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WATER TREATMENT ESTIMATION ROUTINE (WATER) USER MANUAL

Water Desalination Research & Development Program Report No. 43

August 1999

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Technical Service Center
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As with anything else, water treatment cost estimates are difficult to get a handle on without somewhere to begin. This document and the spreadsheet program it describes are just that – a place to begin. With minimal information, such as a rough idea of the water analysis and the capacity of the treatment systems, this program provides cost estimates based on theoretical equipment sizes and chemical requirements. It is not intended to be a final design cost estimate. It is intended as a tool for comparing different process options at an early phase in the planning process. Processes included in the program are microfiltration, reverse osmosis/nanofiltration, electrodialysis, ion exchange, gravity filtration, granular activated carbon, disinfection and chemical feed systems.

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

U.S. Department of the Interior
Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

Bureau of Reclamation
Mission Statement

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer

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Several people have been vitally important to the success of this project. Bill Boegli has been a fount of information; I must thank him for the loan of his water treatment books, and advice on determining dosage rates (without a water sample). Pat Giarrantano, now retired from the National Institute of Standards and Technology (NIST), provided the loan of her personnel for the start of this effort. Kim Linton's review resulted in many improvements in the user experience which were sorely needed, as any who tried to review the draft product will appreciate. Most of all, this final product would not be possible without funding from the Water Desalination Research and Development (DesalR&D) Program.

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INTRODUCTION

One of the primary concerns in updating an older water treatment plant, or building a new one is: "How much will it cost?" These days, there are many alternative water treatment processes in use, with pros and cons for each. Before one gets mired in the differences, similarities, and potential for success, it is reassuring to look at the price tags. Cost is one tangible way to eliminate options. Yet cost is one of the most difficult aspects of a process to get a handle on before the design process has begun. According to Peters and Timmerhaus, in *Plant Design and Economicsfor Chemical Engineers* (1980), an order of magnitude estimate should cost about $4000 (1979$). It requires knowledge of the water composition, plant capacity, location and site requirements, utility requirements, raw materials and finished product handling and storage requirements. Yet, the cost is needed before any agreements are made.

In 1994, the Bureau of Reclamation built a mobile Water Treatment Plant Trailer for the purpose of exploring 'water treatment alternatives. One of the questions most frequently asked is "How much will these systems cost?" Because of that, we have tried to automate the cost estimation process so that we can provide a reasonable answer based on production capacity, and the water analysis. Sure, there are many ways to specify which equipment is used, but when you step back and look at a long history of water *treatment* system costs, *it* is possible *to* come up with a set of good generalizations.

Back in 1979, the EPA published a very thorough study on water treatment costs (EPA-60012-79-162). It separates costs into different categories for manufactured equipment, labor, pipes and valves, electrical and instrumentation, housing, etc. Then costs are repotted and graphed for different sizes of plants. The trouble is that you cannot use the graphs until you know the size of the process. For instance, chlorine feed cost is based on the number of kg/day of chlorine needed. Chlorine demand is usually determined through jar tests, which require money, time, and a fresh water sample. In addition, if you wanted to compare chlorination with ozonation, you would need to have the size of the ozone contact chamber. These items are not generally included in a standard water analysis.

In a joint effort between the Bureau of Reclamation, and the National Institute of Standards and Technology, a water treatment design spreadsheet program has been developed to address this problem. This Excel spreadsheet estimates the design parameters needed to drive the EPA cost estimates, then updates cost information for several water treatment processes to current dollars. The capacity requirements and minimal input about the process are entered on Capacity worksheet. Also, the water data report based on *water* analysis is shown *on* the Capacity worksheet. The *water* analysis is entered in the H20 Analysis worksheet. Cost indices based on the Engineering news Record construction cost index and Bureau of Labor Statistics (February, 1999 built in) are entered on the Cost Index worksheet and may be updated by the user. Cost and sizing calculations for the different processes are performed on linked worksheets. These worksheets contain the parameters that may be refined when the equipment is specified more exactly. Cost and relevant design parameters are reported back to the Report worksheet.

The program calculates dosage rates and cost estimates for the following water purification processes:

- pH adjustment with sulfuric acid.
- Disinfection with chlorine, chloramine, and ozone.
- Coagulation/Flocculation with alum, ferric sulfate, and lime/soda ash using upflow solids contact clarifiers.
- Filtration enhancement with polymer feed.
- Filtration with granular activated carbon, and granular media.
- Microfiltration as pretreatment to remove particulate materials

- Demineralization with ion exchange, electrodialysis, and reverse osmosis
- Pumping: raw water, backwash, and finished water pumping.

The Water Treatment Estimation Routine (WaTER) is based primarily on the EPA report *Estimating Water Treatment Costs, Vol. 2, Cost Curves Applicable to 200 mgd Treatment Plants* (EPA-600/2-79-1626, August 1979). For estimates using cost curves from this EPA report, or from Qasim et al. (AWWA, Aug. 1992). the assumptions used in the EPA report are pertinent. The EPA report details the configuration of each process, and what is not included. The EPA is working on an update to that cost study. When it is published, we hope to incorporate the new cost curves and parameters into this program.

OVERVIEW OF WATER TREATMENT ESTIMATION ROUTINE

The Water Treatment Estimation Routine is an Excel workbook. WTCOST.xls is the name for this Excel workbook. Computer requirements are as follows:

- Windows 95 or higher
- Microsoft Excel Office 97.
- Pentium Co-processor is desirable.

Open the workbook by double clicking on the file name. To bring a desired worksheet into the window, single-click on the name of the worksheet tab at the bottom of the screen. To navigate through the worksheets, simply, click on the name of the worksheet tab. Remember that the worksheets are linked so that changes in one worksheet will be reflected in the other worksheets. The worksheets included are:

- Capacity-Production capacity and water data report.
- H20 Analysis -Water analysis
- Cost Index -Current cost indices
- Report-Reports for water treatment processes
- Micro Input-Input for Microfiltration sizing
- Micro Output – Output for Microfiltration cost
- RO&NF Input – Input for Reverse Osmosis or Nanofiltration sizing
- Rejection -Calculates observed rejection for given water and recovery rates
- RO&NF Output – Output for Reverse Osmosis or Nanofiltration cost.
- ION-EXH – Ion exchange resin volume and cost
- ED2 – Electrodialysis sizing and cost
- CL2 -Chlorination dosage and cost
- NHCl – Chloramine dosage and cost
- OZONE – Ozone dosage and cost
- DG&ACID – Acid dosage
- ACID -Acid feed cost
- ALUMFD – Alum dosage and cost
- LRONFD -Ferric sulfate dosage and cost
- POLYFD -Polymer dosage and cost
- $KMnO_4$ – Potassium permanganate dosage and cost
- LIMEFD -Lime and soda ash dosage and cost
- GAC -Granular activated carbon cost
- GRAVFILT – Granular media filter sizing and cost
- UFSCC – Upflow solids contact clarifier sizing & cost
- PUMPS -Pump sizing and cost
- CLEARWELL – Below ground and ground level clearwell cost
- Water Analyses – A collection of general water analyses in case you need one.

Most worksheets contain a set of data that have been used to create graphs to demonstrate the relationship between cost and capacity for a range of dosage rates, or sizes, depending on the appropriated parameter for the process. You may perform sensitivity studies with these worksheets to determine how the cost is effected by the various process parameters.

To create a new set of data for the worksheet of interest, first, erase the old set of data, then change the desired parameters, click on the Macro command button with the name of the worksheet on it located on top of the data set. Repeat this process to generate the data. The graphs incorporated into the worksheets will update automatically when data are changed. Samples of the graphs are included in the appendix.

The applicable ranges for some treatment process are listed in Table 1. If the calculated values for your system are outside these ranges, the cost values may not be representative.

Table 1. Valid Dose ranges for chemical addition processes.

Name	Range	Metric Units	Range	English Units
CL_2	4 - 4500	kg/day	9 - 9921	lb/day
NHCL	110-2300	kg/day	243-5071	lb/day
ACID	0.04 - 20	m^3/day	11 -5264	gal/day
ALUM (Dry)	4 - 2300	kg/hr	9 - 5071	lb/hr
ALUM (Liquid)	2 - 2500	kglhr	4-5512	lb/hr
IRONFD	6 - 3000	kg/day	13-6614	lb/day
POLYMER	0.5 - 100	kg/day	1 - 220	lb/day
$KMnO_4$	0.5 - 100	kg/day	l-220	lb/day
LIME	4 - 4500	kg/hr	9 - 9921	lb/hr

INPUT REQUIREMENTS

You may refer to the copy of [WTCOST.XLS] Capacity, H20 Analysis, and Cost Index worksheets in the appendix or, better yet, the screen version on your computer.

Production and Index Input: The Capacity, H20 Analysis, Cost Index, and Report worksheets allow the user to estimate costs for each treatment process separately. It requires following general information:

- Required plant feed flow rate in L/sec
- Desired plant product flow rate in L/sec
- Water analysis
- Cost Indices: February 1999 included.

Water Analysis Input: This table summarizes metals and inorganic components. Water analysis data is entered in the shaded column labeled "Water Analysis" in the units specified. Concentration is compared with the USEPA Drinking Water Standards Maximum Contaminant Level (MCL). If there is an exceedance, it is calculated and appears in BOLD in the next column, labeled "Amount over MCL." Equivalents per liter, and concentration in moles/liter, are calculated for your convenience, and for bookkeeping purposes.

Water Data Reports: Vita1 data from the water analysis are listed in the Capacity worksheet. These data, calculated or repeated from the water analysis, are used in the design algorithms.

Cost Indices: The cost components are based on those used by Qasim (1992). Each is tied to one of the Engineering News Record (ENR) or Bureau of Labor Statistics (BLS) indices. Table 2 lists the cost components from February 1999 used in updating water treatment costs. Cost curves from the Qasim paper were updated from April 1992. Cost curves developed directly from the EPA report were updated from October 1978.

Cost Reports: The Report worksheet is set up with sections for each process. Each contains the name of the process in the upper left comer. Variables are listed that are either taken from the Capacity worksheet, or are entered in the colored or shaded cells.

Construction cost, and operation and maintenance costs are reported in each section. This represents the first level of generalization. To refine the estimates further, it is necessary to adjust process design parameters that have assumed values on their separate worksheets.

Table 2. Indices used in updating water treatment costs.

Cost Component	Index 1967 = 100	1999 Value
Excavation & site work	ENR Skilled Labor Wage Index	548.67
Manufactured equipment	BLS General Purpose Machinery & Equipment Commodity Code 114	149.10
Concrete	BLS Concrete Ingredients Commodity Code 132	150.20
Steel	BLS Steel Mill Products Commodity Code 1017	106.60
Labor	ENR Skilled Labor Wage Index	548.67
Pipes and valves	BLS General Purpose Equipment Producer Price Index 1149	164.30
Electrical equipment and instrumentation	BLS Electrical Machinery & Equipment Commodity Code 117	120.60
Housing	ENR Building Cost Index	505.81
Energy requirements	Local $/kWh	0.07
Maintenance material requirements	BLS Producer Price Index for Finished Goods Code SOP3000	131.30
Labor requirements	Local $/hr	30

Now we get to the major drawback of using a spreadsheet for this type of application. The costs reported here are based entirely on the water analysis and production data as they are entered in the water analysis tables. If you want to use only one of the processes, that would be fine. However, the composition of the water will change after it has left any one of the processes. Then, the next process cost is based on the wrong water composition. You, the user, will have to pick the process flow scheme for your application, and adjust water analysis accordingly. The cost report should then be copied to another area of the spreadsheet and converted to values so that it will not change when you adjust the water analysis. In this way you can build a more accurate report for your application.

MICROFILTRATION
(MF INPUT & OUTPUT)

Introduction:

Microfiltration is used as pretreatment to remove particulate material from water, including microorganisms such as protozoa, bacteria (*Giardia* and *Cryptosporidium*) to meet new and future environmental requirements. The purpose of this section is to provide cost estimation for Microfiltration. This section consists of two worksheets: Micro-input and Micro-output. The cost estimation is based on factory-assembled hollow fiber Microfiltration units.

Most of the Microfiltration membranes system includes the following equipment:

- Membrane module skids - membrane modules, backwash manifold pipework, integral valves and instruments, support legs, control panels.
- Air supply system - air compressors, air dryers, coalescers and air filters, process air receiver, air regulator, plant pneumatic control enclosure, solenoid valves and instruments.
- Clean in place - 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 PLC, plant I/O, man-machine interface.

The Microfiltration membrane manufacturers can provide more details on the scope of supply.

Micro input worksheet consists of:

- Process input
- Operation and maintenance cost input
- Process flow calculation

Micro output worksheet consists of:

- Capital cost estimation(direct and indirect)
- Operation and maintenance cost estimation

Microfilltration Input:

Process input from Micro input worksheet:

The following parameters are needed for cost estimation:

- Design product flow rate (gpd)
- Plant availability (%)
- Microfilters system equipment cost ($)
- Cost per MF membrane ($)
- MF modular system flow rate (gpm)
- No. membranes per microfilter
- Pump efficiency (%)
- Motor efficiency (%)
- Design feed pressure (psi)

- Backflush pressure (psi)
- Backwash intervals (minutes)
- Backwash and backflush duration (minutes)

Operation and maintenance cost input:

- Electricity rate ($/kwh)
- Chemical costs (sodium hypochlorite, $/L)
- Design dosage (mg/L)
- Specific gravity of sodium hypochlorite
- Solution concentration (%)
- Membrane life (year)
- Staff days/day
- Labor rate (salary and benefits, $/hr)
- Amortization time (year)
- Interest rate (%)

Process flow calculation: All values in this section are calculated from inputs listed above. MF feed flow is the total feed flow to the Microfiltration plant. It is calculated by:

$$MFF = \frac{MFP}{Y}$$

Where:
MFF = Microfiltration feed flow (L/sec)
MFP = Microfiltration product flow (L/sec)
Y = Recovery rate

MF reject flow (MFR (L/sec)) is the amount of water used for backwash and cleaning of the membranes. It is calculated by:

$$MFR = \frac{BBD * BBF}{BI}$$

Where:
BBD = backwash and backflush duration (sec)
BBF = backwash flow rate (L/sec)
BI = backwash interval (sec)

Recovery rate (R) is calculated by:

$$R = \frac{MFP}{MFF}$$

Feed pump brake horsepower (HP) is calculated by:

$$HP = \frac{MFF * DFP * 2.31}{PP\% \ * \ 3960}$$

Where: DFP = design feed pressure (psi)

	PP%	= pump efficiency (%)
	2.31	= conversion factor for feet of vertical head of water per lb/in^2
	3960	= another English-Metric conversion factor.

Feed pump kilowatt-hour (kwh) is calculated by:

$$kWh = \frac{MFF * DFP * 2.31 * 0.00315}{PP\% * M\% * 1000}$$

Where:	M%	= motor efficiency (%)
	0.00315	= conversion factor for consumption of electrical energy

Building area in square meter is estimated to be 1.23 percent of the design product flow rate in cubic meter per day.

Microfiltration Output:

The cost estimate does not include concentrate disposal, National Environmental Policy Act (NEPA) compliance, or water system storage and distribution cost.

Capital coot estimation:

Direct capital costs are the sum of microfilters, building, MF installation, miscellaneous, plant interconnecting piping, engineering. These cost elements are discussed below:

Microfilters: The actual price for microfilters is obtained from membrane manufacturers. The price will vary upon the type of microfilters and quantities involved. The total microfilters cost is estimated as the cost per skid unit times the number of units.

Building: The building cost is estimated $1076 per square meter times the total building area in square meter.

MF installation: The microfilter installation cost is estimated $70,000 per unit for a large system (at 37.85 L/s flow rate).

Miscellaneous: This cost includes that any miscellaneous items needed to complete the project. It ***is*** estimated 5 percent of the total microfilter cost.

Plant interconnecting piping: This cost estimated 5 percent of the sum of total microfilter and miscellaneous costs.

Engineering: Engineering cost is estimated 10 percent of the sum of total microfilter and miscellaneous costs.

Indirect capital cost:

The indirect capital costs are the sum of:

- Interest during construction (6% of total direct capital cost)
- Contingencies (20% of total direct capital cost)

- A&E fees and project management (10% of total direct capital cost)
- Working capital (4% of total direct capital cost)

Operation and maintenance cost estimation:

Operation and maintenance costs include:

- Electricity
- Labor
- Chemicals (sodium hypochlorite)
- Membrane replacement
- Cleaning chemicals
- Repairs and replacement and miscellaneous

Total annual cost equals the capital recovery cost plus the total operation and maintenance costs. These major O&M cost elements are discussed below:

Electricity: Electricity cost is the total kilowatt-hour for the feed pump and backflush pump times the electricity cost ($/kwh).

Labor: This cost is estimated by the number of staff days times the going rate per day.

Chemicals: The cost of Sodium hypochlorite for disinfection is estimated based on the correlated formula from the Microfiltration membrane quotation data:

$$SHC * (.0025 * MFP - 333.33)$$

Where: SHC = sodium hypochlorite cost ($/L)

Membrane **replacement:** The cost is estimated by

$$\frac{Elements * \$ \ I \ Element}{MemebraneLife}$$

Cleaning chemicals: Sodium hypochlorite cost is estimated based on the correlated formula from the Microfiltration membrane quotation data:

$$(0.00005 * MFP + 66.67) * SHC$$

Repairs and replacement and misc.: The cost for repairs and replacements assumed to be 0.5% of the total direct capital cost.

Capital recovery cost: The capital recovery cost equals

$$TCC * \left[\frac{i * (1+i)^n}{(1+i)^n - 1}\right]$$

Where:	TCC	= total construction cost
	i	= interest rate
	n	= number of years

REVERSE OSMOSIS AND NANOFILTRATION
(RO&NF INPUT, REJECTION AND RO&NF OUTPUT)

Introduction:

The purpose of this section is to provide cost estimation for Reverse Osmosis (RO) and Nanofiltration (NF). This section is made up of three worksheets: RO&NF Input, Rejection and RO&NF Output.

RO&NF Input worksheet consists of:

- Process input
- Data from membrane product specification
- Determination of operating pressure
- Membrane system size estimation
- Pump size estimation
- Operation and maintenance cost input parameters

The Rejection worksheet calculates the actual membrane rejection and water permeation rates from the membrane specifications for the present water quality. These values are used to calculate the osmotic pressure differential and the membrane area needed.

RO&NF Output worksheet consists of:

- Capital cost estimation (direct and indirect)
- Operation and maintenance cost estimation

RO&NF Input:

Process *input:* The calculation routine is based on desired product or permeate flow rate. Desired product flow rate is the value entered on the Capacity worksheet. The percent recovery, the ratio of product flow rate to feed flow rate, is entered on the Report worksheet in the Reverse Osmosis section. If the recovery value is too high, there will be problems with the cost estimate. To give you an idea of what recovery rates should be, first check the delta G value in the water data report section in Capacity worksheet. If it is negative or close to zero, or if you plan to use acidification and/or antiscalants, you can use the following estimates.

Seawater	50 %
15,000 to 20,000 TDS	75 %
5,000 to 15,000 TDS	85 %
Nanofiltration	90 %

These values are only estimates; the maximum recovery possible depends on the composition of the feed water.

If the product water concentration is lower than necessary, as is often the case with RO, it may be possible to decrease the membrane system capacity by blending the product water with pretreated feed water. The blending option is specified in the RO and NF section of the Report worksheet. If the response is yes (Y). the ratio of blend water to product will be calculated based on the target product water TDS. The membrane system will be sized for the resulting smaller capacity. If no (N) is entered, this value will be zero. The maximum portion of blend water that can be used, assuming the blend water has the same TDS as the feed water is calculated as follows:

$$C_T V_T = C_p V_p + C_b V_b$$
$$V_b = \frac{C_T - C_p}{C_b - C_p}$$

Where C stands for concentration in mg/L, V is flow, with $V_T = 1$. Subscripts T is for target, p is for RO permeate and b is for blend water.

***Data from membrane product specifications*:** Information for this section is obtained from the membrane product specification sheets provided by membrane manufacturers. Table 3 lists data needed. This data should be on all manufacturers specification sheets.

Table 3: Membrane Data

Type of membrane	Film Tec, BW30-400	
Productivity	40	m^3/day
Area per module	37	m^2
Operating pressure, P_{app}	1550	kPa
Test solution TDS	2000	mg/L
MW of test salt	58.44	mg/mmol NaCl
Chloride Rejection	0.995	
Sulfate Rejection	0.998	
Recovery Rate	15	%
Temperature	25	°C

These parameters are used to calculate the water transport coefficient, A, and the intrinsic and actual rejection rate. The water transport coefficient measures the permeation of water through a membrane for a unit of applied pressure. It is calculated by:

$$A = \frac{J_v}{NDP_o}$$

Where: A = water transport coefficient, $m^3 m^{-2} sec^{-1} Pa^{-1}$
J_v = initial module productivity taken from the specification sheet, m^3/day
NDP_o = net driving pressure under test conditions, kPa

$$\boldsymbol{NDP, = P_{app}\ Pm}$$

Net driving pressure under test conditions, NDP,:
Where: P_{app} = operating pressure at test conditions, kPa
P_{osm} = osmotic pressure of the feed water, kPa

Osmotic pressure of the feed water, P_{osm}:

$$P_{osm} = 0.99 * 2 * R * (273.15 + T) * C_w / 1000$$

Where:
- R = universal gas constant, $m^3.Pa/mole.K$
- T = temperature, °C
- C_w = concentration at the membrane surface. As a first approximation this is taken as the average of the feed and concentrate concentrations, $mole/m^3$
- *0.99* = NaCl dissociation constant.

Concentration of salt in feed water, C_f:

$$C_f = TDS_f \,/\, Avg\ MW$$

Where: TDS_f = feed TDS, mg/L
Avg MW = feed average molecular weight, assuming NaCl is used to test the membranes, this would be 58.4 g/mole.

Osmotic pressure of the feed solution, concentration polarization and the resulting decrease in productivity are accounted for using a model method developed by Rao and Sirkar (1978) for the perfectly mixed feed and permeate model, with concentration polarization

Let C_w = boundary layer concentration at the membrane interface caused by concentration polarization. Assume that no gel formation occurs. Because the feed side is perfectly mixed, C, = C_b, where C_b = bulk concentration.

Then: $C_b = \dfrac{C_f - \theta C_p}{1 - 0}$

where θ = recovery rate of water. The intrinsic rejection of a membrane is defined as $R° = 1 - C_p/C_w$. This is different from the apparent rejection, $R_a = 1\ C_p/C_f$. The intrinsic rejection is a characteristic of the membrane. The apparent rejection is determined by the operating conditions. For lack of anything better, we assume that the reported rejection, most likely measured under optimum conditions with a minimum challenge, is close to the intrinsic rejection. We can then use this to estimate C_w, the wall concentration and the C,, the product concentration to be expected with the current operating conditions.

From the simple boundary layer model for concentration polarization and assuming that $R°$ is constant, the following relationship for C_p is obtained:

$$C_p = C_r \left[\frac{(1 - R°)\exp\left(\frac{J_v}{k}\right)}{R° + (1 - R°)\exp\left(\frac{J_v}{k}\right)} \right]$$

The wall concentration is

$$C_w = C_r \frac{\exp\left(\frac{J_v}{k}\right)}{R^\circ + (1-R^\circ)\exp\left(\frac{J_v}{k}\right)}$$

From the material balance $C_r = C_b$ is defined by:

$$C_r = C_b = \frac{C_f}{(1-\theta) + \frac{\theta(1-R^\circ)\exp\frac{J_v}{k}}{R^\circ + (1-R^\circ)\exp\frac{J_v}{k}}}$$

With k = the boundary layer mass transfer coefficient. The variable 'k' is obtained via a correlation that assumes that $J_v \ll U_c$, where U_c is the average cross flow velocity. The correlation used in this model is from Schock & Miquel (1987) for RO membrane in spacer filled flat channels.

$$k = 0.065 * \mathrm{Re}^{0.875} Sc^{0.25}$$

Re is the Reynolds number and Sc is the Schmidt number.

$$\mathrm{Re} = \frac{\rho \bar{U}_c d}{\eta}$$

$$Sc = \frac{\bar{U}_c}{D}$$

d	=	representative channel or tube dimension for flow (i.e., diameter)
$\bar{U}_c$	=	average cross flow velocity
ρ	=	density
η	=	shear viscosity
D	=	solute diffusivity

Now we can calculate the actual rejection, R_a

$$R_a = 1 - \left(\frac{C_p}{C_f}\right)$$

The actual permeation rate J_v is now:

$$J_v = A(P_{app} - P_{osm})$$

As calculated above with the new estimation for C_w. This group of relationships is non-linear because of the exponential term and must be solved iteratively (using successive substitutions). There is a graph of R_a and J_v on the Rejection sheet showing the solution progress through much iteration. If the solution fails to stabilize, check the inputs for accuracy.

***Determination* of *operating pressure*:** The NDP used for the specification testing is the default NDP used to determine the recommended operating pressure. The user can change this value. The osmotic pressure of the feed water is calculated as described above and then the operating pressure is calculated as follows:

$$P_{app} = NDP_i + P_{osm}$$

Where: P_{app} = applied operating pressure under the conditions of interest for the cost estimate, kPa

NDP_i = net driving pressure entered by the user (may chose to enter the manufacturer's test NDP,), kPa

P_{osm} = osmotic pressure difference between the bulk stream and product stream based on the membrane rejection and recovery rate and the water analysis provided, kPa

It is assumed that the water transport coefficient, A, is constant under all conditions, independent of feed water TDS and operating pressure. The new J_v is calculated as above using the new pressure conditions.

Membrane system size estimation: With J_v calculated for the water quality and operating pressure, the number of membrane modules can be calculated. There are user inputs for the number of modules per vessel and number of vessels per block. The required number is rounded up to tit into the specified configuration. The number of blocks determines the number of chemical feed systems and pressure pumps. The user specifies the number of product water pumps, transfer pumps, raw water pumps and the administrative building area.

There are three different types of pumps: single stage turbine (SST), centrifugal single speed (CSS) or variable speed turbine (VST). There is a different cost correlation for each type based on horsepower. All of the pumps sizing calculations are the same. Pomp horsepower is based on the capacity per block, pressure differential, pipe diameter, length of piping and vertical lift needed. Pipe diameter is tied in with the capacity per block. The lengths of piping and vertical lift have default values. Pressure differential for the high pressure pumps is based on the calculated operating pressure. The other pumps have default values.

Operation and maintenance cost inputparameters: Chemical costs, membrane life, cleaning rate, and operation!; labor can be input in this section. Number of labor hours includes only hours required for the reverse osmosis system. Electrical costs and labor cost are brought over from the Cost Index sheet.

RO&NF Output:

Capital cost estimation:

The relations for most of the direct capital costs are extracted from technical paper presented by Suratt (1995). Direct capital costs are the sum of membranes, RO skids, building, electrical, instrumentation & controls, high pressure pumps, raw water transfer pumps, product water pumps, degasifiers, odor control, process piping, yard piping, chemical feed with pumps, cartridge filters, membrane cleaning equipment, contractor engineering & training, concentrate treatment & piping, generators, and sitework. These major construction cost elements are discussed below:

Membranes: The actual price for membrane is obtained from membrane distributors. The price will vary upon the type of membrane and quantities involved. The total membrane cost is estimated as: $750 per high rejection RO element is used for membrane estimation.

RO skids: This cost is a function of the number of pressure vessels. The cost is estimated as

$$\$/vessel * Number\ of\ vessels$$

RO skids include the pressure vessels supported by structural painted steel skid support frame, piping connector sets for each vessel, and piping manifolds. $5000 per pressure vessel **is** assumed (Suratt, 1995).

Building: The cost is estimated as

$$Unit\ Cost(\$/m^2) * Building\ Area(m^2)$$

Unit costs vary depending on the level of architectural treatment and the location of the plant being built. $1,076 per m^2 is used for this spreadsheet (Suratt, 1995).

Electrical: The cost is estimated using a model adapted from Suratt, 1995.

$$\$/m^3 * product\ capacity^{0.65}$$

Product capacity is in m^3/day. $614 per m^3 of product water *is* used for this spreadsheet (Suratt, 1995).

Instrumentation & control: The formula for this cost is

$$\$300,000 + \$65,000 * Number\ of\ RO\ skids$$

$300,000 is for the central computer system. Additional of $65,000 is for the local instrumentation and controls per skid.(Suratt, 1995)

High pressure, raw water transfer, product water pumps: The cost of equipment and installation is a function of horsepower. An IF statement is built in this cell as follows: the cost for Single Speed Turbine (SST) is

$$58,000 * (HP/100)^{0.65}$$

The valid horsepower range for SST **is 3** HP to 300 HP.

Variable Speed Turbine (VST) is

$$85{,}000 * (HP/100)^{0.65}$$

The valid horsepower range for VST is 3 HP to 500 HP.

Centrifugal Single Speed (CSS) equals

$$35{,}000 * (HP/100)^{0.65}$$

The valid horsepower range for CSS is 3 HP to 350 HP.

The horsepower (HP) is determined by using equation (10) in page 516 (Peters and Timmerhaus,1980) as:

$$W = \Delta Z + \Delta(V^2/2g_c) + \Delta(pv)$$

Where:	W	= theoretical mechanical energy, hp
	Z	= vertical distance above datum plane, m
	V	= linear velocity of fluid, m/sec
	g_c	= gravitational acceleration, 9.81 m/s^2
	p	= absolute pressure, kPa
	v	= specific volume of the fluid, m^3/kg

Degasifiers: The equation used to estimate this cost is

$$1.5006 * X + 3765.7$$

where X is product capacity in m^3/day.

Product degasifiers are used when hydrogen sulfide exists in raw water and large amounts of carbon dioxide are liberated when the raw water pH is lowered.

Odor **control:** If odor control is specified yes (y) in the RO&NF input worksheet. The cost is estimated by

$$320.9 * X^{0.6}$$

where X is product capacity in m^3/day. Otherwise, it is zero

Process piping: The size is a function of plant capacity and recovery rate. The cost is

$$15.852 * X/Y$$

Where X is product capacity in m^3/day and Y is recovery rate in percent

Chemical feed with pumps (acid, antiscalant, chlorine): Pump size is a function of dose rates and flow rate of feed water and product water. An IF statement is built into the cost of the acid system. It stated that

$$AC * 1000 * (X/Y) * 30 * SC/(1000^2 * \rho) + 30{,}000 * NS$$

if acid concentration is greater than zero, the formula to calculate the cost is
where

AC = acid concentration, mL/L
SC = storage cost
NS = number of skids
X = product capacity, m^3/day
Y = recovery rate, %
ρ = density, g/mL

If concentration is less than zero, then cost is zero.

Cost formula for antiscalant and chlorine is

$$(AS \text{ or } CCC) * 1000 * (X/Y) * 30\ SC/(1000^2 * \rho) + 20{,}000 * NS$$

where

AS = antiscalant concentration, mg/L
CCC = chlorine concentration, mg/L
SC = storage cost
NS = number of skids
X = product capacity, m^3/day
Y = recovery rate, %
ρ = density, g/mL

Cartridge filters: cartridge filters are a function of feed water flow rate. The cost is estimated by

$$112{,}836 * CS^{0.8031} * NS * 1.2$$

where CS is capacity per skid, m^3/s. NS is number of skids.

Membrane cleaning equipment: Use $67,000 as an installed system price. This system is based upon cleaning 14 tubes at one time at a flow rate of 50 gpm per tube.

Concentrate treatment & piping: The cost is
where COC is concentrate cost ($\$/m^3$), X is product capacity (m^3/day), and Y is recovery rate (%).

$$COC * X * (1 - Y)/Y$$

Generators: The cost is estimated at

$$150{,}000 * (kwRO/1000)^{0.85} + 50{,}000$$

Where kwRO is the RO & Building electricity usage estimated as

$$14 * (x/Y)/3785$$

X is product capacity (m^3/day). Y is recovery rate (%).

Sitework: The cost is

where TC is the feed flow in m^3/day. SWC is sitework cost in $\$/m^3$.

$$TC * SWC$$

Indirect capital cost:

The indirect capital costs are the sum of:

- Interest during construction (4% of total construction cost)
- Contingencies (6% of total construction cost)
- A&E fees and project management(12% of total construction cost)
- Working capital(4% of total construction cost).

