

RECLAMATION

Managing Water in the West

Desalination and Water Purification Research
and Development Program Report No. 130

WT Cost II

Modeling the Capital and
Operating Costs of Thermal
Desalination Processes Utilizing a
Recently Developed Computer
Program that Evaluates Membrane
Desalting, Electrodialysis, and Ion
Exchange Plants



U.S. Department of the Interior
Bureau of Reclamation

February 2008

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD-MM-YYYY) February 2008		2. REPORT TYPE Final		3. DATES COVERED (From - To) Final	
4. TITLE AND SUBTITLE WT Cost II Modeling the Capital and Operating Costs of Thermal Desalination Processes Utilizing a Recently Developed Computer Program that Evaluates Membrane Desalting, Electrodialysis, and Ion Exchange Plants				5a. CONTRACT NUMBER Agreement No. 04-FC-81-1038	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Irving Moch, Jr., I. Moch and Associates, William R. Querns, Querns Engineering Services, LLD, and Darlene Steward, Boulder Research Enterprises, LLC				5d. PROJECT NUMBER	
				5e. TASK NUMBER Task F	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of the Interior Bureau of Reclamation, Technical Service Center ,Denver Federal Center PO Box 25007, Denver CO 80225-0007				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) DWPR Report No. 130	
12. DISTRIBUTION / AVAILABILITY STATEMENT Available from the National Technical Information Service (NTIS), Operations Division, 5285 Port Royal Road, Springfield VA 22161					
13. SUPPLEMENTARY NOTES Report can be downloaded from Reclamation Web site: www.usbr.gov/pmts/water/publications/reports.html					
14. ABSTRACT (Maximum 200 words) A water treatment cost estimating program, WTCost II [®] , has been developed for all commercial desalting processes involving membrane desalinations (reverse osmosis and nanofiltration), thermal evaporative desalination plants using technologies of multistage flash distillation, multieffect distillation and vapor compression (mechanical and thermal), ion exchange, and electrodialysis. These processes and their associated unit operations have been seamlessly blended into an already developed computer program called WTCost [®] . The thermal processes include both single purpose (production of desalted water only – power obtained from the grid) and dual-purpose (manufacture of desalinated water wherein the power is derived from a coupled powerplant) plants and, also, hybrid concepts. The program also scopes media filtration and low-pressure membranes, microfiltration and ultrafiltration. All these water treatment processes can be employed singularly or in series or parallel combinations.					
15. SUBJECT TERMS Desalination, Cost Estimation, Distillation, Thermal Desalination, Construction Cost, Operation and Maintenance Cost					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 40	19a. NAME OF RESPONSIBLE PERSON Michelle Chapman
a. REPORT UL	b. ABSTRACT UL	c. THIS PAGE UL			19b. TELEPHONE NUMBER (include area code) 303-445-2264

**Desalination and Water Purification Research
and Development Program Report No. 130**

WT Cost II

Modeling the Capital and Operating Costs of Thermal Desalination Processes Utilizing a Recently Developed Computer Program that Evaluates Membrane Desalting, Electrodialysis, and Ion Exchange Plants:

**Case Study for a Seawater 20-million-gallon-per-day (MGD) Hybrid System
Involving 10-MGD Multistage Flash Distillation Plus 10-MGD Reverse Osmosis**

Prepared for Reclamation Under Agreement No. 04-FC-81-1038

by

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**U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Water and Environmental Services Division
Water Treatment Engineering Research Team
Denver, Colorado**

February 2008

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Abstract

A computer cost estimating program, WTCost II[®], has been developed for all commercial desalting processes involving membrane desalinations (reverse osmosis and nanofiltration), thermal evaporative desalination plants using technologies of multistage flash distillation, multieffect distillation and vapor compression (mechanical and thermal), ion exchange and electrodialysis. The Bureau of Reclamation has been a sponsor. These processes and their associated unit operations have been seamlessly blended into an already developed computer program called WTCost[®]. The thermal processes include both single purpose (production of desalted water only - power obtained from the grid) and dual-purpose (manufacture of desalinated water wherein the power is derived from a coupled power plant) plants and, also, hybrid concepts. The program also scopes media filtration and low pressure membranes, microfiltration and ultrafiltration. All these water treatment processes can be employed singularly or in series or parallel combinations.

With these water technologies on one CD ROM program, a user can now evaluate any treatment system using a standard desalination cost format. Thus, direct comparisons can be made, enabling a customer to define what are the least costly process and technology alternatives for a project tender. Further, this procedure is a teaching tool and will also enable researchers to evaluate their studies for commercial viability at any point in time. Experts have assessed the consistency and accuracy of all subsystems against recent awards and found the results to be very reasonable.

The initial WTCost[®] program has been enhanced to cover such additional areas of currency exchanges, land acquisition, insurance, electrochlorination, and value added tax. Over 90 copies of it have been released to the domestic and international markets. Reports back have been very positive as to the program's content and user friendliness; it has been found to provide reasonable results in comparison to past projects and in answering questions on future tenders.

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Introduction

One of the many problems faced by policy and decisionmakers, end-users, consultants, contractors etc. when evaluating alternative water treatment and resource options, is defining, with some accuracy, all of the capital and operating costs associated with a treatment plant. The credibility of a planning estimate usually depends a great deal on the cost reports received from various operating facilities. However, the capacity requirements, water characteristics, and local conditions such as water intake, brine disposal options, land cost, electricity price, and labor rates for the contemplated facility rarely match conditions for the plant under study. These inconsistencies also make comparisons between alternative technologies (e.g., between reverse osmosis (RO) and multistage flash distillation (MSF) difficult and evaluations of planning, research, and development projects onerous.

To make a planning cost evaluation meaningful, it is desirable to have available a defined format. Such a format is, today, nonexistent, highly fragmented, or subject to the agenda of the evaluator. To create an unbiased, comparative, and planning standard means that cost estimates must include the same basis items and variable factors such as electricity, chemicals, labor, maintenance, equipment, building costs, overheads, interest rates, amortization period, land costs, insurance, contingencies, and profit. In this manner, cost estimates can be adjusted and analyzed on a common basis. One way of ensuring that these criteria are met is to develop a common computer model for process capital and operating and maintenance costs.

The Middle East Desalination and Research Center (MEDRC) and the Bureau of Reclamation (Reclamation) have deemed these problems as urgent and, in late 2004, convened a conference in Cyprus to address the issues. The conference program included presentations of existing costing procedure models, varying methodological approaches to project planning, analyses of case studies, and followup recommendations. While thoughtful papers were given, it was obvious that inter- and intra-water plant comparisons were not possible because of the uniqueness of each approach. Thus, a major conclusion to the conference was that there is a need to address these issues so laymen and engineers, alike, have a common, logical basis for selecting technologies and systems that represent, to the public and regulatory agencies, common cost, health, environment, and safety positions.

A flexible-cost computer program would seem to be the mechanism for achieving these goals. Using adjustable indices and variable inputs to account for unique site conditions and inflationary pressures, the program should include cost equations for (1) water treatment processes, (2) estimating pre- and post-treatment unit operations, (3) intake and outfall infrastructures and concentrate disposal methods, (4) product water storage and pumping, and (5) different packages of project financing. The computer program could, then, be employed for limiting

the cost of preparing tender specifications, facilitating project comparisons, and assisting in evaluating new water treatment concepts.

Reclamation sponsored the first phase of a computer related desalting cost estimating program. The output of this work, WTCost[®], contains the ability to evaluate high- and low-pressure membranes, ion exchange, and electro dialysis desalination processes. This report records Phase 2 of this water treatment cost estimation concept by adding the thermal processes, MSF, multieffect distillation (MED), and thermal vapor compression (TVC) and mechanical vapor compression (MVC). Upgrades to the other desalination processes have been made to account for 5 years of technical improvements. Also included is the ability to combine these treatment processes in series and in parallel for project purposes. This report discusses the development this computer directed cost program, WTCost II[®], again sponsored by Reclamation. A case study is presented that shows how the program is employed in cost estimating a 20-million-gallon-per-day (mgd) hybrid plant, 10 mgd MSF and 10 mgd RO.

Program Content

The program contains default dose rates and costs estimations for water treatment processes and components as noted below. Importantly, this CD is a costing tool, not a design mechanism. Changes can be considered by merely adjusting default values.

- Microfiltration (MF) and ultrafiltration (UF) for contaminated drinking water purification and as a pretreatment process
- RO and nanofiltration (NF) for desalination
- MSF, MED, and VC (mechanical and thermal) for desalination
- Electro dialysis (ED and EDR) for desalination
- Ion exchange (IX) to produce high-purity water
- Using all the above processes in series or parallel combinations
- Energy recovery
- Disinfection with chlorine, chloramine, electrochlorination, ozone, and ultraviolet irradiation
- De-chlorination with sodium bisulfite, sodium sulfite, and sulfur dioxide
- pH adjustment with sulfuric or hydrochloric acid

- Coagulation with alum, poly-aluminum chloride (PAC), ferric chloride, and ferrous sulfate
- Lime/soda softening
- Filtration enhancement with flocculants as polyelectrolytes
- Filtration with granular activated carbon and other granular material installed as single and multibed media
- Air and/or water filter bed back washing
- Cleaning equipment for processes and piping
- Several options for feed water intake and disposal of brine concentrate
- Appropriate storage tanks, pumps and land and feed water acquisition costs
- Summaries of indirect and direct capital; operating and maintenance (O&M), land acquisition and feed water costs, and recovery of capital

Technical Approach

The concept of this program was to build on WTCost[®]. All desalting technologies employ nearly the same unit operations. These common items include such things as feed water intake, brine disposal, pre- and post-treatment of feed and product, chemicals, transfer pumps, tanks, instrumentation, piping, etc. Their cost equations have been modified, primarily on range of applicability, to be suitable for all technologies. The key systems that have been added for the evaporative systems are specific for MSF, MED, and VC (i.e., boilers, evaporator effects, heat exchangers, condensers, and compressors). Printing and formatting the new technologies have been seamlessly added to what already existed. Thus, a standard system of costs has been developed for essentially all commercial water treatment technologies and their interrelationships with each other.

WTCost[®] was a Windows based application developed in a collaborative effort among the Bureau of Reclamation, Denver, Colorado; I. Moch & Associates, Wilmington, Delaware; and Boulder Research Enterprises (BREI), Boulder, Colorado. The current version, programmed by BREI, has been tested and runs on Windows 98 and later systems. The program is in English, with the option of selecting from a variety of English and metric units for numeric input values. Costs are stored in United States dollars but can be presented in any currency by providing a currency symbol and an exchange rate to dollars on the project screen. Thus, the user can change exchange rate or currency type without having to re-input cost information. Output is provided in a variety of reports that can be printed or exported in several formats. The program offers the option of saving

data in an Excel spreadsheet. The program user's manual is presented in "Documentation" in Adobe PDF if Adobe Acrobat Reader is installed. No other software is required to run WTCost II[®].

Program Options

Table 1 depicts some of the process scenarios that can be employed in operating this program, though other combinations do exist. The various desalting processes that can be run include:

- (1) Singularly such as RO or MSF alone (figure 1).

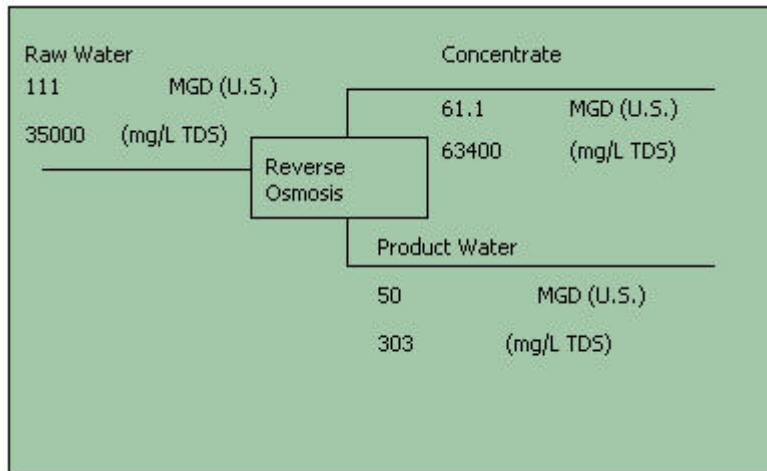
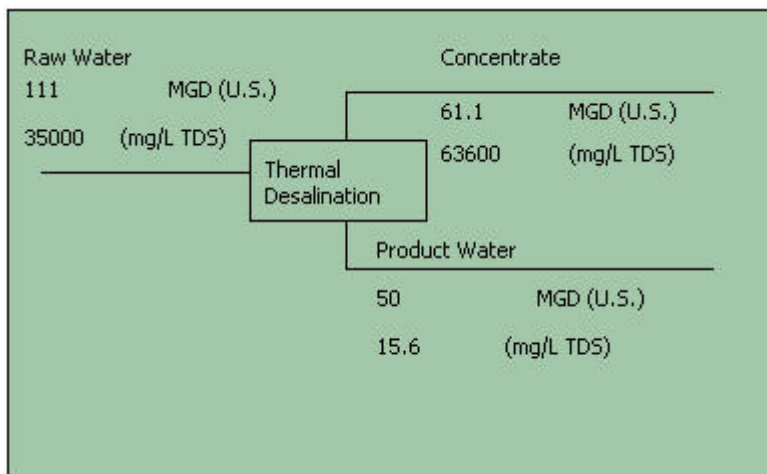


Figure 1. Typical Examples of a Singular Process.

- (2) In a series mode (figure 2), such as RO seawater followed by RO brackish water. (Figure 2 also depicts blending first and second, pass products, bypassing a portion of first pass product to second pass product, and recycling of any amount of second pass brine to first pass feed.)

