FINAL REPORT

FEASIBILITY STUDY TO DETERMINE THE PRACTICALITY OF USING POTABLE MUNICIPAL WATER SUPPLIES AS A SOURCE OF CONDENSER COOLING WATER FOR POWER GENERATING FACILITIES

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OWRT Project No. B-226-TEX
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Texas
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WATER
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Prepared for

Office of Water Research and Technology
U.S. Department of the Interior

by

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ABSTRACT

This report discusses the feasibility of using water supplies of a municipality in a once-through cooling system for a thermal power generation unit prior to treatment and distribution in the municipal system. The concept was examined on the assumption that electricity is the primary product produced by the utility and that outlet temperatures for the condenser could be in a range of from 90° to 120°F. The effects of elevated water temperature on water treatment processes and the probable water temperature profile exhibited in a municipal system were investigated. It was determined that treatment conditions would be enhanced and that decreases could be obtained in sedimentation basin size and in the amounts of coagulent required. The length of filter runs would be increased and the use of the powdered activated carbon process for removal of dissolved organics also benefited would be rendered more effective. The heat loss model showed that only slight decreases in water temperature would be experienced in the larger transmission and distribution mains. Greater heat losses would occur in the smaller distribution mains and customer service lines; there would still, however, be an increase in water temperatures so that the amount of energy needed to heat water would be reduced. A questionnaire sent to residents in seven southwestern cities gave a 73.3% favorable response for implementations of the concept. It was determined that most of the detrimental environmental impacts could be mitigated by the utilities through proper system design and management.

ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

The recent requirements of additional electric power have intensified the competition for scarce water supplies in many parts of the country. The use of large volumes of cooling water in energy generation facilities creates conflicts with other demands for consumptive use. Some utilities are left with few alternatives for water acquisition. In some locales, only a single acquisition strategy may be open to the utility whereas in other places several alternatives may be feasible from a physical, technological, economic and legal basis. Such alternatives include:

- Purchase of water rights
- Initiation of application procedures for appropriation of water from local supplies
- Location, obtaining, and importation of water from other areas to the use site
- Reclamation of wastewater

Because of limited physical availability of water, and/or the cost associated with implementation of these strategies, it may well be necessary that the water which is obtained for use will have to be recirculated through the cooling system. This practice adds additional costs to the energy producer in the form of cooling towers, pumps, piping, and water treatment systems. The water must be so treated that biological growth is minimized, to prevent foaming, and to maintain a desired pH level. Quality of water deteriorates due to the increased concentration of inorganics and organics caused by evaporation losses during the cooling cycle, as well as to the chemicals added to condition the water during its use as a coolant. The quality deterioration may necessitate that the "boiler blowdown," obtained when releasing cooling water to maintain favorable concentration levels in the cooling system, be treated prior to its release to area receiving streams or be disposed of on-site.

In addition to paying for the ever-increasing costs of fuel to generate electricity, the consumer in water deficient areas will, therefore, bear the costs for water acquisition, cooling water management, and the treatment and disposal of the boiler blowdown stream. The recirculation of cooling water, despite the fact that it may be dictated by availability and costs, may have environmental impacts more detrimental than those of other methods of cooling water management (Reynolds, 1980).

An Untried Alternative

This report, based on a study conducted at Texas Tech and funded by the Office of Water Research and Technology, explores the feasibility of using municipal water supplies, prior to treatment, as condenser cooling water. In this concept, portrayed on Figure 1, the raw water from the municipal supply source would be transported to a storage reservoir located adjacent to the energy generation facility. The water would then be drawn from this reservoir and piped to the condenser of a generating unit or to the condenser in a power plant if the water supply required by the city is large enough. A once-through cooling system supplied with the raw water to the municipal treatment plant would be used for the unit or the plant. If other units were on a closed cycle system using cooling towers, no pipe connections between the units would be allowed. The hot water exiting from the condenser would be piped to a storage reservoir located adjacent to the municipal water treatment plant; from here it would be drawn, treated, and distributed to

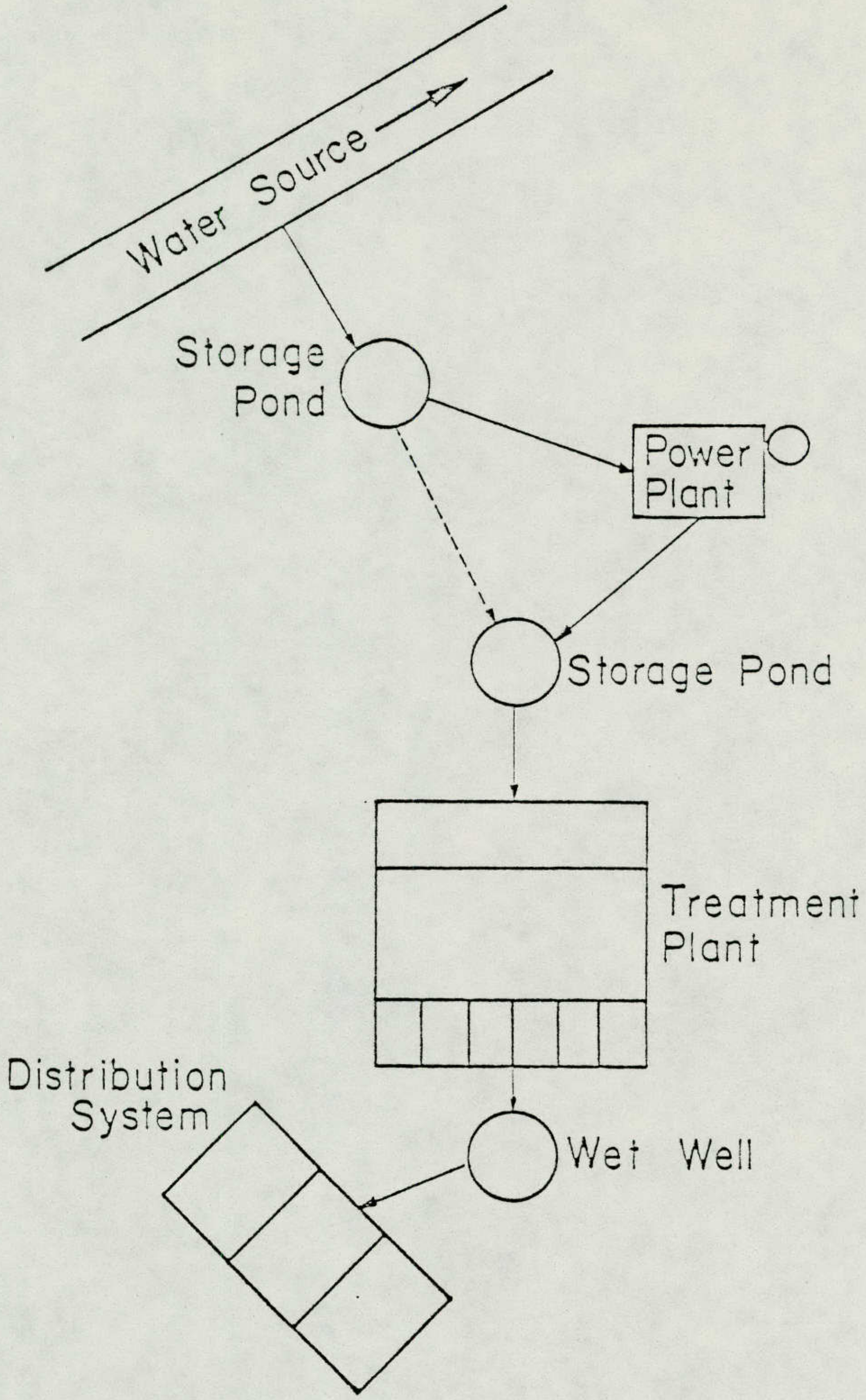

Figure 1. Flow Pattern For System Concept.

water consumers in the system.

The utility and its customers could benefit from the implementation of this concept in the following ways:

1. By having access to an additional water source expansion of generating capacity to meet growing energy demands would be simplified.
2. Capital investment could be reduced since the once-through cooling system requires the lowest investment cost for cooling water management (Hill, 1977).
3. Since higher exit water temperatures would be acceptable, less water would be required for cooling; thus pipe size, pump size, and operational costs would be reduced.

A warm water influent to the water treatment plant would lead to benefits in that warm water could require both less chemicals in treatment and less time for treatment. The use of less chemicals could reduce operational costs. A reduction in the time of treatment could either reduce the volume of reactors required in new facilities or allow increased production at existing facilities.

Potential benefits would also be possible for customers of the municipal water system. Any of the heat gained during the use of the water as a coolant that still remained in the fluid at the customer's intake point could aid in reducing the energy required by the customer for hot water heating. Savings could occur in two ways. First, higher temperatures at the inlet to the water heater reduce: the amount of heat required to raise the temperature to the desired level. Second, a reduction would occur in the amount of hot water required for blending with the unheated stream to produce a desirable temperature at the lavatory, sink, or bath. The reductions in energy employed for hot water heating could also reduce the energy demand imposed upon local electrical water heaters or in the gas flows of the local gas utility.

The principal study objective was to determine whether the concept of using public water supplies as a cooling water source would have a beneficial economic effect on the public utility which subsequently treats and distributes this water to municipal users. The secondary objectives were:

1. To determine the probable ranges of temperature gradients existing in the water treatment and municipal distribution systems under different cooling water temperature regimes.
2. To determine the effects on energy consumption when the waste heat remaining in the cooling water is utilized in normal municipal uses.
3. To determine the effects of elevated water temperatures on water treatment processes.
4. To determine public acceptance of elevated water temperatures in domestic water supplies.
5. To determine the environmental impacts associated with the approach.

CHAPTER II

HEAT CHARACTERISTICS OF MUNICIPAL WATER SYSTEMS

The water temperature profile to be anticipated at different use points in a municipal water system which employs the study concept would be a function of many parameters. Some of these parameters, such as ambient weather conditions, will vary continuously; system flow rates and solar radiation will vary diurnally; and seasonal variations will occur in system flow rates and soil temperatures. Some parameter values will be fixed in that size, materials of construction, and location in the system will not vary after installation, and thus will affect the temperature regime continuously in a uniform way. This chapter will present an examination of the different system components, the assumptions made for the heat transfer analysis of the system components, and examples of water temperature profiles in a municipal water treatment system using the analysis procedure developed in the study

Electrical Generating Facilities

Today, in conventional generating units powered by fossil fuels or by nuclear energy, the primary product produced is electrical energy. The efficiency achieved is 40% in a well-designed modern steam turbine, and 33% in a nuclear reactor (Thorndike, 1976). The system energy that is not converted into electricity is dissipated to the environment primarily in the cooling water system. In fossil fuel plants some 10 to 15% goes up the stack in exhaust gases with the remaining 40 to 45% being carried away by cooling water. Since nuclear plants do not have stacks, a correspondingly larger amount of cooling water is required.

The waste heat removed by the cooling water has been examined for agricultural uses. Fuel efficiency would be greater if some use could be made of a portion of the waste heat that is currently voided as well as of the energy contained in the electricity that is generated. The waste heat generated in conventional systems, being at a rather low temperature, has low availability. If the temperature of the cooling water were to be raised, the efficiency of electric powered generation would be reduced. The co-generation of electric power and hot water or steam, common in Europe, gives a higher fuel use efficiency than when electric power is the only product. The project staff, however, restricted its examination to water temperature conditions which would be common in conventional practice if limiting water supplies were a concern for the utility needing to expand its present power generation capacity.

Electrical energy is produced by passing steam generated at high temperatures and pressures through a turbine and allowing the heat energy in the steam to be converted to mechanical energy as the steam causes the trubine to rotate. The spinning turbine, in turn drives an electrical generator in which electrical conductors attached to a rotor cut across stationary magnetic lines of force, thereby generating electrical energy by induction.

The influence of cooling water on the power production cycle is exerted in the condenser. The steam enters the turbine at one end at high pressure, then flows through the system as a result of the pressure differential which exists between the inlet to the turbine and its exit into the condenser which is located just downstream from the turbine outlet. In the condenser the steam gives up heat and condenses to liquid water as a result of its continuously contacting the cool surfaces of a pipe system which passes through the condenser unit. The pipe surfaces, in turn, are kept cool by pumping water through the pipes. Large volumes of water must be used to carry away the heat transferred to the pipe surface by the heat of condensation which is liberated when the steam condenses on the pipe surface. The phase change which occurs when the steam condenses causes the specific volume to drop by a large amount. This creates a partial vacuum which maintains the pressure differential across the turbine.

Generally, the steam space in the condenser is at a nearly uniform temperature and pressure, but the temperature in the water circulation system varies from the inlet side to the outlet side. The temperature differential between the water and the steam space is greatest at the inlet side and therefore the heat transfer rate is at its maximum there. The temperature differential and the heat transfer rate is reduced rapidly with increasing pipe length. A condenser in which the outlet water temperature equalled the steam space temperature would need to be extremely large since the lower rates of heat transfer which occur as the temperature differential between the circulating water and the steam space is eliminated would necessitate long lengths of pipe to accomplish the needed amount of heat transfer to reach the equilibrium level. Condensers are designed, therefore, so that some terminal temperature differential occurs between the steam space and the cooling water outlet.

The temperature increase in the cooling water is of importance to the utility for several reasons. Where the heated water is to be released to an aquatic ecosystem, permit requirements will dictate an allowable temperature increase, and thus affect the water requirements and water management facilities that must be constructed for the needed heat transfer capabilities. Where a closed cycle is used in association with evaporative cooling towers, the lower boundary for the increase in cooling water temperature will be affected by the ambient atmospheric conditions which exist where power is generated at high levels of temperature and relative humidity. These conditions, though occuring infrequently, will require a design for a high flow rate cooling water operational capacity through the condenser since high electrical demand for air conditioning coincides with these conditions.

The study concept avoids the condition cited above since discharge into an aquatic system will not occur nor will recirculation be allowed. However, this concept still is influenced by the operational efficiency desired in the system and by the amount of cooling water required to obtain this efficiency at the desired load. To illustrate, a Rankine turbine operating under ideal conditions receives steam at 1000°F and 3000psia. The work of the turbine, its heat rejection rate, and cooling water needs using inlet water temperatures of 50°F and 85°F were calculated at four steam chamber temperatures on the basis of a steam flow rate of 100,000 lbs. per hour. It was assumed that the terminal temperature difference between the steam chamber and the outlet water was 8°F in all cases. The results are presented on Table 1. As can be seen, the work per pound of steam decreases and power generation drops by 6.7% as the steam chamber temperature increases from 100°F to 130°F. The cooling water requirements drop by 41% for water entering at 50°F and by 81% for water entering at 85°F between the two extreme conditions in the condenser. Assuming that the daily water supply required by a city is sufficient to meet some of the cooling water needs of a utility, the decrease in efficiency with increased condensation temperature levels in the condenser can be evaluated against the economic returns posed by the availability of cooling water offered by the municipal supply and the existing need for extra generation capacity. A condenser system can be designed for these conditions. The temperature range shown on Table 1 serves as the basis for

TABLE 1

Operational Characteristics Under Ideal Conditions of a Rankine Turbine Receiving Steam at 1,000°F and 3,000 psia for a Steam Flowrate of 100,000 lbs./hr.

Steam Chamber Temperature in Condenser (°F)	Work			Heat Rejection		Cooling Water Rates*	
	$W=h_1-h_2$ (BTU/per lb of Steam)	W=kwh per 100,000 lbs. Steam/hr.	% Change in Power Generation Efficiency	$Q_n=h_2-h_{f2}$ (BTU/per lb. of Steam)	Q_n=kwh thermal per 100,000 lbs. Steam/hr.	85°F Inlet Temperature (cfs)	50°F Inlet Temperature (cfs)
100	608	17,800	0	782	22,900	49.7	8.3
110	594	14,000	2.25	786	23,000	20.5	6.7
120	580	17,400	4.50	790	23,200	13.0	5.7
130	567	16,600	6.7	794	23,300	9.54	4.9

* outlet water temperature at 8°F below steam chamber temperature.

the rest of the analysis since the range shown encompasses the levels of efficiency desired for electric power generation and condenser temperatures required which occur under current practices.

Municipal Water Treatment

The purpose of municipal water treatment is to transform raw water into a form in which it can be utilized for human consumption and to meet the water needs of many supportive activities on which society is dependent without causing health problems or excessive economic costs to the consumer. The effect of the raw water temperature regime normally encountered in water treatment situations on accomplishing this purpose is minimal since the consumer adjusts water temperature levels to meet his needs. Water temperature, however, does influence the design and operation of treatment facilities.

Temperatures of raw water entering a treatment plant are dependent on source characteristics. If a surface water supply is used, temperature variations will occur on a seasonal basis and often on a daily basis. Season variations can range over a span encompassing several tens of degrees. Waters from groundwater sources exhibit a fairly constant temperature regime at all times. A treatment facility incorporates features designed to accommodate low temperature regimes. Methods or structural measures are used to prevent icing or freeze-up of system components so that treatment can continue during extended periods with temperatures below freezing. Also, the rate of chemical reactions and the settling of suspended particles is slower in colder water. These two factors generally determine the sizing of the treatment reactors. Heat transfer analysis may be performed to determine what structural measures must be used to prevent excessive heat losses from occurring in treatment facilities in arctic or permafrost conditions. Normally no concern is expressed by the designer for water temperatures outside of the probable low water temperature regime. Plant operations, however, will require information on the frequency distribution of cold temperatures because of the effects on chemical use and treatment efficiency.

In the following sections the purposes of conventional water treatment will be examined, and the development of a method for evaluating the temperature profile in a treatment plant will be presented. This latter factor is necessary if a determination of the amounts of heat which enter the distribution system is to be made.

Conventional Treatment

The treatment of raw water for municipal use is generally accomplished by transporting water continuously through a sequence of reactors where physical or chemical processes are explored to remove suspended organic and inorganic particles which are contained in the water and where chlorine is added to effect the destruction of pathogens that could cause sickness. Other processes are included in the treatment sequence to remove contaminants that cause odor or taste problems, or to remove or alter specific inorganic or organic compounds that exist in the dissolved phase and which might cause problems either in the ingestion of water by the consumer or in the use of water in some other activity. The reactors used for each treatment step are normally sized according to the detention period or treatment rate required to accomplish the necessary level of contaminant removal.

The processes for a typical water treatment facility utilizing a surface water supply source and the normal range of detention times, overflow rates, and treatment rates for each process are shown on Table 2. In Chapter 3 of this report, a more complete description of the treatment processes will be presented to explain the functions performed in water treatment. The sizing and configuration of the reactors, and their positioning within the treatment sequence are based

TABLE 2

Range of Detention Times and Rates of Treatment For Processing Components in Water Treatment Facilities Using a Surface Water Supply Source

Operation	Application	Detention Time	Surface Loading Rates (gallons/ft^2/d)
Raw Water Storage	Used for settling of discrete inorganic particles and for protection from disruptions in supply system	Variable—dependent on source or supply conduit reliability	———
Mixing	Used to mix chemicals added for coagulation or precipitation	30 to 60 seconds	dependent on depth of reactor
Flocculation	Stirring of water to promote particle aggregation	20 to 30 minutes	dependent on depth of reactor
Sedimentation	Used to remove suspended organic or inorganic particles		
	Sand-Silt-Clay *	.01 to 15 hours	146 - 144,000
	Aluminum and Iron Floc *	2 to 8 hours	600 - 800
	Calcium Carbonate *	1 to 4 hours	600 - 2880
Sand Filter	Used to filter out organic and inorganic particles		2880 - 5760
Clear Well Storage	Treated water storage for meeting variable system demands	30% to 40% of daily treatment needs**	

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* Source: Weber, W. J. Physicochemical Processes For Water Quality Control New York: Wiley-Interscience, 1972.

** Source: Lindsey, R.K. and Franzini, J. B. Water Resources Engineering 3rd Ed. New York: McGraw-Hill, 1979.

upon the material being removed and the characteristics of the separation processes.

Heat Losses in Water Treatment

In this study, the determination of the water temperature profiles at points through the treatment cycle was of interest. The water temperature present at the inlet and outlet of each reactor when treating raw water at elevated temperatures is important because of its impact or influence on treatment processes and in determining the amount of heat entering the distribution system. No effort was made to determine optimal configurations of treatment units to minimize heat losses through the system. The analysis was conducted using conventional guidelines for the sizing and layout of processing units in a water treatment sequence.

A heat transfer analysis was conducted to determine the temperature profile to be expected in the treatment facility. Variables which influence the heat transfer properties of the system include the water temperature at the inlet to the reactor, the size and shape of the reactor, the flow rate through the reactor, the exposure of the reactor to solar radiation and ambient atmospheric conditions, materials of construction, and such characteristics of the soil adjacent to the reactor as type of material and soil moisture conditions. A heat loss model was developed to examine the influence of these factors on the heat transfer rates in the system.

Heat losses will occur from each of the several reactors required in the water treatment process. They also occur from the raw water storage basin, flocculator, sedimentation basin, and rapid sand filter units; all can be treated in a similar manner from a heat transfer standpoint. Heat transfer will occur due to convection, radiation, and evaporation at the free surface. In addition, heat gain due to solar insolation is possible. Heat transfer will also occur because of conduction between the walls and bottom of the reservoir and the surrounding earth.

The general methodology requires that the outlet temperature from each of these reservoirs be calculated as a function of the inlet temperature and the heat loss from the reservoir. The heat loss from the reservoir is, however, a function of the outlet temperature which is unknown. Therefore an iterative solution is required. The temperature of the reservoir is assumed to be equal to the outlet temperature within the reservoir. The exit temperature from a reservoir can be given as

$$T_o = T_i - \dot{q}_{loss}/\dot{m}C_p \tag{1}$$

where T_i is the inlet temperature, $\dot{q}_{loss}$ is the total heat transfer from the reservoir, $\dot{m}$ is the mass flow rate through the reservoir, and C_p is the specific heat of the water.

