CPET, Continued Professional Education and Training

Water Globe

THE MIDDLE EAST DESALINATION RESEARCH CENTER

Cost Estimating of SWRO Desalination Plants

Day 1: Plant Cost Fundamentals

June 25, 2013

9:00-10:30

1.1 Project Cost Estimating - Overview

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Project Cost Estimating Overview - Outline

- Project Cost Definitions;
- General Methodology for Preparation of Project Cost Estimates;
- Type and Accuracy of Project Cost Estimates;
- Cost Models.

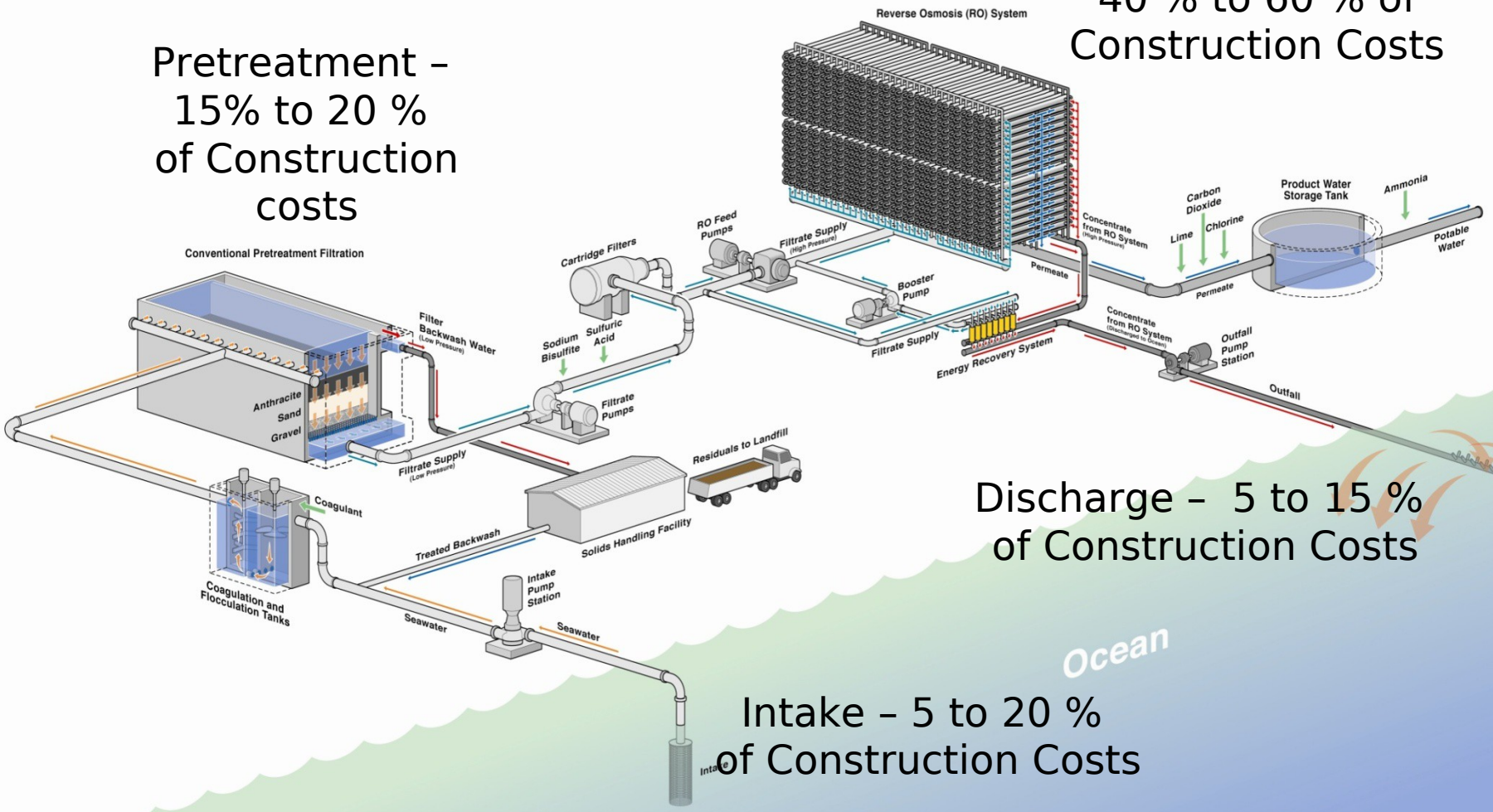
Desalination Cost Components

- Capital Costs:
  - Construction (Direct or “Hard”) Capital Costs;
  - Indirect (“Soft”) Capital Costs.
- Operation & Maintenance Costs:
  - Variable;
  - Fixed.
- Cost of Water:
  - Annualized Capital Costs;
  - O&M Costs.
  - Variable + Fixed