Table 1. Defining Process Options

Case	Pretreatment		Plant 1	Plant 2
	Media	MF/UF ¹		
1A and 1B ²				
Technology	Case 1A	Case 1B	RO	RO
Feed from	Low-pressure pumps		Pretreatment product	RO Plant 1 product
Product to	RO Plant 1 as feed		RO Plant 2 as feed	Final product
Concentrate to	Waste		Waste	Plant 1 feed
2A and 2B ³				
Technology	Case 2A	Case 2B	MSF/MED/TVC/MVC	RO
Feed from	Low-pressure pumps		Pretreatment product	Pretreatment product
Product to	MSF/MED and RO		Final product	Final product
Concentrate to	Waste		Waste	Waste
3A and 3B				
Technology	Case 3A	Case 3B	NF	RO
Feed from	Low-pressure pumps		Pretreatment product	NF Plant 1 product
Product to	NF Plant 1 as feed		RO Plant 2 as feed	Final product
Concentrate to	Waste		Waste	NF Plant 1 feed
4A and 4B				
Technology	Case 4A	Case 4B	NF	MSF/MED/TVC/MVC
Feed from	Low-pressure pumps		Pretreatment product	NF Plant 1 product
Product to	NF Plant 1 as feed		MSF/MED Plant 2 as feed	Final product
Concentrate to	Waste		Waste	NF Plant 1 feed
5A and 5B				
Technology	Case 5A	Case 5B	NF	NF
Feed from	Low-pressure pumps		Pretreatment product	NF Plant 1 product
Product to	NF Plant 1 as feed		NF Plant 2 as feed	Final product
Concentrate to	Waste		Waste	NF Plant 1 feed
6A and 6B				
Technology	Case 6A	Case 6B	RO	IX
Feed from product	Low-pressure pumps		Pretreatment product	RO Plant 1
Product to	RO Plant 1 as feed		IX Plant 2 as feed	Final product
Concentrate to	Waste		Waste	RO Plant 1 feed
7				
Technology	Standard intake screening		MSF/MED/TVC/MVC	
Feed from	Low-pressure pumps		Intake screens	
Product to	Thermal processes		Final product	
Concentrate to	Waste		Waste	

Table 1. Defining Process Options (continued)

Case	Pretreatment		Plant 1	Plant 2
	Media	MF/UF ¹		
8A and 8B				
Technology	Case 8A	Case 8B	RO	
Feed from	Low-pressure pumps		Pretreatment product	
Product to	RO Plant		Final product	
Concentrate to	Waste		Waste	
9A and 9B				
Technology	Case 9A	Case 9B	NF	
Feed from	Low-pressure pumps		Pretreatment product	
Product to	NF Plant		Final product	
Concentrate to	Waste		Waste	
10				
Technology	No	Yes		
Feed from	Low-pressure pumps			
Product to	Final product			
Concentrate to	Waste			
11				
Technology			IX	
Feed from			Ground water	
Product to			Final product	
Concentrate to			Waste	
12				
Technology			ED/EDR	
Feed from			Surface/ground water	
Product to			Final product	
Concentrate to			Waste	

¹ Need to have provision to add a sand filter before MF/UF as a possible additional pretreatment step.

² Provision for bypassing part of Plant 1 product to Plant 2 product – blending.

³ RO product to be blended with MSF or MED product in ratio set by program user.

- (3) In parallel such as the feedwater split in whatever ratio is desired, for example, to a RO system and to a MSF plant (figure 3). Further, the pretreatment can be media filtration or MF/UF alone, similar to what is shown in figure 1.
- (4) Preceding a desalination step, for example, one such scenario could be MF/UF with the filtrate feeding NF trains with its permeate as a feed for a MED facility. Another combination could be media filtration followed by a RO plant with its permeate used as feed to an IX facility.

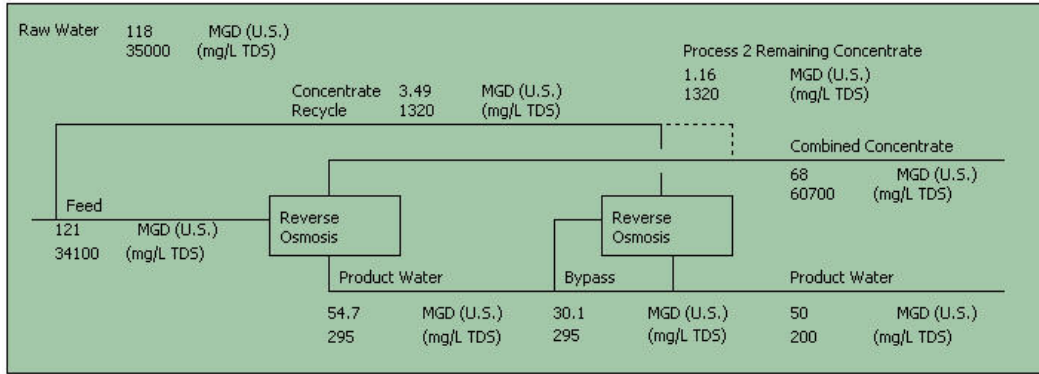


Figure 2. Typical Example of Series Processes.

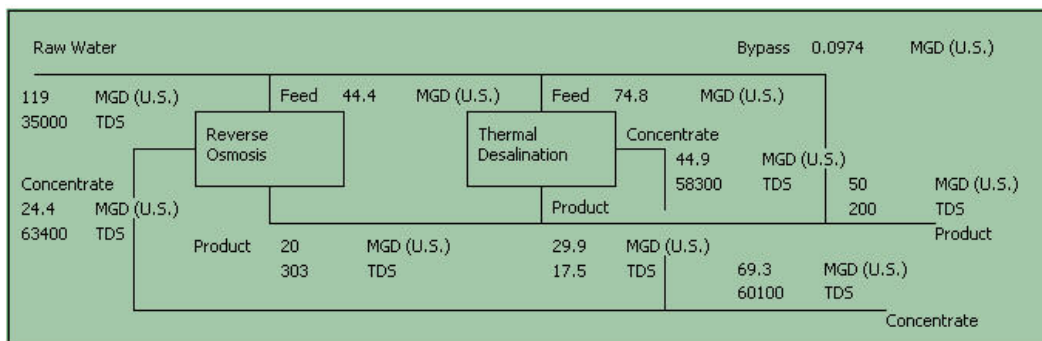


Figure 3. Typical Example of Parallel Processes (Hybrids).

- (5) Also, brine from a brackish RO used as a feed to seawater RO or thermal plant (figure 4).

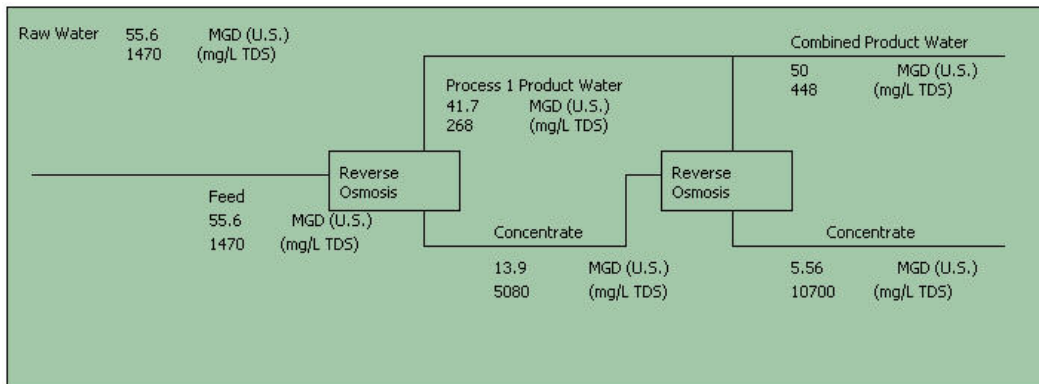


Figure 4. Typical Example of Concentrate (Brine) Processing to Increase Water Production.

Thus, for the first time there is available a cost estimating program that can evaluate many options for water treatment using common denominators. The

program is supplier neutral and the same cost equations are, generally, relevant to all processes. Plant sizes are applicable in capacity ranges of 50,000 gallons per day (gpd) to 200 mgd. The program is viable for assessing/comparing technologies, defining optimum project conditions, writing specifications, teaching and evaluating new water treatment concepts.

Comments

1. Further options are available wherein the brine from the first desalting plant is used as a feed to another desalination technology.
2. Case 1 – RO Plant 2 modules are low-pressure, brackish water elements with user input for pressure – 150 pounds per square inch gauge pressure (psig) default.
3. Case 2 – RO Plant 2 is seawater model with user input for the pressure – default 1,000 psig.
4. Case 3 – RO Plant 2 is seawater model with user input for the pressure – default 650 psig.
5. Cases 1, 6, and 8 – Plant 1 RO can be brackish or seawater modules with user input for the pressure – default values given below.
6. RO models with user input on pressure are:
 - a. Brackish standard pressure – 275 psig to 400 psig – default 325 psig.
 - b. Brackish low pressure – 125 psig to 275 psig – default 200 psig.
 - c. Brackish extra low pressure – <125 psig – default 100 psig.
 - d. Seawater – one model – default 1,000 psig.
 - e. Fouling free elements – not listed as a separate category, but are classified by pressure use.
7. NF scenarios
 - a. Cases 4 and 5 – user selects appropriate pressure for the intended use, no default values.
 - b. Case 9 – default value 275 psig.
8. MF/UF cases
 - a. No differentiation among cross flow, dead end, and inside/out or outside/in – all treated the same.

- b. Vacuum and pressure systems differentiated because of pressure use.
User to choose:
 - (1) Vacuum – vacuum pump - 10 psig default
 - (2) Pressure – 45 psig default
 - (3) Energy consumption incorporated into calculations
- 9. System recoveries and other default operating parameters provided when specific technology is chosen.
- 10. RO and NF plants concentrate staging are NF up to two stages, RO brackish up to three stages, and seawater up to two stages.
- 11. There may be a booster pump between the concentrate of stage 1 and the feed of stage 2 and between the concentrate of stage 2 and the feed of stage 3. Energy use, when this booster pump is included, is in the energy consumption calculation.
- 12. There can be break tanks/clear well between pretreatment step and Plant 1, assumes 15 minutes storage. For cases 1, 3, 4, 5 and 6, between Plant 1 and Plant 2, there are hold tanks; sizing assumes 15 minutes storage and equal flows in and out. Each tank is sized for no more than a 5-train capacity.
- 13. Under pretreatment, the options available for processing the raw water, brackish or sea, are mechanical media filtration, sand, gravity, pressure, and multimedia, and low-pressure membranes, specifically MF or UF as noted in item 7 above.
- 14. Bypassing of first pass product around second pass system in whatever ratio desired is possible.
- 15. Recycling of second pass concentrate to first pass feed possible in whatever ratio is desired.
- 16. RO, NF, MSF, MED, MVC, TVC, IX and ED/EDR are technologies that can be employed in whatever combinations desired.

Case Study for 20-mgd Plant with 10 mgd RO and 10 mgd MSF

Design parameters used to drive the cost estimates are calculated from the inputs. Indices from the *Engineering News Record* (ENR) are employed to update cost information to current values. Table 2 is a list of the indices and their value as of April 2006. In using this program, it is necessary that these indices be adjusted at any given time interval to account for inflation and country and site specific conditions.


In progressing through each process option, there are prompts for specifics such as preferred chemical dose, media filtration rate, membrane productivity, and rejection. The thermal processes, ion exchange, and electro dialysis have their own specific inputs and prompts. At the end, all information, imputed and calculated, is summarized on one screen followed by a window established to define indirect capital costs and possible land acquisition and/or feed water costs. The last screen contains a table summarizing all the cost estimations—capital, operations, and capital recovery. As an assist to the user, default values are offered throughout, but, if more definitive information is available, it can be entered, thus enhancing accuracy.

Table 2. Indices for Updating Costs¹

Cost Indices Categories	April 2006
ENR construction cost index	7,695.1
ENR building cost index	4,335.46
ENR skilled labor index	7,212.69
ENR materials index	2,577.74
ENR steel cost (\$/cwt) ²	37.44
ENR cement cost (\$/ton) ²	92.24
Electricity cost (\$/kWh) ²	0.08
Water rate (\$/kgal) ²	0
Interest rate (%) ²	6
Amortization time (years)	30

¹ All ENR indices are from <http://www.enr.com/features/coneco/subs/recentindexes.asp>. The rest are defaults.

² \$/cwt = dollars per hundredweight; \$/ton = dollars per ton; \$/kWh = dollars per kilowatt hour; \$/kgal = dollars per kilogallon; % = percent.

WTCost II[®] has two forms of output. Printing is available at each screen by choosing “Print” from the File menu or by pressing the  printer icon. When

there is a Print Form button, all visible tabs will be printed. Several reports can also be generated for projects that have been saved to the database by selecting “Reports” on the File menu. Detail and summary reports are available for individual projects, and up to four projects can be compared in a side-by-side tabular format. The reports can be exported as text or html files, which can then be opened in other applications. Saving the report in html format gives the best results for importing into Microsoft Excel. Reports are generated from information that has been stored in the database. Therefore, a complete report will only be generated for a project in which the user has run through the entire program, including the final report screen. Reports can be generated for all saved projects, but will have blanks for incomplete projects.

Program Flow

The program starts with a simple screen offering six choices, as shown in figure 5.

