

AN AUTOMATIC UPFLOW WATER  
FILTRATION SYSTEM

By

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## CHAPTER I

### INTRODUCTION

#### The Problem

Water is a necessity for the continuation of life, but there are some areas which do not have a source of good quality water. This problem is sometimes eased by the rural water districts and the ability of people to transport domestic water by tank truck. If a great distance exists between the source and the point of use, these alternatives would be economically infeasible.

Another alternative is the use of a small water treatment unit to produce a desirable water from existing surface water sources. This unit might resemble municipal water treatment installations on a greatly reduced size and capacity. It would produce a potable water for a few households at the most and could also be used by cabins or other recreational facilities near lakes or streams which could serve as a suitable water source.

Since lakes are formed by the accumulation of runoff from the watershed surrounding the lake, the condition of the lake water is dependent on the upstream land use. If the land is farmland, erosion conditions might cause the lake water to be quite turbid. If the land is pasture, the water should be less turbid.

Water traveling from the point where it reaches the ground as

precipitation until it becomes part of the lake water has many chances to be contaminated by soil particles as well as fertilizers which are leached from the soil. Also, animal and human waste contamination are possible. Bacteria could enter the lake from animal and human waste products, and also be deposited in the water from the air. If these constituents are found to be present in the water source, the treatment unit will need to be effective enough so that the quantity of foreign material in the finished water will not be greater than the values given for a potable water by the United States Public Health Department as of April, 1962. The Oklahoma State Department of Health recommends that these standards be followed for all public water supplies and will be the basis for determining the effectiveness of the system.

Other specifications to which the unit must conform are ease in maintenance and operation. The unit should be self-contained except for the filtered water line which is connected to the house, raw water line from source, and power supply. The unit must also be weatherproofed to withstand weather conditions where it is installed.

### Objectives

The objectives of this research are:

1. Develop an outdoor pond water treating unit.
2. Evaluate the performance of the unit to provide a potable water using pond water as a source.

### Limitations

The water treatment unit was tested on Ham's Lake located eight km (five miles) west of Stillwater, Oklahoma. This was the only water

source on which the unit was tested. The watershed of Ham's Lake is all grassland. Therefore, the raw water supply may have been of higher quality than other supplies where the unit might be used. While other research projects are conducted at Ham's Lake, the only one which would affect the unit would be the lake destratification project and it would improve the quality of the source water.

## CHAPTER II

### LITERATURE REVIEW

#### Previous Upflow Filter Research

The filter configuration used in this research is an upflow type. Operation of this type filter is opposite to the gravity type which is used in most municipal systems in that the movement of water is upward through the filter instead of downward with the pull of gravity. An upflow filter requires a pump to move the water through the filter media.

The water treatment system considered in this research project is a working model of the laboratory studies conducted by Daniel and Garton (1). They conducted experiments with several filter media to determine their performance in upflow filter systems. They concluded that medium sand, 10% by weight with a particle diameter less than or equal to 0.4 mm (0.02 in.) and uniformity coefficients of 1.5 to 2.0, gave satisfactory results. The model was made of 10 cm (4.0 in.) diameter by 183 cm (72.0 in.) long plastic tubing. They found that water with high and low turbidities required approximately the same amount of coagulant aid. The flow rate of water through the filter was restricted to 0.4 liters/min per  $m^2$  (1.0 gal/min/ft<sup>2</sup>) of filter area.

Since the model filter was constructed with a clear plastic tube, observations on the condition of the system below the filter could be

made. They found that as the mud deck thickened on the lower side of the filter, greater head requirements were needed to overcome the decreasing permeability of the filter.

In other research, Daniel (2) found that 95 to 100 mg/l alum was needed for quick flocculation (about 10 minutes contact time) regardless of the turbidity of the water. This concentration of coagulant aid was four to six times the concentration used in a gravity sand filtration system.

#### Water Use Characteristics

To determine the size of the filtration system, it is necessary to know the amount of water consumed by the users. Goodwin (3) investigated the demand characteristics of users on a rural water district and found the optimal design values for daily demand to be 1325 liters (350 gallons) per house. Also, he determined the cumulative frequency curves of daily demand per person as shown in Figure 1.

#### Coagulation and Flocculation

Natural waters, whether polluted by man or by nature, are likely to contain dissolved inorganic and organic substances, biological forms such as bacteria and plankton, and suspended inorganic material. To remove these substances, the usual unit processes include plain sedimentation, removal by coagulation generally followed by filtration, and chemical precipitation to remove dissolved minerals like hardness components and iron and manganese. Other processes important in the removal of dissolved substances include adsorption, aeration, ion exchange, oxidation, and distillation.

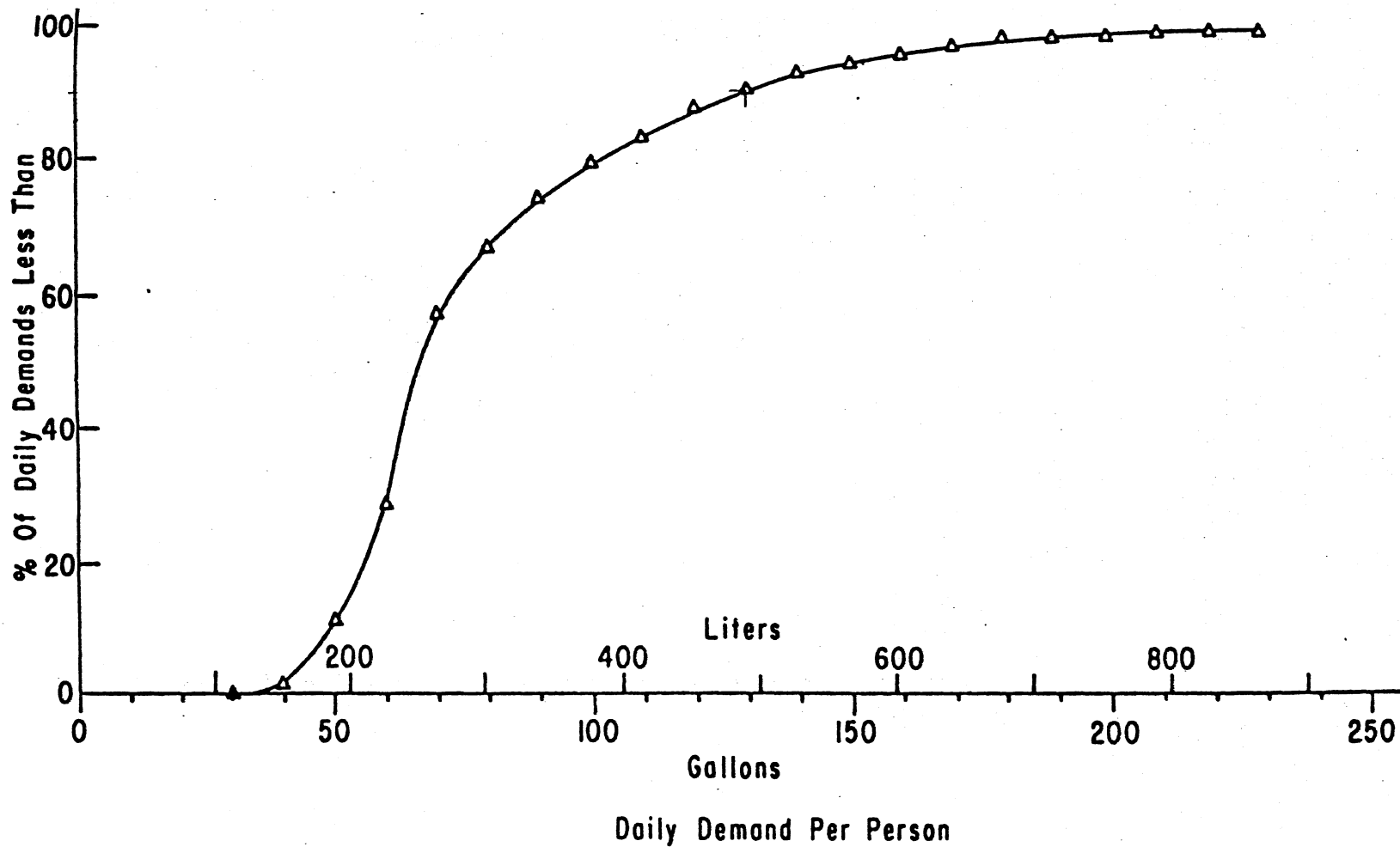


Figure 1. Cumulative Frequency of Daily Demand Per Person

Coagulation generally followed by filtration is the most widely used process in the clarification of turbid waters. Turbidity in water is due mostly to clay particles and microscopic organisms which can be large enough that they settle readily or so small that they remain suspended for a very long period of time which makes sedimentation impractical. This is the reason that coagulation and flocculation are used. This causes small, colloidal material to agglomerate to form larger particles called floc which settle faster.