As mentioned previously, the heat loss is composed of losses due to convection, radiation, evaporation, and conduction.

$$\dot{q}_{loss} = \dot{q}_{conv} + \dot{q}_{rad} - \dot{q}_{sol} + \dot{q}_{evap} + \dot{q}_{cond} \tag{2}$$

Here $\dot{q}_{conv}$ is the heat loss due to convection, $\dot{q}_{rad}$ is the heat loss due to radiation, $\dot{q}_{evap}$ is the heat loss due to evaporation, $\dot{q}_{cond}$ is the heat loss due to conduction and $\dot{q}_{sol}$ is the heat gain due to solar insolation.

The heat loss due to conduction can be written as

$$\dot{q}_{cond} = k\,S(T_o - T_g) \tag{3}$$

where k is the termal conductivity of the surrounding earth, S is a conduction shape factor, and T_g is the ground temperature. The conduction shape factor can be obtained from Figure 2 for a cylindrical reservoir of radius "r" and depth "b" (Holman, 1972).

The heat loss due to radiation exchange with the surrounding air can be expressed as

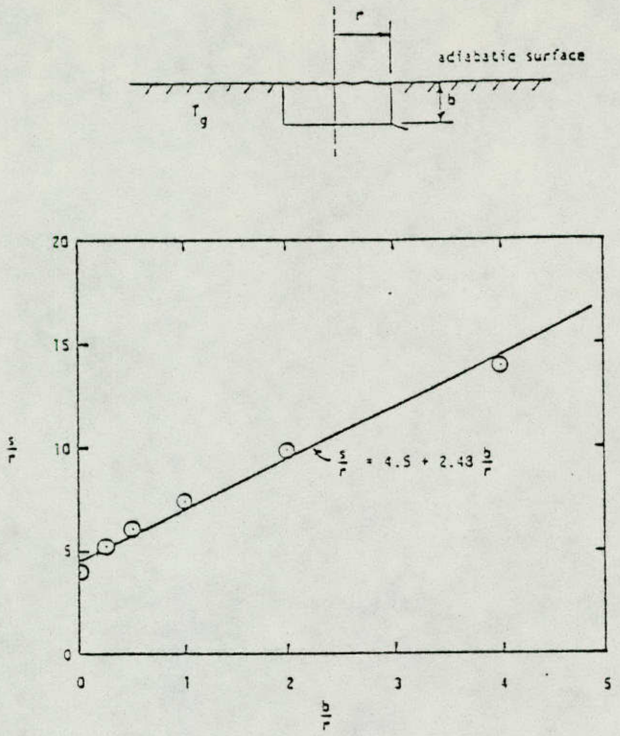

Fig. 2 Conduction Shape Factor for Cylindrical Reservoir

Source: Holman, J.P., Heat Transfer, 3rd Ed. (New York: McGraw-Hill, 1972), p. 56.

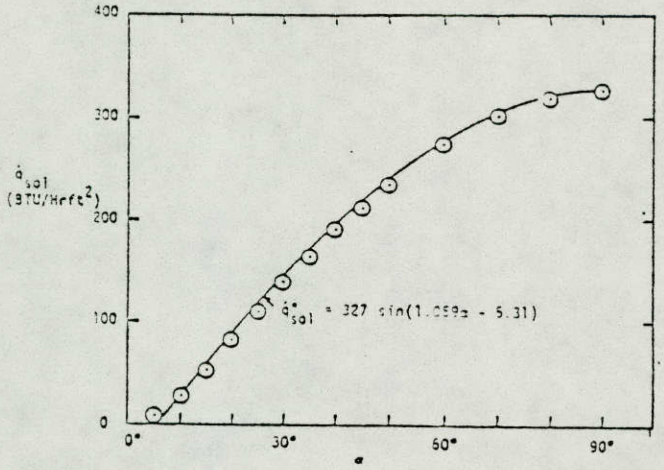

Fig. 3 Absorption of Solar Radiation by a Horizontal Water Surface for Average Sky Conditions.

Source: Holman, J. P., Heat Transfer, 3rd Ed. (New York: McGraw-Hill, 1972), p. 405.

$$\dot{q}_{rad} = \delta \ A \ (T_o^4 - T_a^4) \tag{4}$$

where δ Stefan-Boltzmann constant, A is the surface area of the reservoir, and T_a is the ambient air temperature. The heat gained per unit surface area due to solar insolation $\dot{q}_{sol}^{11}$ can be estimated from Figure 3. These data are for average sky conditions and consider the reflectivity of the water surface at various solar elevations α.

The heat loss due to evaporation can be estimated from

$$\dot{q}_{evap}^{11} = (64.1 + 9.49 \ U_{30})(P_{s0} - P_{w5})^{.88} \tag{5}$$

where $\dot{q}_{evap}^{11}$ has units of BTU/hr ft^2, the wind velocity in mph at a thirty foot elevation is denoted by U_{30} and the water vapor pressures at the surface and at five feet above the surface are given by P_{s0} and P_{w5} respectively (Holman, 1972). These pressures, in inches of mercury, can be estimated from

$$\begin{aligned} P_{s0} &= .059e^{.035T_0} \\ P_{w5} &= .59\phi_5 e^{.035 \ T_a} \end{aligned} \tag{6}$$

where ϕ_5 is the relative humidity five feet above the surface and T_0 and T_a are the dry bulb temperatures in degrees Fahrenheit at the indicated locations. This equation is based upon the definition of relative humidity and a curve fit of water properties between 32°F and 100°F.

The convection heat transfer can be approximated by use of Reynold's analogy between heat and mass transfer. In general, the ratio of the convective heat loss to the evaporation heat loss can be

$$\frac{\dot{q}_{conv}}{\dot{q}_{evap}} = \frac{\rho_a c_{pa} Le^{2/3}}{h_{fg}} \ (\frac{T_0 - T_a}{\rho_{s0} - \rho_{w5}}) \tag{7}$$

where ρ_a is the air density, C_{pa} is the specific heat of the air, h_{fg} is the heat of vaporization of the water, ρ_{s0} and

ρ_{w5} are the vapor densities at the zero and five foot elevations respectively, and Le is the Lewis number (Holman, 1972). For standard atmospheric pressures equation (7) can be written as

$$\frac{\dot{q}_{conv}}{\dot{q}_{evap}} = 0.0103\left(\frac{T_0 - T_a}{P_{s0} - P_{w5}}\right) \tag{8}$$

where the temperatures are in degrees Fahrenheit and the pressures are in inches of mercury.

Equation 1 through 8 can be used to determine the total heat loss from the reservoir as given by equation (2). Upon examination of equation (1) it may be noticed that the right hand term can be cast in terms of a temperature loss. It is therefore informative to define the temperature loss due to the individual and combined heat transfer mechanisms by an equation of the form

$$T_{loss} = \frac{\dot{q}^{ll}_{loss}}{C_p}\,\frac{A}{\dot{m}} = \frac{\dot{q}^{ll}_{loss}}{R_0\ C_p} \tag{9}$$

where R_0 is the rate of overflow for the given reservoir. The input-output parameters for the water treatment heat loss model are indicated in Table 3.

In order to obtain an order of magnitude estimate for the temperature loss or gain due to each heat transfer mechanism the following example calculations were made for a sedimentation tank. From these results it would appear that the conduction losses are in general small and can be neglected. The other losses are of equal order of magnitude and should be retained.

Example

r=40 ft, b=6.4 ft, R_0=200 lbm/hr ft^2, $\dot{m}$=1 x 10^6 lbm/hr

T_0=70°F, T_g=50°F, T_a=40°F, k=0.5 Btu/hr ft $^\circ$F, U_{30}=20 mph

ϕ_5=40%, C_p=1 Btu/lbm $^\circ$F, α=35°

Input

$\dot{m}_o$ - system mass flow rate	general information
T_i - inlet water temperature	
T_g - temperature of the ground	
T_a - ambient air temperature	
U_{30} - wind velocity (mph) at 30 ft.	
ϕ_5 - relative humidity at 5 ft. above the surface	
S_r - latitude, day number, and hour	
C_p - specific heat of water	
ρ_a - density of air	
C_{pa} - specific heat of air	
hfg - heat of vaporization of water	
r - radius of reactor	information from each stage
b - depth of reactor	
T_o - outlet water temperature	
R_o - overflow rate in lbm/hr/ft^2	

Output

T_j - outlet temperature at each stage

Q_j - heat loss for each stage

Q_{TOT} - total system heat loss

Table 3 - Input-Output for Water Treatment Heat Loss Model.

$$
\begin{aligned}
T_{conv} &= .417^{\circ}F \\
T_{rad} &= .140^{\circ}F \\
T_{cond} &= .002^{\circ}F \\
T_{sol} &= -.860^{\circ}F \\
T_{evap} &= \underline{.796^{\circ}F} \\
T_{loss} &= .495^{\circ}F
\end{aligned}
$$

Water Distribution Systems

The function of a water distribution system is to convey treated water to the utility customers through an interconnected pipe network. The objective sought in the design of the distribution system is that the customer be supplied a water free of disease pathogens and in the amount needed whenever required and wherever located in the service area.

To accomplish these objectives, the water requirements of the service area will be determined by examining and compiling water requirements of activities currently being served and by estimating the water requirements of the expected land use and population density to be anticipated in the undeveloped parcels of the service area when fully developed. The community plan and zoning regulations for the service area can provide the needed information on expected types of land use and population density for the undeveloped parcels in the area. In some cases, potential customers, such as industries, may supply the design engineer with their expected needs. Since individual use requirements cannot be predicted over time, methods for determining system demands under heavy consumer needs must be used. Previous system water use records can be examined and a ratio of peak use to average use can be developed for calculating a design demand. Load or weighting factors, developed after examination of water use records in many sytems, can be used to formulate a maximum demand figure for the water uses anticipated in the service area.

A proposed pipe network is laid out on a map of the area to points where existing customers are located and to points where growth of an expected nature is foreseen. Through hydraulic analysis, the pipes in the grid are sized to meet the flow demands required at the various points in the service area. Facilities needed to support these flow demands such as control valves, pump stations, and distribution storage are located in the sevice area and sized. A system designed and constructed so as to meet performance standards should provide ample water to the service area over the system life.

Flow Patterns in Distribution Systems

The flowrates in a well-designed and well-maintained system will normally be less than the design rate except for possibly a few hours per year once the service area has become fully developed. Flow in the pipe system occurs when a pressure differential is developed between the higher pressures in the distribution system and the lower pressure at the point of use by the customer. In periods of high use, such as the interval from 6:00 a.m. to 8:00 a.m., flows in the transmission and distribution mains are generally in the directions determined in the design analysis phase with possible exceptions in the smaller sized distribution mains. In the smaller distribution mains changes in flow direction may occur because of the storage capacity of the pipe and the demands of the consumers which occur episodically along the length of the main. The pressure fields established during the satisfaction of customer demands favors flow reversal. During low use periods, such as the time interval between 1:00 a.m. and 3:00 a.m., flow reversals can also occur in the larger distribution mains and in the transmission lines if the pertubation established in the pressure field by the consumer is large enough and at the proper location in the service area.

Flow reversals in the distribution system, the distance water must travel to the point of use, and the residence time of a water molecule in the distribution mains are not important factors in the normal operation of a municipal treatment system. These characteristics may, however, be of interest in light of the project objectives. The answers sought concern the determination of the heat losses in the distribution system and the probable temperature at the final exit point from the system. The temperatures at exit will also vary over the year in response to ground temperatures and seasonal use patterns.

The usage patterns exhibited in the system will vary greatly between customers. At a domestic use point, variations in water requirements occur as the result of the time of day, day of week, season of the year, number of people in the household, and the lifestyle of the residents. A water use pattern which was developed for a family of four for a typical week day during the winter season is shown on Table 4. The cumulative use schedule is shown on Figure 4. The water use pattern of the household will determine the number and times of water changes experienced in the service pipe connecting the municipal system to the residence. For example, the length of pipe containing one gallon of water for various sizes is as follows:

Pipe I. D. in Inches	Pipe Length in Feet per Gallon of Water Stored
0.50	98.0
0.75	43.6
1.00	24.5
1.50	10.9
2.00	6.1
4.00	1.5

The greater the use of water in a time period, the greater the chance that water at warmer temperatures will be entering the household since the initial flows will be from the coldest

TABLE 4

Water Use Patterns for a Family of 4

Time Interval	Water Use Frequency					
	Lavatory (4 l/use)*	Kitchen Sink (4 l/use)	Shower (100 l/use)	Toilet (20 l/use)	Washing Machine (170 l/use)	Dishwasher (22 l/use)
630-700	2	3	1	2		
700-730	3	3		2		
730-800	4	3		1		
800-830	2	4		1	1	
830-900						
900-930						
930-1000	3			1		
1000-1030					1	
1030-1100						
1100-1130						
1130-1200	1	2		1	1	
1200-1230	1	3				
1230-1300						
1300-1330						
1330-1400						
1400-1430						
1430-1500	1		1			
1500-1530						
1530-1600	3	2		2		
1600-1630		1				
1630-1700	1	3		1		
1700-1730		3				
1730-1800	3	2		1		
1800-1830	2	4		1		
1830-1900		1				
1900-1930		1		1		
1930-2000						
2000-2030						
2030-2100	1	2	1	1		
2100-2130	1	1				
2130-2200						
2200-2230						
2230-2300	4	3	2	3		
2300-2330						1
2330-2400						
Total Uses	32	41	4	19	3	1
Amount Used	128 l	164 l	400 l	380 l	510 l	22 l

* Source: Metcalf and Eddy, Inc. Wastewater Engineering: Treatment, Disposal, Reuse. New York: McGraw-Hill, 1979.

Figure 4. Cumulative Water Use For Family Of 4.

regime (the smaller pipes). To the consumer the value of heat contained in the water will depend on the expected use. The temperature differential between the entrance point at the service connection at the distribution main and the desired level at the use point serves as an indication of the benefits to the consumer. The smaller the differential the more valuable the heat contained.

The use patterns of the individual household and in household groups also influence the water renewal rates in the distribution mains. In a pipe network such as that shown on Figure 5, the water demand at B can initiate water flows from either the 8 inch pipe or the 14 inch pipe. The direction will depend on the pressure field existing in the pipe system at the time of use. It is also apparent that either points A or C which are closer to the large pipe lines will have a better chance to receive warmer water than those points located around B. Location in the distribution system will play a role in determining the accessibility to the consumer of warm water. Therefore, it may be concluded that water users located closer to major transmission or distribtution mains will have better access to warmer water than other users. Also, use sites closer to the water treatment plant will obtain warmer water than sites located further away because flowrates will be higher and, therefore, the rate of water renewal in the pipes will be faster.

Heat Losses in Distribution

A heat loss model was developed to determine the temperature profiles that would occur in the distribution system. A previous study had analyzed the heat losses that would occur in the Seattle distribution system if treated municipal water were to be used as the cooling water source for a thermal powered electrical generation facility which discharged the heated water back into the system (Hansen, et. al., 1973). General heat loss calculations were performed for buried pipes as a function of the pipe diameter and the initial temperature

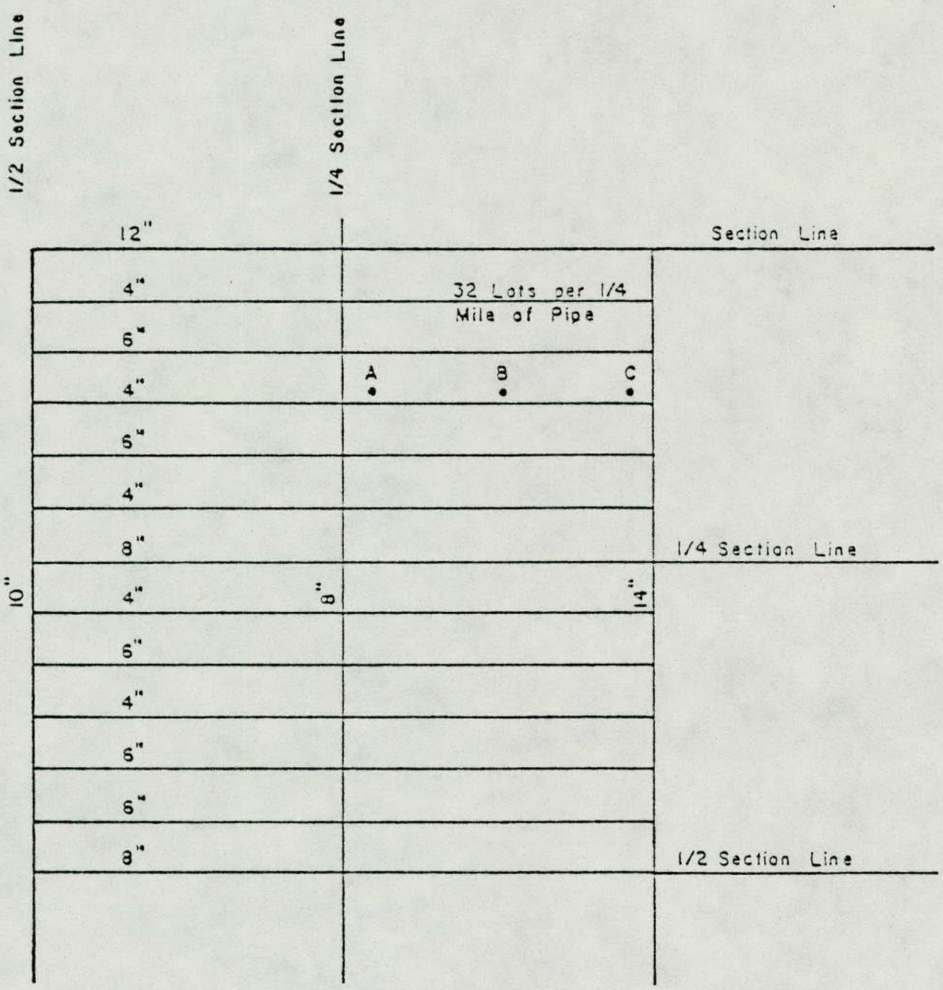

Figure 5. Typical Pipe Grid For Residential Service Area.

difference between the water and soil. These analyses were performed for both flowing and stagnant water. The specific objective of the investigation was to determine the temperature envelope within which the temperatures in the distribution system would fall. The results which were obtained indicated relatively minor temperature reduction in the system when flow conditions--a 4°F drop for water initially at 100°F after flowing through 10,000 feet of 20 inch pipe, 6,000 feet of 8 inch pipe, and 1,500 feet of 2 inch pipe. The minimal temperature which would occur in the same pipe configuration under stagnation conditions was 70°F which was the initial soil temperature.

In developing a heat loss model for project use to estimate the losses in a water distribution sytem, several simplifying assumptions were made. The first of the two major assumptions made presupposes that the distribution system branches from a single main to the residence mains in a "uniform" manner. The term uniform, in this case, means that at each stage of the branching process all pipe diameters, lengths, and other parameters affecting heat transfer are the same for each branch. This idealization is depicted in Figure 6. The second major assumption is that quasi-steady-state heat transfer equations can be used to yield satisfactory results. This latter assumption requires that the thermal heat capacity of the earth surrounding the buried pipe be ignored.

The general methodology requires that the exit temperature from each stage be calculated as a function of the inlet temperature, the ground temperature, and heat transfer properties related to that stage. It can be shown from a simple energy balance that the exit temperature T_j from the j^{th} stage can be given as

$$T_j = T_g + (T_{j-1} - T_g) \exp \left(- \frac{1}{\dot{m} C_p R_{TH}}\right)_j \tag{10}$$

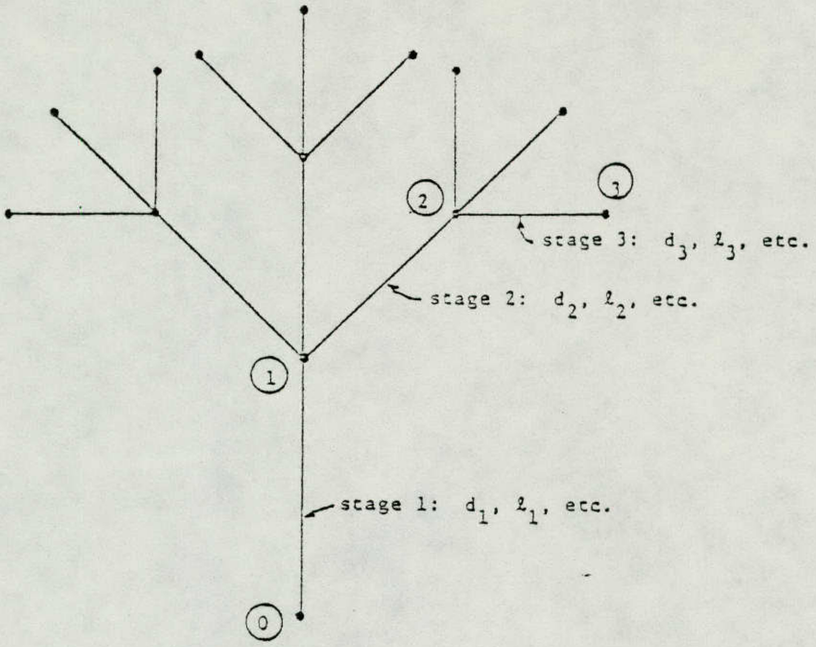

Figure 6 Example of Uniform Branching Pipe Network

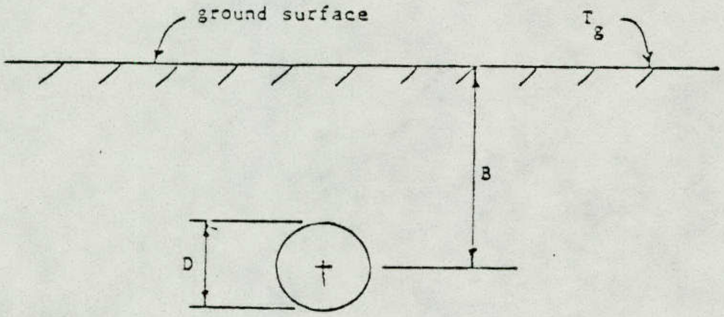

Figure 7 Schematic of Pipe Burial

where T_g is the ground temperature, $\dot{m}$ is the mass flow rate through a single branch of stage j, C_p is the specific heat of the fluid, and R_{TH} is the thermal resistance for a single branch of stage j.