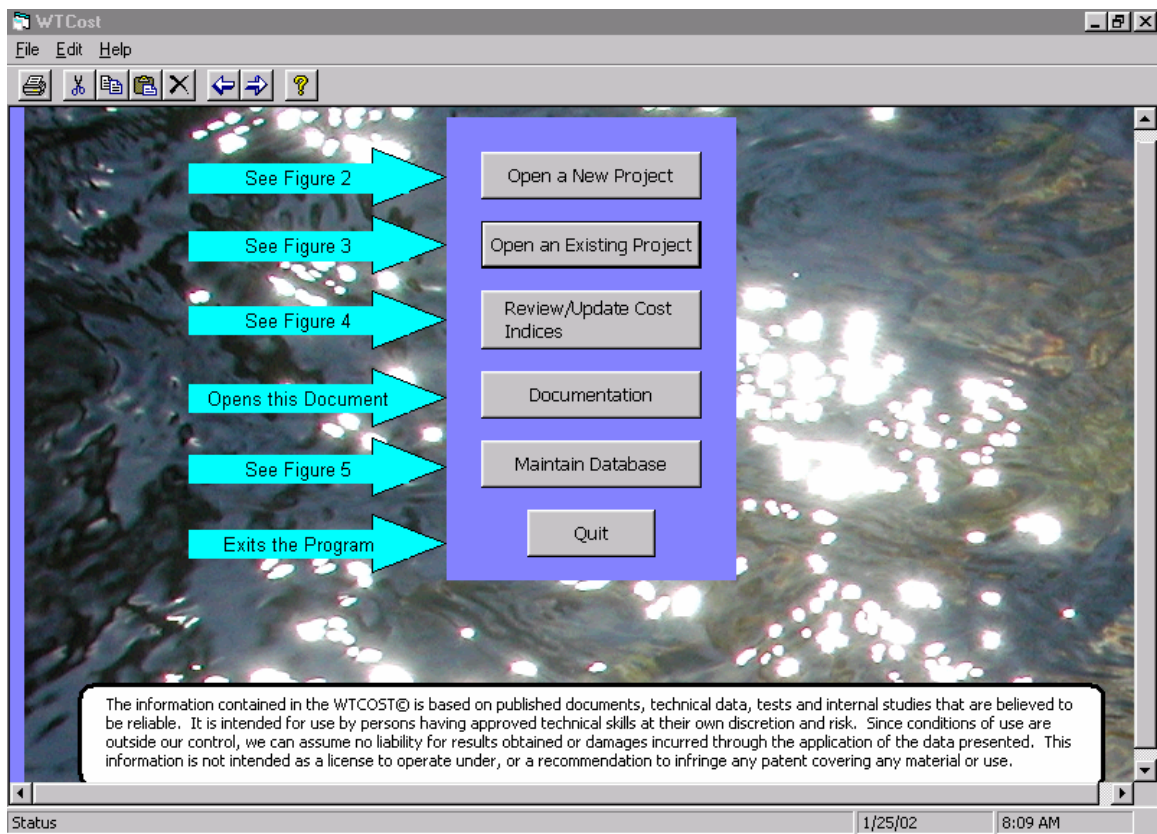


Figure 5. WTCost II® Start Screen.

To initiate the program for a new project after defining/naming the plant, the primary required inputs are (figure 6):

- (1) Product capacity
- (2) Choosing metric, Imperial or English unit systems
- (3) Defining the monetary currency
- (4) Hours per day online
- (5) Plant availability
- (6) Plant staffing labor rates

The screenshot shows a software window titled "PROJECT INFORMATION" with a blue header bar. The window is divided into several sections:

- PROJECT**: Contains input fields for "Project Name" (filled with "Bureau of Reclamation"), "Project Location", "Project Manager", "Project Description", and "Date".
- SPECIFY CURRENCY**: Shows a currency selection interface with "1 \$ X 1 = USD".
- CAPACITY SPECIFICATIONS**: Includes "Desired Product Water Flow Rate" (20 MGD), "Plant Availability" (95 [0,100]%), and "Planned Operation" (24 Hrs/Day).
- PLANT STAFFING**: Contains a text instruction and four input fields for labor rates: "Management" (80), "Engineering and Laboratory" (60), "Supply, Office, and Administration" (20), and "Operators and Maintenance" (38.7).

Figure 6. Defining the Project.

Water Analysis

The water analysis, the next window, is important for determining product water composition for blending, calculating chemical dose rates, sizing the various membrane processes, and electro dialysis reversal and ion exchange systems. It also has an impact on the sizing and costs for the thermal desalination processes. Figure 7 shows the water analysis data entry table for this hybrid seawater case.

PROJECT INFORMATION		WATER ANALYSIS																			
Select a Water Analysis <input checked="" type="radio"/> Edit Project Analysis <input type="button" value="OK"/> <input type="radio"/> Enter a New Analysis seawater Enter Multiplier: 1.0 <input type="button" value="CALCULATE"/>		Metals Boron: 0 mg/L Barium: 0.03 mg/L Calcium: 406 mg/L Iron: 0.01 mg/L Magnesium: 1290 mg/L Manganese: 0.002 mg/L Potassium: 385 mg/L Sodium: 10741 mg/L Strontium: 14 mg/L	Inorganic and Dissolved Solids Alkalinity-Bicarbonate: 144 mg/L Alkalinity-Carbonate: 0.5 mg/L CO2: 2.13 mg/L Chloride: 19333 mg/L Fluoride: 1.3 mg/L Nitrate (as N): 0.5 mg/L o-Phosphate: 0.07 mg/L Sulfate: 2688 mg/L Silica: 0 mg/L Total Organic Carbon (TOC): 0 mg/L Total Dissolved Solids (TDS): 35,005.9 mg/L Total Suspended Solids (TSS): 1.3 mg/L																		
Water Properties pH: 8 Specific Gravity: 1.0234 Turbidity: 0 NTU Conductivity: 53,966 uS/cm Temperature: 25 deg C		Water Analysis Values <table border="0"> <tr> <td>Free Energy (dG) = dG' + R*T*ln(Q)</td> <td>1.73</td> <td>Total Equivalents, Valence >1 (Eq/L)</td> <td>0.127</td> <td>pH for dG = 0</td> <td>6.73</td> </tr> <tr> <td>Total Equivalents per Liter (Eq/L)</td> <td>1.22</td> <td>Average Molecular Mass (g/Mol)</td> <td>31.4</td> <td>Cations (Eq/L)</td> <td>0.604</td> </tr> <tr> <td>Average Equivalent Mass (g/Eq)</td> <td>29</td> <td>Total Ionic Strength (Mol/L)</td> <td>0.696</td> <td>Anions (Eq/L)</td> <td>0.604</td> </tr> </table>		Free Energy (dG) = dG' + R*T*ln(Q)	1.73	Total Equivalents, Valence >1 (Eq/L)	0.127	pH for dG = 0	6.73	Total Equivalents per Liter (Eq/L)	1.22	Average Molecular Mass (g/Mol)	31.4	Cations (Eq/L)	0.604	Average Equivalent Mass (g/Eq)	29	Total Ionic Strength (Mol/L)	0.696	Anions (Eq/L)	0.604
Free Energy (dG) = dG' + R*T*ln(Q)	1.73	Total Equivalents, Valence >1 (Eq/L)	0.127	pH for dG = 0	6.73																
Total Equivalents per Liter (Eq/L)	1.22	Average Molecular Mass (g/Mol)	31.4	Cations (Eq/L)	0.604																
Average Equivalent Mass (g/Eq)	29	Total Ionic Strength (Mol/L)	0.696	Anions (Eq/L)	0.604																

Figure 7. Feed Water Composition.

1. “Select a Water Analysis” section must be filled in before a different water analysis can be designated.
2. “Use of a WTCost II[®] Analysis” radio button allows a choice from a variety of generic water types. Table 3 lists the names and characteristics for each type.
3. “Edit Project Analysis” is for changing an analysis that has been previously stored in the database.
4. “Enter a New Analysis” allows naming and describing a new water type to store in the database. Input cells are filled with the seawater analysis to begin the new analysis.

For this case study, the default seawater composition is used for calculations related to the character of the water.

Table 3. Generic Water Analyses

Parameter (Values in milligrams per liter [mg/L])	Brackish 1	Brackish 2	Brackish 3	High Brackish	Seawater
Boron	0	0	0	0	0
Barium	0.05	0.098	0	0	0.03
Calcium	100	182	110	637	406
Iron	0.05	0.019	0	0	0.01
Magnesium	35	85	80	283	1,290
Manganese	0.55	0.081	0	0	0.002
Potassium	1.8	4.78	10	131	385
Sodium	110.9	175.8	815	3,284	10,741
Strontium	1.3	2.7	5	15	14
Alkalinity-bicarbonate	232	189	125	163	144
Alkalinity-carbonate	0	0	0	0	0.5
Carbon dioxide	8.44	11.84	12.27	41.2	2.13
Chloride	95	560	811	6,545	19,333
Fluoride	0.64	0.31	1	1	1.3
Nitrate (as N)	1	10.7	0	40	0.5
o-Phosphate	0.04	0.37	0	0	0.07
Sulfate	300	231	110	680	2,688
Silica	17	11.9	12	18	0
Total organic carbon (TOC)	0	0	0	0	0
Total dissolved solids (TDS)	905	1,466.8	3,082.7	11,802	35,006
Total suspended solids (TSS)	1.3	1.3	0	0.6	1.3
Ph	7.62	7.39	7.2	6.8	8
Specific gravity	.998	.998	.999	1.006	1.0234
Turbidity (nephelometric turbidity unit [NTU])	0.5	0.5	0.5	0	0.5
Conductivity (microsiemens per centimeter [μ S/cm])	2,280	3,131	5,580	18,796	53,966
Temperature	25	25	25	25	25
Total organic carbon (TOC)	0	0	0	0	0
Total dissolved solids (TDS)	905	1,466.8	3,082.7	11,802	35,006
Total suspended solids (TSS)	1.3	1.3	0	0.6	1.3
Ph	7.62	7.39	7.2	6.8	8
Specific gravity	.998	.998	.999	1.006	1.0234
Turbidity (NTU)	0.5	0.5	0.5	0	0.5
Conductivity (μ S/cm)	2,280	3,131	5,580	18,796	53,966
Temperature	25	25	25	25	25

Unit Operations

Figure 8, the next window, shows the selection of unit operations. The box next to the category of processes needed is chosen. More than one category may be selected. Save the choices to keep them with the project in the database. Click “Continue” at this point to go to forms for specifying the processes in more detail. The program progresses through the selected categories starting with Desalting, then Filtration, Pretreatment Disinfection, Chemical Feed Systems, Dechlorination, Post-treatment, and finally Miscellaneous Equipment and processes. Desalting and filtration are specified first to define the overall recovery and, thus, the amount of water treated by each of the methods, as determined by the combination of these processes.

When starting a new project that will use MF/UF in conjunction with one of the primary desalting methods, it is helpful to start by selecting only the pretreatment filtration box on the Process Selection form (figure 8). After completing the filtration step, click “Save,” and then click the back arrow to go back to the process selection form. Select all the desired processes and click “Continue” to specify the rest of the project. In this way, the plant overall recovery will be correctly calculated on the Separation Process form. If later a change to the overall plant recovery happens, the entire project is rerun to recalculate the costs.

At the end of each category, costs are summarized on a printable form.

PROJECT INFORMATION	WATER ANALYSIS	UNIT OPERATIONS
Select Unit Operations		
<input checked="" type="checkbox"/> Pretreatment Disinfection		
Chlorination		
Chloramination		
Electro-Chlorination		
Ozone		
UV		
<input checked="" type="checkbox"/> Chemical Feed Systems		
Acidification		
Alum (Dry Feed)		
PAC		
Ferrous Sulfate		
Ferric Chloride		
Lime and Soda Ash		
Anti-scalant		
Polyelectrolyte		
Potassium Permanganate		
NaOH		
<input checked="" type="checkbox"/> Filtration		
Granular Activated Carbon		
Gravity Filtration		
Microfiltration/Ultrafiltration		
<input checked="" type="checkbox"/> Dechlorination		
Sodium Bisulfite		
Sodium Sulfite		
Sulfur Dioxide		
<input checked="" type="checkbox"/> Desalting		
Reverse Osmosis/Nanofiltration		
Electrodialysis		
Ion Exchange		
Thermal Desalination		
<input checked="" type="checkbox"/> Post-treatment		
Chlorination		
Chloramination		
Ozone		
UV		
Chemical Addition		
<input checked="" type="checkbox"/> Miscellaneous Equipment		
Upflow Solids Contact Clarifier		
Intake/Outfall		
Clearwell Storage		
Pumps		
Additional Equipment		

Edit

Save

Cancel Changes

Continue

Main Menu

Print Form

Help

Figure 8. Unit Operations Selection Form.

Desalting Processes

Desalting processes are used for the production of quality water. There are eight desalting processes included in this program: reverse osmosis, nanofiltration, multistage flash distillation, multieffect distillation, mechanical vapor compression, thermal vapor compression, electro dialysis reversal, and ion exchange. Figure 9, "Separation Process Options," shows the selection form.

In this form, the user chooses the desalting processes and their combinations with each other. The program allows for a wide variety of process flow schemes, which are illustrated, along with the water balance and TDS concentrations, in the simplified process flow diagram at the bottom of the page. The recovery for the combined desalting processes (combined product water/total raw water) and an estimate of the overall plant recovery is displayed above the flow diagram. The estimated overall plant recovery includes the recovery for MF/UF pretreatment if MF/UF has been selected. The overall plant recovery may change when the MF/UF system is fully specified. Figure 9 shows the information for this 20-mgd hybrid case.

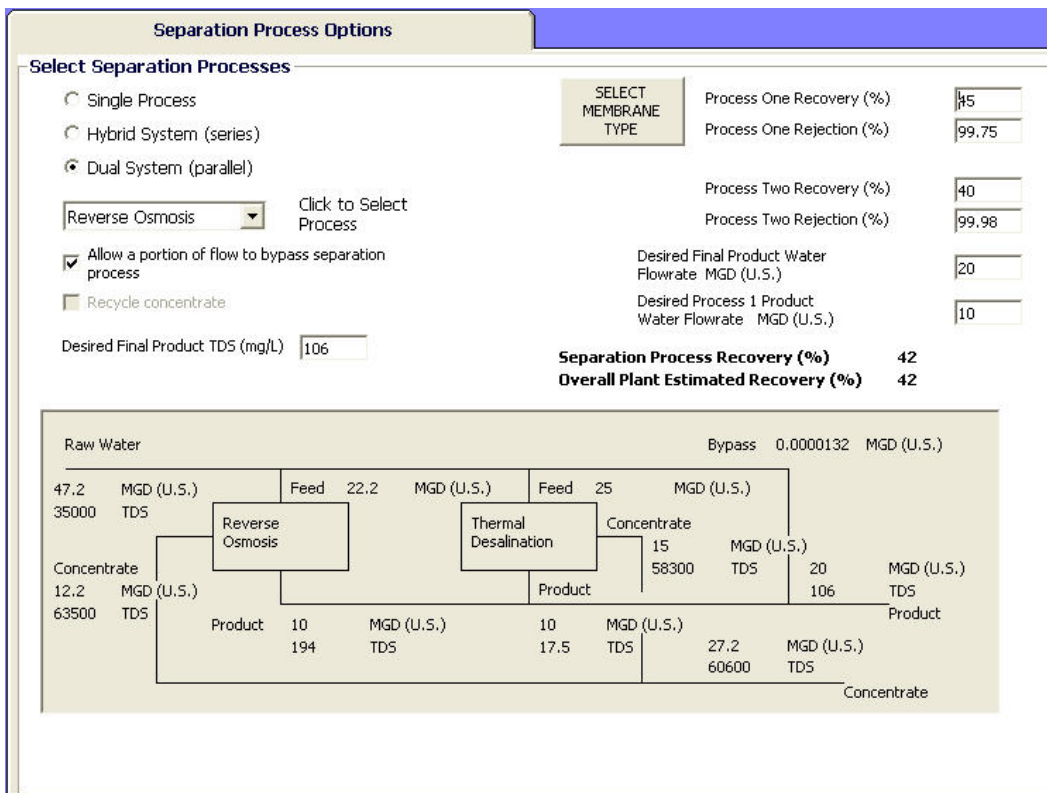


Figure 9. Separation Processes Options with Schematic of Hybrid System.

