

New Desalination Plants

Subjects: Others

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This entry analyzes the requirements for the construction of new desalination plants within a framework of sustainability: technology used, energy sources, correction of the environmental impacts generated and appropriate contractual model for their development. These attributes justify that reverse osmosis is the safest and most efficient technology among those available. It is proposed to incorporate renewable energy production sources. The need to adopt corrective measures to mitigate the impact produced on the environment and implement monitoring plans to confirm the validity of these measures will also be demonstrated. Finally, turnkey contracts are proposed because osmosis technology is complex, although the election must be justified by a decision support system.

Keywords: sustainable development ; desalination ; reverse osmosis ; renewable energies ; environmental impacts ; decision support systems ; types of contract

1. Definition

Seawater desalination plants are an alternative to ensure water supplies to near-shore populations that meet current needs *“without threatening the ability of future generations to meet their own needs”* Brundtland [1]. For this condition to be met, the critical variables that must be studied in the development of desalination plant projects are technology used, energy sources, correction of environmental impacts and the type of contract appropriate for its development.

2. Introduction

Population growth has increased dramatically throughout the world in the last two centuries. Global population is expected to go from the present 7.7 billion inhabitants to some 10 billion people by the year 2050. One of the biggest challenges to face in the near future is how to guarantee drinking water supply all over the world. This is an important challenge for humanity, since drinking water availability will have to increase significantly.

Another effect that has been observed in the past few decades are the rural exodus to the big cities. This migration is causing demographic imbalance, depopulating certain areas and causing big population increases in others. In the driest countries, the most densely populated areas are actually on coastal regions due to very well-known social and economic reasons.

As the global population grows and climate change increases temperatures, water will become even more scarce.

In AQUASTAT [2], three types of water withdrawal are distinguished: agricultural (including irrigation, livestock, and aquaculture), municipal (including domestic), and industrial water withdrawal. A fourth type of anthropogenic water use is the water that evaporates from artificial lakes or reservoirs associated with dams. It is worth highlighting the consensus on the use of water by humans, allocating 12% for domestic use, 19% for industry, and 69% for agricultural use. These numbers, however, are strongly biased by a few countries which have very high-water withdrawals. Table 1 shows the water withdrawal percentages by continent.

Table 1. Water withdrawal percentages by continent.

	Agricultural	Municipal	Industrial
World	69	19	12
Europe	21	57	22

Americas	51	34	15
Oceania	60	15	25
Asia	81	10	9
Africa	82	5	13

Source: AQUASTAT.

The above shows not only the scarcity of the water resources and the difficulty to guarantee water supply, but also that there are not many water supply alternatives. Water desalination is particularly suitable for cities situated near the coast or with brackish water.

According to data published by the International Desalination Association (IDA) and Global Water Intelligence (GWI) in the Water Security Handbook 2019–2020 [3], over 17,000 desalination plants have been contracted, reaching a total of 107 Hm³/day of cumulative installed desalination capacity in 2019. Desalination is operational in 174 countries. There are more than 300 million people around the world who rely on desalinated water for some or all their daily needs, with 146 Hm³/day of cumulative installed reuse capacity in 2019.

The various desalination technologies are differentiated by cost, product quality, and energy consumed. Most plants desalinate through a thermal process or using membranes.

Thermal desalination methods use heat to evaporate saltwater and they condense it again, now without salt. They basically imitate the natural water cycle of evaporation and rainfall.

Torres Corral [4] pointed out that from these beginnings until the 1980s, desalination was mainly done by distillation processes, building dual water and electric power plants, as long as the market for the power plant was viable.

In the following section we will show how the cost of the selected desalination technology is the most significant cost in the final price of desalinated water. Torres justified how the various oil crises have significantly affected applied technology. The first crisis in 1973 led to optimizing the process. The second crisis in 1979 caused a shift to the use of the reverse osmosis process, by developing membranes which removed over 99% of salt, with mechanical resistance capable of withstanding 70 Kg/cm² to overcome the osmotic pressure.

Reverse osmosis is based on the natural osmosis which occurs in cell membranes in living organisms, in which water diffusion moves from an area with low concentration of solutes to another with a higher concentration. The system used to desalinate is the opposite (hence the term “reverse”)—the saltwater propelled to break the osmotic pressure goes through a semi-permeable membrane, which retains water with higher saline concentration (brine) and allows water for human consumption to pass.