### Theory of Coagulation

The terms coagulation and flocculation have in the past been used interchangeably, but they refer to separate phases of the overall process of turbidity removal. Coagulation refers to the effect produced by the addition of a chemical to colloidal dispersion resulting in particle destabilization by the reduction of the forces tending to separate the particles. The second phase is flocculation which is the formation of particles that are large enough to settle from the destabilized colloidal particles.

The American Water Works Association, Inc. (4) lists two theories which cause the colloidal particles to remain in suspension. The forces that act here are referred to as being stable or instable. Stability refers to the ability of particles to remain suspended, while instability refers to the breaking down of these forces so that the colloidal particles can agglomerate when contact is made with each other. The theories are as follows:

The older (chemical) theory assumes that colloids acquire electrical charges on their surfaces by ionization of chemical groups present at the surface and that coagulation



or destabilization is accomplished by chemical interactions between colloid particles and the coagulant. The physical theory . . . emphasizes such factors as electrical double layer and counterion adsorption where destabilization occurs through reduction of forces such as zeta potential. . . . it now appears that the mechanisms are not mutually exclusive, and both theories have to be invoked to explain the process of coagulation in water-plant systems where a heterogeneous mixture of colloid systems exists.

Clays and metal oxides which cause turbidity are of the hydrophobic class of colloid particles. This indicates that a dispersion of these substances that have been dehydrated will not redisperse spontaneously in water as a hydrophilic substance would. This is a result of the differing types of forces which hold the particles in suspension. In hydrophilic suspension, hydration causes the particles to form a barrier of water molecules around the particles, keeping them apart. Hydrophobic particles possess an electrical double layer which prevents particle contact. The theory uses the idea that the particles obtain an electrical charge on their surface, which for particles in natural water is usually negative. The fluid around the particle sets up an ion cloud around the particle which is of opposite polarity. As distance from the particle increases, the potential of the ion decreases to zero. Nearest the particle is the bound-water layer which is held tightly enough that it moves with the particle. The ion potential which occurs at the shear plane on the outside edge of the bound-water layer is referred to as the zeta potential.

The effect of the particles forming the electrical double layer around themselves prohibits the approach of other particles since like charges repel. This causes the stability of the suspension. Thus, if the proper ion was added to the solution to change the ion concentration, the thickness of the electrical double layer would be reduced and

the surface-charge density changed so that mixing can initiate sufficient particle collisions to begin flocculation.

Simplified Procedure for Water Examination (5) indicates a jar test technique to determine the best coagulant aid concentration to be used which best achieves the desired floc formation.

### Chlorination

The objectives in applying chlorine to water in the treatment process are: (1) disinfection to kill microorganisms which would be harmful if consumed by humans, and (2) oxidation to destroy unwanted constituents in the water. Either or both objectives may be important depending on the water and also the desired final state of treatment.

The addition of chlorine to pure water produces a mixture of hypochlorous acid (HOCl) and hydrochloric acid (HCl):

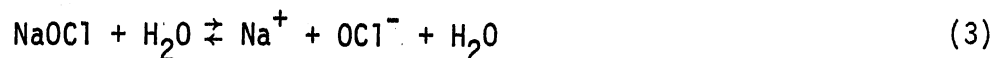


The HOCl gives the oxidizing properties to the chlorine, and thus is the most important factor in the disinfecting action. HOCl further ionizes into hydrogen and hypochlorite ions as follows:



Concentrations at which these substances coexist in the solution depend on pH and temperature. Chlorine in solution as hypochlorous acid and hypochlorite ions is defined as free available chlorine.

Sodium hypochlorite (NaOCl), another source of chlorine used in water treatment processes, will dissociate as follows:



From this, HOCl is formed from hydrogen ions as shown in Equation (2.2). Thus, the oxidizing ability of the chlorine is present whether chlorine gas or sodium hypochlorite is used.

Chlorine residual is defined as the chlorine concentration remaining after a specified contact period. This chlorine residual is the way by which the chlorination process is monitored.

If the water contains ammonia or organic nitrogen, combined available chlorine is the product of the reaction of the ammonia and the hypochlorous acid to form a chloramine. The oxidizing ability of the chlorine is in the chloramine, but the disinfecting potential of the chlorine in this form is greatly reduced as shown in Figure 2. This shows the minimum safe chlorine residual required at the specified temperature and contact time for free and combined chlorine as a function of pH. Notice that at any value of pH, not only must the chlorine residual be at a higher level, but also a longer contact time is required by a chloramine to produce a 100% bacteria kill.

At other contact periods and temperatures the minimum residual is different from that shown above. The American Water Works Association, Inc. (4) indicated that for a contact time of 30 minutes, the minimum free chlorine residual is 0.2 mg/l for a pH less than 9.2, then increasing to 0.7 mg/l at a pH of 10.0 and to 1.8 mg/l at a pH of 11.0. The minimum combined chlorine residual is 2.0 mg/l for a pH less than 6.8, then increasing to 2.4 mg/l at a pH of 7.0, and then increasing almost linearly to a residual of 3.6 mg/l at a pH of 11.0. At temperatures between 0° and 25°C and 30 minutes contact time, the minimum recommended free chlorine residual is 0.2 mg/l for a pH less than 9.1, then increasing to 0.6 mg/l at a pH of 10.0, and then increasing to 1.5 mg/l free

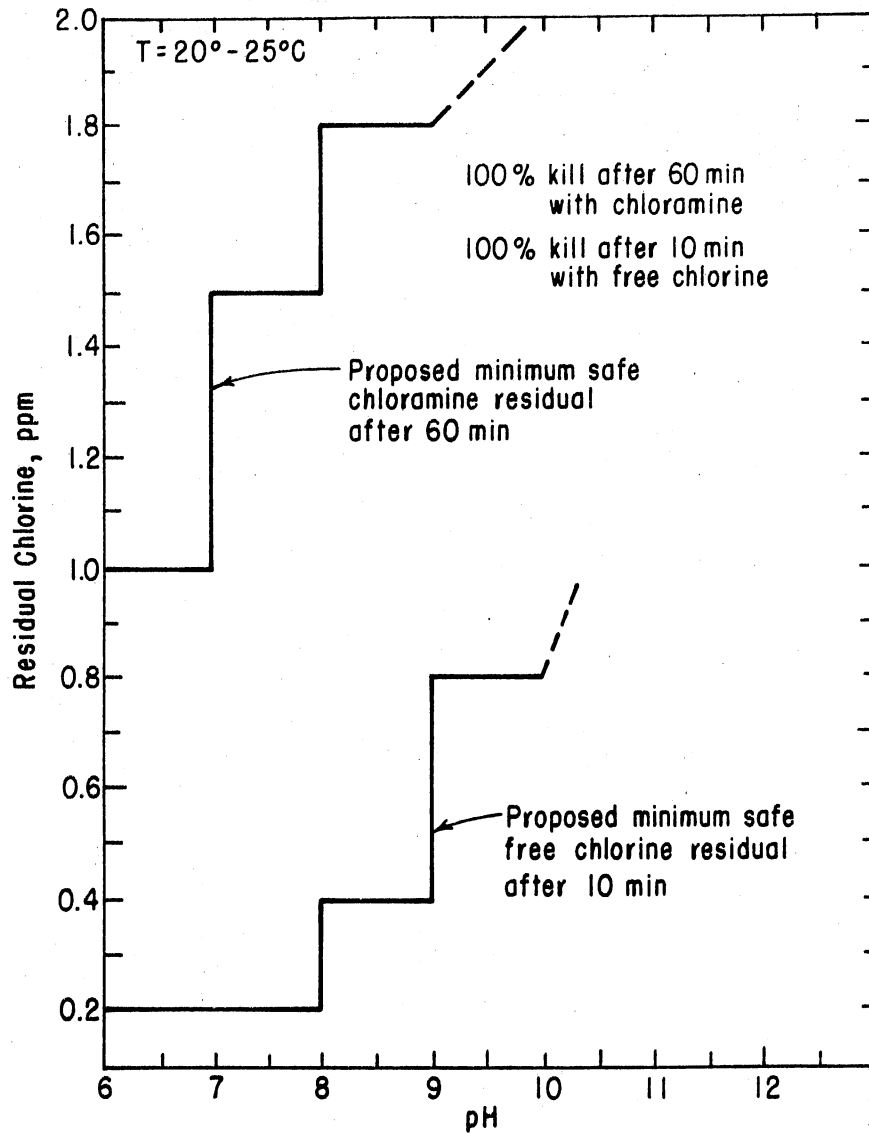


Figure 2. Minimum Free and Combined Bactericidal Chlorine Residuals (from Water Quality and Treatment Handbook by the American Water Works Association. Copyright 1971 by American Water Works Assn., Inc. Used with permission of McGraw-Hill Book Company)

chlorine at a pH of 10.8. In the same temperature range and contact time, the minimum recommended combined chlorine residual is 2.0 mg/l at a pH less than 6.8, then increasing to 2.2 mg/l at a pH of 7.0, and increasing linearly to 3.5 mg/l at a pH of 10.5.