Membrane Processes

If RO is selected, a button labelled “SELECT MEMBRANE TYPE” will appear beside the recovery and rejection input boxes for the process. Click the button to select the membrane type. The available membrane types are:

- For TDS range 0 to 1,500 mg/L; Standard, Ultra Low Pressure, and Softening (NF)
- For TDS range 1500 to 12,000 mg/L; Standard and Softening
- For TDS greater than 12,000 mg/L; Softening and Seawater membranes

Select the desired membrane type; then, change the default operating temperature and pressure for the membrane. A new rejection value will be calculated and displayed. Click “Finish” to close the pop-up screen and transfer the new rejection value to the rejection input box for the process.

Table 4 lists the ranges of default values for the available membrane types.

Table 4. General Membrane Characteristics

	Seawater	Standard	Ultra-Low Pressure	Softening
Element flow, gpd (cubic meters per day [m ³ /d])	4,000-9,000 (15.1-34.1)	9,000-14,000 (34.1-53.0)	8,500- 14,000 (32.2-53.0)	7,500-12,000 (28.4-45.4)
Fouling factor	0.8-1.0	0.8-1.0	0.8-1.0	0.8-1.0
Feed pressure, psig (bar)	700-1200 (47.6-81.5)	175- 350 (12-24)	45-150 (3-10)	1125- 350 (8.5-24)
Pressure drop, pounds per square inch [psi] (bar)	25-60 (1.7-4)	25-60 (1.7-4)	25-60 (1.7-4)	25-60 (1.7-4)
Elements per vessel	6-8	6-8	6-8	6-8
Chloride rejection, % ²	99.0-99.8	99.0-99.7	98.5-99.7	65-85
Sulfate rejection, %	99.5-99.9	99.3-99.7	99.3-99.7	95.0-99.0

¹ Seawater softening membranes can have feed pressures up to 650 psig (44 bar).

² High-rejection membranes are at the top of the range.

In figure 10, input parameters concerning the membrane are in the left column. These values can be changed on this form by pressing the “Edit” button and changing the values to match any particular membrane. The parameters on the right were input previously in the project on the Project Information form, Water Analysis form, Separation Process Selection form, and Membrane Selection form. To change these parameters, press the “Select Membrane Type” button and select “Yes” to leave the System Configuration form and open the Membrane Selection form. When finished, there is a return to the Separation Process Selection form so that the water balance can be recalculated for the new membrane. Click “Continue” to return to the System Configuration form.

Select Membrane Properties

Seawater Membranes

6,000	Element Flow	(Gallons/Day)	35,000	Feed TDS (mg/L)
0.8	Fouling Factor		22,200,000	Feed Flow (Gallons/Day)
20	Pressure Drop	(psi)	10,000,000	Product Flow (Gallons/Day)
7	Elements/Vessel		45	Recovery (%)
			25	Temperature (C)
			900	Feed Pressure (psi)

2961 Number of Elements
423 Number of Pressure Vessels

Figure 10. Calculation of Elements and Pressure Vessels.

The calculated “Number of Elements” and “Number of Pressure Vessels” are reported at the lower center of figure 10. These numbers are based on the membrane characteristics, water recovery rate, feed TDS, membrane rejection rate, temperature, and experience. Changing any of the parameters on this form will change the resulting numbers of elements and vessels. (For more precise information on the number of elements and pressure vessels, a membrane supplier should be consulted.)

If the membrane pressure drop or TDS is too high in relationship to the feed pressure, the number of elements will not be calculated. In this case, decrease the pressure drop or click “Select Membrane Type” or “Cancel” to return to the Separation Process form to adjust the feed pressure and/or feed TDS.

The above figure also shows the specifications for a standard RO membrane that are used to estimate the number of elements and pressure vessels needed to produce the required water production. Once the membrane and blending fractions have been chosen and the number of elements and pressure vessels has been calculated, the separation process can be defined more completely on the RO-NF Process Sizing and Cost Estimation forms. Starting with the Membrane Module Data section, follow the steps below to estimate the cost of a membrane

system. Reverse Osmosis - Page 1 and Page 2, figures 11 and 12, are customized for the most accurate cost estimate. (This information is also applicable to nanofiltration.)

For the RO 10-mgd portion of the 20-mgd hybrid case, in figure 11:

- **Enter Number of RO Trains.** Charges are associated with the number of trains. Some redundancy adds the capability to clean or maintain one portion of the treatment plant while operating another portion. Too many trains can become cost prohibitive—each one needs a pump, for instance.
- Note: A “pressure vessel” (PV) is the housing for a series of membrane “elements.” Most systems have six or seven elements per vessel. Some systems have eight elements. For brackish water systems, the vessels are generally arranged in a 2:1 array such that the concentrate from the first stage of vessels feeds the second set. Up to 50% recovery can be obtained from each stage. For seawater systems, there is usually one stage; but two stages as in brackish systems are also frequently used to increase system recovery or enhance the brine flow velocity.
- The number of elements or modules and number of pressure vessels are calculated. These numbers are repeated in the lower left of RO-NF Page 1.

Reverse Osmosis - Page 1		Reverse Osmosis - Page 2	
Membrane Type	Seawater Membranes	Membrane Element Recovery (%)	45
		Membrane Element Salt Rejection (%)	99.8
Membrane Module Data		Capital Cost (\$ 000)	Replacement Cost (\$ 000/year)
Number of RO Trains	5	Membrane Cost	1,590
Membranes (cost/Module)	535	Membrane Replacement Rate (%/yr)	12
Pressure Vessels (cost/Vessel)	1740	Cartridge Filters	211
		RO Trains	740
		Cleaning Equipment and Operating Costs	
Elements/ Pressure Vessel	7	Membrane Cleaning Equipment Cost	100000
Membrane Capacity kgal/d	10000	Cleaning Chemical/ Mixture	None
Number of Elements	2975		
Number of Pressure Vessels	425	Chemical Cost (cost/Cleaning Cycle per module)	18
Number of Pressure Vessels per Train	85		
		Cleaning Rate (Cycles/yr)	4
			Cleaning (/yr) 249

Figure 11. Reverse Osmosis - Page 1.

Costs -Pumps		<input checked="" type="checkbox"/> High Pressure Pumps	<input checked="" type="checkbox"/> Transfer Pumps	<input checked="" type="checkbox"/> Product Pumps
Select Pump Type	CF-WFC	<input checked="" type="checkbox"/> Energy Recovery	CF	CF
Number of Pumps	5		1	2
Number of Backup Pumps	1	Energy Recovery System Efficiency (%)	0	0
Height Differential (ft)	6.56		6.56	6.56
Discharge Pressure (psi)	900		45	45
Pump Efficiency (%)	83	85	75	75
Velocity (ft/s)	8.2		8.2	8.2
Motor Efficiency (%)	95		95	95
Length of Inlet Pipe (ft)	32.8		32.8	32.8
Coupling Efficiency (%)	100		100	100
Inlet Pressure (psi)	29		45	45
Capacity/Pump (gallons/s)	51.4		257	57.9
HP	1990		41.6	9.38
Power Req. (kWhr/Y)	43600000		258000	116000
Capital Cost				
Pump, Drive and Drivers	3,567,364		19,801	15,032
Piping	5,682		11,084	3,260
Controls	24000			
Energy Recovery	399,308			
Capital Cost	\$ 3,996,353		\$ 30,885	\$ 18,292
Operating Cost				
Power cost		3,490,155	20,668	9,313
Lubrication (cost/L oil)	1.8	62,873	263	118
Maintenance (hr/HP)	1.	385,779	1,611	726
O and M Cost	\$ 3,938,807		\$ 22,542	\$ 10,157

Figure 12. Reverse Osmosis Pumping.

- **Enter Membranes (\$ per module).** \$450 per element and \$535 per element are the default values for 8-inch-diameter brackish and seawater modules, respectively.
- **Enter Pressure Vessels (\$ per vessel).** Default values for pressure vessels are given in table 5. A factor such as 10% for plumbing and support should be added to the unit pressure vessel price.
- **Enter Membrane Replacement Rate (% per year).** Enter the percentage of membrane to be replaced each year. The default is 6% for brackish water membrane and 10% for seawater membrane.
- **Enter Membrane Cleaning Equipment Cost.** Small cleaning systems are available for under \$1,000, medium size for about \$67,000, and a large one for about \$100,000. Full trains are seldom cleaned all at once.

Table 5. 2006 Default Membrane Prices

Pressure	Price USD¹ Six Membranes	Price USD Seven Membranes
300 psi	\$965	\$1,035
600 psi	\$1,200	\$1,300
1,000 psi	\$1,475	\$1,575

¹ USD = United States dollars.

Usually trains are subdivided, for cleaning purposes, into blocks, thereby reducing the size of the cleaning system. The number of blocks is dependent on a number of items, such as acceptable down time, logistics of cleaning the plant, or number of anticipated cleanings per year.

- **Cleaning Chemical.** This is mainly for information.
- **Enter the Chemical Cost for Cleaning.** Cost is dollars per cleaning per module. A good estimate is \$0.14 per module.
- **Cleaning Rate (cycles per year).** This value is a function of the quality of the feed water. Once per year can be used for well water and four times per year for surface intakes.

Figure 13 shows RO-NF Page 2 after the pumps have been specified with pump and energy costs and the other screen information entered. Press “Save” and “Continue” or click on the “Reverse Osmosis - Page 2” tab to go into RO-NF Page 2, Without Pumping. On this page are important site-specific costs with default values. First, select the pumps. The cost of the pumps is heavily dependent on the inputs on this form. Check the boxes above the types of pumps needed (figure 12, “Reverse Osmosis Pumping”).

- **Choose Pump Types.** There are three choices of pump types: variable frequency drive centrifugal (CF-VFD) pumps, constant speed centrifugals (CF), and positive displacement (PD) pump. Pump choices are a function of flow rate, efficiency, and desired flexibility.
- **How Many?** Enter the number of each type of pump. There is usually one high-pressure pump per train plus one installed spare in case a pump is down for maintenance. Size is based upon capacity, velocity, efficiency, estimated height difference, length of pipe, and pressure differential. Default values are provided for all inputs. If the default number is changed, be sure to adjust the flow to match. Capital and O&M costs are calculated at the bottom. Transfer and product pumps are necessary to move the feed and product from one place to another.

Reverse Osmosis - Page 1		Reverse Osmosis - Page 2	
Direct Capital Cost - Construction (\$)		Direct Capital Cost - Misc. (\$)	
Building Cost (\$/sq ft)	100	<input type="checkbox"/> Odor Control	
Administrative Area (sq ft)	43	Instrumentation and Controls	401,000
Electrical Cost Base \$/kgal(US) Capacity	2,320	<input type="checkbox"/> Degasifiers	
Sitework \$/kgal(US)	55	Contractor Engr and Training	60,800
Backup Generator (MW)	0	Process Piping	1,550,000
		Yard Piping	575,000
		Operating and Maintenance Costs	
		Electricity	3,520,000
		RO-NF Operating and Maintenance Staff	25
		Repairs and Replacement	68,800
		Laboratory Fees	55,800
		Total Direct Capital Cost	\$11,800,000
		Total Ops. and Maint. Cost	\$6,560,000
<p>Review/Calculate Pumps Costs</p> <p>After calculating the pump costs, you will be returned to page 1 of the RO-NF calculations</p>			
Pumps Direct Capital Cost			
	\$ 4,050,000		
Pumps Operating Cost (excluding electricity)			
	\$ 451,000		

Figure 13. Reverse Osmosis - Page 2.

- Determine the height for each pump to move the water. For the high-pressure pump, this is at least 7 feet to the top of a smaller RO system.
- Each transfer and product pump discharge pressure must be higher than the inlet pressure. A pump's inlet or suction pressure of 30 psig is adequate to prevent cavitation. The discharge pressure of the product pumps must be adequate to get the water to the top of a tank if above-surface tanks are used. The discharge pressure of the high-pressure pump should be higher than the feed pressure of the system in order to compensate for feed line transfer pressure drop.
- Enter motor, pump, and coupling efficiencies if available or use the defaults. Enter the linear velocity or use the default of 8.2 feet per second (ft/sec) (2.5 meters per second [m/sec]). Enter a pipe length prior to the pump or use the default. Enter the capacity per pump. If there is more than one pump, split the flow between the pumps that will be operating at one time.
- Edit the O&M costs or use the defaults. Press "Save" and "Done." Return is to "Separation Process Options – Reverse Osmosis - Page 1" as changes in number of pumps will change the cartridge filters. Next, click "Save" to return to Reverse Osmosis - Page 2, (figure 13). Enter the number of personnel needed to run the RO-NF portion of the plant or use the defaults. The defaults, table 6, are based on capacity ranges as follows:

Table 6. Number of Personnel by Capacity

Capacity (mgd)	Total Personnel
0-1	4
1 –3	8
3 – 6	16
6 – 12	24
12 – 24	30
24 – 50	45
50- 75	55
75	65

Thermal Processes

Figure 14, “Summing MSF Costs,” is used as an illustration of the thermal processes; in this case, 10 mgd of the 20-mgd hybrid plant. Note that the overall process recovery will change as the thermal system recovery is probably different from the recovery of another desalination process used in combination with an evaporative system. The default values of the thermal systems are 40% recovery and salt rejection of 99.98%.