According to Stover [5], in the 1990s and 2000s, the innovation in the desalination industry focused on reducing energy consumption, improving the performance and reliability of the reverse osmosis membranes and the innovation of energy recovery devices. It is also worth highlighting the improvement in the processes, such as the use of a second layer of reverse osmosis for the retained water on the first stage (brine), increasing fresh water compared to raw water and decreasing residual brine. With these measures, not only did the energy used for desalination fall by half, but it was also possible to build fairly big reverse osmosis desalination plants.

Scott [6] showed that the fact that desalination costs have decreased in recent years is due to the progressive incorporation of membrane processes by those countries where energy is expensive, thus being able to replace thermal processes.

However, even in these oil exporting countries, the tendency is changing due to oil prices, as Ibáñez Mengual [7] stated, since the evaporating processes are associated with a thermal power plant. When there is an imbalance between supply and demand for electric energy, this is reflected in desalinated water production decreasing. This explains why at the time of writing desalination projects in the Middle East used 50% evaporation technology and 50% reverse osmosis technology, with a tendency to increase this latter technology.

Another relevant question to consider is the cost. There are several factors that contribute to costs: the type of technology used, the type of water to desalinate, the quality of the water that is demanded, the cost of energy, etc. Usually, the cost is divided into three blocks: investment costs, fixed operating costs and variable operating costs.

Voutchkov [8] estimated a cost share for the membrane desalination technology: approximately 35% costs are for energy; the recovery part roughly 30%, then personnel (5%), taxes (8.5%), and industrial profit (6%). The remaining percentage to reach 100% would be made up by membrane replacement, chemical products, maintenance, and other costs. It is clear from these figures how important the cost of energy is. Voutchkov reported the worldwide evolution of energy consumption, which has gone from 22 kWh/m³ in the early 1970s to a consumption of the order of 2.8 kWh/m³ (pure desalination) nowadays. It was during the 1990s when the greatest technological advances occurred. The impact of these advances can be seen on the production price of the cubic meter of desalinated water, which in the 1980s was around more than \$2/m³, and currently it is hovering around \$0.60/m³ of desalinated water.

However, desalination is not free from controversy and criticism related to the impact in the environment caused by the desalination plants. Latteman and Höpner [9] warned that the Persian Gulf has always had intense desalination activity, but that other regional centers were prominently emerging, such as the Mediterranean Sea, the Red Sea, the coastal waters of California, China, and Australia. Kämpf and Clarke [10] claimed in 2012 that the brine discharge was non-compliant with the Environmental Impact Assessment (EIA). The monitoring process in South Australia was flawed, and in 2015 the current license was modified based on the results of an independent review of the monitoring performed for the desalination plant operations. The Environment Protection Authority (EPA) has set strict compliance limits and monitoring requirements for the environmental license for the plant. Fuentes-Bargues [11] published a study on the environmental impact assessment process in Spain for seawater desalination projects with 12 years' worth of data, identifying brine discharge as the main impact. However, Shemer and Semiat [12] defended the use of reverse osmosis desalination and claimed that brine discharge has minimal impacts. Recently, Saracco [13] warned of the risk of brine contamination and pointed out how substantial damage to the marine ecosystem can be observed in the Persian Gulf area, that requires corrective action. Most of the cited authors agree that the main effect of seawater desalination plants is the discharge of the brine and its impact on the marine environment. They also agree that the solution is for the environmental authorities of each country to implement environmental impact studies that establish strict compliance limits and monitoring requirements to verify that the measures adopted are adequate.

The desalination process has required technology development these past decades at all the stages of the technology to reduce cost and negative impact and still meet the needs of society. This is more pressing where there are not enough freshwater resources to supplement quality desalinated water.

Finally, it is worth mentioning that to achieve more efficiency in the process, more complex and expensive technologies have been developed, resulting in increasing the size of the desalination plants to decrease operation and maintenance costs. Thus, in 2018, each of the ten biggest desalination plants in the world produced more than half a million cubic meters a day, with the largest of them reaching a million cubic meters daily. The following factors have to be taken into account before justifying the decision to implement a project: technical complexity, efficiency, size, and cost, forcing a search for the best-suited method of procurement to develop the project, and achieving its objectives.

The objective of the present entry is to present the requirements that new desalination plants need to meet to be compatible with sustainability requirements. Four areas are considered:

- Desalination technology, the necessary energy;
- Energy sources;
- Environmental impact and measures to neutralize it;
- Management of the construction and smooth running of the plants.