Seawater Desalination Plant – Construction (Direct) Capital Costs

Pretreatment – 15% to 20 % of Construction costs

RO System – 40 % to 60 % of Construction Costs



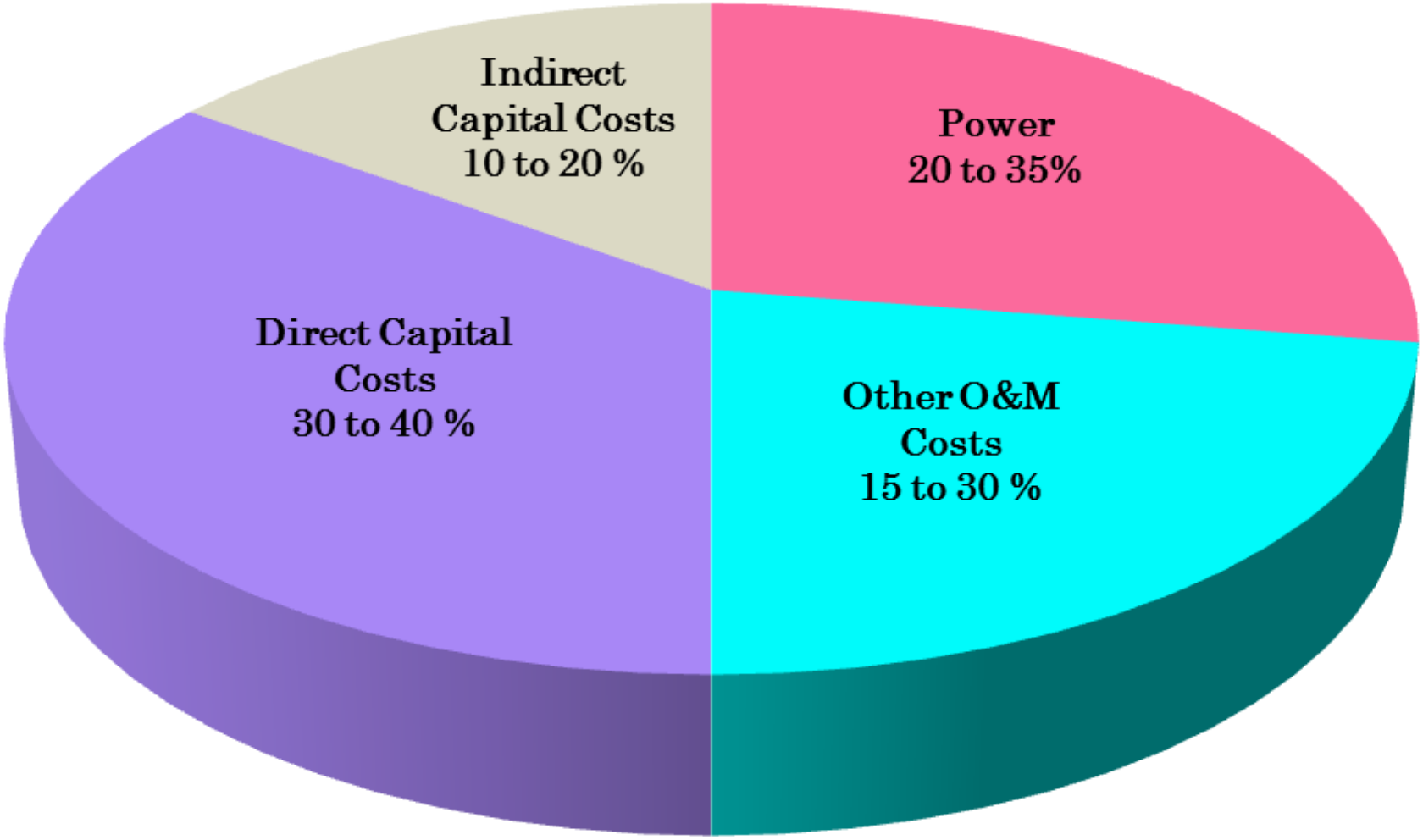
Discharge – 5 to 15 % of Construction Costs

Intake – 5 to 20 % of Construction Costs

Seawater Desalination Plant – Soft (Indirect) Capital Costs

- Project Engineering
- Project Development & Environmental Review
- Project Financing
- Contingency

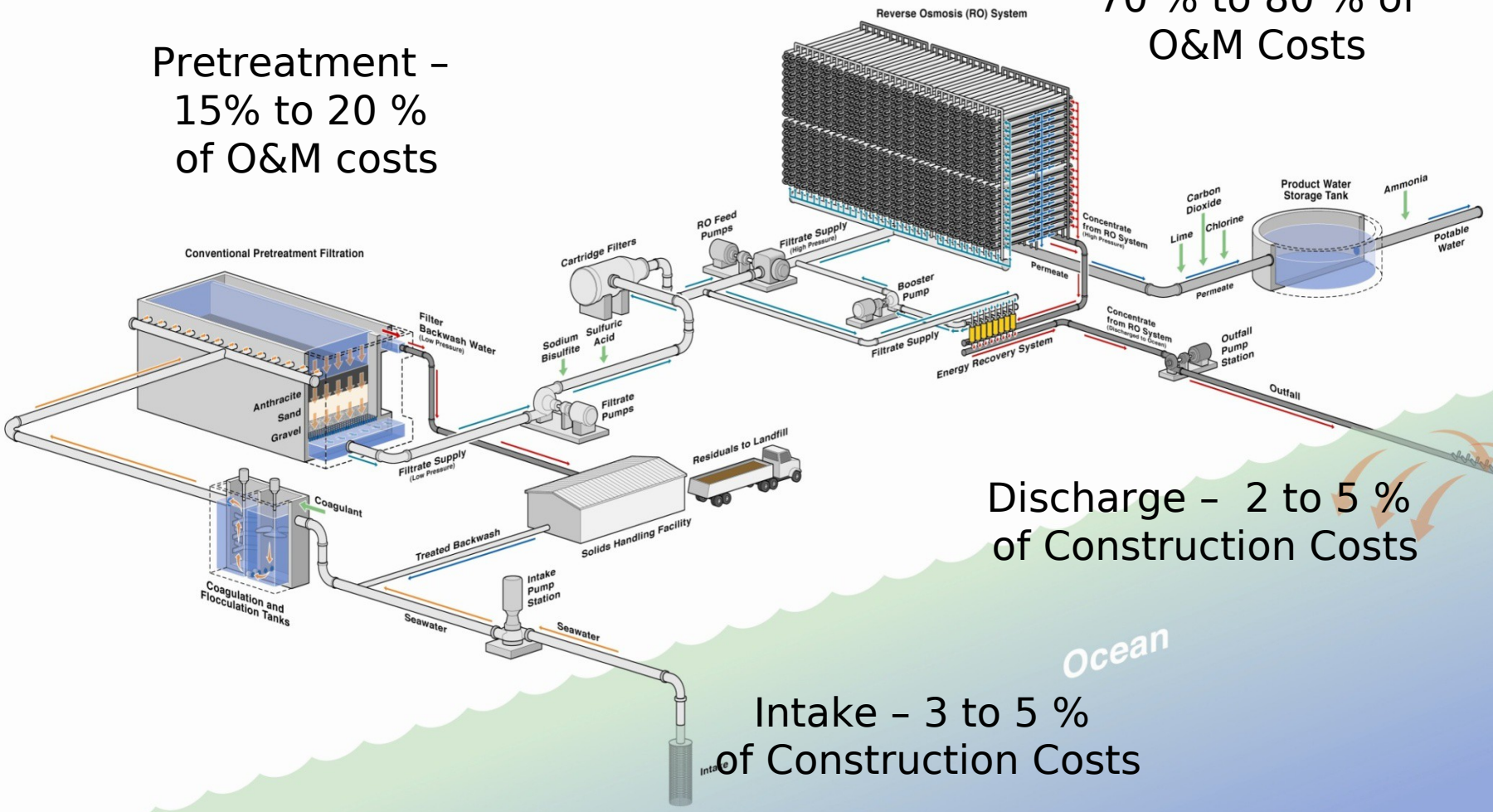
SWRO Desalination Plant Cost Breakdown



Seawater Desalination Plant – O&M Costs

RO System – 70 % to 80 % of O&M Costs

Pretreatment – 15% to 20 % of O&M costs



Discharge – 2 to 5 % of Construction Costs

Intake – 3 to 5 % of Construction Costs

Typical Cost of Water (in US$2013) and Energy Ranges
(Medium & Large SWRO Plants)

Classification	Cost of Water Production (US$/m³)	SWRO System Energy Use (kWh/m³)
Low-End Bracket	0.5 – 0.8	2.5 – 2.8
Medium Range	1.0- 1.5	3.0 – 3.5
High-End Bracket	2.0 – 4.0	4.0 – 4.5
Average	1.1	3.1

