DEVELOPMENT OF NEUTRON ACTIVATION FOR INVESTIGATION

OF WATER CLARIFICATION

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ABSTRACT

The applicability of power spectral density techniques, Fourier series analysis, and linear regression to the mathematical modeling of river water temperature is demonstrated. Consideration is also given to the problem of estimating thermal inputs to rivers from man-made sources such as electrical power plants. First, power spectral density techniques are used in the time-series analysis of water temperature records which were taken from the Missouri River. Two spectral ranges are then studied from the standpoint of their applicability to (1) mathematical model building and (2) detection and identification of cyclic thermal inputs. Next, a Fourier regression fit to the time-series data is used to show that normal random variates having zero mean are obtained when the regression curve is extracted from the data. A 60-day prediction of daily-average water temperature is then made using a model which is based upon a polynomial regression fit to the fluctuating amplitudes of significant Fourier components. A final predictive model, which is based on the above analysis methods, is proposed.

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ABSTRACT

Development of Neutron Activation for Investigation of Water Clarification

The objective of this research was to determine if activation
analysis could be used to investigate coagulation-flocculation reactions.
Experimental study of the coagulation-flocculation reaction was developed
by preparing clay-water mixtures using montmorillonite and illite clay
samples and a standard ionic solution. Samples of the clay material were
subjected to neutron activation for various times and neutron flux values.
The irradiated clay samples were blended with stable clay materials and
subjected to electrophoresis.

Results of this study showed that clay minerals can be activated
to a high value by thermal neutron irradiation and that the neutron
irradiation can be controlled to increase the yield of specific radio-
nuclides. Experimental results also showed that the clay particle
migrated as a integral unit particle during electrophoresis.

KEY WORDS: Water clarification, coagulation-flocculation, neutron
            activation, zeta potential

INTRODUCTION

The operations which form the basic processes of water treatment are coagulation-flocculation and filtration. In practice, both processes are designed and optimized to do the same task - remove turbidity and extraneous particulate matter from water. The apparent dissimilar nature of the two processes suggests that turbidity removal is not a simple or straight forward operation. Experience in water treatment plant design and operation has shown that the problems associated with coagulation-flocculation and filtration are major, i.e., the performance, maintenance and evaluation of these processes require continual attention.

Both coagulation-flocculation and filtration are well established operations. The major chemical and hydraulic parameters associated with both processes have been identified in qualitative and quantitative terms and incorporated into standard engineering design. However there are several troublesome features unique to each process which contribute to malfunction and low efficiency.

For example, the basic purpose for both processes are the same - yet the amount of work accomplished by each process has not been defined. It is obvious if either process could be completely defined in terms of specific performance or activity based on comprehensive quantitative relationships then optimization could be developed.

Most of the chemistry relative to coagulation-flocculation has been developed as an extension of basic collodial chemistry. The basic concept, formulated in collodial chemistry and used extensively in water treatment chemistry, is that certain natural inorganic materials form

effective collodial micelles. Probably the most effective natural materials which are capable of this action are the natural clay minerals. The action and behavior of clay minerals established by analysis and experimentation has shown that montmorillonite and illite species form stable collodial solutions. Water treatment plant experience has also shown that water containing clay mineral turbidity can often be very difficult to clarify.

The most significant deterrent relative to development of specific quantitative control of the coagulation-flocculation reaction is measurement. The single most effective measurement of the nature and course of this reaction is zeta potential measurement. This measurement is based on the principle of electrophoresis in which the velocity of migration in a standard electrical field is measured by microscopic observation. Although this measurement provides a quantitative index of the coagulation-flocculation reaction, it is tedious and subject to extensive variation. In addition, the zeta potential measurement is limited to a static system and cannot be used to measure the course of the coagulation-flocculation in a flow system. Consideration of the limitations of the zeta potential measurement system shows that development of a rapid response, high sensitivity instrument capable of monitoring zeta potential or a directly related function would be of value. Such an instrument would permit direct in-stream measurement of the rate of reaction, and would provide a method for automatic control of coagulation-flocculation.

The requisite for development of realistic and hopefully effective analytical methods is based to some extent on accurate knowledge of the subject. Thus this research was designed to evaluate the concept of

electric mobility (zeta potential) and to be a first effort towards development of a new method. Specifically, the purpose of this research was aimed at determining if it was possible and practical to use neutron activation techniques to study the collodial chemistry of the coagulation-flocculation reaction.

METHOD AND MATERIALS

The study program developed for this research consisted of preparing
and standardizing solutions of neutron activated montmorillonite and
illite clay minerals and measurement of migration activity in controlled
electrophoresis experiments. Preparation of the clay mineral species for
neutron irradiation consisted of suspension in distilled water followed
by decantation and drying at 103°C for 48 hours. Samples of the dried
clay mineral materials were sealed in 1 cm. diameter 3 cm. deep polyethene
plastic cylinders and prepared for neutron activation. Preliminary
neutron radiation studies showed that the clay mineral samples were acti-
vated to a high degree. Results of this study also showed that the
predominant gamma activity induced by short-term (1 minute) irradiation
possessed high intensity and relatively short half-life decay character-
istics. The latter feature was undesirable since it would complicate the
planned experiments. Additional neutron radiation study showed that a
neutron radiation time of 10-15 minutes would produce a clay sample with
sufficient gamma radioactivity intensity and relatively long half-life.
Experimentation established that a 10 minute exposure of a one-gram clay
mineral sample to a thermal neutron flux of 5×10^{13} neutrons cm^2 sec^{-1}
was sufficient to produce 10^6 counts per minute per milligram of sample.
In order to minimize the thermal degradation which accompanied neutron
activation, standardized slurries of the clay samples were irradiated
and used throughout the study. Although it was not necessary for this
study, a preliminary determination of neutron activation precision was
completed. Results of this study showed that the gamma radiation activity

per unit mass of clay sample varied significantly from calculated values and from sample to sample. This variable, which can limit quantitative determination, was resolved by subjecting a small standardized gold foil to the neutron irradiation along with the sample. This operation permitted accurate determination of the neutron flux in the sample location and provided a method for normalizing variations in thermal neutron flux.

Following completion of the neutron activation study, three grams of neutron activated clay mineral samples (in slurry form) were reserved for use in the experimental program. Samples of the neutron activated clay materials were blended with stable clay mineral samples and various dilution solutions and stored in calibrated glass vessels.

A standard ionic solution, somewhat representative of a moderately hard water supply was prepared for the experimental study. The composition of this solution is listed in Table 1. In order to provide a stable collodial solution similar to the quality and quantity ranges of raw water supplies, various ratios of clay-water mixtures were formulated, mixed for 24 hours in a laboratory size mechanical mix machine and monitored for turbidity. Turbidity measurements were made daily for 30 days using a Klett-Sumerson colorimeter*. The results of this activity are shown as turbidity in relative units vs. time.

All of the electrophoresis measurements were conducted using a commercial zeta meter**. Measurement of the gamma radioactivity associated with the clay sample materials was accomplished using the 400 channel

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*Product of Klett Manufacturing Company, New York, N.Y.
**Product of Zeta-Meter, Inc., New York, N.Y.

gamma spectrometer provided by the UM Research Reactor Facility. This instrument was equipped with a 3 inch diameter thallium activated sodium iodide crystal detector.

The behavior and migration of radioactive clay particles was determined experimentally be observing the migration direction microscopically at various voltage values. Following this observation, the migration velocity of the particle was determined by replicate measurement of velocity. During this study period, samples of the electrophoresis mixture were removed from each electrode by means of lambda pipettes.

RESULTS

Results of the first phase of this study, determination of the gamma activity induced in clay mineral sample by neutron irradiation, were derived by calculation. The equation used for the calculation of expected activities was;

$$N = \frac{\phi \sigma N_0}{\lambda} \ (1-e^{-\lambda t i})$$

where:

N = number of radioactive atoms

ϕ = neutron flux, 2×10^{12} neutrons/cm^2/sec

σ = neutron cross section capture for each element

λ = radioactive decay constant

ti = neutron irradiation time.

A summary of the calculated amounts of gamma activities contributed by each metallic portion of the clay composition are listed in Table 3. Preliminary experimental results showed that these calculations were approximately correct qualitatively, however the quantitative amounts of each radionuclide produced were much greater. Further experimental work showed that a 1.0 gram clay sample subjected to a 2×10^{12} neutron/ cm^2/sec. flux produced an intensely radioactive source. This finding showed that the major experimental problem involved in using neutron activated clay material was determination of sample size and neutron radiation conditions sufficient to produce "managable" quantities of gamma radionuclides.

Experimental results showed that it was possible to produce a radioactive clay sample which could be used in the study by using small samples

of clay materials and short term neutron irradiation periods. These results also showed that it was possible to selectively activate certain elements in the clay structure for specific studies. For example, high specific activities of ^{28}Al and ^{30}Si could be induced by 1 minute irradiations at 5×10^{15} neutrons/cm^2/sec. However any experimental work conducted after the neutron radiation period would have to be accomplished in a short period since both of these materials decay out rapidly. The half-life of ^{28}Al is 2.3 minutes and ^{30}Si is 2.62 hours.

Turbidity measurements showed that the procedure of mixing 1.0 gram samples of montmorillonite and illite clay minerals in one liter of ionic solution for 24 hours produced a solution with turbidity characteristics similar to raw surface waters. Laboratory testing of the clay-water mixture showed that it possessed the most desired characteristic, i.e. a stable and rather low, persistent turbidity. This desired characteristic is based on the observation that the rate and possibly the extent of the coagulation-flocculation reaction is concentration dependent. Experience has shown that raw water containing relatively large amounts of sediment and associated turbidity responds readily to coagulation-flocculation. Hence the most challenging problem is the development of effective and efficient methods for treating low turbidity waters.

The change of turbidity with respect to time showed that initially there was a rapid decrease in turbidity followed by a very slow change. This pattern of change was evidenced by all of the solutions irrespective of the clay to water ratio. High clay concentrations yielded higher initial values of turbidity but after about five days the turbidity

values for all solutions were approximately equal. Typical turbidity values at various time periods are shown in Figure

Neutron activation study results showed that a 10 minute irradiation period of a 0.5 gram sample of either montmorillonite or illite clay was sufficient to produce enough gross gamma radioactivity for the purposes of this study. Inspection of the gamma activity spectrum developed by the neutron irradiated clay samples showed that both illite and montmorillonite yield a similar gamma radioactivity response. The half-life of irradiated specimens was determined experimentally to be about 102 days. The most significant photo peaks which were typical for both clay samples were determined by measuring the intensity (counts per minute) at selected energy ranges at daily intervals for a period of two months. Results of this study showed that ^{22}Na, ^{46}Sc, ^{47}Ca and ^{54}Mn were the dominant activated species. The specific activity in terms of counts per minute per gram of material was determined for a diluted sample and adjusted to yield a value of 10^6 counts per minute per 10^{-3} grams of clay.

Results of the electrophoresis study using non-activated clay materials and activated clay materials suspended in the ionic solution showed zeta potential values ranging from -20 to -15 m.v. Microscopic observation of the two materials failed to show any significant difference in the migration behavior of the two samples. This observation together with the similarity of zeta potential value showed that the tendency of the gamma species to form radio colloids was not great enough to alter the electromobility characteristics.

Sampling and counting of the anode and cathode solutions showed that there was a continuous increase in radioactive materials at the anode. This finding was in agreement with the zeta potential measurement which established that the clay particles moved or streamed towards the anode, i.e. the particles were negatively charged. Results of this study, in terms of accumulated radioactivity as a function of time are shown in Figure 2.

Observation of the radioactivity curve shown in Figure 2 shows that there was an immediate and increasing rate of accumulation of radioactive clay particles in the anode region. The bulk accumulation of the radio-active clay particles in the anode region was completed in about 9 minutes. The plotted data shown in Figure 2 display a fair degree of variation and the variation seems to increase with time. Repetition of this experiment established that the variation was inherent to the system and was probably due to the heating which accompanies electrophoresis. Gamma spectrometer analysis of the anode solutions showed that the gamma intensity vs. energy distribution was identical to the initial neutron activated clay material. This finding is in agreement with the micro-scopic observation and indicates that the radioactive clay migrated as a unit and was not deposited in the anode area as elemental material.