3. Data, Model, Applications and Influences

3.1. Desalination technology and energy sources

The main desalination technologies are divided into evaporation (distillation) and membranes. To evaporate, heat and electricity are necessary, while membranes only need electrical energy and have a considerably low consumption.

Torres [4] explained that in the distillation processes there are several systems depending on the use of the condensation heat of steam.

The most relevant are:

- Multi-stage evaporation or multi-stage flash distillation, known by its acronym MSF;
- Multi-effect evaporation (MED);
- Mechanical Vapor Compression (MVC).

A multiple-effect evaporator is an apparatus for efficiently using the heat from steam to evaporate water. In a multiple-effect evaporator, water is boiled in a sequence of vessels, each held at a lower pressure than the previous one. MSF is a water desalination process that distills sea water by flashing a portion of the water into steam in multiple stages that are essentially countercurrent heat exchangers.

The MED is similar to the previous process but operating at a lower pressure. In the case of multiple-effect evaporation plants, the exhaust vapors from the product are used to heat the downstream-arranged evaporation effect so that the steam consumption is reduced accordingly.

MVC refers to a distillation process where the evaporation of sea or saline water is obtained by the application of heat delivered by compressed vapor. This system is the most thermodynamically efficient process of single-purpose thermal desalination plants.

Reverse osmosis (RO) is a water purification process that uses a partially permeable membrane to remove ions, unwanted molecules, and larger particles from drinking water. In reverse osmosis, an applied pressure is used to overcome osmotic pressure. A part of the inlet water is desalinated, producing a certain amount of water with a high concentration of salt called brine.

Voutchkov [8] estimated a cost share, that approximately 35% goes to energy. Table 2 shows the energy consumption of the desalination technologies described (own elaboration).

Table 2. Desalation technologies' power requirements.

Desalination Technology	Energy Requirement (kWh/m ³)
MSF	21–58
MED	15–58
MVC	7–12
RO	3–5

Source: Own elaboration.

Desalination by nanofiltration has a similar principle to the one used for reverse osmosis. The main difference with the latter is the characteristics of the semipermeable membranes used in this technique, which offer a higher percentage of rejection of some ions from salts, which can operate at lower pressures (Parlar et al. [14]). Nanofiltration is a process that has been used in recent years but basically limited to some stages of the drinking water purification, such as softening, discoloration, and elimination of micro contaminants.

Desalination by electrodialysis consists of the passage of ions under the effect of a continuous electric current through a series of selective cationic and anionic permeable membranes, which allows the electrochemical separation of ions. The membranes, separated from each other by a few millimeters, are placed between two electrodes so that the incoming water circulates. The membranes let the ions in, by being transferred through them from a low concentrate to a higher concentrate (Lee and Kang [15]).

Electrodialysis has proved very viable, especially in brackish water desalination, in effluent treatment, and in industrial processes. It is suitable for connecting directly to photovoltaic panels, taking advantage of the use of solar energy, and it is particularly recommended in areas with isolated saline aquifers where the connection to the electrical network is difficult and expensive.

AEDYR [16] states that nowadays the most globally used technique to desalinate water is reverse osmosis, which reaches almost 70% of the total available technologies; followed by MSF (18%), MED (7%), nanofiltration (3%), and finally electrodialysis (2%).

The question is whether there is room for improvement in desalination technology, although advances in this field will undoubtedly continue to occur. Inside the reverse osmosis system, the key component is the membranes. The ones that are used at present are the result of more than 50 years of research in polymers. In the USA, MIT researchers are experimenting with graphene membranes, which require less pressure and therefore, less energy. Other researchers have studied the use of carbon nanotube membranes. Unfortunately, these technologies have not yet been developed for industrial use.

Jeff Urban [17] from Berkeley Laboratory described the line of open investigation to develop desalination by direct osmosis through a highly concentrated extraction solution to extract water from sea water. In a Berkeley Laboratory, they are developing extraction solutions, in gel form, which would extract water effectively and would then separate spontaneously from this water thanks to the application of low amounts of heat. This line is still in the research stage and the first steps would be taken by giving direct osmosis a complementary role in the brackish water treatment.

Another open line of investigation is desalination by solar energy. Many areas with water scarcity usually have a decent insolation level that can be used as solar energy. De Luis López and Gómez Benítez [18] mentioned small installations (up to 15m³/day) of solar stills to provide drinking water in Greece. The Freeport Plant, in the Gulf of Mexico, is more important, with a multiple stage system (LTV, Long Tube Vertical Multiple Effect Distillation), which guarantees a relatively good output through a progressive evaporation process at a constant decreasing pressure, producing 4000 m³/day of desalinated water. It is a small installation if we compare it with the big desalination plants that have been built in recent years. Some current investigations also revealed a model which has a manifold, an evaporation tower, and a condensation tower, but with no conclusive results yet.