Cost Comparison of Alternative Desalination Technologies

Energy and Water Production Costs for Alternative Desalination Technologies

Process/Energy Type	MED	MSF	VC	BWRO	SWRO
Steam Pressure, ata	0.2 – 0.4	2.5-3.5	Not Needed	Not Needed	Not Needed
Electric Energy Equivalent, kWh/m³ (kWh/1,000 gal)	4.5 – 6.0 (17.0-22.7)	9.5-11.0 (35.9-41.6)	NA	NA	NA
Electricity Consumption, kWh/m³ (kWh/1,000 gal)	1.2-1.8 (4.5-6.8)	3.2-4.0 (12.1-15.1)	8.0 – 12.0 (30.3-45.4)	0.3 – 2.8 (1.1-10.6)	2.5 – 4.0 (9.5-15.1)
Total Energy Use, kWh/m³ (kWh/1,000 gal)	5.7-7.8 (21.5-29.5)	12.7-15.0 (48.0-56.7)	8.0 – 12.0 (30.3-45.4)	0.3 – 2.8 (1.1-10.6)	2.5 – 4.0 (9.5-15.1)
Water Production Costs, US$/m³ (US$/1,000 gal)	0.7 – 3.5 (2.6-13.2)	0.9 – 4.0 (3.4-15.1)	1.0 – 3.5 (3.8-13.2)	0.2 – 1.8 (0.8-6.8)	0.5 – 3.0 (1.9-11.3)

Note: NA – Not applicable.

General Methodology for Preparing Cost Estimate

1. Determine Project Size, Availability and Location/Site;
2. Establish Source and Product Water Quality;
3. Identify the Location of:
   - Intake;
   - Discharge;
   - Point of Delivery to the Water Supply System;
   - Source of Power Supply.
4. Complete Initial Environmental Review;
5. Use Cost Curves, Models or Detailed Cost Calculations to Determine Capital and O&M Costs;
6. Identify the Source and Conditions of Project Funding;
7. Calculate Cost of Water Production.

Type and Accuracy of Cost Estimates

- Conceptual Cost Estimate
  - Developed During Initial Planning/Phasing;
  - Accuracy – 50 % to + 100 %.
- Preliminary Cost Estimate
  - Developed when Project Scope is Well Defined;
  - Accuracy – 30 % to + 50 %.
- Budgetary Cost Estimate
  - Used to Determine Project Budget and Procure Services;
  - Accuracy – 15 % to + 30 %.
- Preliminary Cost Estimate
  - Developed based on Detailed Project Design.
  - Accuracy – 5 % to + 10 %.

Type and Accuracy of Cost Estimates

Estimate Type	Cost Basis	Purpose	Expected Accuracy (Percent of Actual Costs)
Conceptual (Incremental Budgeting)	• Initial Project Scope and Conceptual Design; • Costs of Similar Projects; • Scale Factors; • Cost – Plant Capacity Curves and Tables.	• Conceptual Planning; • Fatal-flaw analysis; • Project Scope Definition.	- 50 to +100 %
Preliminary	• Preliminary Project Design; • Cost Models; • Cost Graphs, Formulas and Tables for Individual Treatment Processes and Equipment.	• Process, Technology and Equipment Selection; • General Evaluations; • Guidance for Future Investigations.	- 30 to +50 %

Type and Accuracy of Cost Estimates (continued)

Budgetary	• Advanced Project Development and Design; • Budgetary Vendor Quotes for Key Equipment, Piping and Facilities; • Cost Estimates Based on Sizing and Quantification of Construction Materials and Labor.	• Facility Owner Budget; • Project Authorization.	- 15 to +30 %
Detailed (Zero-Based Budgeting)	• Detailed Project Design; • Equipment and Material Specifications and Quantification; • Firm Vendor Quotes/Purchase Orders; • Guaranteed Subcontractor Prices for Various Activities.	• Preparation of Project Tender (Bid) Price; • Control of Project Implementation.	- 5 to +10 %

Conceptual Cost Estimate

Purpose – to Determine an Order-of-Magnitude values of capital, O&M and water production costs.

Typically Used for:

- Preliminary Screening of Water Supply Alternatives;
- General Cost-of-water Comparisons with Other Sources of water supply;
- Preliminary Site Screening;
- Fatal Flow Analysis.

Estimate Usually Based on:

- Cost-capacity curves;
- Scale-up or down empirical factors and exiting project costs;
- Source and product water quality, location and size.

Preliminary Cost Estimate

- Purpose – higher-accuracy estimate developed for specific site and conditions.
- Typically Used for:
  - Site-specific project cost assessment;
  - Evaluation of alternative treatment processes & equipment.

Preliminary Cost Estimate - Information Needed for Development

- Average Annual, Daily Average, Minimum and Maximum SWRO Plant Production Capacities;
- Design Plant Capacity Availability Factor;
- Source Water Quality Specification;
- Product Water Quality Specification;
- Plant Intake and Discharge Type, Size and Configuration;
- Selection and Size of Key Facilities, Equipment and Piping for:
  - Source Water Pretreatment;
  - SWRO Desalination and Energy Recovery;
  - Product Water Post-Treatment;
  - Concentrate Disposal;
  - Solids and Liquid Waste Handling.
- Process Flow Diagram;
- Preliminary Facility Layout;
- RO System Performance Projections;
- Solids Mass Balance.

Budgetary Cost Estimate

- Purpose – for inclusion in owner's fiscal planning and budgeting process.
- Typically Used for:
  - Project Funding;
  - Project Comparison;
  - Refinement of Project Design/Value Engineering.

Budgetary Cost Estimate - Information Needed for Development

- Preliminary Geotechnical and Hydro-geological Investigations;
- Preliminary Design of:
  - Key Project Structures and Foundations;
  - Electrical Supply System;
  - Instrumentation and Control System;
  - Architectural Facades and Appearance of Key Buildings;
- Plant Hydraulic Profile;
- Basic Specifications of Key Equipment and Piping, Equipment Data Sheets and Budgetary Quotes from Vendors;
- Project Implementation Plan and Schedule.

Detailed Cost Estimate

- Purpose – to determine construction contract price. Costs based on actual design, equipment vendor firm prices, and quantity of materials, labor and other consumables.
- Typically Used for:
  - Contractor procurement;
  - Determination of most probable construction, O&M and water costs;
  - Tracking of project construction progress and expenditures.