CONCLUSIONS

Results of this study showed that the technique of thermal neutron activation analysis can be used to study the rate and probably the extent of coagulation-flocculation reactions. The procedure of using a natural clay showed that clay materials migrate rapidly as an integral unit toward the collecting electrode. This finding suggests that application of a radioactive turbidity tag might permit accurate determination of mass accumulation per unit time on a voltage applied basis. Further research will be required to evaluate this process.

Table 1. Chemical Composition of Clay Minerals Found in Surface Water Sediments*

Oxide	Montmorillonite	Kaolinite	Hallosite	Illite
SiO_2	50.20%	45.20%	43.98%	52.23%
Al_2O_3	16.19	37.02	38.46	25.85
Fe_2O_3	4.13	0.27	trace	4.04
FeO	trace	0.06	0.03	trace
MgO	4.12	0.47	trace	2.69
CaO	2.18	0.52	0.32	0.60
K_2O	0.16	0.49	0.48	6.56
Na_2O	0.17	0.36	0.14	0.33
TiO_2	0.20	1.26	0.01	0.37
H_2O-	15.58	1.55	2.58	trace
H_2O+	7.57	13.27	14.59	7.88

*Analytical data courtesy American Petroleum Institute Project #49-A cooperative program with the University of Missouri.

Table 2. Composition of Ionic Solution

Cation	MEQ	Anion	MEQ
Na^+	3.50	Cl^-	2.65
Mg^{++}	2.50	NO_3^-	0.35
Ca^{++}	3.00	$SO_4^=$	3.00
		$HCO_3^=$	3.00
Total	9.00		9.00

pH = 8.0
Hardness = 275 mg/1 as $CaCO_3$
Alkalinity = 275 mg/1 as $CaCO_3$
Total dissolved solids = 500 mg/1

Table 3. Calculated Amounts of Gamma Radionuclides Produced at Various Neutron Irradiation Periods.

| Radionuclide | Neutron Irradiation Period | | |
	10 min.	10 hrs.	10 days
^{28}Al (2.3 min)	23.8 mc	24 mc	24 mc
^{45}Ca (160 days)	0	0	1.98 μc
^{49}Ca (8.8 min)	3.34 μc	6.11 μc	6.11 μc
^{59}Fe (45.1 days)	0	0.062 μc	9.7 μc
^{27}Mg (9.5 min)	29.3 μc	56.4 μc	56.4 μc
^{41}K (12.4 hrs)	0.027 mc	1.24 mc	2.9 mc
^{30}Si (2.62 hrs)	0.0432 mc	0.928 mc	1.0 mc
^{24}Na (15 hrs)	6.6 μc	0.31 mc	0.84 mc
^{51}Ti (5.8 min)	16.5 μc	23.7 μc	23.7 μc

Assumed flux, 2×10^{12} neutrons/cm^2/sec
1.0 gm clay sample

Figure 2. Accumulated Radioactivity of Neutron Activated Clay in Anode Solution

Figure 2. Turbidity vs. Time Curve for Montmorillonite and Illite Clay-water Mixtures

Montmorillonite

Illite
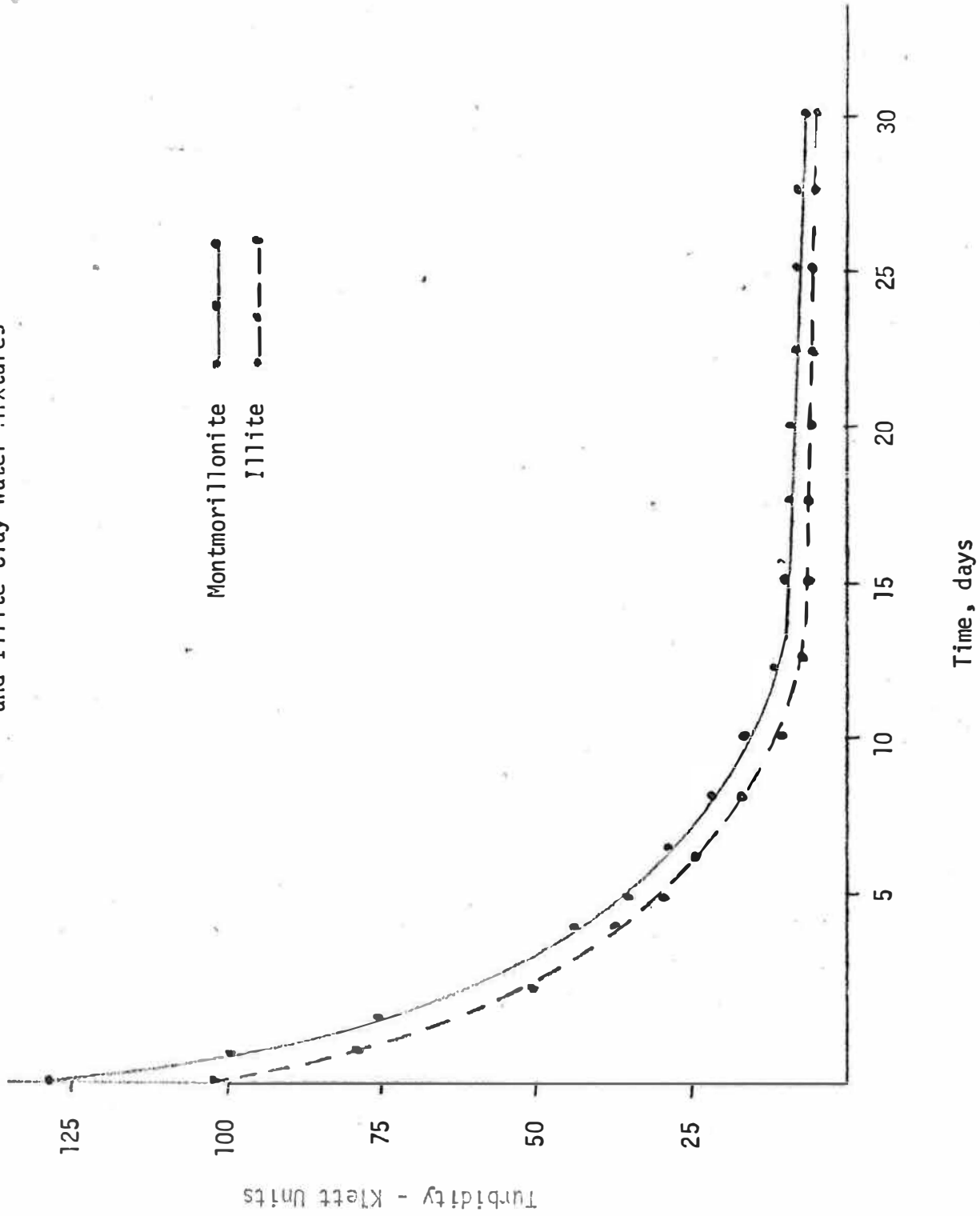
APPENDIX B

UPGRADING THE QUALITY OF MISSOURI'S
DRINKING WATER

(Unit Processes and Cost)

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UPGRADING THE QUALITY OF MISSOURI'S DRINKING WATER

(UNIT PROCESSES AND COST)

Introduction

There is serious concern for the quality of drinking water in Missouri's
rural communities. Rural customers are often consuming water of an
inconsistent chemical and microbiological quality in excess of maximum
levels. The cost involved in assuring that the water does not exceed
pre set maximum contaminant and quality levels can seriously strain
the budget of a small community. The developers of rural water systems
must be knowledgeable of water treatment processes applicable for small
systems. They must be aware of the advantages and disadvantages of
these processes or combinations of processes when compared with the
quality problems of their particular system. The limited funds of a
small community requires the selection of the most efficient and
economical water treatment system.

The report describes unit processes that are advantageous to small
rural water systems using ground water as a source. A relationship
is given between treatment plant capacity and cost for the various unit
processes. Cost equations are furnished to provide for treatment plant
capacity range of 227 cubic metres/day (60,000 gallons per day) to
5678 cubic metres/day (1,500,000 gallons per day). These capacities
correspond to capacities required to serve to populations of 25 to
10,000 persons. Each unit process has an included captial cost equa-
tion and annual operation and maintenance cost equation relevant to

the process proper operation. Cost equations for chemicals useful in water treatment are given for various treatment dosages. To aid the users of these equations, the equations are provided in a form such that, treatment to current costs are possible. The United States Environmental Protection Agency publication "State of the Art of Small Water Treatment System" was the primary source used to derive the cost equations and acquire applicable unit processes.

Water is essential for the existence of man on earth. The water consumption in this country is 625 liters per day per capita and the demand is on the increase. In addition to personal requirements of drinking, bathing, food preparation and recreation, water is used for industrial production and fire protection.

The availability of an adequate water supply can be often linked to the growth of a community. A question often asked by a prospective resident is "Is there a safe water distribution system available?"

Community leaders have as an objective the providing of safe and economical drinking water to the people of their community. In order to meet the requirements of the National Interim Primary Drinking Water Regulations, the expense to a small rural community could be costly. The total cost for the treatment of the water will basically be a function of the water quality and the contaminate reduction desired. The financial requirements to comply with the Drinking Water Regulations will greatly strain the financial resources of many communities with their small tax base. Therefore, it is imperative that the treatment processes employed to produce quality drinking water be the most economical and efficient for the communities' needs.

Ideally, research would be conducted to determine which of the various water treatment processes would best solve their quality problems. It would be necessary to do cost/benefit comparisons of the various processes to assure the selection of a water treatment system sufficiently geared to the specific water problem at hand.

Generally the initial step in supplying a community with water is the selection of ground water as a source. Ground water has the advantage over surface water in that it is of a consistent quality and less

or brownish stains on plumbing fixtures, fabrics, dishes or utensils. The use of soap or detergent will not remove these stains. After a period of time the build-up of iron deposits can be found in water heaters and pipe lines, thereby reducing the quality and hydraulic pressure of the system.

Iron removal can be complicated by the presence of iron bacteria. When dissolved iron and oxygen are present in water; therefore, these bacteria obtain the energy they need for their life pocesses from the oxidation of iron to its insoluble form. This insoluble form accumulates within a gelatinous mass which coats submerged surfaces. This iron bacteria contributes an undesirable taste, odor and discoloration to fabrics and impairs the hydraulics of the water system.

The proposed maximum level of iron in drinking water is 0.3 mg/l. Sources of iron pollution include iron bearing ground water, seepage and leaching from impoundments containing industrial waste and corrosion of iron and its alloys.

Nitrate

The ingestion of drinking water containing nitrate occasionally causes fatal poisoning in infants, particularly when concentrations greater than 10 mg/l are present. The maximum allowable level of nitrate in drinking water is 10 mg/l (as Nitrogen). This is equivalent to 45 mg/l of the nitrate ion (NO_3).

The source of nitrate pollution is by nitrate fertilizers, cesspool leaching, waste from chemical fertilizer producing plants, municipal wastewater plants and improperly constructed wells.

Sulfates

High concentration of sulfate contributes to the formation of scale in boilers and heat exchangers. Unpleasant taste in water can be attributed to concentrations greater than 250 mg/l. Sulfate in excess of 600 mg/l results in a laxative effect.

The maximum permissible level is 250 mg/l. Sulfate pollution is caused by tanneries, sulfate pulp mills, textile mills and other plants that use sulfate and sulfuric acid. Leaching from gypsum and other common minerals and oxidation of sulfides, sulfites and thiosulfate yielding sulfates can contaminate a water supply.

pH

Often the pH of Missouri water will have to be adjusted to insure the adequate operation of treatment operations. The proposed range of pH level as set by the National Interim Primary Drinking Water Regulations are 6.5 to 8.5. The optimum pH range is a function of the particular water chemistry. Operation outside of optimum range can result in a wasting of chlorine, ineffectiveness of coagulation, flocculation, encaustation and unwanted taste.

Hardness as CaCO

The presence of calcium and magnesium are the primary cause of hardness in Missouri's waters. Hard water reduces the cleaning action of soap and detergents, causing an expense in extra working and cleansing agents.

Turbidity

Normally the filtering action of water seeping through the soil results in turbidity not being a problem in ground water. Although during periods of heavy and/or prolonged rainfall, the turbidity of ground water will increase significantly. Highly turbid waters can interfer with disinfection, maintenance of chlorine residual and is aesthetically displeasing to the consumer.

The maximum level for turbidity as proposed by the National Interim Drinking Water Regulations is one turbidity unit (monthly average) and five turbidity unit (two day average).

Manganese

Manganese is removed from water for aesthetic and economical reasons rather than for any possible physiological reasons. A brownish or purplish color will be given to water and laundered goods when manganese is present and oxidation takes place. The unsatisfactory taste sometimes found in coffee and tea can be attributed to manganese.

