Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.794573

52 (2014) 1350–1356
February

Taylor & Francis
Taylor & Francis Group

Comparative assessment of feasible options for delivery of potable water to remote coastal locations: North-West Egypt

S.A. Ahmed[a,b], M.H. Sorour[a], A.G. Abulnour[a], H.A. Talaat[a], M.M.H. El-Sayed[a,c,*]

[a] *Chemical Engineering and Pilot Plant Department, National Research Center, Cairo, Egypt*
Tel. (+202) 2615-2564; emails: Mayyada@aucegypt.edu, Mayyadas@gmail.com
[b] *Information Systems Department, National Research Center, Cairo, Egypt*
[c] *Chemistry Department, American University in Cairo, New Cairo, Egypt*

Received 6 April 2012; Accepted 13 March 2013

ABSTRACT

Growing potable water demand associated with water shortage in remote coastal communities mandates identification and evaluation of viable water supply options. This paper addresses technical and financial analysis of water supply options in northwest Egypt as a typical remote coastal community on the Mediterranean. Water supply and energy availability are the main challenges hindering possible potential development schemes. Population reallocation programs being the core of any development plan should rely upon availability and accessibility of water and energy resources. The technically feasible proposed options for water supply scenarios to northwest Egypt comprise long-distance water transfer pipeline (LDWTP), large-scale desalination, or a combination of the two. Each option has been incorporated with a water reuse component and investigated for a daily capacity of 200,000 m^3/d of fresh water. Since all the options are energy intensive in nature, they have been assessed from economic and energy standpoints. Thus, both conventional and small nuclear energy supply schemes have been considered. The estimated capital costs were \$M 741.9, 260.0, and 634.5, while the unit water costs were \$/m^3 0.92, 0.73, and 0.81 for LDWTP, desalination and joint LDWTP/desalination options, respectively. The merits of cost-effectiveness, energy saving, technical reliability, and environmental aspects were manifested by the second proposed option.

Keywords: Desalination; Potable water; Pipeline; Techno-economic study; Energy supply; North West Egypt

1. Introduction

The alarming indicators concerning potential water shortage in Egypt mandate identification of feasible water supply options for remote coastal communities and arid desert locations. The problem may approach a catastrophic limit considering potential global changes and increasing population pressure as well as the limited current water budget that amounts to less than 700 m^3/capita annually.

The northwestern coastal zone of Egypt is a rapidly developing area that accommodates the majority of holiday making and beach tourism. This area is also exposed to heavy exploitation and other economic activities such as irrigated agriculture,

---

*Corresponding author.

industry, quarrying, fishing, animal breeding, and expanding urbanization. It constitutes a strip of land that averages about 15 km in depth from the Mediterranean shoreline and in some places exceeds 30 km. The area can be divided into two main physiographic provinces: an eastern province between Alexandria and Ras El-Hikma (about 230 km west of Alexandria) and a Western province between Ras El-Hikma and Salloum at the Libyan border [1]. The landscape is divided into a northern coastal plain characterized by variable-altitude ridges dissected by depressions and a southern tableland [2].

Water and land resources for purposes of agricultural development and industrialization as well as animal resources remain limited depending on rainfall, rainwater harvesting, and water transferred via Al-Hammam Canal and its extension as well as through the existing pipeline connecting Alexandria to Matrouh [3].

The alternative sources to be considered for potential long-term supply include principally, but not limited to, water transfer through long-distance pipelines and sea water desalination with or without intensive water reuse programs. This paper proposes cornerstones for long-term water supply management as demanded by envisaged urban development. Three options will be investigated from the technical and economical standpoints, and these comprise water supply by long-distance pipeline, water desalination, and a combination thereof. The three alternatives will be compared with and without incorporating water reuse. The third option was particularly proposed in order to cope with the requirements of phased implementation plans.

From the technical point of view, the question of energy is of high priority when implementing a desalination program. For instance, a 200,000 m^3/d RO desalination plant will require a minimum of 30 MW installed power. Therefore, an array of desalination networks comprising four desalination plants of the stated capacity may require 125 MW.