Since chlorine can exist in the two different forms of free and combined available chlorine, methods of detection and application must be determined. The orthotolidine test (OT) and the orthotolidine-arsenite test (OTA) are two similar methods outlined in Standard Methods (6). These are sensitive, fairly rapid, and simple indicators of both free and combined chlorine. The OTA test has the advantage of making free chlorine measurements less hurriedly.

To find the concentration of chlorine which must be added, a decision must first be made concerning the form of the disinfecting chlorine. A chlorine demand test, Standard Methods (6), would indicate the concentration of applied chlorine to achieve the appropriate chlorine residual. The general curve resulting from the chlorine demand test would appear as Figure 3.

#### Chemical Metering Rates

Vennard and Street (7) described a method to calculate the flow rates from stock chemical solutions which were needed to produce the desired chemical concentrations in the water chamber. The alum and chlorine flow rates were determined by using their idea which states that the sum of the products of flow rate and concentration entering a point must equal the product of the flow rate and concentration leaving the same point. The equation describing this is as follows:

$$Q_L C_L + Q_C C_C = (Q_L + Q_C) C_T \quad (4)$$

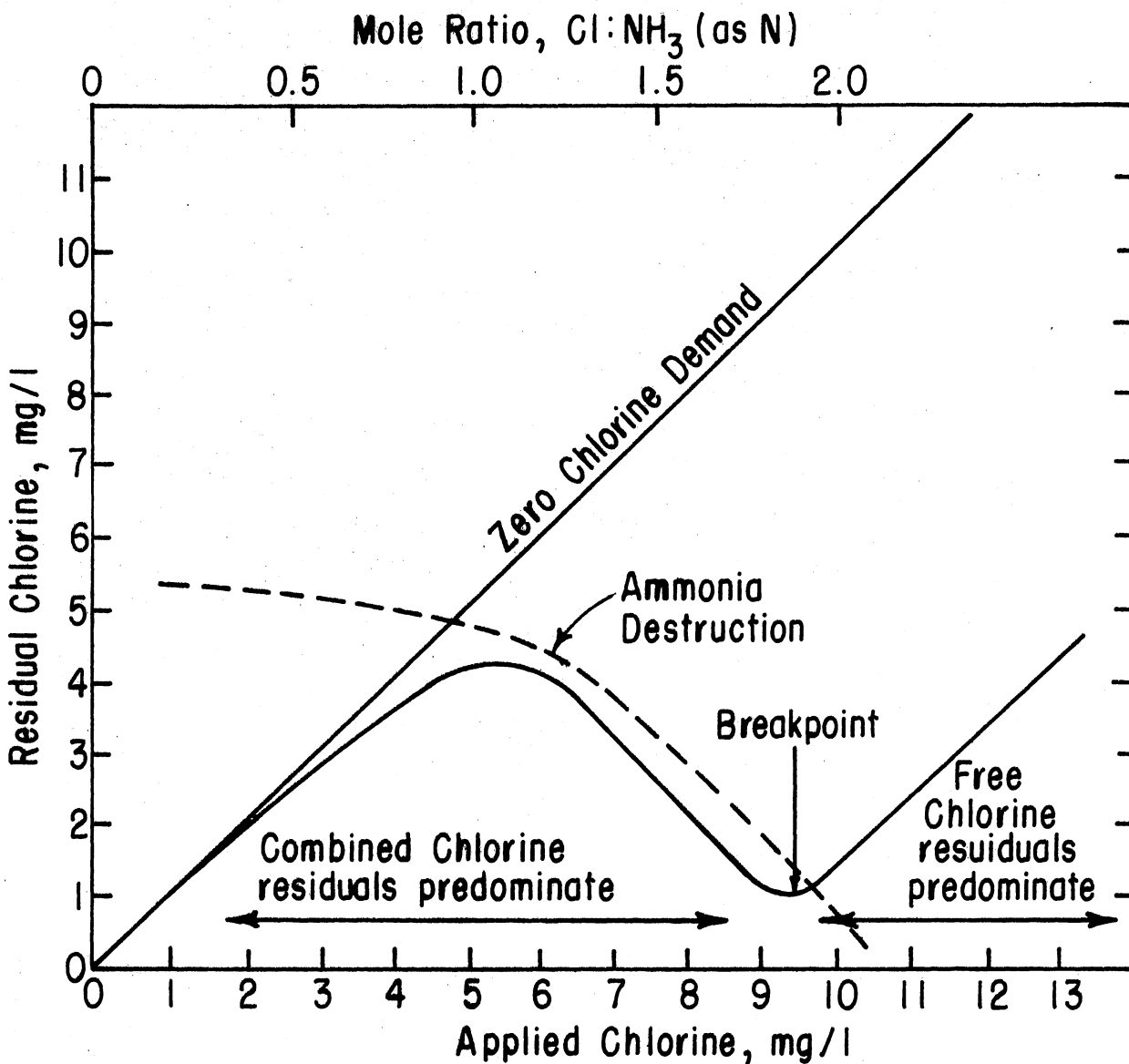


Figure 3. Representative Breakpoint Chlorination Curve (N = 1 mg/l) (from Water Quality and Treatment Handbook by the American Water Works Association. Copyright by American Water Works Assn., Inc. Used with permission of McGraw-Hill Book Company)

where

$Q_L$  = flow rate of the lake water;

$C_L$  = concentration of the chemical in the lake water (assumed to be zero);

$Q_C$  = flow of the stock solution;

$C_C$  = concentration of the chemical in the stock solution;

$C_T$  = concentration of the chemical desired in the filter tank.

### Public Health Drinking Water Standards

On October 21, 1914, the Treasury Department established the first standards for drinking water to the public by any common carrier engaged in interstate commerce. After subsequent revisions in 1925 and 1946, the 1962 Advisory Committee recommended minimum requirements on domestic water supplies and federal approval was granted. Limitations were placed on substances which might be found in water supplies and were considered harmful to the health and well-being of individuals. These constituents and their limitations are given in Table I. At the present time the Environmental Protection Agency has responsibility for drinking water standards, but they really have no standards in effect. However, the Oklahoma State Department of Health recommends that United States Public Health Services standards as of 1962 be followed for all public water supplies.

From contact with the Soil and Water Service Analytical Laboratory at Oklahoma State University, a list of constituents and their limits were obtained which are recommended by the Oklahoma State Department of Health. The list is shown in Table II.