Subramani and Jacangelo [19] made a critical review of new emerging desalination technologies, considering membranes that incorporate nanoparticles, carbon, or graphene nanotubes; they also analyzed alternative technologies like the ones based on the deionization and on microbial desalination cells. From all these options only nanocomposite membranes have been commercialized.

Jia et al [20] analyzed the energy consumption, greenhouse gas (GHG) emissions, and cost of seawater desalination in China. The energy consumption and GHG increased from 81 MWh to 1561 MWh from 2006 to 2016. The unit product cost (UPC) of seawater desalination is shown in the table 3. They concluded that there was potential for energy consumption, GHG emission, and cost reduction with the application of energy recovery units, the integration of desalination plants and renewable energies or low potential heat, as well as the development of new technologies.

Table 3. Unit product cost of seawater desalination technologies.

Desalination Technology	UPC (USD in 2016)
RO	0.8 to 1.3
MED	2.0
MSF	3.6
ED	3.0

Source: Jia et al.

However, the energy cost is still the most significant in large industrial desalination plants, as well as the consequences regarding the sustainability of generating the necessary energy.

Improvement is still possible, mainly in three aspects:

- Design;

- Equipment and materials, especially highlighting membranes and pumps;
- Energy recovery systems.

The next significant step would be to lower the working pressure, which would reduce energy consumption (AEDYR [16]).

For years, there has been progress in renewable energy production plants, mainly solar and wind, associated with big desalination plants. Kalogirou [21] studied seawater desalination using renewable energy sources. Charcosset [22] provided a state-of-the art review on membrane processes associated with renewable energies for seawater and brackish water desalination. Eltawil [23] provided a review of renewable energy technologies integrated with desalination systems. Petersen et al. [24] and Lindermann [25] studied wind and solar powered desalination plants for the Mediterranean, Middle East, and Gulf countries. Ghermandi and Messalem [26] provided a state-of-the art on renewable powered seawater desalination plants. Palenzuela et al. [27] valued the use of solar power and desalination plants in arid regions.

Initially, renewable energies were not efficient enough to meet the energy demand of large desalination plants. The technological development produced in recent years allows a wind or solar plant to guarantee the demanded electricity supply. For this reason, it is now common to award construction contracts for seawater desalination plants associated with photovoltaic or wind solar plants. In 2019, ACWA Power [28] awarded the Taweelah desalination plant (reverse osmosis) in the United Arab Emirates with a capacity of 909,000 m³/day, including the construction of a 40 MW solar photovoltaic plant. In 2020, ACWA Power [29] awarded the construction of the 600,000 m³/day Jubail 3A osmosis plant in Saudi Arabia, associated with a solar plant.

As another example, Southern Seawater Desalination Plant, SSDP, located in Binningup, Australia, produces up to 100 billion liters of fresh drinking water a year, around 30% of Perth's water supply. It started production in 2011. The plant is owned by Water Corporation, a public company dependent on the Western Australian Government, which is the main provider of drinking water supply and wastewater treatment services to more than two million people throughout more than 2.6 million square kilometers in Western Australia. Water Corporation [30] says that since production commenced in 2011, WC has purchased energy from a wind farm and a solar farm near Geraldton: Mumbida Wind Farm [31] (55 MW) and Greenough Solar Farm [32] (80 Has, 10 MW). Both the wind and solar farms were developed on the back of a long-term energy purchase agreement associated with the Southern Seawater Desalination Plant.

Stover [5], a member of the Board of Directors of the International Desalination Association, claims that reverse osmosis is still the dominant technology for desalination. Innovation is promoted to increase freshwater performance, to reduce residual brine, and to deal with harder water sources, because innovation stimulates the growth of desalination in industrial and inland brackish water applications.

3.2. Environmental impact of desalination plants

There used to be a huge controversy about the environmental impact of desalination plants, but measures taken these past few years have improved the situation and people now accept the technology. The actions taken to minimize the environmental impact have been simultaneously studied with the technological developments done to make desalination plants more efficient. Some countries have passed strict environmental regulations for both environment effect investigation and control of compliance with the corrective measures approved, significantly improving this matter.