Process Information		Water Recovery (%)	40
Product Water Flowrate		MGD (US)	m3/day
9.993		37850	

Process Input		Direct Capital Costs	
Select Thermal Desalting Process		Boiler (single purpose plant only)	
MSF		Distiller Hardware	
<input type="radio"/> Single Purpose <input checked="" type="radio"/> Co-generation		Vessels and Heat Transfer Tubes	24,580,000
Select Fuel		Pumps	2,371,000
#6 Fuel Oil		Chemical Dosing/Gas Extraction Eq.	592,700
Fuel Cost \$/Kg	0.1	Pipes and Valves	1,482,000
Fuel heat Value kJ/Kg	46500	Instrumentation and Control Valves	889,100
Anti-Foam Addition		Distiller Supports, Platforms, misc.	592,700
Dose (mg/L)	2	Compressor or Thermal Ejector	
Price (\$/lb)	1.347	Ancillary Equipment and Building	
Select Power Cycle		Cleaning Equipment	529,200
CCGT		Building (switchgear and Control room)	1,588,000
Electrical Load (% of MCR)	100	Erection	7,735,000
Boiler Efficiency (%)	95	Total Direct Capital Cost (000)	\$ 40,360
Power Consumption (KWh/M3)	3.7	Operating and Maintenance Costs	
Distiller Performance Ratio (GOR)	8	Electricity	3,885,000
Prime Energy Factor (PEF)	0.4	Steam	3,528,000
Construction Multiplier	1	Chemicals	194,500
		Other Operating Costs and Labor	1,185,000
		Total Operating and Maintenance Cost (000)	\$ 8,793

Figure 14. Summing MSF Costs.

On the left side of the screen, the specific information needed to define the thermal processes is provided. For a single-purpose thermal desalination plant, fuel is combusted solely to provide heat for the distillation process. In this case, the cost of energy is fully allocated to the production of water. Likewise, the cost of the boiler is allocated to the production of water for single-purpose thermal desalination plants. In dual-purpose power and thermal desalination plants, all or part of the heat in the power cycle exhaust is recovered as the energy source for the desalination process. In this case, only part of the energy in the fuel is allocated to the production of water. The rest is used to generate electricity. The prime energy factor (PEF) can be defined as the amount of energy consumed as fuel to produce a given quantity of fresh water. For a single-purpose thermal desalination system, $PEF = 1$. For systems where fuel is used to generate power and water, the proportion of fuel allocated to water production gives a $PEF < 1$. WTCost II[®] utilizes the PEF as a simple method for costing the energy used to produce water based on the cost of fuel and its energy content (kilojoule per kilogram [kJ/kg]), while avoiding the requirement for a detailed knowledge of the power generation cycle. WTCost II[®] provides default values for the PEF, which are a function of the type of power cycle selected and the utilization of the power plant for the generation of electricity expressed as a percentage of the maximum continuous rating (MCR). Note that WTCost II[®] recalculates the PEF whenever the power generation method is changed or the percent of MCR is changed. The user may also adjust the PEF. Antifoam agents are usually a requirement for these processes and here a default dose and price are given.

The other major factor affecting the energy cost for thermal desalination is the gained output ratio (GOR) or distiller performance ratio, which is the ratio of water produced to steam consumed (measured as condensate). The GOR is also sometimes quoted as water produced per latent heat of a unit mass of steam. The default value used is 8.

For single-purpose thermal desalination plants, the cost of the boiler and all fuel consumption is included in the desalination cost estimate. For dual-purpose plants, only the distiller and associated equipment and the cost of energy allocated to production of water are included in the cost estimate. Compressor or thermal ejector assemblies are included in the capital equipment cost estimate for the vapor compression technologies: mechanical vapor compression and thermal vapor compression. The cost formulations are based on cost data valid for the vapor compression technologies in use or planned. Currently, available mechanical compressors have a maximum capacity of about 3,000 m³/day (793 kilograms per day [kgpd]) for extended continuous operations, and the maximum capacity of operating or planned TVC units is about 36,000 m³/day (9.5 mgd). WTCost II[®] does not have a maximum capacity cutoff for these technologies, but the user should be aware that the cost estimate may have error for larger capacity units.

To develop the cost estimate, first select the distillation process to be cost estimated by using the drop down menu. MSF, MED, MVC and TVC are the

options available. Next, select whether the thermal plant is to be a single purpose facility or co-generation. Then, select the fuel. The options are: #6 Fuel Oil, #2 Fuel Oil, Natural Gas, Coal, Hog (dry), and Electricity. The first time this form appears for a given project, the cost of electricity will be imported from the cost indices. Thereafter, the value will be saved separately from the cost indices and not reset even if the cost indices value is changed. The fuel cost and heating value are supplied as defaults when the fuel type is selected. These values may also be changed and saved as new defaults by the user. Note WTCost II[®] will only save values for the currently selected fuel. To save new default values for more than one fuel, select the first fuel, change the cost and energy content to the desired values, and click “Save.” Do the same for the other fuel types. Unlike other default values, changes to the fuel values will be permanently saved in the default table in the database and the new values will be the default values for all subsequent projects. Note the program will reset the fuel heating value and cost to the default value whenever a new fuel type is selected. Changes will only be saved when the “Save” button is clicked or the user exits the form answering “Yes” to the exit query. To go back to the most recently saved values, click “Cancel.”

If co-generation has been selected, the type of power plant must now be chosen. The options are: CCGT (combined cycle gas turbine), BPST (back pressure steam turbine), GT/HRB (gas turbine/heat recovery boiler), and POST (passout steam turbine). Whenever the type of power plant is changed, the value for the PEF will be reset to the default value for the power cycle and electrical load (% of MCR). The default value for electrical load (% of MCR) is 100% for dual-purpose plants and 0 (disabled) for single-purpose plants. WTCost II[®] resets the PEF to the appropriate default value whenever the electrical load is changed. The distiller performance ratio (also referred to as the gained output ratio or GOR) default value is 8. The GOR typically varies between 6 and 9.

Power consumption (kilowatt-hour per cubic meter [kWh/m³]) refers to power requirements for auxiliary equipment such as pumps, except in the case of mechanical vapor compression, in which electrical power is the energy source for the desalination. Default values in kWh/m³ product water are: MSF – 3.7, MED and TVC – 2.2, and MVC – 12.

The default boiler efficiency is 95% for single-purpose plants and disabled for dual-purpose plants. The PEF should be adjusted, if desired, after setting the power cycle and electrical load for dual-purpose plants. The PEF is 1 for single-purpose plants. The construction multiplier adjusts the erection costs up or down based on site conditions. At the top of this screen is the process recovery and flow rate already chosen. The right side of the screen gives the direct capital costs and operating and maintenance costs resulting from the process inputs.

Desalination Process Summary

When all the separation processes have been defined individually, press “Save” and “Continue” or “Done” to complete the estimate. A summary of selected

separation process costs is presented in figure 15. Shown in one place is a summary of all separation processes capital and O&M costs that were calculated in the preceding screens. Note that the costs are given per volume of final plant product water. Depending on other water quality parameters, further treatment may be necessary for one process that would not be needed for another, all of which could alter system economics.

Separation Process Options			Separation Process Cost Summary			
Feed Basis						
Plant Availability (%)	95.		MGD (U.S.)	m3/year	kgal/y (US)	
Planned Operation (hours/day)	24.	Plant Output	20.00	26,250,000	6,935,000	
Plant Recovery (%)	41.93	Plant Input	47.70	62,610,000	16,540,000	
	Construction Cost			Operating Cost		
	Total (000)	*/m3/day	*/gal/day (US)	Annual (000)	*/m3	*/kgal (US)
Reverse Osmosis	11,800	157.	.59	6,560	.25	.947
Thermal	40,400	533.	2.02	8,790	.335	1.27
Total	\$ 52,200	\$ 690.	\$ 2.61	\$ 15,400	\$.585	\$ 2.21

* Cost per volume of plant product water output

Figure 15. Summary of Separation Process Costs.

Pretreatment Processes

If “Filtration” was chosen on the Unit Operations Selection form, then the screen in figure 16, “Filtration Costs,” appears. The user may select from granular activated carbon, gravity filtration and/or MF/UF.

Granular activated carbon (GAC) is used to remove color, odor, organic chemicals (TOC), disinfection byproducts (DBP), and chlorine from water through the process of adsorption. If the water has not been prefiltered, the carbon bed may also serve as a granular filter; in which case, backwashing is a more significant design criterion. Granular filtration removes particulate matter such as algae, colloidal humic compounds, asbestos fibers, and colloidal clay from water. Matter accumulates on the surface, or is collected throughout the

Select Filtration Method	Gravity Filtration		Cost Summary																									
	<input type="checkbox"/> Granular Activated Carbon <input checked="" type="checkbox"/> Gravity Filtration <input type="checkbox"/> Micro/Ultra Filtration	Alternate Bed Area <table border="1"> <tr> <td>2.9</td> <td>Loading (gal/min/ft2)</td> <td>1.</td> <td>Wash Cycle (h)</td> <td>879</td> <td>Calculated Bed Area/ filter (ft2)</td> </tr> <tr> <td>3.28</td> <td>Media Depth (ft)</td> <td>16</td> <td>Number of Filters</td> <td>0.00</td> <td>Alternate Bed Area (ft2)</td> </tr> <tr> <td></td> <td>Media Cost (\$/yd3)</td> <td>Sand 32.15</td> <td>Coal 35.07</td> <td>Garnet 236.74</td> <td></td> </tr> <tr> <td></td> <td>Percent of Bed Volume</td> <td>33.3</td> <td>33.3</td> <td>33.4</td> <td></td> </tr> </table>				2.9	Loading (gal/min/ft2)	1.	Wash Cycle (h)	879	Calculated Bed Area/ filter (ft2)	3.28	Media Depth (ft)	16	Number of Filters	0.00	Alternate Bed Area (ft2)		Media Cost (\$/yd3)	Sand 32.15	Coal 35.07	Garnet 236.74			Percent of Bed Volume	33.3	33.3	33.4
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	Percent of Bed Volume	33.3	33.3	33.4																								
Process Information Water Analysis <input checked="" type="checkbox"/> seawater Calculated Bed Area (ft2) 14,071 Calculated Media Volume (yd3) 1709.4 Calculated Tank Depth (ft) 4.3	1978 Capital Cost \$ 2,203,000		Backwash Pump Current Cost		Gravity Filter Structure \$ 7,763,000 Current Cost																							
		Fraction		Fraction		Current Cost																						
	Manufactured and Electrical Equipment	0.69	3,456,000	0.26		4,590,000																						
	Housing	0		0.18		1,946,000																						
	Excavation, Site Work and Labor	0.07	208,400	0.22		2,309,000																						
	Piping and Valves	0.24	690,400	0.23		2,332,000																						
	Steel	0		0.05		489,600																						
	Concrete	0		0.06		636,100																						
	Media					173,400																						
	4/1/2006 Capital Cost		\$ 4,355,000			\$ 12,480,000																						
	1978 O and M Cost		\$ 67,070			\$ 379,800																						
	Materials	0.24	20,370	0.12		57,680																						
	Energy	0.52	93,010	0.36		364,600																						
	Labor	0.24	29,360	0.52		360,100																						
	4/1/2006 O and M Cost		\$ 142,700			\$ 782,400																						
	Total Capital Cost		\$ 16,830,000			Total Operations Cost \$ 925,100																						

Figure 16. Filtration Costs.

depth of the bed. Figure 16 shows the worksheet for sizing and cost estimation of granular filtration systems. There are two components: the backwash system and the gravity filter structure with the media. Costs for both are based on the area of the filter bed. Flow rate is taken from the project information form. Total suspended solids concentration is from the water analysis form. Wash cycle is the time for one backwash per day. Density of suspended solids and the maximum media capacity are used to determine how long it will take to exhaust the media. Assuming that the wash cycle is adequate to completely clean the media, a volume is calculated from the TSS and media capacity. Media depth is used to calculate a bed area for the calculated volume. Three types of media are available: sand, coal, and garnet. There are default values for all inputs.

MF/UF are used as pretreatment for desalination. The two processes are also employed to remove particulate material from water, including micro organisms such as protozoa (*Giardia and Cryptosporidium*), bacteria, and viruses to meet new and future environmental requirements. MF or UF membrane systems include the following equipment:

- Membrane module skids - membrane modules, backwash manifold piping, integral valves and instruments, support legs, control panels.

- Air supply system - air compressors, air dryers, coagulants and air filters, process air receiver, air regulator, plant pneumatic control enclosure, solenoid valves, and instruments.
- Clean-in-place (CIP) – concentrate tank, concentrate transfer pump, solution tank, solution tank heater and control panel, re-circulation pump, valves and instruments.
- Control system – main control panel, master programable logic controller, plant input/output, man-machine interface.
- The membrane manufacturers can provide more details on the scope of supply.

Costs are based on data presented by Elarde and Bergman at the American Waterworks Association (AWWA) Membrane Conference in 2001 and the *AWWA Manual of Water Supply Practices (M53) – Microfiltration and Ultrafiltration Membranes for Drinking Water*, First Edition 2005. The only parameters in the cost estimate are membrane flux, flow rate, number per module, replacement cost and life; design pressure backwash design information; disinfectant use; capacity; and number of operators.

A summary of all filtration costs are presented in figure 17, “Filtration Cost Summary.”

Select Filtration Method	Gravity Filtration		Cost Summary			
	<input type="checkbox"/> Granular Activated Carbon	Feed Basis				
<input checked="" type="checkbox"/> Gravity Filtration	Plant Availability (%)	95.		Plant Input	Plant Output	
<input type="checkbox"/> Micro/Ultra Filtration	Planned Operation (hours/day)	24.	MGD (U.S.)	53	20	
	Plant Recovery (%)	37.89	(kgal/year)	18,300,000	6,935,000	
			(m3/year)	69,300,000	26,300,000	
Process Information	Construction Cost		Operating Cost			
Water Analysis	Total (000)	*/m3/day	*/gal /day (US)	Annual (000)	*/m3	*/kgal (US)
seawater						
	Granular Activated Carbon	-	-	-	-	-
	Gravity Filtration	16,830	222.314	.841	925	.035 .133
	Micro/Ultra Filtration	-	-	-	-	-
	Total	\$ 16,830	\$ 222.314	\$.841	\$ 925	\$.035 \$.133
	* Cost per volume of plant product water output					

Figure 17. Filtration Cost Summary.