TABLE I

U. S. PUBLIC HEALTH SERVICE DRINKING  
WATER STANDARDS OF 1962

Criterion	Standards
A. Bacteriological Constituents	
Coliform bacteria (B. <u>coli</u> prior to 1942)	
a. Dilution technique (five 10-ml portions)	<ol style="list-style-type: none"> <li>1. Not more than 10% of all portions examined each month shall show presence of coliform bacteria (coliform MPN &lt; 1.0 per 100 ml)</li> <li>2. No two consecutive samples taken from the same location, and not more than one (or 5%) of all samples examined each month, shall show presence of coliform bacteria in three or more of the five portions</li> </ol>
b. Dilution technique (five 100-ml portions)	<ol style="list-style-type: none"> <li>1. Not more than 60% of all portions examined each month shall show presence of coliform bacteria (coliform MPN &lt; 0.9 per 100 ml)</li> <li>2. No two consecutive samples taken from the same location, and not more than one (or 20%) of all samples examined each month, shall show presence of coliform bacteria in all five portions examined</li> </ol>
c. MF technique (using 50, 100, 200, or 500 ml)	<ol style="list-style-type: none"> <li>1. The arithmetic mean coliform count for all samples examined each month shall not exceed one per 100 ml</li> <li>2. The coliform count shall not exceed three per 50 ml, four per 100 ml, seven per 200 ml, or thirteen per 500 ml in two consecutive samples taken from the same location, nor in more than one (or 5%) of all samples examined each month</li> </ol>



TABLE I (Continued)

Criterion	Standards	
Frequency of sampling	Regulated jointly by reporting agency and certifying authority	
Minimum number of samples to be examined in specified period	A minimum number, dependent on population served, shall be examined each month	
Laboratory procedures	Current edition of <u>Standard Methods</u>	
Inspection of laboratories	Subject to inspection by certifying and reporting agencies	
B. Physical Constituents		
Criterion	Recommended Limit (Concentrations which should not be exceeded when more suitable water supplies can be made available)	Tolerance Limit (Concentrations in excess of those listed shall constitute grounds for rejection of the supply)
Color, units	15	
Odor, threshold number	3, inoffensive	
Residue: filtrable, mg/l	500	
Taste	Inoffensive	
Turbidity, units	5	
Frequency of sampling	At least once each week	
Minimum number of samples to be examined in specified period	Not specified	

TABLE I (Continued)

C. Chemical Constituents		
Substance	Recommended Limit, mg/l (Concentrations which should not be exceed- ed when more suitable water supplies can be made available)	Tolerance Limit, mg/l (Concentrations in ex- cess of those listed shall constitute grounds for rejection of the supply)
Alkyl benzene sulfonate (ABS)	0.50	
Arsenic (AS)	0.01	0.05
Barium (Ba)		1.00
Cadmium (Cd)		0.01
Carbon chloroform extract (CCE)	0.20	
Chloride (Cl)	250	
Chromium, hexavalent (Cr <sup>+6</sup> )		0.05
Copper (Cu)	1.00	
Cyanide (CN)	0.01	0.20
Fluoride (F)	0.8-1.7 <sup>a,b</sup>	1.4-2.4 <sup>a</sup>
Iron (Fe)	0.30	
Lead (Pb)		0.05
Manganese (Mn)	0.05	
Nitrate (NO <sub>3</sub> )	45 <sup>c</sup>	
Phenols	0.001	
Selenium (Se)		0.01
Silver (Ag)		0.05
Sulfate (SO <sub>4</sub> )	250	
Zinc (Zn)	5	

TABLE I (Continued)

D. Radioactivity, c/l	
Substance	Recommended Limit <sup>d</sup>
Radium 226 (Ra <sup>226</sup> )	3
Strontium 90 (Sr <sup>90</sup> )	10
Gross beta activity	1000 <sup>e</sup>

<sup>a</sup>Dependent on annual average maximum daily air temperature over not less than a five-year period.

<sup>b</sup>Where fluoridation is practiced, minimum recommended limits are also specified.

<sup>c</sup>If NO<sub>3</sub> concentration exceeds 45 mg/l, public should be warned against use of water for infant feeding.

<sup>d</sup>Water supplies containing concentrations in excess of these limits will be approved if surveillance of total intakes of radioactivity from all sources indicates that such intakes are within the limits recommended by the Federal Radiation Council for control action.

<sup>e</sup>In absence of strontium 90 and alpha emitters.

TABLE II  
 DRINKING WATER STANDARDS RECOMMENDED BY THE  
 OKLAHOMA STATE DEPARTMENT OF HEALTH

Constituents	Recommended Maximum Amount in mg/l	Mandatory Limits for Rejection of Water in mg/l
Total Dissolved Solids	500	
Chloride (Cl)	250	
Sulphate (SO <sub>4</sub> )	250	
Iron (Fe)	0.30	
Nitrates (NO <sub>3</sub> )	45	
Manganese	0.05	
Copper	1.00	
Magnesium	50	
Zinc	5	
Arsenic	0.01	0.05
Fluoride	1.70	3.40
Lead		0.05
Selenium		0.01
Silver		0.05
Barium		1.00
Cadmium		0.01
Chromium		0.05
Cyanide		0.20
pH	7.0 to 10.6	
<u>Hardness (expressed as calcium carbonate (CaCO<sub>3</sub>))</u>		
Soft water	0 to 8.55 mg/l*	
Slightly hard water	8.55 to 60.0 mg/l	
Moderately hard water	60.0 to 119.7 mg/l	
Hard water	119.7 to 180.0 mg/l	
Very hard water	above 180.0 mg/l	

\*Grains per gallon x 17.1 = mg/l.

## CHAPTER III

### EXPERIMENTAL DESIGN AND EQUIPMENT

#### Experimental Design

##### Principle of Operation

Daniel and Garton (1), in their work with water filtration systems, noted that downflow or gravity configurations developed a layer of mud on the upper surface of the filter media. This layer, along with the top few inches of the filter media, would need to be removed periodically. This caused the eventual replacement of the entire filter media.

In the research of this thesis the upflow configuration was investigated to try to avoid replacing the filter media. By providing an open volume below the filter media, this would provide time for the flocs to settle before the water passed through the filter media. The settled material could then be flushed from the bottom of the water chamber with a backflushing procedure.

An H-shaped manifold made of PVC pipe with slits cut on one side half way through the pipe parallel to a cross-section was designed to set in the bottom of the water chamber. This was used to provide even removal of water and settled floc so that a conical shaped residue would not form as it would if a single orifice drain in the center of the floor was used.

The water filtration unit was designed to utilize the principles of operation of chlorination and flocculation used in municipal water treatment facilities. A hypochlorite was used to destroy the unwanted organisms, and alum was used to form floc from the minute particles.

### System Organization

Design requirements for the water filtration system were: to provide a structurally sound enclosure to operate outdoors in the vicinity of a lake or pond; to provide a potable chlorinated water under pressure; and to be a self-contained system except for electrical, raw-water inlet, and treated water outlet connections.

The design of the enclosure was as shown in Figures 20 and 21, Appendix A. Some minor variations from these plans were made. The enclosure consisted of two compartments. One was the water chamber where the filtration process was conducted, and the other was the equipment room which housed pumps, tanks, and electrical controls. The frame of the enclosure was made of five cm (two in.) by 10 in. (four in.) studs spaced against 30.5 cm (one ft) apart (Figure 4). To provide protection against freezing, styrofoam sections were cut and placed between the studs. The styrofoam is the white areas shown in Figure 4.

In the design of the water chamber, consideration was given to weight of the water on the floor and the pressure on the walls. With the water chamber full, the depth of water was 2.8 meters (7.5 ft), and the area of the floor was  $1.2\text{m}^2$  ( $13.3\text{ft}^2$ ). The design weight of water on the floor would be no less than 27,760 N ( $6240\text{lb}_f$ ). The horizontal pressure exerted at the floor of the water chamber would be 22,400 Pa (3.2 psi). Therefore, angle braces were placed on both sides of the

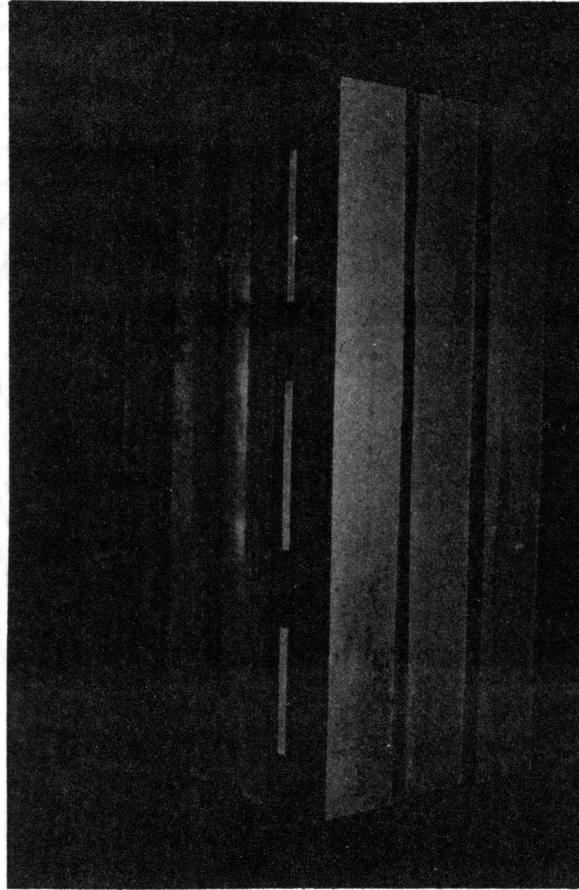


Figure 4. Frame and Insulation of Unit

lower end of the studs to strengthen the connection of the studs to the floor. These angle braces can be seen in Figure 4 with a closer view shown in Figure 5. Also, five cm (two in.) by 10 cm (four in.) rectangular walers were installed on the outside of the water chamber to provide added strength.