The manganese in ground water can be attributed to leaching from mineral deposits and leaching from surface impounded from industry where manganese is used.

The proposed maximum contaminant level is 0.05 mg/l chiefly because of the difficulty in obtaining such a level and difficulties in measuring 0.05 mg/l.

Total Dissolved Solids

TDS is associated with excessive hardness, taste, mineral deposits and corrosion. 500 mg/l is the proposed maximum contaminant level.

Coliform Organism

These organisms are used to indicate the presence of pathogenic organism. They are not usually considered pathogenic when present in a water supply system. Coliform organism present in a water supply warns the plant operator that the water environment is favorable to pathogenic organism. The absence of coliform bacteria or a relative small number of them indicates the absence of harmful bacteria.

The National Interim Primary Water Regulations does not set a maximum number for coliform organisms. The maximum permissible level is a function of the population served and number of tests conducted per month.

Chlorides

Excessive amounts of chloride in drinking water contributes to the deterioration of plumbing and affects the taste of the water. Chloride in excess of 250 mg/l results in an objectionable salty taste in the water. Chloride in excess of 500 mg/l cuts down the useful life of water heaters and plumbing. There are no known detrimental health effects.

The Safe Drinking Water Act has determined maximum contaminate levels for both organic contaminants found in drinking water. These levels were determined to insure water that would be aesthetically pleasing, free of pathogenic organisms and free of the effects of corrosion and scale. The various treatment processes used to accomplish the above health and aesthetic requirements are briefly discussed below. The choice of the optimum unit process is a function of the contaminants found in the water and the economical analysis of the process.

Aeration

Aeration is the process of bringing about the intimate contact between air and a liquid such as water for the purpose of transferring volatile substances to or from the water. The volatile substances of interest are oxygen, methane and other unidentified organic compounds. The addition of dissolved oxygen aids in the reduction of iron and manganese.

Gravity and mechanical draft are the methods of aeration generally used in small water treatment systems. Generally diffused aeration is not generally economically advantageous.

Gravity Aeration

The most practical of the various methods of gravity aeration for small water treatment systems consists of a stack of multiple trays which are often filled with contact media. Water flows by gravity over the layers of media and trays.

Mechanical Aeration

Water droplets fall and air ascends in counterflow from a tower. The tower is made up of a series of trays with wire mesh, slat or perforated bottoms over which water flows. The efficiency of this process is increased by the placement of coke, stone or ceramic balls in the trays.

Oxidation

Oxidation is the addition of oxygen, removal of hydrogen or removal of electrons. The removal or destruction of obnoxious taste and odor in a water supply is obtained by use of this method. Oxidation also promotes the removal of iron and manganese and helps improve clarification and color removal. The most commonly used oxidating agents are as follows:

A. Air. Soluble iron is readily oxidized by the addition of oxygen, but manganese oxidation is promoted or made easier by aeration. For precipitation of 1 mg/l of iron, 0.14 mg/l of oxygen is required, and 0.24 mg/l of oxygen is required for precipitation of 1 mg/l of manganese.

Oxidation of organic substances responsible for undesirable taste and odors using aeration is usually too slow to be of value. However, if dissolved gases such as hydrogen sulfide are the cause of taste and odor problem, aeration will effectively remove them through oxidation and stripping.

B. Chemical. Chlorine, chlorine dioxide, ozone and potassium permanganate are the most often used chemical oxidants. Chemicals are more effective oxidizers than air. A cost versus benefit analysis should be made for aeration and chemical oxidation before either is chosen as a method of water treatment. The relatively expensive ozone and chlorine dioxide require on-site generation.

Iron and manganese are readily oxidized to oxides when chlorine, chlorine dioxide and potassium permanganate are used as oxidizing agents. These chemicals are capable of oxidizing

organic substances, thereby make clarification and color removal more effective.

A comparison of chlorine with potassium permanganate will reveal that chlorine requires a longer contact time to effectively oxidize manganese at levels greater than 0.2 mg/l. Theoretical amounts of chlorine required are 0.64 mg/l per 1.0 mg/l of iron and 1.3 mg/l per 1.0 mg/l of manganese. However, higher values are used to increase the rate of reaction and provide chlorine for completing reaction in practice. Chlorine's oxidation of manganese is dependent on the pH level, mixing conditions, chlorine dosage, and other factors. High pH values aid in the oxidation of manganese.

Potassium permanganate has the advantage in that it is much faster reacting and does not form by-products which can intensify odors that are present in the water. Theoretically 0.94 mg/l of potassium permanganate is required to oxidize 1.0 mg/l of iron and 1.92 mg/l to oxidize 1.0 mg/l of manganese. In actual practice, the amount used is less than the theoretical amount. Potassium permanganate is not as pH dependent as chlorine; an increase in pH does speed up reaction.

The evaluation of the amount and type of the contaminants to be removed, (economic evaluation of the chemical and tendencies toward trihalomethane formation), must be weighed before a choice between chlorine and potassium permanganate is made. Since chlorine is used for disinfection, it is the recommended choice for a small treatment plant. If chlorine oxidation is impractical, consider air or potassium permanganate. However, if high manganese levels

are present, potassium permanganate should be chosen out of
necessity. Potassium permanganate is more effective than air
if intermittent taste and odor are a problem. From a cost
standpoint, chemical feed equipment is less costly than aera-
tion equipment. The operating cost of a chemical feed unit
could be reduced if operated on an "as need" basis.

Clarification

The single unit in which rapid mixing, coagulation, flocculation,
sedimentation and sludge removal takes place is called a clarifier. Its
basic function is the reduction of suspended solids and flocculent par-
ticles before filtering of the water occurs.

Coagulation is conducted by the rapid mixing of a chemical coagulant
in the raw water. Chemical coagulants used are aluminum sulfate, pot-
ash alum, ferric sulfate, ferrous sulfate, chlorinated copperas, ferric
chloride, magnesium hydroxide and certain polyelectrolytes at low dosages.
The proper coagulant and dosage is determined by laboratory testing. The
pH of the raw water effects the effectiveness of the coagulant, thus care
must be taken for operation within the optimum pH range.

During the rapid mix operation, chemical for coagulation as well as
those for pH adjustment and flocculation can be added.

As a result of the coagulant, the suspended particles in the water
will combine to form floc. The floc can be settled out by passing the
water through a relatively large basin at a low velocity.

The clarification unit is useful for the removal of turbidity, color,
and a significant reduction in the amount of pathogenic organisms in
water.

Filtration

Filtration is the process of removing suspended matter from water as it passes through a bed of porous material. The removal efficiency is dependent on the size and characteristics of the filter media, the thickness of the porous media, and the size and quantity of the suspended matter in the effluent. Filtration will reduce the matter in the effluent. Filtration will reduce the bacterial population of the raw water, but will not make it bacterially free. Turbidity is removed from raw water by filtration if it is clarified before entry.

The classification of filters are gravity and pressure filters.

Gravity Filters. Gravity is employed to move the effluent through the filtering medium. Gravity filters are characterized by downflow operation followed by the backflow of water to cleanse the medium of foreign matter.

Pressure Filters. Pressure filters are characterized by having the entire filter apparatus, including media layer, gravel bed, and underdrains enclosed in a steel shell. An advantage of a pressure filter is that any pressure in the water line, leading to the filter is not lost, as in gravity filters, but can be used for distribution of water once it has passed through the pressure filter. A disadvantage is the potential loss of media during backwash which cannot be observed. The filtering media are classified as follows:

Single Media. Single media filters include rapid sand, slow sand and anthracite. The most commonly used single media filter is the rapid sand filter.

Diatomaceous Filters. The use of the filter medium is advantageous when suspended solids must be removed from low turbid waters, without coagulation. The upper limits for turbidity, for clarification without coagulation, is about 30 units. The fine powdered forms have the advantage of a relatively large surface area.

These filters are more dependent on effective operation than rapid sand filters. They have a greater head loss in comparison to sand filters. The filter runs are reduced by floc clogging if coagulated and settled water is fed through them.

Rapid sand filters usually operate at a rate of 120 to 240 M^3 /M^2 /day (2 to 4 gpm/ft^2). Ground water is usually filtered at 180 to 240 M^3 /M^2 /day (3 to 4 gpm/day). Efficiency of high rate filter operation is based on the proper prefiltration treatment.

The most frequently used filter medium is silica sand generally supported by a gravel bed.

Slow Sand Filter. Slow sand filters require large land areas to filter a substantial quantity of raw water. The filtration rate is far below that of rapid sand filtration. Therefore, slow sand filtration is not recommended as an effective and ceonomical water treatment process.

Anthracite Filters. Anthracite coal filtering media operates at a rate of 120 to 240 M^3 /M^2 /day (2 to 4 gpm/ft^2).

Activated Carbon Filters. Granular activated carbon may

be used as a filter medium for the removal of taste and odor causing organics.

Dual Media Filter. The anthracite coal-sand filtering media is the most common type of filtering media arrangement. A coarse layer of coal is placed over a fine layer of sand whereby intermixing takes place at the common boundaries, thus improving filtration. Dual media filters have the advantage over single filters of an increased effective depth of the filter bed and longer filter length run. The employment of dual filters in rapid sand filters will improve efficiency.

Mixed Media. The improved water quality is one of the benefits of a mixed media filter. The more common arrangement would be from top to bottom anthracite coal, sand and garnet, each having a specific gravity greater than the media above it. The thoroughly mixed materials throughout the bed results in increased surface area and an increase in filter run. The increase in surface area results in a filter bed much more resistant to breakthrough and more tolerant to surges in flow rates.

Ion-Exchange Softening

This procedure is carried out by the replacing of sodium cation for the calcium and magnesium ions in water. The net result is the calcium and magnesium sulfates or chlorides are changed to sodium sulfate or chloride. The material used in this process is insoluble, granular materials that process a unique property of ion exchange such as polystyrene resins, natural green sand, process green sand, synthetic silicates, sulfanated coal and phenolic resins.

Ion exchange is worth consideration in the treatment of any small system. This process can be utilized to render a water supply to virtually zero hardness. The disposal of large quantities of sludge, which is problem with line softening, is not a problem with ion exchange softening.

Electrodialysis

Electrodialysis is the process of using special membranes which allow ions to pass through them, but not permitting the water to pass. Special membranes are available which permit the passage of only positive ions (cation) or only negative ions (anions). The process is activated by a direct charge which causes ions to move from the water leaving the demineralized water.

Electrodialysis is effective in the removal or reduction to the maximum permissible levels of the following contaminants: manganese, total dissolved solids, chloride, sulfate, nitrate and fluoride.

Reverse Osmosis

Reverse osmosis is a technique in which a semi-permeable membrane is used as a highly selective barrier to inhibit the passage of contaminants. A semi-permeable membrane separates two solutions of water with different mineral concentrations, relatively pure water will flow through the membrane from the more dilute compartment to the compartment containing the higher concentrates of minerals. The membrane prevents the passage of organic, inorganic and microbial species and is very effective for water with high TDS.

The high equipment cost and appreciable manual labor involved in membrane assembly and replacement are this process' disadvantages.

Specifically reverse osmosis will remove or reduce manganese, total dissolved solids, chloride, iron, sulfate, nitrate, bacterial, radio-nuclides and color.

Stabilization

The finish water should leave the plant in a state that is neither scale forming nor corrosive. Unstable water damages the distribution system by dissolving the pipe and redepositing the iron, thereby reducing the pipe diameter. This reduced pipe diameter hinders the hydraulics of the system. The unstable water causes the water to be reddish when iron pipe is used. The consumers in the distributary may have water heaters damaged.

The methods employed to stabilize water are adjusting the pH, addition of polyphosphates or silicas. The stabilization involves the coating of the piping within the distribution system with a protective coating. In water with low hardness and calcium ion deficiency, lime is added to raise the pH. In hard water with sufficient calcium ions in solution, sodium hydroxide or soda ash should be added to raise the pH without adding to the hardness. The poly-phosphate additive method operates on the principal that the phosphates react with iron and other minerals in the water to form positive charged particles. These particles deposit a thin film to the pipe wall by migrating to the cathodic area of a corrosive cell, thus inhibiting corrosion of the metal. The most effective polyphosphate are bimetallic (zinc) or zinc orthophosphate. For water with pH less than 8.4, low hardness and alkalinity sodium silicate can be used.