The heat loss Q_j for an entire stage j is given by

$$Q_j = \dot{m}_{o_j} C_p \ (T_{j-1} - T_j) \tag{11}$$

where $\dot{m}_o$ is the total mass flow rate entering the system. The total heat loss for the system is then simply the sum of the Q_j's.

The mass flow rate in a branch is the total system mass flow rate divided by the number of branches n_j in the j^{th} stage.

$$m_j = \frac{\dot{m}_o}{n_j} \tag{12}$$

The thermal resistance is made up of three parts. These resistances to heat transfer are resistance due to convection between the fluid and inner pipe wall, resistance due to conduction through the pipe wall, and resistance due to conduction through the surrounding earth. The total resistance in a particular stage can be expressed according to

$$R_{TH} = \left(\frac{t}{k_w} + \frac{1}{h} + \frac{\pi D \ell}{kgS}\right) / \pi D \ell \tag{13}$$

where t is the pipe wall thickness, k_w is the pipe wall thermal conductivity, h is the convection coefficient, D is the pipe diameter, ℓ is the pipe length, kg is the thermal conductivity of the ground, and S is a conduction shape factor (Holman, 1972).

The convection coefficient h is normally given in terms of the Nusselt number Nu which is equal to the product of the convection coefficient and pipe diameter divided by the thermal conductivity k of the fluid. Empirical relationships for laminar and turbulent flow regimes are given by

$$Nu = \frac{hD}{k} = 3.66 \text{ for } Re < 2300$$
$$Nu = 0.023\, Re^{0.8}\, Pr^{0.4} \text{ for } Re > 2300 \qquad (14)$$

where Re is the Reynolds' number based on the pipe diameter and Pr is the Prandtl number of the fluid (Holman, 1972).

The conduction shape factor S is associated with the heat conduction from the outer pipe wall to the ground surface. Parameters related to this factor are shown in Figure 7. This factor (Holman, 1972) can be expressed by

$$S = \frac{2\pi \ell}{\ell n(4B/D} \qquad (15)$$

Implementation of the water distribution heat loss model is reasonable straightforward when programmed on a digital computer. Input-output parameters are indicated in Table 5.

Computer Program for Heat Loss Estimation

After identifying the parameters which exerted the greatest influence on the heat losses estimated by the two models, a computer program was written which linked the models together. The resulting program can be used to estimate the temperature profile that will develop as water at a particular inlet temperature flows through a specified water treatment facility and distribution network. The inputs that are necessary for running the program are listed on Table 3 and 5. The program is presented in the Appendix. Some of the characteristics of the system will take but a single value; others, such as the ambient weather conditions and solar angle, will vary. It may be necessary to use the weather data from some city in the region other than the point of study. In areas of similar climatic conditions, any error resulting should be well within the range of validity of the model.

The program as developed has limitations. The primary ones are the following:

1. Figure 6 is not an accurate representative of a

Input

n_s = number of stages $\dot{m}_o$ - system mass flow rate T_o - system inlet temperature T_g - ground temperature k_g = thermal conductivity of ground C_p - specific heat of water k - thermal conductivity of water ν - viscosity of water	general information
n_b - number of branches ℓ - pipe length D - pipe diameter B - burial depth t - pipe wall thickness k_w - pipe wall thermal conductivity	information for each stage

Output

T_j - temperature at each stage outlet

Q_j - heat loss for each stage

Q_{TOT} - total system heat loss

Table 5. Input-Output for Water Distribution Heat Loss Model

municipal system. These are designed to consist an interconnected grid in order to eliminate possible points of stagnation and to provide opportunities for continuing service through easy isolation of a point in the system where a break or leak occurs. In a interconnected grid, water flows back and forth through the system as the pressure field increases or decreases in response to water use. This factor has the effect of increasing the residence time of water in the system.

2. The model assumes that flows within the distribution system are constant in any time period. This may be approximately true for the large transmission and distribution mains, but will not be true in the smaller distribution lines serving commercial or light industrial activity where an 8- to 10-hour workday is common. In residential areas, water use is also minimal or nonexistent in the 5- to 6-hour period from midnight to morning. The water temperatures in these areas of the distribution system where stagnation or near stagnation conditions can exist during low-use periods will approach that of the ground temperature, which is the lower bound for water temperature in any distribution system handling heated water. The model is not suitable for analyzing the conditions that exist between the point where the service line connects to the distribution main and the use point. Flow in this line is episodic and periods of stagnation alternate with use periods. Because of the small volume of water stored in a residential service line, however, the cold water which results during stagnation is replaced rapidly with warmer water from the distribution line upon use.

3. The linear system portrayed in Figure 6 is not representative of the consumer distribution pattern in a normal system. More consumers are normally located in the pipe length between (0) and (1) in the system than between (2) and (3). This creates a more favorable condition for conserving energy than that portrayed in the figure.

4. Heat losses are calculated throughout the system based upon the hourly use rate of water. In an actual system, water treatment plants generally

operate at a constant rate during their hours of operation. This should have a dampening effect on temperature extremes. More time is spent in the raw water storage basin, allowing more heat to be lost instead of being conserved, than if a plant were to be operated to meet on-line demands at high use periods. In like manner, less heat is lost in the detention basin and in other exposed reactors when water is treated at a constant rate rather than being treated to satisfy demands during low use periods.

5. The model assumes steady state conditions in the soil and disregards the thermal capacity of the soil. This, however, is not the case in a normal system as the temperatures of the water and the conduit change with time. Since heat flows from hot to colder regimes, a decrease in water temperature may cause a reversal of heat flow from the soil to the water therby mitigating the temprature decrease predicted by the model.

6. The equations used in the analysis assume that heat transfer is occuring in a homgeneous isotropic medium. In soils, this is generally not the case. In addition to variability of the solid fraction of the soil, variablity is introduced by the presence of soil water. When water is present in the soil, there is mass transfer of water from the hot to the cold zone with an accompaning transfer of heat. If vaporization of water were to occur in the hot zone, then condensation of vapor in the cold zone would transfer an amount of heat equal to the mass distilled multiplied by the latent heat of vaporization of water (Taylor, 1972).

Case Study

To illustrate the use of the program in obtaining temperature profiles under different inlet water temperatures, and different seasonal conditions, an example water treatment and distribution system was designed. The area conditions used were those characteristic of Lubbock, Texas. The water treatment plant has a design capacity of 50 MGD. The system characteristics are as follows:

1. Raw water storage pond
   detention time = 3 hours
   overflow rate = 1500 gpd/ft^2
   area = 33,400 ft^2
   depth = 25 ft
2. Flocculation basin
   detention time = .5 hour
   overflow rate = 3600 gpd/ft^2
   area = 13,900 ft^2
   depth = 10 ft
3. Sedimentation basin
   detention time = 1.8 hours
   overflow rate = 1000 gpd/ft^2
   area = 50,000 ft^2
   depth = 10 ft
4. Sand filter
   overflow rate = 2880 gpd/ft^2
   area = 34,700 ft

The example distribution system is shown in the second column of Table 6. The distribution pipes are of concrete. In the computer program to determine a test network the input NP (number of pipes) at each stage is calulated to be the number of pipes with ID X_2 which can carry the same flow at the design velocity at the NP + 1 stage as was carried at the design velocity in the pipes with ID X_1 at the NP stage. In case this calculation yields a non-integral number of pipe, the next higher integral value is to be selected (with a corresponding decrease in velocities).

The flow pattern in the system was developed from the ratio of hourly demand rate to maximum day demand rates shown on Table 7. An additional use pattern was developed to test an extreme case condition that could occur under winter conditions. The flow in stages 1 to 8 (flow through 4 stages of treatment to stage 4 on Table 6) would be half the value

TABLE 6

Example Distribution System

Stage	Size (inches)	Length (feet)	Flow (MGD)
1	45	2600	44.9
2	30	"	21.5
3	27	"	18.3
4	24	"	10.5
5	24	"	7.8
6	20	"	5.2
7	20	"	3.8
8	18	"	1.3
9	10	"	0.15
10	8	1300	0.03
11	8	"	0.03
12	6	"	0.03
13	4	"	0.03

TABLE 7

Water Use on the Maximum Day*

Hour	Ratio of Hourly Demand Rate to Max.-Day Demand Rate
7-8 AM	1.00
8-9	1.10
9-10	1.25
10-11	1.28
11-12	1.20
12-1 PM	1.18
1-2	1.16
2-3	1.10
3-4	1.00
4-5	1.08
5-6	1.15
6-7	1.30
7-8	1.60
8-9	1.40
9-10	1.25
10-11	0.90
11-12	0.85
12-1 AM	0.70
1-2	0.60
2-3	0.50
3-4	0.50
4-5	0.50
5-6	0.60
6-7	0.80

* Source: American Water Works Association, Water Distribution Training Course AWWA No. M8, 1962

of the maximum daily rate. The flow from stage 5 to stage 13 would be at 0.66 times the value for the maximum daily rates. This sequence would be more typical of cold weather conditions in the Lubbock area when outside usage of water for lawn watering, car washing, or the hosing off of outdoor areas would be minimal.

Four outlet water temperatures that could be obtained from a condenser unit were evaluated. These were 90°, 100°, 110°, and 120°F. In addition, inlet temperatures of 45° and 80°F which were representative of water conditions in the winter and summer were evaluated.

Weather conditions for Lubbock on the following dates in 1977 were used as inputs to the program: March 21, June 21, September 21, and December 21. Of the four patterns the conditions of ground temperature, solar radiation, and ambient atmospheric condition leading to maximum heat dissipation would be those represented by characteristics for December 21. The March date portrays equal day and night lengths and a cool ground temperature. Warm ground temperatures and long day length are represented by June 21. Warm ground temperatures, warm atmospheric conditions, and equal day and night lengths are represented by the September date.

Heat Loss Evaluation

The output from the program gives the results in the form of a temperature profile for each sample point in the system. Table 8 shows the input environmental and water properties at noon on Dec. 21, 1977 and the resultant temperature profile in the system for a 50 MGD treatment rate. The Q shown on the figure is the rate of treatment and use in the system for a one-hour period.

The daily range of the temperature profile for each sample point in the test system for the four seasonal patterns at a treatment rate of 50 MGD is shown on Tables 9 through 12. The

Table 8. System Temperature Profile For Noon On Dec. 21, 1977.

```
TIME= 1200

ENVIRONMENTAL PROPERTIES                 VARIABLE WATER PROPERTIES

TA     = 41.00DEG.F                      MDOT= 0.2050E 08 LB/HR
RH     =  0.18                           TI   =110.00 DEG.F
U      = 11.50 MPH                       Q    =  58.96MGD
ALPHA= 32.86 DEG.


ELEMENT         INLET TEMP (F)    OUTLET TEMP (F)    HEAT LOSS (BTU/HR)
   1               110.0000          109.2993            0.1423E 08
   2               109.2993          109.0106            0.5967E 07
   3               109.0106          108.0088            0.2047E 08
   4               108.0088          107.3304            0.1387E 08
   5               107.3304          107.3159            0.2356E 06
   6               107.3159          107.2919            0.4908E 06
   7               107.2919          107.2694            0.4614E 06
   8               107.2694          107.2272            0.8635E 06
   9               107.2272          107.1639            0.1294E 07
  10               107.1639          107.0776            0.1766E 07
  11               107.0776          106.9627            0.2351E 07
  12               106.9627          106.7180            0.5007E 07
  13               106.7180          105.0094            0.3496E 08
  14               105.0094          102.7783            0.4565E 08
  15               102.7783           99.5951            0.6513E 08
  16                99.5951           96.9476            0.5417E 08
  17                96.9476           94.8605            0.4270E 08
```

TABLE 9

Diurnal Temperature Range Exhibited in 50 MGD
Example Municipal Water System for Different
Inlet Water Temperatures for Weather Conditions
in Lubbock, TX on Mar. 21, 1977.

Sample Point	Description	Inlet Temperature			
		90^0	100^0	110^0	120^0
(1)	Exit from Raw Water Storage	88.1-89.8	97.5-99.7	106.9-109.4	116.1-119.2
(2)	Exit at Flocculation Basin	87.4-89.8	96.6-99.5	105.7-109.2	114.5-118.9
(3)	Exit at Sedimentation Chamber	84.9-89.6	93.3-99.1	101.7-108.4	109.6-117.9
(4)	Exit at Filter Unit	88.2-89.5	91.2-98.3	99.1-107.9	106.5-117.1
(5)	(4) + 2500' of 45" pipe	83.2-89.5	91.2-98.3	99.1-107.9	106.5-117.1
(6)	(5) + 2600' of 30" pipe	83.2-89.5	91.2-98.3	99.1-107.9	106.5-117.1
(7)	(6) + 2600' of 27" pipe	83.2-89.5	91.2-98.8	99.1-107.9	106.5-117.1
(8)	(7) + 2500' of 24" pipe	83.2-89.5	91.2-98.8	99.1-107.9	106.5-117.1
(9)	(8) + 2600' of 24" pipe	83.2-89.5	91.2-98.3	99.1-107.9	106.5-117.1
(10)	(9) + 2600' of 20" pipe	83.2-89.5	91.2-98.3	99.1-107.9	106.5-117.1
(11)	(10) + 2600' of 20" pipe	83.2-89.5	91.2-98.3	99.0-107.9	106.5-117.1
(12)	(11) + 2600' of 18" pipe	83.2-89.5	91.2-98.8	99.0-107.9	106.4-117.1
(13)	(12) + 2600' of 10" pipe	83.2-89.5	91.2-98.3	99.0-107.9	106.4-117.1
(14)	(13) + 2600' of 8" pipe	83.1-89.5	91.1-98.8	99.0-107.9	106.4-117.1
(15)	(14) + 1300' of 8" pipe	83.1-89.5	91.1-98.7	98.9-107.9	106.3-117.1
(16)	(15) + 1300' of 6" pipe	83.1-89.4	91.0-98.7	98.8-107.8	106.2-117.0
(17)	(16) + 1300' of 4" pipe	83.0-89.4	91.0-98.7	98.8-107.8	106.1-117.0

Note: Ground temperature is approximately 55° F at depth of four feet.

TABLE 10

Diurnal Temperature Range Exhibited in 50 MGD Example Municipal Water System for Different Inlet Water Temperatures for Weather Conditions in Lubbock TX on June 21, 1977

Sample Point	Description	Inlet Temperature				
		80°	90°	100°	110°	120°
(1)	Exit from Raw Water Storage	79.5-80.3	89.2-90.1	98.8-99.9	108.3-109.7	117.7-119.4
(2)	Exit at Flocculation Basin	79.3-80.5	88.8-90.2	98.3-99.9	107.6-109.6	116.8-119.2
(3)	Exit at Sedimentation Chamber	78.6-81.0	87.7-90.4	96.6-99.8	105.3-109.2	113.8-118.4
(4)	Exit at Filter Unit	78.2-81.3	87.0-90.6	95.5-99.8	103.9-108.9	111.8-117.9
(5)	(4) + 2600' of 45" pipe	78.2-81.3	87.0-90.6	95.5-99.8	103.8-108.9	111.8-117.9
(6)	(5) + 2600' of 30" pipe	78.2-81.3	87.0-90.6	95.5-99.8	103.8-108.9	111.8-117.9
(7)	(6) + 2600' of 27" pipe	78.2-81.3	87.0-90.6	95.5-99.8	103.8-108.9	111.8-117.9
(8)	(7) + 2600' of 24" pipe	78.2-81.3	87.0-90.6	95.5-99.8	103.8-108.9	111.8-117.9
(9)	(8) + 2600' of 24" pipe	78.2-81.3	87.0-90.6	95.5-99.8	103.8-108.9	111.8-117.9
(10)	(9) + 2600' of 20" pipe	78.2-81.3	87.0-90.6	95.5-99.8	103.8-108.9	111.8-117.9
(11)	(10) + 2600' of 20" pipe	78.2-81.3	87.0-90.6	95.5-99.8	103.8-108.9	111.8-117.9
(12)	(11) + 2600' of 18" pipe	78.2-81.3	87.0-90.6	95.5-99.8	103.8-108.9	111.8-117.9
(13)	(12) + 2600' of 10" pipe	78.2-81.3	87.0-90.6	95.5-99.7	103.8-108.9	111.8-117.9
(14)	(13) + 2600' of 8" pipe	78.2-81.3	86.9-90.6	95.5-99.7	103.8-108.9	111.7-117.9
(15)	(14) + 1300' of 8" pipe	78.2-81.3	86.9-90.6	95.5-99.7	103.7-108.9	111.7-117.8
(16)	(15) + 1300' of 6" pipe	78.2-81.3	86.9-90.6	95.4-99.7	103.7-108.9	111.6-117.8
(17)	(16) + 1300' of 4" pipe	78.2-81.3	86.9-90.6	95.4-99.7	103.7-108.9	111.6-117.8

Note: Ground temperature is approximately 76° F at depth of four feet.

TABLE 11

Diurnal Temperature Range Exhibited in 50 MGD Example Municipal Water System for Different Inlet Water Temperatures for Weather Conditions in Lubbock, TX on Sept. 21, 1977.

Sample Point	Description	Inlet Temperature			
		90°	100°	110°	120°
(1)	Exit from Raw Water Storage	89.0-90.3	98.5-100.1	107.9-109.9	117.2-119.6
(2)	Exit at Flocculation Basin	88.6-90.4	98.0-100.1	107.1-109.8	116.1-119.4
(3)	Exit at Sedimentation Chamber	87.3-90.9	96.0-100.3	104.5-109.7	112.6-118.9
(4)	Exit at Filter Unit	86.5-91.2	94.8-100.5	102.7-109.6	110.3-118.5
(5)	(4) + 2600' of 45" pipe	86.5-91.2	94.8-100.5	102.7-109.6	110.3-118.5
(6)	(5) + 2600' of 30" pipe	86.5-91.2	94.8-100.5	102.7-109.6	110.3-118.5
(7)	(6) + 2600' of 27" pipe	86.5-91.2	94.8-100.5	102.7-109.6	110.3-118.5
(8)	(7) + 2600' of 24" pipe	86.5-91.2	94.8-100.5	102.7-109.6	110.3-118.5
(9)	(8) + 2600' of 24" pipe	86.5-91.2	94.8-100.5	102.7-109.6	110.3-118.5
(10)	(9) + 2600' of 20" pipe	86.5-91.2	94.8-100.5	102.7-109.6	110.3-118.5
(11)	(10) + 2600' of 20" pipe	86.5-91.2	94.8-100.5	102.7-109.6	110.3-118.5
(12)	(11) + 2600' of 18" pipe	86.5-91.2	94.8-100.5	102.7-109.6	110.3-118.5
(13)	(12) + 2600' of 10" pipe	86.5-91.2	94.7-100.5	102.7-109.5	110.2-118.5
(14)	(13) + 2600' of 8" pipe	86.4-91.2	94.7-100.4	102.7-109.5	110.2-118.4
(15)	(14) + 1300' of 8" pipe	86.4-91.2	94.6-100.4	102.6-109.5	110.2-118.4
(16)	(15) + 1300' of 6" pipe	86.4-91.2	94.6-100.4	102.6-109.5	110.1-118.4
(17)	(16) + 1300' of 4" pipe	86.4-91.2	94.6-100.4	102.5-109.5	110.1-118.4

Note: Ground temperature is approximately 74° F at depth of four feet.