Detailed Cost Estimate - Information Needed for Development

- Advanced Level of Project Design (30 to 50 % of design completion);
- Detailed Construction Survey;
- Detailed Geotechnical Investigation and Soil Analysis;
- Comprehensive Project Implementation Schedule;
- Detailed Quantification and Cost Estimates of Key Construction Activities;
- Binding Vendor Price Quotes for All Equipment and Prefabricated Facilities of Unit Value In Excess of US$10,000 including:
  - Source Water Intake, Screening and Pretreatment Equipment;
  - RO and Pretreatment Membranes and Cartridge Filters;
  - Large Pumps;
  - Energy Recovery Equipment;

Project Cost Models

- Most Popular Models:
  - WTII Cost – USBR – 2008 (latest)

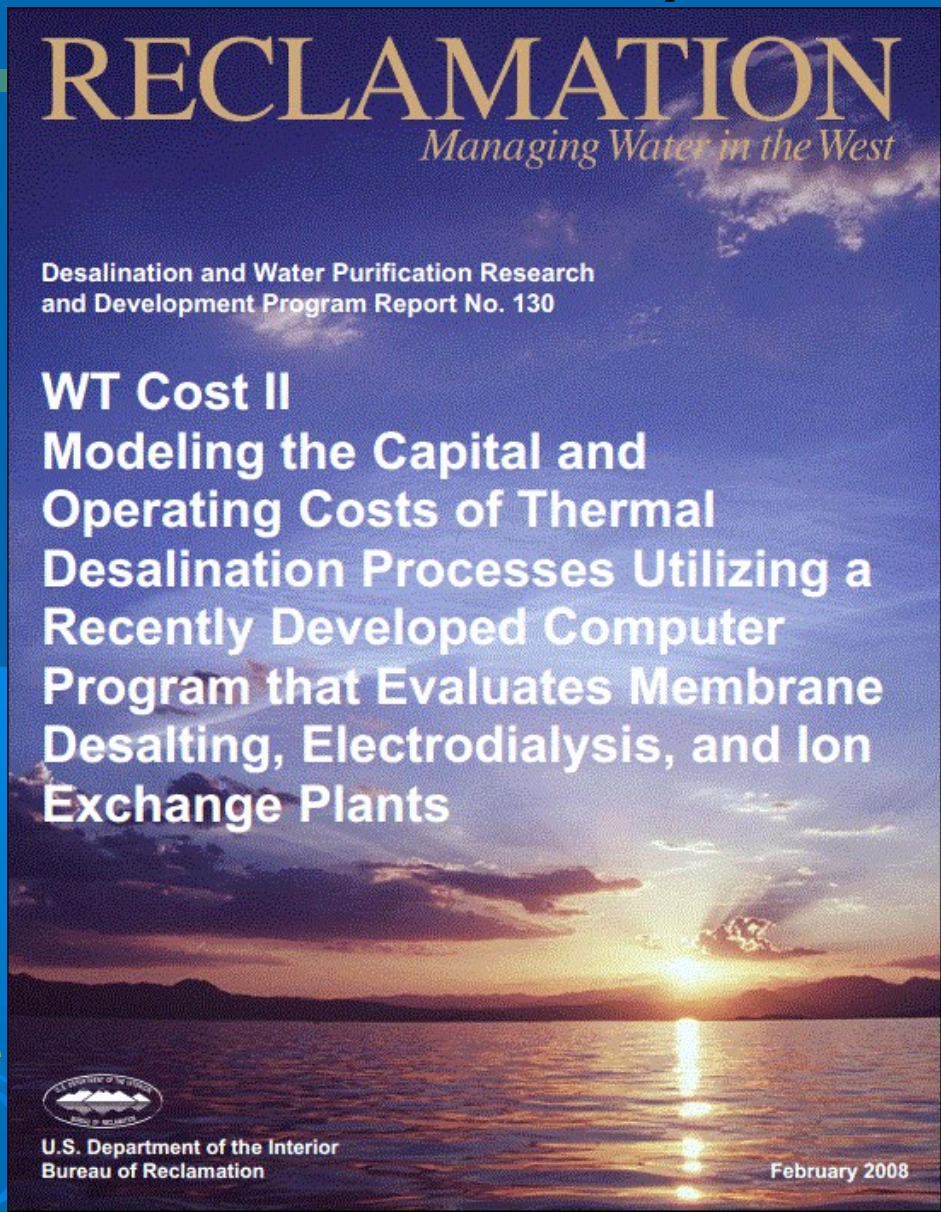
http://www.usbr.gov/research/AWT/reportpdfs/report130.pdf

  - International Atomic Energy Agency (IAEA) Desalination Economic Evaluation Program (DEEP – version 4)

http://www.iaea.org/NuclearPower/Desalination/index.html

WTCost II Program - USEPA (latest version - 2008)

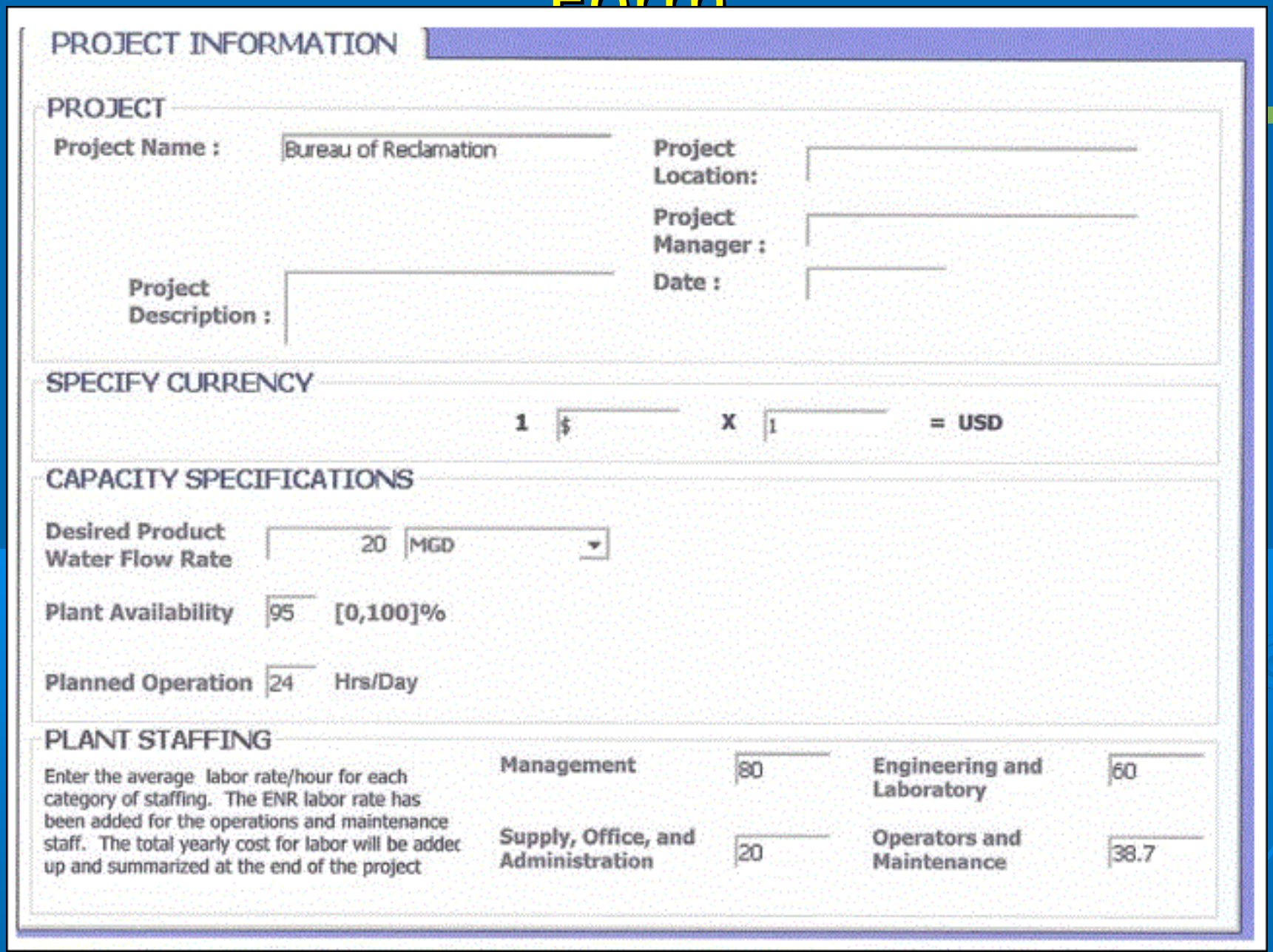
- ❑ Allows Comparison of:
  - Thermal and RO Desalination
  - Membrane and conventional granular media filtration
- ❑ Incorporates:
  - Ion Exchange
  - ED/EDR
  - MSF, MED, TVC
  - Hybrid (Thermal & RO) Desal Systems
  - Other Processes
- ❑ Reflects Use of Pretreatment Chemicals
- ❑ Equipment Supplier and Energy Source Neutral