Disinfection

Disinfection is an essential step in the assurance of the destruction or deactivation of pathogenic organisms. Although most harmful bacteria is removed from water by the treatment process of coagulation, sedimentation, filtration and natural die-away of organisms during storage in unfavorable environments, disinfection is never omitted. Chlorination is the preferable method of disinfection. Chlorination including the use of chlorine dioxide and ozonation are the most frequently used and accepted method of disinfection.

Chlorine is available as elemental chlorine, hydrochloric salts or as chlorine dioxide. Chlorine has the advantage of being cheaper and is actively present in the distribution system longer than commonly used disinfectant. The optimum conditions for the most effective chlorination are long contact time, low pH, and high temperature. Before a choice is made as to the form of chlorination to use, cost/benefit studies should be performed. The studies should reflect such factors as potential health hazards, stability, necessary storage and handling and on-site generation.

Ozone is a method of disinfection that must be generated on site. It is effective in the destruction of bacteria and can destroy amebic cysts unlike chlorination. Temperature and pH are not great influencing factors on ozones efficiency. Disadvantages of ozone are, requirement of on-site generation, large electric energy usage, no residual disinfection, and high possibility of system break down.

Chlorination is the recommended choice as a disinfectant for small water treatment systems. The choice of the particular type of chlorine will result from cost/benefit studies.

Waste Disposal

After the communities' water has been treated all waste produced must be disposed of. The raw water quality and treatment process used will determine the quantity of the waste.

The selection of a disposal method will be partly determined by factors such as the type of waste to be disposed of, the economics of the various methods of disposal and the contaminate level of the waste.

Methods of disposal which are available to the small communities are:

a. The dumping of the waste into a surface water. This was the most economical method of disposal prior to EPA's regulations prohibiting such practices. This practice may be resumed for communities near Mississippi or Missouri Rivers.

b. Vacuum Filtration reduces the water content of the waste but is not efficient enough for all types of solid waste. Alum waste solids are not liquified sufficiently to make this method practical but lime waste are liquified in total. The major drawback for this method other than liquifying inefficiencies is the expensive equipment, operating and maintenance cost and waste disposal problems. These drawbacks make this method undesirable for a small community.

c. Centrifugation is a method of dewatering solid waste in which the waste is not of a consistent water content. Its high capital, operation and maintenance costs and liquifying waste disposal problem makes it too costly for use by a small community.

d. Sand beds can be utilized to liquify the solid waste by
    evaporation and drainage. This method requires substantial
    land because the waste is applied in a thin layer. This
    method is dependent on the weather condition and waste re-
    moval will result in additional capital, operation and
    maintenance cost. This method can be utilized by a small
    community but weather conditions will dictate the efficiency
    of the method.

e. Lagooning is a method of waste liquifying using evaporation
    and freezing to reduce the water content. Where sufficient
    land is available, lagoons can be used until they are filled
    before utilizing another, thereby eliminating a need for
    further disposal of solids. When waste disposal is neces-
    sary, sanitary landfills or using the waste as a soil
    stabilizer can be utilized.

Of the disposal methods discussed lagooning and drying beds are
the most economical methods of disposal for a small community. The
cost of operating these processes is relatively low in comparison to
other methods. A small community would not have to appropriate funds
for costly mechanisms using these methods.

One of the most important questions that will have to be answered
by the engineer in charge of supplying potable water, is how much will
the total project cost? In order to estimate a reasonable figure many
factors must be considered. The quality of the water source must be
determined as an initial step. The various treatment processes should
be evaluated to decide which process or combination of processes

efficiently and economically treat the contaminants particular to your water supply.

After the quality of the raw water and the finished water have been determined, the engineer must decide which of the various processes available can economically and effectively treat his community's water. The engineer will take into consideration the capacity required, local attitudes and any particular design parameters especially required for his community in the treatment selection process.

The following paragraphs give the basic parameters used in the formulation of cost equations for various processes.

Cost Data

Initial investment costs, operation and maintenance cost are offered herein as an aid in estimating the preliminary cost for a new water treatment facility. The cost equations were developed from data presented in "State of the Art of Small Water Treatment Systems" (1). The descriptions and assumptions used in expressing the data can be found in that document.

The costs were derived by using the relationship between population and water consumption as shown in the following table.

TREATMENT PLANT DESIGN CAPACITY[1]

Population (1)	Plant Per Capita Design Rate (2)		Design Plant Capacity (3) = (1) X (2)	
	m^3/c/day	gpcd	m^3/day	gpd
25	9.0	(2400)	227	(60,000)
250	4.6	(1200)	1136	(300,000)
1,000	1.9	(500)	1893	(500,000)
2,500	1.1	(300)	2839	(750,000)
5,000	0.8	(200)	3785	(1,000,000)
10,000	0.6	(150)	5678	(1,500,000)

polluted, thus reduced treatment cost. Some communities are fortunate to have a ground water source in which the only treatment need is disinfection. With agricultural runoff from fertilized field, animal feedlots, mining waste and other advances of an industrialized society, the nation's water quality has deteriorated from the quality at the time many of the small water systems were initiated.

The Environmental Protection Agency is conducting an investigation of the effect of surface impoundments on ground water. This slow and insidious contamination results from seepage of unlined impoundments. Some of the leaking contaminants will be weakened by soil but concern should be given to shallow unconfined aquifers. A number of Missouri's communities receive their water supply from shallow wells. Should the soil atop these aquifers have their absorption capacity exhausted the water quality will be reduced and treatment cost would increase. A great expense would result if the present treatment system was totally outmoded to handle the purification and a new system was required. Many water systems presently reflect problems in equipment design, construction or condition of the basic water treatment plant.

The vast majority of Missouri's small communities acquire their water from wells. The quality varies such that purification methods range from disinfection to more extensive treatment techniques to remove iron, manganese, hardness, etc. Generally one would find Missouri's ground water to be characterized by the following conditions:

Iron

This impurity can impart a metallic taste to water or to any food in whose preparation such supply was used. Deposits of iron produce rusty

For power cost equations the following form is used:

$$\frac{C}{\$0.033} \text{ (Equation)} = \text{Cost (Dollars)}$$

C = Power cost for one kilowatt hour of energy plus desired contingency.

$0.033 = Sum of power cost of one kilowatt hour of energy at $0.03 plus 10% contingency used at time of equation development.

Mechanical Draft Aeration

Capital Cost.

$$\text{cost} = \frac{A}{1489} (-3.57659E-4 \ X^2 + 8.538728 \ X + 13050) \qquad [1]$$

OPERATION AND MAINTENANCE COST

The equations used in the development of the operation and maintenance cost of mechanical aeration covers a plant treatment range of 227 m^3 /day to 4567 m^3 /day.[1]

$$\text{Supply Cost} = \frac{B}{(1-8.4)} (-3.8E-9X^3 + 2.982E-5X^2 + 8.76927E-2X + 218) \qquad [2]$$

$$\text{Power Cost for 800 to } 5678m^3/\text{day} = \frac{C}{(0.033)} (+8.0E-10X^3 - 7.0E-8X^2 + 1.6E-2X + 92) \qquad [3]$$

$$\text{Power Cost for 227 to } 800m^3/\text{day} = \frac{B}{0.033} (105) \qquad [4]$$

DIFFUSED AERATION

Capital Cost.

The capital cost equation for diffused aeration is applicable to a plant treatment range of 227m^3/day to 5678m^3/day.

$$\text{Captial Costs} = \frac{A}{1489} (7.0E-8X^3 - 8.075E-4X^2 + 6.19X + 13733) \qquad [5]$$

Operation and Maintenance Cost

The operation and maintenance equations for diffused aeration are for treatment capacities ranging from 227m^3/day to 5678 m^2/day.

$$\text{POWER COST} = \frac{C}{0.033}(-1.6E{-}8X^3 + 1.6988E{-}4X^2 - 0.29221251X + 482) \qquad [6]$$

$$\text{Supplies Cost (for 227 to 3000m}^3/\text{day)} = \frac{B}{(188.4)}(132X^{0.077}) \qquad [7]$$

$$\text{SUPPLIES COST (for 3000 to 5678 m}^3/\text{day)} = \frac{B}{188.4}(4.0E{-}9X^3 - 6.557E{-}5X^2 + 0.3606X - 336) \qquad [8]$$

RAPID MIX

Capital Cost.

The equation used to determine the capital cost is applicable for a plant treatment range of 1000 m^3 /day to 5678 m^3 /day.

$$\text{CAPITAL COST} = \frac{A}{1489}(-9.64E{-}8X^3 + 1.33507E{-}3X^2 - 3.21633X + 21226) \qquad [9]$$

Operation and Maintenance Cost

$$\text{POWER COST (for 1750 to 5678 m}^3/\text{day)} = \frac{C}{0.033}(-2.47E{-}8X^3 + 2.318E{-}4X^2 - 0.481212X + 696) \qquad [10]$$

$$\text{Power Cost (for 1000 to 1750m}^3/\text{day)} = \frac{C}{0.033}(415) \qquad [11]$$

$$\text{SUPPLIES COST} = \frac{B}{188.4}(-9.0E{-}10X^3 + 1.115E{-}5X^2 - 2.1483E{-}2X + 253) \qquad [12]$$

FLOCCULATION

Capital Cost.

The equation used to determine the flocculation process capital cost is applicable for plant treatment capacity range of 1000m^3/day to 5678m^3/day.

$$\text{CAPITAL COST} = \frac{A}{1489}(-1.5E{-}7X^3 + 2.001E{-}3X^2 - 1.27013X + 50269) \qquad [13]$$

Operation and Maintenance Cost

The equations used to determine the flocculation operation and maintenance cost are applicable for plant treatment capacity ranges of 1000m^3/day to 5678m^3/day.

$$\text{Power Cost for 1000 to 2000} = \frac{C}{0.033}(302) \qquad [14]$$

POWER COST (FOR 2000 to 5678 m^3/day) $= \dfrac{C}{0.033}$ (-5.1E-9X^3 + 7.331E-5X^2 $\quad$ [15]
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ -0.2373122X + 527)

SUPPLIES COST $= \dfrac{B}{188.4}$ (9.0E-10X^3 + 1.943E-5X^2 - 4.170568E-2X + 479) $\qquad$ [16]

FLOCCULATOR--CLARIFIER

Capital Cost.

The equation used to determine flocculator-clarifier cost is applic-able for a plant treatment capacity range of 1000 m^3/day to 5678 m^3/day.

$\dfrac{A}{1489}$ (1.63E-6X^3 - 9.32053E-3X^2 + 56.89X + 183542) $\qquad\qquad\qquad$ [17]

Operation and Maintenance Cost

The equations are applicable for a plant treatment capacity range for 1000 m^3/day to 5678 m^3/day.

POWER COST $= \dfrac{C}{0.033}$ (+2.0E-9X^3 - 4.8E-7X^2 + 6.766783E-2X + 519) $\qquad$ [19]

SUPPLIES COST $= \dfrac{B}{188.4}$ (1.42E-9X^3 + 9.73E-6X^2 + 0.03X + 552) $\qquad\qquad$ [20]

SEDIMENTATION

Capital Cost

The equation used to develop sedimentation capital cost is applic-able for a treatment range of 1000 to 5678m^3/day.

$\dfrac{A}{1489}$ (1.7E-7X^3 + 2.50658E-3X^2 +13.322X + 212964) $\qquad\qquad\qquad$ [21]

Operation and Maintenance Cost

The operation and maintenance cost equation for this process is based on the horsepower requirements for uninterrupted operation of the sludge collector motor. A supply cost equation is alos provided.[1]

POWER COST $= \dfrac{C}{0.033}$ (1.89E-9X^3 - 2.545E-5X^2 + 0.123X + 240) $\qquad\qquad$ [22]

SUPPLIES COST $= \dfrac{B}{188.4}$ (5.0E-10X^3 + 1.268E-5X^2 - 3.582155E-2X + 323) $\quad$ [23]

ION EXCHANGE SOFTENING

Capital Cost.