From the economic point of view, the desalination alternative will be assessed using Desalination Economic Evaluation Program (DEEP) [4] as well as parametric cost estimation system [5]. In addition, the different options for energy supply will be considered and of particular interest, nuclear energy and nuclear power plants performing with gas cycle turbine, which will be considered in comparison with fossil electricity.

2. Methods

Techno-economic studies have been conducted using DEEP software that performs evaluations and screening analyses of various desalination and energy source options. DEEP output includes the levelized cost of water and power, a breakdown of cost components, energy consumption, and net saleable power for each selected option.

Other costs for large-scale desalination plants and pipelines have been estimated based on international data [6–8]. The cost indexes (Dec 2011) used to compare the obtained results with the international recorded estimates are Marshal and Swift equipment cost index for the RO option [9] and Engineering News Records (ENR) index for the pipeline option [10].

3. Developed water supply scenarios

3.1. Long-distance water transfer pipeline (LDWTP) from a suitable surface water treatment plant

This is a simple scenario for water supply that comprises installation of a conventional treatment plant at a Nile branch in Alexandria (Mahmoudia Canal) and construction of a pipeline that delivers water to the served communities. Pumping of water through pipeline is effected by a main pumping station and booster pumping stations with power

Table 1
Technical specifications of water supply pipelines and pumping stations for water supply capacity of 200,000 m^3/d

Transfer distance (km)	Pipe size (inch)	Total head (m)	Main pumping station		Booster pumping stations		Total installed power (MW)
			Number	Power (hp)	Number	Power (hp)	
50	60	72.6	1	1,807	1	1,807	2.71
100	60	115.3	1	1,909	2	1,909	4.30
150	60	157.9	1	1,968	3	1,968	5.90
200	60	200.5	1	1,998	4	1,998	7.50
250	60	243.0	1	3,200	4	2,250	9.15

Table 2
Technical specifications for RO desalination (200,000 m^3/d) option

Technical specification	Value
RO plant capacity	200,000 m^3/d
Feed water total dissolved solids	35,000 mg/l
Feed water inlet temperature	25°C
Energy recovery type	Power exchange
Recovery ratio	42%
Brine dissolved solids	60,000 mg/l
Product water dissolved solids	243 ppm
Design average permeate flux	13.6 l/(m^2h)
Nominal permeate flux	27.8 l/(m^2h)
Nominal net driving pressure	28.2 bar
Maximum design pressure	69 bar
High head pumping pressure	60 bar

capable of providing the total head required for transfer of water to the served communities. Table 1 presents the main technical specifications of water supply pipelines and pumping stations at different transfer distances and a capacity of 200,000 m^3/d. The basis and sample calculations are presented in Annex (A1).

3.2. Desalination/water reuse

In this option, drinking water is supplied via RO seawater desalination. The wastewater from the served communities is to be reclaimed for reuse in some agricultural and industrial purposes. The technical specifications of the desalination plant are given in Table 2.

3.3. Joint desalination/LDWTP

This option enables phased implementation of a dual-supply alternative. The long-distance pipeline is constructed in the first phase enabling gradual supply of 50% of the water load to the demanding area. In the second phase, the RO seawater desalting facility is to be established on a modular basis with a capacity of 100,000 m^3/d.

3.4. Advanced water reuse treatment program

The reuse concept has been evaluated technically and financially by a number of authors, especially for agricultural drainage water [11–17].

Conventional activated sludge treatment followed by tertiary treatment (fine filtration and disinfection) could be adopted to produce water suitable for some agricultural and industrial purposes. The installed power is estimated to be 1.25, 2.50, 3.75, and 5.00 MW for the selected water supply capacities of 50,000, 100,000, 150,000, and 200,000 m^3/d, respectively. The technical criteria on which these calculations were based are given in Annex (A2), and the capacity of the water reclamation plant was taken as 80% of the specified water supply capacity. The reuse component will be incorporated in the three options investigated in this paper.

4. Energy demands

Due to the intensive energy needs for the three specified options, both fossil and nuclear power will be considered.