Operation and maintenance cost estimation:

Operation and maintenance costs include:

- Electricity
- Labor
- Chemicals (acid, caustic, antiscalant, and chlorine)
- Membrane replacement
- Cleaning chemicals
- Cartridge filters
- Repairs and replacement

- **Insurance**
- Lab fees

Total annual cost equals to capital recovery cost plus the total operation and maintenance costs. These major O&M cost elements are discussed below:

Electricity: Electricity is the largest operating cost. It is estimated by:

kwRO is the RO &Building electricity usage. X is product capacity (m^3/day). Y is recovery rate (%)

$$(kwRo + kwHPP + (kwRWT + kwPWP)) * PA * 365 * 24 * Z$$

kwHPP equals: $746 * NS * PS/1\,000$

kwHPP is the high pressure. pump electricity usage. NS **is** number of skids. PS is the pump size (hp). kwRWT and kwPWP equal

$$746 * NP * PS/1000$$

kwRWT is raw water transfer pump electricity usage. kwPWP is product water pump electricity usage. NP is number of pumps. PS is pump size (hp).

Labor: This cost is estimated by

$$SD * LR * 8 * 365$$

where SD is staff days. LR is labor rate.

Chemicals: IF statements are built in for both acid and caustic. If acid concentration is less than zero, then cost is zero. Otherwise, acid cost equals

$$AC * (X/Y) * 365 * PA * ACC * \rho_{acid} /1000$$

Where:

AC	=	acid concentration, mL/L
X	=	product capacity, m^3/day
Y	=	recovery rate, %
PA	=	% availability
ACC	=	acid cost, $/kg
ρ_{acid}	=	density of acid, g/ml

If caustic concentration is less than 1, then cost is zero. Otherwise, caustic cost equals

$$CC * TC * 1000 * 365 * PA * CAC/(\rho * 1000^2)$$

Where:
- CC = caustic concentration, mL/L
- TC = total capacity, m^3/day
- PA = % availability
- CAC = caustic cost, $/kg
- ρ_{base} = density, g/mL

Antiscalant cost is

$$AS * TC * 1000 * 365 * PA * ASC/(\rho * 1000')$$

Where:
- AS = antiscalant concentration, mg/L
- TC = total capacity, m^3/day
- PA = plant % availability
- ASC = antiscalant cost, $/kg
- ρ_{As} = density, g/mL

Chlorine cost equals

$$CCC * TC * 1000 * PA * 365 * CLC/(\rho_{Cl_2} * 1000^2)$$

Where:
- CCC = chlorine concentration, mg/L
- TC = total capacity, m^3/day
- PA = % availability
- CLC = chlorine cost, $/kg
- ρ_{cl2} = density, g/mL

Membrane replacement: The cost is estimated by

*(Number of elements * $/element)/membrane life*

Cleaning chemicals: Cleaning chemicals are H_2PO_4 and NaOH. H_2PO_4 solution concentration is 0.05%

$$F * NM * (D^2 * \pi * 102/4) * 1.15 * (0.005 * PHC + 0.001 * SDC * 2)/1000$$

NaOH solution concentration is 0.1%. The cost equals

Where:
- F = cleaning frequency
- NM = **number** of modules
- D = membrane diameter, cm
- PHC = H_2PO_4 cost, $/kg

SDC = NaOH cost, \$/kg
π = 3.14
1.15 = correction factor for pipe tilling

Cartridge filters: The cost is estimated by

$$23097 * CPS \cdot 6.245 * NS * 12$$

Where: CPS = capacity per skid, m^3/sec
NS = number of skids

Repairs and replacements, insurance: The cost for repairs and replacements assumed to be 0.5% of the total capital cost and 0.2% of the total capital cost for insurance.

Lab fee: The cost equals

$$\$800 * 12 * NS$$

where \$800 is the cost for one water analysis sample test and 12 samples per year. NS is number of skids.

The install cost in (\$/m^3 per day and \$/gallon per day) and total annual cost in (\$ per m3, \$ per acre-foot, \$ per 1000 gallons) of product water also can be found in the RO&NF Output worksheet.

$$TCC * i * (1+i)^n / ((1+i)^n - 1)$$

Capital recovery: Capital recovery cost equals

Where: TCC = total construction cost
i = interest rate
” = number of years

ION EXCHANGE
(ION-EXH)

Introduction:

Ion exchange resins are insoluble granular materials which have free cationic, or anionic radicals in their structure. These ions can be exchanged for ions of the same sign in the solution. Ion exchange is used for de-mineralization.

Design:

The purpose of this worksheet is to provide a cost estimation for an ion exchange unit based on available design parameters. Data required from the Capacity worksheet includes:

·	Desired flow rate	L/sec
·	Equivalents/L of Cation > +1 in water	Equiv/L
·	Equivalents/L of Anion > -1 in water	Equiv/L

Parameters with default values can be modified on the ion exchange worksheet. They are shown in the table 4. Table 5 lists suggested ranges for resin parameters.

Table 4: Default values for ion exchange operational parameters.

Parameter	Value	Unit
Desired run cycle	7	Days
Resin expansion coefficient	200	%
Cost factor for pressure	1	
Aspect ratio	2	Height/diameter
Cost of NaCl	$0.02	/kg

Table 5: Default values for resin parameters.

Parameter	Value	Unit
Required service flow rate	Range 16-40	L/(hr*L resin)
Cation equivalents/L of Resin	1.9	Equiv/L
Anion equivalents of Resin	1.4	Equiv/L
Resin price	$6700	/m^3
Volume NaCl/volume resin for regeneration	483	kg/m'
Regeneration fluid concentration	10	%

Resin Medium:

The minimum resin volume(m^3) is calculated by:

$$\text{Min resin } Volume(m^3) = \frac{Desired\ flow\ rate(L/s)}{Service\ flow\ rate(L/hr * L\ resin)}$$

Time until resin exhaustion (days) is calculated by:

$$Time\ until\ Resin\ exhaustion(days) = \frac{MRV * (EQC + EQA)}{FR * (ECR + EAR)}$$

Where: MRV = minimum resin volume, m^3
EQC = Equivalents/L of Cation > +1 in water, Equiv/L
EQA = Equivalents/L of Anion > -1 in water, Equiv/L
ERC = Cation Equivalents/L of Resin, Equiv/L
EAR = Anion Equivalents/L of Resin, Equiv/L
FR = Desired flow rate (L/s)

An IF statement is built in for the resin volume required to meet exhaustion time. It states that if time until resin exhaustion is greater than the desired run cycle, then the resin volume required to meet exhaustion time is equal to the minimum resin volume. Otherwise, the resin volume required to meet exhaustion time is calculated by:

$$RVET = \frac{RC * FR * (EQC + EQA)}{(ECR + EAR)}$$

Where: RVET = resin volume required to meet exhaustion time, days
RC = desired run cycle, days

Resin manufacturers recommend an expansion coefficient of two to provide ample room for the resin to expand during upflow regeneration.

Total Vessel Volume (TVV) is calculated by:

$$TW = RVET * Resin\ expansion\ coefficient$$

Resin Cost (RC) is calculated by:

$$RC = MRV * RP$$

Where: RP = nominal resin price, \$/m^3

Vessel Cost:

The fiber glass pressure vessel cost is calculated by the following formula:

$$\text{Log}(\$) = 3.44609 + 0.561757 * \text{Log}(TVV)$$

Regeneration:

NaCl is used for the resin regeneration. Amount of NaCl required is calculated by the following equation:

$$NaCl\ required = \rho_{NaCl} * RVET$$

Where: ρ_{NaCl} = density of NaCl, kg/m^3

The total chemical cost per year is calculated by:

$$NaCl_{required} * NaCl_{cost} * \frac{365}{DRC + 1}$$

Where: $NaCl_{cost}$ = sodium chloride cost, \$/kg
DRC = desired run cycle, days
365 = days per year

Storage tank cost is calculated by:

$$Tank\ Cost = 0.1427\ X^3 - 5.6691\ X^2 + 257.56X - 467.45$$

where X is the tank volume in m^3. This formula is developed from the Snyder cone bottom tank, HDLPE model tank prices.

Regeneration and Backwashing Pump:

Construction cost and O&M cost formulas for regeneration and backwashing pump are developed from the 1979 EPA report (EPA-600/2-79-162b).

Construction cost(CC):

$$CC = 36000 + 1254.21X - 0.1212\ X^2$$

Operating and Maintenance cost (O&M):

$$O + M = 73.3 * X^{0.75} + 2200$$

Where X is the filter area in m^2

Output:

Total construction costs include resin cost, resin operating tank cost, storage tank cost, and regeneration and backwashing pump cost. This total construction cost and Operating cost are output to the Report worksheet.

ELECTRODIALYSIS
(ED2)

Design::

The design model for electrodialysis is from a paper presented by Thomas D. Wolfe of HPD Inc. at the American Water Works Association meeting in August, 1993. It is a simplified version of the complex calculations required to design an ED system but, according to Mr. Wolfe, it is adequate for one pass desalination of brackish water. If the desalination ratio (input TDS/output TDS) is less than 3.6, the model

$$\frac{Kwh}{m^3} \; \frac{\Delta N * 26.8 * V_c}{Curr\ eff} * \frac{1\,kW}{1000\,W}$$

gives a good estimate of power and membrane requirements as follows:

$$\Delta N = \frac{Feed\ TDS\ (g/m^3)\ Diluate\ TDS\ (g/m^3)}{Ave.EqWt.(g/eq)}$$

$$Current\ Eff = \left[\sum C^+ Eff + \sum A^- Eff\right] - \frac{.006 * \Delta N * 26.8}{100 * CD}$$

Where: 26.8 Amp*hrs/eq is Faraday's constant.

C^+ and A^- represent each cation and anion species.

0.006 (eq/(cm^2*hr*eq/m^3)) is the Salt Diffusion Coefficient.

$$Total\ Resistance,\ R_t = R_d + R_c + R_m$$

Where: R_d is the dilute side resistance,

R_c is the concentrate side resistance,

R_m is the membrane resistance,

$$V_c = R_t * CD + V_m$$

V_c is the electric potential per cell pair,

V_m is the membrane electric potential,

CD is current density.

Power requirement is given by:

$$KWatts = \frac{m^3\ treated}{hr} * \frac{kwh}{m^3}$$

Membrane area requirements:

$$Area\,(m^2) = \frac{watts}{Amps\ per\ m^2 * Volts}$$

The number of pairs required:

$$No.\ of\ Pairs\ = \frac{Area\,(m^2)}{\text{Area}\ (m2)/pair}$$

Input:

There are several input requirements for this model which are taken from the Capacity and Cost Index worksheets:

- Feed and product TDS: mg/L
- Average equivalent weight: g/eq
- Flow rate: m^3/day
- Percent recovery: %
- Cost of electricity: $/kWh

The following table includes variables that are entered on the electrodialysis worksheet. The current values are approximations. More exact information can be obtained from the membrane manufacturer for the membrane in question.

Table 6: Default parameters for Electrodialysis cost estimates.

Variable	Value	Unit
Cost of Membrane	$100	m^2
Cation and Anion transport efficiencies	0.874	
Area per membrane pair	0.862	m^2/pair
Resistances (Rt)	2.5	Ohms/cm’
Current density	38	Amp/dm^2
Membrane electric potential per pair	0.25	Volt/pair
Electra-osmotic coefficient	0.003	ml/ma*hr

Cost Computation:

Capital cost is determined by multiplying the membrane cost by the construction factor. The construction factor used here is 1.65. This value was arrived at by adjusting the membrane operation variables till the electrical and membrane requirements matched those listed in a published cost estimate (Pittner, 1993) and then multiplying by an appropriate construction factor so that the costs matched also.

Operation and maintenance costs are the sum of chemical addition, maintenance, membrane replacement, labor, electricity and capita1 recovery costs. Chemical addition costs are dependent on the TDS of the feed water and are indexed to the "Maintenance Material Index." General maintenance is 5% of the capital cost and is also indexed to Maintenance Material. Membrane replacement is the amortized cost of replacing the membranes in 15 years at the given interest rate. Labor cost is simply $/year at the given labor wage rate. Electricity requirements are calculated above. Capita1 recovery is the amortized cost of the capital over the life of the plant at the given interest rate.

DISINFECTION WITH CHLORINE AND CHLORAMINE (CL2 AND NHCL)

Design:

Cost estimation for chlorine and/or chloramine disinfection is based on the amount of chemicals used per day. Chlorine demand is determined from the concentration of nitrite and reduced inorganic transition metals, such as chromium, copper, iron, and manganese, present in the water. These metals are oxidized from +2 charge to +3 by the hypochlorite ion by the following reaction (Snoeyink & Jenkins, 1980, pp. 391-395):

$$Cl_{2(aq)} + H_2O \_ HClO^- + H^+ + Cl$$

$$HClO^- + H^+ + 2\,Fe^{2+} \_ 2\,Fe^{3+} + Cl^- + H_2O$$

Hypochlorite reacts with nitrite to form nitrate:

$$HClO^- + NO; \_ NO; + Cl- + H^+$$

Therefore, one mole of aqueous chlorine is needed for each two moles of divalent transition metal, and one mole for each mole of nitrite, before the required chlorine residual will accumulate.

For disinfection with chloramine, ammonia is reacted with free chlorine in the water to form mono- and di-chloramine:

$$NH_{3(aq)} + HOCl \_ NH_2Cl + H_2O$$

$$NH_2Cl + HOCl \_ NHCl_2 + H_2O$$

The ratio of ammonia to hypochlorite used for maintenance of a combined chlorine residual is 1:1

Input:

$$[Cl_{2(g)}] = \frac{[Cr^{2+}] + [Cu^{2+}] + [Fe^{2+}] + [Mn^{2+}]}{2} + [NO_2^-]$$

The concentration of chromium, copper, iron, manganese, and nitrite is taken from the H20 Analysis worksheet. Chlorine demand is given by:

Chlorine residual and chloramine residual are input from the Report worksheet. The volume of water treated is input from the Capacity worksheet. The kilograms of chlorine needed per day is then:

$$\left(\frac{mg\ Cl_{2d}}{L}+\frac{mg\ Cl_{2r}/L * 71\ mg\ Cl_2/L}{85mg\ HClO^-/L}\right) * \frac{L}{\sec} * \frac{86400 \sec}{day} * \frac{kg}{10^6\ mg}$$

where $Cl_{2\,d}$ is the chlorine demand and $Cl_{2\,r}$ is the free chlorine residual.

If chloramine disinfection is used, chlorine demand is determined as for chlorine disinfection, then ammonia and chlorine are added in a one to one molar ratio to produce the required residual.

$$\frac{mg\ NH_3}{L} = \frac{mg\ NH_2\ Cl/L}{51.4\ mg\ NH_2\ Cl/mmole} * \frac{17\ mg\ NH_3}{mmole\ NH_2\ Cl}$$

$$\frac{mg\ Cl_{2(aq)}}{L} = \frac{mg\ Cl_{2d}}{L} + \frac{mg\ NH_2\ Cl/L}{51.4\ mg\ NH_2\ Cl/mmole} * \frac{71\ mg\ Cl_{2(aq)}}{mmole\ NH_2\ Cl}$$

Cost Computation:

Capital cost, and operation and maintenance costs are calculated from the formulas for chlorine storage and feed with cylinder storage in Qasim et al. (1992).

$$CC = 680.75 * X^{0.763} + 11010$$

$$O + MC = 47.6 * X^{0.89} + 6000$$

Where X = kg Cl_2 per day.

Cost formulas for ammonia addition are based on anhydrous ammonia feed:

$$CC = 3849.2 * X^{0.448} * e^{-3.5E-5*X}$$

$$0 + MC = -28063 * e^{(-2.41E-4*X)} + 36160$$

Where X = kg NH, per day (Qasim, et al, 1992).

Output:

The worksheet for chlorine disinfection returns the capital, and O&M cost for chlorine addition sufficient to supply the chlorine demand, and provide the indicated chlorine residual. The chloramine disinfection worksheet returns capital cost and O&M cost for addition of both chlorine and ammonia, sufficient to produce the combined chlorine residual specified. This cost estimate may be high if there are overlapping costs associated with the combination of chlorine addition and ammonia addition formulas.

Links:

- Transition metal and nitrite concentration is taken from the water analysis table on the H20 Analysis worksheet.
- Treatment requirements input from the Report worksheet.
- Costs output to Report worksheet.

Assumptions:

There are three important assumptions made in the cost modeling for chlorine and chloramine disinfection:

- The sum of the concentrations of metals and nitrite will give an adequate estimate of chlorine demand. The oxidation state of these metals is not usually given in a water analysis, so it is assumed that the whole concentration is at a +II state. This is probably not accurate, but it may balance out other chlorine demand that is not accounted for in this model.

- A 1:1 ratio of residual chlorine to ammonia will produce the necessary combined chlorine residual. According to V.L Snoeyink and D. Jenkins (Water Chemistry, p 395, 1980, John Wiley & Sons), the ratio of residual chlorine, as Cl_2, to initial NH, oxidized is 1 at a ratio of 1:1, Cl_2 dose:NH_3 initial. The combined residual at this point is composed of NH_2Cl with a trace of $NHCl_2$.

- For chloramine disinfection, Qasim's cost models for chlorine addition and ammonia addition are added together using the amounts of each needed for the required residual. This may give a high cost estimate due to overlap in cost items in the two models. It is assumed that the overlap is insignificant. Manufactured equipment is the highest component for each of the processes. Housing is second for chlorine feed and storage. The two chemicals would need their own equipment for feed and storage, so these components are not highly overlapping. The portion that may be significant is the labor cost for O&M. This cost may need modification in the future.

OZONE DISINFECTION
(OZONE)

Introduction:

Ozone (O_3), an allotrope of oxygen (O_2), is one of the most powerful oxidizing agents available for water treatment. A substantial amount of energy is required to split the stable oxygen-oxygen covalent bond to form ozone. The resulting O_3 molecule is highly unstable. It was thought that ozone might be a suitable replacement for chlorine, which forms tri-halomethanes. Ozone has the potential to form the same byproducts though, as long as halides are available to react with the oxidized organic compounds. Ozone decomposes rapidly, however, which makes it a safer choice for pretreatment ahead of chlorine sensitive membrane processes.

Purpose!:

This worksheet provides an estimation of capital costs and yearly power costs for an ozone system. The capital cost estimation includes costs associated with the ozone generator and the contact chamber. Estimates are derived from equations found in Qasim et al. (1992). Electricity costs are computed using a nominal power requirement per kilogram of ozone produced, and the local cost of electricity per kWh.

Links:

Ozone dosage in mg/L, and contact time in minutes, are taken from the Report worksheet. Values of 3 mg/L, and 2 minutes, are suggested as normal levels. Flow rate is taken from the Capacity worksheet. Electrical cost is taken from the Cost Index worksheet.

Cost Computation:

Ozone generation, and contact chamber costs are calculated by the following equations for 1992 dollars, then updated with the current index values.

$$OMC_{GEN} = 392.4 * x^{0.919} + 68000$$

Where x = chlorine feed capacity in kg/day

$$CC_{CONT.CHAMB.} = 1771.4 * x^{0.5967} - 1700$$

Where x = chamber volume in m^3.

Operation and maintenance costs for the contact chamber are included with those for ozone generation.

ACID FEED
(DG&ACID AND ACID)

Acid feed may be used in reverse osmosis to lower the pH of the feed water to levels compatible with the membranes used. With cellulose acetate membranes, this is about pH 5.5. Thin film composite membranes are not as sensitive to pH as cellulose acetate, but acid feed still may be used to control scaling

Design:

The Langelier Saturation Index (LSI) is normally used to predict the carbonate scaling tendency of water. In this model the Gibbs Free Energy (AG) is used instead. The AG calculations can be used for determining other solubility equilibria whereas, LSI is only for determining carbonate solubility. LSI can be calculated from AG as follows.

$$LSI = \frac{\Delta G}{2.3 * RT}$$

Where: R = 1 .987x10^{-3} kcal/mol*°K
T = Temperature in °K
2.3 is a factor for converting from natural log to log base 10

The reaction equations of interest in carbonate solubility are:

$$CO_{2(g)} + H_2O \leftrightarrow CO_{2(aq)} : \log K_H = -1.41$$

$$CaCO_{3(s)} \leftrightarrow Ca^{2+} + CO_3^{2-} : \log K_{so} = -8.15 \qquad (1)$$

and

$$H^+ + CO_3^{2-} \leftrightarrow HCO_3^- : \log \frac{1}{K_{a,2}} = 10.49 \qquad (2)$$

Summations of equation (1) and (2) equal:

$$CaCO_{3(s)} + H^+ \leftrightarrow Ca^{2+} + HCO_3^- : \log K = 2.34$$

Activity coefficients are calculated for calcium and bicarbonate ions from the ionic strength taken from the Capacity worksheet.

$$\log \gamma_i = 0.5091 * Z_i^2 * \left[\frac{\sqrt{\mu}}{1+\sqrt{\mu}} - 0.2 * \mu \right]$$

$$\mu = 0.5 * \sum C_i * Z_i^2$$

Where:	C_i	=	Concentration of the i^{th} ionic species,
	Z_I	=	charge of the i^{th} ionic species,
	μ	=	ionic strength,
	γ	=	activity coefficient of the i^{th} ionic species

Gibbs Free Energy is given by:

$$\Delta G = \Delta G° + RT * lnQ$$

Where:	R	= 1.987×10^{-3} kcal/mol*°K, is the universal gas constant.
	AG”	= theoretical solubility of calcium carbonate at 298°K and,
	RT*lnQ	= solubility under the pH, temperature conditions with the reported concentrations of Ca^{2+} and HCO_3^-, adjusted for ionic strength.

If AG is positive, the water is over-saturated, and will tend to deposit calcium carbonate scale.

The following charge balance equation is used to calculate the amount of acid needed to change the pH:

$$[Cations] + [H+] = [Anions] + [C^-] + [HCO_3^-] + 2[CO_3^{2-}]$$

All terms are expressed as functions of $[H^+]$, solubility constants, ionization fractions, and concentrations adjusted with their activity coefficients. This equation is solved for the target pH.

Input:

Ca^{2+} and HCO_3^- concentrations, total cations and anions, water temperature, and current pH, are input from the water analysis table of the H20 Analysis worksheet. Ionic strength is input from the water data report section on the Capacity worksheet.

Cost Computation:

Cost computations are done with ACID worksheet. Liters/second treated is input from the Capacity worksheet, and acid feed/day from DG&ACID worksheet. Formulas for capital and O&M costs are from Qasim et al, 1992.

$$cc = 61{,}010.6 * X^{0.7934} + 8{,}8180$$

$$0 + MC = -42{,}397.4 * e^{(-6.82E-3*X)} + 43{,}670$$

Where X = m^3 of sulfuric acid per day.

Output::

AG is output to the water data report section in the Capacity worksheet. Capital cost, O&M cost and liters 96% H_2SO_4 per day is output to the Report worksheet.

Links:

DG&ACID worksheet is linked to ACID worksheet, H20 Analysis, water data report in the Capacity worksheet and the Report worksheet. ACID worksheet cost reports to the Report worksheet.

Assumptions:

Ionic strength is accounted for, but the only scaling tendency checked is that of calcium carbonate. The system is assumed to be at equilibrium with the atmosphere. Assumptions used in the EPA report are in effect for this estimate as well.

Improvements:

Scaling tendencies for other constituents should be calculated. The AG calculation could be modified for this purpose by entering the proper solubility constants. Some good candidates would be silica, calcium sulfate, barium sulfate, strontium sulfate, and ferric hydroxide.

ALUM OR FERRIC SULFATE FEED
(ALUMFD AND IRONFD)

Alum or ferric sulfate coagulation is used for clarification. It is another process, like lime softening, that is designed to lower turbidity through precipitation of a sparingly soluble salt.

Design:

Alum or ferric sulfate react with alkalinity in the water to produce a hydroxide precipitate. Both react according to the following formula:

$$Fe_2(SO_4)_3 + 6\,HCO_3^- \leftrightarrow 2\,Fe(OH)_3 \downarrow + 3\,SO_4^{2-} + 6\,CO_2$$

Commercial grade alum and ferric sulfates are available as $Al_2(SO_4)_3 \bullet 18H_2O$ (MW: 666.41), and $Fe_2(SO_4)_3 \bullet 9H_2O$ (MW: 562), respectively.

Input:

Alkalinity is taken from the water analysis section of the H20 Analysis worksheet. Volume of water treated is taken from the Capacity worksheet.

Cost Computation:

Formulas For ferric and alum sulfate feed capital and O&M costs are from Qasim et al. (1992). There are formulas for both dry, and liquid (50% by weight), alum sulfate feed. Generally, the dose of liquid alum needed is twice that for dry alum.

$$\text{Ferric Sulfate}: CC = 10613 * X^{0.319} * e^{(3.93E\text{-}4*X)}$$

$$\text{Ferric Sulfate}: O+MC = 1{,}260{,}926 * e^{(1.394E\text{-}5*X)} - 1{,}257{,}710$$

X = Kg per day of ferric sulfate.

$$Dry\ Alum : CC = 12{,}333.4 * X^{0.3205} * e^{(5.15E\text{-}4*X)}$$

$$Liquid\ Alum : CC = 13{,}223.3 * X^{0.285} * e^{(3.77E\text{-}4*X)}$$

$$Dry\ Alum : O + MC = 1{,}205{,}293 * e^{(1.9433E\text{-}5*X)} - 1{,}202{,}070$$

$$Liquid\ Alum : O + MC = -6880.7 * e^{(-6.59E\text{-}4*X)} + 8{,}700$$

X = kg per hour of Alum.

output:

Capital and operation and maintenance costs are output to the Report worksheet

Links:

The links are to the Capacity, H20 Analysis, Cost Index, and Report worksheets.

Assumptions:

Those assumptions made in the EPA report on which the cost formulas are based are made here

POLYMER FEED
(POLYFD)

Polymer is added to prevent scaling in RO and NF systems. It is also used for clarification and as a coagulant or flocculant aid.

Design:

The amount of polymer needed depends on the type of polymer and the purpose for adding it. In any case, very little is needed. The precise amount is determined through jar testing. For design purposes, we will *use 0.5* grams per cubic meter *as* suggested in the *Water Treatment Handbook (0.05* to *0.5* g/m^3, Degrémont, 1991, p144) for a combination of synthetic flocculant and coagulant for clarification of surface waters.

Input:

Volume of water treated is taken from the Capacity worksheet

Cost Computation:

Formulas for polymer feed capital and operation and maintenance costs are from Qasim et al, 1992:

$$CC = 11760.71 * X^{6.65E-3} * e^{(8200*X)}$$
$$O+MC = 3000.8 * e^{(2.07E-3*X)}$$

Where X equals Kg polymer per day.

output:

Capital and operation and maintenance costs are output to the Report worksheet

Links:

The links are to the Capacity, H20 Analysis, Cost Index, and Report worksheets.

Assumptions:

The only assumption, other than those made in the EPA report on which the cost formulas are based, is that 0.5 mg per liter is a representative dosage of polymer.

POTASSIUM PERMANGANATE
$(KMNO_4)$

Potassium permanganate is an oxidizing agent. It is used for iron, manganese removal

A combination of $KMnO_4$ oxidation and manganese-greensand filtration was selected for testing. Manganese-greensand provides effective filtration and also controls under and over dosing of KMn04 (prevents the development of pink water breakthrough). Manganese (II) removal depends on the precipitation of $MnO_2(s)$(manganese[IV] [manganic dioxide], as follows:

$$3\,Mn^{+2} + 2\,KMnO_4 + 2\,H_2O \leftrightarrow 5\,MnO_2(s) + 2\,K^+ + 4\,H^+$$

Manganic dioxide is insoluble over the entire pH range of interest in drinking water treatment. Also, the oxidation of both Mn^{+2} and Fe^{+2}(ferrous iron) using $KMnO_4$ is reported to be quite rapid at pH 7 and higher (Glase, 1990).

The stoichiometry for manganese and iron oxidized with permanganate is:

1.92 mg/L $KMnO_4$ per mg/L of Mn^{+2} removed
0.94 mg/L $KMnO_4$ per mg/L of Fe^{+2} removed

Input:

Volume of water treated is taken from the Capacity worksheet.

Cost Computation:

$$CC = 9681.7\,X^{0.0304}\,e^{0.00122X}$$

Formulas for potassium permanganate feed capital and operation and maintenance costs are from Qasim et al, 1992:

$$O+MC = -2125.9\,e^{-0.01689X} + 5600$$

Where X equals dry potassium permanganate feed in kg/day.

output:

Capital and operation and maintenance costs are output to the Report worksheet.

Links:

The links are to the Capacity, H20 Analysis, Cost Index, and Report worksheets

LIME & SODA ASH FEED
(LIMEFD)

Design:

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.

$$Ca^{2+} + 2\,HCO_3^- + Ca(OH)_2 \leftrightarrow 2\,CaCO_3 \downarrow + 2\,H_2O$$

$$Mg^{2+} + 2\,HCO_3^- + 2Ca(OH)_2 \leftrightarrow Mg(OH)_2 \downarrow + 2\,CaCO_3 \downarrow + H_2O$$

The sum of these two reactions is:

$$Ca^{2+} + Mg^{2+} + 4\,HCO_3^- + 3Ca(OH)_2 \leftrightarrow 4\,CaCO_3 \downarrow + Mg(OH)_2 \downarrow + 3\,H_2O$$

This reaction is used when all components are available. The Mg^{2+} and Ca^{2+} are reacted with alkalinity and lime to form $CaCO_3$ and $Mg(OH)_2$.

The limiting reagent is determined by the mole ratio of each component. Then the amount of lime required for the initial reaction is calculated. The remaining Mg^{2+} or Ca^{2+} is reacted with remaining alkalinity. If carbonate alkalinity is zero, no more lime is needed. If Mg^{2+} is zero, formula (1) is used to calculate amount of lime to complete softening. Reaction (1) requires one mole of $Ca(OH)_2$ per mole of Ca^{2+}.

If Mg^{2+} is not zero, the Ca^{2+} is zero, formula (2) is used to calculate amount of lime needed to complete softening,, Reaction (2) requires 2 moles of $ca(OH)_2$ per mole of Mg^{2+}.

If HCO_3+CO_2 were the limiting reagent, which means that Ca^{2+} and Mg^{2+} are in excess of alkalinity. The soda ash is used to precipitate Ca^{2+} and Mg^{2+}. The following reactions demonstrate the relationship between soda ash and Ca^{2+} and Mg^{2+}:

$$Ca^{2+} + Na_2CO_3 \leftrightarrow CaCO_3 \downarrow + 2\,Na^+$$

$$Mg^{2+} + Na_2CO_3 + Ca(OH)_2 \leftrightarrow Mg(OH)_2 \downarrow + CaCO_3 \downarrow$$

Input:

Calcium, magnesium, carbon dioxide and alkalinity content of the water are taken from the water analysis in the H20 Analysis worksheet. If the percent reduction column is blank or zero for **these** values, the cost estimate will consider the total hardness, resulting in high cost estimates. Volume of water treated is taken from the Capacity worksheet.

Cost Computation:

Formulas for lime & soda ash feed capital, and operation and maintenance costs are developed from the 1979 EPA report (R.C. Gumerman, 1979)

$$CC = -24{,}950.92 + 20{,}424.67 * \ln(x)$$
$$O+MC = 866.29 * x^{0.51435}$$

Where X equals Kg Lime per day

output:

Capital and operation and **maintenance** costs are output to the Report worksheet

Links:

The links are to the Capacity, H20 Analysis, Cost Index, and Report worksheets. Water analysis data is taken from the H20 Analysis worksheet and cost data is returned to the Report worksheet.

Assumptions:

It is **assumed** that calcium and magnesium react with bicarbonate ion and calcium hydroxide at the same rate. If calcium was preferentially precipitated with bicarbonate before the magnesium, more soda ash would be needed to precipitate the magnesium. This would mean higher capital and O&M cost.

Improvements:

Since lime and soda ash softening is not the technology of choice, cost estimates for this process are primarily for comparison. Lime softening is not a precision process. As **long** as lime is added in excess, the process works. Therefore, refinement of the cost estimate would have to come from new price information, rather than improvements to the design of the cost model.