TABLE 12

Diurnal Temperature Range Exhibited in 50 MGD
Example Municipal Water System for Different
Inlet Water Temperatures for Weather Conditions
in Lubbock, TX on Dec. 21, 1977

Sample Point	Description	Inlet Temperature				
		45°	90°	100°	110°	120°
(1)	Exit from Raw Water Storage	44.5-45.1	88.5-89.6	98.1-99.5	107.7-109.3	117.1-119.1
(2)	Exit at Flocculation Basin	44.3-45.2	87.9-89.4	97.4-99.3	106.7-109.1	115.9-118.7
(3)	Exit at Sedimentation Chamber	43.7-45.4	85.9-88.9	94.9-98.6	103.7-108.2	112.2-117.5
(4)	Exit at Filter Unit	43.3-45.6	84.5-88.5	93.2-98.1	101.6-107.6	109.7-116.7
(5)	(4) + 2600' of 45" pipe	43.3-45.6	84.5-88.5	93.2-98.1	101.6-107.6	109.6-116.7
(6)	(5) + 2600' of 30" pipe	43.3-45.6	84.4-88.5	93.1-98.1	101.5-107.6	109.6-116.7
(7)	(6) + 2600' of 27" pipe	43.3-45.6	84.4-88.5	93.1-98.1	101.5-107.6	109.5-116.6
(8)	(7) + 2600' of 24" pipe	43.3-45.6	84.3-88.5	93.0-98.1	101.4-107.5	109.4-116.5
(9)	(8) + 2600' of 24" pipe	43.3-45.6	84.2-88.4	92.9-98.0	101.2-107.5	109.3-116.5
(10)	(9) + 2600' of 20" pipe	43.3-45.6	84.1-88.4	92.7-98.0	101.1-107.4	109.1-116.4
(11)	(10) + 2600' of 20" pipe	43.3-45.6	83.9-88.3	92.5-97.9	100.8-107.3	108.8-116.3
(12)	(11) + 2600' of 18" pipe	43.4-45.6	83.5-88.2	92.0-97.7	100.3-107.2	108.2-116.0
(13)	(12) + 2600' of 10" pipe	43.4-45.5	81.0-87.3	89.0-96.6	96.7-105.9	104.1-114.2
(14)	(13) + 2600' of 8" pipe	43.4-45.5	77.9-86.1	85.1-95.2	92.2-104.2	98.9-111.9
(15)	(14) + 1300' of 8" pipe	43.5-45.4	73.6-84.4	80.0-93.1	86.2-101.7	92.1-108.4
(16)	(15) + 1300' of 6" pipe	43.5-45.3	70.4-82.9	76.0-91.3	81.5-99.6	86.8-105.6
(17)	(16) + 1300' of 4" pipe	43.6-45.3	67.9-81.1	73.1-89.9	78.1-98.0	82.9-103.4

Note: Ground temperature is approximately 44° F at depth of four feet.

results for a treatment rate of 26 MGD for conditions on Dec. 21, 1977 are shown on Table 13. As can be expected, the minimul temperature range between sample point 1 and the other sample points within the distribution system occurred on the June date. The mximum-minimum ambient temperature for the June date was 83°-65°F, whereas, the maximum-minimum span for the September date was 94°-73°F. The higher temperatures for the September date did effect the maximum water temperatures at the first four sample points and thus subsequently influenced the temperatures in the rest of the system. The influence of the 2°F decrease in ground temperature from the June date to the September date was exhibited by the minimal temperatures generated for each sample point.

The temperature differential exhibited in the larger pipes for all four dates is slight as evidenced by the temperature range at sample point 10 for December 21 (101.1°-107.4°F) and for June 21 (102.8°-108.9°F) for an inlet temperature of 110°F. This situation is apparent even in the temperature regime at sample point 10 (92.5°-104.7°F) at an inlet temperature of 110°F for the average use day on December 21 on Table 13. Customers, therefore, connected to the large pipes in the system or to distribution mains connected to the large pipes would have access to higher water temperatures throughout the year than those at the extremities of a system such as at sample point 17. Also, customers located closer to the larger lines would experience less diurnal temperature variation once the "stagnant water" has been removed from the service line and a use cycle is begun.

Table 14 shows the diurnal temperature regime for sample point 17 for the two treatment modes at an inlet temperature of 110°F. That the flow amounts in the system do affect the temperatures can be seen from a comparison of the two columns.

TABLE 13

Diurnal Temperature Range Exhibited in 50 MGD
Example Municipal Water System for Different
Inlet Water Temperatures for Weather Conditions
in Lubbock, TX for Average Use Day on Dec. 21, 1977.

Sample Point	Description	Inlet Temperature			
		90°	100°	110°	120°
(1)	Exit from Raw Water Storage	86.8-89.1	96.1-98.9	105.2-108.6	114.0-118.3
(2)	Exit at Flocculation Basin	85.6-88.8	94.5-98.5	103.3-108.1	111.7-117.6
(3)	Exit at Sedimentation Chamber	81.5-87.6	89.6-97.0	97.3-106.2	104.7-115.2
(4)	Exit at Filter Unit	78.8-86.9	86.4-96.0	93.5-105.0	100.2-113.7
(5)	(4) + 2600' of 45" pipe	78.7-86.8	86.3-96.0	93.5-104.9	100.2-113.7
(6)	(5) + 2600' of 30" pipe	78.7-86.8	86.2-96.0	93.4-104.9	100.0-113.6
(7)	(6) + 2600' of 27" pipe	78.6-86.8	86.1-95.9	93.3-104.9	99.9-113.6
(8)	(7) + 2600' of 24" pipe	78.5-86.7	86.0-95.9	93.1-104.8	99.7-113.5
(9)	(8) + 2600' of 24" pipe	78.3-86.7	85.8-95.8	92.8-104.7	99.4-113.4
(10)	(9) + 2600' of 20" pipe	78.0-86.6	85.5-95.7	92.5-104.6	99.0-113.2
(11)	(10) + 2600' of 20" pipe	77.7-86.4	85.1-95.5	92.0-104.4	98.5-113.0
(12)	(11) + 2600' of 18" pipe	77.0-86.2	84.2-95.2	91.0-104.0	97.4-112.6
(13)	(12) + 2600' of 10" pipe	72.5-84.3	78.7-92.9	84.6-101.3	90.1-109.5
(14)	(13) + 2600' of 8" pipe	67.4-81.8	72.5-89.9	77.3-97.8	81.8-105.5
(15)	(14) + 1300' of 8" pipe	61.4-78.5	65.2-85.8	68.8-93.1	72.2-100.1
(16)	(15) + 1300' of 6" pipe	57.5-75.8	60.4-82.6	63.2-89.2	65.8-95.7
(17)	(16) + 1300' of 4" pipe	54.9-73.6	57.2-80.1	59.5-86.3	61.6-92.3

Note: Ground temperature is approximately 44° F at depth of four feet.

TABLE 14

Diurnal Temperature Regime at Final Outlet in Example Distribution System for Maximum Flow Day and Average Day at Inlet Temperature of 110°F Using Weather Conditions at Lubbock, TX on 21 December, 1977.

Time	°F for Maximum Flow	°F for Average Flow
0100	85.4	67.6
0200	82.2	63.6
0300	78.1	59.5
0400	78.3	59.7
0500	78.4	59.8
0600	82.4	64.1
0700	91.6	79.8
0800	93.1	78.3
0900	95.1	81.5
1000	95.5	82.2
1100	94.8	81.1
1200	94.8	81.1
1300	94.7	80.9
1400	94.5	80.6
1500	93.8	79.7
1600	92.2	77.0
1700	93.6	78.8
1800	94.4	80.4
1900	95.8	82.6
2000	98.0	86.3
2100	96.2	83.4
2200	94.9	81.2
2300	90.2	74.0
2400	89.3	72.8
Average	90.7	75.6

Additionally, the variations in the daily flow pattern affect the temperature at the sample point. The highest daily temperature coincides with the period of greatest use (2000 hours). Under stagnant conditions, which can occur in the smaller distribution mains during non-use periods such as between midnight and 0600, lower water temperatures could be expected under both treatment modes.

The water use rate in the system is not always the primary determinant of the system temperature profile. An examination of the data revealed that the impact of solar radiation on the exposed reactors overrode the use rate in the system for all inlet temperature conditions tested at the June period and for all inlet temperatures except the 120°F condition at the March and September dates. Even though the use ratios during the early afternoon hours (1.20, 1.18, 1.16) are lower than that exhibited at 2000 (1.6) the temperatures at point 4 for those periods were higher as a result of solar insolation and the effects were transmitted to the rest of the system.

Resource Conservation Potential

The primary benefit from receiving warm water at the point of consumption will be the reduction in energy required for producing hot water. It is estimated that hot water heating accounts for 24% of the energy required in buildings and approximates 7.9% of the energy used in the United States (Dorf, 1978). In residential usage, the energy required for hot water has been estimated to range from 20% to 25% of the total fuel used in the household (Jarmul, 1980). Hospitals also require large amounts of hot water for bathing, food preparation, and laundering operations. In food service facilities, hot water needs can approximate 13% of the energy budget, whereas, in offices and most other commercial establishments requirements for hot water heating are minimal (Jarmul, 1980).

The amount of hot water required in households varies. Estimates of use also vary. For a family of four, estimates range from 50 gallons per day (Hand, 1978) to approximately 115 gallons per day for the inhabitants of a model home (Bailey et al., 1969). For other family sizes, one-third of the total daily water consumption will be hot water (Anderson, 1977).

The potential impacts on energy use and annual cost for water heating were investigated. The kilowatt hours of electricity and the cubic feet of natural gas used to heat 50 gallons of water per day to different water heater outlet temperatures from the level of the annual water temperature at sample point 17 with and without implementation of the study concept was determined. Where no dishwasher is used, water at temperatures of 120° to 125°F may be adequate, but with a dishwasher water at 145°F is recommended (Jarmul, 1980). The annual costs were determined based upon the daily energy requirments. The results are shown in Tables 15 and 16.

The discrepency in energy costs for fuels delivered to the point of use per 10^6 Btu is apparent from the figures shown on the tables...$14.65 for electricity and $3.33 for natural gas. The unit costs for the fuels are based upon price paid in mid-year 1980 in the Lubbock area. In areas where natural gas is plentiful and cheap, the savings of $43.31 per year for raising water to 150°F from 100.9°F rather than from 62.5°F may not be worth the uncertainty of what difficulties the warmer water might cause at the point of use. In areas dependent on electricity, greater interest may be aroused by the savings of $105.67 per year in water heating costs. Actual savings in water heating may be greater than those shown because of the reduced needs for hot water for the washing of hands in the kitchen and lavatory because of the higher ambient water temperature in the house.

The impact of the study concept in an area dependent primarily on elctric energy for hot water heating will be greater than that at present in an area where natural gas is available for domestic use. If 5.79 kwh of electric energy

TABLE 15

Daily Energy Requirements in KWH for Heating 50 Gallons per day and Annual Costs for Electric Water Heaters with and without Implementation of Concept for Example System*

Outlet Temperature at Condenser (°F)	Average Annual Water Temperature at Sample Point 17 (°F)	Outlet Temperature at Electric Water Heater (°F)				
		120	130	140	150	160
120	108.5	1.73** (31.66)†	3.24 (59.13)	4.75 (86.68)	6.26 (114.24)	7.77 (141.80)
110	100.9	2.88 (52.56)	4.39 (80.12)	5.90 (107.68)	7.41 (135.23)	8.92 (162.79)
100	93.8	3.95 (72.08)	5.46 (99.65)	6.97 (127.20)	8.48 (154.76)	9.99 (182.31)
90	82.3	5.68 (103.66)	7.19 (131.22)	8.70 (158.78)	10.21 (186.33)	11.72 (213.89)
	62.5	8.67 (158.22)	10.18 (185.78)	11.69 (213.34)	13.20 (240.90)	14.71 (286.48)

* Efficiency of electric hot water heater is 81%

** KWH per day to heat 50 gallons of water to outlet temperature at 81% efficiency.

† Annual cost in dollars of heating water at $ .05 per kwh.

TABLE 16

Daily Energy Requirements in ft.^{3} of Natural Gas for Heating 50 Gallons Per Day and Annual Costs for Gas-Fired Water Heater with and without Implementation of Concept for Example System*

Outlet Temperature at Condenser (°F)	Average Annual Water Temperature At Sample Point 17 (°F)	Outlet Temperature at Gas-Fired Heater (°F)				
		120	130	140	150	160
120	108.5	10.2** (13.03)†	19.0 (24.27)	27.8 (35.51)	36.6 (46.76)	45.5 (58.13)
110	100.9	16.9 (21.58	25.7 (32.83)	34.5 (44.07)	43.3 (55.31)	52.1 (66.56)
100	93.8	23.1 (29.51)	31.9 (40.75)	40.8 (52.12)	49.6 (63.36)	58.4 (74.60)
90	82.3	33.3 (42.54)	42.1 (53.78)	50.9 (65.02)	59.7 (76.26)	68.6 (87.64)
---	62.5	50.7 (64.77)	59.5 (76.01)	68.4 (87.38)	77.2 (98.62)	86.0 (109.86)

*Efficiency of gas-fired heater is 45%. (Bond, 1980)

**Ft.^{3} of natural gas (1050 Btu/ft^3) to heat 50 gallons of water to outlet temperature at 45% efficiency.

† Annual cost in dollars of heating water at \$3.50 per 1000 ft^3 of gas.

are saved per day per household in raising the temperature of water to 150° from 100.9°F rather than from 62.5°F, this would represent a savings of 18.68 kwh of thermal energy which need not be generated at the plant if electricity is delivered to the residence with an efficiency of 31%. Per 1000 homes the savings in fuel consumed at the plant would be approximately 11 barrels of oil per day. The savings to a utility in fuel costs and in installed generating capacity to provide the 5,790 kwh of power required for heating water during the daily activity period in 1,000 homes, and the savings in cooling water management costs for either an alternate once-through system or a closed-cycle system using an evaporation tower can be considerable.

The energy transferred to the cooling water for various municipal water use rates is shown on Table 17. The increase in heat storage per pound of water is an aid in increasing the power generation capacity. An 80°F raw water temperature to the condenser was used as a representative summer temperature. In cooler periods of the year water use in the municipality is normally less. The increased capacity for heat transfer per pound of water will serve to offset the decreased water flow rates.

TABLE 17

Energy Output From Various Water Treatment Rates for an Input Water Temperature of 80°F

Water Treatment Rate (MGD)	Water Temperature at Condenser Outlet ($^{\circ}$F)				
	85	90	100	110	120
10	4.5*	9.0	18.0	27.2	36.2
25	11.3	22.6	45.3	67.9	90.5
50	22.6	45.3	90.6	135.8	181.0
100	45.3	90.5	181.1	271.6	362.0

* Electric energy output in megawatts

Note:
- cooling water is to carry away 45% of heat energy produced
- stack losses are 15% of heat energy produced
- Electricity generated at 40% thermal efficiency

CHAPTER III

EFFECTS OF ELEVATED WATER TEMPERATURES ON WATER TREATMENT

The purpose of this phase of the study was to investigate the effects of elevated temperatures on selected unit operations and processes of water treatment. The temperatures chosen were from 30° to 60°C in ten degree increments, in order to bracket the temperature variations which could occur in a treatment plant recieving heated effluent. Investigations were made on the following (1) alum floc sedimentation, (2) adsorption of organics by powdered activated carbon, and (3) rapid sand filtration. Temperature effects on disinfection using sodium hypochlorite are currently under investigation, but no data from these studies is available. These operations were chosen for study because little is known about their behavior at elevated temperatures and because they represent the major portion of the capital investment and operating costs in a conventional water treatment plan.

In addition to reducing the viscosity of the water, temperature could also affect floc size and density, rate of floc formation, chemical nature of the flocculation agent, and adsorption rates and capacities. Although the viscosity effects might be adequately predicted, relative effects of the other variables would be more difficult to model. The sedimentation rate, and prediction of this rate would become difficult if particle density and size changed with temperature.

Adsorption of organic compounds is an exothermic process which is also subject to temperature effects as predicted by the Van't Hoff-Arrhenius equation. Since each mechanism exerts an opposing influence on reaction rates it was felt that laboratory studies were necessary to adequately determine the predominant effect at elevated temperatures.

Head loss through a porous medium is related to temperature due to the effect of viscosity. However, if the physical or chemical nature of a floc is altered at elevated temperatures, floc penetration in a rapid sand filter could modify the effects of viscosity. Sand columns were employed to study filtration of an alum floc at various temperatures.

The disinfection studies are being conducted because little information concerning elevated temperature effects in water treatment for municipal use is available. Although HOCl dissociates to the less effective disinfectant form, OCl^- at elevated temperature, its bactericidal effects may increase due to accelerated reaction rates. Additionally, in the upper ranges temperature may have a bactericidal effects, but may promote growth at the lower ranges. The effects of the four test termperatures and various concentrations of NaOCl on bacterial survival are currently under investigation.

Although other unit processes and operations could have been included in this study, it was felt that elevated temperatures would have the greatest impact on the areas studied.

Sedimentation

The use of agents to remove suspended material from drinking water was an ancient practice, although flocculation was not used in a water treatment process until 1881. The first quantitative investigations were conducted by Schultze in 1882. His discoveries, together with those of Hardy in 1900, constituted the so called Schultze-Hardy rules concerning ionic charge of suspended particles and valency of flocculating agents. In 1917, Smoluchowski formulated mathematical equations concerning orthokinetic and perikinetic effects on particle size.

By 1924, the double-layer model of electric charges around a particle had been developed by Gouy, Chapman, and Stern. The model was substantiated by Verwey and Overbeek who showed, in 1948, that the attractive-repulsive forces associated with a particle were important in the prevention of flocculation (Mohtadi, et al, 1973).

Destabilization by adsorption has been supported by many studies although the process is difficult to describe mathematically. Polyelectrolytes have been employed to study this phenomenon.

Although the mechanisms of flocculation have been elucidated, the influence of temperature has not been well studied and the existing data are inconclusive. A study by Leipold showed that temperature had no effect on flocculation (Leipold, 1934). Another showed that increases in temperature had a detrimental effect (Velz, 1934). Later studies on river water showed that a decrease in temperature reduced flocculation size and increased the flocculant dosage required for a specified clarity (Chojnacki, 1968).

In the above studies, temperatures varied from 4° to 25°C, the range normally encountered in water treatment. However, no information has been found concerning the effect of elevated temperatures (30°- 60°C) on flocculation of potable water supplies.

Experimental Methods

The effect of temperature on the coagulation and sedimentation of an alum-bentonite floc was investigated by means of the jar test. The procedure was performed at each of the four test temperatures: 30°, 40°, 50°, and 60°C. The jar test is a commonly used bench scale method, but many investigators have their own variation. The following steps were used in these studies. The appropriate number of 1000-ml beakers were filled with tap water and brought to temperature in a Napco Model 230 bath. Water temperature was maintained with a Haake Model E 12 constant temperature circulator. An aliquot of a bentonite suspension was added and dispersed with Phipps-Bird Model 300 paddle stirrers. The bentonite suspension was prepared by dispersing 100 mg of the clay for 30 seconds in tap water with a Tekmar Model SDT high speed mixing probe before dilution into the reaction vessel. Although such high concentrations of suspended matter are not normally encountered in municipal water supplies, this concentration aided spectrophotometric analysis. After the bentonite was completely dispersed, paddle speed was increased to a maximum, approximately 150 rpm, before the addition of the flocculant. The alum concentrations used were 0.0, 1.0, 5.0, 10.0, and 20.0 mg/l. The reagent solution was made by dissolving enough $Al_2(SO_4)_3 \cdot 18H_2O$ in distilled water to give a final concentration of 1.0 mg/ml $Al_2(SO_4)_3$. The final reaction volume was 500 ml. Rapid mix was continued for two minutes followed by slow stirring at 30 rpm for ten minutes before further procedures were initiated. At times of 0, 10, 20, 30, 40, 50, and 60 minutes after the completion of this slow mix, duplicate 3-ml samples were withdrawn 13 mm below the water surface of each beaker using a syringe fitted with 30 cm of tygon tubing, 1-mm in diameter. Each sample was held in a 5-ml test tube until all samples for that particular time period had been taken. Samples were then transferred to a quartz cuvette, and optical density (OD) was measured at 450 nm in a Beckman Model 24 spectrophotometer. All OD measurements were completed before the next series of samples was collected.

Results

The reaction of bentonite with various concentrations of alum produced proportional changes in optical density which were stable at the temperature ranges used in this study. The optical density readings obtained at 450 nm in a solution containing 50 ppm of alum and 200 ppm of bentonite were as follows:

Temperature (C^{o})	OD (450 nm)
30	0.50
40	0.46
50	0.47
60	0.46
70	0.47

It was found that these turbidities remained constant for at least one hour during the slow-stir phase of the jar test.

The effect of various concentrations of alum on a 200-ppm suspension of bentonite at a temperature of 30°C is shown in Figure 8. This temperature probably represents the upper limit normally experienced in water treatment plants in the United States. As would be expected, increasing amounts of flocculating agent produced greater amounts of removal of suspended material, although removal in these experiments was not proportional to dosage.

Figure 9 shows the effect of temperature on turbidity after 20 minutes of settling using 5-ppm alum. An increase in temperature was found to reduce the amount of time required to achieve a given optical density. At 30°C, 50 minutes was required to reduce residual OD to 12% as compared with only 20 minutes at 60°C.

By increasing the flocculant dosage the time required for reduction of turbidity was decreased. Figure 10 shows that an alum concentration of 10-ppm at 60°C reduced turbidity by 88% in ten minutes, as compared with 50 minutes required for a 5-ppm alum concentration at 30°C.