Provisions in the design of the water chamber were made to make the walls watertight. The walls were made of solid sheets of plywood so there would be no seams except in the corners. These corner seams were beveled and filled with caulk to make them watertight.

Strength was added to the walls of the water chamber by installing wood screws through the plywood wall into the studs (Figures 6 and 7). The screws were placed 15 cm (six in.) apart. This configuration would approach the strength of a T-beam. Caulking was placed over the counter-screw heads to further prevent loss of water.

Design of the support for the filter media deserved some attention because of its location and duties. Since it was in the water chamber and would be under water, it was made of redwood which resists deterioration in water. The water level is at times lowered below the bottom of the filter, and some water is retained in the sand. The support needs to be strong enough to hold the weight of 30 cm (one ft) of the sand plus the retained water over the entire cross-sectional area of the water chamber. Therefore, it was constructed of five cm (two in.) by 15 cm (six in.) redwood lumber with the same size support running around the inside perimeter of the water chamber at one-half its depth. The grid-shaped media platform was designed to merely rest on this support.

Two layers of screen was stretched over the grid-shaped media platform to hold the sand filter (Figure 8). Since the screen would be





Figure 5. Close-Up of Angle Braces

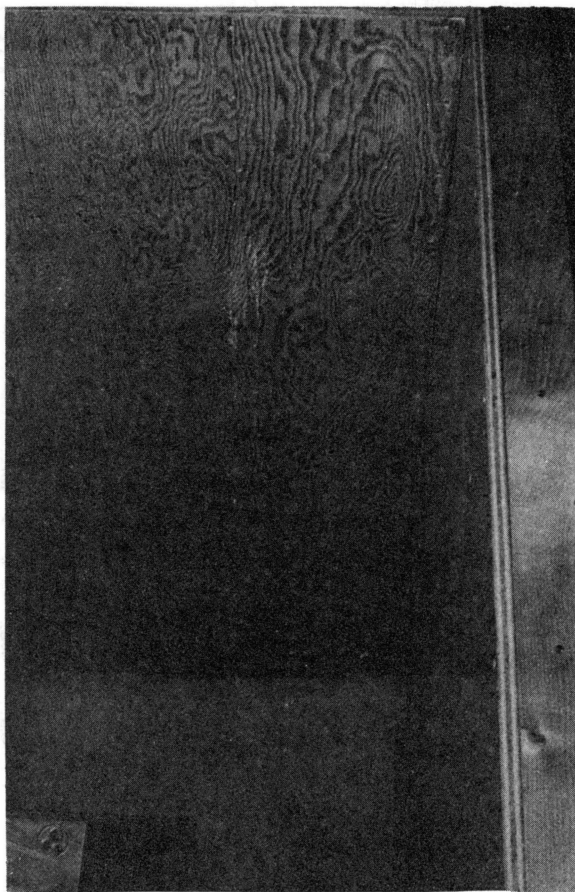


Figure 6. Top View of Water Chamber

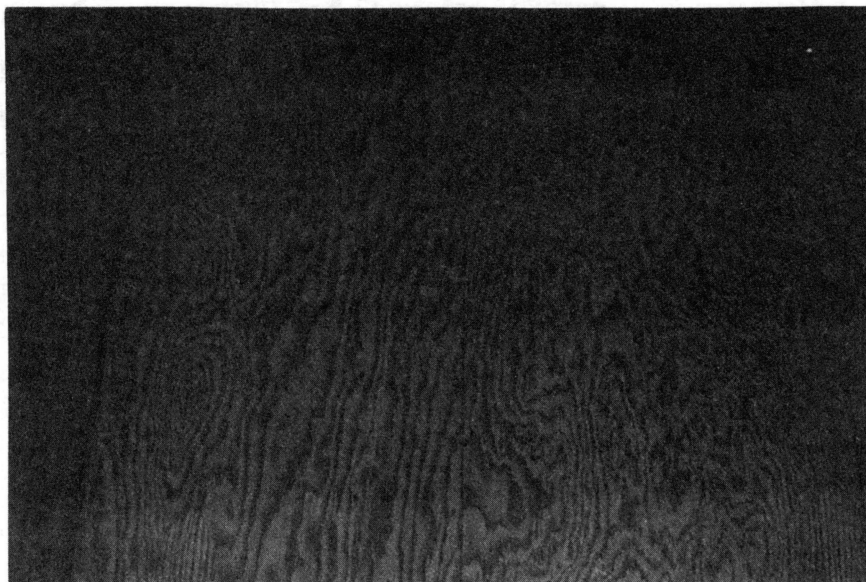


Figure 7. Close-Up of Wood Screws and Corner Seam  
in Water Chamber



Figure 8. Filter Media Support and Screen

under water, a bronze screen was used to prevent corrosion and contamination of the water. For the same reason the nails used in holding the screen were aluminum. This configuration provided for a space in the lower part of the water chamber for the settlement of the floc before the water passed through the filter media. A space was provided above the filter for storage of the filtered water.

The filter media consisted of 15 cm (six in.) of fine sand over 15 cm (six in.) of coarse sand. The fine sand was concrete sand while the coarse sand was made by sifting and washing the finer particles from a portion of the concrete sand. The coarse sand particles were placed on the bottom to keep the fine sand from falling through the screen. The effective diameter and the uniformity coefficient for the layers determined by a sieve analysis were:

<u>Sand</u>	<u>Uniformity Coefficient</u>	<u>D<sub>50</sub> Particle Diameter, (mm)</u>
Fine	0.27	0.490
Coarse	0.41	1.950

Chemicals used in the treatment system of this research were filter alum (aluminum sulfate) and sodium hypochlorite. Filter alum was used as a coagulant aid and some properties include the following:

Appearance	White to light tan crystalline solid, readily soluble in water
Chemical formula	$Al_2(SO_4)_3 \cdot 14.3 H_2O$
Molecular weight	599.8
Bulk Density	1000.2 kg/m <sup>3</sup> (62.4 lb <sub>m</sub> /ft <sup>3</sup> ) approx.
Solubility at 20°C (68°F)	0.87 kg/l. (7.28 lb <sub>m</sub> /gal) of water
pH of 1% solution	3.5

The source of chlorine was D-X Solution, a liquid sodium hypochlorite. This solution contained 10% sodium hypochlorite and 90% inert ingredients.

## Equipment

### System Equipment

Equipment utilized in the operation of the water filtration system, most of which was housed in the filter equipment room (Figure 9), consisted of chlorine and alum solution containers with metering pumps, a time clock and electric solenoid valve for backflushing the unit, a pressure pump, and a pressure tank. A pond water pump was located at the lake.

The pond water pump was a submersible pump floated with a styrofoam block so that the intake was 1.1 m (42 in.) below the water surface. This pump served to pump the water from the lake to the unit. The pump was located near the surface so that the raw water pumped would be of the best quality available having a high level of dissolved oxygen. The pump was located 10.7 m (35 ft) from the shore in water which had a depth of 3.7 m (12 ft). The pump had a capacity of 34.3 liters/min (nine gal/min).

Polyvinyl chloride (PVC) pipe was used exclusively in the system. This prevented contamination of the water by corroding pipe.