The cost estimate provided for lime feed is only for the lime feed system; it does not cover the cost a clarifier, or sludge processing or disposal.

GRANULAR ACTIVATED CARBON (GAC)

Introduction:

Granular activated carbon (GAC) is used to remove color, odor, organic chemicals, disinfection by-products, and chlorine from water through the process of adsorption. If the water has not been pre-filtered, the carbon bed may also serve as a granular filter, in which case, backwashing is a more significant design criteria.

Cost Eetimate:

This worksheet provides estimates of the capital and operating costs of a granular activated carbon (GAC) bed. Both are based entirely on flow rate and bed life. Costs are estimated using relationships derived from cost data in the 1979 EPA report. It is apparent from this data that there is a change in size versus cost relationship at 4000 m^3/day. Capital costs for GAC are fairly constant with respect to capacity until a production level of 4000 m^3/day. Above this level, there are different cost curves for a bed life of 3, 6, and 12 months. Regeneration costs are not included. The cost parameter used in these equations is m^3/day. The composition of the water is not considered.

Cost equations are as follows.

3.6, or 12 month bed life, capacity ≤ 4000 m^3/day.

$$CC = 9875 * x^{(1-.4596)}$$

12 month! bed life:

$$OM_{\leq 4000} = 2631.18 * x^{(1-.4706)}$$

$$CC_{>4000} = 1948.8 * x^{(1-.2569)} \quad OM_{>4000} = 225.42 * x^{(1-.1692)}$$

6 month bed life:

$$OM_{\leq 4000} = 2089.46 * x^{(1-.4187)}$$

$$CC_{>4000} = 150 * x \quad OM_{>4000} = 235.91 * x^{(1-.15)}$$

3 month bed life:

$$OM_{\leq 4000} = 1563.45 * x^{(1-.3463)}$$

$$CC_{>4000} = 200 * x \quad OM_{>4000} = 515.91 * x^{(1-.203)}$$

GRAVITY FILTRATION (SLOWSAND)

Introduction:

Granular filtration removes particulate matter such as algae, colloidal humic compounds, viruses, asbestos fibers, and colloidal clay from water. Matter accumulates on the surface, or is collected throughout the depth of the bed. The purpose of this worksheet is sizing and cost estimation of granular filtration systems.

Design:

There are two components: the backwashing system and the gravity filter structure with sand as the media. Costs for both are based on the area of the filter bed. Required input for area determination are:

· Flow rate	(Wsec)
· Total suspended solids	(mg/L)
· Backwash cycle	(24 hrs/cycle)
· Density of suspended solids	(35 g/L)
· Maximum media capacity	(110 L TSS/m^3 media)
· Media depth	(1 m)

Flow rate is input on the Capacity worksheet. Total suspended solids is input on the H20 Analysis worksheet. The other parameters are input on the gravity filtration worksheet. Default values are listed above.

Cost Estimation:

Costs estimates are derived from equations in Qasim et al. (1992):

$$CC_{BW} = 36,000 + 1254.21 * x - 0.1212 * x^2$$

$$CC_{GF} = 35,483.47 * x^{0.591} * e^{(13.62*10^{-4} * x)}$$

$$OM_{BW} = 73.3 * x^{0.75} + 2,200$$

$$OM_{GF} = 359.5 * x^{0.8568} + 8,100$$

Where x is the area of the filter bed in meters.

Improvements:

Future developments may include modifications of the generalized cost estimation equations to accommodate using different media.

UPFLOW SOLIDS CONTACT CLARIFIER (UFSCC)

Introduction:

Upflow solids contact clarifiers can be used with lime softening, and alum, or ferric sulfate precipitation. The chemical slurry is fed into the reaction zone in the center of the clarifier. Feed water flows up through the precipitate at the bottom. Contact with the solids speeds precipitation so that a shorter detention time is needed. As the water flows away from the center of the reactor, the solids settle out. Water is collected at the sides from the surface. Sludge is pumped out periodically from the bottom.

Design:

The size of the clarifier is determined from the flow rate and the detention time. Flow rate is taken from the Capacity worksheet, and detention time from the Report worksheet. The height of the tank is assumed to be 4.8 meters. Operation and maintenance cost have three options based on the "rapid mix G value." The "rapid mix G value", or mean velocity gradient is used to determine the size of the flocs produced as a function of the viscosity of the fluid at a certain temperature, and the rate of power dissipated into the tank volume. These terms are used to calculate G.

$$G = \sqrt{\frac{P}{\mu V}}$$

where: G= mean velocity gradient, 1/s
P = power requirement, Watt
μ = dynamic viscosity, $N.s/m^2$.
V= tank volume, m^3

Costs for G values of 70, 110, and 150 are computed. Number of clarifiers can be specified in the Report worksheet.

Cost Computation:

Cost curves were derived from data in EPA-600/2-79-162b. These are updated with current index values.

PUMPS
(PUMPS)

Introduction:

There are different types of pumps commonly employed in industrial operations. The ones examined in this worksheet are Single Speed Turbine (SST), Variable Speed Turbine (VST), and Centrifugal Single Speed pomps.

Design::

For each type of pump, the horsepower (HP) required by the pump to deliver the volume the water has to be determined. The horsepower is determined by using equation (10) in page 5 16 (Peters and Timmerhaus,1980) as:

$$W = \Delta Z + \Delta(V^2/2g_c) + \Delta(pv)$$

Where:	W	= theoretical mechanical energy, hp
	Z	= vertical distance above datum plane, m
	V	= linear velocity of fluid, m/sec
	g_c	= gravitational acceleration, 9.81 m/s^2
	p	= absolute pressure, kPa
	v	= specific volume of the fluid, m^3/kg

Direct Costs:

The cost of these pumps are determined as follows,

Speed Turbine (SST):

$$58{,}000 * (HP/100)^{0.65}$$

The valid horsepower range for SST is 3 HP to 300 HP.

Variable Speed Turbine (VST):

$$85{,}000 * (HP/100)^{0.65}$$

The valid horsepower range for VST is 3 HP to 500 HP

Centrifugal Single Speed (CSS):

$$35{,}000 * (HP/100)^{0.65}$$

The valid horsepower range for CSS is 3 HP to 350 HP.

Operating Cost:

The operating costs are power consumption, lubrication, cooling water, and maintenance for the pump. The cost information are based on the Pump Handbook (page 9-66) edited by Karassik, Krutzsch, Fraser, and Messina. Lubricating oil consumption is based on 0.02 gal/100 hp-hr for each pair of bearings. A motor driven centrifugal pump results in 0.04 gal/100 hp-hr total. Cooling water requirements are based on 10 °F temperature rise and 2 percent energy loss to the water for each pair of bearings.

The annual operating costs associated with each pump arrangement are developed from the following:

Lubricating oil 0.7 x 0.04 (bhp per 100) x 8760
Cooling water - (0.075 per 1,000) (bhp per 100) x 60 x 8760
Maintenance - 1.5 x bhp
Where bhp is brake horsepower.

output:

The direct costs and operating costs for the pumps are output to the Report worksheet.

CLEARWELL STORAGE
(CLEARWELL)

Introduction:

Product water is commonly stored at the plant site with clearwells. Clearwell storage can be constructed by either below ground in reinforced concrete structures, or above ground in steel tanks. Instrumentation and control of the clearwell water level is very important to pace the plant output.

Input:

The below ground and above ground level clearwell storage capacities are input on the clearwell storage section of the Report worksheet.

Cost Computation:

Construction cost formulas for clearwell storage below ground and above ground costs are developed from the 1979 EPA report (EPA-600/2-79-162b,page 453-454).
Below ground:

$$CC=-0.0002X^2+99.004X+37941$$

(for capacity less than or equal to 3785 m’)

$$CC = 49.084X + 224887$$

(for capacity greater than 3785 m^3)

Ground level:

$$CC=-0.054X^2+104.88X+21400$$

(for capacity less than or equal to 333 m^3)

$$CC = 0.054X^2 + 104.88X + 21400$$

(for capacity greater than 333 m^3)

$$CC = 0.0002X^2 + 39.556X + 58237$$

Where X is the clearwell capacity in m^3

Output:

Construction costs for below ground and above ground level clearwell storage are output to the Report worksheet.

WATER ANALYSIS

This worksheet contains several different water analyses from locations around the country. These are listed as desert well, brackish, desert surface, seawater intrusion, agricultural influence, seawater, alkaline and range land. Feel free to use one of these that seems to tit your application if you do not have an actual water analyses. Just copy the water analyses of interest and choose "Paste Special" from the edit menu on the H20 Analysis sheet with your cursor at the top of the water analysis column and choose "paste as dues".

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APPENDIX

APPENDIX

FLOW RATE INPUT PAGE, WATER DATA REPORT

Yellow colored cells are mandatory input cells

Enter Availability.	
Plant availability due to down time:'	0.95
*Plant availability is used to calculate energy and chemicals costs.	

	L/M	GPH	GPD	MGD
INPUT CELLS: enter **flowrate** in ONE of these cells, set rest cells to **0=>**	0	0	0	5
Flow rate converted to Liters/second and entered in workbook calculations.	0.001	0.00	0.01	219.0
Flow rates converted to a variety of units.	***131421***	***208,333***	5,000,000	5.00

PLANT FLOW RATES	u s	GPM
Required Plant Feed Flow Rate:"	292.1	***4630***
Desired Plant Product Flow Rate:	219.04	***3472***

"Feed Flow = Plant Product Flow / RO Recovery entered on cost report

WATER DATA REPORTS (based on Water Analysis)

Total dissolved solids (TDS):	***700*** mg/L		
Average equivalent wt.:	***26.0*** g/equiv		
Total equiv./L:	***0.024*** eq/L	2.09E-02	mol/L
Total equiv./L (Valence >+1):	***0.004*** eq/L	1.78E-03	>1 valence
Average MW	***30.32*** g/mol		
Ionic Strength:	0.015 mole*charge^2/L		
Delta G:	-0.409		
LSI:	***-0.326***		
Tendancy to corrosion, may need **remineralization.**			

WATER ANALYSIS

Input analysis in Yellow cells

Component	Example Water Analysis	Units	MCL (mg/L)	Amount Over MCL	Percent Removal Required	Valence Charges	Molecular Wt.	Equivalent Weight	Moles/ Liter	Equiv./ Liter	Ionic Strength
METALS:											
Aluminum		mg/L	0.05		0.00	3	26.97				
Antimony		mg/L	0.006		0.00	3	121.75				
Arsenic		mg/L	0.05		0.00	3	74.92				
Barium		mg/L	2		0.00	2	137.33				
Beryllium		mg/L	0.004		0.00	2	9.01				
Cadmium		mg/L	0.005		0.00	2	112.41				
Calcium	51.00	mg/L	---			2	40.08	20.04	1.27E-03	2.54E-03	5.09E-03
Chromium, total		mg/L	0.1		0.00	2	52				
Copper		mg/L	1		0.00	2	63.55				
Iron		mg/L	0.3		0.00	2	55.85				
Lead		mg/L	0.015		0.00	2	207.2				
Magnesium	7.50	mg/L	---			2	24.3	12.15	3.09E-04	6.17E-04	1.23E-03
Manganese	0.03	mg/L	0.05		0.00	2	54.94	27.47	5.10E-07	1.02E-06	2.04E-06
Mercury		mg/L	0.002		0.00	2	200.59				
Nickel		mg/L	---		0.00	2	58.71				
Zinc	13.00	mg/L	5	8	61.54	2	65.38	32.69	1.99E-04	3.98E-04	7.95E-04
Strontium		mg/L	---			2	87.6				
Selenium		mg/L	0.05		0.00	4	78.96				
Potassium	93.00	mg/L	---			1	39.1	39.10	2.38E-03	2.38E-03	2.38E-03
Silver		mg/L	0.1		0.00	1	197.87				
Sodium		mg/L	---			1	22.99				
Thallium		mg/L	0.002		0.00	1	204.37				
INORGANICS:											
Alkalinity-Bicarbonate	211.50		---			-1	61	61.00	3.47E-03	3.47E-03	3.47E-03
Alkalinity-Carbonate	0.00		---			-2	60				
Carbon Dioxide (aq)			---			0	44				
Asbestos		MF/L	7		0.00						
Boron					[illegible]						
Chloride	114.80	mg/L	250		0.00	-1	35.45	35.45	3.24E-03	3.24E-03	[illegible]
Residual Disinfectant		mg/L	detectable		0.00		71				
Color		cu	15		0.00						
Conductivity	889.00		---								
Corrosivity		mg/L	non-corrosive								
Cyanide, free		mg/L	0.2		0.00						
Fluoride	0.33	mg/L	4		0.00	-1	19	19.00	1.74E-05	1.74E-05	1.74E-05
Foaming Agents		mg/L	0.5		0.00						
Nitrate (as N)	3.30	mg/L	10		0.00	-1	14	14.00	2.36E-04	2.36E-04	2.36E-04
Nitrite (as N)	1.10	mg/L	1	0.1	9.09	-1	14	14.00	7.86E-05	7.86E-05	7.86E-05
Ammonia (as N)	20.00	mg/L	10	10	50.00	1	14	14.00	1.43E-03	1.43E-03	1.43E-03
Odor		ton	3		0.00						
pH	7.30	pH	6.5-8.5		0.00	1	1	1.00	7.30E-03	7.30E-03	7.30E-03
o-Phosphate			---		0.00	-3	95				
SiO2	27.00		---		0.00						
Silicon											
Solids (TDS)	700.00	mg/L	500	200	28.57						
Sulfate	90.00	mg/L	250		0.00	-2	96	48.00	9.38E-04	1.88E-03	3.75E-03
Temperature			---								
Total Suspended Solids:		mg/L	---								

Cost Index

COST INDICES DATA:

Input: Current Cost Indicies Values

Cost Indices Categories:	Input Current Values Here Feb 1999	January 1995	Source:
A) Excavation and Site Work	548.67	489	ENR Skilled Labor Wage Index (1967=100)
B) Manufactured Equipment	149.1	136	BLS General Purpose Machinery & Equipment WPU I 14 (I 91 12 = 100)
C) Concrete	150.2	130.2	BLS Concrete Ingredients PPI 132 (1982 = 100)
D) Steel	106.6	115.7	BLS Steel Mill Products WPU 1017 (1982 = 100)
E) Labor	548.67	489	ENR Skilled Labor Wage Index (1967=100)
F) Piping and Valves	164.3	148	BLS Miscellaneous General Purpose Equipment WPU I 149 (I 982 = 100)
G) Electrical Equip. and Instmnt.	120.6	123.4	BLS Electrical Machinery & Equipment WPU I 17 (I 982 = 100)
H) Housing	505.81	460.6	ENR Building Cost Index (1967=100)
I) Energy ($/kWhr)	0.07	0.1	Local Energy Cost $/kWhr
J) Maintenance Material	131.3	126.2	BLS: PPI Finished Goods (I 982 = 100)
K) Labor ($/hour)	30	20	Local Skilled Labor Rates $/hr
Interest Rats	8		
Amortization time (yr)	20		

ENR Engineering News Record Construction Cost Index published monthly by McGraw Hill in New York City (212-512-2000)
BLS Bureau of Labor Statistics headquartered in Kansas City (Denver, Colorado Number: 303-844-17261
OR Check the BLS web site at http://stats.bls.gov/sahome.html

Cost reports for water treatment processes

Yellow colored cells are mandatory input cells

Capacity:	18,925	m^3/day							
	5,000	kgal/day							
	Cost			Construction Cost			Operating Cost		
				Total	$/m³				
Process	Parameter	Units		$1000	Cap	$/kgal Cap	$1000/yr	$/m³	$/kgal
Desalination									
Microfiltration				$3677	$194	$0.151	$665	$0.10	$0.38
Microfilter system equipment	Memcor, 90M10C								
Number of microfilter	6								
Recovery	0.96								
Reverse Osmosis/Nanofiltration				$6142	$325	$1,228	$1780	$0.27	$1.03
Membrane Type	Film Tec, BW30-400								
Number of elements	792								
Operating Pressure	653	kPa	95 lb/in²						
NaCl Rejection	0.995								
Recovery	0.75								
Target Product (TDS mg/L)	500								
Blending? (Y or N)	n								
Ratio Blend:Product	0								
Ion Exchange				$517	$27	$103	$17	$0.00	$0.01
Cation Equivalents/L Resin	20								
$/m³ Cation Exchange Resin	$6,700								
Cation Resin Volume:	105	m³	3755 ft³						
To Remove Cation Equivalents/L:	3.56E-03								
Anion Equivalents /L Resin	11								
$/m³ Anion Exchange Resin	$6,700								
Anion Resin Volume	63	m³	2246 ft³						
To Remove Anion Equivalents /L:	1.76E-02								
Run Cycle (days)	6								
Electrodialysis				$2080	$110	$416	$486	$0.07	$0.28
Membrane Area:	12,606	m²	135697 ft²						
Product TDS	400	mg/L							
Number of Stages (1 or 2)	1								
Recovery per Stage	0.5								
Recovery	0.50								
Disinfection									
Chlorination				$60	$3	$12	$25	$0.00	$0.01
Residual;	3.0	mg/L							
Calculated Dose Rate:	3.0	mg/L							
Alternative Dose Rate:	0.0	mg/L							
Chloramination				$622	$33	$124	$439	$0.07	$0.25
Residual:	3	mg/L							
Calculated Chlorine Dose:	105.59	mg/L							
Calculated Ammonia Dose:	0.99	mg/L							
Alternative Chlorine Dose	0.0	mg/L							
Alternative Ammonia Dose	0.0	mg/L							
Ozone				$364	$19	$73	$34	$0.01	$0.02
Dose Rate (~5mg/L):	1.0	mg/L							
Contact Time (~2 min):	2.0	min							

Cost reports for water treatment processes

Yellow colored cells are mandatory input cells

Capacity: 18,925 m^3/day
5,000 kgal/day

Process	Cost Parameter	Units			Construction Cost Total $1000	$/m³ Cap	$/kgal Cap	Operating Cost 1000/yr	$/m³	$/kgal
Chemical Feed Systems										
Acidification					$27	$1	$5	$45	$0.01	$0.03
Calculated Dose Rate 96% H_2SO_4	0.030	ml/L								
Alternative:		ml/L								
Target LSI:	-0.05									
Target pH:	7.58									
Alum (dry feed)					$210	$11	$42	$2286	$0.35	$1.32
Calculated Dose Rate:	385	mg/L								
Alternative Dose Rate:		mg/L								
Based on:	405	kg/hr	891	lb/hr						
Alum (liquid feed)	Dose Rate				$246	$13	$49	$4512	$0.69	$2.60
Calculated:	770	mg/L								
Alternative:		mg/L								
Based on:	810	kg/hr	1782	lb/hr						
Ferric Sulfate	Dose Rate				$138	$7	$28	$33	$0.01	$0.02
Calculated:	325	mg/L								
Alternative:	10	mg/L								
Based on:	252	kg/day	555	lb/day						
Lime & Soda Ash	Dose Rate				$183	$10	$37	$49	$0.01	$0.03
Leave out Soda Ash "Y" or "N"?	Y									
Calculated Lime:	135	mg/L								
Calculated Soda Ash:	0	mg/L								
Alternative Lime	30	mg/L								
Alternative Soda Ash:	30	mg/L								
Based on Lime dose:	32	kg/hr	69	lb/hr						
Based on Soda Ash:	32	kg/hr	69	lb/hr						
Polymer	Dose Rate				$42	$2	$8	$20	$0.00	$0.01
Suggested:	0.5	mg/L								
Alternative:	0.3	mg/L								
Based on: (english)	7.6	kg/day	17	lb/day						
Potassium Permanganate	Dose Rate				$21	$1	$4	$36	$0.01	$0.01
Calculated:	No Need	mg/L								
Alternative:	1	mg/L								
Based on:	25	kg/day	56	lb/day						

Cost reports for water treatment processes

Yellow colored cells are mandatory input cells

				Construction Cost			Operating Cost		
Capacity:	18,925	m³/day							
	5,000	kgal/day							
Process	Cost Parameter	Units		Total $1000	$/m³ Cap	$/kgal Cap	$1000/yr	$/m³	$/kgal
Media Filtration									
Granular Activated Carbon									
Flow rate	292.0524691	L/sec	4630 gal/min						
Alternative Flow Rate:		L/sec	gal/min						
	Bed Life								
Months	12			$3638	$192	$728	$1024	$0.16	$0.59
Months	6			$3785	$200	$757	$1301	$0.20	$0.75
Months	3			$5047	$267	$1,009	$1663	$0.25	$0.96
Gravity Filtration									
Calculated Surface Area:	1.44	m²	16 ft²						
Alternative Surface Area:									
Structure:				$92	$5	$18	$23	$0.00	$0.01
Backwashing:				$77	$4	$15	$5	$0.00	$0.00
Media									
Rapid Sand				$104					
Coal/Sand				$109					
Coal/Sand/Garnet				$327					
Misc. Equipment									
Pumps									
Single Stage Tubine				$723	$38	$145	$767	$0.12	$0.44
Variable Speed Turbine				$938	$50	$188			
Centrifugal, Singe Stage				$555	$29	$111			
Number of pumps:	4								
Height differential:	1	m	2.9 ft						
Discharge pressure:	1750	kPa	254 psi	Operating Cost Depend on Number and Horsepower of					
Full flow rate:	0.292	m³/s	4630 gal/min						
Basis flow rate	0.073	m³/s	1157 gal/min						
Pump Efficiency:	75	%							
Pipe Diameter:	0.1	m	4 in						
Motor Efficiency:	67	%							
HP	236								
Power consumption:	271	kWhr							
Upflow Solids Contact Clarifier				$932	$49	$186.50			
How Many?	2								
Retention Time (min)	180								
Calculated Surface Area:	328.6	m²	3537 ft²						
Alternative Surface Area:		m²	ft²						
G Rating %	70						$41	$0.01	$0.02
G Rating %	110						$45	$0.01	$0.03
G Rating %	150						$51	$0.01	$0.03
Clearwell									
Below Ground Capacity:	1500	m³	396.4 kgal	$358					
Ground Level Capacity:	1500	m³	396.4 kgal	$237					
Daily Production:	18,925	m³	5001.3 kgal						

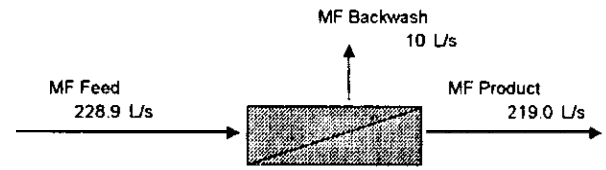
Microfiltration Cost **Estimation** Program

Yellow colored **cells** are mandatory input cells

Process input					
(Inputs in yellow cells)					
Design MF product flow rate	5,000,000	208,333	3472	219	18925
	GPD	GPH	GPM	L/s	m³/day
Plant availability (%)	95				
Microfilters system equipment cost	$270,000	90M10C			
Cost per membrane	$650				
MF modular system flow rate	600	gpm	37.85	L/s	
No. membranes per microfilter	90				
Pump efficiency	80	%			
Motor efficiency	93	%			
Design feed pressure	30	psi	207	kpa	
Backflush pressure	29	psi	200	kpa	
Backwash intervals	60	minutes	3600	second	
Backwash and backflush duration	2.5	minutes	150	second	

Operations & Maintenance Cost Input		
Electricity Rate	0.08	$/kWh
Chemical Costs		
Sodium Hypochlorite	0.43	$/L
Design dosage	200	mg/l
Specific gravity (NaOCl)	1.168	
Solution concentration	12	%
Membrane Life	5	Years
Staff Days/day	5	
Labor Rate (salary and benefits)	35	$/hr
Amortization time	30	Years
Interest Rate	8	%

Process Flow Calculation				
MF feed flow	228.9	L/s	3629	gpm
MF product flow	219.0	L/s	3472	gpm
MF reject flow (backwash)	10	L/s	157	gpm
Recovery rate	95.7	%		
Feed pump horsepower	79	hp		
Feed pump (kwh)	61	kwh		
Backflush (kwh)	3	kwh		
Number of microfilters	6			
Number of membranes	540			
Building Area	2500	ft2	232	m2



Microfiltration

Estimating Construction Costs for Microfiltration Membrane Treatment Plant

Direct Capital Costs						
Microfilters	$	1,620,000	@	270000	$/90M10C	
Building	$	250,000	@	100	$/ft^2	1076 $/m2
MF installation	$	420,000	@	70000	$/90M10C	
Miscellaneous	$	81,000		5	% of microfilters	
Plant interconnecting piping	$	85,050		5	% of microfilters and misc.	
Engineering	$	170,100		10	% or microfilters and misc.	
Total Direct Capital Costs	**$**	**2,626,150**				
Indirect Capital Costs						
Interest During Construction	$	158,000		6	% of Total direct	
Contingencies	$	525,000		20	% of Total direct	
A&E Fees, Proj. Management	$	263,000		10	% of Total direct	
Working Capital	$	105,000		4	% of Total direct	
Total Indirect Captial Cost	**$**	**1,051,000**				

Total Construction Cost	$	3,677,150
Cost per gpd capacity	$	0.74

Operations & Maintenance Cost Estimation

Electricity	$	45,000
Labor	$	485,000
Chemicals (Sodium Hypochlorite)	$	10,000
Membrane Replacement	$	70,000
Cleaning Chemicals(NaOCl)	$	2,000
Repairs and Replacement and Misc.	$	53,000
Total O & M Cost	**$**	**665,000**

Total costs		
Capital Recovery	$	327,000
O&M	$	665,000
Annual cost	$	992,000
$/m^3 Product	$	0.151
$/1000 gal Product	$	0.57
$/acre foot Product	$	186

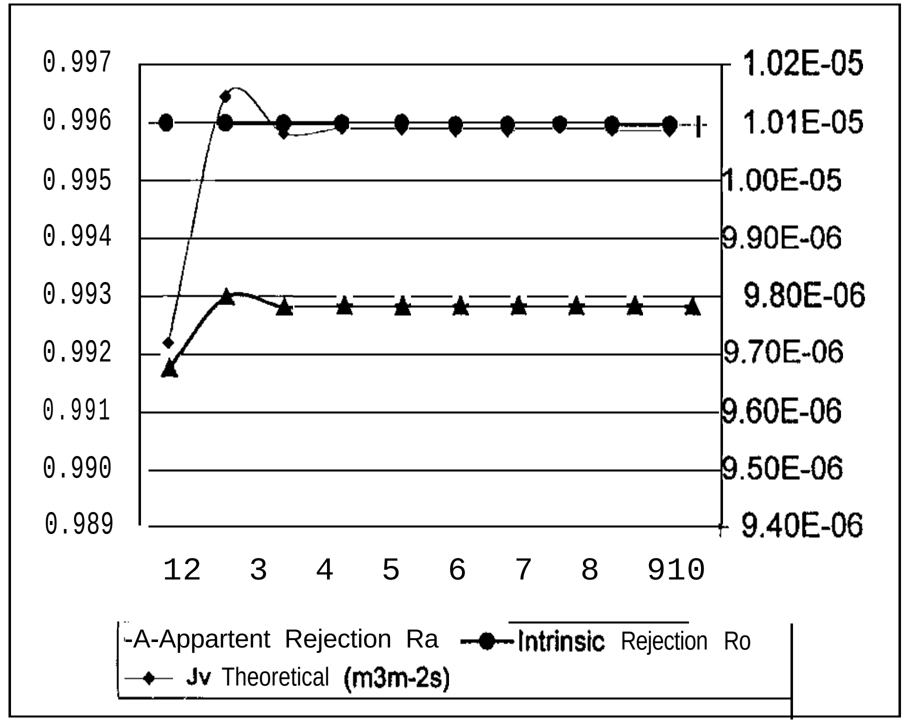
Available Flow	292.1	L/s	4630	gpm
Target Flow	219.0	L/s	3472	gpm
Total Disolved Solids	700	mg/L		
Target Disolved Solids	500	mg/L		
Mono valent	0.91	Decimal		
Multi-valent	0.09	Decimal	271.65	
Average Molecular Mass	30.32	g/mol	69.86	
Allow Blending	n	"Y" or "N"	19.588	
Recovery Rate	0.75	Decimal		
Product TDS	4	mg/L		
Product Flow	219.0	L/s	3472	gpm
Membrane Feed Flow	292.1	L/s	4630	gpm
Concentrate TDS	2789	mg/L		
Concentrate Volume	73.0	L/s	1157	gpm
Bypass flow for blending	0.0	L/s	0	gpm
% blending	0.0	%		
Data from Membrane Manufacturer Specification				
Type of membrane	Film Tec. BW30-400			
Productivity	40	m^3/day		
Operating pressure, P_{app}	1550	kPa	224.93	psi
Test solution TDS	2000	mg/L		
Avg. MW of TDS	58.44	mg/mmole NaCl		
Salt rejection	99.5	%		
Recovery Rate	85	%		
Temperature	25	C		
NaCl dissociation constant	0.99			
C_f, conc. of salt in feed water	34	mole/m^3		
C_p, conc. of salt in product water	0.17	mole/m^3		
Cr, conc. of salt in reject	227	mole/m^3		
C_m, conc. of	131	mole/m^3		
Osmotic pressure	641	kpa	93	psi
Net driving pressure, NDP_e	909	kpa	131.96	psi
A, water transport coefficient	0.044	m/sec.Pa		
Determination of operating pressure				
User input pressure, NDP_i	550	kPa	79.812	psi
Cf, conc. of salt in feed water	23.087	mole/m^3		
C_p, conc. of salt in product water	0.115	mole/m^3		
Cr, conc. of salt in reject	22.740	mole/m^3		
C_m, conc. of	22.913	mole/m^3		
Osmotic pressure, P_{osm}	103	kpa	15	psi
Operating pressure, P_{app}	653	kPa	95	psi

Colored cells are changeable here.
White cells are equations or taken from
the input, cost indices, and cost report worksheets.