Chloramine or electrochlorination are available for pretreatment disinfection. Figure 18 shows the pretreatment chlorine disinfection cost estimation form. Tabs will only be visible for selected pretreatment methods. Click on the tab or click “Continue” to develop the cost estimate for each method. All of the process definitions are the same for pre-disinfection as they are for the post-disinfection options except for the capacity. The total feed flow is treated in pre-disinfection and only the final product water is treated with post-disinfection. If the same methods are selected for pre- and post-treatment disinfection, the post-treatment costs will only include the incremental costs for the additional capacity. Electrochlorination is only used as pretreatment because there are not enough salts in the product water to make electrochlorination economical for post-treatment. Like all other inputs, there are default values for each system. Figure 19 shows the pretreatment cost summary sheet.

After clicking “Continue,” the Chemical Feed Options form comes up, shown in figure 20. Here, specific chemicals feed processes are selected. Acidification and antiscalant addition have been chosen for this example. Press “Save” and then “Continue.”

Select Pretreatment Disinfection Method	Chlorination	Cost Summary		
Chlorination <input checked="" type="checkbox"/> Chlorination <input type="checkbox"/> Chloramination <input type="checkbox"/> Electrolytic Chlorine Generation <input type="checkbox"/> UV <input type="checkbox"/> Ozonation	Process Input <input type="text" value="0.5"/> <input type="text" value="3"/> <input type="text" value="3752"/>	Desired Residual (mg/L) Alternative Dose (mg/L) Cl2 Cost (/ton), tanks	Calculated Dose (mg/L) 0.5 Calculated Dose (kg/day) 599	
Process Information Water Analysis <input type="text" value="seawater"/>	1978 Capital Cost \$ 100,600	Fraction	Current Cost	
	Manufactured and Electrical Equipment Housing Excavation, Site Work and Labor Piping and Valves Steel Concrete	0.52 0.38 0.06 0.04 0 0	119,000 53,250 8,162 5,257 0 0	
	4/1/2006 Capital Cost		\$ 185,700	
	1978 O and M Cost \$ 20,120			
	Materials Energy Labor Cost of Cl2 (/Year)	0.18 0.18 0.64	4,583 9,657 23,480 859,700	
	4/1/2006 O and M Cost		\$ 897,400	

Figure 18. Pretreatment Disinfection Costs.

Select Pretreatment Disinfection Method	Chlorination		Cost Summary																																																																																
	Chlorination <input checked="" type="checkbox"/> Chlorination <input type="checkbox"/> Chlor-amination <input type="checkbox"/> Electrolytic Chlorine Generation <input type="checkbox"/> UV <input type="checkbox"/> Ozonation Process Information Water Analysis seawater	<table border="1"> <thead> <tr> <th colspan="5">Feed Basis</th> </tr> <tr> <th></th> <th>Plant Availability (%)</th> <th>95.00</th> <th>MGD (U.S.)</th> <th>Plant Input</th> <th>Plant Output</th> </tr> </thead> <tbody> <tr> <td>Planned Operation (hours/day)</td> <td>24.</td> <td></td> <td>(kgal/year) (US)</td> <td>18,310,000</td> <td>6,935,000</td> </tr> <tr> <td>Plant Recovery (%)</td> <td>37.89</td> <td></td> <td>(m3/year)</td> <td>69,290,000</td> <td>26,250,000</td> </tr> </tbody> </table> <table border="1"> <thead> <tr> <th rowspan="2"></th> <th colspan="3">Construction Cost</th> <th colspan="3">Operating Cost</th> </tr> <tr> <th>Total (000)</th> <th>* /m3 /day</th> <th>* /gal /day (US)</th> <th>Annual (000)</th> <th>* /m3</th> <th>* /kgal (US)</th> </tr> </thead> <tbody> <tr> <td>Chlorination</td> <td>186</td> <td>2.453</td> <td>.009</td> <td>897</td> <td>.034</td> <td>.129</td> </tr> <tr> <td>Chlor-amination</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Electrolytic Chlorination</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>UV</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Ozonation</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Total</td> <td>\$ 186</td> <td>\$ 2.453</td> <td>\$.009</td> <td>\$ 897</td> <td>\$.034</td> <td>\$.129</td> </tr> </tbody> </table> <p>* Cost per volume of plant product water output</p>					Feed Basis						Plant Availability (%)	95.00	MGD (U.S.)	Plant Input	Plant Output	Planned Operation (hours/day)	24.		(kgal/year) (US)	18,310,000	6,935,000	Plant Recovery (%)	37.89		(m3/year)	69,290,000	26,250,000		Construction Cost			Operating Cost			Total (000)	* /m3 /day	* /gal /day (US)	Annual (000)	* /m3	* /kgal (US)	Chlorination	186	2.453	.009	897	.034	.129	Chlor-amination							Electrolytic Chlorination							UV							Ozonation							Total	\$ 186	\$ 2.453	\$.009	\$ 897	\$.034
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Figure 19. Pretreatment Disinfection Cost Summary.

Chemical Feed Options	
Select Chemical Feed	
<input checked="" type="checkbox"/> Acidification	<input type="checkbox"/> Lime and Soda Ash
<input type="checkbox"/> Alum (Dry Feed)	<input type="checkbox"/> Antiscalant
<input type="checkbox"/> PAC	<input type="checkbox"/> Polyelectrolyte
<input type="checkbox"/> Ferrous Sulfate	<input type="checkbox"/> Potassium Permanganate
<input checked="" type="checkbox"/> Ferric Chloride	<input type="checkbox"/> Sodium Hydroxide

Figure 20. Chemical Feed Options.

Aluminum salts (Alum) polymers such as poly-aluminum chloride (PAC), ferrous sulfate, and ferric chloride coagulation are used for reducing turbidity by producing precipitates. All of the input forms for these chemical feed systems are similar to the one shown in figure 21, “Coagulant Costs.” Cost is based on a dose estimated as described or a user specified alternate dose. Chemical cost is based on use rate and the chemical cost input by the user. Current costs have been provided as a default.

The screenshot shows a software interface with three main sections: 'Acidification', 'Ferric Chloride', and 'Process Data'. The 'Acidification' and 'Process Data' sections are currently selected.

Ferric Chloride Dose Rate

12.76	Calculated Dose (mg/L)	10.00	Alternative Dose (mg/L)
2,550.36	Calculated Dose (kg/day)	1,998.20	Alternative Dose (kg/day)

Enter Ferric Chloride Cost (/US gallon 40% soln)

Process Data

Plant Operating Data

Plant Recovery (%)	37.89
Planned Operation (h/day)	24.00
Plant Availability (%)	95.00

Process Flowrate (plant output at planned hours of operation per day)

20.00	MGD (U.S.)
75,703.68	m3/day
20,000	kgal/day (US)

Plant Input Flow (plant input at planned hours of operation per day)

52.79	MGD (U.S.)
199,820.0	m3/day
52,790	kgal/day (US)

1978 Capital Cost

	Fraction	Current Cost
Manufactured and Electrical Equipment	0.71	424,000
Housing	0.21	76,900
Excavation, Site Work and Labor	0.02	7,110
Piping and Valves	0.05	17,200
Steel	0	0
Concrete	0	0
4/1/2006 Capital Cost		\$ 526,000

1978 O and M Cost

	Fraction	Current Cost
Materials	0.07	3,440
Energy	0.09	9,320
Labor	0.84	59,500
Cost of Ferric Chloride (/Year)		511,038
4/1/2006 O and M Cost		\$ 583,000

Buttons on the right: Edit, Save, Cancel Changes, Continue, Finish, Print Form, Help.

Figure 21. Coagulant Costs.

Lime and soda ash are added to precipitate excess carbonate and, in the process, removes metals and constituents that cause turbidity. Lime, Ca(OH)_2 , and soda ash, (Na_2CO_3) , react with carbonate hardness to precipitate calcium carbonate and magnesium hydroxide.

Potassium permanganate is an oxidizing agent. It is used for iron and manganese removal. A combination of potassium permanganate (KMnO_4) oxidation and manganese-greensand filtration provides effective filtration and also controls under and overdosing of KMnO_4 . Manganese (II) removal depends on the precipitation of $\text{MnO}_2(\text{s})$, manganese[IV] (manganic dioxide).

Sodium hydroxide is used for raising the pH prior to precipitation processes or for post treatment of membrane process effluent. Since it can be used for a variety of purposes, there is no calculated dose rate. The default dose is 1 mg/L. The user can change this value and the chemical cost.

Figure 22 shows the Input form for acidification. A default dose rate is estimated based on the concentrate Langelier Saturation Index (LSI) or Stiff & Davis Saturation Index (S&DSI), assuming the water composition, calculated recovery, and desalting rejection. The objective is to lower the pH enough to bring the concentrate LSI or S&DSI to zero or slightly negative. Acid feed is used to lower the pH to levels compatible with the membranes employed. With cellulose acetate blends, this is about 5.5; tri-cellulose acetate is 6.0–6.5. Thin film composite membranes are not as sensitive to pH as cellulose acetate, but still may be used to control scaling.

A default chemical cost is provided. The capital costs and operations and maintenance costs are displayed with the percentages that are attributed to each cost index. This window shows a typical input form for chemical processes.

Figure 23 is the Chemical Feed Cost Summary form. It is possible to choose other chemical costs now by returning to figure 17, “Chemical Feed Options.” The procedure is repeated for each process again and, finally, back to the Summary form. Note, after adjusting inputs at each of the selected chemical feed forms, press “Save” and “Continue” to the next tab until all have been adjusted and saved. When satisfied with the chemical feed systems of the pretreatment portion, press “Continue” at the Chemical Feed Cost Summary form to go on to the next category of processes.

Acidification **Ferric Chloride**

Select Acid to Add

93% H₂SO₄ 37% HCl Enter Acid Cost (/ton)

0.38 Calculated Dose (mg/L) Alternative Dose (mg/L)

75.66 Calculated Dose (kg/day) 1,998.20 Alternative Dose (kg/day)

-0.68 Concentrate Stiff and Davis Saturation Index

1978 Capital Cost		Fraction	Current Cost
Manufactured and Electrical Equipment		0.7	23,700
Housing		0.07	1,450
Excavation, Site Work and Labor		0.16	3,210
Piping and Valves		0.07	1,360
Steel		0	0
Concrete		0	0
4/1/2006 Capital Cost			\$ 29,700

1978 O and M Cost		Fraction	Current Cost
Materials		0.04	81
Energy		0.05	214
Labor		0.91	2,660
Cost of Acid (/Year)			26,736
4/1/2006 O and M Cost			\$ 29,700

Process Data

Plant Operating Data

Plant Recovery (%) 37.89

Planned Operation (h/day) 24.00

Plant Availability (%) 95.00

Process Flowrate (plant output at planned hours of operation per day)

20.00 MGD (U.S.)

75,703.68 m³/day

20,000 kgal/day (US)

Plant Input Flow (plant input at planned hours of operation per day)

52.79 MGD (U.S.)

199,820.0 m³/day

52,790 kgal/day (US)

Buttons: Edit, Save, Cancel Changes, Continue, Finish, Print Form, Help

Figure 22. Acidification Costs.

Chemical Feed Options		Chemical Feed Cost Summary				
Feed Basis				MGD (U.S.)	(m3/year)	kgal/y (US)
Plant Availability (%)	95.			Plant Output	20.00	26,250,000
Planned Operation (hours/day)	24.			Plant Input	52.79	6,935,000
Plant Recovery (%)	37.89					18,310,000
		Construction Cost			Operating Cost	
		Total (000)	*/m3/day	*/gal/d (US)	Annual (000)	*/m3
						*/kgal (US)
Acidification H2SO4		30	.392	.001	30	.001
Alum (Dry Feed)						
PAC						
Ferrous Sulfate						
Ferric Chloride		526	6.943	.026	583	.022
Lime and Soda Ash						
Anti-Scalant						
Polyelectrolyte						
Potassium Permanganate						
Sodium Hydroxide						
Total		\$ 555	\$ 7.335	\$.028	\$ 613	\$.023
						\$.088
* Cost per volume of plant product water output						

Figure 23. Chemical Feed Cost Summary Form.

De-chlorination is necessary if chlorine was employed for pretreatment disinfection and oxidation sensitive membranes are to be used. There are three chemical methods: sodium bisulfite, sodium sulfite, or sulfur dioxide. In figure 24, check the proper box to select the chemical needed. More than one can be chosen. The default is based on the free chlorine expected in the feed, or other dose rates can be used. Figure 25, “De-chlorination Cost Summary,” is the summary for dechlorination.

Post-Treatment Processes

For post-treatment of product water, there are four possible disinfectants: chlorine, chloramination, ozone, and ultraviolet (UV). Cost estimation (figure 26) for chlorine and/or chloramine is based on the amount of chemicals used per day (i.e., a default dose). It is assumed that the chlorine demand has been removed or satiated in previous separation processes. The default dose for both chemicals is 0.8 mg/L in the product water. Electrochlorination is not used for post-treatment disinfection.

Ozone capital cost estimation includes costs associated with the ozone generator and the contact chamber. Electricity costs are computed using a nominal power use per kilogram of ozone produced, and the local cost of electricity per kilowatt-hour (kWh) (set on the Cost Index form). Inputs for cost estimation are ozone dose in mg/L and contact time in minutes. Values of 3 mg/L and 2 minutes are suggested as normal levels. The product capacity is used. As for chlorination,

Process Information	Dechlorination Methods		Cost Summary		
	Process Input				
Water Analysis seawater	Select Dechlorination Method(s)		<input checked="" type="checkbox"/> NaHSO3	<input type="checkbox"/> Na2SO3	<input type="checkbox"/> SO2
	Chemical Cost (/ton)		300.	300.	300.
	Alternative Dose (mg/L)		0.00	0.00	0.00
	Free Chlorine (mg/L)	0.50			
1978 Capital			\$ 39,432	\$ 29,586	\$ 29,586
		Fraction		Current	
Manufactured and Electrical Equipment	0.72		64,559	48,439	48,439
Housing	0.19		10,433	7,828	7,828
Excavation, Site Work and Labor	0.04		2,132	1,600	1,600
Piping and Valves	0.01		515	386	386
Steel	0				
Concrete	0.04		2,154	1,616	1,616
4/1/2006	Capital Cost		\$ 79,793	\$ 59,869	\$ 59,869
1978 O and M Cost			\$ 4,067	\$ 3,615	\$ 3,615
		Fraction		Current	
Materials	0.24		11,977	8,986	8,986
Energy	0.1		10,515	7,890	7,890
Labor	0.66		47,461	35,610	35,610
Chemical Cost/yr			16,844		
4/1/2006	O and M Cost		\$ 86,797	\$ 52,486	\$ 52,486

Figure 24. Dechlorination Cost.