However, the type of technology used to desalinate, and the environmental regulations of certain countries or regions can still cause significant impacts. Raluy et al [33] studied life cycle assessment of MSF, MED, and RO; Mezher et al [34] analyzed technoeconomic assessment and environmental impacts of desalination technologies such as MSF, MED, RO, and hybrid MSF/MED-RO; Van der Bruggen and Vandecasteele [35] gave an overview of process evolutions in desalination of seawater by distillation versus membrane filtration; Najafi et al [36] developed environmental cost analysis of MSF, MED, MVC, and RO, making a performance comparison between MSF and RO (Table 4).

Table 4. Performance comparison of multi-stage flash distillation (MSF) and reverse osmosis (RO).

Component	MSF	RO
Recovery percentage	10–20%	30–50%
Investment (\$/m ³ ·day)	1000–1500	1500–7000 (Including 10% for membranes)
Chemicals \$/m ³	0.03 to 0.05	0.06 to 0.10

Component	MSF	RO
Brine Quality	Chemicals and Heat	Chemicals
Robustness	High	Medium (Problems: fouling sensitive and feed water monitoring)
Improvement Potential	Low	High

Source: Najafi et al.

In this respect, Saracco [13] warned of the risk of contamination by brine disposal, which is significantly higher using evaporation as compared to osmosis. Saracco also pointed out the substantial damage done to the marine ecosystem in the Persian Gulf area.

Jones et al. [37] reported that according to their estimates, brine production is around 142 Hm³/day, approximately 50% higher than had been foreseen. Brine production in Saudi Arabia, the United Arab Emirates, Kuwait, and Qatar represents 55% of the global total, where there are not even emissaries with diffusers or prior dilution. They warn of the need to establish brine management strategies to limit negative environmental impacts and to reduce the economic cost of its disposal, thus stimulating new developments in desalination plants to safeguard water supplies for current and future generations.

According to AEDYR [16], Table 5 shows the salinity of different types of water, indicating the level of salt reduction that desalination plants must achieve.

Table 5. Different salinity water.

Water Type	Salinity (gr/l)
Freshwater	Less than 1 gr/l
Sea water average salinity	35
Sea water	35–45
Brackish water	3–25
Red Sea	42–46
Persian Gulf	40–44
Mediterranean Sea	36–39
Caribbean Sea	34–38
Indian Ocean	33–37
Pacific Ocean	33–36
Atlantic Ocean	33–36
Baltic Sea	6–18
Caspian Sea	12
Dead Sea	350–370

Source: AEDYR.

Nevertheless, there are already countries that are working on the correction of environmental impacts. Spain, Australia, and other developed countries have applied legislation that guarantees the correction of environmental impacts through follow-up programs whose reports are made public.

The environmental impacts and the corresponding corrective measures must be studied as much during the construction of a plant as during the desalination plant lifetime.

In Spain, Law 21/2013 on Environmental Assessment [38] includes the Directives of the European Union in this regard. This law requires an Environmental Impact Statement to be made for each project, which must be approved by the Ministry of the Environment. In the case of desalination plants, ACUAMED, a public company under the Ministry of the

Environment, supervises compliance with environmental impact measures.

Martínez de la Vallina [39], Environment Director of the Public Company ACUAMED in charge of the construction and operation of desalination plants in Spain, presented a technical communication in the National Environment Congress held in 2008, where he explained the adopted measures to minimize and restore the environmental impacts caused by the construction and operation of desalination plants on the coast of the Mediterranean Sea.

From the requirements established by ACUAMED and the experience accumulated in the projects developed by the authors, the aspects to consider are indicated.

The most relevant points to bear in mind during construction are:

- Starting from the study phase, the representatives of the communities that live near or within the catchment area of a possible plant location should be included in the decision process that may affect these communities;
- The location of the plant and its integration into the environment. This is always difficult because the plant will necessarily always be situated near the coastline;
- The areas affected by work installations, quarries, landfill sites, etc., in order to consider restoration measures;
- The seawater intake area and its connection to the plant;
- The marine and land fauna which might be either temporarily or permanently affected, which would require studies for corrective measures;
- The marine and land flora affected by the works;
- The connections of the plant with the nearby road network and the effects construction vehicles have on it;
- The connections with the electricity grid and its possible environmental impact;
- The piping connections with the general system supply network.

The most relevant points to consider during the operation of the plant are:

- Maintenance of the adopted measures for the environmental integration of the plant;
- Brine discharge control measures to preserve the marine flora and fauna in the area;
- Purification of reject waters resulting from the treatment of drinking water supplied to the network;
- Conservation and maintenance of the adopted measures not to harm or damage the marine and land fauna;
- Conservation and maintenance of the road network due to the deterioration by the vehicles from the plant;
- Adequate surveillance of the plant's connection pipe network.