Bypass	-	m^3/day	0	gpd
Total Capacity	18,925	m^3/day	,000,000	gpd
Module Productivity	24	m^3/day	6,392	gpd
Membrane Diameter	20.32	(10.16 or 20.32 cm)	8.0	in
Number of modules per vessel	6			
Max Vessels per Skid	24			
Membrane Area	792	# of modules		
Number of Pressure Vessels	132	for 2:1 array		
Number of RO Skids	3			
Recovery Rate	0.75	Decimal		
Chemical Feed Dosages				
Acid	0.03	mL Conc H_2SO_4/L		
Antiscalant	0.3	mg/L		
Disinfectant	3.0	mg/L		
Building Area	604	m^2	6500	ft2
Administrative Area	20	m^2	215	ft^2
Odor Control?	n	Yes (Y) or No (N)		
Emergency Generatore Size		hp		
High Pressure Pump	VST			
Height Difference	1	m	3.28	ft
Pipe Diameter	0.10	m	4	in
Length of Pipe	10	m	32.8	ft
Efficiency	82			
Number of High Service Pumps	2			
Operating Pressure	653	kPa	95	psi
Capacity per Skid	0.146	m^3/s	2315	gpm
Size	182	hp		
Transfer Pumps	SST	*SST, VST or CSS		
Height Difference	1	m	3.28	ft
Pipe Diameter	0.12	m	0.40	ft
Length of Pipe	10	m	32.81	ft
Efficiency	78			
Number Transfer Pumps	2			
Pressure Differential	200	kPa	29.0	psi
Capacity per Pump	0.146	m^3/s	2314.8	gpm
Size	46.8	hp		
Product Water Pump	SST	*SST, VST or CSS		
Height Difference	10	m	32.81	ft
Pipe Diameter	0.14	m	0.47	ft
Length of Pipe	20	m	65.62	ft
Efficiency	78			
Number Pumps	2			
Pressure Differential	50	kPa	7.3	psi
Capacity per Pump	0.110	m^3/s	1736.1	gpm
Size	13.1	hp		

[illegible]	[illegible]	[illegible]	
Chemical Costs			
Acid	0.14	$/kg	
Antiscalant	4.37	$/kg	
Disinfectant	0.2	$/L	
H_3PO_4	23.7	$/kg	
NaOH	18	$/kg 50%	
Membrane Life	3	Years	
Ave Intrinsic Rejection	0.996	.7 for NF, .987 for RO	
Ave Observed Rejection	99.5	.45 for NF, .85 for RO	
Chloride Rejection	0.995	%	
Sulfate Rejection	0.998	%	
Productivity	40	m^3/module	
Cleaning Rate	12	per Year	
Staff Days/day	6		
Labor Rate	30	$/hr	
Lifetime	20	Years	
Interest Rate	8	%	

Pure water permeability (m^3/s)	4.63E-04
Feed Flow (m^3/s)	3.09E-03
Transmembrane pressure (Pa)	1550000
Area (m^2)	37
Channel height d,(m)	1.67E-03
C_f (mol/m^3)	34.22
Density (kg/m^3)	1000
Viscosity (Pa s)	0.001
a (Pa $m^3 mol^{-1}$)	4908
Diffusivity of NaCl (m^2/s)	1.20E-09



Calculated paramters determined by configuration and operating conditions

J_v (m/s) 1st pass	1.25E-05
P_v/t_m ($m^3 m^{-2} s^{-1} Pa^{-1}$)	8.07E-12
Average U_c (m/s)	9.99E-02
Schmidt Number	838
Renolds Number	166
a	0.875
b	0.250
c	0.065
k (m/s) for laminar flow in flat channel	2.20E-05

Solving the design equations

J_v/k	0.57	0.44	0.46	0.46	0.46	0.46	0.46	0.46
Recovery	0.1500	0.1165	0.1216	0.1209	0.1210	0.1210	0.1210	0.1210
Intrinsic Rejection R^o	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996
Appartent Rejection R_a	0.9917	0.9930	0.9928	0.9928	0.9928	0.9928	0.9928	0.9928
C_w (mol/L)	70.7728	6.01E+01	6.16E+01	6.13E+01	6.14E+01	6.14E+01	6.14E+01	6.14E+01
C_p (mol/L)	0.2831	2.40E-01	2.46E-01	2.45E-01	2.46E-01	2.45E-01	2.45E-01	2.45E-01
C, (mol/L)	40.2126	38.7050	38.9262	38.8950	36.8994	38.8988	38.8989	38.8989
J_v Theoretical ($m^3 m^{-2} s$)	9.72E-06	I.OIE-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05
Exp (J_v/k)	1.77	1.56	1.59	1.58	1.58	1.58	1.58	1.58

Rejection

Estimating Construction Costs for BW-30-400 Membrane Treatment Plant						
Membranes	$	594,000	@	750	$/element	
RO Skids	$	660,000	@	5000	$/Vessel	
Building	$	650,000	@	1076	$/m^2	$100/ft2
Electrical	$	370,064	With base of	614	$/m^3	
Insturmentation & Controls	$	495,000				
High Pressure Pumps	$	250,962		272	kWh	
Transfer Pumps	$	70,836		70	kWh	
Product Water Pumps	$	30,996		20	kWh	
Degasifiers	$	32,165				
Odor Control	$	-				
Process Piping	$	399,999				
Yard Piping	$	200,688				
Chemical Feed w/ Pumps						
Acid	$	91,157		1	$/L storage for 45 days	
Antiscalant	$	60,076		1	$/L storage for 30 days	
Chlorine	$	61,706		1	$/L storage for 30 days	
Cartridge Filters	$	57,605				
Membrane Cleaning Equip	$	67,000				
Contractor Engineering & Training	$	50,000				
Concentrate Treatment & Piping	$	62,500		13	$/m^3	Concentrate
Generators	$	69,981		93	kWh	RO & Building
Sitework	$	275,000		$ 14.53	$/m^3	
Total Direct Capital Costs	$	4,549,735				
Indirect Capital Costs						
Interest During Construction		245,686		4	% of Total	
Contingencies		367,050		6	% of Total	
A&E Fees, Proj. Management		733,986		12	% of Total	
Working Capital		245,686		4	% of Total	
Total Indirect Captial Cost	$	1,592,407				

Total Construction Cost	$	6,142,143
Cost per m^3/day capacity	$	325
Cost per gpd capacity	$	1.23

Estimating Operations & Maintenance Costs		
Electricity	$	264,726
Labor	$	525,600
Acid	$	69
Antiscalant	$	2,868
Chlorine	$	3,945
Membrane Replacement	$	198,000
Cleaning Chemicals	$	17,299
Cartridge Filters	$	80,797
Repairs and Replacement	$	22,749
Insurance	$	9,099
Lab fees	$	28,800
Total O & M Cost	$	1,153,951

Total Costs		
Capital Recovery	$	625,591
O&M	$	1,153,951
Annual cost	$	1,779,542
$/m^3 Product	$	0.27
$/1000 gal Product	$	1.03
$/acre foot Product	$	334

Based on "Estimating the Cost of Membrane (RO or NF) Water Treatment Plants" By William B. Suratt, P.E., Camp Dresser & McKee Inc. Vero Beach Florida Presented at the AWWA Membrane Technology Conference, Reno, NV, 1995. also published as

"Estimating the cost of membrane water treatment plants." AWWA Proceedings

Membrane Technologies in the Water Industry. Orlando, Florida, March 10-13, 1991.

Calculation of Free Energy to determine scaling propensity.
If dG is < 0 water is corrosive, if it is > 0 it is oversaturated.
(from Snoeyink & Jenkings, Water Chemistry, 1980, John Wiley & Sons, Inc. p288)

Some water analyses include LI calculation.
LI = dG/2.3*R*T

Equations:
Act Coef. = 10^-(.5*qi^2*(u^.5/(1+u^.5)-0.2*u))
qi is the charge on the i'th species, u is ionic strength.
log K = log Kso + log 1/Ka,2
dG = dG' +R*T*ln Q
dG' = - R*T*ln K
Q = {Ca2+}*{HCO3-}/{H+}
u = @SUM(Ci*Zi^2)/2

Tendancy to corrosion, may need remineralization.

Acid addition calculations:
Assume system open to the atmosphere, H2CO3* is approximately $K_H P_{CO2}$
The calculation is based on carbonate system equilibrium. Bicarbonate concentration is input from the water analysis. [CO3 2-] is calculated from 2nd dissociation constant

The equations behind these caluclations are derived from the charge balance equation:
[Cations] + [H+] = [Anions] + [OH-] + [HCO3-] + 2[CO3 2-] + 2[SO4 2-]

All terms expressed as functions of [H+] concentration, the above constants, ionization fractions, and given concentrations.

[Anions] =	Sum of Anions other than sulfate and bicarbonate
[Cations] =	Sum of Cations from interface
[H+] =	10^-(Target pH)
[OH-]	Kw/[H+]
[H2CO3*] =	$K_H * P_{CO2} = 10^{-1.5} * 10^{-3.5} = 10^{-5}$ M
[HCO3-] =	{HCO3}
[CO3 2-] =	[H2CO3*]*a2/a0
[SO4 2-] =	Input adjusted by solver
a0 =	[H+]^2/E
a1 =	[H+] * Ka,1/E
a2 =	Ka,1 * Ka,2/E
E =	[H+]^2 + [H+]*Ka,1 + Ka,1*Ka,2
E =	10000

p 432, Water Chemistry, Snoeyink & Jenkins, 1980.

Calculation of ionic strength:
3 methods:

1) Lewis & Randall, J.Am. Chem. Soc. 43:1111 (1921)
u = @SUM(Ci*Zi^2)/2
Ci = Concentration of i'th species in moles/L.
Zi = Charge on i'th species.

2) W.F. Langelier, J. Am. Water Works Assoc., 28:1500 (1936).
u = 2.5E-5* TDS

3) L.L. Russel Ph.D. Thesis, U of California, Berkeley, Dec. 1976.
u = 1.6E-5* specific conductance (umho/cm)

Species	Zi	MW	Conc. mg/L	Moles/L	Ci*Zi^2
Ca 2+	2	40	51.0	0.00128	0.0051
Mg 2+	2	24.3	7.5	0.00031	0.001234568
Na +	1	23	0.0	0	0
K +	1	39	93.0	0.00238	0.002384615
CO3 -2	-2	60	0.0	0	0
HCO3 -	-1	61	211.5	0.00347	0.003467213
SO4 -2	-2	96	90.0	0.00094	0.00375
Cl-	-1	35.4	114.8	0.00324	0.003242938
Ionic Strength =		0.01918		Charge Balance	
			+	0.00158	
			-	0.00765	

Input from water analysis.

Species:	Concentration	Activity Coefficient	Concentration w/ Activity Coef.
ionic strength:	1.451E-02	square root u:	0.12
Ca 2+ and Mg 2+ moles/L:	1.581E-03	0.61	9.682E-04
HCO3- moles/L:	*3.467E-03*	*0.88*	*3.087E-03*
pH:	7.30		5.012E-08
Temp deg.C:	0	deg K:	273
H2CO3*:	0.00E+00		0.000E+00

Constants at 20 deg C:		w/activity coef.
log Kw:	-14.17	-14.06
log Kso:	-8.28	-7.85
log Ka,1:	*-6.38*	*-6.27*
log Ka,2:	-10.38	-10.59
log K:	2.10	.
log Kh:	-1.5	
gas const. R (kcal/deg K*mole):	1.987E-03	

Calculations:			
Q:	5.925E+01		
dG':	*-2.623*		
dG:	-0.409	LSI :	-0.328
Fine - pH is:	7.30		
Target dG	-0.062	Target LSI:	-0.05
pH for Target dG	7.58	**Looks fine**	

Input: From above.	Concentration	w/Activity Coef	Units
[H+]	*2.646E-08*	*2.341E-08*	moles/L
[H2CO3*]	1.000E-05	1.000E-05	moles/L
[HCO3-]	1.575E-04	1.575E-04	moles/L
[CO3 2-]	2.482E-07	1.520E-07	moles/L
[OH-]	2.555E-07	2.260E-07	moles/L
$C_{T,CO3}$	1.678E-04	1.677E-04	
Target pH:	7.58		
H2SO4 added:	5.709E-04	moles/L	
mL 96% H2SO4/Liter	*0.030*	*mL/L*	

Acid addition cost estimation

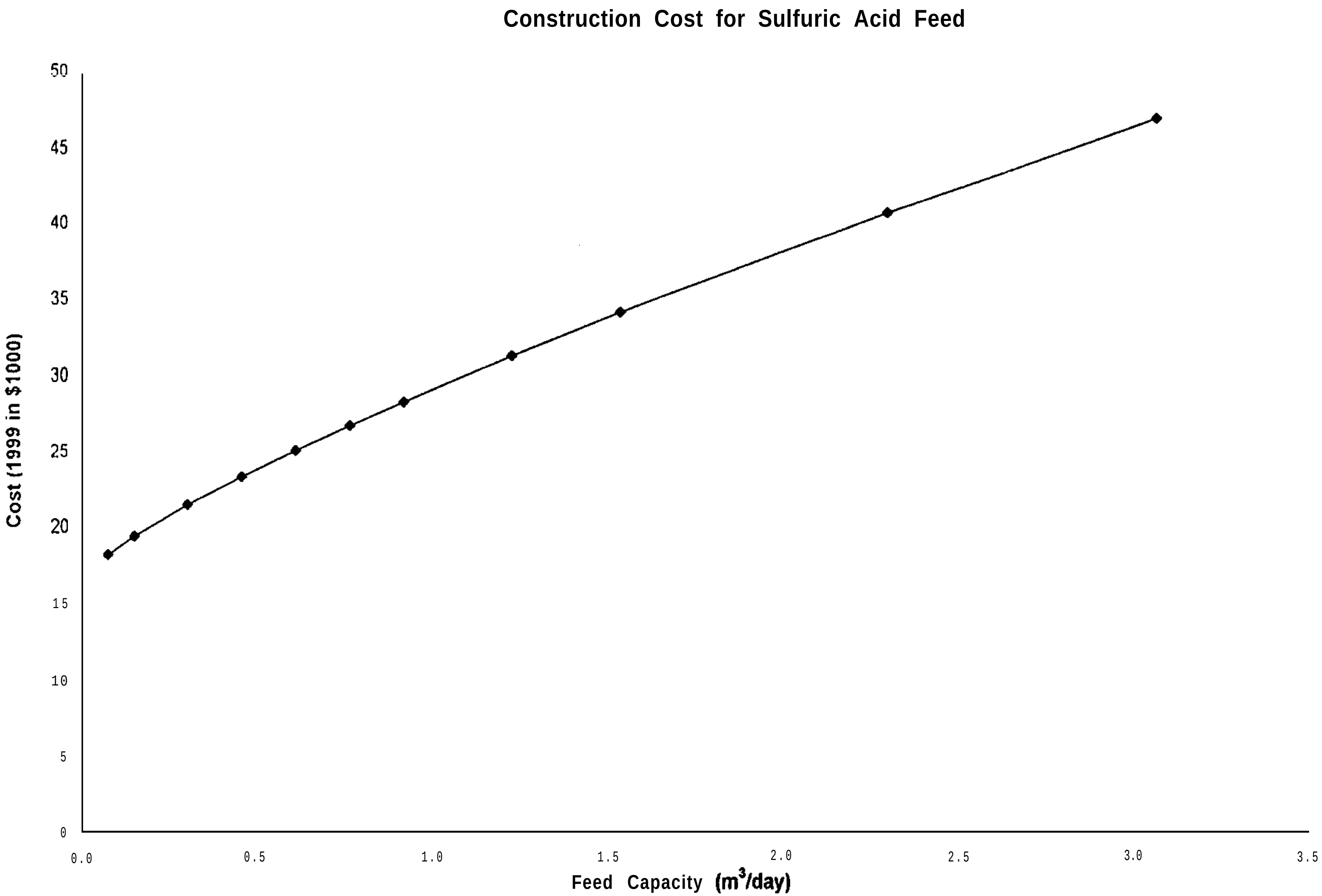
Litershec treated	292.05			
H_2SO_4 (96%) mL/L	0.03			
H_2SO_4 (96%) m^3/day	0.77			
Basis:	0.77	Applicable Range: 0.04 - 20 m^3/day		
Acid Cost ($/ton):	75			

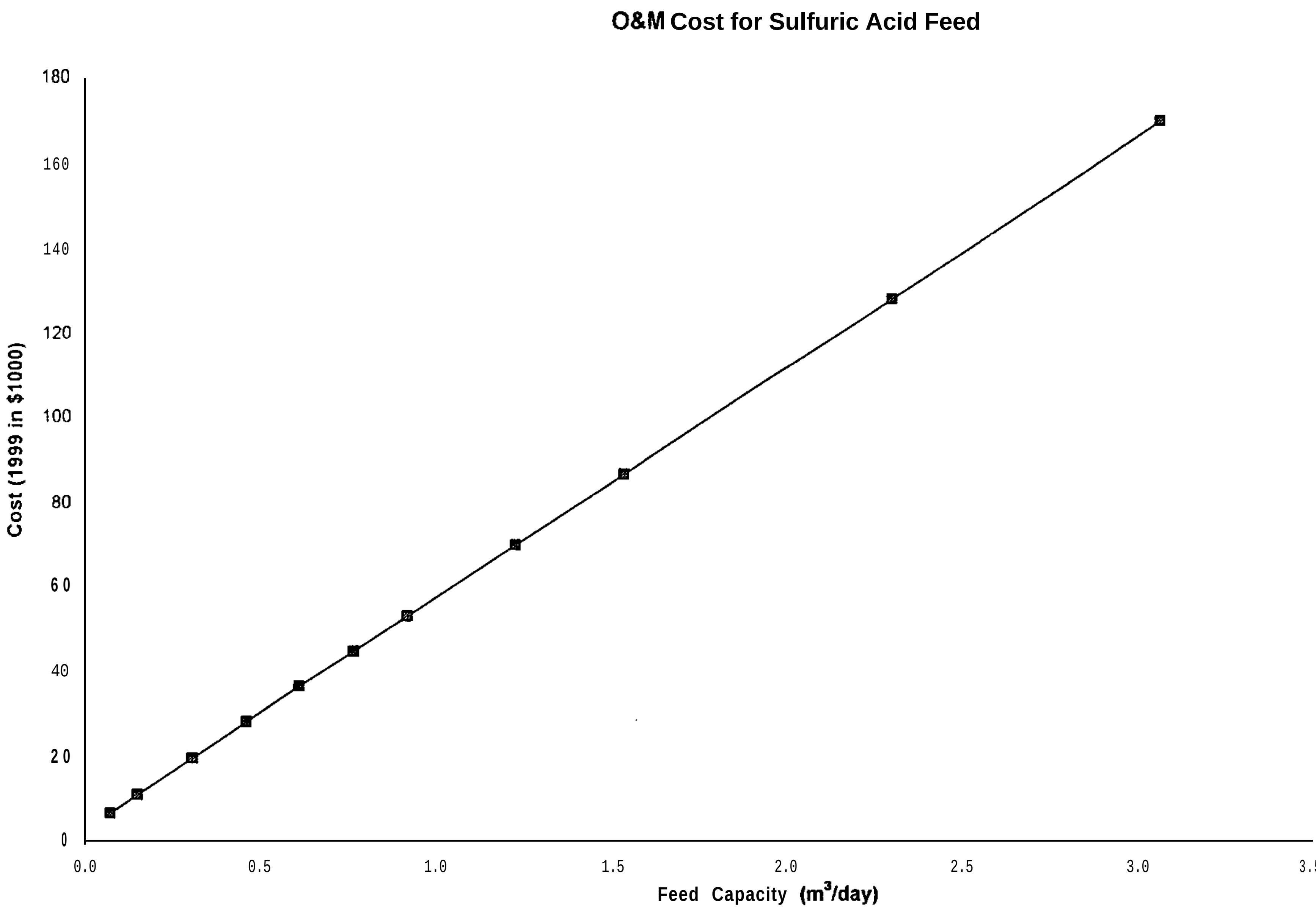
1978 Capital Cost:	Percentages	13,052	1978 index value basis	Current index value 1999
A) Excavation and Site Wor	0	0	247	548.67
B) Manufactured Equipment	0.6	16,017	72.9	149.1
C) Concrete	0	0	71.6	150.2
D) Steel	0	0	75	106.6
E) Labor	0.16	4,639	247	548.67
F) Piping and Valves	0.07	2,138	70.2	164.3
G) Electrical Equip. and Inst	0.1	2,177	72.3	120.6
H) Housing	0.07	1,814	254.8	505.81
1999 Capital Cost:	1 .OO	$26,784		

1978 O&M Cost:			1,445		
I) Energy	$/kW*h	0.05	169	0.03	0.07
J) Maintenance	Material	0.04	106	71.6	131.3
K) Labor	$/hour	0.91	3,945	10	30
Chemical Cost $/yr:			40,886		
1999 0 & M Cost:		1.00	$45,105		

Sulfuric Acid feed
Formula from Qasim. et al, Aug. 1992, AWWA
General Form: A*X^B + C

	Capital Cost		O&M Cost A*e^(B*X) +C
A =	6010.6	A =	-42397.4
B =	0.7934	B =	-0.00682
c=	8180	c=	43670


Construction Cost for Sulfuric Acid Feed
Cost (1999 in $1000)
50
45
40
35
30
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Feed Capacity (m3/day)


O&M Cost for Sulfuric Acid Feed
180
160
140
120
100
80
60
40
20
0
Cost (1999 in $1000)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Feed Capacity (m3/day)

Chlorine disinfection Cost Estimation Worksheet

Input	mg/L	mMoles/L
Chromium (Cr 2+):	0.00	0.00E+00
Nickel (Ni 2+):	0.00	0.00E+00
Iron (Fe 2+):	0.00	0.00E+00
Manganese (Mn 2+):	0.03	5.10E-07
Total:		5.10E-07
Nitrite (NO2 -)	1.10	7.86E-05
Desired Residual (mg/L):	3.00	4.23E-02
mg Cl2 needed/L	3.01	4.23E-02
Volume to be treated (L/sec):	292.05	
Cl_2 needed kg/day:	75.84	Applicable Range: 4 - 4,500
Basis kg/day:	75.84	
Cl2 Cost	250	$/short ton, tanks

1978 Capital Cost:	Percentages	29,517.83	1978 index value basis	Current index value 1999
A) Excavation and Site Work	0	0.00	247	548.67
B) Manufactured Equipment	0.47	28,374.77	72.9	149.1
C) Concrete	0	0.00	71.6	150.2
D) Steel	0	0.00	75	106.6
E) Labor	0.06	3,934.14	247	548.67
F) Piping and Valves	0.04	2,763.41	70.2	164.3
G) *Electrical Equip. and Instmnt.*	*0.05*	*2,461.86*	*72.3*	*120.6*
H) Housing	0.38	22,266.71	254.8	505.81
1999 Capital Cost:	1.00	59,800.88		
1978 O&M Cost:		8,242.45		
I) Energy $/kW*h	0.18	4,945.47	0.03	0.1
J) Maintenance Material	0.18	2,615.02	71.6	126.2
K) Labor $/hour	0.64	10,550.34	10	20
Chemical Cost		7,315.05		
1999 Operation and Maintenance:	1.00	25,425.88		

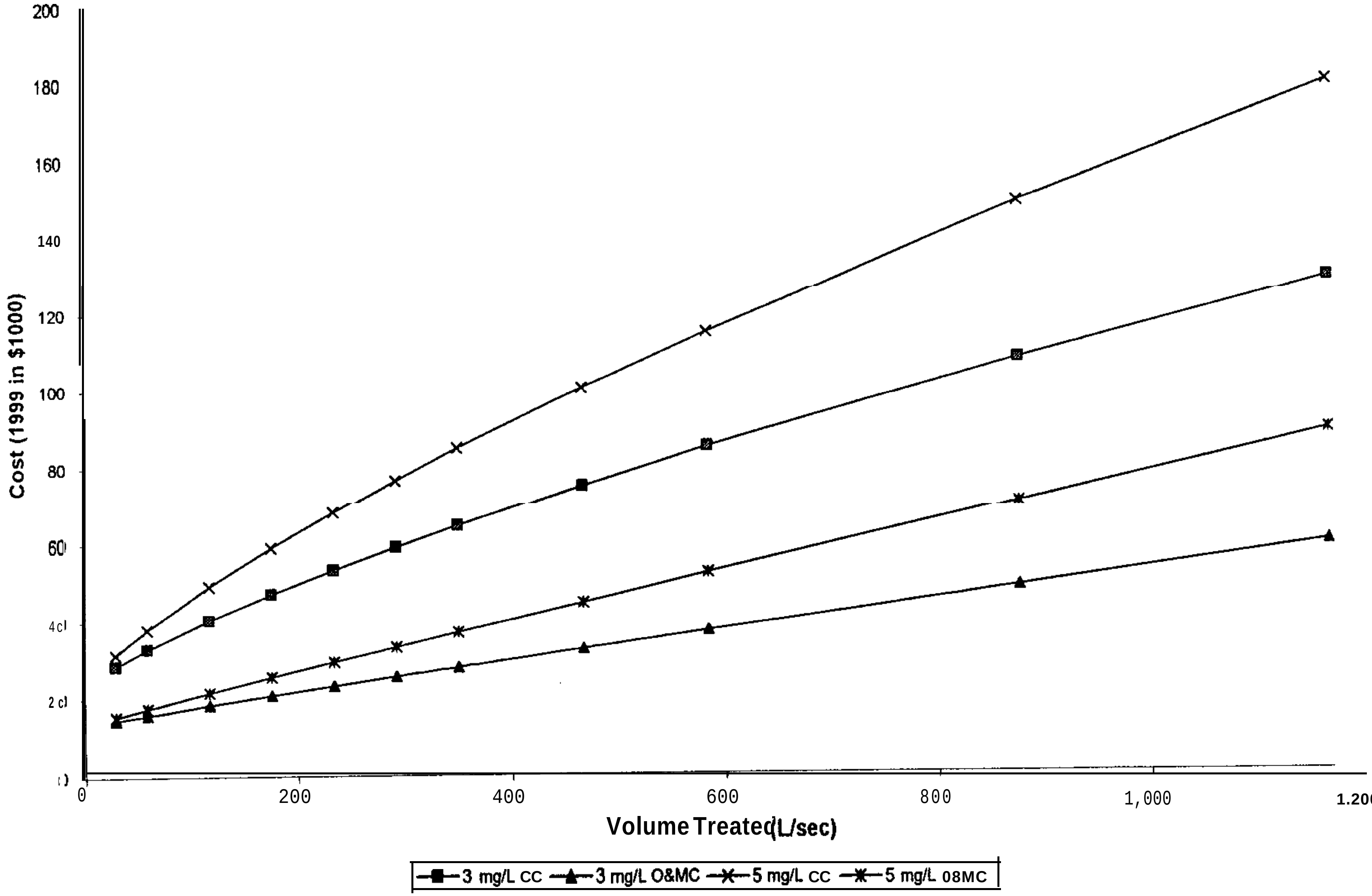
Chlorine demand is usually found by experimentation, but in this case we will use the concentration of reduced transition metal ions and nitrite to calculate a chlorine demand. The molar ratio is 1:2 Cl2 to +2 metal cation and 1:1 for Cl2 to NO2-.

Chlorine storage and feed with Cylinder storage
Formula from Qasim, et al, Aug. 1992, AWWA

General Form: A*X^B + C

Capital Cost		O&M Cost	
A=	680.75	A=	47.6
B=	0.763	B=	0.89
C=	11010	C=	6000

Construction and O&M Cost for Chlorine Disinfection at Different Dosage Rates



Chloramine disinfection Cost Estimation Spreadsheet

Data from water analysis	mg/L	mMoles/L	
Chromium (Cr):	0.00	0.00E+00	
Copper (Cu):	0.00	0.00E+00	
Iron (Fe):	0.00	0.00E+00	
Manganese (Mn):	0.03	5.09E-04	
Nitrite (NO2- as N):	20.00	1.43E+00	
Desired NH2Cl Residual (mg/L):	3.00	5.84E-02	
Current Cl2 Concentration:	0.00	0.00E+00	
Cl2 needed/L:	105.59	1.49E+00	
Ammonia Needed/L:	0.99	5.84E-02	
Volume to be treated (L/sec):		292	
Calculated Cl2 Dose kg/day:		2664.40	Applicable Range: 4 - 4,500
Alternative Cl2 Dose kg/day:		0.00	
Basis:		2664.40	
Cl2 Cost $/ton:	250		
Calculated Aqua Ammonia kg/day:		25.04	Applicable Range: 110 - 2300:
Alternative Aqua Ammonia kg/day:		0.00	
Basis:		25.04	
NH4OH Cost $/ton:	285		

Total Capital Cost 1999 $:	622,490
Total O&M Cost 1999 $:	438,577

Chlorine Feed

	Percentages		1978 index value basis	Current index value 1999
1978 Capital Cost:		290,727.99		
A) Excavation and Site Work	0	0.00	247	548.67
B) Manufactured Equipment	0.47	279,469.76	72.9	149.1
C) Concrete	0	0.00	71.6	150.2
D) Steel	0	0.00	75	106.6
E) Labor	0.06	38,748.27	247	548.67
F) Piping and Valves	0.04	27,217.44	70.2	164.3
G) Electrical Equip. and Instmnt.	0.05	24,247.44	72.3	120.6
H) Housing	0.38	219,310.00	254.8	505.81
1999 Capital Cost:	1.00	588,993		
1978 O&M Cost:		59,258.74		
I) Energy $/kW*h	0.18	24,888.67	0.03	0.07
J) Maintenance Material	0.18	19,560.35	71.6	131.3
K) Labor $/hour	0.64	113,776.78	10	30
Chlorine Cost:		256,987.58		
1999 O&M Cost:	1.00	415,213		

Ammonia Feed

	Percentages		1978 index value basis	Current index value 1999
1978 Capital Cost:		16,276.26		
A) Excavation and Site Work	0	0.00	247	548.67
B) Manufactured Equipment	0.56	18,642.01	72.9	149.1
C) Concrete	0	0.00	71.6	150.2
D) Steel	0	0.00	75	106.6
E) Labor	0.15	5,423.26	247	548.67
F) Piping and Valves	0.1	3,809.39	70.2	164.3
G) Electrical Equip. and Instmnt	0.1	2,714.96	72.3	120.6
H) Housing	0.09	2,907.94	254.8	505.81
1999 Capital Cost:	1.00	33,498		
1978 O&M Cost		8,265.80		
I) Energy $/kW*h	0.06	1,157.21	0.03	0.07
J) Maintenance Material	0.4	6,063.13	71.6	131.3
K) Labor $/hour	0.54	13,390.60	10	30
Ammonia Cost:		2,752.95		
1999 O&M Cost:	1.00	23,364		

The addition of Chlorine and Ammonia to water produces chloramines. Chloramines are the "combined chlorine residual." They are more persistent in the water lines than "free chlorine," which is HOCl, and OCl-.
If there is sufficient ammonia in the water already, it doesn't need to be added, of course. If not, chlorine and aqueous ammonia should be added at the molar ratio of 1:1, Cl2:NH3(aq). We will use the moles of divalent metal ions and NO2- to calculate a chlorine demand. The molar ratio is 1:2 Cl2 to divalent cations, and 1:1 for Cl2:NO2-. The residual for Chloramines must be at least 2 mg/L which translates to approximately .03 moles per liter at pH 7.