WTCost II - Inputs

- Product Capacity
- Overall Recovery Rate
- Percent of Time Online (Availability Factor)
- Water Quality Analysis

WTCost II – Project Description Form



WTCost II – Input Water Quality Data

PROJECT INFORMATION

WATER ANALYSIS

Select a Water Analysis

- (•) Edit Project Analysis
- ( ) Enter a New Analysis

OK

Enter Multiplier: 1.0

CALCULATE

Water Properties

pH	8	
Specific Gravity	1.0234	
Turbidity	0	NTU
Conductivity	53,966	uS/cm
Temperature	25	deg C

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

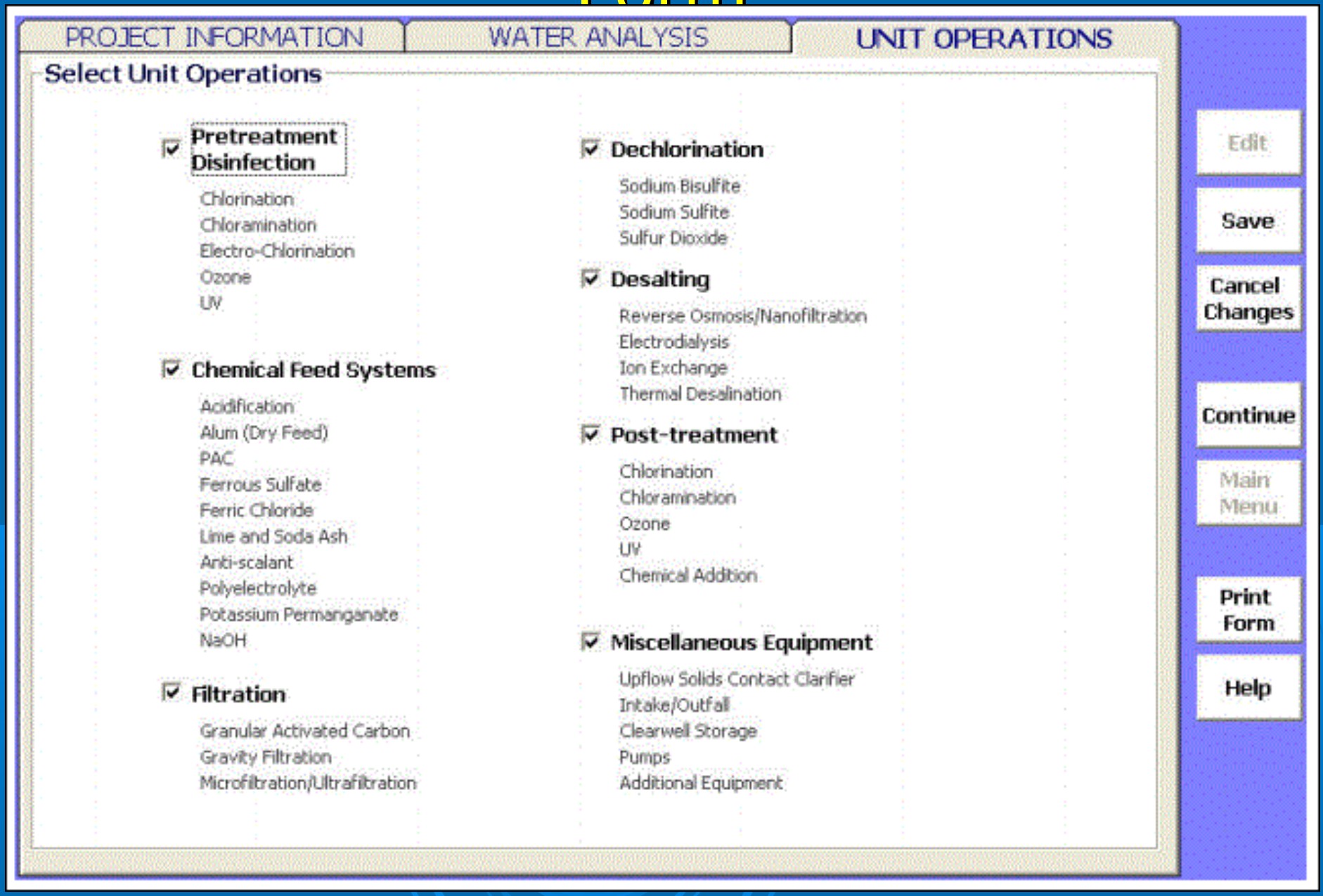
Inorganic and Disolved Solids

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

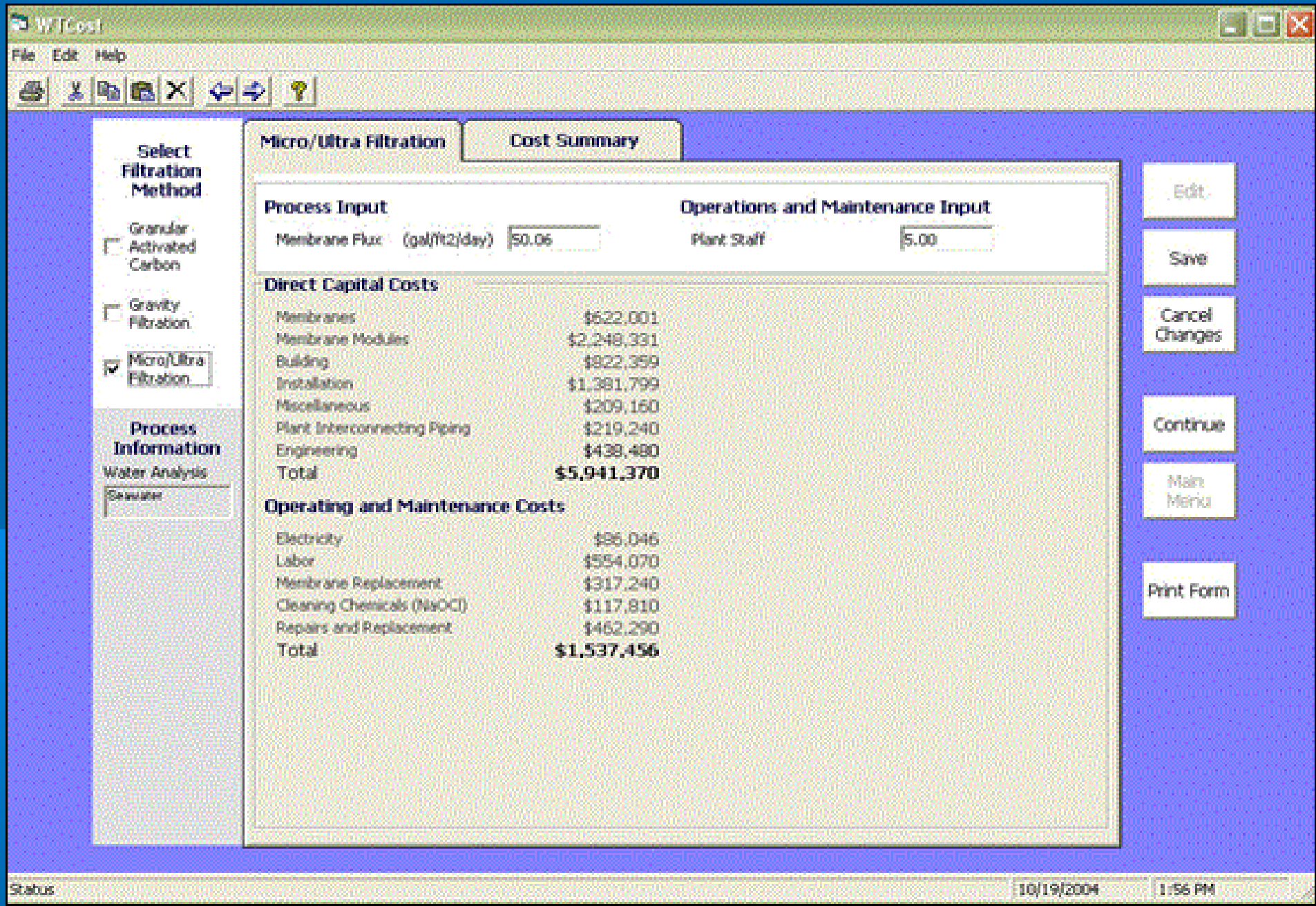
Water Analysis Values

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

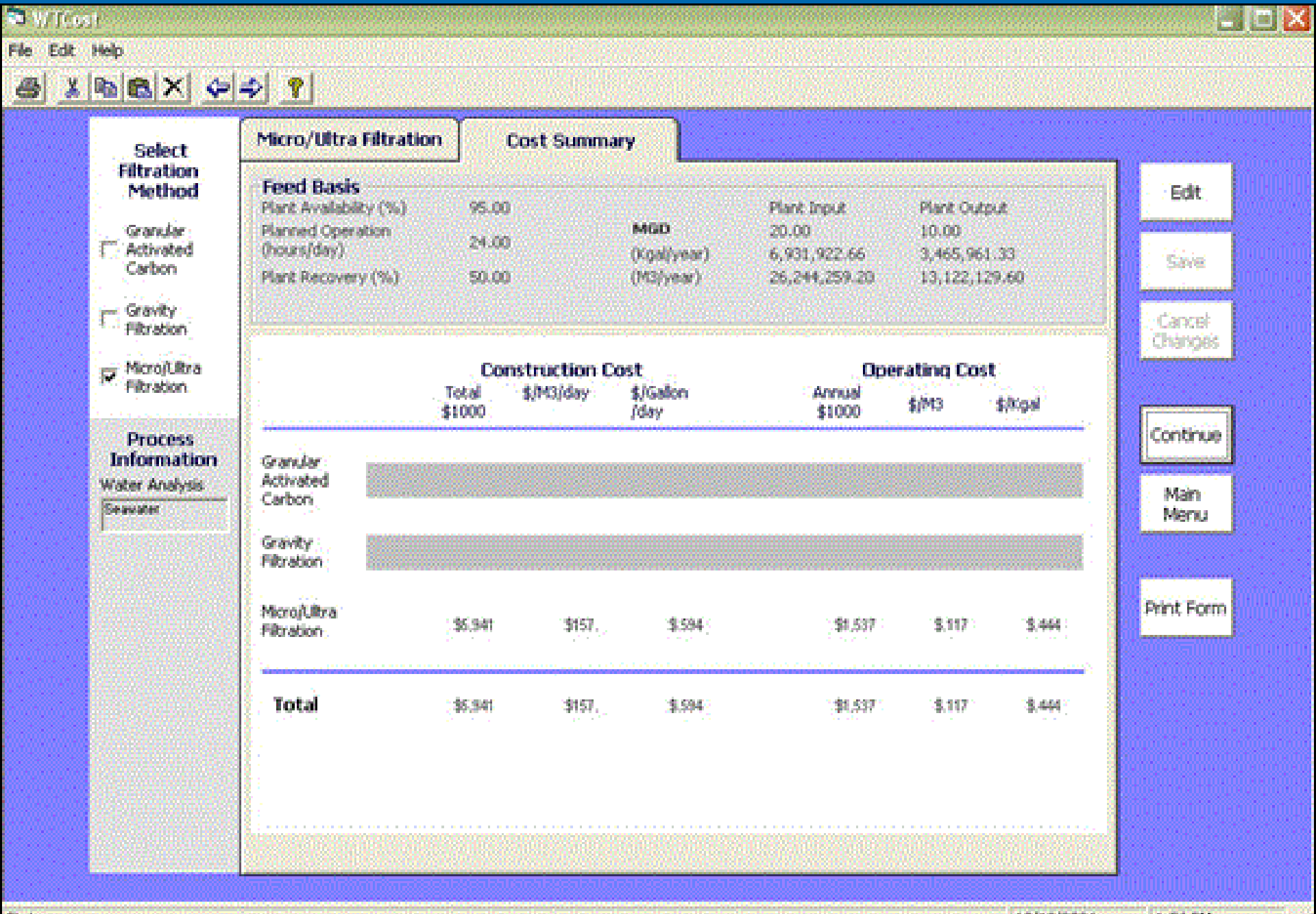
WT Cost II – Process Selection Form



WT Cost II – Membrane Pretreatment Cost Form



WT Cost II – Membrane Pretreatment Cost Form



WTCost II - RO Form

Reverse Osmosis - Page 1 | Reverse Osmosis - Page 2

Direct Capital Cost - Construction ($)