In the absence of a floc, sedimentation of a bentonite suspension was also improved at elevated temperatures, as

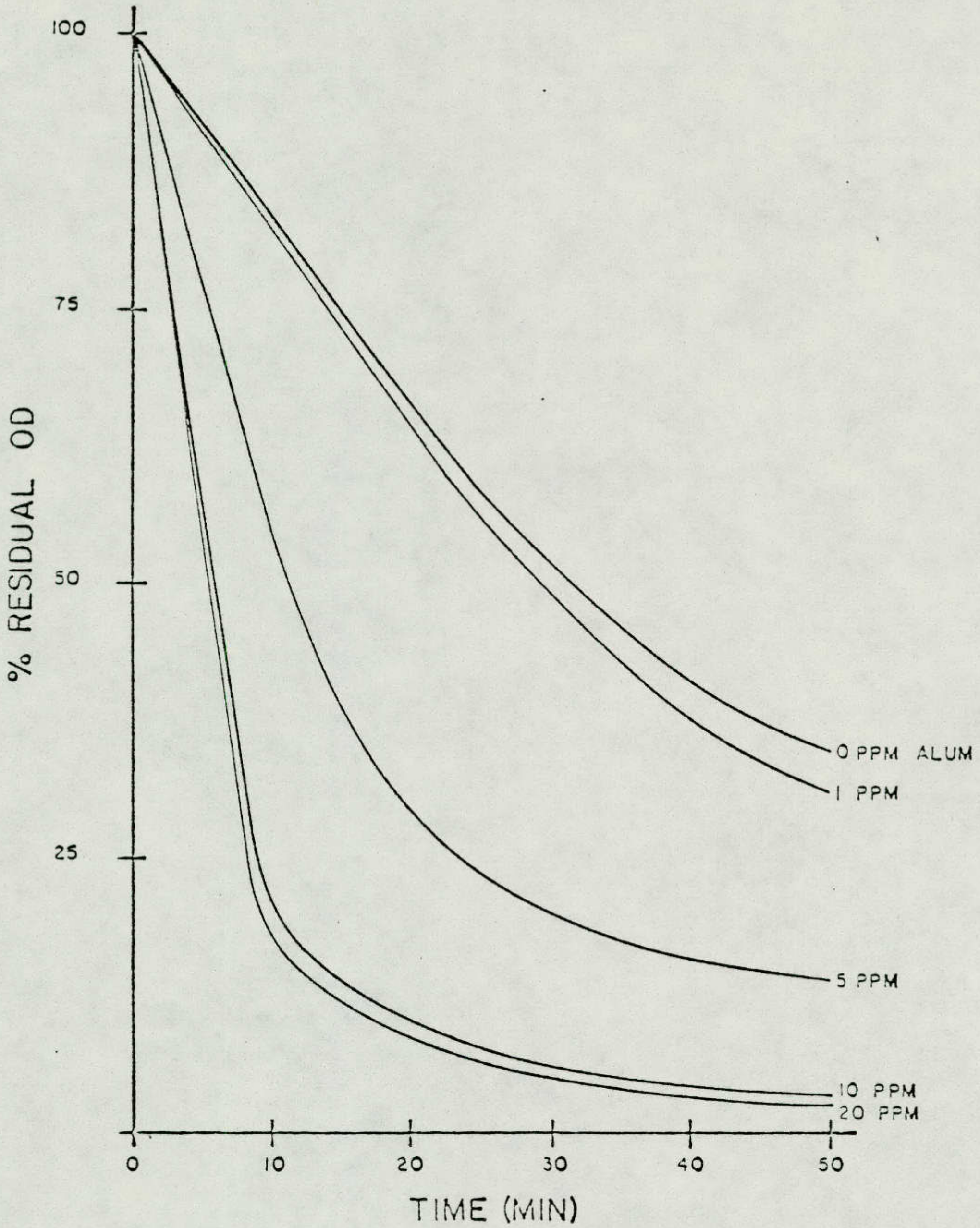

Figure 8 . Effect Of 5 Alum Concentrations On Sedimentation Of Bentonite Clay. Temperature = 30°C. Bentonite = 200.0 mg/l.

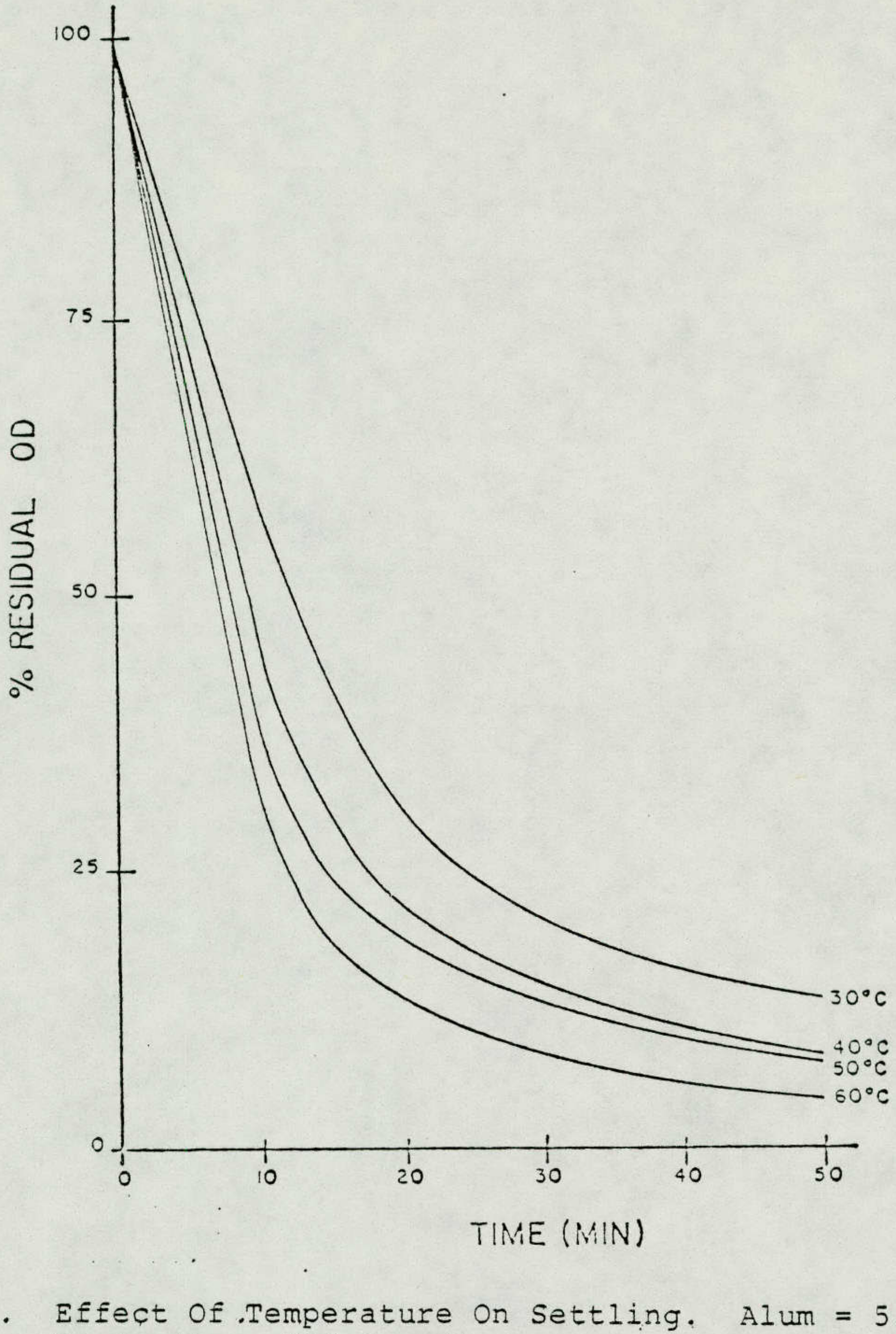

Figure 9 . Effect Of Temperature On Settling. Alum = 5.0 mg/l, Bentonite = 200.0 mg/l.

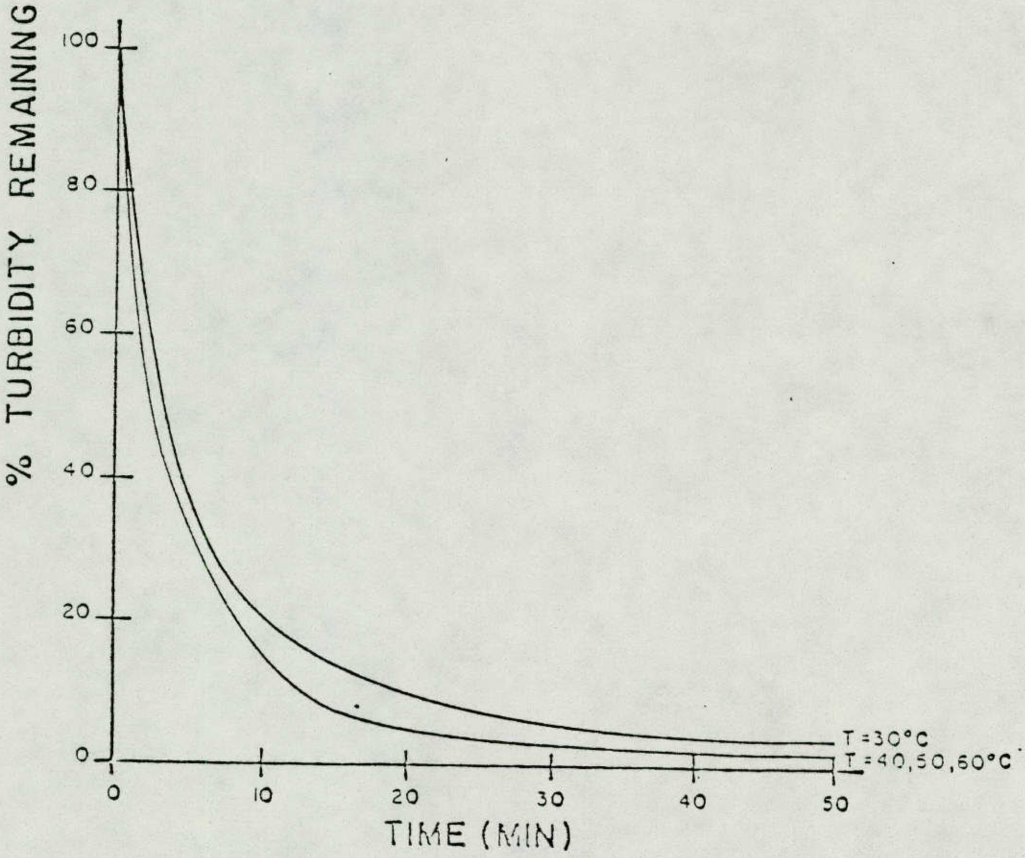

Figure 10. Effect Of Temperature On Settling. Alum = 10.0 mg/l, Bentonite = 200.0 mg/l.

illustrated by Figure 11. Comparison of this Figure and Figure 9, for 5-ppm alum shows that at 60°C and 0.0-ppm alum, or at 30°C and 5.0-ppm alum, approximately 20% residual turbidity remains after 30 minutes of settling.

In a study concerning the effects of temperature on wastewater, it was suggested that in addition to viscosity, properties of the coagulant and floc size could change with temperature. Preliminary spectrophotometric data which included similar optical density readings for various temperatures do not support Wright's hypothesis (Wright, 1974).

These data suggest that temperature has the greatest effect on viscosity of water which, in turn, is important in the rate and extent of settling. Other investigations have also found that elevated temperatures increase settling rates of floc suspensions formed between 1° and 20°C. However, in accordance with Smoluchowski's equations they also found that if coagulation were induced at the optimum pH for a given alum concentration, temperature effects were minimized (Mohtadi and Rao, 1973).

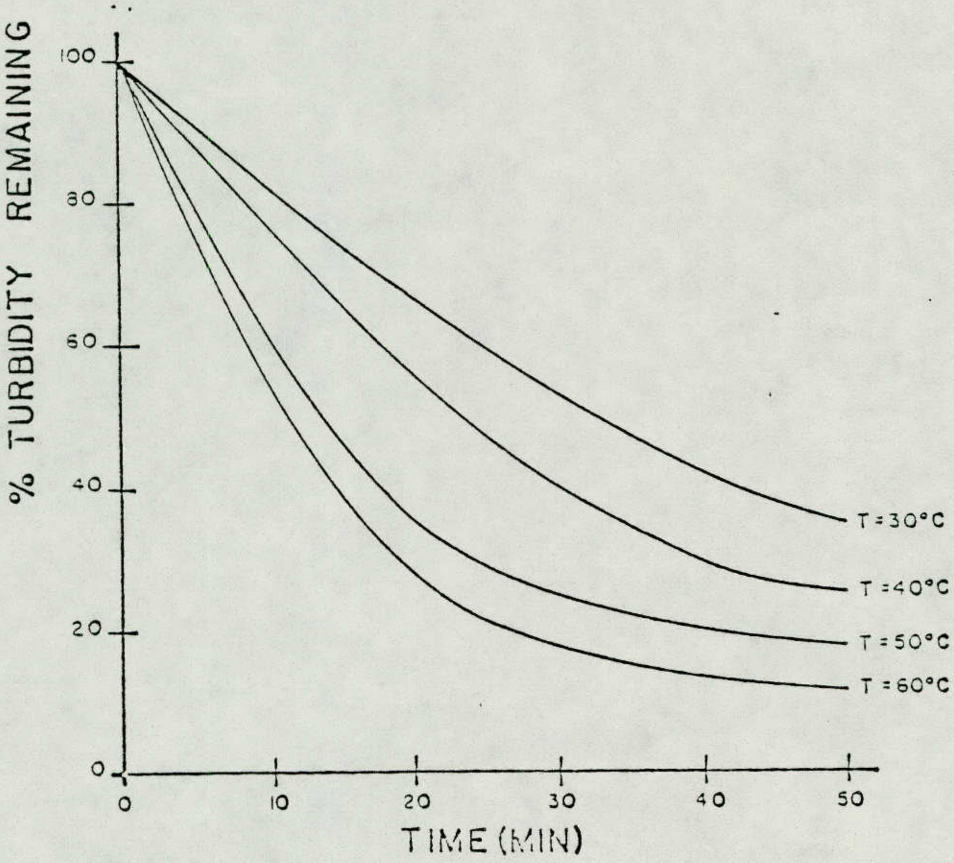

Figure 11 . Floc Sedimentation At Four Temperatures Alum = 0.0 mg/l, Bentonite = 200.0 mg/l.

Adsorption

In 1785, activated carbon was observed to adsorb organics from solution; it was first used in a water treatment process in the U. S. in 1930. In 1977, it was found that, of 645 U. S. water treatment facilities surveyed, 25% were using powdered activated carbon(PAC), primarily for taste and odor control (AWWA Committee Report, 1977).

Increasingly stringent government regulations in recent years have generated research concerning the ability of activated carbon to remove dissolved organics from water supplies and effluent waste streams. Activated carbon, both in granular and in powdered forms, is being used to remove a variety of compounds including substances associated with the carbon chloroform and carbon alcohol extracts, pesticides, hydrocarbons, and haloforms (McCreary et. al., 1977).

Although the literature contains a large amount of data pertaining to the adsorption of organics onto carbon surfaces, there is very little information concerning the mechanism and actual kinetics of adsorption (Parkash, 1974). There are three rate-limiting steps in the adsorption of materials from solution by activated carbon (Weber, 1972). These include rate of transport of adsorbate through the surface film to the surface of the adsorbent, diffusion of the adsorbate within the micropores of the adsorbent, and attachment of the adsorbate within the micropores of the adsorbent. These rates may be influenced by a variety of factors including surface area, nature of adsorbate and adsorbent, pH, and also temperature, the concern of this study.

Experimental Methods

The jar test was also used to study the effects of temperature on adsorption of organics by powdered activated carbon (PAC), in the presence of bentonite. The adsorbable organic used was methyl orange (MeOr) for the following reasons: (1) it does not evaporate and is stable at the temperature and pH ranges used in these experiments, (2) it is water soluble,

(3) it is readily adsorbed by PAC, and (4) it is easily detected by spectrophotometric methods.

Granular PAC was weighed directly into each beaker because slurry addition often gave variable results. Concentration of PAC in the final reaction volume of 500 ml was 300 mg/l. Immediately after the addition of alum to the PAC-bentonite suspension, 5.0 ml of a stock solution of MeOr was added to one of a set of two beakers for each alum concentration, the other beaker being the control. Bentonite and alum concentrations were the same as those used in the sedimentation experiments. The stock solution of MeOr was 200 mg/l, aqueous concentration. After the required ten minutes of slow stirring, aliquots were withdrawn from each reaction set at ten-minute increments for fifty minutes. All beakers were continuously stirred during the experiment. Each control and reaction sample was vacuum filtered through a Whatman GF/A glass fiber membrane to remove alum floc and PAC. All aliquots were filtered before initiation of the next sampling sequence. After all samples were filtered, optical density was measured at 450 nm. When the control OD exceeded 0.01 units, the sample pair was discarded.

Since adsorption is an exothermic process, the extent of adsorption should decrease with an increase in temperature (Weber, 1972). Figure 12 illustrates the effect of temperature on the adsorption of methyl orange by PAC in the presence of 1-ppm alum and 200-ppm bentonite. During continuous agitation of the PAC floc suspension, adsorption was time dependent for at least one hour. The Figure shows that at elevated temperatures, the rate and extent of MeOr adsorption was increased. The removal of 70% of color required approximately 40 minutes at 30°C as compared with twenty minutes at 60°C. Similar results were obtained using 0.0, 5.0, 10.0, and 20.0 milligrams per liter of alum, indicating that PAC, and not the floc, was responsible for the major portion of color removal. Results of incubation mixtures containing MeOr only, showed that a stable

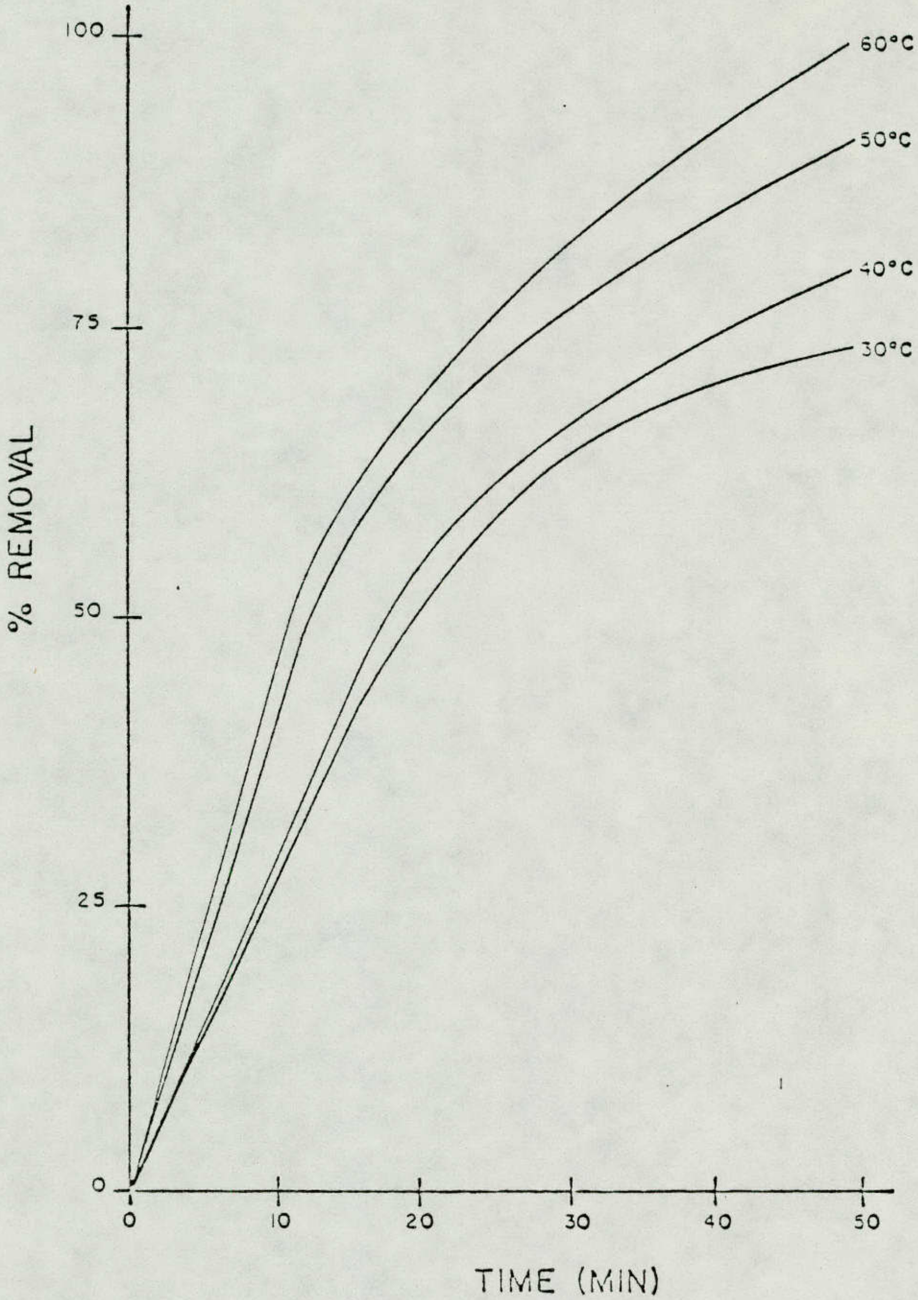

Figure 12, Removal of Methyl Orange By Powdered Activated Carbon At Various Temperatures.

optical density could be maintained for at least one hour, an indication that organic concentration was not influenced by evaporation.

Although Wright conducted his studies on settled wastewater, he found that floc formation had little effect on organic removal (Wright, 1974). He also reported that the organic content of his test solutions was reduced when incubated at 60°C in the presence of PAC.

In his discussion of factors influencing adsorption, Weber states that adsorption may be considered as a type of reaction rate which, as predicted by the Arrhenius equation, should increase with temperature (Weber, 1972). The influence of temperature on reaction rates is also dependent upon the type of adsorption involved, i. e. ion exchange, physical adsorption, or chemisorption. The latter is most strongly affected by high temperatures, although most adsorption phenomena are combinations of all three types.

Weber also states that in batch reactor systems, such as those used to conduct these experiments, porous diffusion is the principal rate-limiting step. In these studies, this rate may have been affected by reduced viscosity of the water at elevated temperatures, subsequently influencing transport rate of adsorbate to the micropores of the adsorbent.

Filtration

Filtration in municipal water treatment is the unit operation in which water is passed through a porous medium to remove suspended solids. The solids can include silts, clay, organic colloids, and micro-organisms. Although several types of media in different combinations have been employed as filter media, the most common is sand, first used in England in the 1850's.

A number of theories have been developed to elucidate the complex mechanisms which occur in filtration (O'Melia *et. al.*, 1967 and Yao *et. al.*, 1971). These mechanisms generally include the phenomena of straining, flocculation, sedimentation, and adsorption.