The equations to be used to estimate this processes capital cost are:

$$\text{UNIT PROCESS COST} = \frac{A}{1489} (2.41E\text{-}6X^3 - 1.8233E\text{-}2X^2 + 61.4X + 18037) \qquad [24]$$

$$\text{ENCLOSURE COST} = \frac{A}{1489} (6.32E\text{-}8X^3 - 4.7438E\text{-}4X^2 + 1.816X + 3131) \qquad [25]$$

Operation and Maintenance Cost

$$\text{POWER COST} = \frac{C}{0.033} (-2.0E\text{-}10X^3 + 5.9E\text{-}7X^2 + 3.3072E\text{-}2X + 14) \qquad [26]$$

$$\text{UNIT PROCESS SUPPLIES COST} = \frac{B}{188.4} (1.7E\text{-}9X^3 - 3.47E\text{-}6X^2 + 0.892X + 416) \qquad [27]$$

$$\text{ENCLOSURE SUPPLIES COST} = \frac{B}{188.4} (-2.0E\text{-}10X^3 - 9.1E\text{-}7X^2 + 3.6E\text{-}2X + 59) \qquad [28]$$

$$\text{REGENERATIVE CHEMICAL COST} = \frac{B}{188.4} (2.0E\text{-}8X^3 - 4.8027E\text{-}4X^2 + 9.729X - 430) \qquad [29]$$

PRESSURE FILTRATION

Capital Cost.

The equations used to estimate the cost for the three surface loading are:

Loading of $120m^3/m^2/day$ (2 gpm/ft^2)

$$\text{Unit Process Cost} = \frac{A}{1489} (-2.005E\text{-}6X^3 + 2.23724E\text{-}2X^2 + 11X + 69817) \qquad [30]$$

$$\text{Enclosure Cost} = \frac{A}{1489} (1.9E\text{-}7X^3 + 4.912E\text{-}5X^2 + 0.5059X + 17765) \qquad [31]$$

Loading of $240m^3/m^2/day$ (4 gpm/ft^2)

$$\text{Unit Process Cost} = \frac{A}{1489} (1.6E\text{-}7X^3 + 2.8862E\text{-}3X^2 + 18.09X + 43534) \qquad [32]$$

$$\text{Enclosure Cost} = \frac{A}{1489} (1.2E\text{-}7X^3 - 7.419E\text{-}4X^2 + 3.081X + 10826) \qquad [33]$$

Loading of $360m^3/m^2/day$ (6 gpm/ft^2)

$$\text{Unit Process Cost} = \frac{A}{1489} (-4.0E\text{-}8X^3 + 2.008E\text{-}3X^2 + 16.38X + 28918) \qquad [34]$$

$$\text{Enclosure Cost} = \frac{A}{1489} (-6.0E\text{-}8X^3 + 7.43E\text{-}4X^2 - 0.161X + 8246) \qquad [35]$$

Operation and Maintenance Cost

The equations used to determine the operation and maintenance cost for the three surface loading are applicable for a treatment plant capacity of 1000 to 5678 m^3/day.

LOADING OF 120m^3/m^2/day (2 gpm/day)

Unit Process Supplies Cost = $\frac{B}{188.4}$ (1.4E-9X^3 + 2.48E-6X^2 + 0.1302X + 198) [36]

Power Cost = $\frac{C}{0.033}$ (1.5E-10X^3 + 5.78E-6X^2 + 2.096E-2X + 61) [37]

Enclosure Supplies Cost = $\frac{B}{188.4}$ (1.6E-9X^3 + 2.94E-6X^2 + 3.678E-2X + 259) [38]

LOADING OF 240m^3/m^2/day (4gpm/day)

Unit Process Supplies Cost = $\frac{B}{188.4}$ (3.0E-10X^3 + 3.58E-6X^2 + 5.968E-2X + 189) [39]

Power Cost = $\frac{C}{0.033}$ (-8.0E-10X^3 + 1.082E-5X^2 - 1.682E-2X + 70) [40]

Enclosure Supplies Cost = $\frac{B}{188.4}$ (1.936E-5 - 4.87E-2X + 281) [41]

LOADING OF 360m^3/m^2/day (6 gpm/day)

Unit Process Supplies Cost = $\frac{B}{188.4}$ (1.0E-10X^3 + 1.97E-6X^2 + 5.0E-2X + 123) [42]

Power Cost = $\frac{C}{0.033}$ (7.0E-8X^3 - 5.164E-4X^2 + 1.134X - 697) [43]

Enclosure Supplies Cost = $\frac{B}{188.4}$ (1.4E-9X^3 + 1.62E-5X^2 - 9.12E-3X + 146) [44]

GRAVITY FILTRATION

Capital Cost.

The equations used to estimate the capital cost for the three surface loading are applicable for a treatment capacity of 1000 to 5678m^3/day.

LOADING OF 120m^3/m^2/day (2 gpm/day)

Unit Process Cost = $\frac{A}{1489}$ (-7.4E-7X^3 + 1.239024E-2X^2 - 11.61X + 113340) [45]

Enclosure Cost = $\frac{A}{1489}$ (-2.1E-7X^3 + 3.34E-3X^2 - 4.542X + 20213) [46]

LOADING OF 240m^3 /m^2 /day (4 gpm/day)

Unit Process Cost = $\dfrac{A}{1489}$ (-3.2E-7X^3 + 5.3627E-3X^2 - 7.779X + 94097)　　　　[47]

Enclosure Cost = $\dfrac{A}{1489}$ (1.2E-7X^3 - 1.356E-4X^2 + 0.938X + 13326)　　　　[48]

LOADING OF 360m^3 /m^2 /day (6 gpm/day)

Unit Process Cost = $\dfrac{A}{1489}$ (-6/7E-7X^3 + 7.462E-3X^2 - 13.87X + 85931)　　　　[49]

Enclosure Cost = $\dfrac{A}{1489}$ (-6.0E-8 + 7.939E-4X^2 - 0.584X + 10642)　　　　[50]

Operation and Maintenance Cost

　　　The operation and maintenance cost equations for the three surface loading rates are applicable for a treatment capacity of 1000 to 5678 m^3/day.

LOADING OF 120m^3 /m^2 /day (2 gpm/day)

Unit Process Supplies Cost = $\dfrac{B}{188.4}$ (8.16E-10X^3 + 1.23E-5X^2 + 3.67E-2X + 290)
　　　　[51]

Power Cost = $\dfrac{C}{0.033}$ (-6.0E-10X^3 + 1.055E-5X^2 + 5.3E-3X + 71)　　　　[52]

Enclosure Supplies Cost = $\dfrac{B}{188.4}$ (-2.7E-9X^3 + 1.07E-5X^2 + 0.1921X - 14)　　　　[53]

LOADING OF 240m^3 /m^2 /day (4 gpm/day)

Unit Process Supplies Cost = $\dfrac{B}{188.4}$ (-9.0E-10X^3 + 1.076E-5X^2 + 6.0E-3X + 274)
　　　　[54]

Power Cost = $\dfrac{C}{0.033}$ (-6.0E-10X^3 + 1.018E-5X^2 - 2.18E-2X + 87)　　　　[55]

Enclosure Supplies Cost = $\dfrac{B}{188.4}$ (3.0E-9X^3 - 2.097E-5X^2 + 0.1168X)　　　　[56]

LOADING OF 360m^3 /m^3 /day (6 gpm/day)

Unit Process Supplies Cost = $\dfrac{B}{188.4}$ (2.0E-10X^3 - 8.5E-7X^2 + 3.66E-2X + 211) [57]

Power Cost = $\dfrac{C}{0.033}$ (3.0E-10X^3 - 2.18E-6X^2 + 2.08E-2X + 18)　　　　[58]

Enclosure Supplies Cost = $\dfrac{B}{188.4}$ (8.3E-10X^3 - 1.63E-5X^2 + 0.121X + 28)　　　　[59]

DEMINERALIZATION

Capital Cost.

The equations used to estimate the capital cost for this process are applicable for a treatment plant capacity of 227 to 5678 m^3 /day.

$$\text{Unit Process Cost} = \frac{A}{1489} (1.09\text{E-}5X^3 - 0.1149X^2 + 473X + 107436) \qquad [60]$$

$$\text{Enclosure Cost} = \frac{A}{1489} (-9.833\text{E-}8X^3 + 8.6827\text{E-}4X^2 + 5.65X + 3581) \qquad [61]$$

Operation and Maintenance Cost

The operation and maintenance cost equations for demineralization are applicable for a treatment plant capacity of 227 to 5678m^3 /day.

$$\text{Power Cost} = \frac{C}{0.033} (-1.9\text{E-}9X^3 + 2.1\text{E-}6X^2 + 0.145338X - 36) \qquad [62]$$

$$\text{Enclosure Supplies Cost} = \frac{B}{188.4} (-2.0\text{E-}10X^3 + 1.67\text{E-}6X^2 + 0.122388X + 78) \qquad [63]$$

$$\text{Regenerative Chemical Cost} = \frac{B}{188.4} \; 67 \; X^{1.014} \qquad [64]$$

$$\text{Unit Process Supplies Cost} = \frac{B}{188.4} \; 242 \; X^{0.535} \qquad [65]$$

REVERSE OSMOSIS

Capital Cost.

The equation used to determine the capital cost for reverse osmosis are:

$$\text{Unit Process Cost} = \frac{A}{1489} (-7.85\text{E-}6X^3 + 0.13754X^2 - 22.88X + 122357) \qquad [66]$$

$$\text{Enclosure Cost} = \frac{A}{1489} (-1.9\text{E-}7X^3 + 6.3898\text{E-}4X^2 + 14.83X + 2486) \qquad [67]$$

Operation and Maintenance Cost

The operation and maintenance cost equations for reverse osmosis are:

$$\text{Unit Process Supplies} = \frac{B}{188.4} (98 \; X^{0.866}) \qquad [68]$$

$$\text{Power Cost} = \frac{C}{0.033}\ (26X) \qquad [69]$$

$$\text{Enclosure Supplies Cost} = \frac{B}{188.4}\ (2.097E\text{-}5X^3 + 0.277245X + 24) \qquad [70]$$

ELECTRODIALYSIS

Capital Cost.

The equations used to determine the capital cost for electrodialysis are:

$$\text{Unit Process Cost} = \frac{A}{1489}\ (-1.31E\text{-}6X^3 + 1.2897E\text{-}2X^2 + 214.61X + 65344) \qquad [71]$$

$$\text{Enclosure Cost} = \frac{A}{1489}\ (2.3E\text{-}7X^3 + 3.248E\text{-}3X^2 + 5.711X + 5067) \qquad [72]$$

Operation and Maintenance Cost

The operation and maintenance cost equations for electrodialysis are:

$$\text{Unit Process Supplies Cost} = \frac{B}{188.4}\ (55.5\ X^{0.8903})$$

$$\text{Power Cost} = \frac{C}{0.033}\ (20\ X^{1.0375}) \qquad [74]$$

$$\text{Enclosure Supplies Cost} = \frac{B}{188.4}\ (-2.0E\text{-}8X^3 + 2.0052E\text{-}4X^2 - 0.1575X + 194) \qquad [75]$$

CHEMICAL FEED SYSTEM

Costs (Capital and Operation and Maintenance)

Powdered Activated Carbon Chemical Feed System

The capital cost equations for this chemical feed system are applicable for dosages of 20 mg/l or less and 50 mg/l. The applicable plant treatment capacity range is 1000 to 5678 m^3/day.[1]

Dosage of 50 mg/l

$$\text{Unit Process Cost (for 1000 to 3000 } m^3 \text{ /day)} = \frac{A}{1489}(\$6200) \qquad [76]$$

$$\text{Unit Process Cost (for 3000 to 5680 } m^3 \text{ /day)} = \frac{A}{1489}\begin{array}{l}(-2.44E\text{-}8X^3 + 6.576E\text{-}4X^2 \\ -3.13235X + 10393)\end{array} \qquad [77]$$

Enclosure Cost (for 1000 to 4500 m^3 / day) = $\frac{A}{1489}$($3700) [78]

Enclosure Cost (for 4500 to 5578 m^3 /day) = $\frac{A}{1489}$ (0.58 X $^{1.0415}$) [79]

Dosage of 20 mg/1 or less

Unit Process Cost = $\frac{A}{1489}$ (6200) [80]

Enclosure Cost = $\frac{A}{1489}$ (3700) [81]

Dosage of 50 mg/1 or less

Power Cost = $\frac{C}{0.033}$(80) [82]

Enclosure Supplies Cost = $\frac{B}{188.4}$(70) [83]

Unit Process Supplies Cost = $\frac{B}{188.4}$(60) [84]

Coagulant Chemical Feed System

The capital cost equations for this chemical feed system are based on a system dosage capacity of 50 mg/1 or less. The applicable plant treatment range is 1000 to 5678m^3 /day.[1]

Unit Process Cost = $\frac{A}{1489}$ (15,000) [85]

Enclosure Cost = $\frac{A}{1489}$ (3650) [86]

The annual operation and maintenance cost equations for this chemical feed systme are based on the power usage, unit process and enclosure supplies expenditures. The applicable plant treatment range is 1000 to 5678m^3/day.