The chlorine and alum containers held 113 liters (30 gal) of solution each. The metering pumps (Figure 10) had a range of flow adjustment between 0.8 ml/min (0.3 gal/day) and 74.9 ml/min (28.5 gal/day) under the conditions which they operated. This variable flow combined

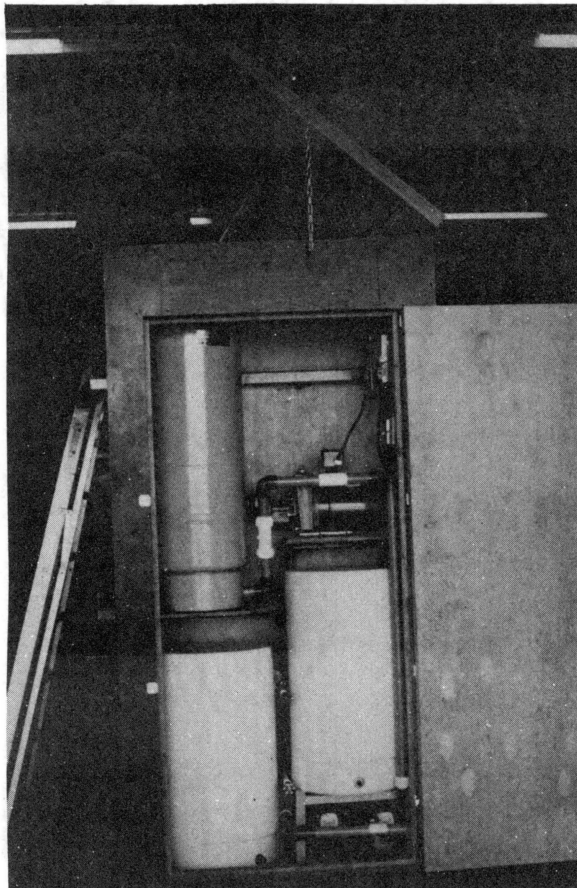


Figure 9. View of Equipment Room

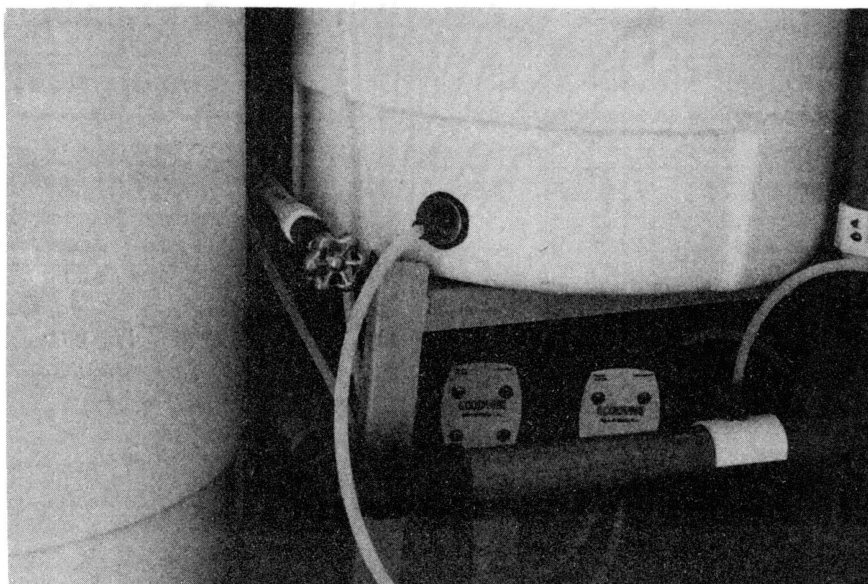


Figure 10. Close-Up of Chemical Containers and Metering Pumps in Lower Portion of Equipment Room



with the ability of having different concentrations of chlorine and alum solutions, gave a wide range of values which could be used in metering the chemicals. These pumps were connected to the electrical circuit with the pond water pump. The metering pumps only ran when water was pumped into the filter system by the pond water pump.

The chemicals were injected directly into the raw water inlet line (Figure 10). The alum was injected at the first tap followed later down the line by the chlorine at the next tap. Turning the right angles in the line helps the mixing of the chemicals in the water.

Located in the upper portion of the equipment room was the pressure pump, pressure tank, and electrical controls (Figure 11). Not shown here but later added were time clocks wired into the circuits of the pumps to compare the amount of time the pumps run with actual time elapsed.

The pressure pump was a 0.560 kW (0.75 hp) jet pump with an adapter for use with shallow wells. A foot valve was installed on the pump inlet line to prevent pressure loss back into the water chamber. This pump had a capacity of 30 liters/min (8 gal/min).

The pressure tank was a Well-X-Trol tank which had a diaphragm separating the water and air spaces. This type was used to help prevent water-logging. Its capacity was approximately 227 liters (60 gal).

Operating of the pumps was controlled by a liquid level control. It served as a starter and as a safety device. With the water chamber empty, the controls started the submersible pump which filled the water chamber, when the water level rose to a point over the filtered water outlet to the pressure pump, the control allowed the pressure pump to start. Once the water chamber filled, the submersible pump was shut

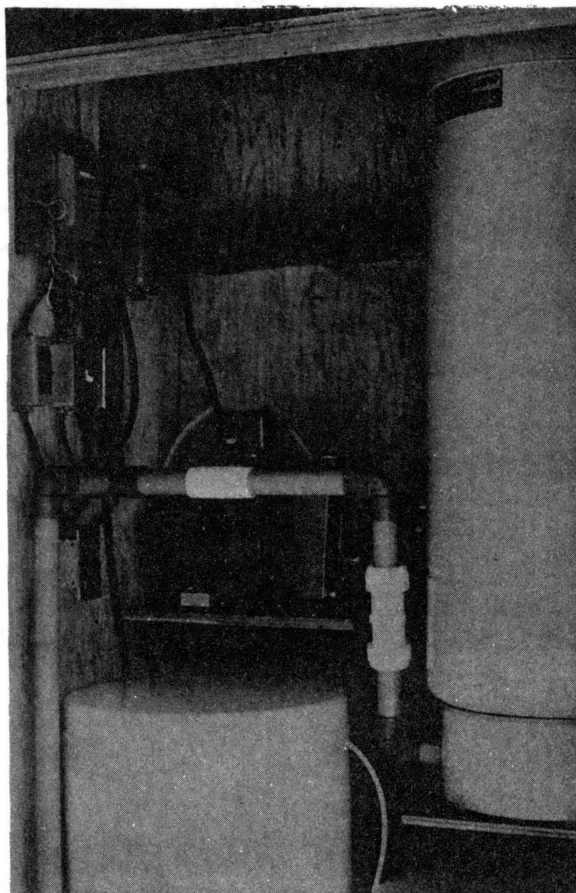


Figure 11. Close-Up of Upper  
Portion of  
Equipment Room

off. As water was used by the pressure pump, the water level lowered and at a certain level the submersible pump was restarted. If the pressure pump continued to remove treated water faster than the submersible pump could supply raw water, the pressure pump was shut off until a water level was obtained which would not let the pressure pump run while it was dry.

The finished water was provided by freezeless water hydrants standing just outside the unit. This type was used since weather conditions would cause the freezing and rupturing of an ordinary faucet.

Installed in the water chamber drain was an electrically controlled solenoid valve. This valve was connected to an electric clock to provide an automatic draining system.

### Lab Equipment

The laboratory where the water analysis data was collected contained basic glassware needed in the research. Various beakers, pipets, burets, volumetric flasks, scales, graduated cylinders, sample collecting containers, and a few reagents were available in the laboratory.

Laboratory testing equipment used included a Hach turbidimeter which was used to measure turbidity in terms of Nephelometer Turbidity Units (NTU). These are approximately the same as the commonly used Jackson Turbidity Units (JTU) but are more accurate since the human eye is not involved in the measurement. A Yellow Springs instrument was used to measure conductivity, a Sargent-Welch pH meter was used to measure pH, and a mercury thermometer was used to measure temperature. A water-grabber was used to obtain water samples from the lake.

## CHAPTER IV

### PROCEDURE

#### Construction and Installation

The water filtration system was constructed from the plan described in the previous chapter. Facilities at the Oklahoma State University Agricultural Engineering Department Laboratory at Stillwater, Oklahoma were used. After construction, the unit was transported to Ham's Lake eight km (five miles) west of Stillwater. The unit was transported by a trailer and loaded and unloaded with a forklift. Once at the lake, the unit was set on a concrete pad located 45.7 m (150 ft) from the edge of the water and about 4.6 m (15 ft) higher than the water surface elevation. Trenches were dug for the PVC pipe (Figure 12). Final connections were made (Figure 13), and the system was ready for operation (Figure 14).