4.1. Power requirements and energy consumption for the specified options

The power requirements for the three specified options and their complementary water reuse schemes for water supply capacity of 200,000 m^3/d are shown in Table 3.

Being the most energy-intensive option, RO seawater desalination power requirements at capacities ranging from 50,000 to 200,000 m^3/d were estimated and are shown in Fig. 1. It is clear that the required power increases linearly with increase in capacity.

4.2. Technical characteristics for conventional and nuclear power supply

Small-scale nuclear power supply reactors commonly used for desalination are gas cooled of the types high-temperature pebble–bed modular reactor, pebble bed modular reactor, gas turbine modular helium reactor, and gas turbine high-temperature reactor. They produce electrical power ranging typically from 165–274 MWe with an efficiency of 41–48%, respectively. Capital costs range between 1,200–2,600

Table 3
Installed power and unit energy consumption at 200,000 m^3/d for the three proposed options

Option	Installed power (MW)		Consumed energy (kWh/m^3)	
	I	II	I	II
Pipeline	14.47	23.10	1.34	2.14
Desalination	33.60	42.12	3.15	3.95
Pipeline/desalination (50/50)	18.00	29.26	2.97	3.77

I—without water reuse II–with water reuse.

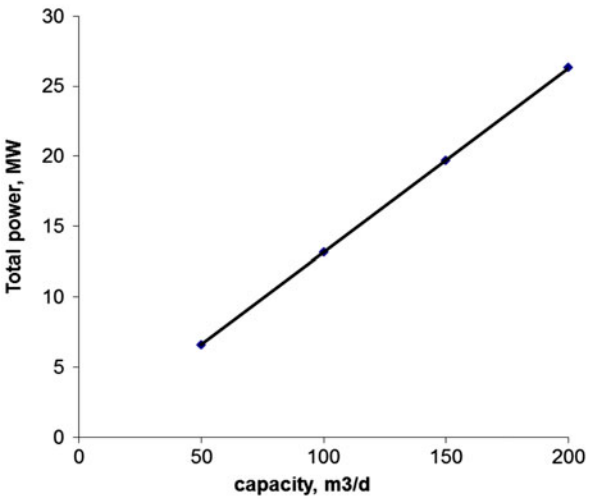

Fig. 1. Power required for RO seawater desalination at different capacities.

$/KWe, while operating, maintenance and fuel costs range between 0.021–0.012 $/KWh, respectively [18–20]. The cost of fossil fuel electricity, on the other hand, is estimated at $0.05/KWh.

5. Financial Analysis

In this section, the three proposed water supply options are compared with regard to capital, operating, and water unit costs, in addition to the cost of energy from conventional and nuclear sources for the desalination option.

5.1. LDWTP

The capital cost estimates for the pipeline and the pumping stations are presented in Tables 4 and 5, respectively, whereas the water unit cost estimates are shown in Fig. 2. Cost estimates are based on published data, ENR, and construction cost index for capital costs. Amortized capital is based on 5% interest rate. Other costs were estimated according to national practices, while revenue of reclaimed water was estimated at $0.3/m^3. Furthermore, the capital cost estimates for the surface water treatment plant for the capacities of 50 000, 100 000, 150 000, and 200 000 m^3/d are $Million 31.87, 52.75, 70.84, and 85.89, respectively.

Table 4
Pipeline capital cost ($)

Capacity (m^3/d)	Distance (km)				
	50	100	150	200	250
50,000	46.43	92.86	139.29	185.72	232.15
100,000	67.87	135.75	203.62	271.45	399.37
150,000	92.30	184.60	276.90	369.20	461.50
200,000	105.10	210.20	315.30	420.40	525.50

Table 5
Pumping stations capital cost ($)

Capacity (m^3/d)	Distance (km)				
	50	100	150	200	250
50,000	25.84	39.52	53.43	78.02	102.02
100,000	33.60	53.30	72.45	91.87	102.10
150,000	34.75	53.21	71.67	90.14	95.33
200,000	40.49	62.44	84.59	106.64	113.72

