistical difficulties, the RO plant was installed with a solar power system to save fuel.

8.4 Desalination as a Driver of Economic Development

The availability of reliable fresh water is essential for developing economies (Davies and Mirti 2005). This section considers examples of initiatives to expand economic activity and the attendant need for desalination to supplement available water supplies.

8.4.1 Nauru

The Republic of Nauru (area 22 km^2) is an isolated, elevated limestone island located 41 km south of the equator (South Pacific Applied Geoscience Commission 2007).

Nauru's economic income has traditionally come from phosphate exports, but reserves are expected to be depleted within a few years (South Pacific Applied Geoscience Commission 2007). Nauru has virtually no agriculture and no tourism-related economic income. Phosphate mining, which used to be the main economic activity, has turned central Nauru into a wasteland because of over-intensive excavation (South Pacific Applied Geoscience Commission 2007). Because the mined land is now unusable, rehabilitation of the mines and alternative income from phosphate, as well as adaptation to climate change, are challenges for the sustainable development of their country. Nauru plans to rehabilitate land that was mined and repurpose it for agricultural use over the next 20 to 30 years (South Pacific Applied Geoscience Commission 2007). This could provide Nauruan with fresh fruits and vegetables, which are generally in short supply, and ensure national food security (Chap. 4). There will be greater demand for water for agriculture, which will involve a very high demand for groundwater resources. The use of alternative water sources, such as desalinated seawater for irrigation, could allow the region to maintain adequate water supply needs during drought conditions.

The main water sources include rainwater, shallow groundwater, imported water, and desalinated water (South Pacific Applied Geoscience Commission 2007). Potable water is collected in rainwater tanks on the roofs of residential and commercial buildings, while non-potable water is obtained from boreholes in the homes of island residents. Shallow groundwater is the primary aquifer between rainy seasons. However, seawater ingress due to over-pumping, coupled with the percolation of wastewater from homes, stores, and commercial buildings is having an adverse effect on water quality (SOPAC Water and Sanitation Programme 2018).

There is one large evaporative desalination plant and four small RO desalination plants on the island. A large desalination plant previously built on the island, which could use waste heat from power generation for desalination, was commissioned in 1992 (South Pacific Applied Geoscience Commission 2007). However, due to the age of the generators, they operate at less than maximum capacity, resulting in a lower waste heat output, causing a decrease in desalination capacity. According to the statistics, just 3% of the possible output was supplied to customers in 2005/2006 owing to a scarcity of water tankers (South Pacific Applied Geoscience Commission 2007).

To address the high energy demand of desalination plants, the use of renewable energy is a viable option. Nauru supplied and installed a grid-connected solar power system and a reverse osmosis plant in 2013, providing a daily treatment capacity of 100 m^3 of water (Pacific Island Forum Secretariat 2018). Not only are the operation and maintenance costs low, but the performance and energy efficiency are also high.

8.4.2 Kiribati

The Republic of Kiribati is a tropical atoll nation located between the central and western Pacific Ocean and consists of 32 low-lying coral islands and three main islands (Fraser Thomas Partners 2012).

Kiribati's income is derived from agriculture, industry, fishing, and foreign exchange, with relatively little tourism (Fraser Thomas Partners 2012). The country's export revenue comes from the sale of fishing rights in its vast national waters, exports of copra and seaweed, and remittances from overseas Kiribati. Overseas revenue also comes from the sale of fishing licenses to other countries (Fraser Thomas Partners 2012).

Kiribati has no perennial surface water flow, and its water resources are limited to shallow unconfined groundwater, rainwater, imported water, or desalinated seawater. Rainfall is closely related to the location of the Pacific warm pool which is controlled by the seasonal movements and annual variations of the Intertropical Convergence Zone and the Equatorial Low-Pressure Zone (Fraser Thomas Partners 2012). The country's average annual rainfall ranges from 1,300 mm south of the equator to 2,000 mm in Tarawa, with the northernmost islands exceeding 3,200 mm, while the eastern Lain Islands, Kiritimati averages less than 1,000 mm per year (Fraser Thomas Partners 2012). Kiribati has been using rainwater harvesting techniques for many years, but it is seen as a supplementary water source at best. Shallow fresh groundwater is highly susceptible to natural and anthropogenic changes (Chap. 2) and is more susceptible to rainfall variability and over-extraction. Storm surges, droughts, and overexploitation lead to seawater intrusion (Chap. 10).

Five desalination plants have been established in Kiribati over the past seven years in communities that are entirely reliant on rainwater harvesting due to the absence of surface water or the high salinity of groundwater. These desalination plants require a reliable power supply and on-going maintenance which is difficult to sustain in small, isolated rural island communities. Consequently, only one desalination plant is partially operational on Barnabas Island (Fraser Thomas Partners 2012).