In a properly operated deep-bed granular filter such as employed in rapid sand filtration, the majority of the particles removed should accumulate within the bed. Filtration at the surface only results in rapid head losses and in operational time for each run too short for practical purposes. Once captured in the bed, the adherence of a particle is affected by flocculation, concentration of anions, pH, and temperature.

Experimental Methods

Sand used in these studies was prepared by sieving a gross sample and removing that fraction passing a United States Standard Sieve Size #50 and retained on a USSS #40. The #50 sieve passes grains smaller that 0.59 mm, and the #40 sieve retains grains larger that 0.42 mm.

The sand fraction was cleaned to remove fines until an effluent wash having an OD less than or equal to 0.005 OD units at 450 nm was obtained. The sand was dried overnight at 105°C and stored in a desiccator for at least 24 hours before use. For each filtration run, a locally fabricated glass column, 2.7 cm in diameter and 50.8 cm in height was loaded with 138.9 grams of sand and the resulting volume was reduced to a height of 16 cm by tapping the column. Ten cm of vacuum hose was attached to a port at the base of the sand column, clamped off, and connected to the bottom port of a similar column containing air-free water. A vacuum of 66 cm of mercury was applied to both columns for fifteen minutes. The clamp between the two columns was then opened to allow the water to rise in the sand column by capillary action and head difference. After complete saturation of the sand bed, the vacuum was released (See Figure 13).

The preceding steps were employed to obtain a soil column of constant permeability, which is influenced by the void ratio of the soil, the shapes and arrangement of the pores, and the degree of saturation. Exposure of the column to a high vacuum was necessary in order to eliminate air pockets which could cause binding and excessive head loss during filtration. Once the column was saturated, air dissolved in water passed through the column and did not cause head loss due to the submerged outlet arrangement.

The column was then standardized and its hydraulic conductivity constant was calculated. The column was first connected to an insulated, 9-liter constant-head apparatus containing water at 30°C, and allowed to equilibrate to a constant head loss. Head loss was measured by the difference in height of water in two piezometers attached at points 7.6 cm below and 18.6 cm above the sand surface (Figure 14). The flow was then adjusted to approximately 40 ml/min and the effluent was collected for a measured time increment equal to or greater than ten minutes. The hydraulic conductivity constant of the column was calculated from

$$C_h=Q(L/H_L)$$

where:

C_h is the hydraulic conductivity constant,

Q is flow as volume per time unit,

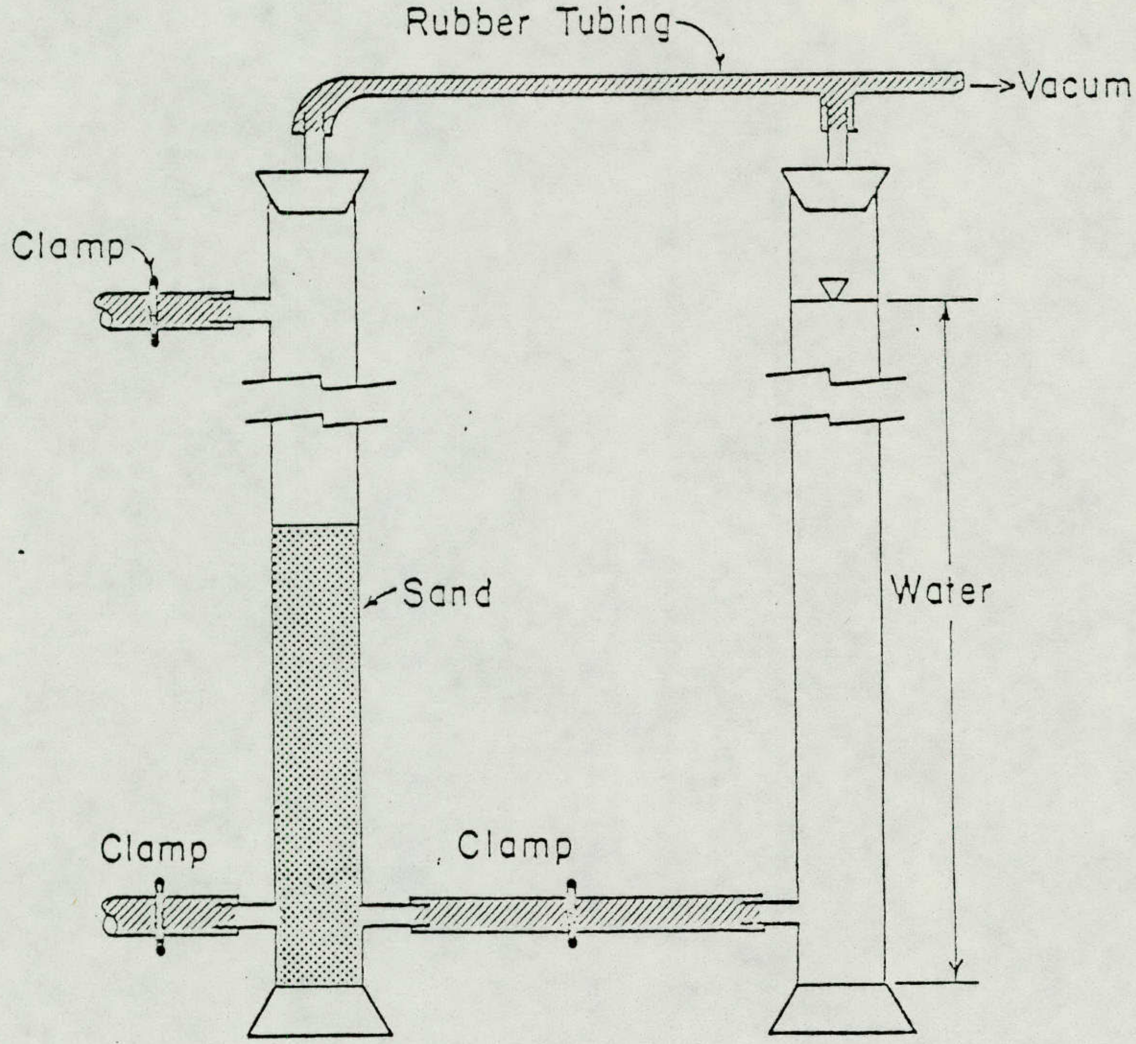

Figure 13 . Column Preparation

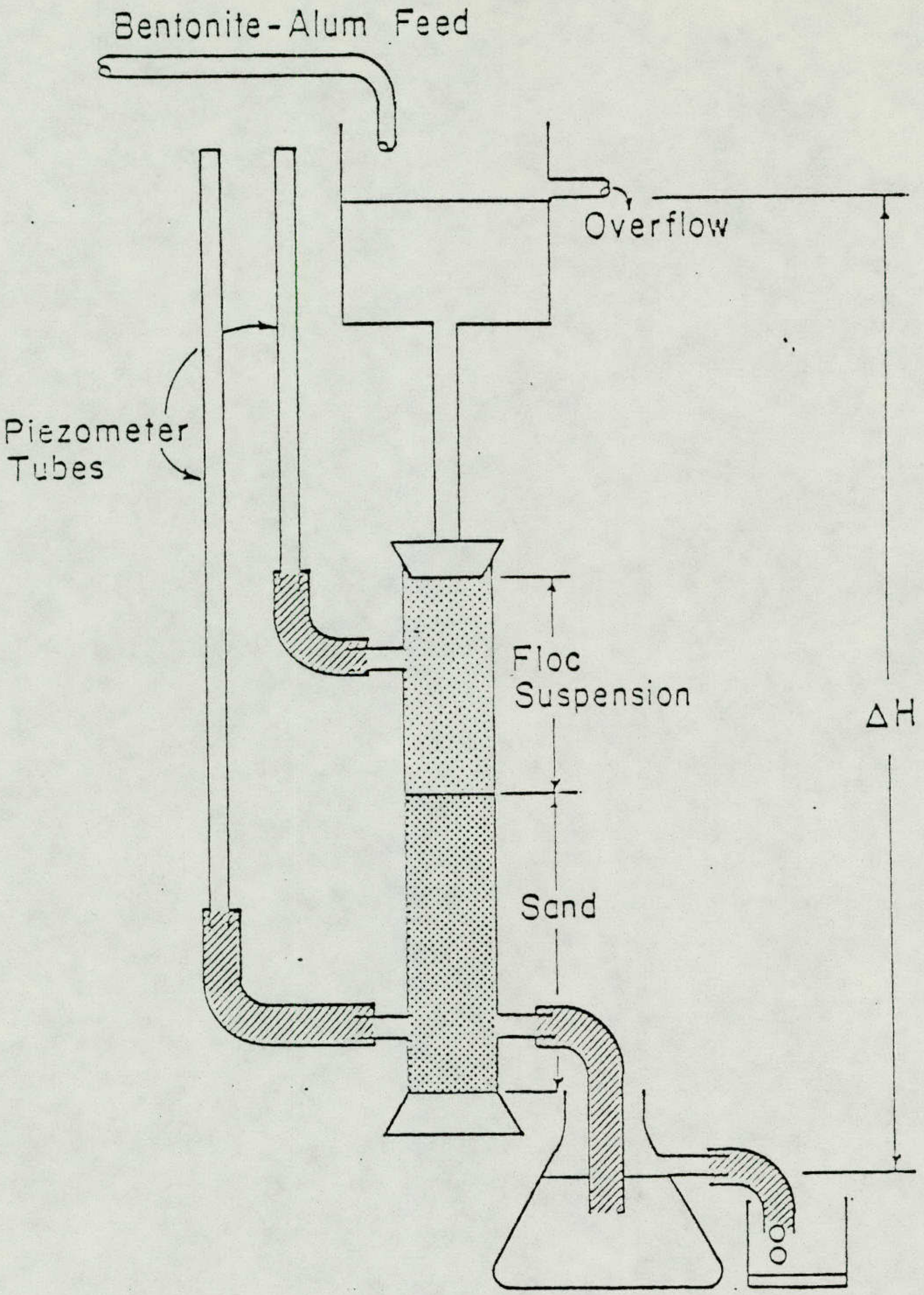

Figure 14 . Column Configuration During Test Run.

L is height of sand bed, and

H_L is the head loss.

C_h has the same units as Q. The computation of C_h is similar to that for k, the coefficient of permeability, associated with the constant head test, upon which this procedure is based.

Columns having a C_h of 70± 1 ml/minute were then equilibrated at the test temperature before initiation of each run. The jar test procedure was used to generate 20 l of floc by using the entire water bath as the reaction vessel. To insure uniform floc size, the pump section of the constant-temperature circulator was isolated. A final concentration of 10 mg/l alum was used to flocculate the suspension containing 100 mg/l bentonite. At specified intervals, head loss was read and effluent volume was collected and measured.

Results

Figure 15 shows the effect of temperature on a sand column receiving floc at a constant head. Temperature appeared to have little effect on floc size, the floc being formed at the test run temperature; however, otical density at 450 nm varied by less than 0.02 OD unit, between any two experiments.

Each isotherm represents normalized data from at least three separate test runs. The hydraulic conductivity of each column is a measure of the similarity of its permeability to that of any other of the columns. Although a C_h which varied by more than three units from 70.0 gave head losses which were considerably different from those shown in Figure 15, such head loss was not predictable, preventing the use of a correction factor.

The flow rate at the exit port was initially adjusted to approximately 2.5 gal/min/ft^2. At the end of each run, the flow rate was often half its original value, prompting the use of a volume rather than time measurement for the abscissa.

In similar experiments, some investigators have used

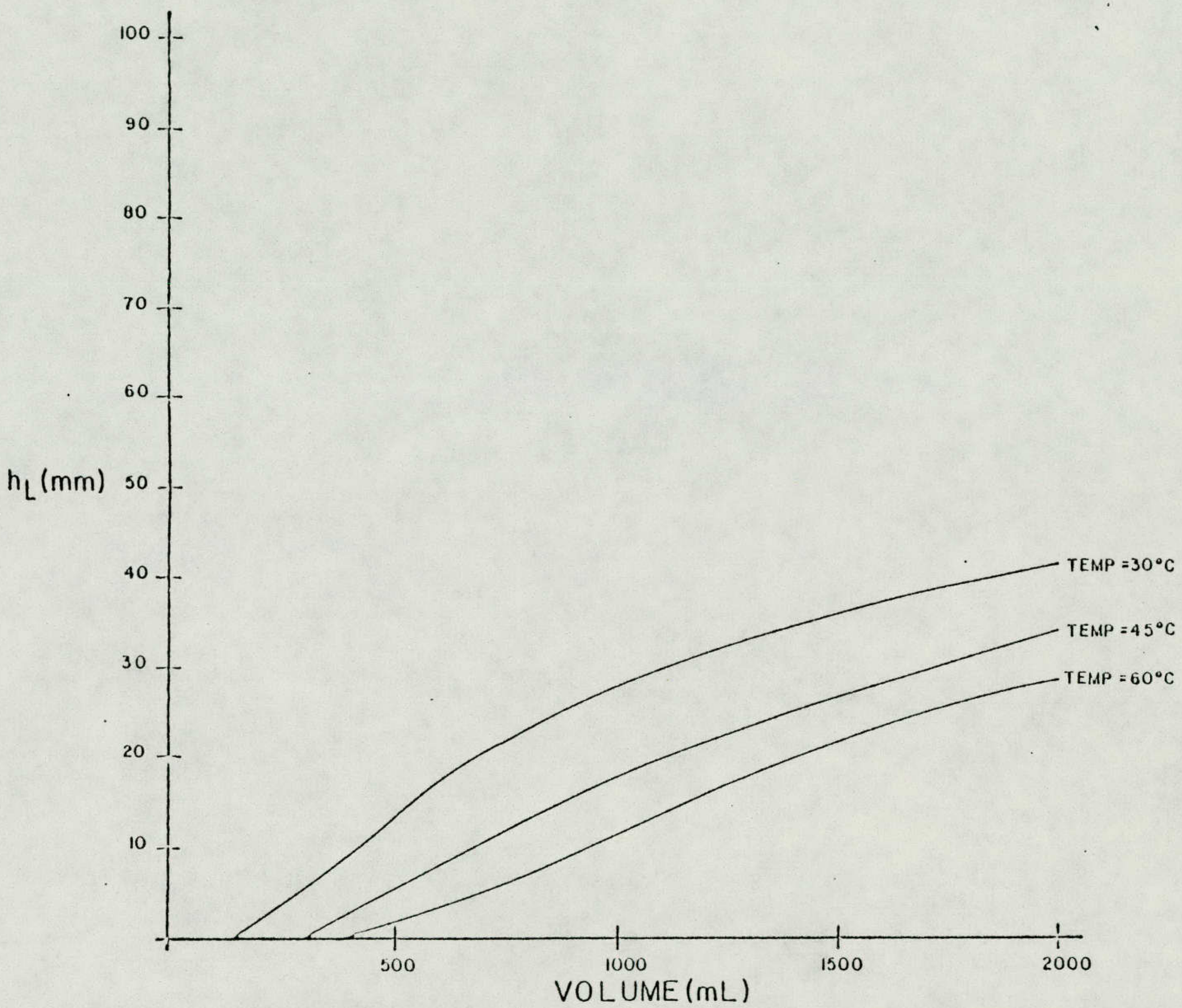

Figure 15. Head Loss Profiles Of Temperature Effects On Contract Filtration Of An Alum Floc. Alum = 10.0 mg/l., Bentonite = 200.0 mg/l.

optical density as a measure of effluent water quality (Adin et. al, 1977). However head loss measurements proved to be more accurate and did not require interruption of the constant head configuration. Adin et. al, reported no problems with air binding; however, in this study, measurement of OD from an exit port at atmospheric pressure was found to introduce air bubles into the column.

Although other parts of this investigation were carried out at four temperatures, it was believed sufficient here to show that an orderly progression of isotherms resulted with temperature increases. Thus the two extreme temperatures, 30° and 60°C, and a median temperature of 45°C, were used for filtration studies.

Figure 15 shows that by increasing the temperature of the influent, head loss increases at a slower rate and is lower for a given volume of water passed through the column. Figure 15 also shows that head loss begins progressively later as temperature is increased. Since columns were prepared by washing with distilled water which was heated to the run temperature, lag in initiation of head loss is probably not due to temperature equilibration.

Camp's equation for head loss during laminar flow through granular material shows a direct relationship between H_L and kinematic viscosity of the transport fluid (Camp, 1964).

Solution of this equation for the ratio of head loss at 30°C to head loss at 60°C gives a value of 1.7. This result is in good agreement with the value of 1.6 obtained from Figure 15. It is possible that certain properties of the alum floc may change with temperature. Baylis et. al., report that in water treatments plant operation, the strongest flocs occur during warm weather. However the close agreement between the preceding theoretical and experimental values suggests that water viscosity exerts the greater influence on head loss in these experiments.

Summary

For the water treatment operations discussed in this report, elevated temperature appears to have a beneficial effect. However, these experiments were designed to facilitate ease and accuracy of measurements and not to precisely model conditions in a water treatment plant. For example, it is doubtful that suspended solids concentrations as used in these investigations would normally be encountered in actual plant operation. The results presented in the preceding sections may suggest certain trends as a result of increased temperature, however, these effects may not be as pronounced in actual practice.

The experimental results shown on Figures 8 to 10 using alum and bentonite at various temperatures are evidence of the role that viscosity plays in sedimentation. To illustrate this better, calculations of settling velocities and overflow rates were made using materials and material characteristics commonly encountered in water treatment at the test temperatures and at a reference winter temperature of 10°C. The results are shown on Table 18. Even though the form of silt particles and alum floc generally depart from a spherical shape, the calculations show the effects of decreased viscostiy values on settling velocities and also the effects of specific gravity on settling rates. The settling rates at 50°C are twice the rate at 10°C for the sand and silt particles with a .01 and .001 cm diameter and for the calcium precipitate. The effect is not so pronounced for larger sand particles with a 0.1 cm diameter where a 28.4% increase is shown. The alum floc exhibits an 690% increase in velocity over the 40°C temperature span.

Using a four fold increase for the overflow rates shown on Table 2 for the alum floc would reduce the volume of reactor and the appurtenances needed in a like manner. By planning the regular maintenance for the power generating unit for summer, the raw water which bypassed the generating unit would be in the highest range of the annual temperature cycle. The design of

TABLE 18

Temperature Effects on Settling Velocities and Overflow Rates for Discrete, Spherical Particles of Common Suspensions in Water*

Temperature (C^O)	Sand and Silt S = 2.65**			Alum Floc S = 1.002 D = .1 cm	Calcium Precipitate S = 1.20 D = .01 cm
	d=.001 cm	d=.01 cm	d=.1 cm		
10	.0069† (146)‡	0.513 (10,900)	14.8 (313,800)	0.087 (1,840)	0.083 (1,760)
30	.0113 (239)	0.970 (20,600)	17.1 (362,600)	0.308 (6,530)	0.141 (2,990)
40	.0138 (292)	1.10 (23,300)	18.5 (392,300)	0.474 (10,100)	0.172 (3,650)
50	.0166 (351)	1.21 (25,700)	19.0 (402,859)	0.689 (14,600)	0.208 (4,410)
60	.0195 (413)	1.36 (28,800)	19.6 (415,600)	0.962 (20,600)	0.240 (5,090)

* Calculated values using $F_D = C_D \rho \frac{U^2}{2} A$ and $I_D = \frac{\pi D^3}{6}(\rho_s - \rho_1)g$.

** S = Specific gravity.

† Settling velocity in cm/S.

‡ Overflow rate in gpd/ft^2.

the sedimentation unit could be at a temperature range where even with a factor of safety the size of the needed reactor would be much less than that dictated by winter conditions. For example, in the Lubbock area, the design of a basin for a minimal temperature of 80°F in which well developed alum floc 0.1 cm in diameter were generated, a 2,400 gpd/ft^2 overflow rate (a fourfold increase in the recommended rate) would still give a good factor of safety for the removal of the floc particle which had a calculated value of 6,500 gpd/ft^2. The use of alum to flocculate the calcium precipitate generated in a softening operation would enable the designer to decrease the size of the reactor in accordance with benefits from increased water temperatures and the enhanced characteristics of the alum floc.

The adsorption studies indicate that increased organic removal at elevated temperatures may occur. In a Granular Activated Carbon system this may affect column life although in a PAC system this would appear to be beneficial.

By assuming that the adsorption of Methyl Orange (MeOr) is a type of reaction rate which follows first-order kinetics, the effect of temperature on adsorption may be calculated.

A first-order reaction is defined as

$$\frac{dC}{dt} = kC$$

This equation may be integrated and solved for k, where

C_t is the organic concentration at any time, t
k is the reaction rate
t is time

The use of Figure 12 and the above equation gives a value of k at 30°C:

$$k_{30} = -0.054 \text{ min}^{-1}$$

Values for k at the other three temperatures may be obtained in a similar manner. The ratio of k_t/k_{30} gives the following values:

Temperature	k_t/k_{30}
30°C	1.0
40°C	1.2
50°C	1.5
60°C	1.8

During the time when adsorption is a first-order reaction, the adsorption rate at 60°C is almost double the 30°C adsorption rate.

Thus, in addition to promoting a more complete adsorption of organics, elevated temperatures can also affect the rates at which organics are adsorbed. At a specified level of organic removal, less PAC would be required and detention times for adsorption could be decreased.

The time for first order decay of a waste in a batch reactor may be calculated by:

$$t = -\frac{1}{k}\int_{C_i}^{C_f} \frac{dC_i}{C_i}$$

where

t is the time required for removal of the adsorbable organic

k is the rate constant for a particular temperature

C_i is the original concentration of adsorbate

C_f is the final concentration of adsorbate

If a 99% removal level of MeOr were required, then

$C_i = 5.0$ mg/l MeOr

$C_f = .05$ mg/l MeOr

$k_{30} = -.054\ \text{min}^{-1}$

$k_{60} = -.096\ \text{min}^{-1}$

The time for removal of 99% of MeOr at 30°C is 1.42 hours as compared with 0.8 hours as 60°C. These theoretical results are in reasonable agreement with the results presented by Figure 12.