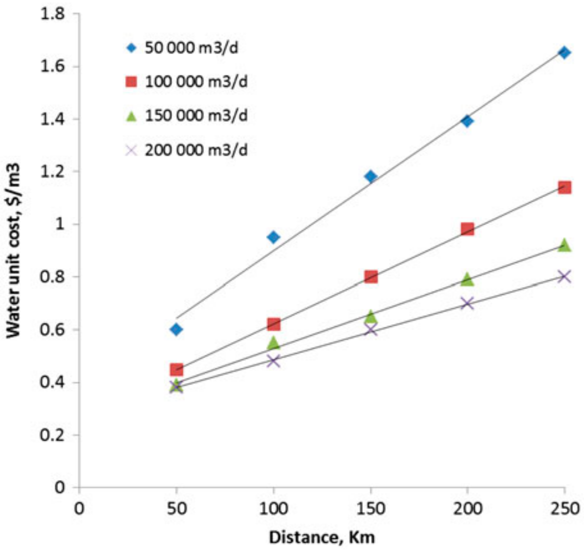

Fig. 2. Water unit cost for potable water transfer to remote coastal locations (north west of Egypt).

Fig. 2. represents the estimated unit cost for supplying potable water with capacities ranging from 50,000 to 200,000 m^3/d for water transfer distances of 50–250 km. In general, the water unit cost decreases with increase in capacity for all distances.

5.2. Seawater desalination

The capital cost estimates for RO systems with a capacity range of 50,000–200,000 m^3/d are shown in Fig. 3. The figure depicts the international capital costs based on reported data. Small differences are shown when comparing the results of the DEEP to its counterpart international capital costs calculated using the equation $y = 11.538x + 57.482$ based on data given by [5,9].

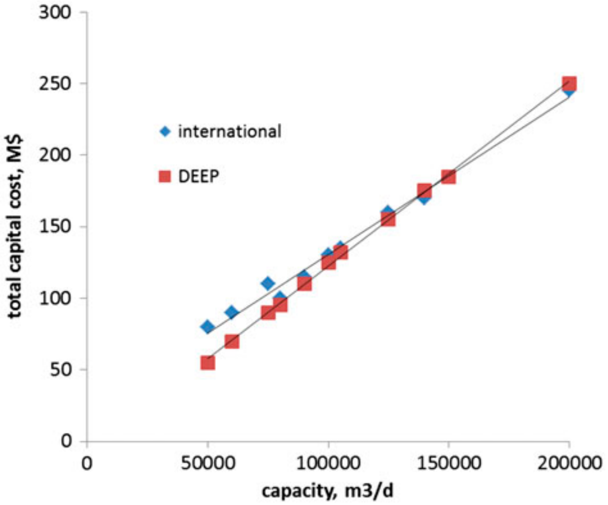

Fig. 3. Effect of RO capacity on the capital costs estimated using DEEP and reported 2010 data [5,9].

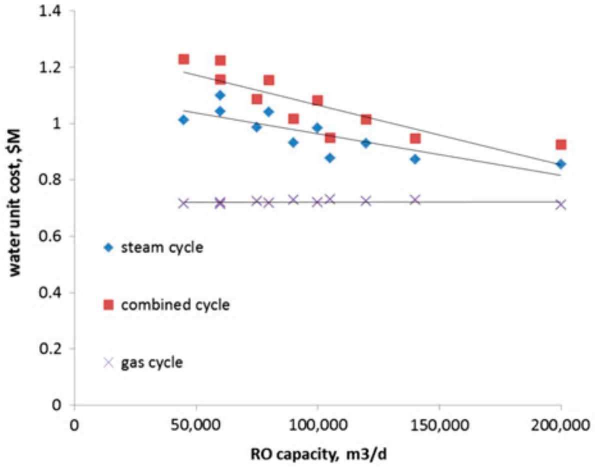

Fig. 5. Comparison of unit cost of water production at different RO capacities using three alternative nuclear energy sources.