The capital of Kiribati, South Tarawa, located on Tarawa Atoll in the Gilbert Islands has a population of 62,000 residents (43.5% of the population) of South Tarawa (Fraser Thomas Partners 2012). South Tarawa rely on rainwater as a primary supply use saline or contaminated groundwater as a reserve water source.

On November 19, 2020, a grant agreement of nearly $42 million was signed to help improve the water supply for the people of South Tarawa (Asian Development Bank 2020). The project addresses the issue of waterborne diseases by providing new, climate-resilient water supply infrastructure including a desalination plant with a maximum capacity of 6000 m^3/day, along with water, sanitation, and hygiene awareness programs. The construction of a solar desalination plant will be central to making South Tarawa's water supply more resilient to climate change (Asian Development Bank 2020).

The most significant impacts of the project will be health benefits and the expected decrease in infant mortality due to diarrheal disease. The installation of solar photovoltaic cells will provide a steady supply of water to customers and will create a network of reliable and dependable sources of drinking water (Pacific Island Forum Secretariat 2018). Solar energy will also help to minimize greenhouse gas emissions by generating energy using renewable energy sources rather than burning fossil fuels. Indirect greenhouse gas reductions will also be achieved by providing uncontaminated, high-quality water, which will ultimately reduce the need to burn fossil fuels to produce water that boils to make it suitable for energy consumption. Rehabilitation of the existing water supply network will reduce the level of non-revenue water use and improve the performance of the pumping system. This has an indirect positive impact by reducing the amount of energy needed to produce and deliver water to all customers.

8.4.3 Uleveu Island—Vanuatu

The Republic of Vanuatu is located in the Western Pacific Ocean and its islands are formed by raised limestone and volcanoes. The population is approximately 200,000, 80% of which is still rural. The main economic sources of this country are agriculture, fishing, forestry, and tourism. Agriculture products, particularly fruit, cocoa, coffee, and dried coconuts, are the main economic exports, while tourism is second only to agriculture in importance to the country's economy. Tourism is concentrated in Port Vila and some of the outer islands (Nath et al. 2006a).

In urban areas of Vanuatu, the main water resource is groundwater, while in rural areas, sources can be wells, springs, rivers, and rainwater. Average rainfall in the area varies from 4000 mm per year in the north to 1500 mm per year in the southern islands (Nath et al. 2006a). The rainy season is from January to March and the rest of the year is the dry season. Rivers and streams are common on the larger islands, but their flow is also seasonal. In addition, the quality of surface water is often polluted from upstream sources (Nath et al. 2006a).

While urban water quality is generally good in Port Vila and Luganville, in rural areas most water supply comes from surface water, rainwater, and groundwater. Also, in most places outside of the major urban centers, water supply systems are either poor or non-existent, for example, the island of Uleu, located within the Vanuatu archipelago, with a population of over 1800 people (Vanuatu's National Advisory Board on Climate Change and Disaster Risk reduction 2012). Contamination of drinking water is primarily bacterial, usually by bacteria from human or animal excrement (Nath et al. 2006a).

In 2012, a solar solution was proposed that was suitable for powering a desalination plant located near the Sangali School on the north side of Uleu Island (Vanuatu's National Advisory Board on Climate Change and Disaster Risk reduction 2012). The system is designed to provide up to 3000 L of water per day during the dry season. With the addition of the water storage facility, the new system can provide

4 L of water to each of the 1500 residents (Vanuatu's National Advisory Board on Climate Change and Disaster Risk reduction 2012). The solar panels that drive the desalination system generate excess solar energy that can be used to make ice, as a secondary product to fund plant maintenance, which is used to keep the fish in the market cool and extend the fishing time by a few days.

8.5 Barriers to Development and Future Projections

Desalination has the potential to supplement water supplies across Polynesia, Micronesia, and Melanesia. While the challenges around desalination in larger urban centers are well understood, deployment of the technology at the local scale will require co-development of energy supplies, water distribution infrastructure, capacity, and training. More importantly, the solutions must be linked to broader community development including economic activity, The following section considers the barriers that must be overcome for wider use of desalination.

8.5.1 Energy

Seawater desalination is energy intensive, typically requiring a minimum of 3.5 kwh/m^3 of water produced (García-Rodríguez 2003). The power required by large desalination plants may be offset by the installation of renewable power; however, continuous operation requires connection to a stable, grid supplied power source. However, in small applications, particularly for plants operating below 10–50 m^3/day a few types of renewable desalination systems have been implemented and piloted in the Pacific. The outcome of the pilot studies was to reduce technical risks that have historically limited continuity of power supply and thus availability of treatment capacity which is needed to improve commercial viability (Davies and Mirti 2005). The following section considers four sources of renewable energy that can be used to directly power desalination plants in the Pacific.