Process Information	Dechlorination Methods			Cost Summary			
	Feed Basis						
Water Analysis seawater	Plant Availability (%)	95.	MGD (U.S.)	Plant Output	20.00	Plant Input	52.79
	Planned Operation (hours/day)	24.	m3/year		26,250,000		69,290,000
	Plant Recovery (%)	37.89	kgal/year (US)		6,935,000		18,310,000
		Construction Cost		Operating Cost			
		Total (000)	*/m3 /day	*/gal /day (US)	Annual (000)	*/m3	*/kgal (US)
Sodium Bisulfite		\$ 80	1.054	.004	\$ 87	.003	.013
Sodium Sulfite							
Sulfur Dioxide							
Total		\$ 80	\$ 1.054	\$.004	\$ 87	\$.003	\$.013
* Cost per volume of plant product water output							

Figure 25. Dechlorination Cost Summary.

Product Water Disinfection Methods	Chlorination	Chemical Addition Page	Chemical Addition Page	Cost Summary																																																																
		1	2																																																																	
<input checked="" type="checkbox"/> Chlorination <input type="checkbox"/> Chlor-amination <input type="checkbox"/> Ozonation <input type="checkbox"/> UV	Process Input <input type="text" value="1"/> Chlorine Dose (mg/L) <input type="text" value="365"/> Cl2 Cost (/ton), tanks																																																																			
Product Water Chemical Addition Lime, Zinc Poly-phosphate, NaOH, Hydrated Lime, CO2 <input checked="" type="checkbox"/>	The cost shown here and on the final report form for product water chlorine disinfection is the incremental increase to the cost of the pretreatment system																																																																			
Process Information Water Analysis <input type="text" value="seawater"/>	<table border="1"> <thead> <tr> <th>1978 Capital Cost</th> <th>\$ 7,443</th> <th>Fraction</th> <th>Current Cost</th> </tr> </thead> <tbody> <tr> <td>Manufactured and Electrical Equipment</td> <td></td> <td>0.52</td> <td>8,801</td> </tr> <tr> <td>Housing</td> <td></td> <td>0.38</td> <td>3,939</td> </tr> <tr> <td>Excavation, Site Work and Labor</td> <td></td> <td>0.06</td> <td>604</td> </tr> <tr> <td>Piping and Valves</td> <td></td> <td>0.04</td> <td>389</td> </tr> <tr> <td>Steel</td> <td></td> <td>0</td> <td></td> </tr> <tr> <td>Concrete</td> <td></td> <td>0</td> <td></td> </tr> <tr> <td colspan="3"><hr/></td> <td></td> </tr> <tr> <td>4/1/2006</td> <td>Capital Cost</td> <td></td> <td>\$ 13,732</td> </tr> <tr> <td colspan="4">1978 O and M Cost</td> </tr> <tr> <td>Materials</td> <td></td> <td>0.18</td> <td>0.00</td> </tr> <tr> <td>Energy</td> <td></td> <td>0.18</td> <td>0.00</td> </tr> <tr> <td>Labor</td> <td></td> <td>0.64</td> <td>0.00</td> </tr> <tr> <td>Cost of Cl2 (/Year)</td> <td></td> <td></td> <td>10,562</td> </tr> <tr> <td colspan="3"><hr/></td> <td></td> </tr> <tr> <td>4/1/2006</td> <td>O and M Cost</td> <td></td> <td>\$ 10,562</td> </tr> </tbody> </table>				1978 Capital Cost	\$ 7,443	Fraction	Current Cost	Manufactured and Electrical Equipment		0.52	8,801	Housing		0.38	3,939	Excavation, Site Work and Labor		0.06	604	Piping and Valves		0.04	389	Steel		0		Concrete		0		<hr/>				4/1/2006	Capital Cost		\$ 13,732	1978 O and M Cost				Materials		0.18	0.00	Energy		0.18	0.00	Labor		0.64	0.00	Cost of Cl2 (/Year)			10,562	<hr/>				4/1/2006	O and M Cost		\$ 10,562
1978 Capital Cost	\$ 7,443	Fraction	Current Cost																																																																	
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4/1/2006	O and M Cost		\$ 10,562																																																																	

Figure 26. Product Water Chlorination.

if ozonation was also used for pretreatment, the costs shown on the post-treatment form are incremental costs for the added capacity.

UV irradiation costs are based on the plant product water capacity only and are the same as for pretreatment UV. Sizing a UV is dependant on water quality and capacity; therefore, the user must take these costs for only a rough estimate. The user can refine the estimate for bulb replacement by entering the bulb cost.

Five choices of product water stabilization method are provided: lime/soda ash, zinc polyphosphate, sodium hydroxide, hydrated lime, and carbon dioxide (CO₂) (see figure 27, “Post-treatment Chemical Addition Page 1”). These chemicals may be needed in cases where the product water LSI is negative. Desalination product generally needs re-mineralization before it can safely be put into a distribution system. The additives each work in a different way to stabilize the water. The LSI of the product water is given in the upper left corner. There are check boxes next to each chemical. The user must follow outlined proscribed steps to determine the necessary dose of each type of chemical. More than one chemical can be employed. For some waters, a combination of chemicals gives the most efficient result.

Re-carbonation basins costs were developed for re-carbonation basins, including the reinforced concrete structure, complete with influent and effluent channels,

Product Water Disinfection Methods	Chlorination	Chemical Addition Page 1	Chemical Addition Page 2	Cost Summary			
Chlorination	Process Input						
	LSI -	<input type="checkbox"/> Lime/Soda	<input checked="" type="checkbox"/> Zinc Polyphosphate	<input checked="" type="checkbox"/> NaOH			
	Dose (mg/L)	0 / 0	2.	1.97			
Chlor-amination	Cost (\$/lb)	.13 / .08	.68	1.09			
Ozonation							
UV	1978 Capital Cost	0	\$ 40,389	\$ 17,685			
Product Water Chemical Addition	Manufactured and Electrical Equipment	Fraction 0.7	Current Cost 0	Fraction 0.7	Current Cost 64,289	Fraction 0.43	Current Cost 17,292
	Housing	0.25	0	0.25	14,061	0.49	12,068
	Excavation, Site Work and Labor	0.02	0	0.02	1,092	0.05	1,195
	Piping and Valves	0.03	0	0.03	1,582	0.03	693
	Steel	0	0	0		0	
	Concrete	0	0	0		0	
	4/1/2006 Capital		0		\$ 81,025		\$ 31,249
	1978 O and M Cost		0		\$ 4,042		\$ 1,593
Water Analysis	Materials	0.06	0	0.06	307	0.05	101
	Energy	0.09	0	0.09	970	0.35	1,487
	Labor	0.85	0	0.85	6,265	0.60	1,743
	Chemicals (/Y)	-	0	-	78,719	-	124,290
4/1/2006 Operating		0		\$ 86,261		\$ 127,621	

Figure 27. Post-treatment Chemical Addition Page 1.

foam suppression piping and sprayers, and handrails surrounding the basin. Liquid CO₂ is used. Costs for the piping and diffusers are included with the cost of CO₂ feed systems. Electrical costs are also included. The applicable range for basin size is 20–1,000 m³. A retention time of 5 minutes is assumed in determining the default size. Costs were developed for systems capable of CO₂ feed rates between 280 and 1,500 pounds per day (lb/day). The costs include a storage tank with 10 days of storage, a vaporizer, a solution-type feeder, an injector pump for the solution basin, and an automatic control system using pH measurement for control to the CO₂ feeder. One standby feeder and vaporizer is included for each installation. Housing costs are only for the CO₂ feed and vaporizing equipment. No provision has been made for the enclosure of the storage tank. Carbon dioxide is delivered to the plant site in bulk to be stored in pressure vessels.

Costs (figure 28, “Post Treatment Chemical Addition Page 2”) are calculated using relations presented earlier for lime and soda ash—the same cost curves are used for hydrated lime. The polyelectrolyte feed cost curve is used for zinc polyphosphate. Curves from reference 1 are used for sodium hydroxide (NaOH).

The summary form in figure 29 itemizes costs for post-treatment product water.

Product Water Disinfection Methods	Chlorination	Chemical Addition Page 1	Chemical Addition Page 2	Cost Summary	
	<input checked="" type="checkbox"/> Chlorination <input type="checkbox"/> Chlor-amination <input type="checkbox"/> Ozonation <input type="checkbox"/> UV	Process Input LSI - <input checked="" type="checkbox"/> Hydrated Lime (93% Ca(OH) ₂) <input type="checkbox"/> Recarbonation with Liquid CO ₂			
	Dose (mg/L)	5.	Basin Volume gal	69,448	Basins 1
	Cost (\$/lb)	.13	CO ₂ Cost (\$/lb)	.09	Dose (mg/L) 5.
Product Water Chemical Addition	1978 Capital Cost		Recarbonation Basins		CO ₂ Feed System
	Fraction	Current Cost	Fraction	Current Cost	Fraction Current Cost
<input checked="" type="checkbox"/> Lime, Zinc Poly-phosphate, NaOH, Hydrated Lime, CO ₂	Manufactured and Electrical Equipment	0.7 282,308	0 0	0.60 0	0
	Housing	0.25 61,747	0 0	0.11 0	0
	Excavation, Site Work and Labor	0.02 4,795	0.46 0	0.21 0	0
	Piping and Valves	0.03 6,949	0.02 0	0.09 0	0
	Steel	0 0	0.32 0	0 0	0
	Concrete	0 0	0.20 0	0 0	0
Process Information	4/1/2006 Capital	\$ 355,798	0	0	0
Water Analysis	1978 O and M Cost				0
	Materials	0.06 10,732	0.6	0	0
	Energy	0.09 33,921	0.23	0	0
	Labor	0.85 219,087	0.16	0	0
	Chemicals (/Y)	- 37,623	-	0	0
seawater	4/1/2006 Operating	\$ 301,363		0	0

Figure 28. Post Treatment Chemical Addition Page 2.

Product Water Disinfection Methods	Chlorination	Chemical Addition Page 1	Chemical Addition Page 2	Cost Summary	
	<input checked="" type="checkbox"/> Chlorination <input type="checkbox"/> Chlor-amination <input type="checkbox"/> Ozonation <input type="checkbox"/> UV	Feed Basis		Plant Input	Plant Output
	Plant Availability (%)	95. MGD (U.S.)	52.79	20.00	
	Planned Operation (hours/day)	24. (m ³ /year)	69,290,000	26,250,000	
	Plant Recovery (%)	37.89 (kgal/year)	18,310,000	6,935,000	
Product Water Chemical Addition	Construction Cost		Operating Cost		
	Total (000)	*/m ³ /day	*/gal /day (US)	Annual (000)	*/m ³ */kgal (US)
<input checked="" type="checkbox"/> Lime, Zinc Poly-phosphate, NaOH, Hydrated Lime, CO ₂	Chlorination	14 .181	.001	11	. .002
	Chlor-amination				
	Ozonation				
Process Information	UV				
Water Analysis	Chemical Addition	468 6.183	.023	515	.02 .074
	seawater	Total	\$ 482 \$ 6.364	\$.024	\$ 526 \$.02 \$.076
	* Cost per volume of plant product water output				

Figure 29. Post-treatment Product Water Summary.

Miscellaneous Equipment

Figure 30, “Miscellaneous Equipment – Upflow Clarifier - Upflow Solids Contact Clarifiers (UFSCC),” if chosen by checking the box, can be used with lime softening, alum, PAC, or ferrous sulfate precipitation. The size of the clarifier is determined from the flow rate and the detention time. Flow rate is taken from the Project Information form, and retention time is entered on the UFSCC Sizing and Cost Estimate form shown in figure 30. The height of the tank is assumed 4.8 meters.

Select Equipment	Pumps	Other Equipment	Cost Summary
	UFSCC	Intake and Outfall	Water Storage and Land
<input checked="" type="checkbox"/> Upflow Solids Contact Clarifier	Process Input		
<input checked="" type="checkbox"/> Intake and Outfall	16	Bed Depth (ft)	
<input checked="" type="checkbox"/> Water Storage and Land	1	Number of Contact Clarifiers	20,886
<input checked="" type="checkbox"/> Additional Pumps	180	Retention Time (min)	0
<input checked="" type="checkbox"/> Other Equipment	G Rating <input checked="" type="radio"/> 70% <input type="radio"/> 110% <input type="radio"/> 150%		
Process Information	1978 Capital Cost		
Water Analysis			\$ 697,300
seawater			Fraction
			Current Cost
	Manufactured and Electrical Equipment		0.516
	Housing		0
	Excavation, Site Work and Labor		0.293
	Piping and Valves		0
	Steel		0.11
	Concrete		0.081
	4/1/2006	Capital Cost	\$ 1,268,000
Plant Input (kgal/day) 52,800			
	1978 Operating and Maintenance Cost		\$ 16,270
			Fraction
			Current Cost
	Materials		0.17
	Energy		0.23
	Labor		0.60
Plant Output (kgal/day) 20,000	4/1/2006	O and M Cost	\$ 31,290

Figure 30. Miscellaneous Equipment – Upflow Clarifier.

Figure 31, “Miscellaneous Equipment – Intake and Outfall Costs.” – Intake costs are for either open surface intakes or well intakes. Surface water intakes include a structure, screen, pump, and 100 feet of pipe. Well intakes include a well with casing, pump and 100 feet of pipe. Pipe size and cost depends on the capacity. Check the box next to “Include Intake Costs” and choose between “Open” or “Well” intake.