Power Cost = $\frac{C}{0.033}$ (240) [37]

Unit Process Supplies = $\frac{B}{188.4}$ (240) [88]

Enclosure Supplies = $\frac{B}{188.4}$(70) [89]

Hydrated Lime Chemical Feed System

The capital cost equations for this feed system are based on chemical dosages of 200 mg/1, 100 mg/1 and 50 mg/1 or less. The applicable plant treatment range is 1000 to 5678 m^3/day.[1]

Dosage of 200 mg/1

Unit Process Cost (for 1000 to 1750 m^3/day) $= \dfrac{A}{1489}(24{,}000)$ [90]

Unit Process Cost (for 1750 to 5680 m^3/day) $= \dfrac{A}{1489}(-2.27E-7X^3 + 3.287E-3X^2 - 10.69X + 34222)$ [91]

Enclosure Cost $= \dfrac{A}{1489}(-1.35E-8X^3 + 2.165E-4X^2 - 0.34260X + 6286)$ [92]

Dosage of 100 mg/1

Unit Process Cost (for 1000 to 2500 m^3/day) $= \dfrac{A}{1489}(15500)$ [93]

Unit Process Cost (for 2500 to 5678 m^3/day) $= \dfrac{A}{1489}(-4.03E-7X^3 + 3.72943E-3X^2 - 6.912X + 15722)$ [94]

Enclosure Cost (for 1000 to 2500 m^3/day) $= \dfrac{A}{1489}(3650)$ [95]

Enclosure Cost (for 2500 to 5800 m^3/day) $= \dfrac{A}{1489}(-1.56E-7X^3 + 1.759E-3X^2 - 5.376X + 8474)$ [96]

Dosage of 50 mg/1 or less

Unit Process Cost $= \dfrac{A}{1489}(15{,}500)$ [97]

Enclosure Cost $= \dfrac{A}{1489}(3700)$ [98]

The annual operation and maintenance cost equations for hydrated lime chemical feed are for dosages of 200 mg/1, 100 mg/1 and 50 mg/1 or less. The applicable plant treatment range is 1000 to 5678 m^3/day.[1]

Dosage of 200 mg/1

Unit Process Supplies Cost $= \dfrac{B}{188.4}(-2.4E-10X^3 + 8.03E-6X^2 - 0.01205206X + 205)$ [99]

Enclosure Supplies Cost (for 1000 to 2000 m^3/day) $= \dfrac{B}{188.4}(112)$ [100]

Enclosure Supplies Cost (for 2000 to 5678 m^3/day) = $\dfrac{B}{188.4}$ (1.6E-10X^3

$$-2.25\text{E-}6\text{X}^2 + 0.024\text{X} + 66) \qquad [101]$$

Power Cost = $\dfrac{C}{0.033}$ (4.56E-10X^3 + 4.21E-6X^2 + 7.13E-3X + 183) $\qquad$ [102]

Dosage of 100 mg/1

Unit Process Supplies Cost (for 1000 to 2500 m^3/day) = $\dfrac{B}{188.4}$(150) $\qquad$ [103]

Unit Process Supplies Cost (for 2500 to 5800 m^3/day) = $\dfrac{B}{188.4}$(1.1E-9X^3

$$- 8.29\text{E-}7\text{X}^2 + 0.044008\text{X} + 76)$$
$$[104]$$

Enclosure Cost (for 1000 to 2500 m^3/day) = $\dfrac{B}{188.4}$(70) $\qquad$ [105]

Enclosure Cost (for 2500 to 5680 m^3/day) = $\dfrac{B}{188.4}$(-2.2E-10X^3 + 7.24E-6X^2

$$-0.02699206\text{X} + 96) \quad [106]$$

Power Cost (for 1000 to 2000 m^3/day) = $\dfrac{C}{0.033}$(127) $\qquad$ [107]

Power Cost (for 2000 to 5680 m^3/day) = $\dfrac{C}{0.033}$(1.13E-9X^3 – 5.822E-6X^2 + 0.033X

$$+ 57) \qquad [108]$$

Dosage of 50 mg/1 or less

Unit Process Cost (for 1000 to 2500 m^3/day) = $\dfrac{B}{188.4}$(150) $\qquad$ [109]

Unit Process Cost (for 2500 to 5680 m^3/day) = $\dfrac{B}{188.4}$(5.33E-10X^3 – 4.0E-6X^2

$$+ 0.012\text{X} + 135) \quad [110]$$

Enclosure Supplies Cost = $\dfrac{B}{188.4}$(70) $\qquad$ [111]

Power Cost = $\dfrac{C}{0.033}$(127) $\qquad$ [112]

Polymer Chemical Feed

The capital cost equations for this chemical feed system are based on chemical dosages of 5, 3, 1 and 0.5 mg/1. The applicable plant treatment capacity range is 1000 to 5678 m^3/day.

Dosage of 5 mg/1

Unit Process Cost = $\dfrac{A}{1489}$ (-2.1E-7X^3 + 2.208E-3X^2 – 4.73X + 15821) $\qquad$ [113]

Enclosure Cost = $\dfrac{A}{1489}$(-2.14E-7X^3 + 3.83E-6X^2 + 1.3E-3X + 55) $\qquad$ [114]

Dosage of 3 mg/1

Unit Process Cost $= \dfrac{A}{1489} (5.75E-8X^3 - 1.0E-4X^2 - 0.617X + 12120)$ [115]

Enclosure Cost $= \dfrac{A}{1489}(1420 \ X^{0.1415})$ [116]

Dosage of 1 mg/1

Unit Process Cost (for 1000 to 2500 m^3/day) $= \dfrac{A}{1489}(7.500)$ [117]

Unit Process Cost (for 2500 to 5800 m^3/day) $= \dfrac{A}{1489} (7.0E-8X^3 + 6.718E-4X^2 - 1.39X + 7880)$ [118]

Enclosure Cost (for 1000 to 2500 m^3/day) $= \dfrac{A}{1489}(\$3650)$ [119]

Enclosure Cost (for 2500 to 5800 m^3/day) $= \dfrac{A}{1489}(1633 \ X^{0.103})$ [120]

Dosage of 0.5 mg/1

Unit Process Cost $= \dfrac{A}{1489}(\$7500)$ [121]

Enclosure Cost $= \dfrac{A}{1489}(\$3650)$ [122]

The annual operation and maintenance cost equations for the polymer chemical feed system are based on power usage, equipment and enclosure supplies for dosages of 5, 3, 1 and 0.5 mg/1. The plant treatment capacity range is 1000 to 5678 m^3/day.[1]

Dosage of 5 mg/1

Unit Process Supplies Cost (for 2500 to 5800 m^3/day) $= \dfrac{B}{188.4} (2.0E-10X^3 + 3.67E-6X^2 + 3.97E-4X + 168)$ [123]

Unit Process Cost (for 1000 to 2500 m^3/day) $= \dfrac{B}{188.4}(\$200)$ [124]

Power Cost $= \dfrac{C}{0.033}(-1.7E-9X^3 + 1.67E-5X^2 - 0.03188X + 219)$ [125]

Enclosure Supplies Cost (for 1000 to 2500 m^3/day) $= \dfrac{B}{188.4}(\$80)$ [126]

Enclosure Supplies Cost (for 2500 to 5800 m^3/day) $= \dfrac{B}{188.4}(-5.2E-10X^3 + 3.83E-6X^2 + 1.3E-3X + 55)$ [127]

Dosage of 3 mg/l

Unit Process Supplies Cost (for 1000 to 3500 m^3/day) = $\dfrac{B}{188.4}$ (200) [128]

Unit Process Supplies Cost (for 3500 to 5800 m^3/day) = $\dfrac{B}{188.4}$ ($-2.67E-9X^3$
$+ 5.0E-5X^2 - 0.2623X + 626$)
[129]

Power Costs (for 1000 to 2500 m^3/day) = $\dfrac{C}{0.033}$ (190) [130]

Power Costs (for 2500 to 5678 m^3/day) = $\dfrac{C}{0.033}$ ($-2.76E-9X^3 + 3.3E-5X^2$
$-0.0974X + 275$) [131]

Enclosure Supplies Cost (for 2500 to 5680 m^3/day) = $\dfrac{B}{188.4}$ (13.3 X$^{0.221}$)
[132]

Enclosure Supplies Cost (for 1000 to 2500 m3/day) = $\dfrac{B}{188.4}$ (70) [132A]

Dosage of 1 mg/l

Unit Process Cost (for 1000 to 3000 m^3/day) = $\dfrac{B}{188.4}$ (125) [133]

Unit Process Cost (for 3000 to 5800 m^3/day) = $\dfrac{B}{188.4}$ ($4.8E-9X^3 - 5.07E-5X^2$
$+ 0.2008X - 166$) [134]

Power Cost (for 1000 to 4750 m^3/day) = $\dfrac{C}{0.033}$ (175) [135]

Power Cost (for 4750 to 5800 m^3/day) = $\dfrac{C}{0.033}$ (2.49 X$^{0.499}$) [136]

Enclosure Supplies Cost = $\dfrac{B}{188.4}$ (70) [137]

Dosage of 0.5 mg/l

Unit Process Supplies Cost (for 1000 to 3000 m^3/day) = $\dfrac{B}{188.4}$ (125) [138]

Power Cost = $\dfrac{C}{0.033}$ (175) [139]

Enclosure Supplies Cost = $\dfrac{B}{188.4}$ (70) [140]

Polyphosphate Chemical Feed

The capital cost equations for the polyphosphate chemical feed
system are based on dosages of up to 5 mg/l. The applicable plant
treatment capacity range is 1000 to 5678 m^3/day.

$$\text{Unit Process Cost} = \frac{A}{1489} (2700) \qquad\qquad [141]$$

$$\text{Enclosure Cost} = \frac{A}{1489} (3700) \qquad\qquad [142]$$

The operation and maintenance cost equations are based on power usage, and supplies for the unit process system and its enclosure. The applicable plant treatment capacity range is 1000 to 5678 m^3/day.

$$\text{Enclosure Supplies Cost} = \frac{B}{188.4} (60) \qquad\qquad [143]$$

$$\text{Unit Process Supplies} = \frac{B}{188.4} (50) \qquad\qquad [144]$$

$$\text{Power Cost} = \frac{C}{0.033} (118) \qquad\qquad [145]$$

Chlorine

The chlorine capital cost equations are based on dosages 10 mg/1 and 5 mg/1 or less. The applicable plant treatment capacity range is 1000 to 5678 m^3/day.

Dosage of 10 mg/1

$$\text{Unit Process Cost (for 1000 to 3500 } m^3/\text{day)} = \frac{A}{1489} (7000) \qquad\qquad [146]$$

$$\text{Unit Process Cost (for 3500 to 5800 } m^3/\text{day)} = \frac{A}{1489} (1.56E\text{-}7X^3 - 1.15E\text{-}3X^2 + 2.27 + 6026) \qquad [147]$$

$$\text{Enclosure Cost} = \frac{A}{1489} (3650) \qquad\qquad [148]$$

Dosage of 5 mg/1 or less

$$\text{Unit Process Cost} = \frac{A}{1489} (7000) \qquad\qquad [149]$$

$$\text{Enclosure Cost} = \frac{A}{1489} (3650) \qquad\qquad [150]$$

Chlorine

The operation and maintenance cost equations for chlorine are based on power usage and the supplies for the unit process system and its enclosure. The applicable plant treatment capacity is 1000 to 5678 m^3/day.

Dosage of 10 mg/1

Unit Process Supplies Cost (for 1000 thru 3000 m³/day) = $\frac{B}{188.4}$ (77)   [151]

Unit Process Supplies Cost (for 3000 thru 5800 m³/day) = $\frac{B}{188.4}$ (-2.3E-9X³

$4.035E-5X^2 - 0.188X + 338$) [152]

Dosage of 5 mg/1 or less

Unit Process Supplies Cost = $\frac{B}{188.4}$ (77)   [153]

Enclosure supplies cost and power for chlorine dosages of 10 mg/1 and 5 mg/1 or less can be determined by the following equations:

Enclosure Cost = $\frac{B}{188.4}$ (70)   [154]

Power Cost = $\frac{C}{0.033}$ (40)   [155]

Ozone (On-site generation)

The applicable plant treatment capacity range is 1000 to 5678 m³/day.