The environmental protection measures adopted in Australia are now outlined here for (a) the construction of large desalination plants compatible with sustainable development, including their corrective measures and (b) the monitoring measures to make sure the compliance and outcome of the measures are followed during the operation of the plant.

In the case of Australia during the tender stage for the award and construction of a desalination plant, all the interested companies were given the report and recommendations from the Environmental Protection Authority (EPA), Report 1302 [40]. Regarding the specific desalination plant mentioned above, the Southern Seawater Desalination Project, the Water Corporation transferred this report from the Environmental Protection Authority in Perth, Western Australia.

The report must set out the key environmental factors identified in the course of the assessment, and the EPA's recommendations as to whether or not the proposal may be implemented. If the EPA recommends that implementation be allowed, the conditions and procedures to which implementation should be subject.

The EPA decided that the following key environmental factors relevant to the proposal required detailed evaluation in the report:

1. Water quality and marine biota—impacts from construction and operation of the desalination plant;
2. Terrestrial fauna—impacts from clearing of habitat;

3. Terrestrial vegetation and wetlands—impacts from clearing during infrastructure construction;

4. Greenhouse gas emissions—proposed no net greenhouse gas emissions.

The following principles were considered by the EPA in relation to the proposal:

1. The precautionary principle;

2. The principle of inter-generational equity;

3. The principle of conservation of biological diversity and ecological integrity; and

4. The principle of waste minimization.

Having considered the proponent's information provided, the EPA has developed a set of conditions that it recommends be imposed if the proposal by the Water Corporation of Western Australia, to construct and operate an 100 GL per annum reverse osmosis seawater desalination plant at Binningup, and associated infrastructure, is approved for implementation. Matters addressed in the conditions include the following:

- Water quality and marine biota;
- Marine fauna;
- Terrestrial fauna;
- Terrestrial flora and vegetation;
- Wetlands; and
- Greenhouse gas emissions.

For the above-mentioned project, EPA required the set of conditions shown in Table 6.

Table 6. Key environmental factors.

Element	Description
General	
Capacity	50 Gigalitres per year initial capacity 100 Gigalitres per year ultimate capacity
Power requirement	50 Megawatts annual average
Power source	100% renewable energy from Western Power Grid
Clearing of vegetation required	Not more than 20 hectares (at plant site)
Rehabilitation	7 hectares minimum
Offset (rehabilitation)	13 hectares minimum
Seawater intake	
Intake volume	Average 722 Megaliters per day
Length (indicative)	Extending from 400 to 600 m offshore
Number	Up to 4 pipes
Diameter	Up to 3 m
Concentrated seawater discharge	
Discharge volume	418 Megaliters per day (average)
Salinity	Up to 65,000 milligrams per liter
Temperature	Not more than 2 °C above/below ambient seawater
pH	6–8
Length (indicative)	Extending not more than 1100 m offshore

Element	Description
Number	Up to 4 pipes
Diameter	Up to 3 m
Diffuser	Located between 600 and 1100 m offshore and up to 450 m in total length
Sludge	
Sludge production	30 tons per day (approximately)
Water Transfer Pipeline	
Length	30 km (approximately)
Diameter	1400 mm
Destination	Harvey Summit Tank Site
Clearing of native vegetation	Not more than 7 hectares (in pipeline corridor)
Rehabilitation	7 hectares minimum
Harvey Summit Tank Site	
Number of tanks	Up to 4
Capacity of each tank	32 Megaliters
Sump size	2 Megaliters (upgradeable to 5 Megaliters)
Clearing of native vegetation	Not more than 0.1 hectares

Source: Water Corporation

Christie and Bonnélye [41], in a conference paper at the world congress of the International Desalination Association, held in Dubai in 2009, presented the results of two years of monitoring the operation and environmental impact of the first large desalination plant using reverse osmosis constructed in Australia, the Perth Seawater Desalination Plant (PSDP), with a production capacity of 45 GL/year, which was completed in November 2006 and handed to the Water Corporation in April 2007.

Every year, Water Corporation publishes a detailed monitoring report on the corrective measures of each of the two desalination plants it operates, PSDP [42] and SSDP [43]. The results obtained from the monitoring plan are very positive, since they demonstrate that the natural environment is not affected.

The way to protect the environment developed by countries such as Spain or Australia are examples to be followed by other countries which are developing important desalination projects without adopting the necessary environmental protection.