Chlorine storage and feed with Cylinder storage

Formula from Qasim, et al, Aug. 1992, AWWA
General Form: A*X^B + C

Capital Cost
A= 680.75
B= 0.763
C= [illegible]

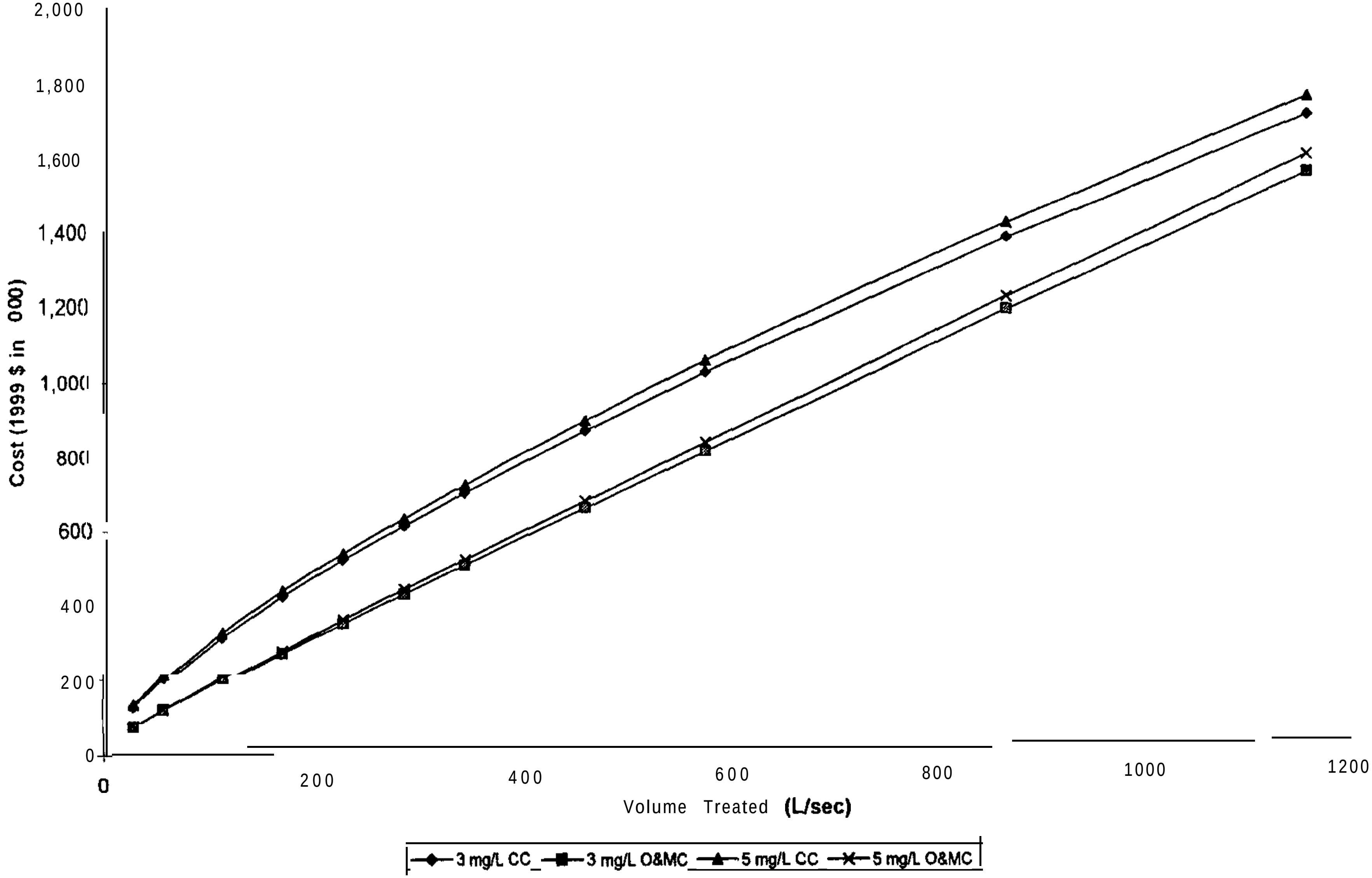
O&M Cost
A= 47.6
B= 0.89
C= 6000

Anhydrous Ammonia Feed,
same place and form.
X=kg/day ammonia feed capacity

Capital Cost: A*X^B*e^(C*X)
A= 3849.2
B= 0.448
C= -0.000035

O&M Cost: A*e^(B*X) +C
A= -28063
B= -2.41E-04
C= 36160

Construction and O&M Cost for Chloramine Disinfection at Different Dosage Rates



OZONE DISINFECTION

Desired Flow Rate:	292.05 L/s		
Flow rate (L/min):	17523 L/min	4630 gpm	
Enter ozone level required (mg/L):	1 mg/L		
(Typically 1-5 mg/L)			
Total ozone needed:	25 kg/day	11.5 lbs/day	
Enter contact time :	2 min		
Contact chamber size:	35.0 m^3	1237.7 ft^3	
Power (~26.5kWh per kg ozone):	304 kWh		

TOTAL CONSTRUCTION COSTS: $364,494

TOTAL OPERATING COSTS: $34,016

Ozone Generator:

Ozone Requirements: 25.23 kg/day

1978 Capital Cost:	Percentages	$163,624	1978 index value basis	Current index value 1999
A) Excavation and Site Work	0.00	0	247	548.67
B) Manufactured Equipment	0.81	271,070	72.9	149.1
C) Concrete	0.00	0	71.6	150.2
D) Steel	0.00	0	75	106.6
E) Labor	0.16	58,154	247	548.67
F) Piping and Valves	0.00	0	70.2	164.3
G) Electrical Equip. and Instmnt.	0.00	0	72.3	120.6
H) Housing	0.03	9,744	254.8	505.81
1999 Capital Cost:	1.00	$338,968		

Contact Chamber:

Applicable Range: 13-2600 m^2

1978 Capita	Percentages	$13,091
A) Excavatio	0.06	1,745
B) Manufact	0.00	0
C) Concrete	0.19	5,218
D) Steel	0.31	5,768
E) Labor	0.44	12,795
F) Piping an	0.00	0
G) Electrica	0.00	0
H) Housing	0.00	0
1999 Capita	1.00	$25,526

1978 O&M Cost:		$14,423		
I) Energy $/kW*h	0.77	25,914	0.03	0.07
J) Maintenance Material	0.11	2,909	71.6	131.3
K) Labor $/hour	0.12	5,192	10	30
1999 O & M Cost:	1.00	$34,016		

Ozone Generation Costs from Qasim, et al, Aug. 1992, AWWA

Construction Costs:

General Form: A *X ^B*e^(C*X)

A=	18631.2
B=	0.674
C=	-0.000121

O & M Costs:

General Form: A*X^B+C

A=	392.4
B=	0.919
	6800

Ozone Contact Chamber Costs from Qasim, et al, Aug. 1992, AWWA

Construction Costs:

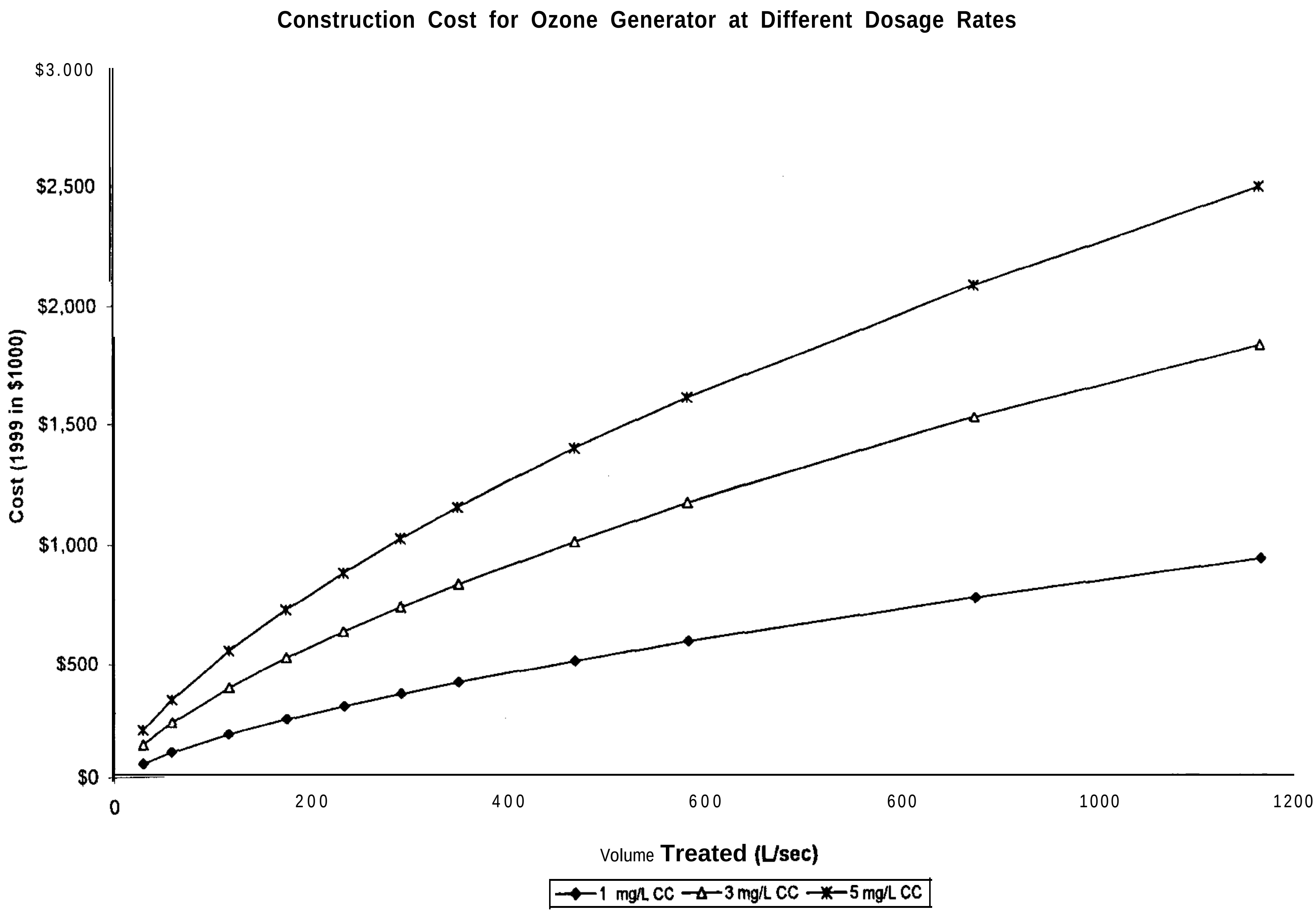
General Form: A *X ^B+C

A=

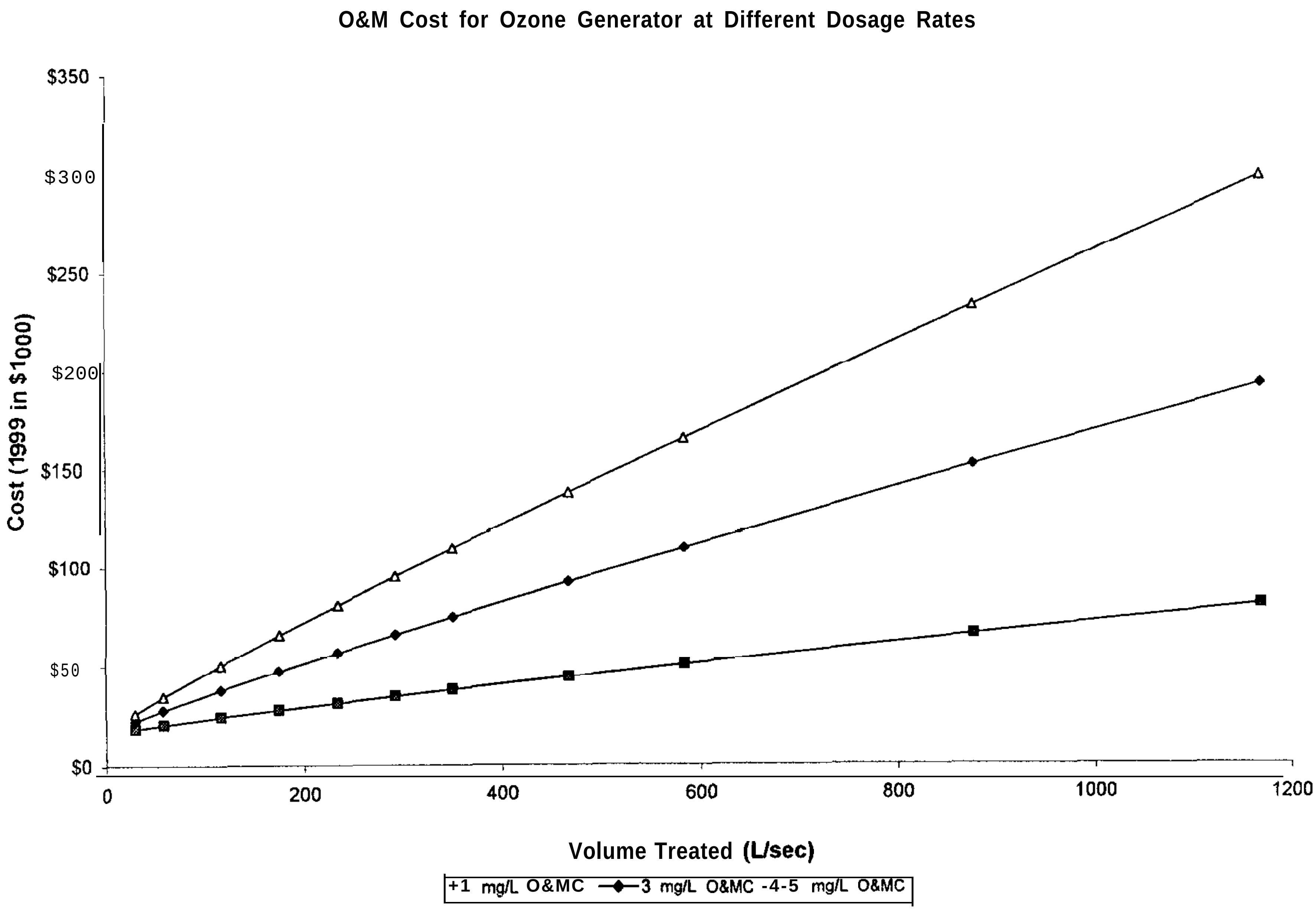
B=

C=

O & M Costs: NONE



Construction Cost for Ozone Generator at Different Dosage Rates
$3.000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost (1999 in $1000)
0
200
400
600
600
1000
1200
Volume Treated (L/sec)
1 mg/L CC
3 mg/L CC
5 mg/L CC


O&M Cost for Ozone Generator at Different Dosage Rates
Cost (1999 in $1000)
$350
$300
$250
$200
$150
$100
$50
$0
0
200
400
600
800
1000
1200
Volume Treated (L/sec)
+1 mg/L O&MC —◆—3 mg/L O&MC -4-5 mg/L O&MC

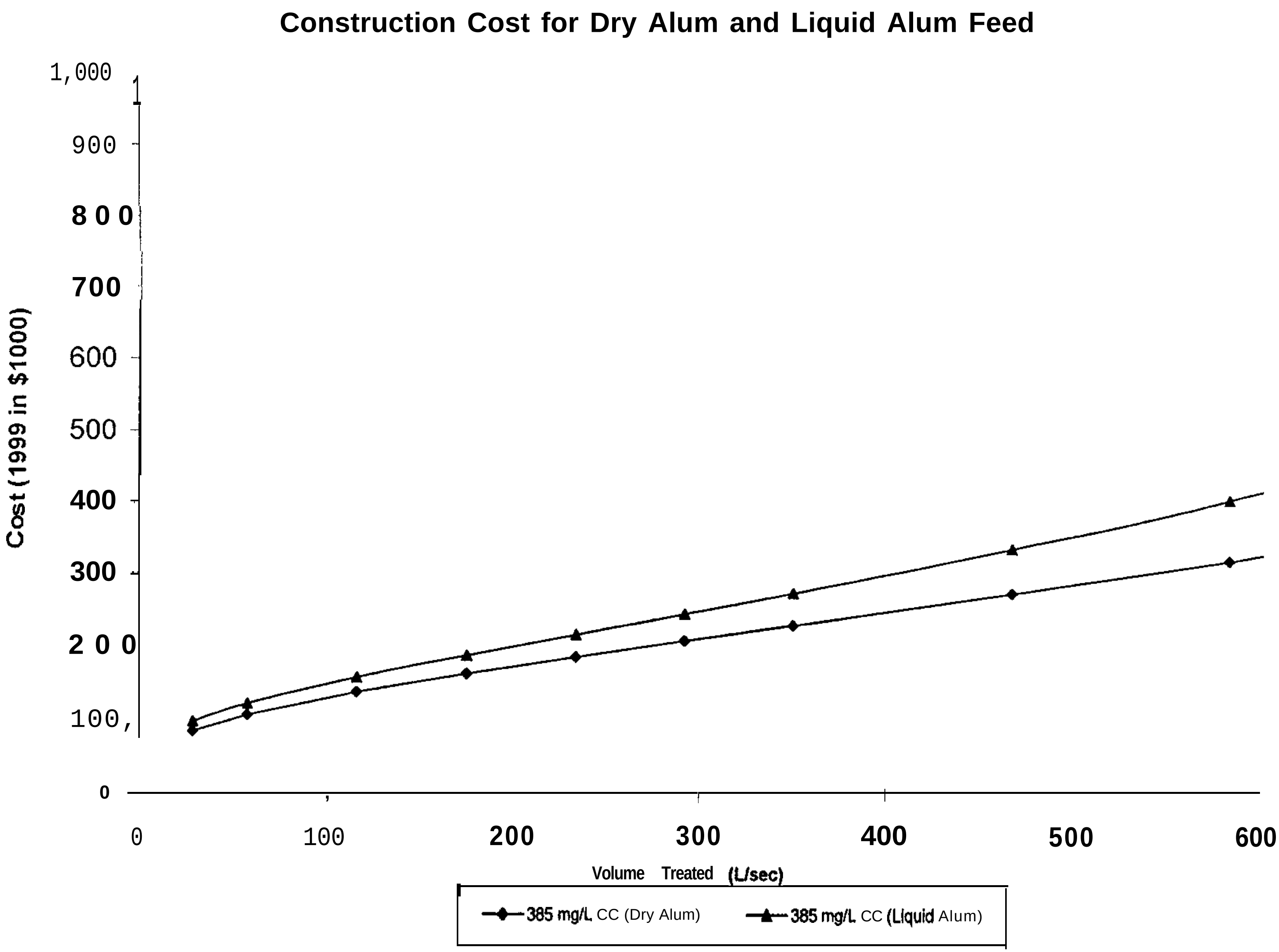
Dry Alum Feed Cost Calculations.

Volume Treated L/Sec:	292			
Volume Treated (m3/Hour):	1051			
Alternative dosage rate mg/L	0	0 kg/hr		
	mg/L	mmoles/L		
Bicarbonate Alkalinity:	212	3.5		
Alum Feed Dry mg/L:	385			
Calculated Alum Feed Dry kg/hour:	405	0.576 Applicable Range 4 - 2,300 kg/hr		
Basis Feed Rate	405			
Alum Cost $/100 lbs.:	30			

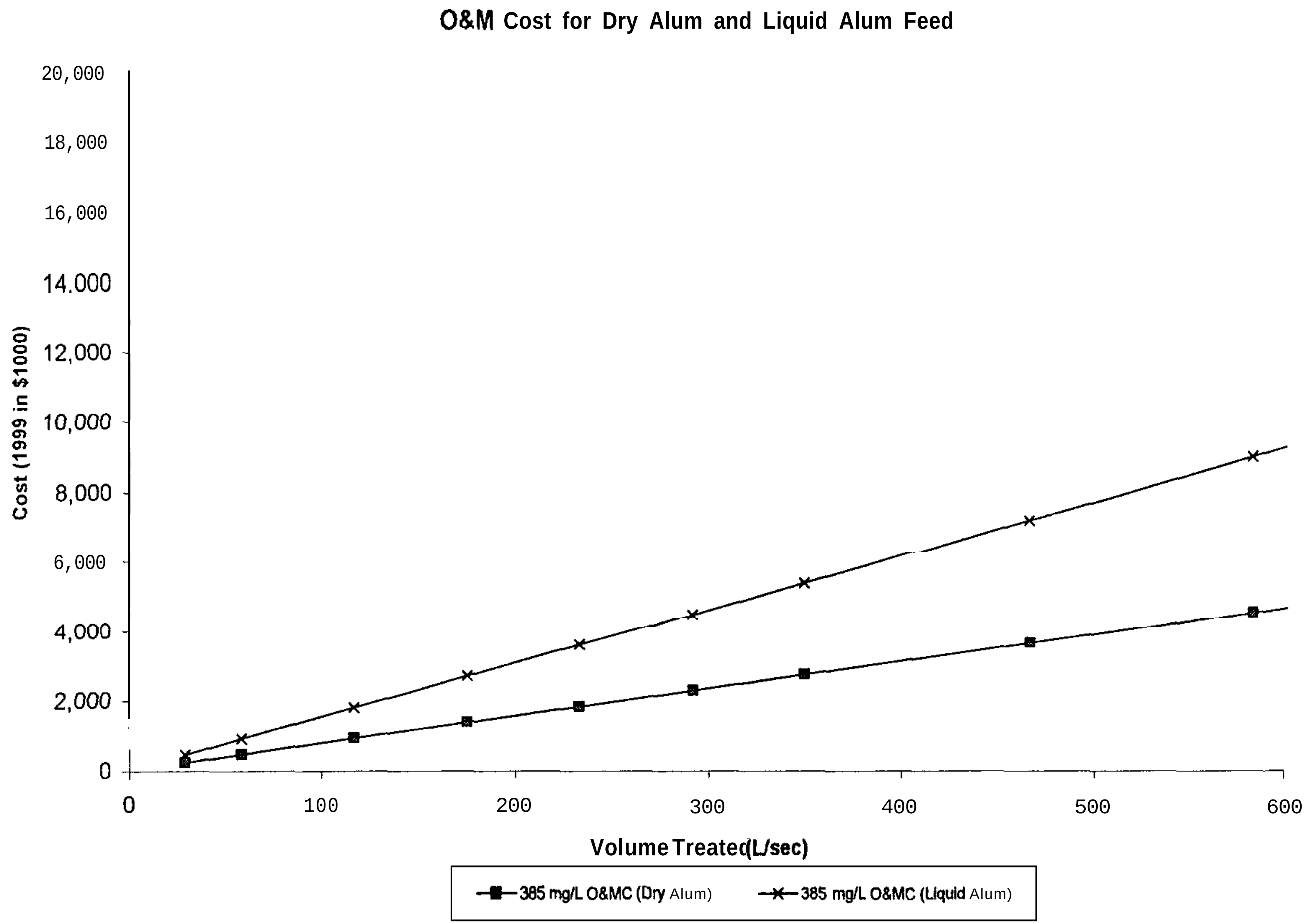
	Percentages		1976 index value basis	Current index value 1999
1976 Capital Cost:		$104,062		
A) Excavation and Siie Work	0	$0	247	546.671
B) Manufactured Equipment	0.41	$87,262	72.9	149.1
C) concrete	0	$0	71.6	150.2
D) Steel	0	$0	75	106.6
E) Labor	0.03	$6,935	247	546.67
F) Piping and Valves	0.04	99.742	70.2	164.3
G) Electrical Equip. and Instmnt.	0.05	$6,679	72.3	120.6
H) Housing	0.47	$97,091	254.6	505.61
1999 Capital cost:	1.00	$209.706		
,976 O&M Cost:		$12,744		
I) Energy $/kW*h	0.17	$5,055	0.03	0.07
J) Maintenance Material	0.03	$701	71.6	131.3
K) Labor $/hour	0.6	$30,585	10	30
Alum cost:		$2,249,797		
1999 Operation & Maintenance:	1.00	$2,286,138		

Alum Feed Liquid kg/hour:	810 -Applicable range 2 - 2500 kg/hour	
Need twice as much as dry.		
Alternative dose rate mg/L	0	0 kg/hr
Basis dose rate kglkhr:	810	

	Percentages		1970 index value basis	current index value 1999
1976 Capital cost:		$121,006		
A) Excavation and Site Work	0	$0	247	548.67
B) Manufactured Equipment	0.64	$156,393	72.9	149.1
C) concrete	0	$0	71.6	150.2
D) Steel	0	$0	75	106.6
E) Labor	0.12	$32.255	247	546.67
F) Piping and Valves	0.02	$5,664	70.2	164.3
G) Electrical Equip. and Instmnt.	0.07	$14.129	72.3	120.6
H) Housing	0.15	$36,032	254.8	505.61
1999 Capital cost:	1.00	$246.4741		
1978 O&M Cost:		$4,665		
I) Energy $/kW*h	0.59	56,422	0.03	0.07
J) Maintenance Material	0.04	$342	71.6	131.3
K) Labor $/hour	0.37	$5,176	10	30
Alum cost:		$4,499,594		
1999 Operation & Maintenance:	1.00	$4,511,535		



Construction Cost for Dry Alum and Liquid Alum Feed
Cost (1999 in $1000)
1,000
900
800
700
600
500
400
300
200
100,
0
0
100
200
300
400
500
600
Volume Treated (L/sec)
385 mg/L CC (Dry Alum)
385 mg/L CC (Liquid Alum)



O&M Cost for Dry Alum and Liquid Alum Feed
Cost (1999 in $1000)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
100
200
300
400
500
600
Volume Treated (L/sec)
385 mg/L O&MC (Dry Alum)
385 mg/L O&MC (Liquid Alum)

Coagulation With Ferric Sulfate

Volume Treated L/sec	292				
	mg/L	mmoles/L			
Bicarbonate Alkalinity:	212	3.47			
Alternative dose rate:	10		252.3	kg/day	
Calculated dose rate:	325	0.578			
Basis dose rate kg/day:	Applicable Range 6 - 3000 kg/day		252.3	kg/day	
Chemical Cost $/ton bulk:			117		

1978 Capital Cost:	Percentages	$68,413	1978 index value basis	Current index value 1999	
A) Excavation and Site Work	0	$0	247		548.67
B) Manufactured Equipment	0.63	$88,151	72.9		149.1
C) Concrete	0	$0	71.6		150.2
D) Steel	0	$0	75		106.6
E) Labor	0.02	$3,039	247		543.67
F) Piping an* Valves	0.05	$8,006	70.2		164.3
G) Electrical Equip. and Instmnt.	0.09	$10,270	72.3		120.6
H) Housing	0.21	$28,520	x4.8		505.81
1999 Capital Cost:	1.00	$137,986			
1978 O&M Cost:		$7,659			
I) Energy $/kW*h	0.09	$1,608	0.03		0.07
J) Maintenance Material	0.07	$983	71.6		131.3
K) Labor $/hour	0.84	$19,301	10		30
Ferric Sulfate Cost $/yr:		$11,390			
1999 Operation & Maintenance:	1.00	$33,283			

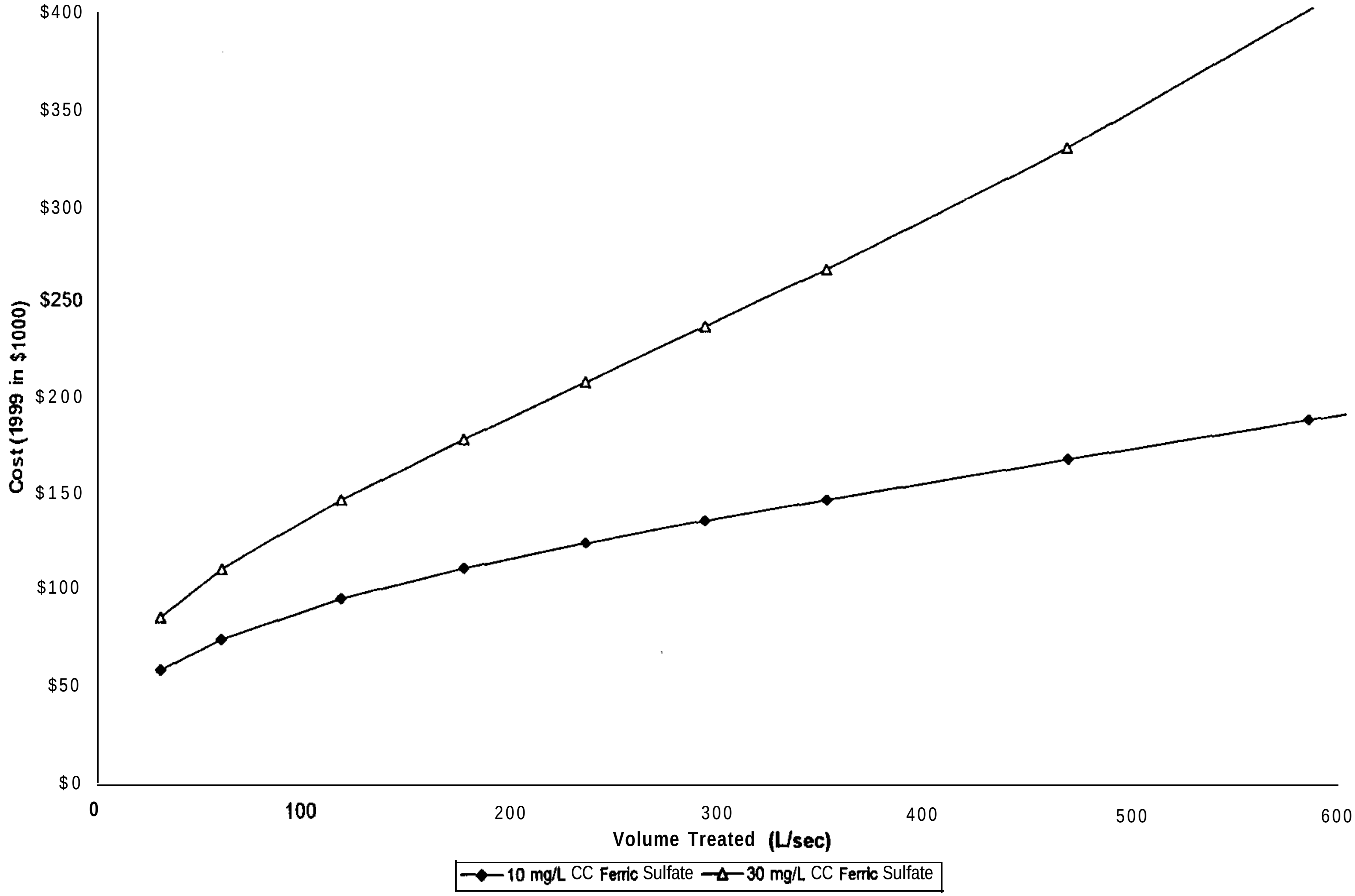
Ferric Sulfate Feed Capital cost
General Form: A*X^B*e^(C*X)

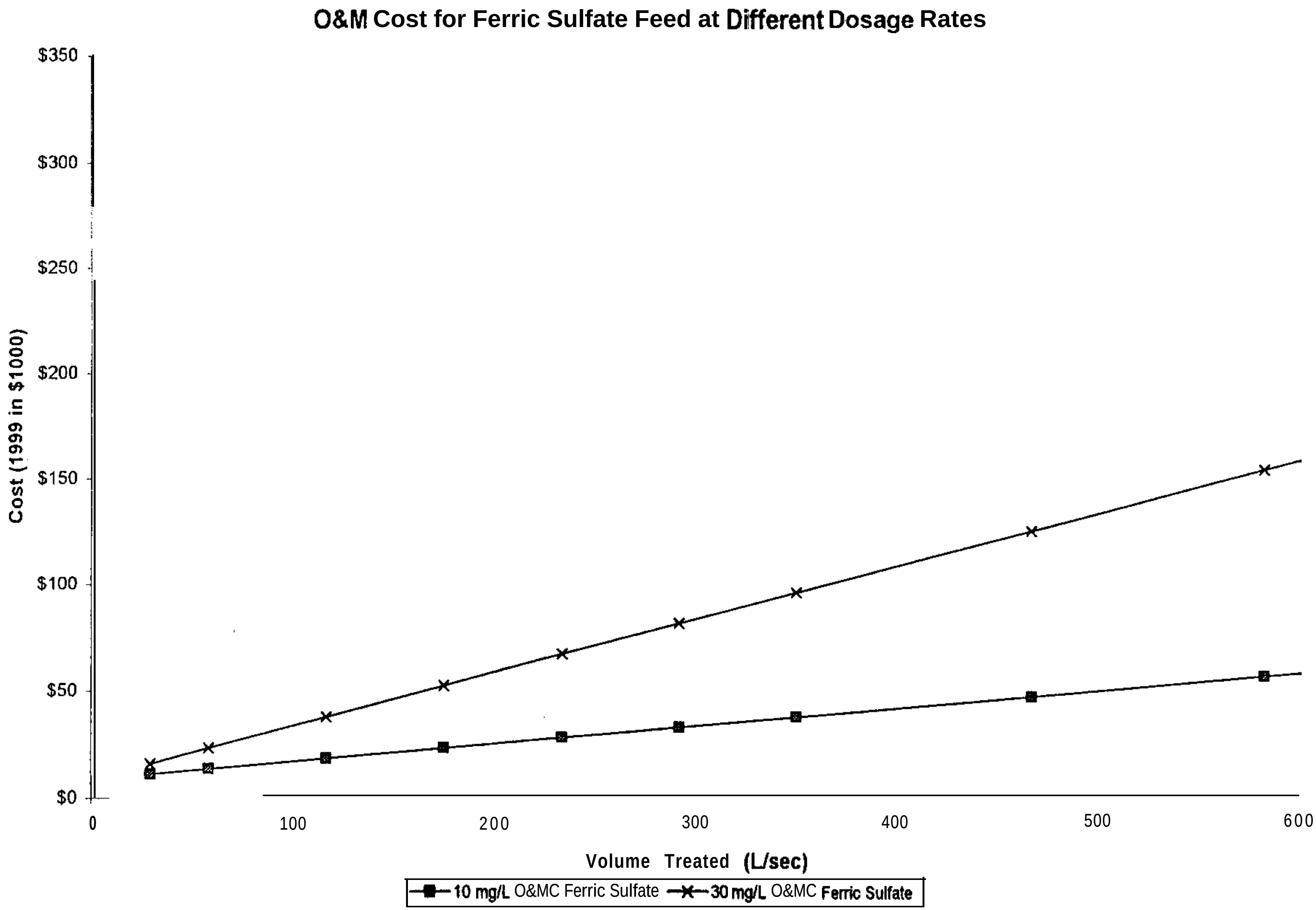
A =	10613
B =	0.319
C =	am393

O&M Cost
General Form: A*e^(B*X)+C

A =	1260926
B =	0.00001394
C =	-1257710

Construction Cost for Ferric Sulfate Feed at Different Dosage Rates




O&M Cost for Ferric Sulfate Feed at Different Dosage Rates
$350
$300
$250
$200
$150
$100
$50
$0
Cost (1999 in $1000)
0
100
200
300
400
500
600
Volume Treated (L/sec)
10 mg/L O&MC Ferric Sulfate
30 mg/L O&MC Ferric Sulfate