Dosage of 10 mg/1

Unit Process Cost = $\frac{A}{1489}$ ($-5.4E-7X^3 + 6.71E-3X^2 + 17.39X + 92185$)   [156]

Enclosure Cost = $\frac{A}{1489}$ ($-5.89E-8X^3 + 4.18E-4X^2 + 0.93X + 2763$)   [157]

Dosage of 5 mg/1

Unit Process Cost = $\frac{A}{1489}$ ($-8.1E-7X^3 + 7.94E-3X^2 + 2.43X + 81386$)   [158]

Enclosure Cost = $\frac{A}{1489}$ ($-1.74E-7X^3 + 1.79E-3X^2 - 4.53X + 6845$)   [159]

Dosage of 1.5 mg/1

Unit Process Cost = $\frac{A}{1489}$ ($1.8E-7X^3 - 4.6 E-4X^2 + 7.67X + 67471$)   [160]

Enclosure Cost = $\frac{A}{1489}$ ($1.745E-8X^3 - 1.436E-4X^2 + 0.526X + 3,005$)   [161]

Ozone (On-site generation)

The annual operation and maintenance cost equations for the on-site generation at ozone are based on power useage and the supplies for the

unit process system and its enclosure. The applicable plant treatment capacity range is 1000 to 5678 m^3/day.

Dosage of 10 mg/1

$$\text{Unit Process Supplies Cost} = \frac{B}{188.4} (3.11E-8X^3 - 2.274E-4X^2 + 1.33X + 1426) \quad [162]$$

$$\text{Power Cost} = \frac{C}{0.033} (-4.4E-9X^3 + 7.62E-5X^2 + 1.52X + 1342) \quad [163]$$

$$\text{Enclosure Supplies Cost (for 2500 to 5800 } m^3\text{/day)} = \frac{B}{188.4} (7.0E-10X^3 + 7.1E-7X^2 - 0.0135X + 122) \quad [164]$$

$$\text{Enclosure Supplies Cost (for 1000 to 2500 } m^3\text{/day)} = \frac{B}{188.4} (6.0E-9X^3 - 3.6E-5X^2 + 0.066X + 58) \quad [165]$$

Dosage of 5 mg/1

$$\text{Unit Process Supplies Cost} = \frac{B}{188.4} (1.69E-8X^3 - 2.14E-4X^2 + 1.36X + 483) \quad [166]$$

$$\text{Power Cost} = \frac{C}{0.033} (-1.07E-8X^3 + 1.63E-4X^2 + 0.216X + 1183) \quad [167]$$

$$\text{Enclosure Supplies Cost} = \frac{B}{188.4} (-4.9E-10X^3 + 5.78E-6X^2 - 0.014667X + 90) \quad [168]$$

Dosage of 1.5 mg/1

$$\text{Unit Process Supplies Cost} = \frac{B}{188.4} (-8.0E-10X^3 + 1.52E-6X^2 + 0.2167X + 1183 \quad [169]$$

$$\text{Power Cost} = \frac{C}{0.033} (-4.8E-9X^3 + 6.994E-5X^2 + 0.0153X + 381) \quad [170]$$

$$\text{Enclosure Supplies Cost} = \frac{B}{188.4} (2.0E-10X^3 - 1.61E-6X^2 + 6.896E-3X + 60) \quad [171]$$

CALCIUM HYPOCHLORITE CHEMICAL FEED SYSTEM

The capital cost equations for this feed system are based on dosages of 1.5, 5 and 10 mg/1. The applicable plant treatment range is 1000 to 5678 m^3/day.

Dosage of 10 mg/1

$$\text{Unit Process Cost (for 1000 to 5678 } m^3\text{/day)} = \frac{A}{1489} (-3.7E-7X^3 + 3.763E-3X^2 - 8.63X + 11588) \quad [172]$$

Enclosure Cost (for 1000 to 2000 m³/day) = $\frac{A}{1489}$ (3900)   [173]

Enclosure Cost (for 2000 to 5680 m³/day) = $\frac{A}{1489}$ (2145 X$^{0.0806}$)   [174]

Dosage of 5 mg/1

Unit Process Cost (for 1000 to 1750 m³/day) = $\frac{A}{1489}$ (5250)   [175]

Unit Process Cost (for 1750 to 5680 m³/day) = $\frac{A}{1489}$ (4.01E–8X^3 – 5.779E–4X^2 + 2.854X + 1784)   [176]

Enclosure Cost (for 1000 to 2000 m³/day) = $\frac{A}{1489}$ (3670)   [177]

Enclosure Cost (for 2000 to 5678 m³/day) = $\frac{A}{1489}$ (1633 X$^{0.104}$)   [178]

Dosage of 1.5 mg/1

Unit Process Cost = $\frac{A}{1489}$ (5360)   [179]

Enclosure Cost = $\frac{A}{1489}$ (3670)   [180]

The annual operation and maintenance cost equations for this process are based on the power usage and the supplies for the unit process and its enclosure. The applicable plant treatment range is 1000 to 5678 m³/day.

Dosage of 10 mg/1

Power Cost (for 1000 to 2000 m³/day) = $\frac{C}{0.033}$ ((175)   [181]

Power Cost (for 2000 to 5680 m³/day) = $\frac{C}{0.033}$ (–2.17E–9X^3 + 3.078E–5X^2 –0.09607X + 256)   [182]

Unit Process Supplies Cost = $\frac{B}{188.4}$ (–9.0 E–10X^3 + 1.489E–5X^2 – 0.0181X + 97)   [183]

Enclosure Cost (for 1000 to 3000 m³/day) = $\frac{B}{188.4}$ (70)   [184]

Enclosure Cost (for 3000 to 5680 m³/day) = $\frac{B}{188.4}$ (6.9E–10X^3 – 1.08E–5X^2 0.058X – 26)   [185]

Dosage of 5 mg/1

Unit Process Supplies Cost (for 1000 to 2000 m³/day) = $\frac{A}{1489}$ (21 X$^{0.189}$)   [186]

Unit Process Supplies Cost (for 2000 to 5678 m^3/day) = $\dfrac{A}{1489}$ (90) [187]

Dosage of 1.5 mg/1

Unit Process Supplies Cost = $\dfrac{A}{1489}$ (90) [188]

Power Cost = $\dfrac{C}{0.033}$ (112) [189]

Supplies Cost = $\dfrac{B}{188.4}$ (70) [190]

SODIUM HYPOCHLORITE CHEMICAL FEED SYSTEM

The capital cost equations for sodium hypochlorite are based on chemical dosages of 10, 5, and 1.5 mg/1. The applicable plant treatment range is 1000 to 5678 m^3/day.

Dosage of 10 mg/1

Unit Process Cost (for 1000 to 2250 m^3/day) = $\dfrac{A}{1489}$ (4000) [191]

Unit Process Cost (for 2250 to 5678 m^3/day) = $\dfrac{A}{1489}$ (1398 X $^{0.139}$) [192]

Dosage of 5 mg/1

Unit Process Cost (for 1000 to 2250 m^3/day) = $\dfrac{A}{1489}$ (3690) [193]

Unit Process Cost (for 2250 to 2500 m^3/day) = $\dfrac{A}{1489}$ (576 X $^{0.247}$) [194]

Unit Process Cost (for 2500 to 5680 m^3/day) = $\dfrac{A}{1489}$ (4000) [195]

Dosage of 1.5 mg/1

Unit Process Cost = $\dfrac{A}{1489}$ (3690) [196]

The enclosure capital cost for all sizes of the sodium hypochlorite chemical feed system is determined by $\dfrac{A}{1489}$ ($3700) [197]

The annual operation and maintenance cost for the sodium hypochlorite chemical feed system is determined by cost equations for unit process supplies, enclosure supplies and power usage for the various dosages. Applicable plant treatment range is 1000 to 5678 m^3/day.[1]

Dosages of 10 mg/l

Unit Process Supplies Cost (for 1000 thru 1800 m^3 /day) = $\frac{B}{188.4}$ (80)   [198]

Unit Process Supplies Cost (for 1800 thru 3500 m3 /day) = $\frac{B}{188.4}$ (-8.0E-10X^3
$+ 2.65E-6X^2 + 6.0E-3X + 64$)
    [199]

Unit Process Supplies Cost (for 3500 thru 5700 m^3/day) = $\frac{B}{188.4}$ (89)   [200]

Enclosure Supplies Cost = $\frac{B}{188.4}$ (70)   [201]

Power Cost (for Treatment of 1000 to 1800 m^3/day) = $\frac{C}{0.033}$ (70)   [202]

Power Cost (for Treatment of 1800 to 5678 m^3/day) = $\frac{C}{0.033}$ (-2.1E-9X^3 + 1.986E-5X^2
$- 0.04367X + 97$)   [203]

Dosages of 5 mg/l

Unit Process Cost (for 1000 to 1800 m^3/day) = $\frac{B}{188.4}$ (70)   [204]

Unit Process Cost (for 1800 to 3000 m^3/day) = $\frac{B}{188.4}$ (6.0E-10X^3 - 4.92E-5X^2
$+ 0.14X - 58$)   [205]

Unit Process Cost (for 3000 to 5678 m^3/day) = $\frac{B}{188.4}$ (80)   [206]

Enclosure Supplies Cost = $\frac{B}{188.4}$ (70)   [207]

Power Cost (for 1000 to 2100 m^3/day) = $\frac{C}{\$0.033}$ (60)   [208]

Power Cost (for 2100 to 2900 m^3/day) = $\frac{C}{\$0.033}$ (1.85 X $^{.456}$)   [209]

Power Cost (for 2900 to 5680 m^3/day) = $\frac{C}{\$0.033}$ (70)   [210]

Dosage of 1.5 mg/l

Unit Process Supplies Cost = $\frac{B}{188.4}$ (69)   [211]

Enclosure Supplies Cost = $\frac{B}{188.4}$ (70)   [212]

Power Cost = $\frac{C}{\$0.033}$ (60)   [213]

SODIUM HYPOCHLORITE (ON SITE GENERATION)

Dosages of 10 mg/1

$$\text{Unit Process Cost} = \frac{A}{1489}\,(1.9E\text{-}7X^3 - 2.364E\text{-}4X^2 + 2.02X + 20{,}046) \tag{214}$$

$$\text{Enclosure Cost} = \frac{A}{1489}\,(-4.5E\text{-}8X^3 + 6.0E\text{-}4X^2 - 0.9034X + 11319) \tag{215}$$

Dosages of 5 mg/1

$$\text{Unit Process Cost} = \frac{A}{1489}\,(-4.0E\text{-}8X^3 + 1.028E\text{-}3X^2 + 2.511X + 3704) \tag{216}$$

$$\text{Enclosure Cost} = \frac{A}{1489}\,(-5.0E\text{-}8X^3 + 3.606E\text{-}4X^2 + 1.557X + 5248) \tag{217}$$

Dosages of 1.5 mg/1

$$\text{Unit Process Cost} = \frac{A}{1489}\,(-1.3E\text{-}8X^3 + 1.83E\text{-}4X^2 + 0.98X + 5428) \tag{218}$$

$$\text{Enclosure Cost} = \frac{A}{1489}\,(-4.0E\text{-}8X^3 + 2.63E\text{-}4X^2 + 1.151X + 3141) \tag{219}$$

Dosage of 10 mg/1

$$\text{Unit Process Supplies Cost} = \frac{B}{188.4}\,(8.0E\text{-}10X^3 + 3.14E\text{-}6X^2 + 0.1096X + 296) \tag{220}$$

$$\text{Salt Cost} = \frac{B}{188.4}\,(3.0E\text{-}9X^3 + 5.552E\text{-}5X^2 + 0.4591X + 558) \tag{221}$$

$$\text{Enclosure Supplies Cost} = \frac{B}{188.4}\,(-5.0E\text{-}10X^3 + 7.82E\text{-}6X^2 - 0.0152X + 249) \tag{222}$$

$$\text{Power Cost} = \frac{C}{\$0.033}\,(-1.144E\text{-}7X^3 + 1.132E\text{-}3X^2 - 2.33X + 2342) \tag{223}$$