The column studies show that for the particular system used, head loss occurs more slowly and is less for a given volume of water at elevated temperatures. Applying this finding to treatment plant operations, the length of filter runs may be increased. This effect may be enhanced because of the improved sedimentation efficiency.

Although the effect of chlorination at various temperatures is being investigated, no data is available at this time. Bacterial growth at the higher temperatures is not expected due to pastuerization effects. However, the intermediate temperatures may promote bacterial growth, particularly in the absence of an adequate chlorine residual. The formation of chlorinated hydrocarbons may be avoided by chlorination after the removal of organics by activated carbon.

CHAPTER IV

CONCEPT ACCEPTANCE FACTORS

The study concept has impacts on three groups--the electric utility, the water utility, and the customers of the utilities. Water is the factor that ties the concept together and links these groups in a user-service-user system. Implementation of the concept into a working system will depend upon a favorable reception by each of the three groups. Additionally, there are governmental agencies that monitor and oversee activities of the electric and water utilities, professional organizations which aid in the development and setting of standards of practice and performance in these areas, are other "concerned"parties that must be in favor of the concept.

Governmental agencies, through examination of plans, proposed practices, or existing operations determine whether standards are violated and thus actively exert controls on implementation of new technology. Professional organizations also play an important role in new technology. An example of the latter's role was in an article studying the feasibility of taking heated municipal water from the distribution system, using it in a once-through cooling water system for a thermal power plant, and then returning the now-heated water back to the distribution system (Hansen et. al., 1973). A footnote accompaning the article explained that the concept was in violation of the position of the American Water Works Association that customer use of treated water from a distribution system precludes the return of that water to the distribution system of the utility. The footnote discussion of secondary use of treated water within the distribution system ended with, "...is not acceptable practice and cannot be approved." Further literature search by the staff did not uncover any follow-up articles on this concept in later periodicals. Other factors may have influenced the concept's demise--the wrong timing, the technical concerns about system components, or the lack of institutional linkages between the water utility and the electric utility. The disclaimer by the AWWA also probably exerted some influence.

Acceptance by the three use groups will depend on how each group views the benefits that can be obtained from concept implementation. If savings in capital and operational costs would occur to the utilities through implementation, then it can be expected that the utilities would favor the use of the concept if other circumstances were favorable. These would include such considerations as new facilities being needed by one or both utilities, construction sites for facilities being available, and suitable transmission infrastructures for water or power being available or planned for construction.

The public, with its many individual concerns, introduces additional complexity in the determination of the true acceptability of the concept. The term "true acceptability" is defined as the state which occurs when an individual is presented the pro and con facts about a topic and makes a choice in agreement with his value standards. In this case, indifference to the topic is a no-action choice. Anytime people must choose to use or not to use new products, ideas, or practices, difficulties arise. Some may allege that the product or practice would exert a detrimental influence on society if permitted. The level and type of pressure exerted for acceptance or rejection of an item or topic may or may not be representative of the public wishes on the matter. However, when choices are to be made about a new product, idea, or practice which will affect everyone once a decision is reached, the problems become even more difficult. Real and imagined problems take on a significance often not warrented by facts, but impossible to ignore because of the importance that individuals attach to the topic.

Implementation of the study concept, even if feasible in terms of benefits to the utilities and the consuming public, will hinge on acceptance of the concept by the public served by the water utility. Concerns for the health of their families, pets, and plants; damage to material; or the inconvenience caused by changed temperature conditions can create insurmountable problems for implementation of the concept.

Questionnaire Results

To obtain a sampling of opinion on the concept, a letter survey was conducted. Rather than preparing an elaborate questionnaire, it was decided to write a letter briefly outlining the concept listing some advantages and disadvantages, and to include a postcard to obtain a yes-or-no answer on the concept. The copy of the letter and postcard appears as Figures 16 and 17.

Fifty letters were sent to each of the following cities: Albuguerque, New Mexico; Amarillo, Texas; Denver, Colorado; El Paso, Texas; Lubbock, Texas; Tucson, Arizona; and Wichita Falls, Texas. To obtain the sample, the number of pages in the phone book from each city was divided by fifty to select the page number from which to draw the sample residents. The fifth listing of a private residence down the first column of the page was selected as a survey point. The results of the survey are shown on Table 19. Replies were received from 86 of the 329 residences where letters were delievered to give a 26.1% response rate. Favorable comments were received from 63 (73.3%) and unfavorable comments from 23 (26.7%).

Comments on the Concept

Comments were received from 36 of the 86 respondents. These have been arranged in two lists based on whether they accompanied favorable or unfavorable responses to the concept. They are as follows:

Favorable:

1. If the water was that hot how could you take cool showers in the summertime?
2. Please note that in the west peak water useage coincides with peak electrical use. Also, that in winter some heat is transferred from the house to warm cold water used.

Texas Tech University

Water Resources Center
P.O. Box 4630

Lubbock, Texas 79409
Phone (806) 742-3597

February 15, 1980

Dear

The conservation of energy and water resources are two of the critical issues facing the American public today. A research project at Texas Tech is concentrating on one possible solution to a problem related to both these issues. We are asking you to assist us by taking about two minutes of your time to read the contents of this letter and to mark your opinion on the enclosed ready-to-mail postcard. Consumer response to this approach is an important part of the project.

Background

The purpose of this study is to determine the practicality of using municipal water supplies as a source of cooling water for power plants. Since large quantities of cooling water are needed for power generation, a severe competition for available water exists in water-short or arid areas.

In the proposed system, water destined for use in municipal supplies would be used by a power plant prior to municipal treatment and distribution. This approach presents several advantages to the power company, the municipality and to you, the consumer. There are also some disadvantages to be considered.

Advantages

The water will be used one time as cooling water and will, therefore, require no elaborate recirculation systems with attendant cooling towers and treatment facilities. This will reduce the investment required by the utility, and such savings may be passed on to the consumer. Water temperatures can be increased since the water will not be released into a natural water body where aquatic life is found. This will also reduce the amount of water needed for cooling and subsequently the size of the pumps and piping in the system.

Benefits to the city include increased efficiency at the water treatment plant. Warm water is easier and less expensive to treat.

Figure 16. Letter Sent to Test Population

Benefits to the consumer will occur in several ways. Temperature of tapwater will be increased (it typically varies from 45° to 75° over the year). The primary benefit will be that less energy will be required in hot water heating. The table that follows shows an example of the savings that could be realized in a family of four with an average requirement of 80 gallons of hot water per day. Also, water used for watering of lawns and shrubs would not harm the plants through thermal shock. Other than the temperature increase, water quality will not be changed.

		Electric Hot Water Heater			Gas Hot Water Heater		
Inlet Temperature to Hot Water Heater in °F	Outlet Temperature from Hot Water Heater in °F	KWH per Day to Heat Water	Cost per Year @ $.05 per KWH	Savings per Year	Ft^3 of Gas per day @ 62% Heater Use Efficiency	Cost per Year @ $2.75 per MCF	Savings per Year
60	130	13.7	$250.02	0	75.3	$75.58	0
80	130	9.8	178.85	71.17	53.8	53.99	21.59
90	130	7.8	142.71	107.31	43.0	43.19	32.39
100	130	5.9	107.67	142.75	32.3	32.39	43.19

Disadvantages

The primary disadvantage to having this water in the home is that drinking lukewarm (80° to 100°F) water from the tap would not be desirable. Drinking water would have to be cooled.

Action

Please mark and return the enclosed postcard. If you have an additional comment, please note it in the space provided.

Again, your help in this project is vital, and will be sincerely appreciated.

Sincerely yours,

R. H. Ramsey

R. H. Ramsey, Ph.D., P.E.
Assistant Professor of
Civil Engineering

Enclosure

Figure 16. Continued

D-29

1. I have considered the advantages and disadvantages of constant lukewarm tapwater (80° to 100°F) entering my residence. I would approve of such a system.

   Yes ☐ No ☐

2. Do you have any other comments or concerns?

Figure 17. Postcard Questionnaire

TABLE 19

Public Opinion Survey Results

Cities	Letters Sent	Letters Delivered	Replies Yes	Replies No
Albuquerque, NM	50	44	7	2
Amarillo, TX	50	48	12	4
Denver, CO	50	47	10	6
El Paso, TX	50	50	9	3
Lubbock, TX	50	49	10	2
Tucson, AZ	50	49	7	4
Wichita Falls, TX	50	43	8	2
Totals	350	329	63	23

3. Why not extract the heat when it enters the house--as a heat pump--a free source of heating.
4. No disadvantage. Most I know of in the Tucson area have water bottles for drinking purposes in refrig.
5. Make solar water heating more available on a do-it-yourself basis.
6. One thing that I would be concerned about is, what will the hotter water do to the plumbing with the mineral content that our water has. The way it is now, water heaters do last as long as they used to... Would the water be considered softer after it has been used for cooling power plants?
7. My wife would be concerned about certain cooking and canning procedures which require use of "cool" water.
8. The advantages are much greater than the disadvantages. I think it is a good idea.
9. Would the warm water have increased hardness? Would it increase the hard water deposits in pipes & heaters. Utility company would have to pump more water from source. Would municipality share this cost?
10. Provisionally, providing normal (in today's world) cost overruns do not outdistance real time monitary gains. Who makes the initial installation? Who provides system upkeep?
11. Why not route the water around the floor or base boards to help heat the house and to cool the water, or store the water in a big tank and use a heat pump to heat & cool the house.
12. I would approve of a system such as you describe as long as no nuclear waste is treated with H_2O.
13. My approval here presupposes that your study of advantages and disadvantages leaves out no significant facts.
14. (1) Saving water & reduced water heating costs are primary reasons for being in favor. (2) I don't

believe for a minute that any savings will be passed on from the utilities to the consumer. Actually I resent anything that will benefit the utilities. (3) If the water & energy savings of this program are to be sold to the public, the advantages to the utilities should not be emphasized.

15. Seems a great idea--not only because of savings in costs, but great for gardens!
16. I would want to be sure that water was safe for drinking. In summer cold water in Tucson gets warmer as desert heats up.
17. I wish we could stop the salt water well water flowing into the Canadian & Lake Merideth.
18. I would approve on the basis of saving a most valuable resource. I do not believe the utility companies will pass on any savings to the consumers, however.
19. I think this is a very good idea.
20. You ignored several important considerations: (1) Type of power plant, if nuclear what would be the H_2O contamination? (2) What is the cost of cooling water for drinking? (3) Just as a question-What temperature will harm plants,-how safe is 100° F water?
21. Adjusting bath water when too hot--I suppose one would just have to let it sit a bit. O. K.

Unfavorable:

1. Further studies needed! What would the other effects be? Additional costs of freezing ice to cool drinking water? Possibility of contamination of water supplies? Ecological effects of higher temperatures in sewage systems?
2. No, but I don't understand why you are surveying me in Tucson, AZ.
3. For anyone to make a decision based on the 'facts' as presented would be short sighted. If you are talking about cooling of nuclear power plants, I'm definately

against it. Possibly for conventional plants, but still I'm concerned about possible pollution. Another question, what about the health risk, it seems like 80^{o} water would enhance any fungal or bacterial problems.

4. I have not studied this phase of the water system. If you think it is a good move, then vote yes for me.
5. No. Unless I could see figures where it would substantially reduce our utility bills.
6. We don't have air conditioning. A cool shower at night is how we cool off.
7. I don't believe I have enough information or personal knowledge applicable to this situation to answer this questionaire. I feel that there maybe misrepresentation inherent in your attempt to get the answer you wish.
8. Would it reduce my water bill?
9. I think the plan has great merit in those outlined plus others as to heating of the house in winter.
10. Trade off in $ savings not enough, also am skeptical that any savings would soon be absorbed by some other higher cost, resulting in hotter tapwater temperature and no savings.
11. (a) What type of power plant? (b) What would be the annual cost to cool drinking water? (c) 100^{o} F... lukewarm?
12. Animals & pets can not drink 100^{o} temperature water, neither can people in the summer. Possible? to mix warm water with well water 50/50?
13. Yes, Bacteria grows faster in warm water.
14. Insufficient data. Will water treatment plant have to modify valves, pipes, etc.? Are you talking about treating river water now or other sources. What assurance does consumer have that saving will be passed on by the utilities?

Summary

As can be seen there was a considerable variety of comments on both sides of the issue. Of the 21 comments received accompaning the 63 favorable responses, 10 could be considered as conditional responses where acceptance is contingent on further clarification. It is evident from the high percentage of respondents (41.2%) who took time to write a comment that this concept would become a much discussed issue in an area where implementation was planned. A well-planned information delivery system would be necessary to inform the public of the concept. After an evaluation of the approach used on the project, it is apparent that a different presentation, a better balance between the pro's and con's, and more data on the economic costs and benefits to the three use groups would generate different response patterns.

CHAPTER V

ENVIRONMENTAL IMPACT ANALYSIS

The National Environmental Policy Act of 1969 (NEPA)* requires all federal agencies to include in every recommendation or report on legislative proposals and other major federal actions significantly affecting the quality of the human environment, a detailed statement covering the following elements:

1. The environmental impact of the proposed action;
2. Any adverse environmental effects which cannot be avoided should the proposal be implemented;
3. The alternatives to the proposed action;
4. The relationship between the local short-term uses of man's environment and the maintenance and enhancement of long-term productivity;, and
5. Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

It is recognized that a municipality contemplating the use of water as outlined in this report is unlikely to be required to become involved in the Environmental Impact Statement (EIS) process. However, it is also recognized that an examination of the environmental implications in an EIS format can be extremely beneficial in weighing the "pros and cons" of the proposal and other alternatives. This section will examine the environmental consequences of the proposed arrangement from a NEPA prospective, incorporating both biophysical and socioeconomic environmental aspects.

Environmental Impacts

Both positive and negative environmental impacts would accompany the implementation of the proposed system of using municipal water supplies, prior to treatment, as condenser cooling water. These potential impacts are enumerated in the

---

*National Environmental Policy Act of 1969 (PL 91-190;83 Stat 852).

following discussion.

Water

Impacts to water resources would be anticipated in terms of both quantity and quality. From the quantity standpoint, impact would be positive, since the proposed alternative represents a multiple use of a single resource. Additional savings would be realized through (1) the elimination of intentional "trickling" of tap water to prevent freezing and pipe damage in extremely cold areas, and (2) the reduction in waiting time for hot and cold supply lines to achieve desired "blend" temperature at the faucet.

In examining water quality impacts, several considerations are warranted--some positive and others negative. These concerns will be discussed from several perspectives.

Physical Effects

The following changes in physical water quality result from temperature increase:

1. Dissolved gas solubility decreases,
2. Evaporation rates increase,
3. Density decreases (beyond 4°C), and
4. Viscosity decreases.

These physical changes are of major concern in systems that release heated water to the environment (eg. into a stream, reservoir, or estuary). Dissolved oxygen saturation is important to aquatic life and biodegradation processes. Evaporation causes a consumptive loss of water and tends to concentrate dissolved solids, density differences may result in stratification, and as viscosity decreases, settling rates increase. This latter phenomenon is of particular importance not only in natural systems but in water treatment as well. It has been demonstrated in this study that savings in chemical coagulants are possible with the temperature increases associated with the proposed system.

Chemical Effects

The chemical effects associated with temperature increase include:

1. Increased rates of reaction,
2. Effects on tastes and odors, and
3. Effects on chlorination (FWPCA, 1968)

The rate of a chemical reaction approximately doubles for each 10°C (18°F) rise in temperature. For irreversible reactions, this means that an increase in temperature will cause a final product to be reached in a shorter time span and for reversible reactions, temperature influences both the time to reach equilibrium and the balance at equilibrium. Tastes and odors are accentuated when oxygen is depleted. Hydrogen sulfide, SO_2, methane, phenols, and other taste/odor-causing agents are more noticible due to increased solubility. The action of disinfection is more rapid at higher temperatures. The dosage and maintenance of a free chlorine residual in water at an elevated temperature needs more study.

Biological Effects

In a manner similar to that of chemical reaction, biological effects are also experienced due to temperature increase. Essentially, biological activity may double or even triple over a 10°C temperature range. Although this may vary with species, temperature changes may be a signal for spawning or migration, it may affect growth rate, or it may affect distribution within a given system. If increase is sufficient, temperature may induce death mechanisms within cells via enzyme inactivity, coagulation of cell proteins, melting of cell fats and/or reduction of permeability of cell membranes (FWPCA, 1968).

Another factor of concern is synergistic action--the simultaneous action of separate agents which together have a total effect differing from the sum of the individual effects. For example, a 10°C rise in temperature might double the toxicity of a given agent, and at the same time double the metabolic rate of fish. A given concentration of the agent may not be harmful at 20°C, but the combined effects may be lethal at 30°C.

These concerns may be significant when contrasting the effects of discharging waste heat into the environment versus the incorporation of this "waste" heat into the municipal supply as proposed.

Distribution System Impacts

Impacts to the distribution system include

1. Corrosion potential
2. Deposition potential
3. Effects on water meters
4. Effects on plastic pipe, and
5. Effects on existing nonplastic pipe,

Most constituents in a water that can cause corrosion or deposition in a water distribution system are active or inactive in response to the pH level in the system. Specifically alkalinity, acidity, or calcium do not change with temperature provided $CaCO_3$ precipitation has not occurred or there has been no CO_2 transfer from the atmosphere (Sanks, 1978). The elevated water temperatures will decrease the gas solubility of the water and thus reduce concentrations of both CO_2 and O_2 in water entering the system.

In some waters, the softening to remove Ca^{++} and Mg^{++} and the subsequent conditioning to the most feasible pH level for the system may be necessary at the treatment plant to prevent scaling in the distribution system. In other cases adjustment of pH at the plant may be necessary to prevent corrosion of the distribution system. Generally, the conditioning and management of waters at the plant to prevent corrosion or deposition is the most efficient means of correction problems that may be prevalant in the system. Even though resources in the form of chemicals are used to maintain the water in a conditioned state, the management of the "input" to the system prevents downstream losses in the form of reduced distribution system life and customer losses. The replacement of water heaters in a city in a hard water area after an average life of three years instead of ten years is an example of this form of resource cost.

Most water meters currently in use are constructed to operate within relatively fixed temperature ranges (Hansen et. al., 1973). Modifications to "cold" meters are possible, but expensive ($30 per meter, estimated by Hansen, et. al., in 1973). Alternatives presented to a municipality adopting the proposed system would include (a) modification and recalibration of existing meters, or (b) meter removal. Since meter removal typically results in increased per capita water usage, Hansen et. al. suggest that modification with the ensuing cost savings in power production is the preferred alternative.

Widespread adoption of plastic pipe in municipal water distribution systems is occurring at present. The desirable features of this pipe are: long service life, low friction losses, resistance to corrosion, light weight, and easy installation. The plastic pipe in common use, however, presents a problem since an upper limit of 100°F is recommended for the material because of its thermostability characteristics. Many points in the system would have temperatures greater than this.

In normal distribution systems the temperature regime of the ground and pipe change gradually over the year. The expansion of pipe materials and perhaps other phenomena associated with possible wide ranges in temperature daily would need further investigation.

Household/Consumer Impacts

As suggested by the potential effect on water meters, increased water temperatures may also have significant impact on house hold piping and appliances. Hansen, et. al. (1973), reported potential damage to plastic pipes, toilet parts, drain tile, and water basins.

Consumer concerns, as indicated by questionnaire response, include the areas of drinking water, some food preparation requirements, and the inability to take cool baths. Drinking and cooling water requirements could be handled by cooling small quantities in the refrigerator.

Lawn and garden watering would take place at elevated temperatures. During summer months, irrigation water temperatures during the daylight hours would be near that of the ambient surface soil temperature, thereby lessening thermal shock normally encountered with cold water. During winter months a "reverse thermal shock" effect is conceivable. Application of warmed water in winter periods could trigger premature budding of fruit trees, resulting in plant damage due to cold air temperature. In the case study it was found that water in the distribution system was approximately 2 to 3 degrees below the outlet temperature of the condenser for many hours of the day, this could also cause thermal shock to plants irrigated in late evenings after they had cooled. Additional studies are needed to evaluate the potential effect on lawns, shrubs and other vegetal material.

Economic Impacts

Major economic benefits may be realized by both utility and consumer. The utility would not be required to invest heavily in conventional cooling water facilities (eg. towers or cooling ponds) and would probably receive the benefit of once-through cooling at a significantly reduced investment level. Additional savings may result as decreased viscosity reduces friciton head loss in pipe systems, resulting in reduced pumping requirements. Savings could be passed on to the consumers. Other consumer economic benefits would include reductions in household energy requirements for water heating.

Other Impacts

Pipelines carrying heated water under streets and sidewalks may induce secondary positive impacts during adverse winter weather conditions. Accumulations of ice and snow may be significantly reduced or even eliminated, resulting in reduced traffic hazards and in more desirable travel conditions.

Some concern may be voiced over the possibility of problems arising in the sewage conveyance and waste water treatment systems. Actually, considering the fact that sewage water temperature typically is much warmer than incoming household water due to heating for washing, cooling, and bathing, the proposed system would yield wastewater temperatures only a few degrees above that normally experienced. As result of the chemical, physical and biological effects previously noted, conventional wastewater treatment systems would tend to become more efficient due to enhanced settling rates and increased biological activity rates.

Adverse, Unavoidable Impacts

The majority of adverse impacts discussed above may be avoided through the selection and control of flow rate, thereby controling the temperature of the water entering the distribution system. If higher temperatures are desired, avoidance of temperature-sensitive materials (of certain plastics) may be necessary. It seems that the only "losers" in the proposed system are those desiring to take cool showers.