Building Cost ($/sq ft)	100	
Administrative Area (sq ft)	43	1,300,000
Electrical Cost Base $/kgal(US) Capacity	2,320	580,000
Sitework $/kgal(US)	55	692,000
Backup Generator (MW)	0	

Review/Calculate Pumps Costs

After calculating the pump costs, you will be returned to page 1 of the RO-NF calculations

Pumps Direct Capital Cost	$ 4,050,000
Pumps Operating Cost (excluding electricity)	$ 451,000

Direct Capital Cost - Misc. ($)

Odor Control	
Instrumentation and Cntrols	401,000
Degasifiers	
Contractor Engr and Training	60,800
Process Piping	1,550,000
Yard Piping	575,000

Operating and Maintenance Costs

Electricity		3,520,000
RO-NF Operating and Maintenance Staff	25	1,940,000
Repairs and Replacement		68,800
Laboratory Fees		55,800

Total Direct Capital Cost	$11,800,000
Total Ops. and Maint. Cost	$6,560,000

Edit | Save | Cancel | Continue | Done | Print Form | Help

WTCost II – Cost Summary Form

Project Summary | Indirect Costs | Project Cost Summary

Project Description: Bureau of Reclamation

Date:

Feed Flow	53.00	MGD (U.S.)
Product Flow	20	MGD (U.S.)
Process Recovery (%)		42
Plant Availability (%)		95
Planned Operation (h/day)		24

Pretreatment Disinfection
- Chlorination

Chemical Feed Systems

	Dose Rate	
Acidification[H2SO4]	10	mg/L
Ferric Chloride	10	mg/L

Media Filtration
- Gravity Filtration

De-Chlorination
- Sodium Bisulfite

Desalting
- Reverse Osmosis
- Thermal Desalination

Product Water Treatment
- Chlorination
- Product Water Chemical Addition

Miscellaneous Equipment
- Upflow Solids Contact Clarifier
- Intake/Outfall
- Clearwell, Storage and Land
- Additional Equipment

WTCost II – Cost Summary Form - 2

Project Summary | Indirect Costs | Project Cost Summary

Indirect Cost Input

		Indirect Capital Cost
Interest during Construction (% of Total Constr. Cost)	6	$ 5,429,000
Contingencies (% of Total Constr. Cost)	12	$ 10,860,000
Architectural and Engineering costs: Project Management, Fees (% of Total Constr. Cost)	12	$ 10,860,000
Working Capital (% of Total Constr Cost)	4	$ 3,619,000
Insurance (% of Total Constr. Cost)	0.5	$ 452,400
Taxes - VAT/Import Duty (% of Total Constr. Cost)	0.5	$ 452,400
Profit (% of Total Constr. Cost)	12	$ 10,860,000
Pilot Plant Cost	75000	$ 75,000
Total Indirect Construction Cost		**$ 42,600,000**
Land Cost		**$**

Data from Cost Indices Form:

Plant Amortization (Y)	30
Interest Rate (%)	6.

Plant Staffing (Number of Full Time People)

Management	2.3
Engineering and Laboratory	3.6
Operators/Maintenance	43.9
Supply, Office and Admin.	6.1

WTCost II – Cost Summary Form - 3

Project Summary | Indirect Costs | **Project Cost Summary**

Process	Construction Cost Total (000)	* /m3/day	* /gal /day (US)	Operating Cost 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
Indiirect 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

International Atomic Energy Association – Desalination Economic Evaluation Programme (DEEP)

- Couples An Number of Power and Heat Technologies with Desalination Technologies

Process	Abbreviation	Description
Distillation	MED	Multi-Effect Distillation
	MSF	Multi-Stage Flash
Membrane	SA-RO	Stand-Alone Reverse Osmosis
	C-RO	Contiguous Reverse Osmosis
Hybrid	MED/RO	Multi-Effect Distillation with Reverse Osmosis
	MSF/RO	Multi-Stage Flash with Reverse Osmosis

Input
Performance calculation of energy source
Performance calculation of water plant
Cost calculation and economic evaluation
Output