As a conclusion regarding the environmental impact caused by desalination plants, it can be asserted that by adopting the appropriate corrective measures and monitoring their implementation and effects, said environmental impact is perfectly acceptable due to the enormous benefits of guaranteeing drinking water supplies to populations with severe supply shortage. Moreover, the use of desalinated water frees other sources of supply, allowing the rise of phreatic values, the recharge of aquifers (depleted in many cases by over-exploitation), freeing river intakes, which allows rivers to be recovered as a fish habitat, and the recovery of wetlands and natural lakes.

3.3. Decision support system and type of contract

A significant increase in the size of the plants has been observed due to technological development and the effect of economies of scale. The bidding process, financing, the selected type of contract, the operation, and maintenance are the key factors for the achievement of the objectives set in the development of a desalination plant. This situation makes these plants increasingly complex, making the choice of contract decisive.

At the end of the 20th century, the type of contract for projects in question was part of the selection process and professional advisors in the sector proposed contract models that helped investors find the best contract for each specific project. These decision support methods or systems are known in the international market as "Decision Support Systems"

(DSS). There are numerous authors who have proposed different methods, such as Gordon [44]; Bennett, Potthecary, and Robinson [45]; Molenaar [46]; Konchar and Sanvido [47]; Ibbs et al. [48]; Gransberg, Koch, and Molenaar [49]; Hale et al. [50]; Touran et al. [51]; Park and Kwak [52]; Sullivan et al. [53]; and Jiyong, Wang, and Hu [54].

From among the numerous decision support systems, authors have proposed the method of determining factors [55], published in 2020: (1) client, (2) contractor, (3) contract, (4) budget, (5) financing, (6) risks, and (7) technological developments. It offers a procedure which adapts to any kind of project, specially indicated for large-scale infrastructure projects.

This method consists of the quantitative and qualitative evaluation of the mentioned factors. The qualitative evaluation analyzes the client and contractor capabilities, the suitability of the contract and the assignment of responsibilities, the feasibility of budget compliance and financial availability to meet payments, the risks of the development of the project, and the technological innovations implemented. The quantitative evaluation consists of assigning a score from 1 to 5 to every determining factor, with an increasing value the higher the degree of compliance. The method that will indicate the degree of compliance of each determining factor is applied to each contract modality, so that the higher the score, the more suitable the type of chosen contract will be to develop the project.

The international industrial construction market has great dynamism, which leads those involved in the project to look for new contracting formulas which adapt to their needs, in order to carry out the project. It is normally done by combining other types of contract or modifying the existing ones according to said particular needs. Many authors have written about the most used types of contracts and their differential characteristics, such as El-Wardani, Messner, and Horman [56]; Ohn and Rogers [57]; Hinze [58]; Chamarro [59]; Franz et al. [60]; and Farnsworth [61].

Therefore, updating the list given by Hernández [62], the most used types of contracts are summarized below:

(a) Traditional contract or "Design then bid" or "Design Bid Build" (DBB). This implies the participation of at least three parties: client, engineering, and contractor. This results in the division of the project into design and construction phases. The construction will start once the project is completed. The client uses this method when they feel more confident about a completed project.

(b) Accelerated construction process or "fast track construction". This contract allows construction work to begin before the project has been drawn up completely. It implies a fragmentation of the project into different phases.

(c) "Project Management". This attribute the functions of supervision, direction, and coordination of the project as a whole to an entity, called the Project Manager, which through their services, tends to get maximum control and a consequent reduction in the time and costs involved in the execution of the work. Compared to the traditional method, it involves the participation in the process of a fourth part.

(d) "Design and build" (DB) and turnkey contracts imply a progressive expansion of the obligations assumed by the contractor. It involves that the general contractor is tasked with gathering a group of designers and constructors to carry out the work. In the late twentieth century, English/American law had a great influence in the international arena of contracts. Thus, through the design and build contract, the contractor undertakes to conceive and execute the industrial project in accordance with the needs and requirements of the client. Therefore, the benefits derived from this contract are limited to the construction operation itself. Obligations outside the contract, such as the commissioning of the installation or the training of personnel, are not included in its content, as in the case of the turnkey contracts.

Based on this difference in content between the two contracts, it can be claimed that while a design and build contract can never be equated to a turnkey contract, a turnkey contract, however, always includes the obligations derived from the design and build contract.