Concentrated solar power (CSP) cogeneration is a technology that uses solar irradiation to generate thermal energy for use in turbines to generate electricity. CSP stores heat at a relatively low cost and maintains the plant in operation during evening peak load hours, which is one of its main advantages. When used in conjunction with a desalination system, heat from the CSP unit can be ejected from the low-pressure turbine and delivered to the brine heater instead of being expanded in a further low-pressure turbine (International Renewable Energy Agency 2015).

Photovoltaic (PV) technology converts solar radiation directly into electricity with PV cells made of semiconductor materials, through which an electric current is generated when exposed to the sun. As the temperature increases, the efficiency of PV cells decreases, so dense PV systems require active cell cooling. This heat can be used for different purposes. Considering the electrical and thermal output, the overall efficiency can be around 80%. Photovoltaic systems can be directly integrated RO systems; however, the capacity is limited (typically less than 10 m^3/day) (International Renewable Energy Agency 2015).

Wind energy is usually converted directly into mechanical energy, and it can be mechanically combined with a desalination system such as RO. To accommodate wind fluctuations, electrical or mechanical energy storage can be integrated into a wind desalination system using flywheels, for example. Wind energy is a proven technology that has proven to be economically viable in combination with desalination systems (García-Rodríguez 2003).

Tidal energy captured from rising and falling tides is converted into electricity by turbines connected to generators. However, because almost all ocean energy technology systems are in the pilot plant or prototype stage, the technology is not yet mature or economically competitive. The lesser-known Ocean Thermal Energy Conversion (OTEC) is the most promising ocean energy extraction method for desalination energy needs (International Renewable Energy Agency 2015). As it is developed and costs are low, it may attract more attention in the coming years.

8.5.2 Water Distribution and Transport

Currently, there are still barriers to water transport in PICTs. In Nauru, for example, the water network serves only a very small area and both the pipeline network and storage tanks have seen continued deterioration and lack of maintenance. Consequently, water produced by desalination plants is usually transported by water tanker trucks to individual homes and other storage tanks. However, due to the lack of tanker trucks, only a small percentage of their output is delivered to consumers (South Pacific Applied Geoscience Commission 2007).

In order to improve the water supply structure on the islands, the aging water pipeline network needs to be repaired or replaced. It is also necessary to expand the service area of the network so that the rural population also has access to fresh and safe water through the piped water network. Additional tanker trucks for water on the island are needed after the installation of desalination facilities to transport the actual amount of water produced to consumers and increase market demand and supply.

8.5.3 Human Skills and Capacity

Each island has a different infrastructure capacity and labor market capacity, which means that desalination projects need to be set up on an island-by-island basis. Low construction capacity and lack of labor can lead to failure in setting up projects, making the already high initial investment a significant barrier for economies without the necessary financial means. This means that staff recruitment and training are factors that affect the continued deployment of renewable desalination. Advances in desalination technology are unlikely to be achieved through breakthrough technological pathways at this time; instead, their operational and economic efficiency will be improved through multidisciplinary optimization and capacity building (Nath et al. 2006b).

Training for construction and ongoing operation and maintenance of desalination systems can be conducted at universities or central training institutions through local workshops. Consideration must be made where a lack of basic education of the staff to be trained exists and where English is not a first language. These must be addressed through country-tailored training programs that include hands-on experience and workshops, and the use of training materials and languages appropriate to the competencies and educational background of the personnel concerned (Nath et al. 2006b).

8.5.4 Economic Factors

Desalination systems require a significant capital investment, typically \$3–4/L of installed treatment capacity. The decision to invest must be supported at the political level and have sufficient administrative resources to ensure that the plants operate at capacity over the life of the asset. According to the World Health Organization, an investment of \$1 in water supply and sanitation yields a return of \$2.80 in developed countries and \$6 in developing countries (International Renewable Energy Agency 2015). The decision to invest in desalination plants over alternative options for the development of reliable water supplies cannot proceed without ensuring reliable energy supplies. As the cost of fossil energy increases, and the cost of renewable energy and desalination technology decreases, the economic return on investment in renewable desalination on islands is likely to rise. The main cost of deploying renewable desalination on small islands is due to energy storage, compared to islands with large grids that use traditional desalination methods. Unless the cost of energy storage decreases significantly in the future (Chaps. 12 and 18), the cost competitiveness of renewable desalination will remain weaker than the cost of freshwater production with conventional water supply infrastructure (International Renewable Energy Agency 2015).