Alternatives

Alternatives to the proposed system include the following:

1. In-plant cooling facilities
2. Once-through systems (discharge to pond, lake or stream)
3. Alternate flow-through rates for the proposed system (selection of discharge temperature)

The first two alternatives represent a heat rejection approach with a resultant loss of potential energy. In-plant facilities are expensive and require significant amounts of make-up water. Alternative once-through systems may result in considerable adverse environmental impacts to water resources and aquatic life systems.

The proposed system eliminates these undesirable features by incorporating energy recovery, multiple use of a valuable resource, and elimination of thermal impacts to water resources and aquatic ecosystems. By selecting an appropriate flow-through rate the discharge temperature may be held to a level that prevents or minimizes adverse impacts to the distribution system, its components, and the consumer.

Short-term/Long-term Relationships

Environmental gains would continue throughout the life of the project. Economic benefits would occur in the form of reduced water heating bills for the consumer and reduction in costs of power generation, pumping, and water treatment for the utility and/or municipality.

Irreversible/Irretrievalbe Commitments of Resources

Implementation of the proposed system would have definite, positive impact on the irreversible and irretrievable commitments of energy and water resources. Since waste heat would be "recovered", fuel consumption associated with domestic water heating would be reduced significantly.

CHAPTER VI

Conclusions

From the results obtained in this study, it can be concluded that:

1. The use of potable water supplies for cooling in a once-through system for thermal power generation units prior to the treatment and distribution of water in a municipal system is both feasible and compatible in locations where cooling water supplies are limited, electric power needs are increasing, and municipal water flow is adequate.
2. Decreased volumes of cooling water and simplified facilities for cooling water management are possible in once-through systems when water temperatures at the condenser outlet are increased over those allowed when cooling water is released into aquatic ecosystems.
3. In all seasons, the slope of the temperature profile is mild throughout the treatment plant and in the large transmission and distribution mains.
4. Reductions in the amount of energy required for heating water will be realized through the implementation of the concept. The location of the consumer in the distribution network will govern the amount of heat available at the use point. In general, the closer the consumer is to the treatment plant and to the larger pipes in the distribution system, the greater his probability is of having higher temperature water at the use point.
5. Additional research is needed to determine the impacts on materials currently utilized in water system facilities due both to elevated water temperature and to daily cycling of water temperatures between an elevated level caused by warm water flowing in the conduits and the lower extreme corresponding to the ground temperature.
6. Elevated water temperatures will increase the rate of chemical reactions, increase the solubility of chemicals used in

treatment, and decrease the amounts of chemicals required to produce an acceptable level of treatment. These factors will reduce the operational costs for water treatment.

7. The decrease in viscocity which occurs at elevated water temperatures leads to an increase in the settling velocity of suspended particles. The increase in the efficiency of solids removal in the sedimentation basin will lead to subsequent reduction of the solids loading on the rapid sand filter units and thus increase the length of filter runs.
8. As a result of the increased solids settling performance, a year-round source of warm water will permit the design of smaller sedimentation units. This will reduce the capital and amortization costs for water treatment facilities.
9. Water temperatures in the municipal treatment and distribution system where the concept is employed could be controlled by the water utilities through the design and management of treatment and storage facilities. This would allow mitigations of unfavorable impacts caused by elevated water temperatures at the points of use.
10. A majority (73.3%) of the respondents to a questionnaire mailed to a test population in seven southwestern cities favored implementation of the concept. Concerns about possible impacts were expressed by both those who favored and those who opposed the concept. A favorable response by the public would be necessary for system implementation even if benefits were to occur to the public and to the electric and water utilities.

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APPENDIX

Program Format

```
FORTRAN IV G LEVEL  21                    MAIN                 DATE = 80207           15/17/07

                 COMMON/WP/XK,XMU,CP
                 COMMON/FP/TA,RH,U,ALPHA
                 COMMON/PP/D(20),XL(20),WT(20),XKP(20),B(20),NP(20)
                 COMMON/GP/XKG,TG
                 COMMON/RP/A(10)
           C
           C     ..... READ IN AND PRINT WATER AND GROUND PROPERTIES .....
                 READ(5,1) XK, XMU, CP
                 READ(5,17) XKG, TG
                 WRITE(6,7)XK, XKG, XMU, TG, CP
           C
           C     ..... READ IN AND PRINT OUT PIPE PRCPERTIES .....
                 READ(5,3) NS
                 DO 10 I=1,NS
                 READ(5,4) D(I),XL(I),WT(I),XKP(I),B(I),NP(I)
              10 CONTINUE
                 WRITE(6,13)
                 DO 40 I=1,NS
                 WRITE(6,14) I,D(I),XL(I),WT(I),B(I),NP(I),XKP(I)
              40 CONTINUE
           C
           C     ..... READ IN AND PRINT OUT RESERVOIR PROPERTIES .....
                 READ(5,5) NR
                 DO 20 I=1,NR
                 READ(5,6) A(I)
              20 CONTINUE
                 WRITE(6,11)
                 DO 30 I=1,NR
                 WRITE(6,12) I,A(I)
              30 CONTINUE
           C
           C     ..... READ IN AND PRINT OUT CAY NUMBER AND LATITUDE .....
                 READ(5,21) DAYNUM, RLAT
                 WRITE(6,22) DAYNUM, RLAT
                 RLAT=RLAT*(44.0/7.0)/360.0
           C     ..... DETERMINE DECLINATION OF THE SUN .....
                 ARGMT=(284.0+DAYNUM)/(365.0)*44.0/7.0
                 DECLIN=23.45*SIN(ARGMT)
                 WRITE(6,9) DECLIN
                 DECLIN=DECLIN*(44.0/7.0)/360.0
           C
           C     ..... READ IN AND PRINT OUT VARIABLE PROPERTIES .....
                 READ (5,22)XIT
                 DO 70 J=1,24
                 TI=XIT
           C
           C     .....CALCULATE HOUR ANGLE .....
                 HRANG=-15.0*(FLOAT(J)-12.0)
                 ITIME=100*J
                 READ(5,2) TA, RH, U, XMDAY
                 XMDOT=XMDAY*9.345E6/24
                 WRITE (6,19) ITIME
                 HRANG=HRANG*(44.0/7.0)/360.0
           C
           C     ..... CALCULATE ALPHA .....
                 X=SIN(RLAT)*SIN(DECLIN)
                 Y=COS(RLAT)*COS(DECLIN)*COS(HRANG)
                 ALPHA=ARSIN(X+Y)
```

```
FORTRAN IV G LEVEL  21                         DHT                    DATE = 80207             15/17/07

 0001                     SUBROUTINE DHT(XMDOT,TI,TO,Q,I)
 0002                     COMMON/WP/XK,XMU,CP
 0003                     COMMON/PP/D(20),XL(20),WT(20),XKP(20),B(20),NP(20)
 0004                     COMMON/GP/XKG,TG
 0005                     PI=3.14159
 0006                     RE=4.0*XMDOT/(PI*D(I)*XMU*NP(I))
 0007                     PR=CP*XMU/XK
 0008                     IF (RE.LE.2300.0) GO TO 10
 0009                     XNU=0.023*(RE**0.8)*(PR**0.4)
 0010                     GO TO 20
 0011          10         XNU=3.66
 0012          20         H=XK*XNU/D(I)
 0013                     S=2.0*PI*XL(I)/ALOG(4.0*B(I)/D(I))
 0014                     RTH=(WT(I)/XKP(I)+1.0/H+PI*D(I)*XL(I)/(XKG*S))/(PI*D(I)*XL(I))
 0015                     TO=TG+(TI-TG)*EXP(-NP(I)/(XMDOT*CP*RTH))
 0016                     Q=XMDOT*CP*(TI-TO)
 0017                     RETURN
 0018                     DEBUG SUBCHK
 0019                     END
```

```
FORTRAN IV G LEVEL  21                         DHT                    DATE = 80207             15/17/07

   *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
   *OPTIONS IN EFFECT*  NAME = DHT        , LINECNT =        60
   *STATISTICS*     SOURCE STATEMENTS =        19,PROGRAM SIZE =       1328
   *STATISTICS*  NO DIAGNOSTICS GENERATED

   *STATISTICS*  NO DIAGNOSTICS THIS STEP
```

```
                                                 VS LOADER
OPTIONS USED - PRINT,MAP,LET,CALL,NORES,NOTERM,SIZE=98304,NAME=**GO

      NAME   TYPE  ADDR        NAME   TYPE  ADDR        NAME   TYPE  ADDR        NAME   TYPE  ADDR        NAME   TYPE  ADDR

    MAIN        SD 450010    RHT         SD 450C80    DHT         SD 451000    IHCECOMH*   SD 451530    IBCOM#   *  LR 451530
    FDIOCS#  *  LR 4515EC    INTSWTCH*   LR 452476    IHCCOMH2*   SD 452498    SEQDASD  *  LR 452810    IHCSSCN  *  SD 452AFB
    COS      *  LR 452AF8    SIN      *  LR 452B10    IHCSASCN*   SD 452C08    ARCOS    *  LR 452CD8    ARSIN    *  LR 452CFF
    IHCFRXPR*   SD 452EB8    FRXPR#   *  LR 452EB8    IHCSEXP  *  SD 453040    EXP      *  LR 453040    IHCDBUG  *  SD 4531C4
    DEBUG#   *  LR 45310A    IHCSLOG  *  SD 4539F0    ALOG10   *  LR 4539F0    ALOG     *  LR 453A08    IHCFCVTH*   SD 453F1A
    ADCON#   *  LR 453BA8    FCVAOUTP*   LR 453C52    FCVLOUTP*   LR 453C52    FCVZOUTP*   LR 453E32    FCVIOUTP*   LR 454110
    FCVEOUTP*   LR 4546E2    FCVCOUTP*   LR 454BFC    INT6SWCH*   LR 4548E3    IHCEFIOS*   SD 454048    FIOCS#   *  LR 454048
    FIOCSBFP*   LR 454D4E    IHCFIOS2*   SD 455C70    IHCEFNTH*   SD 4551A0    ARITH#   *  LR 4551A0    ADJSWTCH*   LR 45557C
    IHCUOPT  *  SD 4566F8    IHCERRM  *  SD 4569EA    ERRMON   *  LR 4569E8    IHCERRE  *  LR 456A00    IHCSSORT*   SD 456FC0
    SQRT     *  LR 456FC0    IHCUATBL*   SD 457108    IHCETRCH*   SD 457740    IHCTRCH  *  LR 457740    ERRTRA   *  LR 457748
    RP          CM 457900    GP          CM 4579F8    PP          CM 457A00    FP          CM 457BE0    WP          CM 457BF0

    TOTAL LENGTH       7BFC
    ENTRY ADDRESS    450010
```

```
      ALPHA=ALPHA*360.0/(44.0/7.0)
      TEST=1.059*ALPHA
      IF(TEST .LT. 5.31) GO TO 80
      WRITE(6,8)TA, XMDOT, RH, TI, U,XMDAY,ALPHA
      GO TO 81
   80 ALPHA=5.31/1.059
      WRITE(6,23)TA, XMDOT, RH, TI, U,XMDAY
   81 CONTINUE
      IF(XMDOT .EQ. 0.0) XMDOT=0.001
C
C     ..... CALCULATE AND PRINT OUTLET TEMPERATURES AND HEAT LOSSES ....
      WRITE(6,15)
      DO 50 I=1,NR
      CALL RHT(XMDOT,TI,TO,Q,I)
      WRITE(6,16) I,TI,TO,Q
      TI=TO
 50   CONTINUE
      DO 60 I=1,NS
      NE=NR+I
      CALL DHT(XMDOT,TI,TO,Q,I)
      WRITE(6,19) NE,TI,TO,Q
      TI=TO
 60   CONTINUE
   70 CONTINUE
C
C     ..... FORMATS FOR INPUT AND OUTPUT .....
    1 FORMAT (3F10.4)
    2 FORMAT (4F10.2)
   32 FORMAT(F10.2)
    3 FORMAT(I3)
    4 FORMAT(5F10.4,I4)
    5 FORMAT(I3)
    6 FORMAT(F10.4)
    7 FORMAT(///17X,'WATER PROPERTIES',18X,'GROUND PROPERTIES',//17X,'K
     *=',F6.3,' BTU/HR-FT-DEG.F',9X,'KG=',F6.3,' BTU/HR-FT-DEG.F',/17X,'
     *MU=',F6.3,' LB/FT-HR',16X,'TG=',F6.2,' DEG.F'/17X,'CP=',F6.3,' BTU
     */LB-DEG.F')
    8 FORMAT(//17X,'ENVIRONMENTAL PROPERTIES',10X,'VARIABLE WATER PROPER
     *TIES',//17X,'TA    =',F6.2,'DEG.F',17X,'MDOT=',E11.4,' LB/HR',/17X,
     *'RH    =',F6.2,22X,'TI    =',F6.2,' DEG.F',/17X,'U     =',F6.2,' MPH',
     *18X,'Q    =',F6.2,'MGD',
     */17X,'ALPHA=',F6.2,' DEG.')
    9 FORMAT(/17X,'DECLINATION=', F6.2,' DEG.')
   11 FORMAT(///17X,'RESERVOIR PROPERTIES',//17X,'NR',2X,'AREA(SQ FT)')
   12 FORMAT(17X,I2,F10.2)
   13 FORMAT(///17X,'PIPE PROPERTIES',//17X,'NS',2X,'D(FT)',4X,'L(FT)'
     *,4X,'T(FT)',4X,'B(FT)',4X,'NP',4X,'KP(BTU/HR-FT-DEG.F)')
   14 FORMAT(17X,I2,F7.3,F9.1,F9.3,F9.2,I6,F11.3)
   15 FORMAT(///17X,'ELEMENT',6X,'INLET TEMP (F)',3X,'OUTLET TEMP (F)'
     *,3X,'HEAT LOSS (BTU/HR)')
   16 FORMAT(18X,I3,8X,F10.4,8X,F10.4,8X,E11.4)
   17 FORMAT (2F10.4)
   18 FORMAT(/////17X,'TIME= ',I4)
   19 FORMAT(18X,I3,8X,F10.4,8X,F10.4,8X,E11,4)
   21 FORMAT(2F10.2)
   22 FORMAT(///17X,'DAY NUMBER=',F4.0,2X,'LATITUDE=',F6.2,' DEG.')
   23 FORMAT(//17X,'ENVIRONMENTAL PROPERTIES',10X,'VARIABLE WATER PROPER
     *TIES',//17X,'TA    =',F6.2,'DEG.F',17X,'MDOT=',E11.4,' LB/HR',/17X,
```

```
FORTRAN IV G LEVEL  21                    DHT                  DATE = 80207          15/17/07

 0001                    SUBROUTINE DHT(XMDOT,TI,TO,Q,I)
 0002                    COMMON/WP/XK,XMU,CP
 0003                    COMMON/PP/D(20),XL(20),WT(20),XKP(20),B(20),NP(20)
 0004                    COMMON/GP/XKG,TG
 0005                    PI=3.14159
 0006                    RE=4.0*XMDOT/(PI*D(I)*XMU*NP(I))
 0007                    PR=CP*XMU/XK
 0008                    IF (RE.LT.2300.0) GO TO 10
 0009                    XNU=0.023*(RE**0.8)*(PR**0.4)
 0010                    GO TO 20
 0011          10        XNU=3.66
 0012          20        H=XK*XNU/D(I)
 0013                    S=2.0*PI*XL(I)/ALOG(4.0*B(I)/D(I))
 0014                    RTH=(WT(I)/XKP(I)+1.0/H+PI*D(I)*XL(I)/(XKG*S))/(PI*D(I)*XL(I))
 0015                    TO=TG+(TI-TG)*EXP(-NP(I)/(XMDOT*CP*RTH))
 0016                    Q=XMDOT*CP*(TI-TO)
 0017                    RETURN
 0018                    DEBUG SUBCHK
 0019                    END
```

```
FORTRAN IV G LEVEL  21                    DHT                  DATE = 80207          15/17/07

  *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = DHT     , LINECNT =        60
  *STATISTICS*    SOURCE STATEMENTS =        19,PROGRAM SIZE =       1328
  *STATISTICS*  NO DIAGNOSTICS GENERATED

  *STATISTICS*  NO DIAGNOSTICS THIS STEP
```

```
                                                  VS LOADER
OPTIONS USED - PRINT,MAP,LET,CALL,NORES,NOTERM,SIZE=98304,NAME=**GO

     NAME   TYPE  ADDR          NAME    TYPE  ADDR          NAME    TYPE  ADDR          NAME    TYPE  ADDR          NAME    TYPE  ADDR
  MAIN        SD 450010     RHT          SD 450C80     DHT          SD 451000     IHCECOMH*    SD 451530     IBCOM#   *   LR 451530
  FDIOCS#  *  LR 4515EC     INTSWTCH*    LR 452476     IHCCOMH2*    SD 452498     SEQDASD  *   LR 452810     IHCSSCN  *   SD 452A18
  COS      *  LR 452A18     SIN      *   LR 452810     IHCSASCN*    SD 452C08     ARCOS    *   LR 452C08     ARSIN    *   LR 452CFF
  IHCFRXPR*   SD 452EB8     FRXPR#   *   LR 452EB8     IHCSEXP  *   SD 453040     EXP      *   LR 453040     IHCDBUG  *   SD 4531D4
  DEBUG#   *  LR 4531D8     IHCSLOG  *   SD 4535F0     ALOG10   *   LR 4539F0     ALOG     *   LR 453A08     IHCFCVTH*    SD 453FA8
  ADCON#   *  LR 453BA8     FCVAOUTP*    LR 453C52     FCVLOUTP*    LR 453C52     FCVZOUTP*    LR 453F32     FCVIOUTP*    LR 454110
  FCVEOUTP*   LR 454652     FCVCOUTP*    LR 4548FC     INT6SWCH*    LR 4548F3     IHCEFIOS*    SD 454D48     FIOCS#   *   LR 454D48
  FIOCSBEP*   LR 45404E     IHCFIOS2*    SD 455C70     IHCEFNTH*    SD 45[illegible]  ARITH#   *   LR 4551A0     ADJSWTCH*    LR [illegible]
  IHCUOPT  *  SD 4566F8     IHCERRM  *   SD 4569F8     ERRMON   *   LR 4569E8     IHCERRE  *   LR 456A00     IHCSSORT*    SD [illegible]
  SQRT     *  LR 456FC0     IHCUATBL*    SD 457108     IHCETRCH*    SD 457730     IHCTRCH  *   LR 457740     ERRTRA   *   LR 457758
  RP          CM 457900     GP           CM 4579F8     PP           CM 457A00     FP           CM 457BE0     WP           CM 457BF0

  TOTAL LENGTH       7BFC
  ENTRY ADDRESS    450010
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WATER PROPERTIES                            GROUND PROPERTIES

K  = 0.355 BTU/HR-FT-DEG.F                  KG= 0.005 BTU/HR-FT-DEG.F
MU= 2.080 LB/FT-HR                          TG= 55.00 DEG.F
CP=  0.998 BTU/LB-DEG.F


PIPE PROPERTIES

NS   D(FT)     L(FT)      T(FT)       B(FT)      NP    KP(BTU/HR-FT-DEG.F)
 1   3.750    2600.0     0.750        4.00        1      0.670
 2   2.500    2600.0     0.420        4.00        2      0.670
 3   2.250    2600.0     0.420        4.00        2      0.670
 4   2.000    2600.0     0.420        4.00        4      0.670
 5   2.000    2600.0     0.420        4.00        6      0.670
 6   1.670    2600.0     0.410        4.00        9      0.670
 7   1.670    2600.0     0.410        4.00       12      0.670
 8   1.510    2600.0     0.410        4.00       27      0.670
 9   0.840    2600.0     0.370        4.00      250      0.670
10   0.670    2600.0     0.370        4.00      374      0.670
11   0.670    1300.0     0.370        4.00     1122      0.670
12   0.500    1300.0     0.370        4.00     1122      0.670
13   0.330    1300.0     0.370        4.00     1122      0.670


RESERVOIR PROPERTIES

NF   AREA(SQ FT)
 1   33400.00
 2   13900.00
 3   50000.00
 4   34700.00


DAY NUMBER= 80.  LATITUDE= 33.65 DEG.

DECLINATION= -0.34 DEG.
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Sample Of Program Output

```
TIME=  100

ENVIRONMENTAL PROPERTIES                    VARIABLE WATER PROPERTIES

TA    = 45.00DEG.F                          MDOT= 0.1196E 08 LB/HR
RH    =  0.26                               TI   =110.00 DEG.F
U     = 15.80 MPH                           Q    = 34.40MGD
THE SUN IS DOWN


ELEMENT        INLET TEMP (F)   OUTLET TEMP (F)   HEAT LOSS (BTU/HR)
   1             110.0000          108.1123          0.2247E 08
   2             108.1123          107.3428          0.9182E 07
   3             107.3428          104.7598          0.3089E 08
   4             104.7598          103.0474          0.2039E 08
   5             103.0474          103.0472          0.2732E 04
   6             103.0472          103.0468          0.4372E 04
   7             103.0468          103.0465          0.4007E 04
   8             103.0465          103.0459          0.7650E 04
   9             103.0459          103.0449          0.1148E 05
  10             103.0449          103.0436          0.1566E 05
  11             103.0436          103.0418          0.2095E 05
  12             103.0418          103.0381          0.4499E 05
  13             103.0381          103.0102          0.3321E 06
  14             103.0102          102.9716          0.4608E 06
  15             102.9716          102.9138          0.6905E 06
  16             102.9138          102.8609          0.6311E 06
  17             102.8609          102.8138          0.5625E 06
```