#### Operation of Unit

Before the system was started, the concentrations of the chemical stock solutions were determined. To obtain initial concentrations, the Oklahoma State University water treatment facility was consulted. It was found that the water treatment plant was adding four mg/l (four ppm) chlorine and 20 mg/l (20 ppm) alum in the treatment process. This alum concentration was used, but the chloride concentration was reduced to

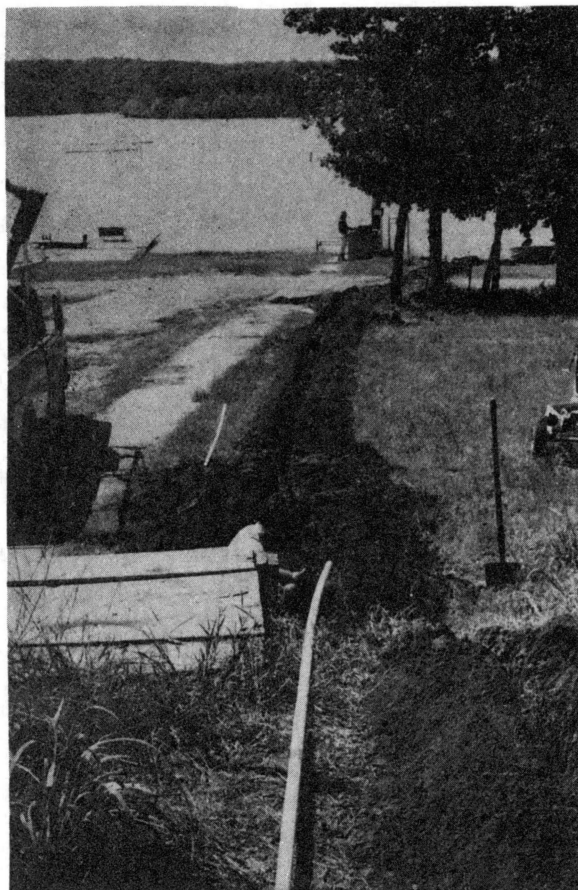


Figure 12. Laying PVC Pipe for  
Submersible Pump

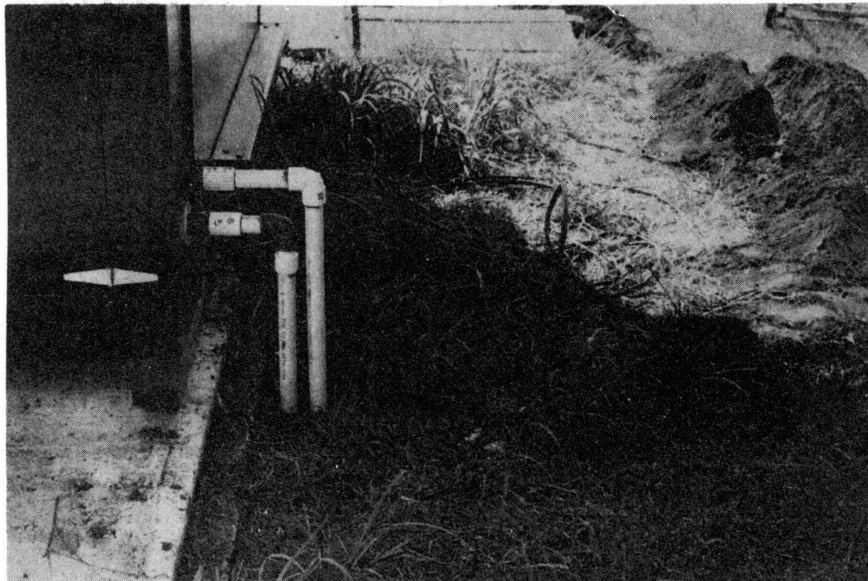


Figure 13. Connections of PVC Pipe to the Unit

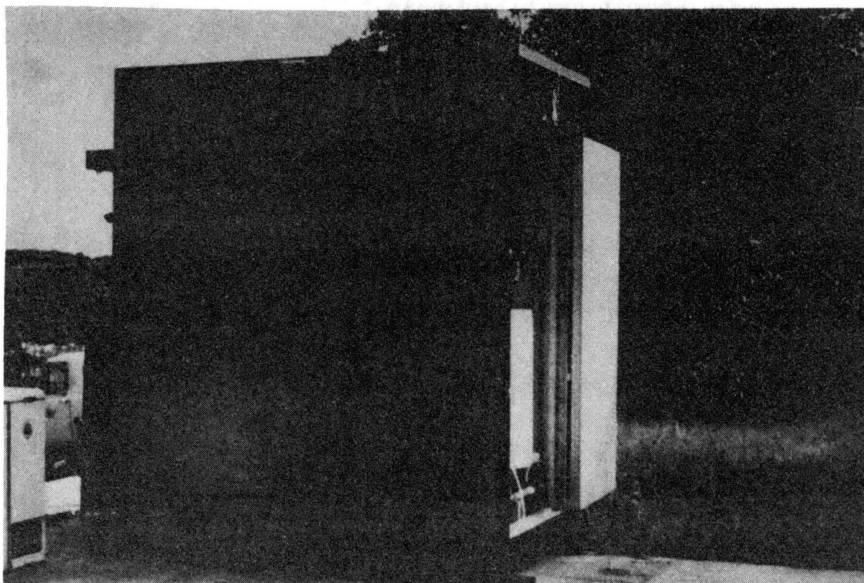


Figure 14. Unit Ready for Operation

two mg/l (two ppm) since a large amount of destruction of chlorine occurs in exposing the water to sunlight which they had done. Equation 4 was used to find values for metering rates and concentrations of the stock solution which would produce these concentrations in the water chamber.

To know the amount of time the pumps operated, time clocks were installed in the circuits of each pump so that they ran only when the pumps did. The clocks were set at zero (12:00 o'clock) each time data were collected. This provided a comparison of pump operation time with actual time elapsed.

The pumps were then ready to be turned on. This started the water filtration system. A water hydrant was turned on and permitted to run continuously to partially simulate the consumption of water by a household. Actual household use varies through the day while this system operated at a constant rate.

At periodic intervals, the solenoid time clock was to open the solenoid valve on the drain pipe to flush sediment particles from the floor of the water chamber. This procedure was referred to as backflushing.

#### Water Sample Collection and Analysis

Water samples were taken and analyzed to determine the performance of the water filtration system. Effectiveness of the system was based on the comparison of the raw and finished samples. Samples representing the raw pond water were obtained with a water-grabber off the end of a dock which extended the same distance from shore as the submersible pump. The water-grabber device was lowered into the water to the same



depth as the intake of the pump. Water temperature was taken and recorded at that time.

Water samples representing the treated water were taken at a faucet located beside the unit. This would be similar to the point where a connection to serve a household would be made. The faucet was turned on and allowed to run a few minutes. The containers were then held under the faucet to collect the sample. Water and ambient temperatures were also determined at this time.

The water samples were taken back to the Agricultural Engineering Laboratory for analysis. Tests run on the samples included conductivity, dissolved oxygen, pH, turbidity, and alkalinity. The procedures for the conductivity, dissolved oxygen, and alkalinity were found in Standard Methods (6). Laboratory equipment was available to read values for pH and turbidity directly.

In addition to this analysis, samples were collected and taken to the Agronomy Lab which analyzed the samples for household use. Also, samples of raw and treated were taken to the County Health Department where coliform bacteria tests were run. Special care was needed in the collection of the bacteria samples. Specially treated bottles obtained from the County Health Department were used. These were sealed and were opened only to collect the sample. Care was used in not contaminating the sample by touching the lip of the bottle while the sample was taken, and not leave the lid off the bottle for a long period of time. Also, if the sample was taken at a hydrant, as this one was, a butane burner was needed to heat the outlet of the hydrant to kill any bacteria which might be there. All of these precautions were taken to try to insure that any bacteria in the sample were obtained from the water.

### Leakage Test

The procedure for determining the amount of water lost from the water chamber is as follows. The chamber was filled with water and the level measured. The system was completely turned off so no water entered or left through the pumps. The system was allowed to stand idle for a known length of time. At the end of this period of time the water level was again measured. The difference in the two levels along with a known cross sectional area and elapsed time enabled the calculation of the water lost.

## CHAPTER V

### RESULTS

#### Results of Operation

Problems were encountered from the beginning of the operation of the unit. Excessive leakage of water occurred from the water chamber. Also, the treated water was very turbid. In fact, the treated water appeared more turbid than the raw water. The poor quality water may have been due in part to the suspension of fine particles that were removed from the sand filter. However, later results showed that this was only part of the cause for the high turbidity of the treated water. Another reason was due to the channeling that occurred through the filter. Channeling is the flowing of water up through the filter through a small area instead of uniformly through the total filter area. If the water flowed uniformly through the filter, the velocity was about 0.025 m/sec (0.08 ft/sec). This is equivalent to 2.1 liters/min per m<sup>2</sup> (0.6 gal/min per ft<sup>2</sup>) of filter area. However, with channeling, the velocities may be many times the normal velocities and this would permit the floc to pass through the filter sand and into the treated water storage area resulting in very turbid water.