(e) BOT and BOOT projects. The formula BOT (Build-Operate and Transfer) as well as the contracts called BOOT (Build-Own-Operate and Transfer) are different mechanisms used to finance projects (Project Financing) of mainly infrastructures or public works, through which the public sector has been transferring to the private sector.

(f) "Engineering" contracts. Through these contracts, a party (the engineering company) subcontracts another party (called client) to develop manage and supervise a project, and when agreed, depending of circumstances, other obligations, including the maintenance and management of the finished work.

(g) "Engineering, Procurement, and Construction Management", also known by its acronym EPCM, which means that in this type of Engineering Contract the Contractor will provide the Client with Engineering Services, Purchasing Management, and Construction Management. In the EPCM contract, the Contractor develops engineering, processes

acquisition, and manages the work on behalf of the Client, but does not construct the project. The Client will be ultimately responsible for the acquisitions and approve all contracts. Thus, the construction risks fall on the client.

(h) "Open Book Estimation", OBE. An OBE contract consists of an agreement between Property/Client and Contractor to carry out work in which the costs are reimbursable to the latter, plus a previously agreed margin. Client and Contractor also agree on how to pay for the works. This type of contract has become important in recent years and has been generalized as a previous phase to the award of a turnkey contract for large industrial installations.

(i) "Progressive Design-Build", PDB, is an emerging variation of alternative contracting methods, which allows the client to hire a project and construction contractor without a price commitment until reasonable design details are defined. They have been used for water treatment plants and for airports. The critical issues are what responsibilities are transferred to the contractor, the need for the client participation during the design and the provision of cost saving measures that do not jeopardize the quality of the project. Gad et al. [63] and Gransberg and Molenaar [64] have studied this new type of contract.

In the area of desalination, the turnkey contract stands out as the most proven and efficient tool for the development of projects, offering the following advantages:

- There is a single contractor responsible for design and work, so that engineering and construction can be developed in parallel, thus shortening deadlines;
- The dialogue is limited to client/contractor;
- The global assumption of responsibility includes not only the quality requirements established by contract, but also the proposed new technological developments, and consequently, changed or modified orders which generate deviations of deadlines and budget are eliminated or reduced.

It is advisable to introduce a phase in the modality of open book estimation, prior to hiring, that allows designs and prices to be adjusted and agreed, which will reduce project risks, contingencies and deviations during the construction, leading to a better final result. This modality has been successfully offering the solutions given in the mentioned PDB.

4. Conclusions

In the present entry, we have defined: the most efficient desalination technology, energy supply sources, corrective measures for environmental impacts, and the most suitable type of contract for the construction of large desalination plants compatible with sustainable development. A discussion was also included for every corresponding point of each of the analyzed factors, their evolution, and present situation.

Considering that the main question is to guarantee the supply of water in quantity, quality, and safety to millions of people, the proposals made below offer sufficiently argued solutions. The technological developments in this field have evolved and still do very fast, so it is reasonable to expect significant improvements in the near future.

However, today, the recommendations and conclusions are the following:

1. The technology to adopt for desalination is reverse osmosis, considering the several stages and energy recovery measures and opportunities available along the process. In addition, adopting the latest generation membranes is essential to achieve the best efficiency. A significant cost reduction in RO is possible in the short term if the working pressure can be reduced without the membranes losing efficiency.
2. Regarding the consumption and production of the energy necessary for desalination, the proposed technology, including all the measures to improve efficiency, offers the safest possible means for desalination. Consumption is getting below 2.7 kWh/m³ through reverse osmosis. It is recommended to associate with the construction of these large desalination plants renewable energy production parks, fundamentally solar or wind farms; even if it is utopian to think of a plant today producing hundreds of thousands of cubic meters a day, through the exclusive supply of renewable energies;
3. From the environmental point of view, it is essential that the construction of any desalination plant, wherever it may be, should include an environmental impact study during the construction of said plant, and also include a monitoring plan that guarantees the corrective measures and the possibility of adopting new ones if impacts on the environment were detected. This monitoring must be guaranteed by an independent body from the plant operating company and must be published regularly with the supporting documentation of the results obtained during the follow-up.

4. As for the development management of these large infrastructures, it is recommended to use one of the decision support systems that justifies the chosen contractual modality for the project and construction. Today, the best contract to achieve the objective of big, complex, and expensive projects is the turnkey contract. The advantages are mainly that turnkey contracts shorten deadlines when combining design and construction and avoid or even reduce extra costs because of the closed price formula. It is, however, advisable to have an Open Book Estimation (OBE) phase before finally agreeing the binding contract.

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