DEEP Cost Model – Input -1

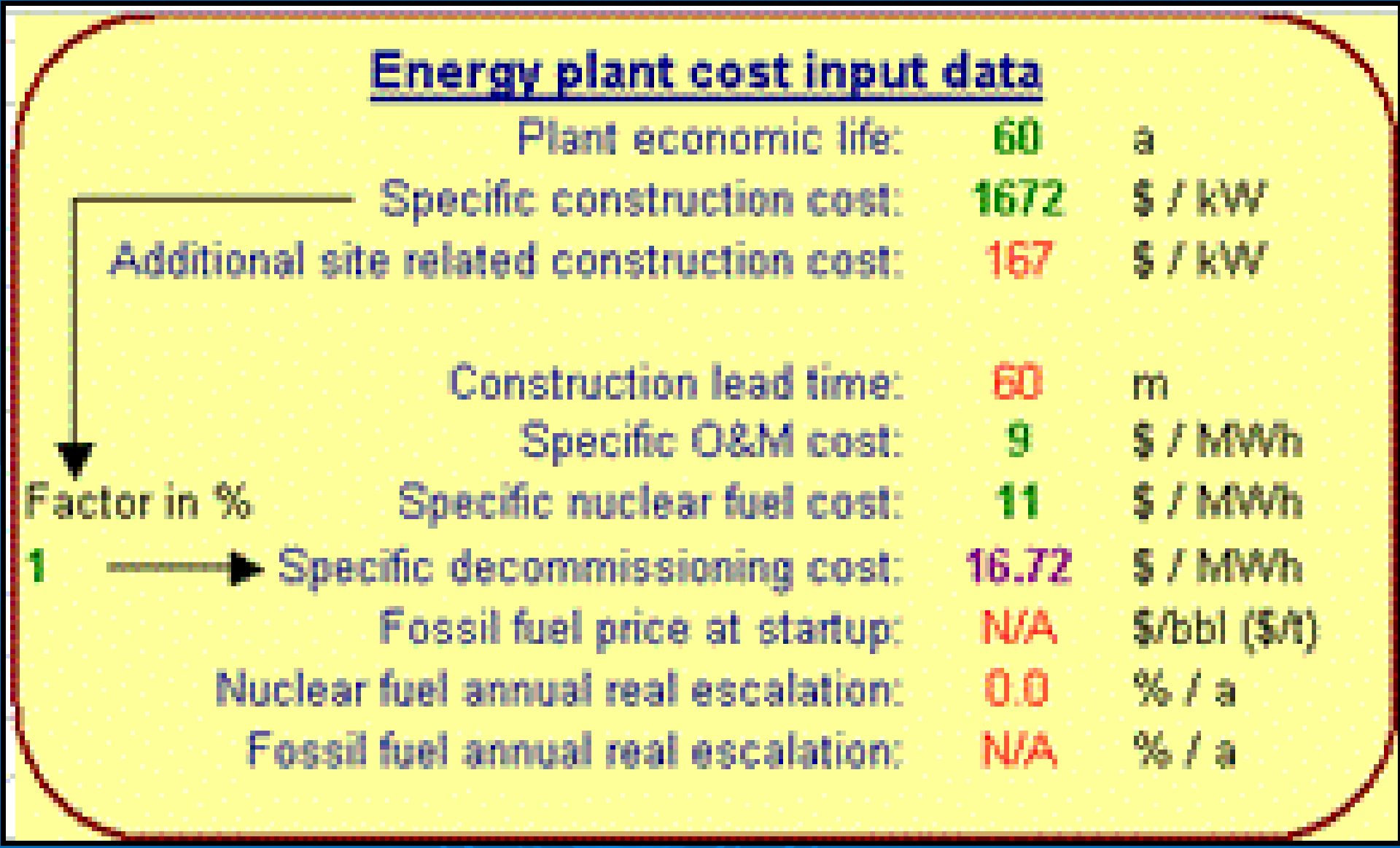
Economic parameters input data

Discount rate:	8.0	% / a
Interest rate:	8.0	% / a
Currency reference year:	2003	
Initial construction date:	2003	
Initial year of operation:	2005	
Purchased electricity cost:	0.06	$ / kWh

Backup heat source input data

		Value set
Lifetime of backup heat source Optional:	0.00	30 a
Backup heat source unit cost:	0.00	$ / MW
Fossil fuel price:	20.00	$ / bbl
Fossil fuel real escalation:	2.00	% / a

DEEP Cost Model – Input -2



DEEP Cost Model – Input -3

Distillation plant cost input data

Plant economic life:	30	a
Distillation plant lead time:	12	m
Optional value (**type 0** for Deep default):	0	m
Reference unit size for cost:	48,000	m^3 / d
Base unit cost:	1200	$ / m^3
Optional in/outfall specific base cost:	0	$ / m^3
Optional intermediate loop cost:	0	$ / m^3
Distillation plant cost contingency factor:	0.100	
Distillation plant owners cost factor:	0.050	
Distillation plant lead time:	12	m
Average management salary:	66000	$ / a
Average labor salary:	29700	$ / a
Optional no. of management personnel:	0	3
Optional number of labor personnel:	0	26
Specific O&M spare parts cost:	0.04	$ / m^3
Tubing replacement cost:	0.00	$ / m^3
Specific O&M cost for pre-treatment:	0.03	$ / m^3
Specific O&M cost for post-treatment:	0.02	$ / m^3
Distillation plant O&M insurance cost:	0.50	%

DEEP Cost Model – Input -4 (RO Data)

RO plant cost input data

Plant economic life:	30	a
RO plant lead time:	24	m
Optional value (**type 0** for Deep default):	0	m
Hybrid plant lead time:	24	m
Optional value (**type 0** for Deep default):	0	m
Base unit cost:	800	$ / (m^3/d)
Optional in/outfall specific base cost:	0	$ / (m^3/d)
Membrane equipment cost to total cost ratio:	0.10	
RO plant cost contingency factor:	0.100	
RO plant owners cost factor:	0.050	
RO plant lead time:	24	m
Average management salary:	66,000	$ / a
Average labor salary:	29,700	$ / a
Optional no. of management personnel:	0	2
Optional number of labor personnel:	0	12
O&M membrane replacement cost:	0.05	$ / m^3
O&M spare parts cost:	0.04	$ / m^3
Specific O&M cost for pre-treatment:	0.03	$ / m^3
Specific O&M cost for post-treatment:	0.01	$ / m^3
RO plant O&M insurance cost:	0.50	%

DEEP Cost Model – Summary Output

WATER & POWER COST SUMMARY

Case identification and site characteristics

Energy plant type:	PWR	Desalination plant type:	MSF-RO	Total required water plant capacity at site:	350,000	m^3/d
Energy source:	NUCLEAR	Backup heat source:	N			
Energy product form:	H & P	Intermediate loop (MSF):	Y	Capacity of distillation part:	140,000	m^3/d
Fuel type:	UO2	RO membrane type:	SW	Capacity of RO part:	210,000	m^3/d
Case:	Case X	Assumed site location:	Site Y			

General input data

Seawater TDS:	38,500 ppm	=	Distillation plant design cooling water temperature:	21.0 °C	
Average annual seawater temperature:	21.0 °C	=	Stand-alone RO design cooling water temperature:	21.0 °C	
Purchased electricity cost:	0.060 $/kWh(e)	Discount rate:	8.0 %	Initial year of operation:	2005
		Interest rate:	8.0 %	Plant economic life:	60 a

Water and power plant cost summary

Specific construction cost:	1,672	$/kW	x P (P = 620 MW)	Power plant total construction cost:	1,104 M$
				Power plant interest during construction:	234 M$
Specific investment cost:	2,156	$/kW	/ P	Total power plant investment:	1,338 M$

DOES THE POWER PLANT ALREADY EXIST ? NO ! CLICK TO CHANGE

Levelized electricity cost: 0.057 $/kWh

		G.O.R. :	6.4
Total installed water plant capacity:	360,000 m^3/d	Recovery ratio :	0.399
Total construction cost:	443.1 M$		
Interest during construction:	35.4 M$	Net saleable power:	508.2 MW
Total investment cost:	478.5 M$	Average daily water production:	307,800 m^3/d
Specific investment cost:	1,329.3 $/($m^3$/d)	Water cost:	0.95 $/$m^3$

Key Challenges with Existing Cost Models

- Need for Frequent Update;
- Need to Reflect New Developments of Membrane Technologies and Products;
- Need to Reflect New Energy Recovery Systems.

2013 Cost Curve Models Used in this Course

- Based on Real-world Costs and SWRO Projects Completed in the Last 5 Years;
- Data Used for Cost Curve Development are Normalized (Adjusted) for:
  - Year of Plant Commissioning;
  - Production Capacity;
  - Source and Product Water Quality'
  - Geographic Location – ENR Construction Cost Index;
  - Currency;
  - Other Factors (Intake and Outfall Type, etc.).

Questions ?

Coffee Break