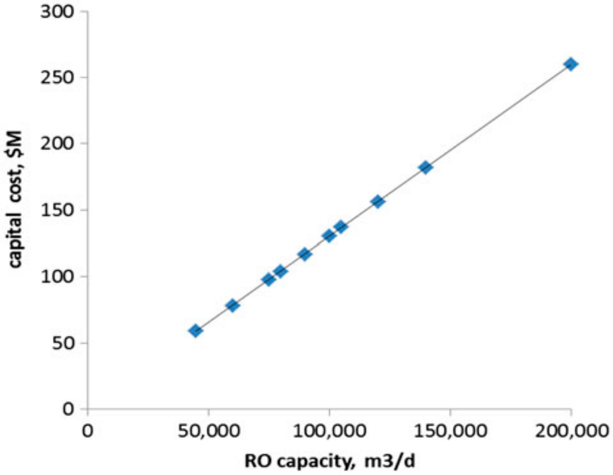

Fig. 4. Effect of RO capacity on capital cost for seawater desalination.

RO seawater desalination capital costs as estimated by DEEP for capacities ranging from 50,000 to 200,000 m^3/d are shown in Fig. 4.

Comparison of the types of small nuclear power electricity plants shows moderate variation in the water unit cost as depicted in Fig. 5. Three alternative sources of energy are investigated, namely steam, gas, and combined sources. In the figure, the unit cost of water production is shown as a function of RO capacity at the four energy alternatives. Providing the lowest unit water production cost, the gas cycle nuclear power plant has been chosen for carrying out the rest of this study. A simple gas cycle operates on the principle of the Brayton Cycle and is comprised of three main units: a compressor, a combustor, and a power turbine.

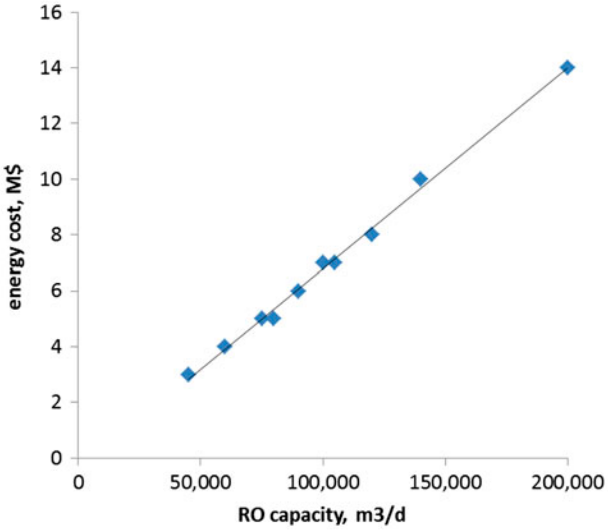

Fig. 6. Energy cost at different RO capacities.

The cost of energy required for RO desalination at different capacities is presented in Fig. 6. As shown, energy cost increases linearly with increase in capacity.

A comparison of the capital, operating and maintenance, and unit water costs for water supplied by the three proposed options (long-term water transfer pipeline, desalination, and combination of both) is presented in Table 6.

For Matrouh city (250 km from Alexandria), the desalination option has the lowest cost among the different proposed scenarios. The hybrid system, with 50% of water supplied by desalination and 50% provided by water transfer through pipelines, has an

Table 6
Comparison of the capital, O&M, and unit costs for long-term water transfer pipeline, desalination, and hybrid system

Capacity (m^3/d)	Capital cost ($M)			
	Water transfer	Desalination	Hybrid system (50/50)	Reuse
50,000	371.7	65	–	31.9
100,000	503.5	131	431	52.8
150,000	640.1	195	558	70.8
200,000	741.9	260	686	85.9
O&M ($M/year)				
50,000	8.4	3	–	2.59
100,000	11.4	6	11.4	4.30
150,000	13.1	10	13.3	5.75
200,000	16.3	13	17.4	7.00
Unit cost (\$/m^3)				
50,000	1.66	0.73	–	0.30
100,000	1.11	0.73	1.19	0.25
150,000	0.92	0.73	1.07	0.23
200,000	0.81	0.73	0.92	0.22

intermediate capital cost value that lies between the value pertaining to desalination *per se* and that pertaining to pipeline water transfer *per se*. The O&M and unit water costs, on the other hand, are slightly higher than those for the desalination option. However, the hybrid system has the merit of providing two sources for water supply, with potentially higher reliability than a single source. In addition, water reuse cost is economically feasible with saleable reclaimed water price of \$0.3/m^3.