Polymer Addition for Antiscalant

Volume Treated L/Sec:	292	
Volume Treated (m3/day):	25233	
Alternative dosage rate (default = 0.5 mg/L):	0.3	
Polymer Feed kg/day:	7.6	Applicable range 0.5 - 100 kg/day
Hypersperse AF200 $1500 lb.:	990	

1978 Capital cost:	Percentages	$20,566	1978 index value basis	current index value 1999
A) Excavation and Site Work	0	$0	247	546.671
B) Manufactured Equipment	0.7	$29,447	72.9	149.1
C) concrete	0	$0	71.6	150.2
D) Steel	0	$0	75	106.6
E) Labor	0.04	$1,828	247	546.67
F) Piping and Valves	0.01	$461	70.2	164.3
G) Electrical Equip. and Instmnt.	0.06	$2,058	72.3	120.6
H) Housing	0.19	$7,758	254.6	505.61
1999 Capital Cost:	1.00	$41,572		
1978 O&M cost:		$3.046		
I) Energy $/kW*h	0.24	$1,707	0.03	0.07
J) Maintenance Material	0.1	$559	71.6	131.3
K) Labor $/hour	0.66	$6.035	10	30
Polymer Cost		$11,567		
1999 Operation & Maintenance:	1.00	$19.869		

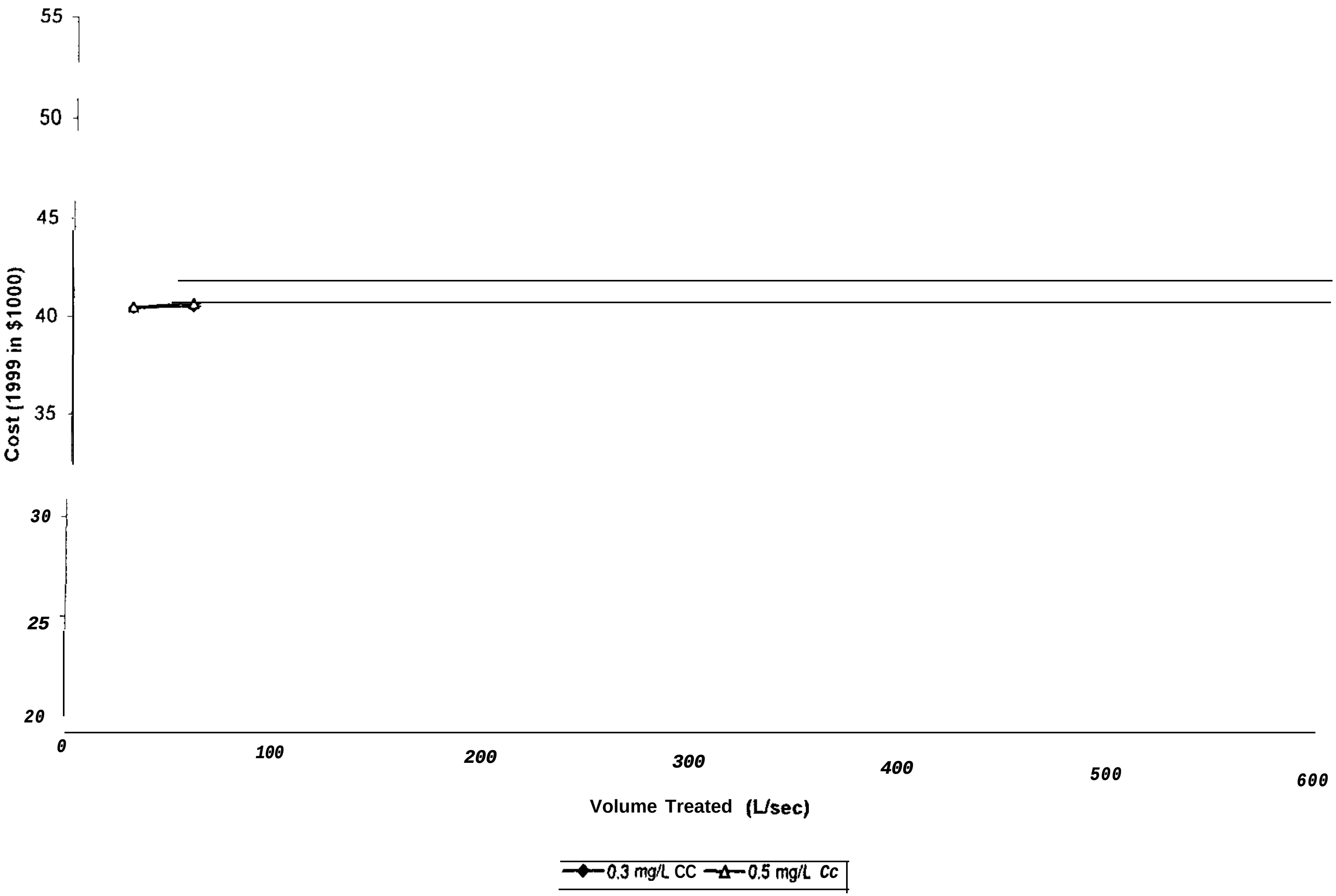
Polymer Feed Capital Cost
General Form: A*e^(B*X)+C

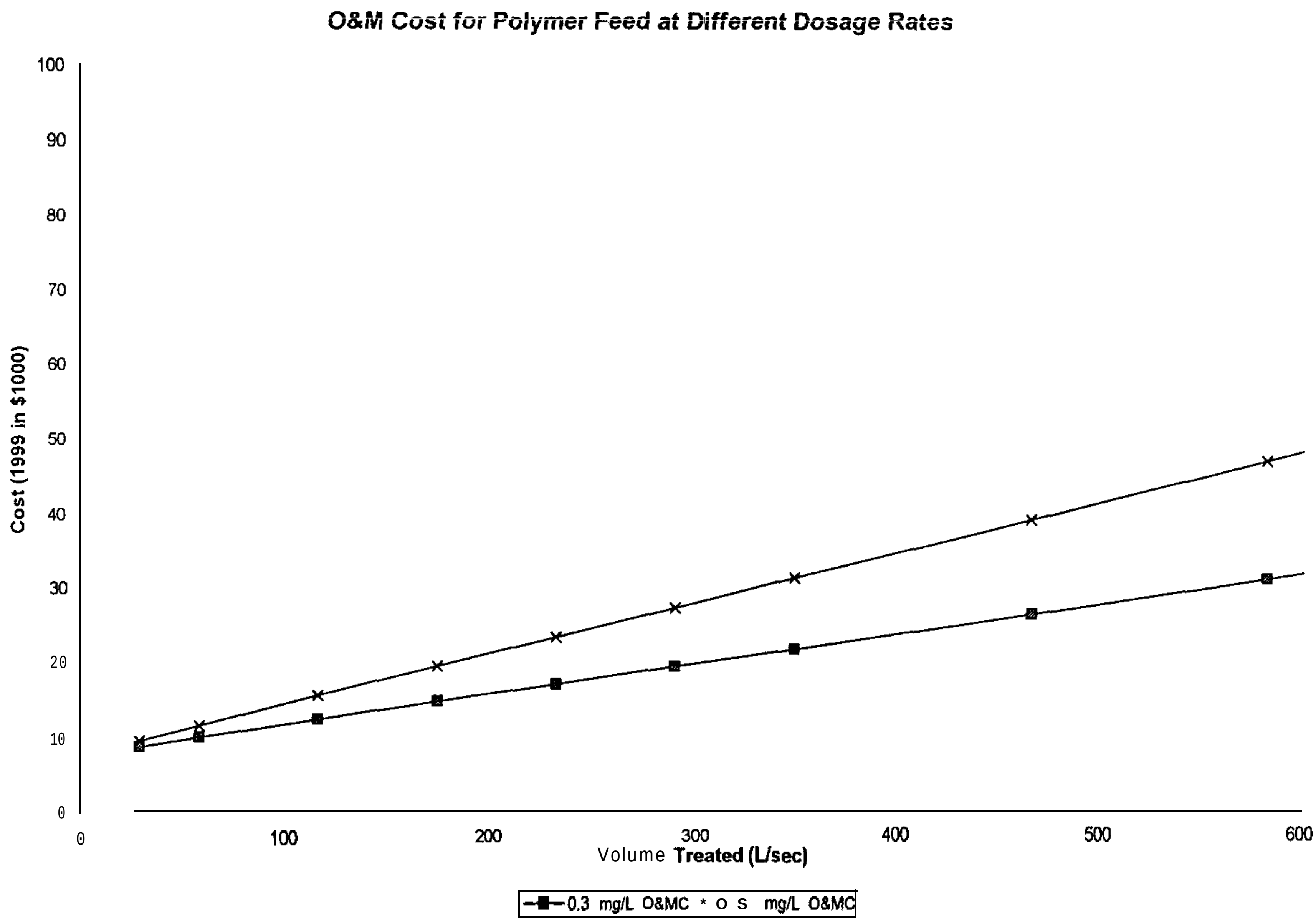
A =	11760.71
B =	0.00665
c =	6200

O&M cost
General Form: A*e^(B*X)

A =	3000.6
B=	0.00207

Construction Cost for Polymer Feed at Different Dosage Rates




O&M Cost for Polymer Feed at Different Dosage Rates
Cost (1999 in $1000)
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
Volume Treated (L/sec)
0.3 mg/L O&MC * O S mg/L O&MC

Potassium Permanganate Oxidation

Mn 2+ concentration:	0.03	mg/L
Fe 2+ concentration:	0.00	mg/L
Calculated KMn04 Dose:	-0.042	mg/L
Volume Treated L/Sec:	292.1	
Volume Treated (m3/day):	25,233	
Alternative dosage rate. mg/L:	1	
KMnO4 kg/day:	25.2	Applicable range 0.5 - 100 kg/day
KMnO4 $/lb (hopper trucks):	1.21	

1978 Capital Cost:	Percentages	$11,014	1978 indexvalue basis	current indexvalue 1999
A) Excavation and Site Work	0	$0	247	546.67
B) Manufactured Equipment	0.34	$7.659	72.9	149.1
C) concrete	0	$0	71.6	150.2
D) Steel	0	$0	75	106.6
E) Labor	0.05	$1,223	247	548.67
F) Piping and Valves	0.1	$2.576	70.2	164.3
G) Electrical Equip. and Instmnt.	0.32	$5,879	72.3	120.6
H) Housing	0.19	$4,154	254.8	505.81
1999 Capital Cost:	1.00	$21,493 J		
1978 O&M Cost:		$4,212		
I) Energy $/kW*h	0.05	$491	0.03	0.071
JK) Maintenance$/hour Material	0.03 0.92	$11.625 $232	71.6 10	131.3 30 I
KMnO4 Cost:		$23,563		
1999 Operation & Maintenance:	1 .00	$35.911		

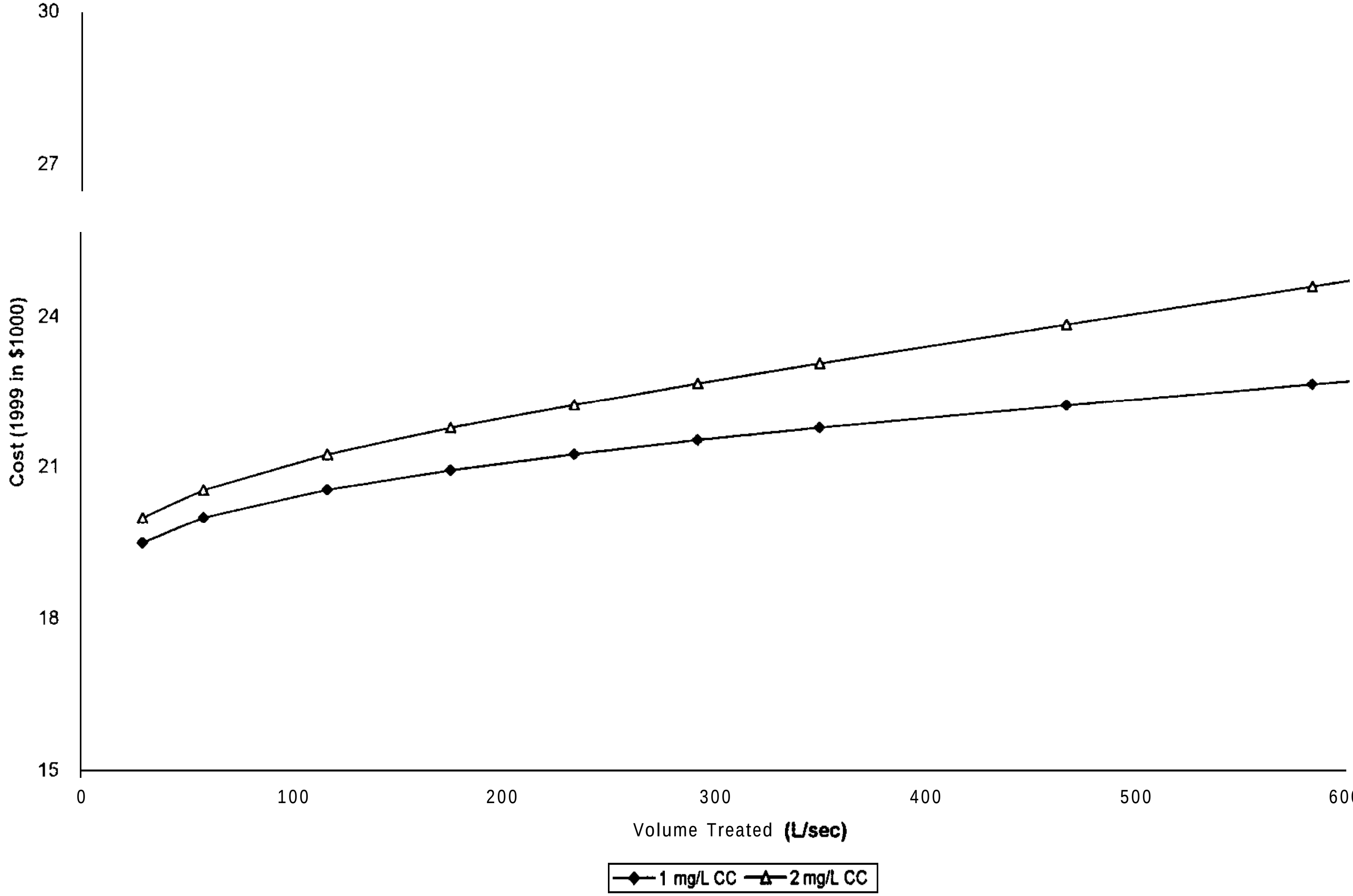
Permanganate Feed Capital Cost
General Form: A*X^B*e^(C*X)

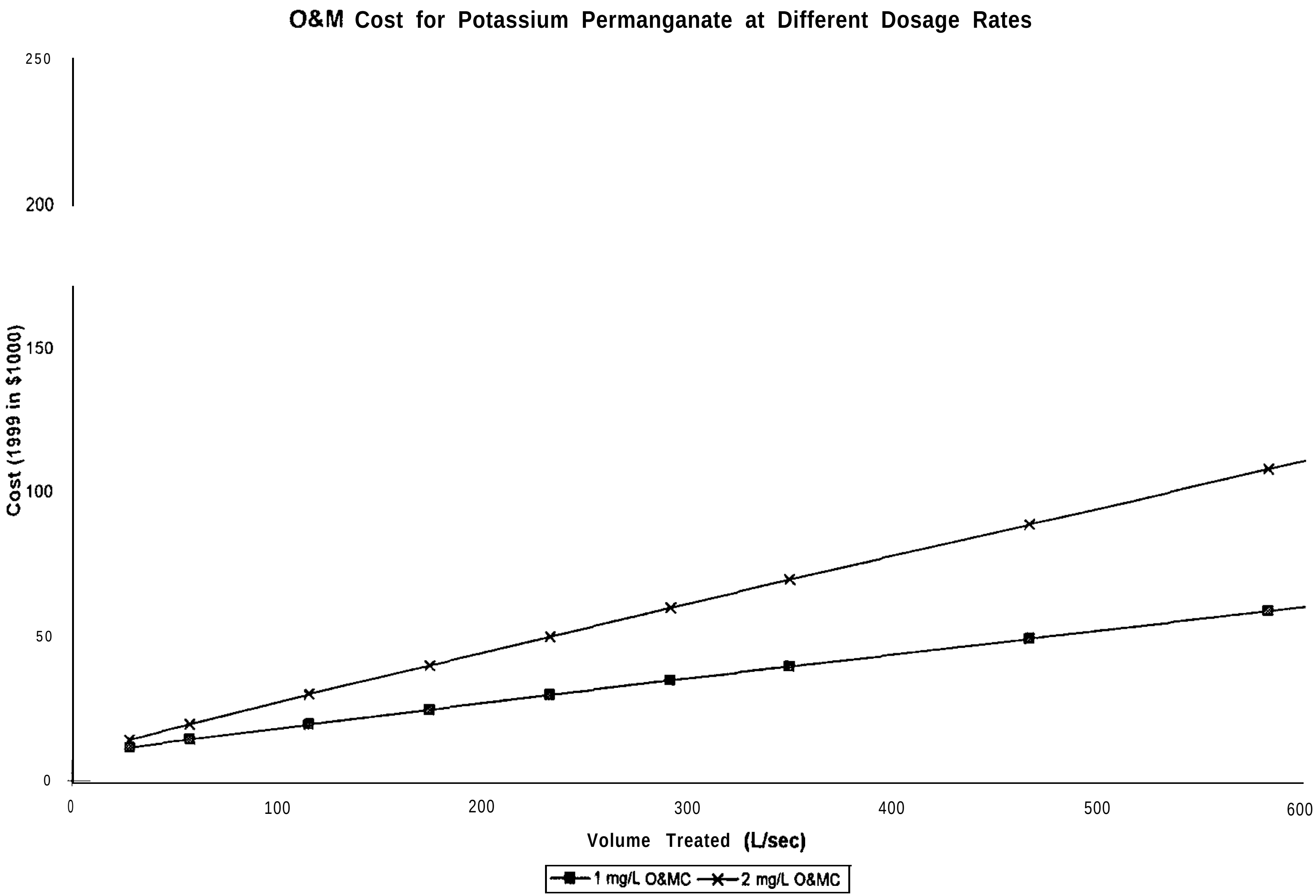
A =	9681.7
B =	0.0304
c =	0.00122

O&M Cost
General Form: A*e^(B*X)+C

A =	-2125.9
B=	-0.01689
c=	5600

Construction Cost for Potassium Permanganate at Different Dosage Rates




O&M Cost for Potassium Permanganate at Different Dosage Rates
Cost (1999 in $1000)
250
200
150
100
50
0
0
100
200
300
400
500
600
Volume Treated (L/sec)
1 mg/L O&MC
2 mg/L O&MC

Lime and Soda Softening

Volume Treated L/Sec:	292				
FROM WATER ANALYSIS			Lime	Soda Ash	
	mg/L	mmoles/L	Requirement	Requirement	
			0.9	0.58	purity
Ca (2+):	51.0	1.3		0.0	
Mg (2+):	7.5	0.3	68.5		
HCO3 (-):	211.5	3.5	22.8		
CO2 (2-):	0.0	0.0	0.0		
Excess:			30.0		
Total g/m3:			134.8	0.0	
m3/hr treated:	1051.4				
kg/hr Lime:	141.8		141.8	0.0	
Lime Cost $/ton:	45.0		Applicable Range 4-4500 kg/hr		
Soda Ash Cost $/ton:	146.0				
Alternative dosage rate Lime (kg/hr):	31.5		Basis Lime:	31.5	kg/hr
Alternative dosage rate Soda (kg/hr):	31.5		Basis Soda:	31.5	kg/hr

			1978	Current
	Percentages		index value	index value
1978 Capital Cost:		$90,969	basis	1999
A) Excavation and Site Work	0	$0	247	548.67
B) Manufactured Equipment	0.63	$117,215	72.9	149.1
C) Concrete	0	$0	71.6	150.2
D) Steel	0	$0	75	106.6
E) Labor	0.02	$4,041	247	548.67
F) Piping and Valves	0.03	$6,387	70.2	164.3
G) Electrical Equip. and Instmnt.	0.07	$10,622	72.3	120.6
H) Housing	0.25	$45,146	254.8	505.81
1999 Capital Cost:	1.00	$183,411		
1978 O&M Cost:		$12,612		
I) Energy $/kW*h	0.09	$2,649	0.03	0.07
J) Maintenance Material	0.06	$1,388	71.6	131.3
K) Labor $/hour	0.85	$32,160	10	30
Lime Cost:		$13,143		
1999 Operation & Maintenance:	1.00	$49,339		

Updated from	Lime & Soda Ash Feed Capital Cost		Operating Cost:	
EPA-600/2-79-162b, Aug. 1979	General Form = A + B(lnx)		General Form = Ax^B	
Estimating Water Treatment Costs	x = kg Lime/hr		x = kg Lime/hr	
Volume 2	A=	-24950.92	A=	866.28504
pp 61-64	B=	20424.674	B=	0.5143525

	Mg	Ca	HCO3+CO2	Ca(OH)2
Ratio	1	1	4	3
Limit	0.309			
eq	0.31	0.31	1.23	0.93
mg/L	7.5	12 3	75.3	68.5

Mg and Ca react with Alkalinity and Lime to precipitate CaCO3 and Mg(OH)2

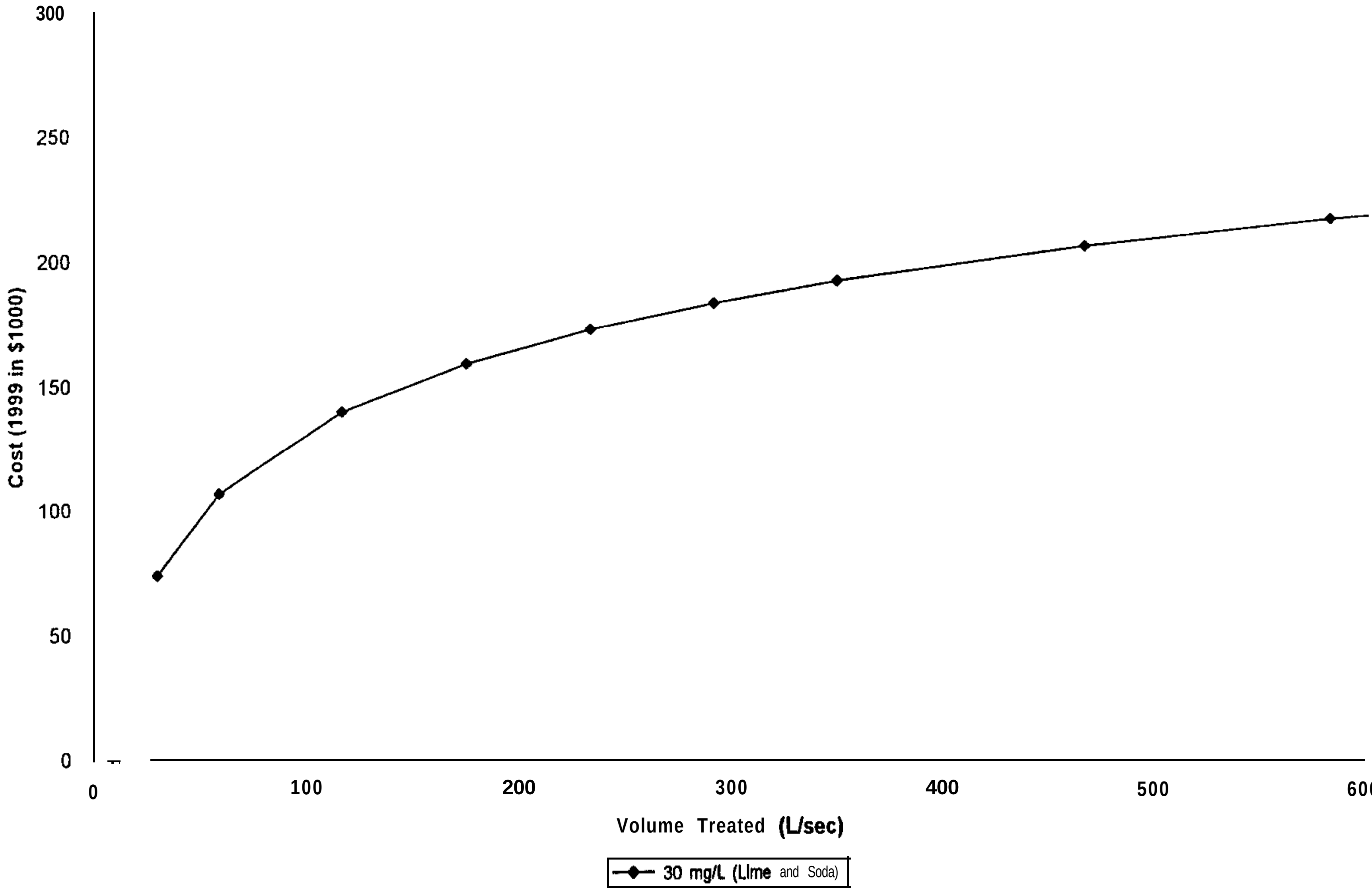
	Mg	Ca	HCO3+CO2	Ca(OH)2
Ratio	1	1	2	1
eq	0.00	0.97	6.32	0.31
mg/L	0.0	38.7	385.3	22.8

Remaining Mg or Ca react with remaining alkalinity

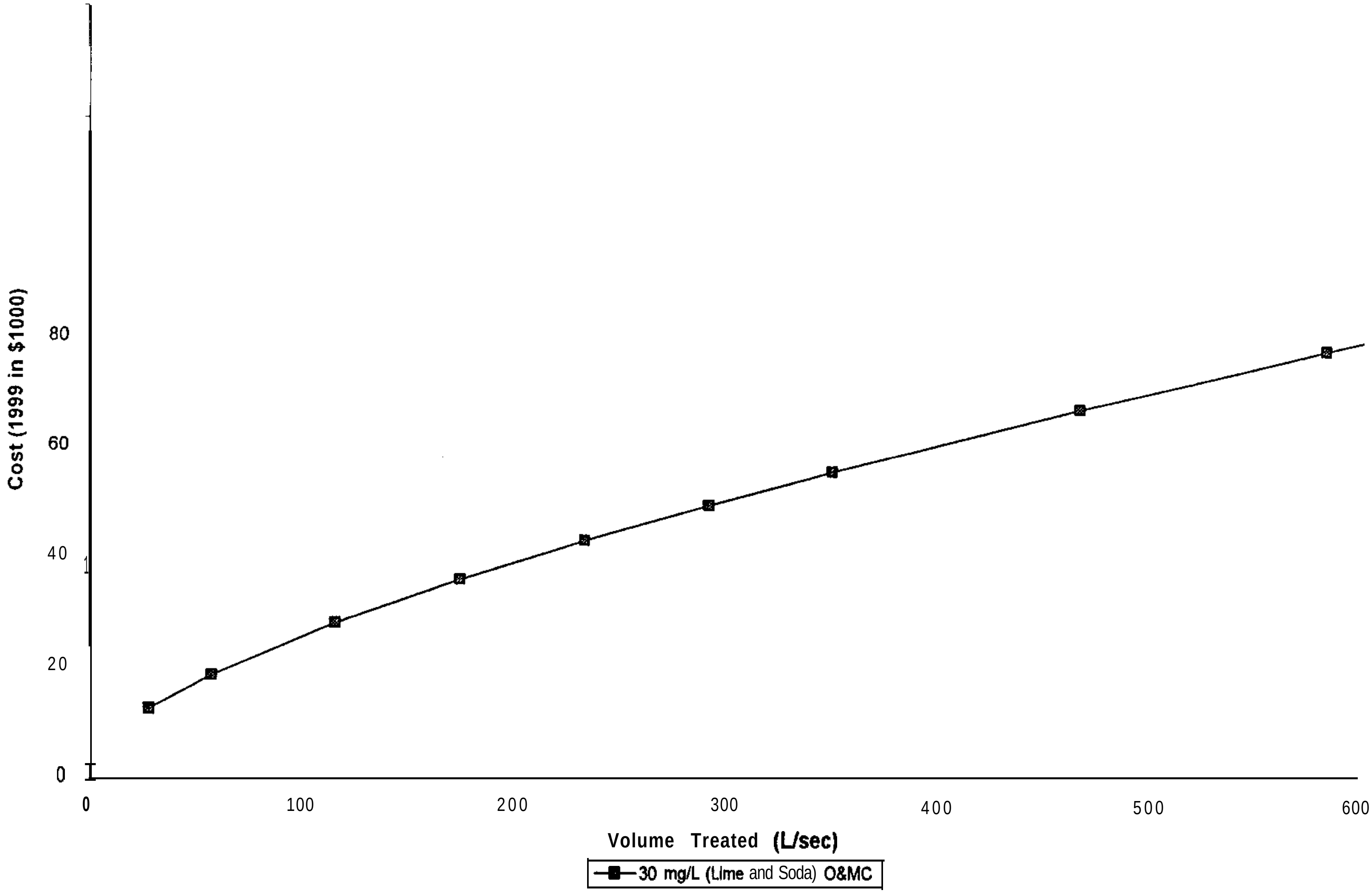
	Mg	Ca	Na2CO3	Ca(OH)2
Ratio	1	1	1*mg+1*Ca	1*Mg
eq	0.000	0.000	0.000	0.000
mg/L	0.0	0.0	0.0	0.0

If Ca and/or Mg are in excess of Alkalinity, then add soda ash

Construction Cost for Lime Softening at 30 mg/L Dosage



O&M Cost for Lime Softening at 30 mg/L Dosage



Upflow Solids Contact Clarifier

Flow Rate L/sec	292	4630 gpm
Retention Time (min.)	180	
Assumed Depth = 4.8 m	4.8	
Calculated Settling Area (m^2)	328.559	Basis: 328.55903
Alternative settling Area (m^2)	0	

	Percentages		1978 index value basis	Current index value 1999
Construction Cost 1978 $		229,695		
A) Excavation and Site Work	0.046	23,471	247	548.67
B) Manufactured Equipment	0.509	239,122	73.9	149.1
C) Concrete	0.081	39,030	71.6	150.2
D) Steel	0.11	35,912	75	106.6
E) Labor	0.247	126,027	247	548.67
F) Piping and Valves	0	0	70.2	164.3
G) Electrical Equip. and Instmnt.	0.007	2,682	72.3	120.6
H) Housing	0	0	254.8	505.81
1999 Capital Cost:		466,244		

	%	G=70	%	G=110	%	G=150		
1978 O&M Cost:		7,713		8,700		10,009		
I) Energy $/kW*h	0.23	4,139	0.38	7,714	0.5	11,677	0.03	0.07
J) Maintenance Material	0.17	2,405	0.14	2,233	0.11	2,019	71.6	131.3
K) Labor $/hour	0.6	13,084	0.48	12,527	0.39	11,710	10	30
1999 Operation & Maintenance Cost:		20,428		22,474		25,406		