Dosage of 5 mg/1

$$\text{Unit Process Supplies Cost} = \frac{B}{188.4}\,(-3.5E\text{-}9X^3 + 4.382E\text{-}5X^2 + 0.0149X + 142) \tag{224}$$

$$\text{Salt Cost} = \frac{B}{188.4}\,(1.62E\text{-}8X^3 + 3.58E\text{-}6X^2 - 0.341X + 110) \tag{225}$$

$$\text{Enclosure Supplies Cost} = \frac{B}{188.4}\,(-2.6E\text{-}9X^3 + 2.765E\text{-}5X^2 - 0.0602X + 208) \tag{226}$$

$$\text{Power Cost} = \frac{C}{\$0.033}\,(2.15E\text{-}9X^3 + 1.102E\text{-}4X^2 - 0.093X + 459) \tag{227}$$

Dosage of 1.5 mg/1

$$\text{Unit Process Supplies Cost} = \frac{B}{188.4}\,(6.0E\text{-}10X^3 - 2.098E\text{-}5X^2 + 0.1226X + 36) \tag{228}$$

$$\text{Salt Cost} = \frac{B}{188.4} \left(3.8E-9X^3 - 3.924E-5X^2 + 0.28X - 140 \right) \qquad [229]$$

$$\text{Enclosure Cost} = \frac{B}{188.4} \left(-2.9E-9X^3 + 2.558E-5X^2 - 0.0389X + 105 \right) \qquad [230]$$

$$\text{Power Cost} = \frac{C}{\$0.033} \left(-1.8E-10X^3 + 2.235E-5X^2 + 0.007X + 170 \right) \qquad [231]$$

WASTE DISPOSAL FACILITIES

The capital cost equation for this facility is:

$$\text{Capital Cost} = \frac{A}{1489} \left(2.0E-8X^3 - 2.399E-4X^2 + 2.98X + 1880 \right) \qquad [232]$$

The operation and maintenance cost equations for waste solid removal is applicable for treatment plant capacities in the range of 227 to 5678 m^3 /day.

$$\frac{B}{188.4} \left(2.7E-8X^3 - 3.2482E-4X^2 + 1.96X + 6 \right) \qquad [233]$$

LABOR COST

The annual labor cost is based on the National Average Earnings Rate published by the United States Department of Labor and Bureau of Statistics as previously explained. The applicable plant treatment capacity range is 1000 to 5678 m^3/day. The labor cost equations include wage and fringe benefits.

Type 1 facility

$$\frac{D}{7.30} \left(1.3E-9X^3 - 6.624E-5X^2 + 1.74X + 2199 \right) \qquad [234]$$

Type 2 facility

$$\frac{D}{7.30} \left(-1.25E-7X^3 - 1.21553E-3X^2 - 0.582X + 63149 \right) \qquad [235]$$

Type 3 facility

$$\frac{D}{7.30} \left(2.69E-7X^3 - 1.7657E-3X^2 + 8.27X + 74102 \right) \qquad [236]$$

D = Current National Average Earnings Rate determined similare to method described on page

7.30 = National Average Earnings Rate applicable at time of cost development.

The above cost equations can be utilized to estimate the cost required to treat drinking water. The developer of a small rural water system would have to be familiar with the initial groundwater quality and the desired finish water quality to adequately select a unit process or processes. The cost equations can be trended to give an estimate of current cost for water treatment which can be a valuable bit of initial information to the rural community. The cost are developed for average conditions and parameters should be altered to take extraordinary conditions into consideration.

"The plant per capita design rates in the above Table are based on water usage or usage rate and on an assumed amount of storage in the system. For the smallest system, no storage was assumed in the system; therefore, the plant design rate is based on the maximum rate of usage which would be for watering lawns or gardens. For the largest system, a normal maximum day per capita usage was assumed along with adequate storage in the system to supply any water requirements which would exceed this rate.

Cost data presented are appropriate for average situations. They should permit development of preliminary cost estimates for water treatment facilities when used with judgment regarding local conditions. An engineer should be engaged to review local conditions and to evaluate the manner in which this report's cost information will be used.

It is emphasized that the cost data contained in this report cannot be used as a substitute for detailed cost estimates based on a particular water treatment situation. Among the many variables which affect actual construction costs are the following:

a. Characteristics and complexity of specific plant design.

b. Current and projected labor costs.

c. Contractor's attitudes regarding their need for work.

d. Availability of materials.

e. Climate and seasonal factors.

Local factors can also have a significant effect both on construction and on operation and maintenance costs." (1)

The capital and operation & maintenance cost equations were generated to cover water treatment plan capacities of 227 m^3/day (0.06 mgd) to 5678 m^3/day (1.5 mgd). Diffused aeration, clarification processes, filtration and disinfection methods cost equations vary from this

capacity range because of the unsound economics of their operation in the lower flow ranges.

A. Capital Costs

"Cost [equations] were developed for treatment processes judged applicable to small water treatment systems. These [equations] relate capital costs to quantities of water treated and to population served. [Estimates of complete water treatment plants may be developed on the basis of these relationships.]

Yard piping, fencing (where applicable), and sitework have been included in the curve for each unit process. When adding unit process costs together some of these items may overlap; this may cause the total cost to exceed actual plant costs by 10 to 25 percent.

Cost data, developed specifically for this report, are based on information from various manufacturers and on the experience and judgment of the investigators. Preliminary designs and engineering cost estimates were developed for each unit process at various low rates. Estimates of construction costs are representative of average price levels as of January, 1977. The Engineering News Record Building Cost Index of that date had a value of 1489.

Included in the capital costs are necessary construction costs, a contingency amount and engineering, legal and administration fees. A cost for fencing is provided for mechanical aeration, diffused aeration, rapid mix, flocculation, sedimentation, ozone contact chamber and waste disposal (lagoons).

Capital costs for unit processes, package plants and enclosures are developed as follows:

1. Construction costs—included are necessary costs for equipment, materials, installation, freight and start-up.

2. Sitework—estimated as 10 percent of the construction cost.

3. Electrical—estimated as 20 percent of the construction cost.

4. Contingency—estimated as 10 percent of the total of construction cost, sitework, electrical and fencing (if applicable).

5. Engineering, legal and administrative—estimated as 15 percent of the total of construction cost, sitework, electrical, fencing (if applicable), and contingency." (1)

"Equipment and materials capital costs are based on use of pre-fabricated, modular, or factory built/field assembled units to minimize on-site construction. Design parameters used for sizing unit processes should not be generally applied to all water treatment situations. Design parameters should be selected on the basis of raw water characteristics for each application.

Enclosure capital costs include costs for a prefabricated insulated metal building, foundation, and necessary plumbing and electrical facilities.

B. OPERATION AND MAINTENANCE COSTS

Based on the average cost information presented, total annual operating and maintenance expenses for various plant components may be developed. Where it was not possible to base operation and maintenance cost data on manufacturers' information, cost elements were estimated.

Actual costs may vary appreciably from the estimated average costs in this report. However, when used with judgment, the data presented should be of value for preliminary cost estimates. The user should recognize the inherent limitations of such estimates and should develop

applicable operating cost estimates based on local conditions.

Cost data adjusted to indicated cost levels for January 1977. To update these costs, they may be trended to the applicable date by using the "Wholesale Prices and Price Indexes" as published by the Bureau of Labor Statistics, U.S. Department of Labor. The Wholesale Price Index for January 1977 is 188.4. If knowledge of a specific local situation indicates a more appropriate updating method, such information should be utilized.

Major elements of operation and maintenance costs considered include labor, power, supplies and chemicals. Annual labor cost equations are provided for the following types of treatment facilities:

Type 1 - minimal treatment such as disinfection only.

Type 2 - conventional facility with chemical addition, clarification, filtration and disinfection.

Type 3 - conventional facility described above with one additional special process such as ion exchange, electrodialysis, reverse osmosis.

The labor costs indicate the total requirements to adequately operate and maintain the facility. Man-hour requirements for these treatment facilities are based on desirable levels of operator attention for each type of plant. [For the Type 1 facility it is estimated that one part-time operator is required. For the Type 2 and Type 3 facilities, round-the-clock operation with one to two operators per shift is recommended.] The average hourly earnings rate (wages plus fringe benefits) used is $7.30. This rate is based on the National Average Earning Rate published by the U.S. Department of Labor, Bureau

of Labor Statistics, for nonsupervisory employees in the public utility industry, under "Water, Steam and Sanitary Systems", SIC Code 494-7, as of January 1977. [If local conditions indicate a different earnings rate, such information should be used.]

[Power cost equations are provided for the applicable unit processes.] These power costs are based on equipment power requirements, and estimate of the operating time of the equipment, a power cost of $0.03 per kWh and a 10 percent contingency.

Cost [equations] for supplies include costs for normal annual upkeep and improvement materials. Unit process supply cost [equations] include costs for oil, grease, belts, chains, etc. Enclosure supply cost equations include cleaning materials, point, etc. [The supply costs are based on 5 percent of the equipment cost for each unit process, 2 percent of the construction cost for each enclosure and a 10 percent contingency.] Supplies cost curves for electrodialysis and reverse osmosis are exceptions. They are based on estimated costs from manufacturers. Electrodialysis supplies range in cost from $0.20 to $0.30 per 3.8 m^3 (1000 gal), depending on plant size. Reverse osmosis supplies range in cost from $0.20 to $0.50 per 3.8 m^3 (1000 gallons), depending on plant size.

[Chemical costs are provided in Table I, for various chemicals used in water treatment.] These chemical costs are for January 1977 and should be trended as necessary by using the Wholesale Price Index as discussed previously.

[Chemicals not listed in Table I include:] granular activated carbon, regenerative chemicals for activated alumina, ion exchange

softening and demineralization, and salt for sodium hypochlorite on-site generation. Costs for these chemicals are provided by cost equations.

The following unit processes include capital cost and operation and maintenance cost equations and parameters used in cost development. It should be remembered that these equations are for average conditions. The engineer may have to make parameter adjustment for his community's special conditions.

WATER TREATMENT CHEMICAL COST (1)
(January 1977 Prices)

Chemical	Packaging	Price
Activated Carbon (Powdered)	65 lb bags	1-14 bags, 44.45 cents per lb 15-28 bags, 41.95 cents per lb 29-50 bags, 39.45 cents per lb
Alum	100 lb bags	1-9 bags, $16 per bag 10-20 bags, $11 per bag 21-100 bags, $9.25 per bag
Calcium Hypochlorite	100 lb drums	$81.60 per drum
Chlorine	100 lb cylinders	1-9 cylinders, $30 per cylinder 10-24 cylinders, $26 per cylinder
Ferric Chloride	175 lb drums	0-630 lb, 18.65 cents per lb 631-12,000 lb, 17.90 cents per lb
Ferric Sulfate	100 lb bags	1 bag, $10.15 2-20 bags, $8.90 per bag 21-100 bags, $7.65 per bag
Hydrated Lime	50 lb bags	1-40 bags, $2.85 per bag 41-200 bags, $2.23 per bag
Polyphosphate (Sodium Hexameta)	100 lb bags	1-9 bags, $36.80 per bag 10-19 bags, $34.80 per bag
Polymer (Dry) (Wet)	50 lb & 100 lb bags 55 gallon drums	varies, use $2.25 per lb varies, use $0.30 per lb
Potassium Permanganate	110 lb bags 550 lb bags	92.35 cents per lb 73.80 cents per lb

TABLE I

The capital cost equation for the unit processes are of a form such that rapid updating is possible. The independent variable "X" to be used in the equations represent the plant treatment capacity. Capital cost equation for unit processes are of the following form: (1)

$$\frac{A}{1489} \text{ (Equation)} = \text{Cost (Dollars)}$$

where

A = Engineering News

Record Cost Index applicable
to time of interest to user

1489 = Engineering News Record
Cost Index applicable at
time of cost development

Operation and Maintenance costs equations for unit process supplies, enclosure supplies, chemicals and media replacement cost are of a form such that rapid updating of cost equations are possible. The user of these equations would only have to know the plant treatment capacity "X" and the current Whole Price Index. To update the power cost equation a knowledge of the plant treatment capacity "X" and the cost of a kilowatt-hour of energy plus the user's desired contingency is needed. Labor cost are not included in the operation and maintenance cost equations.

For Unit Process Supplies, enclosure supplies, chemical and media replacement cost, the independent variable "X" used in all equations represents the plant treatment capacity. The equations are of the following form:

$$\frac{B}{188.4} \text{ (Equation)} = \text{Cost (Dollars)}$$

B = Wholesale Price Index applicable
to the time of interest to the user.

188.4 = Whole Price Index used at the time of the
Operation and Maintenance cost equation
development.