6. Environmental concerns

Perhaps the second alternative for desalination is the worst from the environmental point of view because of the excessive amount of concentrate to be disposed of through marine outfall. The water transfer pipeline exhibits minimal environmental impact since it does not generate any concentrate. However, sludge removed from surface water at the source may be a disadvantage.

7. Implementation action strategy

The development of north-west communities would be controlled by a phased implementation plan, and the water demand would be geared to a population development scenario. Thus, the third alternative for joint LDWTP/desalination may be the appropriate choice since it secures the growing water demand through the long-distance pipeline while implementing the desalting plant at mid-construction period of the pipeline.

8. Conclusions

Water supply cost by LDWTP was found to significantly vary with location (distance from water source) and capacity, while this case does not hold true for the desalination option. The distances corresponding to different capacities and equal unit water cost of 0.73 \$M (value obtained for desalination) are 70, 130, 175, and 210 km for capacities of 50,000, 100,000, 150,000, and 200,000 m^3/d, respectively.

From the economic point of view, desalination would be the option of choice for water supply to north-west communities. However, considering environmental issues and coping with the requirements of phased implementation would lead to selecting the 50/50 joint desalination/LDWTP option.

Acknowledgement

"This work was financially supported by the Science and Technology Development Fund (STDF) of Egypt, under grant number STDF/1689".

References

[1] Y. Ayad, Remote sensing and GIS in modeling visual landscape change: A case study of the northwestern arid coast of Egypt, Landsc Urban Plann 73 (2005) 307–325.
[2] B.B. Salem, Remote Sensing of Vegetation and Land Use in the Northwestern Desert of Egypt, [PhD Thesis], Faculty of Science, Alexandria University, Egypt, 1989
[3] M.A. Ayyad, Regional Environmental Management of Mediterranean Desert Ecosystems of Northern Egypt (REMDENE), A Project Proposal Submitted to the US Environmental Protection Agency for Support, Mimeo, NY, 1978.
[4] Desalination Economic Evaluation Program (DEEP), Computer Manual Series No. 14, International Atomic Energy Agency, Vienna, 2000.
[5] Reclamation managing water in the west, Desalination and Water Purification Research and Development Report No. 114, Industry Consortium Analysis of Large Scale RO/NF Element Diameters, Agreement No. 03-FC-81-0916, U.S. Department of the Interior Bureau of Reclamation, 2004.
[6] R. Borsani, S. Rebagliati, Fundamentals and costing of MSF desalination plants and comparison with other technologies, Desalination 182 (2005) 29–37.
[7] TWDB Report Chapter 4 Appendix 4C—Cost Estimating Procedures, Region H Water Planning Group Regional Water Plan, Texas, TX, 2006.
[8] Economics of Nuclear Desalination: New Developments and Site Specific Studies, Final Results of A Coordinated Research Project (2002–2006), IAEA-TECDOC-156, July 2007.
[9] Marshal and Swift Index. Available from: http://www.scribd.com/doc/54267761/Chemical-Engineering-Plant-Cost-Index-ei-201102, Dec 2011
[10] ENR. Available from: http://enr.construction.com/economics/, Dec 2011

[11] H.A. Talaat, N.M.H. El-Defrawi, M.H. Sorour, A.G. Abulnour, A short cut procedure for the design and monitoring of continouus flow sedimentation or thickening tanks, J. Bioprocess. Biosyst. Eng. 6 (1991) 249–257.

[12] M.H. Sorour, A.G. Abulnour, H.A. TALAAT, Desalination of agricultural drainage water, Desalination 86 (1992) 63–75.

[13] A.G. Abulnour, M.H. Sorour, H.A Talaat, Comparative economics for desalting of agricultural drainage water (ADW), Desalination 152 (2003) 353–357.