The outfall is where the concentrate and other discharge streams from the plant are directed. There are four choices: Open Outfall, Evaporative Ponds, Spray Irrigation, and/or Deep Well Injection. Enter the percentage of the concentrate to discharge in each of the methods. The percentage will add up to 100 because the last option, Deep Well Injection, gets the remainder. The concentrate volume was calculated from the values entered on the Separation Process Specification form

Select Equipment	Other Equipment		Cost Summary	
	UFSCC		Intake and Outfall	Water Storage and Land
<input checked="" type="checkbox"/> Upflow Solids Contact Clarifier	<input checked="" type="checkbox"/> Include Intake Costs		Outfall Costs Cont.	
<input checked="" type="checkbox"/> Intake and Outfall	100. Percent of Total Plant Input		0 Evaporation Ponds (% of Total Flow)	
Water	<input checked="" type="radio"/> Open Intake		10118 Land Cost (\$/acre)	
<input checked="" type="checkbox"/> Storage and Land	<input checked="" type="radio"/> Well Intake		4007 Land Clearing Cost (\$/acre)	
Additional Pumps	<input checked="" type="checkbox"/> Include Outfall Costs		8.2 Dike Height (ft)	
<input type="checkbox"/> Other Equipment	100. Open outfall (% of Total Flow)		197.7 Evaporation Area (acre)	
Process Information	300 Length of Pipe in the Water (ft)		60 Liner Thickness (mil)	
Water Analysis	34 Pipe Diameter (in)			
seawater	160.2 Pressure Drop (psi)		0 Spray Irrigation (% of Total Flow)	
	0 Deep Well Injection (% of Total Flow)		11.5 Loading (ft/yr)	
	- Tube Diameter (in)		1 Storage Days	
	3412 Depth (ft)		10118 Land Cost (\$/acre)	
			4007 Land Clearing Cost (\$/acre)	
	Capital Cost		Operating Cost	
Plant Input (kgal/day) 52,800	Intake Total	\$ 14,870,000	Intake Total	\$ 74,330
Plant Output (kgal/day) 20,000	Open Outfall	\$ 53,350	Open Outfall	\$ 267
	Evaporation Ponds	0	Evaporation Ponds	0
	Spray Irrigation	0	Spray Irrigation	0
	Deep Well Injection	0	Deep Well Injection	0
	Outfall Base Cost	\$ 665		
	Outfall Total	\$ 54,020	Outfall Total	\$ 267

Figure 31. Miscellaneous Equipment - Intake and Outfall Costs.

and the recovery from MF/UF, if used. For a given site, one discharge method may be more appropriate than another for reasons that do not involve cost. This program only assesses the cost of discharge.

Figure 32, “Miscellaneous Equipment –Water Storage and Land Costs.” – Product water is commonly stored at the plant site before high-service pumping, as a supplement to distribution system storage. In many cases, filter or granular activated carbon wash water pumps also draw from the clearwell, eliminating the need for a separate sump. Clearwell storage may be either below ground in reinforced concrete structures, or above ground in steel tanks. Instrumentation and control of the clearwell water level is very important in terms of pacing the plant output. In addition, instrumentation for turbidity and chlorine measurement, as well as other quality control operations, is normally provided with the clearwell. For some facilities, acquiring land to build a water plant and for concentrate disposal can incur cost. If true, the appropriate boxes in figure 32 are filled. An estimate for the amount of land required for the plant is calculated based on other plant experiences.

Cost estimates are also provided for extra pumps (not shown here), tanks, and any other specialized or miscellaneous equipment that may be needed for a project. Figure 33 shows tank costs, which are based on storage capacity and number. Other equipment can be described by checking the appropriate box next to

Select Equipment	Other Equipment	Cost Summary		Water Storage and Land										
	UFSCC	Intake and Outfall												
<input type="checkbox"/> Upflow Solids Contact Clarifier <input checked="" type="checkbox"/> Intake and Outfall <input checked="" type="checkbox"/> Water Storage and Land <input type="checkbox"/> Additional Pumps <input checked="" type="checkbox"/> Other Equipment	Water Storage Input <table border="1"> <tr> <td>4400</td> <td>Below Ground Storage Capacity (kgal)</td> <td>Daily Production (kgal/day)</td> <td colspan="2"></td> </tr> <tr> <td>10000</td> <td>Above Ground Storage Capacity (kgal)</td> <td>20,000</td> <td colspan="2"></td> </tr> </table>				4400	Below Ground Storage Capacity (kgal)	Daily Production (kgal/day)			10000	Above Ground Storage Capacity (kgal)	20,000		
4400	Below Ground Storage Capacity (kgal)	Daily Production (kgal/day)												
10000	Above Ground Storage Capacity (kgal)	20,000												
Process Information Water Analysis <input type="checkbox"/> seawater Plant Input (kgal/day) 52,800 Plant Output (kgal/day) 20,000	1978 Capital Cost \$ 1,042,000	Below Ground (concrete) Storage \$ 1,269,000												
		Fraction	Current Cost	Fraction	Current Cost									
	Manufactured Equipment	0.02	47,400	0.6891	1,988,000									
	Housing (Misc. and Contingency)	0.13	188,700	0.13	229,700									
	Excavation and Site Work	0.32	450,900	0.01	17,150									
	Piping and Valves	0		0.07066	117,100									
	Steel	0.28	368,200	0.04	64,030									
	Concrete	0.26	370,100	0.06	104,000									
	4/1/2006 Capital Cost		\$ 1,425,000		\$ 2,520,000									
	Land Cost Input <input type="checkbox"/> Include Land other than for brine disposal Calculated Land Requirement (Acres) 9.5 Land Cost (\$/acre) 10,117 Land Area (Acres) 7.5		Land Cost \$ 0 Total Capital Cost \$ 3,946,000											

Figure 32. Miscellaneous Equipment - Water Storage and Land Costs.

Select Equipment	UFSCC	Intake and Outfall	Water Storage and Land								
	Other Equipment	Cost Summary									
<input checked="" type="checkbox"/> Upflow Solids Contact Clarifier <input checked="" type="checkbox"/> Intake and Outfall <input checked="" type="checkbox"/> Water Storage and Land <input type="checkbox"/> Additional Pumps <input checked="" type="checkbox"/> Other Equipment	<input type="checkbox"/> Include Additional Tank Costs <input type="checkbox"/> Include Other Equipment and Operating Costs										
Process Information Water Analysis <input type="checkbox"/> seawater Plant Input (kgal/day) 52,800 Plant Output (kgal/day) 20,000	In-Process Storage Tanks - Input <table border="1"> <tr> <td>2,000</td> <td>Storage Capacity per Tank (gal)</td> </tr> <tr> <td>1</td> <td>Number of Tanks</td> </tr> <tr> <td colspan="2">Daily Production at full Capacity (kgal)</td> </tr> <tr> <td colspan="2">20,000</td> </tr> </table>		2,000	Storage Capacity per Tank (gal)	1	Number of Tanks	Daily Production at full Capacity (kgal)		20,000		Other Process Input Process/equipment Description Capital Cost Annual Operating Cost
	2,000	Storage Capacity per Tank (gal)									
	1	Number of Tanks									
	Daily Production at full Capacity (kgal)										
	20,000										
	Additional Tanks Capital Cost Manufactured Equipment Excavation, Site Work and Labor Total										
	Other Process Equipment Capital Cost										
	Total Capital Cost \$										
	Total Operating Cost										

Figure 33. Miscellaneous Equipment - Other Equipment.

“Include Other Equipment and Operating Costs.” The description of this equipment is noted and the associated capital and annual costs entered. The costs will be added to the total at the end of the project.

Figure 34 sums up all the costs associated with miscellaneous equipment.

Select Equipment	UFSCC		Intake and Outfall		Water Storage and Land	
	Other Equipment		Cost Summary			
<input checked="" type="checkbox"/> Upflow Solids Contact Clarifier	Feed Basis					
<input checked="" type="checkbox"/> Intake and Outfall	Plant Availability (%)	95.00	MGD (U.S.)	Plant Input	Plant Output	
<input checked="" type="checkbox"/> Water Storage and Land	Planned Operation (hours/day)	24.00	(kgal/year) (US)	53	20	
<input type="checkbox"/> Additional Pumps	Plant Recovery (%)	37.89	(m3/year)	18,310,000	6,935,000	
<input checked="" type="checkbox"/> Other Equipment				69,290,000	26,250,000	
Process Information						
Water Analysis						
seawater						
Plant Input (kgal/day) 52,800						
Plant Output (kgal/day) 20,000						
		Construction Cost		Operating Cost		
	Total (000)	* /m3 /day	* /gal /day (US)	Total (000)	* /m3	* /kgal (US)
Upflow Solids Contact Clarifier	1,268	16.753	.063	31	.001	.005
Intake and Outfall	14,921	197.095	.746	75	.003	.011
Clearwell and Storage	3,946	52.118	.197			
Land						
Pumps						
Other Equipment						
Total	\$ 20,135	265.966	1.007	106	.004	.015
	* Cost per volume of plant product water output					

Figure 34. Miscellaneous Equipment Cost Summary.

Project Summary

Finally, the “Continue” button displays the Project Summary form shown in figure 35. The first tab displays project information, capacity, and the processes chosen. The second tab, shown in figure 36, is for specifying indirect capital costs. Enter a percentage of capital costs for each item or use the default values. Profit and suggested pilot plant costs are also noted here. The amounts are calculated and summarized here. Except for profit and the pilot plant, the indirect costs are added to the direct capital cost for the total project cost, summarized in figure 37 in a variety of units. Summarized costs are taken from the more detailed summary sheets for each category of process. The specific processes are listed on the Project Summary form. (Care is needed about clicking on “End WTCost[®] Session.” If done, the question will be asked if the session is to end. By pressing on “Print Form,” all three tabs will be printed.)

Project Summary		Indirect Costs		Project Cost Summary	
Project	Bureau of Reclamation	Feed Flow	53.00	MGD (U.S.)	
Description		Product Flow	20	MGD (U.S.)	
		Process Recovery (%)		42	
		Plant Availability (%)		95	
Date		Planned Operation (h/day)		24	
Pretreatment Disinfection		De-Chlorination			
Chlorination		Sodium Bisulfite			
		Desalting			
		Reverse Osmosis			
		Thermal Desalination			
Chemical Feed Systems		Product Water Treatment			
Acidification(H2SO4)	Dose Rate 10 mg/L	Chlorination			
Ferric Chloride	10 mg/L	Product Water Chemical Addition			
		Miscellaneous Equipment			
		Upflow Solids Contact Clarifier			
		Intake/Outfall			
		Clearwell, Storage and Land			
		Additional Equipment			
Media Filtration					
Gravity Filtration					

Figure 35. Program Summation of Processes.

Project Summary		Indirect Costs		Project Cost Summary	
Indirect Cost Input		Indirect Capital Cost		Data from Cost Indices Form:	
Interest during Construction (% of Total Constr. Cost)	6	\$ 5,429,000		Plant Amortization (Y)	30
Contingencies (% of Total Constr. Cost)	12	\$ 10,860,000		Interest Rate (%)	6.
Architectural and Engineering costs: Project Management, Fees (% of Total Constr. Cost)	12	\$ 10,860,000		Plant Staffing (Number of Full Time People)	
Working Capital (% of Total Constr Cost)	4	\$ 3,619,000		Management	2.3
Insurance (% of Total Constr. Cost)	0.5	\$ 452,400		Engineering and Laboratory	3.6
Taxes - VAT/Import Duty (% of Total Constr. Cost)	0.5	\$ 452,400		Operators/Maintenance	43.9
Profit (% of Total Constr. Cost)	12	\$ 10,860,000		Supply, Office and Admin.	6.1
Pilot Plant Cost	75000	\$ 75,000			
Total Indirect Construction Cost		\$ 42,600,000			
Land Cost		\$			

Figure 36. Indirect Capital and Land Costs.

Project Summary		Indirect Costs		Project Cost Summary		
Process	Construction Cost			Operating Cost		
	Total (000)	* /m3/day	* /gal /day (US)	000/yr	* /m3	* /kgal (US)
Pretreatment	186	2	.01	897	.03	.13
Chemical Feed Systems	555	7	.03	613	.02	.09
Media Filtration	16,830	222	.84	925	.04	.13
De-Chlorination	80	1	.	87	.	.01
Desalting	52,210	690	2.61	15,360	.59	2.21
Product Water Treatment	482	6	.02	526	.02	.08
Miscellaneous Equipment	20,130	266	1.01	106	.	.02
Non-Operator Labor				1,044	.04	.15
Indirect Capital Cost	42,600	563	2.13			
Capital Recovery				9,574	.36	1.38
Feed Water					.	.
TOTAL	133,100	1,758	6.65	29,130	1.11	4.2

* Cost per volume of plant product water output

Figure 37. Project Cost Summary.

Savings

It is not possible to place a specific value on the cost savings to be accrued through the use of this program. This flexible cost model is an evaluation tool and supplier neutral. Qualitatively, savings will be obtained from:

- Permitting localities to select the most economical desalting process through comparative studies and sensitivity analyses of different technologies and combinations thereof.
- Defining a budget estimate for a desalination tender, thus, lessening the cost and preparation time for issuing bid documents.
- Presenting a system capital requirement for each piece of equipment needed to construct a facility and the operating costs involved. The program can, thus, readily evaluate the systematic cost impacts of process and technology changes.
- Establishing optimum operating conditions for tendering projects.

- Making research and development more efficient through early evaluation of ideas and results and enhancing technology transfers. Improvements to known commercial processes can be facilitated and evaluated. Innovative concepts, with additional programming, can be added by seamlessly incorporating these ideas into this program.
- Aiding in environmental impact studies, such as brine disposal, at different locations and processes.

Conclusions

In the last decades, the cost of water treatment processes has decreased considerably, while the water treatment market, globally, has increased to an estimated range between \$360 billion to \$655 billion. (The wide range of values is due to varying methodologies employed by specific analysers.) Annual growth is about 4% to 5%. Sales of this magnitude have attracted many multinational companies to the industry.

The market can be, generally, segmented into:

Water treatment equipment	9%
Delivery equipment	9%
Chemicals	4%
Consulting/engineering	6%
Contract operations	2%
Maintenance services	2%
Instruments/monitoring	0.8%
Analytical testing	0.5%
Wastewater utilities	32%
Drinking water utilities	34%

The major driving forces for this market growth are the worldwide need for delivering to the public a plentiful supply of good, clean, healthful drinking water and to enhance economical industrial growth in such industries as electronics, power, pharmaceutical, and medical. In many, if not most areas of the world, water is considered a low-cost entitlement. Thus, the pressures on the municipal and industrial contractors to obtain the least expensive source of supply are enormous. Factoring into these problems is that good quality water is limited, all of which means that we must reuse waste water and utilize the almost limitless supply of seawater through desalination. Having the ability to pick and choose the most socio-economical process is the demanding principle of our times. To assist in accomplishing this task is the requirement to have a definitive cost

program that is supplier neutral and allows for “apple-to-apple” comparisons. As viewed from the recent Cyprus cost conference, we are just now beginning this process.

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