8.6 Conclusion

Historically, the development of desalination systems in the Pacific has been tied to military, industrial, and tourism projects. Most plants in the Pacific use reverse osmosis, which is a mature technology, but requires reliable supplies of power and is attended by ongoing operating and maintenance costs. Consequently, the development of desalination as a supply of municipal water has most utility in the capital cities and major population centers when linked to the development of other infrastructure. In rural areas, desalination systems linked to solar and renewable energy are emerging; however, the scale is not suitable to address water supply for food security.

References

Asian Development Bank (2020) ADB and Kiribati sign grant for project for safer water. Asian Development Bank

Australia National Water Commission (2008) Emerging trends in desalination: a review, [electronic resource] Canberra, ACT, National Water Commission

Davies S, Mirti AV (2005) Drinking water quality in the Pacific Island Countries: situation analysis and needs assessment. SOPAC Joint Contribution Report 18

Fraser Thomas Partners (2012) South Tarawa sanitation improvement project TA-7359(KIR): South Tarawa water supply options assessment desalination feasibility study. Pacific Region Infrastructure Facility, Government of Kiribati and Asian Development Bank

García-Rodríguez L (2003) Renewable energy applications in desalination: state of the art. Sol Energy 75:381–393

Global Water Intelligence Desalination Database (2020) Global water intelligence desal data/International Desalination Association [license]. Global Water Intelligence

International Renewable Energy Agency (IRENA) (2015) Renewable desalination: technology options for islands. International Renewable Energy Agency

Nannarone A, Toro C, Sciubba E (2017) Multi-effect distillation desalination process: modeling and simulation. In: Proceedings of Ecos 2017—the 30th international conference on efficiency, cost, optimization, simulation and environmental impact of energy systems July 2–July 6, 2017, San Diego, California, USA

Nath D, Mudaliar M, Loan C (2006a) Water safety plant—water supply description assessment—Vanuatu. In: South Pacific and Asia conference (SOPAC). Water Safety Plans Programme

Nath D, Mudaliar M, Parakoti B (2006b) Water safety plan water supply system description cook islands. In: South Pacific and Asia conference (SOPAC). Water Safety Plans Programme

Pacific Island Forum Secretariat (2018) Pacific environment community consolidated regional report 2018. Pacific Island Forum Secretariat

SOPAC Water and Sanitation Programme (2018) Desalination for Pacific Island countries. UN Climate Technology Centre and Network (CTCN). SOPAC Water and Sanitation Programme

South Pacific Applied Geoscience Commission (2007) National integrated water resource management diagnostic report—NAURU. SPREP LIBRARY. In: South Pacific and Asia conference (SOPAC). Integrated Water Resource Management (IWRM)

Tleimat B (2010) Thermal desalination processes, encyclopedia of desalination and water resources

Truby RL (2008) Seawater desalination by ultralow-energy reverse osmosis. In: Li NN, Fane AG, Ho WSW, Matsuura T (eds) Advanced membrane technology and applications. Wiley, New York, pp 87–100

Vanuatu's National Advisory Board on Climate Change & Disaster Risk Reduction (2012) Solar powered desalination system Uleveu Island—Vanuatu. National advisory board: Government of Vanuatu

Weber E (2007) Water in the Pacific Islands: case studies from Fiji and Kiribati. In: Grover VI (ed) Water: a source of conflict or cooperation? Enfield: Science Publishers, Inc

World Health Organization (2011) Guidelines for drinking-water quality. World Health Organization

The opinions expressed in this chapter are those of the author(s) and do not necessarily reflect the views of the UNESCO: United Nations Educational, Scientific and Cultural Organization, its Board of Directors, or the countries they represent.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-ShareAlike 3.0 IGO License (https://creativecommons.org/licenses/by-sa/3.0/igo/), which permits use, sharing, adaptation, distribution, and reproduction in any medium or format, as long as you give appropriate credit to the UNESCO: United Nations Educational, Scientific and Cultural Organization, provide a link to the Creative Commons licence and indicate if changes were made. If you remix, transform, or build upon this book or a part thereof, you must distribute your contributions under the same licence as the original.

The use of the UNESCO: United Nations Educational, Scientific and Cultural Organization's name, and the use of the UNESCO: United Nations Educational, Scientific and Cultural Organization's logo, shall be subject to a separate written licence agreement between the UNESCO: United Nations Educational, Scientific and Cultural Organization and the user and is not authorized as part of this CC-IGO licence. Note that the link provided above includes additional terms and conditions of the licence.

The images or other third party material in this chapter are included in the chapter's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.