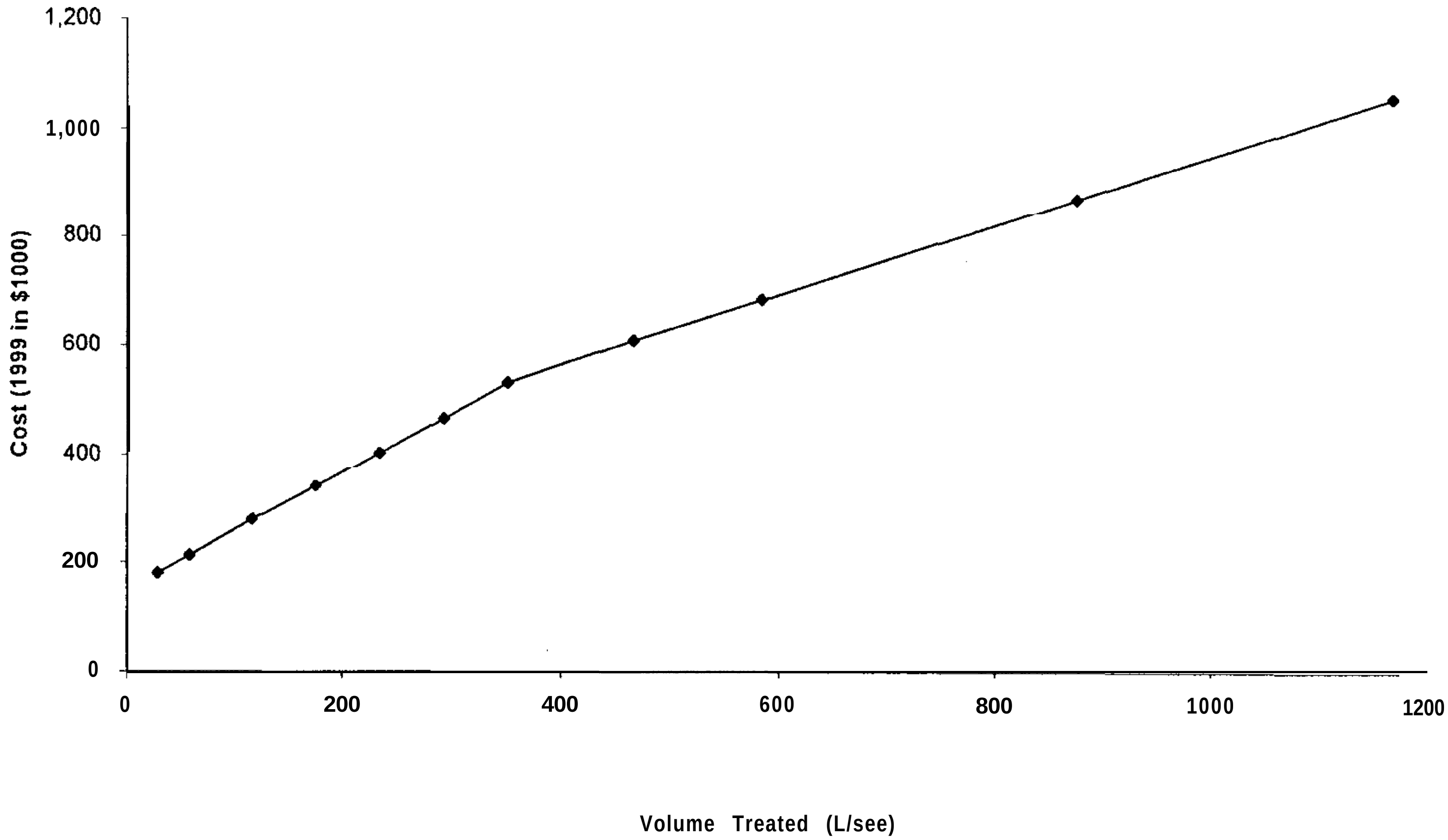
Construction Cost Equations (From EPA-600/2-79-162b)

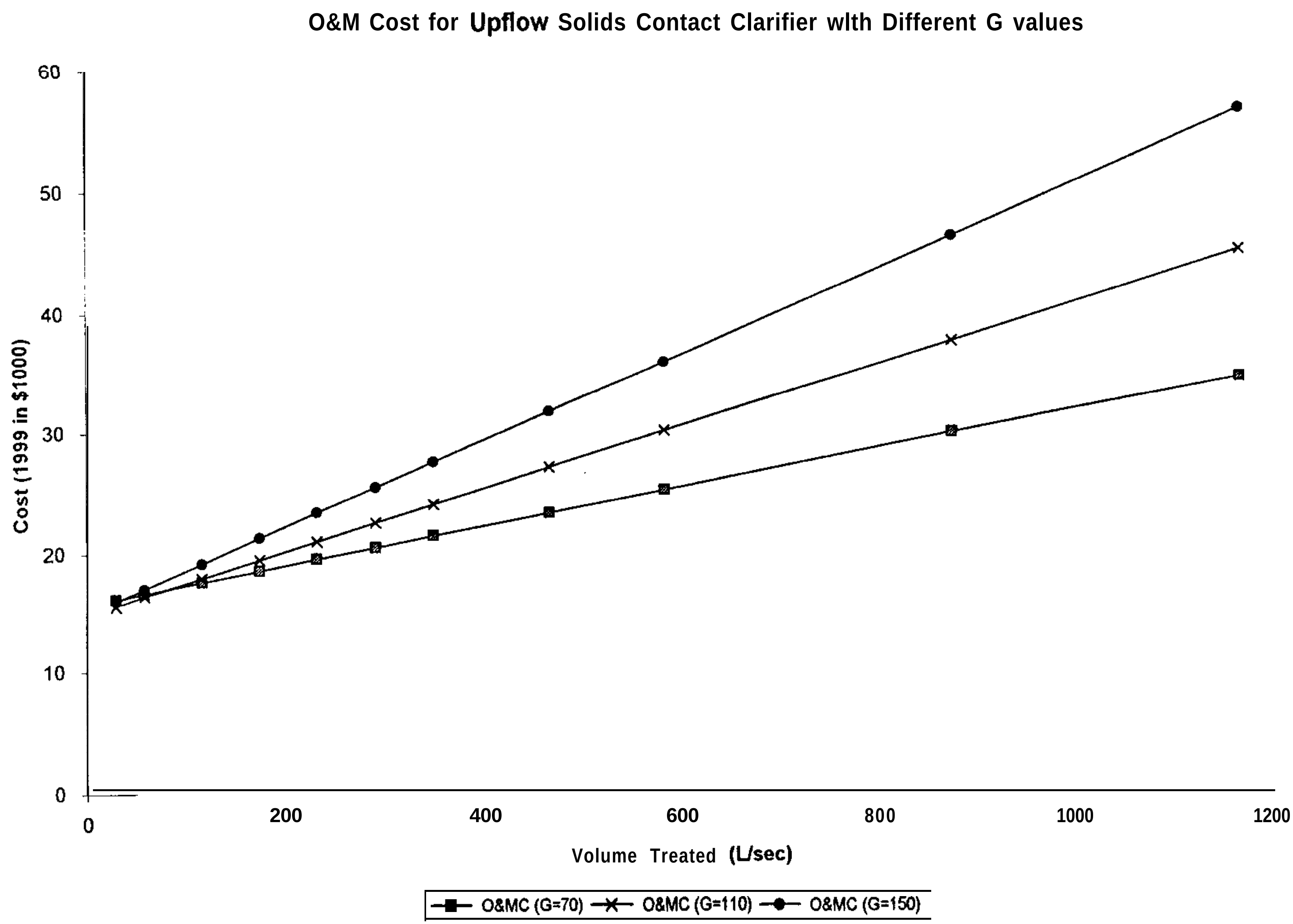
$ = a+b*x		a	b
	<400 m^2	62801.114	416.77163
	>400 m^2	132264.71	244.33215

Operation & Maintenance Cost (From EPA-600/2-79-162b)

$=a+b*x	a	b
G = 70	5967.9519	5.3118202
G = 110	5806.5744	8.80491
G = 150	5939.8245	12.384121

Construction Cost for Upflow Solids Contact Clarifier





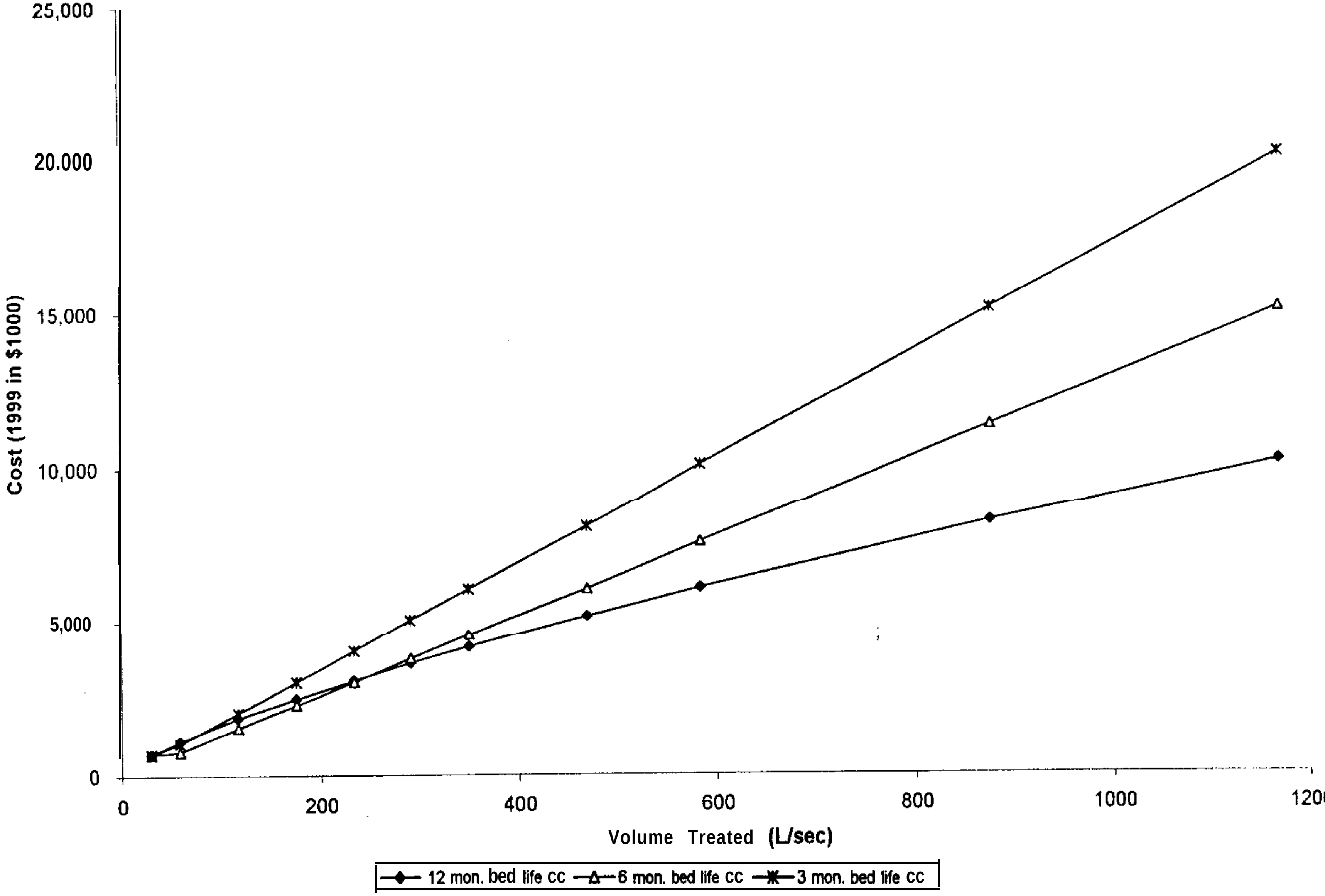
O&M Cost for Upflow Solids Contact Clarifier wlth Different G values
Cost (1999 in $1000)
60
50
40
30
20
10
0
200
400
600
800
1000
1200
Volume Treated (L/sec)
O&MC (G=70)
O&MC (G=110)
O&MC (G=150)

Granular Activated Carbon Filtration

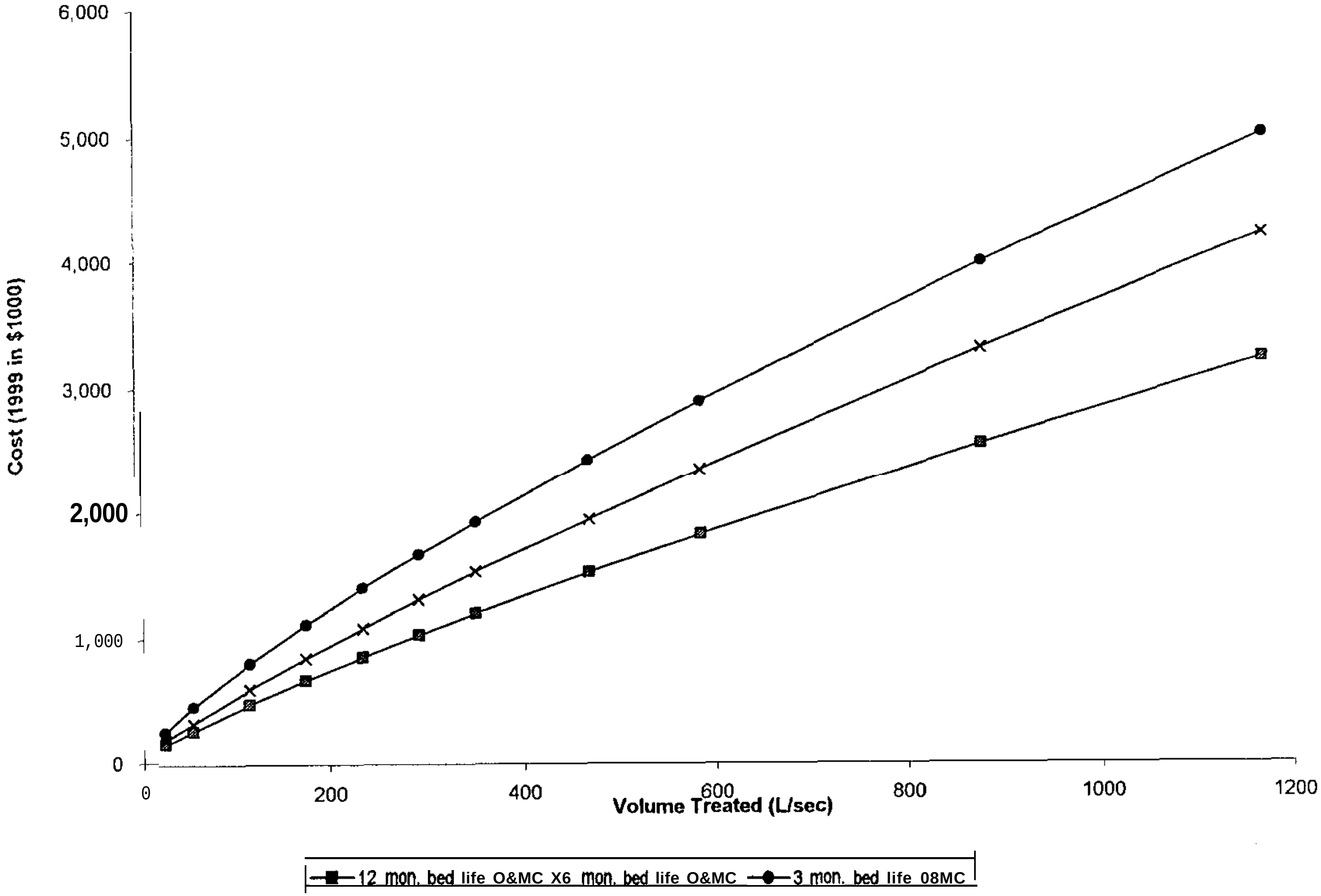
Desired Flow Rate:	292 L/s	4630 gpm
	25233.33 m^3/day	

Bed Life (months)	Construction Costs:	Operating Costs:
12	$3,638,100	$1,023,646
6	$3,785,000	$1,301,467
3	$5,046,667	$1,663,217

Construction Cost for Carbon Filtration



O&M Cost for Carbon Filtration



GRAVITY FILTRATION:

Desired Flow Rate:	292	L/s	4631	gpm
Total Suspended Solids:	0.2	mg/L		
Wash Cycle:	24	hr		
TSS Density:	35	g/L*		
Media Depth:	1	m	0.91	yd
Maximum Media Capacity:	110	L-TSS/m^3*		
Required Media Volume :	1.44	m^3	1.89	yd^3
Calculated Bed Area:	1.44	m^2	1.73	yd^2
Alternative Bed Area:	0.00	m^2	0.00	yd^2
Tank Depth:	1.3	m	1.4	yd
Media Cost Delivered				
$/yd³ Sand	$55.00		42.05	m^3
$/yd³ Coal	$60.00		45.87	m^3
$/yd³ Garnet	$405.00		309.64	m^3

TOTAL CONSTRUCTION COSTS:	$169,507
Rapid Sand:	$104
Coal/ Sand:	$109
Coal/ Sand/ Garnet:	$327
TOTAL OPERATING COSTS:	$27,963

Media costs assume equal parts of each type.

*Media capacity based on information in 'Water Treatment and Plant Design', R.L. Sanks, Co: 1978, Ann Arbor Science Publishers, Inc.

Construction cost is 100% Manufactured Equipment
O&M costs are included with the structure.

BACKWASHING PUMP:

Filter area (m^2):	1.44	Applicable Range: 13-2600 m^2			
			1978	Current	
	Percentages		index value	index value	
1978 Capital Cost:		$37,810	basis	1999	
A) Excavation and Site Work	0.00	0	247	548.67	
B) Manufactured Equipment	0.47	36,346	72.9	149.1	
C) Concrete	0.00	0	71.6	150.2	
D) Steel	0.00	0	75	106.6	
E) Labor	0.07	5,879	247	548.67	
F) Piping and Valves	0.24	21,238	70.2	164.3	
G) Electrical Equip. and Instmnt.	0.22	13,875	72.3	120.6	
H) Housing	0.00	0	254.8	505.81	
1999 Capital Cost:	1.00	$77,339			
1978 O&M Cost:		$2,297			
I) Energy $/kW*h	0.52	2,786	0.03	0.07	
J) Maintenance Material	0.24	1,011	71.6	131.3	
K) Labor $/hour	0.24	1,654	10	30	
1999 O & M Cost:	1.00	$5,451			

Gravity Filter Structure

Filter area (m^2):	1.44	Applicable Range: 13-2600 m^2
	Percentages	
1978 Capital Cost:		$44,091
A) Excavation and Site Work	0.01	979
B) Manufactured Equipment	0.20	18,036
C) Concrete	0.06	5,550
D) Steel	0.05	3,133
E) Labor	0.21	20,568
F) Piping and Valves	0.23	23,735
G) Electrical Equip. and Instmnt.	0.06	4,413
H) Housing	0.18	15,755
1999 Capital Cost:	1.00	$92,168
1978 O&M Cost:		$8,592
I) Energy $/kW*h	0.36	7,218
J) Maintenance Material	0.12	1,891
K) Labor $/hour	0.52	13,404
1999 O & M Cost:	1.00	$22,513

Backwash Pumping Costs from Qasim, et al, Aug. 1992, AWWA
Construction Costs:

General Form: A + B*X + C*X^2	
A=	36000
B=	1254.21
C=	-0.1212

O & M Costs:

General Form: A*X^B+C	
A=	73.3
B=	0.75
C=	2200

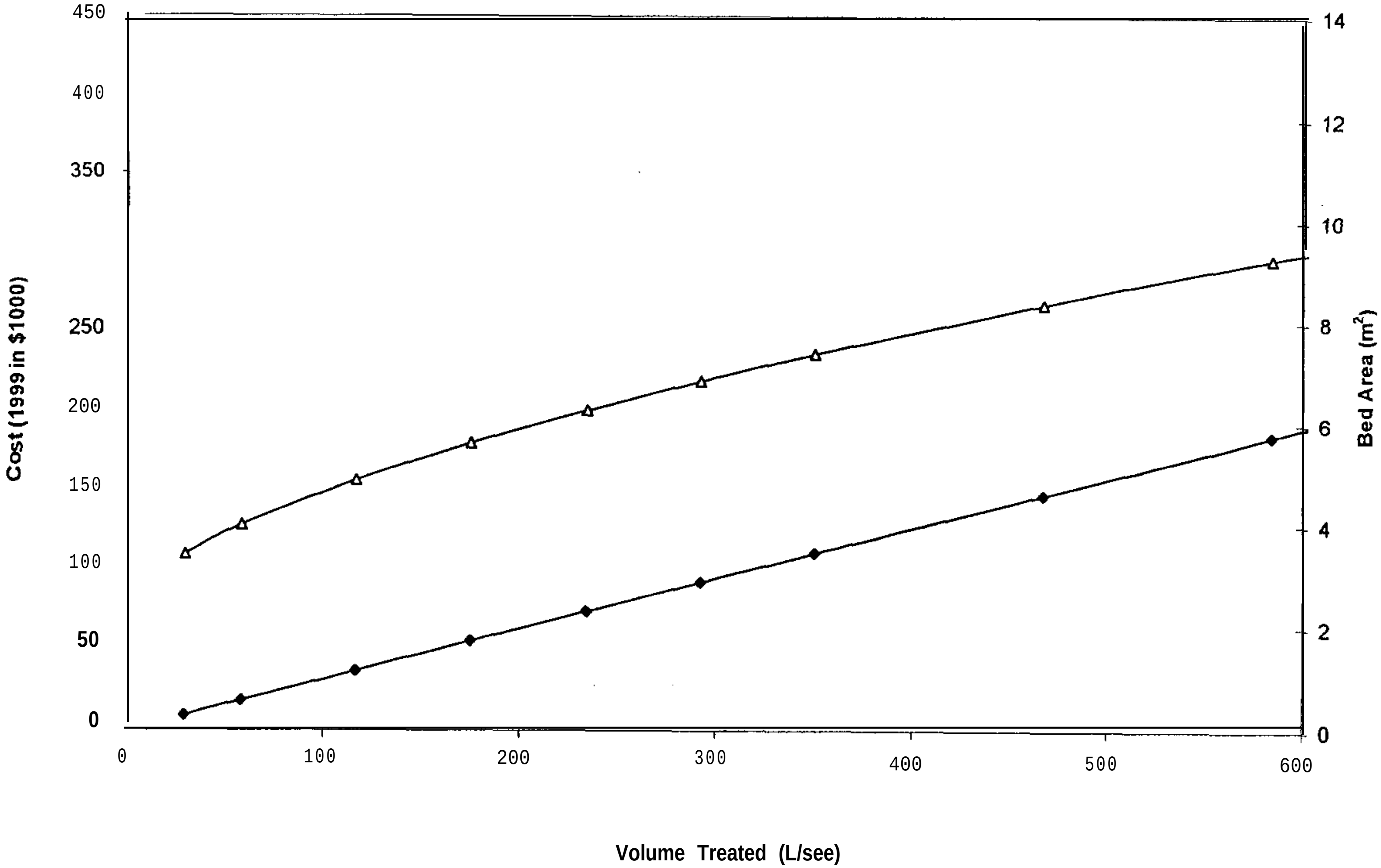
Gravity Filter Structure Costs from Qasim, et al, Aug. 1992, AWWA
Construction Costs:

General Form: A *X^B*e^(CX)	
A=	35483.4
B=	0.591
C=	0.000162

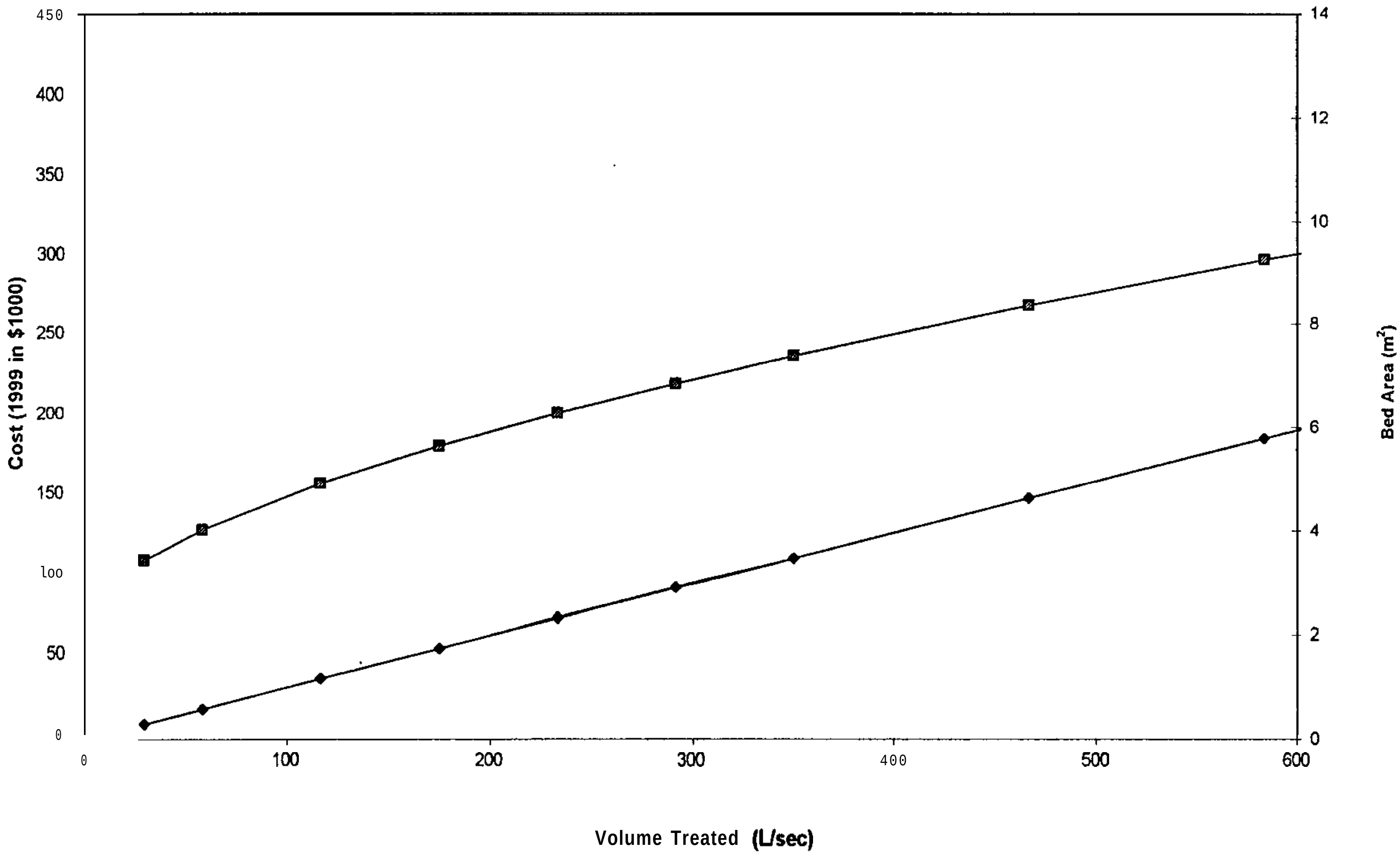
O & M Costs:

General Form: A*X^B+C	
A=	359.5
B=	0.8568
C=	8100

Construction Cost for Gravity Filtration at Different iiow Rates



O&M Cost for Gravity Filtration at Different Flow Rates



Ion Exchange

Desired Flow Rate :	From Capacity	292.1 L/s
Equiv/L , CATION >+1	From Capacity	3.56E-03 equiv/L
Equiv/L , ANION	From Capacity	1.76E-02 equiv/L
Service Flow Rate :	Range = 16 - 40	20 L/(hr*L resin)
Cation Equivalents/Liter of Resin		20 equiv/L
Anion Equivalents/Liter of Resin		11 equiv/L
Desired Run Cycle:		7 days

Medium:	Cation	Anion
Min Volume:	52.6	52.6 m^3
Time until exhaustion of min volume:	11.7	1.3 days
Resin for desired Run Cycle:	52.57	31.45 days
Total Vessel Volum	105	63
Resin Expansion Coefficient	2	2 m^3
Nominal Resin Price $/m^3$	$6,700	$6,700 m^3
Resin Cost:	$352,215	$210,705

Vessel:

Aspect ratio:		5 height/dia
Bed area :		7.03 m^2
Base pressure vessel correlation:		
(446 kPa/ 50 psig)	b=	3.446
log($) = b + m*log(m^3)	m=	0.562
Cost factor for operating pressure:		1
Tank cost at base pressure:		$38,179
TOTAL TANK COST:		$38,179

Regeneration (with NaCl)

Mass of NaCl /vol of resin:	150 kg/m^3	9 lb/ft^3
NaCl required:	12,603 kg	27784 lb
Chemical cost per kg:	$0.02	$0.01 $/lb
TOTAL CHEMICAL COST PER YEAR:	$10,925	
Chemical concentration:	10 percent	
Regeneration fluid req'd :	126 m3	33 kgal
STORAGE TANK COST:	$31,507	

Backwash Pumping Costs from Qasim, et al, Aug. 1992, AWWA
Construction Costs:
General Form: A + B*X + C*X^2

A=	36000
B=	1254.21
C=	-0.1212

O & M Costs:
General Form: A*X^0.75 + B

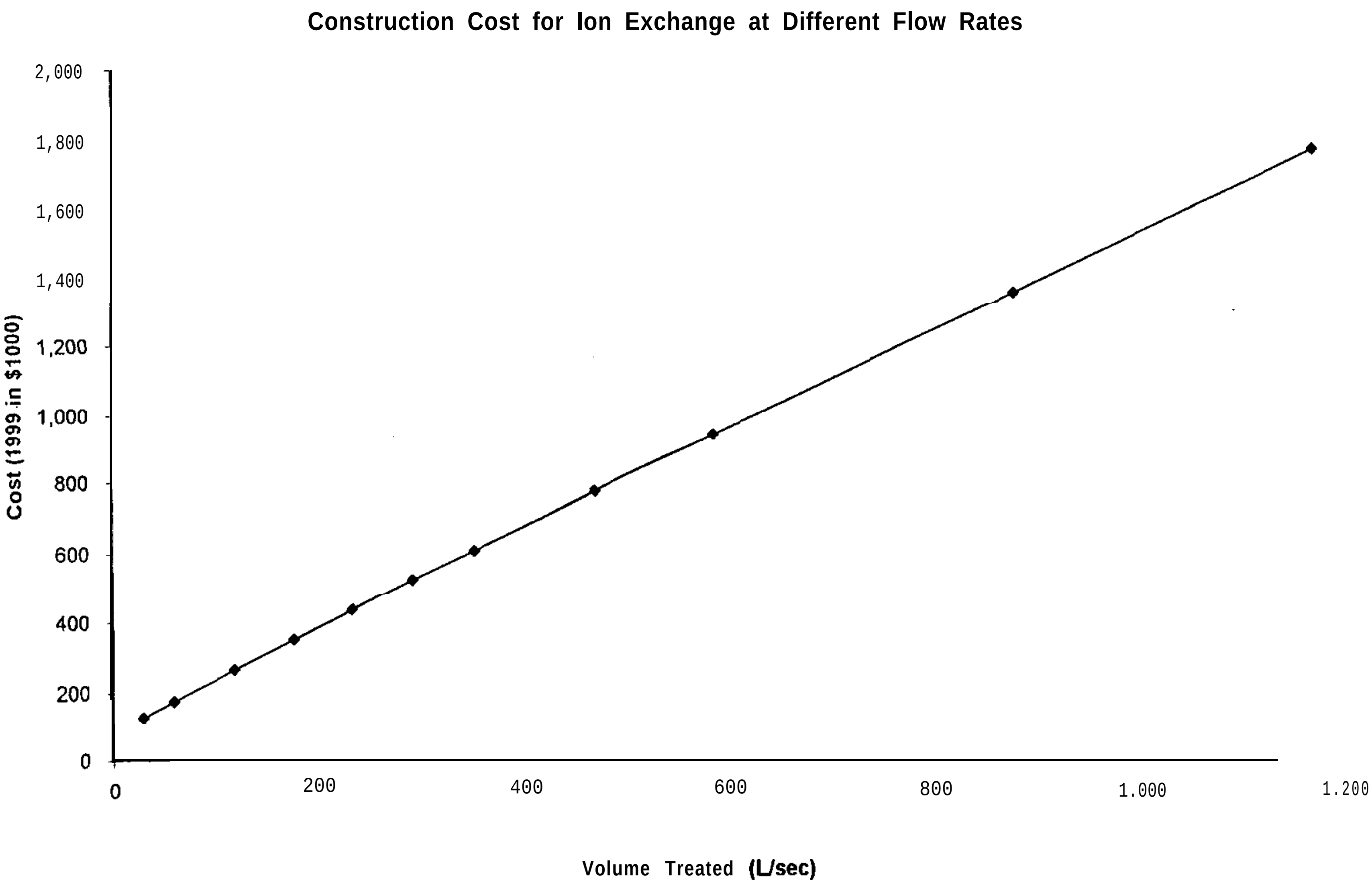
A=	73.3
B=	2200

REGENERATION/BACKWASHING PUMP:

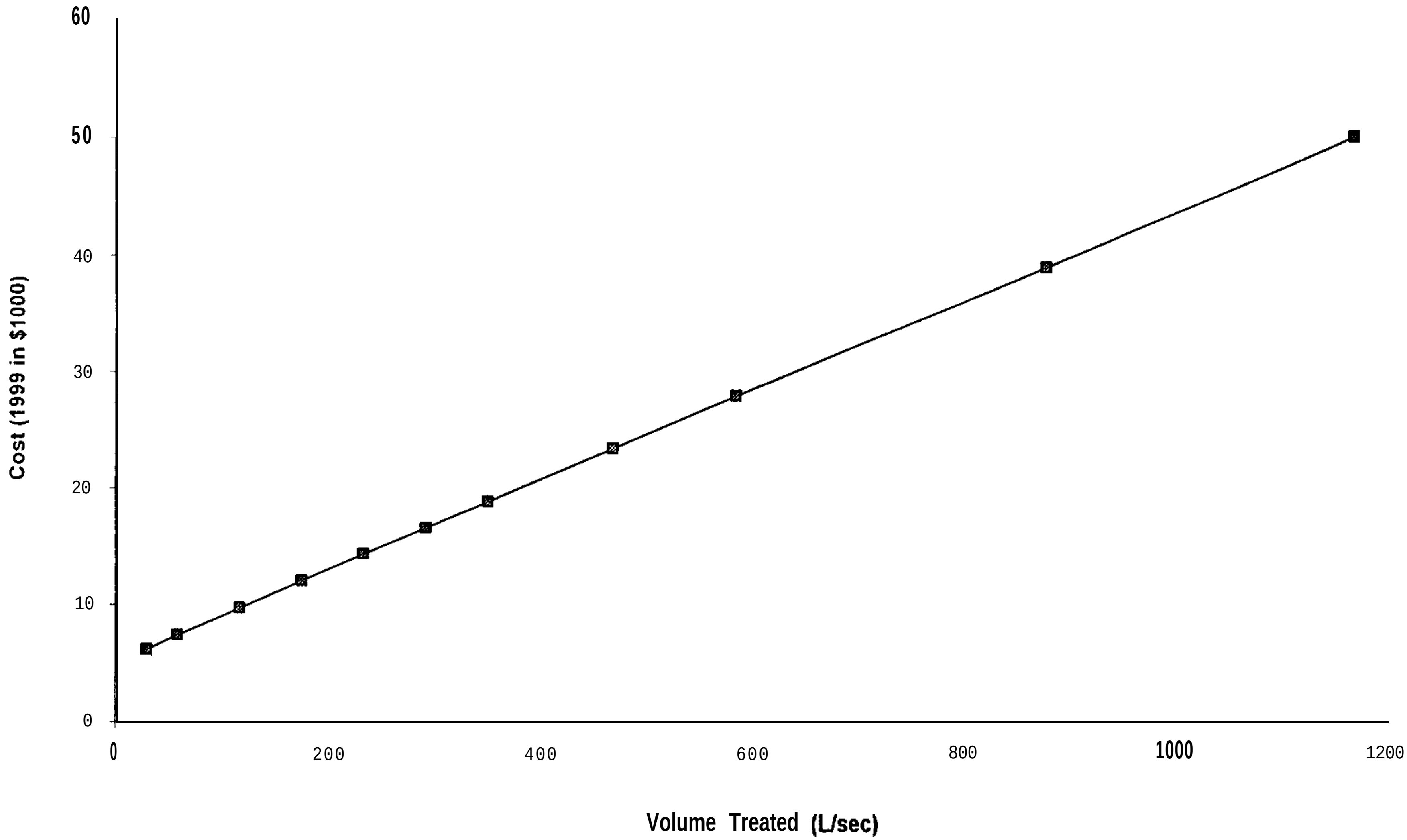
Filter area (m^2): 7.03 Applicable Range: 13-2600 m^2

	Percentages		1978 index value basis	Current index value 1999
1978 Capital Cost:		$44,810		
A) Excavation and Site Work	0.00	$0	247	548.67
B) Manufactured Equipment	0.47	$43,075	72.9	149.1
C) Concrete	0.00	$0	71.6	150.2
D) Steel	0.00	$0	75	106.6
E) Labor	0.07	$6,968	247	548.67
F) Piping and Valves	0.24	$25,170	70.2	164.3
G) Electrical Equip. and Instmnt.	0.22	$16,444	72.3	120.6
H) Housing	0.00	$0	254.8	505.81
1999 Capital Cost:	1.00	$95,061		
1978 O&M Cost:		$2,516		
I) Energy $/kW*h	0.52	$3,053	0.03	0.07
J) Maintenance Material	0.24	$1,108	71.6	131.3
K) Labor $/hour	0.24	$1,812	10	30
1999 O & M Cost:	1.00	$5,973		

Total Construction Cost: $516,962
Total Operating Cost: $16,898


Construction Cost for Ion Exchange at Different Flow Rates
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Cost (1999 in $1000)
0
200
400
600
800
1.000
1.200
Volume Treated (L/sec)

O&M Cost for Ion Exchange at Different Flow Rates



Electrodialysis Cost Estimation

Input from Interface

	Sample Values:	Value:
Flow Rate (L/s):		292.1
Flow Rate (m3/Hr)		1051
Feed TDS (mg/L):		700
Product TDS (mg/L):		400
Ave Equivalent Weight:		25.99
Percent Recovery:		0.50

Production Data

Delta N eq/m3:	11.54
Desal Ratio:	1.75

Membrane Characteristics

	Sample Values	Value
Transport efficiencies Sum<=1.00 Insert rows after Na+ or Cl- to add more ion efficiencies.		
Na+:	0.400	0.470
Sum cations efficiencies:		0.470
Cl-:	0.400	0.470
Sum anions efficiencies:		0.470
Transport effieciency: Sum of Anion & Cation Efficiency.		0.939
Area/membrane pair (m2) Asahi is 0.85 m^2		0.850
Dilute side resistance "Rd" (ohms/cm)/cm2:		0
Concentrate side resistance "Rc" (ohms/cm)/cm2:		0
Membrane resistance "Rm" (ohms/cm)/cm2:		0.070
Total resistance Rt = (Rd+Rc+Rm):	0.860	0.070
Current density (amps/m2):	30 - 300	30
Current Efficiency:		0.860
Membrane Voltage Potential "Vm" (volts/pair):		0.650
Voltage per cell Vc = Rt*CD+Vm:	1.000	0.671

Energy Requirements

Power requirements kWhr/m3:		0.24
Pumping energy requirements KWhr/m3	0.17	0.17
Total kWh/day:		10380

Membrane Requirements

Total Membrane Area (m2):	12,606
Number of cell pairs:	14,831

Membrane Replacement

		Suggested Values
Membrane Cost/m2:	$100.00	100
Membrane Life Expectancy (yrs):	15	15

Construction Cost Items

Construction Cost Factor (%):	1.65	1.65
Contingency (%):	15	15
Electricity Cost $/kWh:	$0.07	0.08

Labor and Overhead

Labor cost, Lh ($/h)	30	15
Labor overhead, LOH (%)	30	30
Shifts per day, S (number/day)	0.2	0.2
Workers per shift, Ws (number/shift)	1	1

Capital Recovery

System lifetime, r (yr)	15	15
Downtime, Dt (%)	15	15
Annual interest rate, i (%)	8	10

Cost Indices Categories:	1999
A) Excavation and Site Work	548.67
B) Manufactured Equipment	149.1
C) Concrete	150.2
D) Steel	106.6
E) Labor	548.67
F) Piping and Valves	164.3
G) Electrical Equip. and Instmnt.	120.6
H) Housing	505.81
I) Energy ($/kWhr)	0.07
J) Maintenance Material	131.3
K) Labor ($/hour)	30
Interest Rate	8

Capital Costs

Based on Membrane Cost @ $100/m2	$2,080,039

Operation & Maintenance Costs/ year

Chemicals	12,894
Maintenance	111,747
Membrane Replacement:	80,189
Labor Cost:	2,628
ED Electicity Cost/year @ $0.07/kWhr:	39,781
Capital Recovery	238,535
Total 1999 O&M Costs:	$485,775

Second Stage
Electrodialysis Cost Estimation

Input from Interface

	Sample Values:	Value:
Flow Rate (L/s):		146.0
Flow Rate (m3/Hr)		526
Feed TDS (mg/L):		779
Product TDS (mg/L):		400
Ave Equivalent Weight:		25.99
Percent Recovery:		*0.50*

Production Data

Delta N eq/m3:	14.58
Desal Ratio:	1.95

Membrane Characteristics

Transport efficiencies Sum<=1.00		
Insert rows after Na+ or Cl-		
to add more ion efficiencies.		
Na+:	0.400	0.470
Sum cations efficiencies:		0.470
Cl-:	0.400	0.470
Sum anions efficiencies:		0.470
Transport effeciency:		0.939
Sum of Anion & Cation Efficiency.		
Area/membrane pair (m2) Asahi is 0.85 m^2		0.850
Dilute side resistance "Rd" (ohms/cm)/cm2:		0
Concentrate side resistance "Rc" (ohms/cm)/cm2:		0
Membrane resistance "Rm" (ohms/cm)/cm2:		0.070
Total resistance Rt = (Rd+Rc+Rm):	0.860	0.070
Current density (amps/m2):	30 - 300	30
Current Efficiency:		0.860
Membrane Voltage Potential "Vm" (volts/pair):		0.650
Voltage per cell Vc = Rt*CD+Vm:	1.000	0.671

Energy Requirements

Power requirements kWhr/m3:		0.30
Pumping energy requirements kWhr/m3	0.17	0.17
Total kWh/day:		5992

Membrane Requirements

Total Membrane Area (m2):	7,964
Number of cell pairs:	9,369

Membrane Replacement

		Suggested Values
Membrane Cost/m2:	$100.00	100
Membrane Life Expectancy (yrs):	15	15

Construction Cost Items

Construction Cost Factor (%):	1.65	1.65
Contingency (%):	15	15
Electricity Cost $/kWh:	$0.07	0.08

Labor and Overhead

Labor cost, Lh ($/h)	30	15
Labor overhead, LOH (%)	30	30
Shifts per day, S (number/day)	0.2	0.2
Workers per shift, Ws (number/shift)	1	1

Capital Recovery

System lifetime, r (yr)	15	15
Downtime, Dt (%)	15	15
Annual interest rate, i (%)	8	10

Cost Indices Categories:	**1999**
A) Excavation and Site Work	548.67
B) Manufactured Equipment	149.1
C) Concrete	150.2
D) Steel	106.6
E) Labor	548.67
F) Piping and Valves	164.3
G) Electrical Equip. and Instmnt.	120.6
H) Housing	505.81
I) Energy ($/kWhr)	0.07
J) Maintenance Material	131.3
K) Labor ($/hour)	30
Interest Rate	8

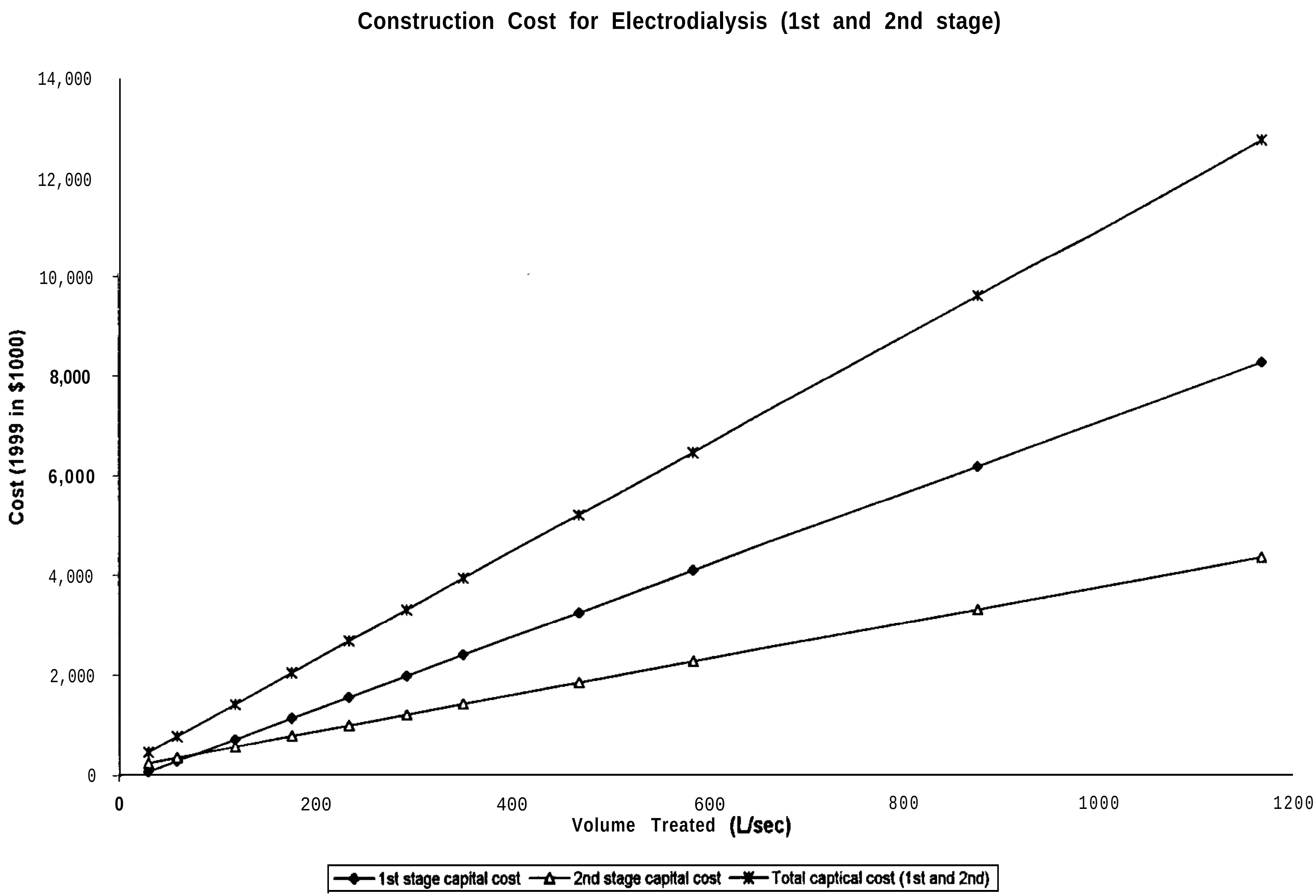
Capital Costs

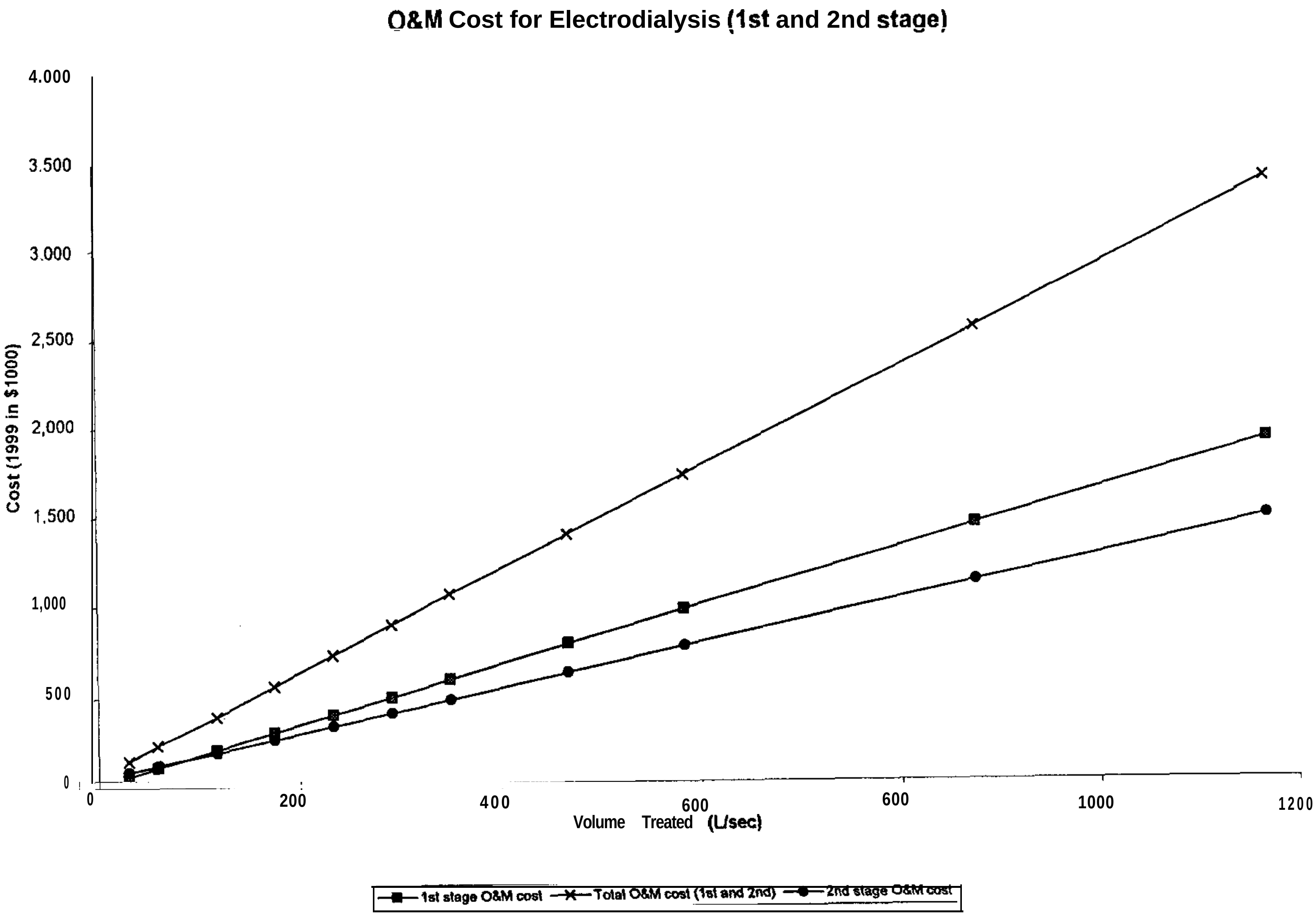
Based on Membrane Cost @ $100/m2	$1,314,050

Operation & Maintenance Costs/ year

Chemicals	12,894
Maintenance	70,595
Membrane Replacement:	50,659
Labor Cost:	2,628
ED Electicity Cost/year @ $0.07/kWhr:	22,966
Capital Recovery	238,535
Total 1999 O&M Costs:	$398,277

Total capital cost (1st and 2nd stage)	$3,394,088
Total O&M cost (1st and 2nd stage)	$884,051


Construction Cost for Electrodialysis (1st and 2nd stage)
Cost (1999 in $1000)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
200
400
600
800
1000
1200
Volume Treated (L/sec)
1st stage capital cost
2nd stage capital cost
Total captical cost (1st and 2nd)


O&M Cost for Electrodialysis (1st and 2nd stage)
Cost (1999 in $1000)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
200
400
600
600
1000
1200
Volume Treated (L/sec)
1st stage O&M cost
Total O&M cost (1st and 2nd)
2nd stage O&M cost

Pumps

Number of pumps:	4	
Height differential:	I m	2.9 n
Discharge pressure:	1750 kPa	254 psi
Full flow rate:	0.29 m^3/s	4630 gal/min
Basis flow rate	0.07 m^3/s	1157 gal/min
Pump Efficiency:	75 %	
Pipe Diameter:	0.1 m	4 in
Motor Efficiency:	87 %	
HP	236	
Power consumption:	271 kWhr	

Direct Costs (material and labor)		SST	VST	CSS
Pump, drive, and driver		405105	593689	244460
Piping		283816	283816	283816
Controls			16000	
Total Direct Cost		688921	893505	528276
Taxes	5.0%	34446	44675	26414
Total Capital Cost		$723,367	$938,180	$554,690

Operating Costs

Power Cost $/year		631389
Lubrication ($/L oil)	1	826
Cooling water ($/$m^3$ water)	0.1	123904
Maintenance (hr/Hp)	1.5	10608
		$766.727

Construction cost for clear well storage

Below Ground (concrete)

Storage Capacity (kgal) 5677.5

m^3 1500

			modified index value	Current index value
1978 Capital Cost:		$185,997		
Components	Percentages		basis	1999
A) Excavation and Site Work	0.05	19,543	247	548.67
B) Manufactured Equipment	0.00	0	72.9	149.1
C) Concrete	0.26	100,256	71.6	150.2
D) Steel	0.28	72,779	75	106.6
E) Labor	0.27	109,955	247	548.67
F) Piping and Valves	0.00	0	70.2	164.3
G) Electrical Equip. and Instmnt.	0.02	7,403	72.3	120.6
H) Housing (Misc. & contingency)	0.13	48,000	254.8	505.81
1999 Capital Cost:	1.00	$357,935		
1999 Unit Cost ($/gal)	$238.62			

Data from EPA-600/2-79-162b, August 1979, pg453-454. They are used in determining cost formula.

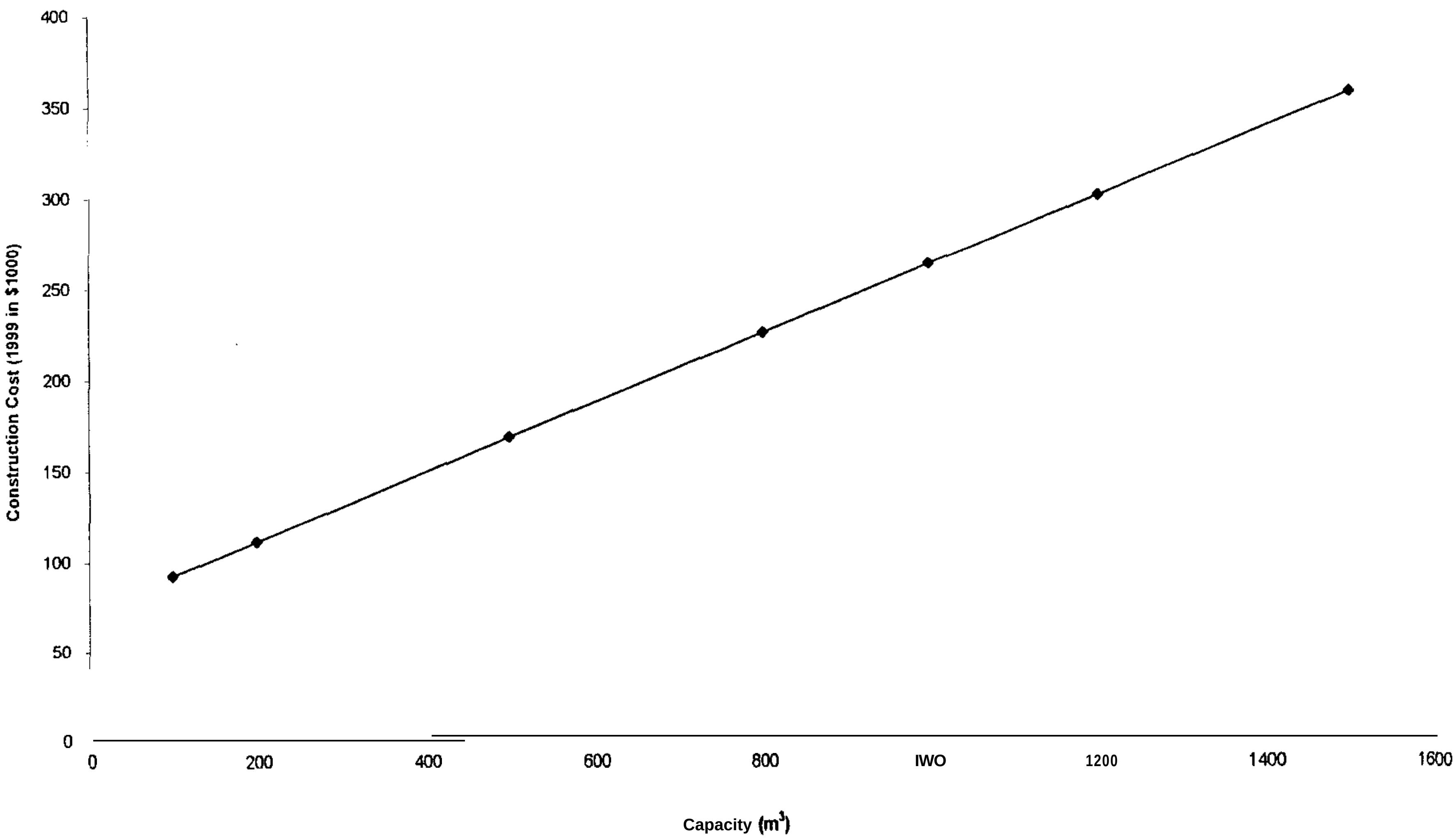
Ground Level (steel)

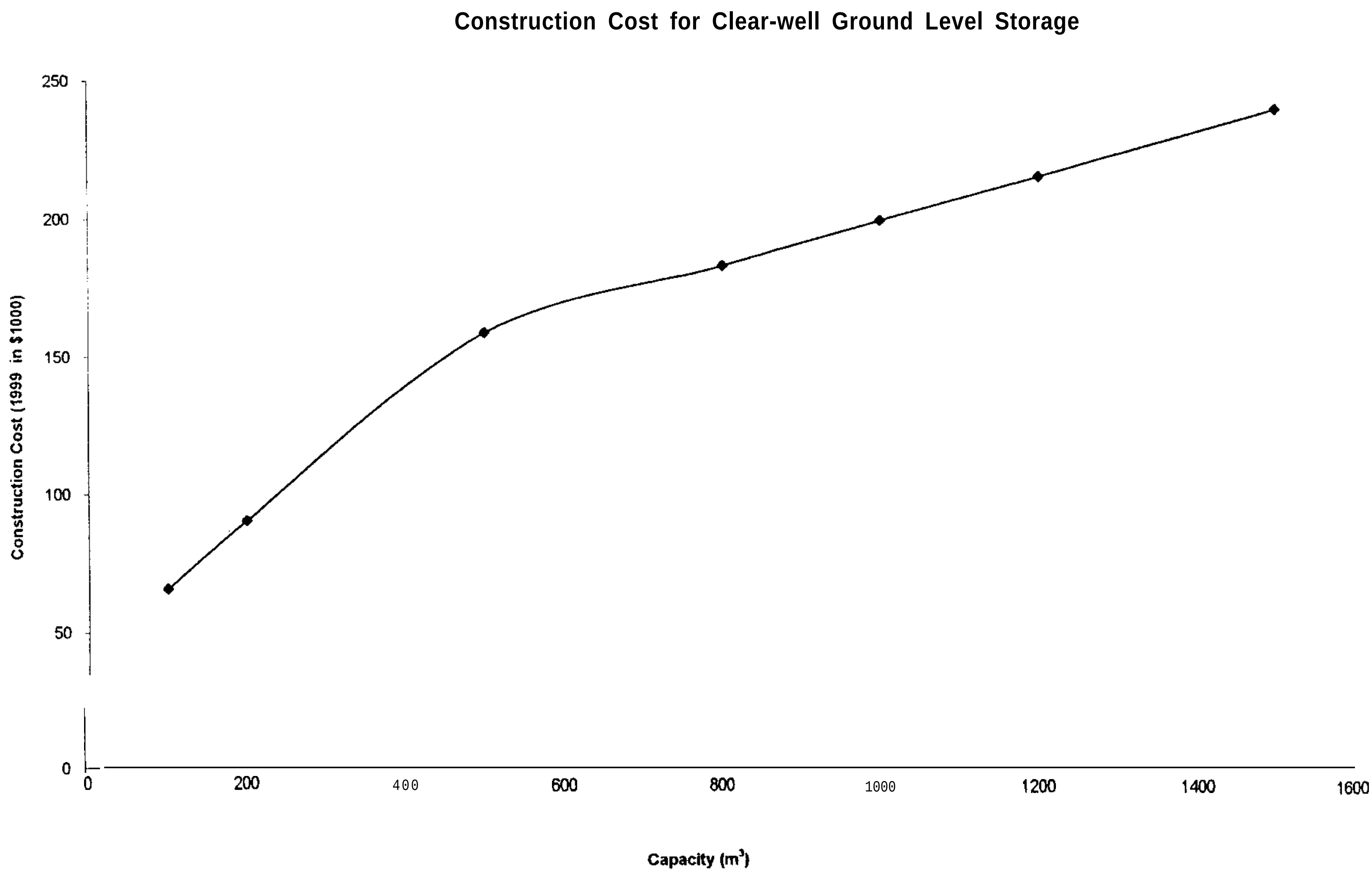
Storage Capacity (kgal) 5677.5

m^3 1500

			modified index value basis	Current index value 1999
1978 Capital Cost:		$117,121		
Components	Percentages			
A) Excavation and Site Work	0.00	0	247	548.67
B) Manufactured Equipment	0.66	157,883	72.9	149.1
C) Concrete	0.06	13,980	71.6	150.2
D) Steel	0.04	7,325	75	106.6
E) Labor	0.01	2,115	247	548.67
F) Piping and Valves	0.07	19,369	70.2	164.3
G) Electrical Equip. and Instmnt.	0.03	6,003	72.3	120.6
H) Housing (Misc. & contingency)	0.13	30,225	254.8	505.81
1999 Capital Cost:	1.00	$236,900		
1999 Unit Cost ($/gal)	$157.93			

Construction Cost for Clearwell Below Ground Storage




Construction Cost for Clear-well Ground Level Storage
Construction Cost (1999 in $1000)
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
1600
Capacity (m3)

	Desert Well	Brackish	Desert Surface	Seawater Intrustion	Agricultural Influence	Seawater	Alkaline	Rangeland	
Component	Water Analysis	Water Analysis	Water Analysis	Water Analysis	Water Analysis	Water Analysis	Water Analysis	Water Analysis	Water Analysis
Metals									
Aluminum		0.35				0.01	0.05		
Antimony						3.30E-04			
Arsenic	0.012					3.00E-03		0.017	
Barium	0.050	0.0983		0.025		0.03	0.01	0.11	
Beryllium						6.00E-07		0.0005	
Cadmium	0.001					1.10E-04			
Calcium	100.000	182	58.7	136	36	400	180	99	51
Chromium	0.010	0.023				5.00E-05			
Copper	0.050	0.09				3.00E-03			
Iron	0.050	0.019		0.1		0.01	1.4		
Lead	0.005	0.006				3.00E-05			
Magnesium	35.000	85	27.3	47	22.1	1.35E+03	90	19	7.5
Manganese	0.550	0.0811		0.04		2.00E-03	0.5	0.03	0.028
Mercury	0.001					3.00E-05			
Nickel						5.40E-03		0.004	
Potassium	1.800	4.78	5.52	6		380	8	12	13
Selenium	0.005					9.00E-05		0.005	
Silver	0.005					3.00E-04			
Sodium	110.000	168	98	101.32	98.1	10500	250	31	93
Strontium	1.300	2.71				8.1	1.3	0.61	
Thallium						1.00E-05			
Zinc	0.050				0.078	0.01		0.02	
Inorganics									
Alkalinity-Bicarbonate	232.000	189.00	98.80	250.00	46.36	142.33	580	260	211.5
Alkalinity-Carbonate	0.000					2.89			0
Carbon Dioxide (aq)						5.15E-04		29	
Asbestos									
Boron									
Chloride	95.000	560	97.5	51	162	19000	29	19	114.8
Residual Disinfectant									
Color		3							
Conductivity		2200					2150	920	889
Corrosivity									
Cyanide									
Flouride	0.640	0.31	0.404	0.6	0.12	1.3		0.5	0.33
Foaming Agents									
Nitrate (as N)	1.000	10.7	20.556	4	1	0.5	0.05	55	3.3
Nitrite (as N)			0.0373				0.01	0.04	1.1
Ammonia (as N)	0.200							0.09	20
Odor		2							
pH	7.620	7.39	7.39	7.6	7.2	8	7.4	7.2	7.3
o-Phosphate		0.37				0.07		0.04	
SiO2	15.000	25.3							27
Silicon	17.000	11.9				3	12	28	
Solids (TDS)	880.000	1800	633	1015		32681	1620	533	
Sulfate	300.000	231	262	450	94	885	729	130	90
Temperature	24	24	24			24	7	13	
Total Suspended Solids:		1.3							