[14] H.A. Talaat, MH. Sorour, N.A. Rahman, H.F. Shaalan, Pretreatment of agricultural drainage water (ADW) for large-scale desalination, Desalination 152 (2003) 299–305.

[15] H.A. Talaat, M.H. Sorour, A.G. Abulnour, H.F. Shaalan, The potential role of brackish water desalination within the egyptian water supply matrix, Desalination 152 (2003) 375–382.

[16] Safaa R. Ahmed, Shadia R. Tewfik, H.A. TALAAT, Development and verification of a decision support system for the selection of optimum water reuse schemes, Desalination 152 (2003) 339–352.

[17] H.A. Talaat, Safaa R. Ahmed, Treatment of agricultural drainage water: technological schemes and financial indicators, Desalination 204 (2007) 102–112.

[18] http://energy-alaska.wikidot.com/

[19] http://www.world-nuclear.org/info/inf33.html

[20] A.C. Kadak, R.G. Ballinger, T. Alvey, C.W. Kang, P. Owen, A. Smith, M. Wright, X. Yao, A Response to the Environmental and Economic Challenge of Global Warming Phase 1 Review of Options & Selection of Technology of Choice, Massachusetts Institute of Technology Independent Activities Period, January 1998, Boston, MA.

[21] M.S. Peters, K.D. Timmerhaus, R.E. West, Plant Design and Economics for Chemical Engineers, fifth ed., McGrawHill, Boston, MA, 2004 (Chapter 12), p. 485.

Annex (A2) technical basis for pipeline option:

System components: pipeline of ductile cast iron or coated steel (16 bar), pumping station with a standby power supply, conventional surface water treatment plant (including in-take pre-chlorination, coagulation and flocculation, settling, filtration, and post-chlorination). Water reclamation for water reuse treatment plant will include the following: a mechanical screen, oil and grit removal unit, primary settling tanks, activated sludge aeration tanks and secondary settling tanks, chlorination, filtration and sludge pumping, and thickening and mechanical dewatering.

Technical pipeline calculation basis: (velocity $\leqslant 1.5$ m/s, load factor 0.9): head losses include frictional losses according to procedures given in Ref. [21], minor losses equal to 0.05 of frictional losses and static head of 30 m. Water treatment from Nile branch, with typical characteristics to be treated according to WHO standards. Wastewater to be reclaimed represents 0.8 of the water supply with conventional domestic sewage characteristics, and this was treated according to standard practice of activated sludge followed by disinfection and filtration. Power requirements in pumping stations were calculated based on actual head required for each case. Power consumptions for water treatment and wastewater treatment are 0.5 and 1 KWh/m^3, respectively.

Appendices

Annex (A1) general specifications of the large-scale desalting plants

Table (A1) technical characteristics of water supply pipelines and pumping stations

Capacity (m^3/d)	Transfer distance (km)	Pipe size (inch)	Total head (m)	Main pumping station		Booster pumping stations		Total installed power (MW)
				Number	Power (hp)	Number	Power (hp)	
50,000	50	30	1,244	1	768	1	768	1.15
	100	30	2,168	1	855	2	855	1.92
	150	30	3,152	1	918	3	918	3.67
	200	30	407.6	1	797	5	797	3.58
	250	30	502.0	1	1,020	6	870	4.68
100,000	50	42	97.6	1	1,203	1	1,203	1.81
	100	42	165.2	1	1,358	2	1,358	3.06
	150	42	232.8	1	1,434	3	1,434	4.30
	200	42	300.4	1	1,480	4	1,480	5.55
	250	42	368.0	1	2,000	4	2000	6.90
150,000	50	54	70.5	1	1,304	1	1,304	1.96
	100	54	111.0	1	1,368	2	1,368	3.08
	150	54	151.5	1	1,400	3	1,400	4.20
	200	54	192.0	1	1,419	4	1,419	5.32
	250	54	231.5	1	2,700	4	1,500	6.53

Based on frictional head static, other minor head losses (5% of frictional loss) and static head of 30 m.