Because of these problems, the sand filter material was removed to inspect the water chamber and to make changes. The excessive leakage was caused by the sagging of the floor between the bottom supports. The

original design was not rigid enough to support the load of water.

The water chamber floor was reinforced by placing wooden beams beneath the floor of the water chamber and the cracks were resealed. Bands were placed around the outside of the water chamber at three locations near the bottom to assist the unit in support against the lateral pressures caused by the water load.

In the installation of the system, the submersible pipe was connected rigidly to the PVC pipe leading to the unit. The motion of the pump caused by waves in the lake eventually caused the pipe to break. The line was repaired with a short segment of flexible Tygon tubing to eliminate the rigid connection.

A tee fitting was placed on the end of the raw water inlet line to split the entering raw water and reduce the velocity of the water entering the chamber. It was hoped this would stop the channeling action through the filter.

The sand filter was replaced and the unit was put back into operation. The unit operated for a time with varying degrees of success, but the results were never completely satisfactory. After four or five weeks the filter began channeling again resulting in turbid water in the treated water storage area.

In an effort to stop the channeling action, the sand filter was removed again and a four-fingered manifold installed on the raw water inlet line to distribute the entrance of the water over the entire water chamber instead of two concentrated points as the tee fitting did. The manifold extended the length and width of the water chamber cross-section. Holes 1.3 cm (0.5 in.) in diameter were drilled at even spacings along the length of each finger of the manifold to distribute the entering

water uniformly over the entire water chamber. Twenty-seven holes were used and the velocity of flow from each hole was about 0.2 m/sec (0.6 ft/sec).

A problem also occurred with backflushing. The solenoid valve, a globe-type valve, restricted the backflush flow too much. Thus, it was removed and a manually operated gate valve was installed. This improved the backflushing, but it now had to be done manually. This is not a severe limitation as the unit can be backflushed when the chlorine and alum stock solutions are replaced.

The unit had been backflushed just prior to the removal of the sand. However, there was a large enough sediment deposition around the backflushing intake manifold to obstruct the backflush flow. In an attempt to solve this, pressurized water was injected into the drain line in an effort to stir the sediment deposition and force the material into suspension so that the sediment would be removed satisfactorily.

The sand filter was again replaced but before the unit was put back into operation, a jar test was run on the raw water. The test indicated that the 20 mg/l. (20 ppm) alum concentration being used was too low. The tests indicated that 100 to 125 mg/l (100 to 125 ppm) was needed for optimum flocculation of the raw water. Thus, an alum concentration of 100 mg/l. (100 ppm) was used.

After these adjustments and changes were made, the unit was put back into operation. This point marks "Day of Operation Number One", the beginning of the data collected for presentation in this thesis.

A satisfactory quality of water was obtained during this period of operation. Also, the channeling action did not occur. This was the

only time this happened. The system operated satisfactorily for several days, then backflushing was determined to be necessary. The pressurized water was injected into the drain line for one minute, then turned off and the manual drain valve opened. This process was repeated until it appeared there were no more settled particles in the water chamber.

The use of the pressurized water in backflushing caused an area of the filter to begin channeling which had not before developed in this period. This prompted the discontinuation of the use of pressurized water. Instead, the submersible pump was turned on just before the backflushing period to help remove settled particles.

Several periods of operation followed but none with results like this first time. The channeling action continued. It was thought that the channeling action might be caused by floc particles clogging the under side of the screen and the lower few centimeters (inches) of the filter sand. As a result, a higher pressure was needed to move water through the filter. This pressure was great enough to start the channeling action. This idea was supported by the fact that when a hole was dug into the sand down to the screen, and then the sand replaced, the channeling action began in this area as soon as the water covered the filter.

Also, reducing the flow rate of water through the filter to stop the channeling was tried. A gate valve was installed in the raw water inlet line and was partially closed to decrease the water flow rate. However, the submersible pump developed so much head at this small flow rate that it broke the connection of the Tygon tubing in the raw water supply line.

### Leakage Test

Since it was evident, from wet areas on the concrete pad and water standing on the floor of the equipment room, that water was leaking from the water chamber, a test was run to determine the amount of water being lost. The test was run for 54 hours and 23 minutes beginning on the thirtieth day of operation. The amount of water lost was 0.2 liters/min (0.05 gal/min).

### Presentation of Data

Measurement made of the water flow rate out of the system indicated a simulated use rate of 4.3 liters/min (1.1 gal/min). This would be a daily supply of about 6100 liters/day (1610 gal/day). This would supply 90% of the demand of 12 people.

Data presented graphically in Figures 15 through 19 are values observed for turbidity, pH, conductivity, dissolved oxygen, and temperature during the entire operation of the unit. Data points connected by straight lines indicate a period of continuous operation. Points which are not connected indicate periods when the unit was not in operation.

Turbidity is the most noticeable parameter of water quality. The United States Public Health Drinking Water Standards (USPHD) gives a recommended limit of five turbidity units. The unit produced water below this level during the first period of continuous operation excluding the first day of operation. It was noted at each time the water level raised through the sand filter, the water above the filter was quite turbid. This usually disappeared by the time the first sample was taken. The values of turbidity during the period of operation varied from a

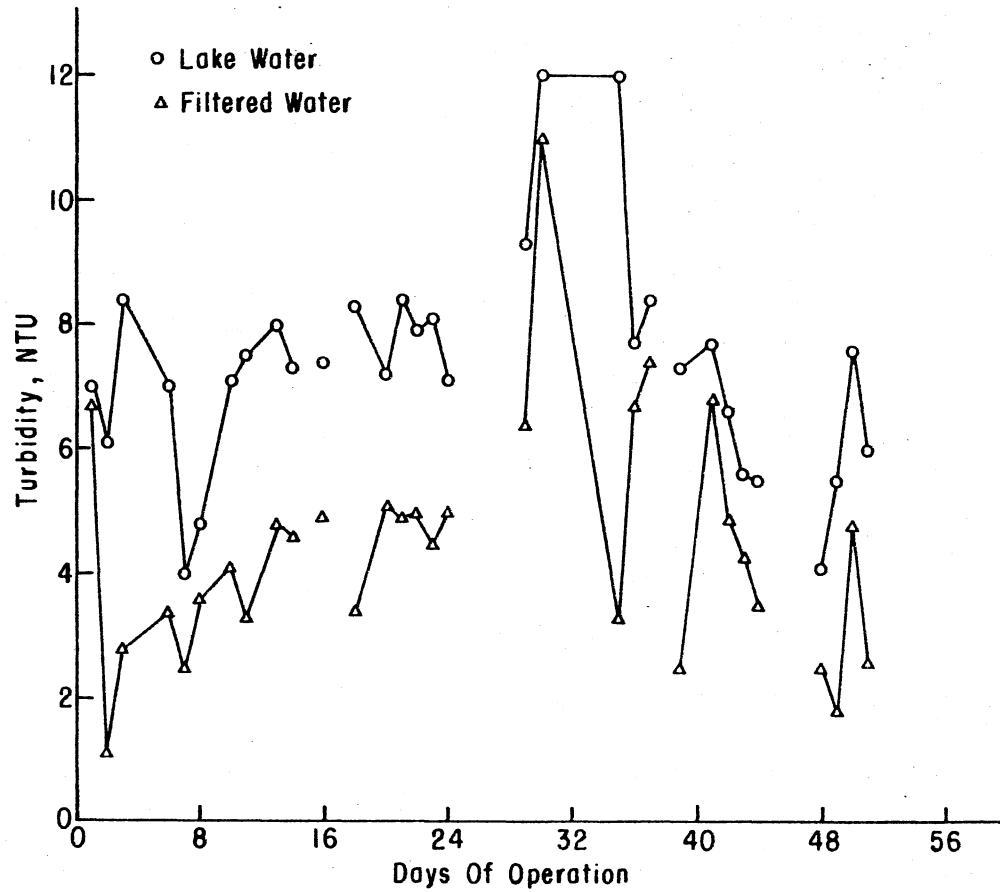


Figure 15. Turbidity Versus Days of Operation



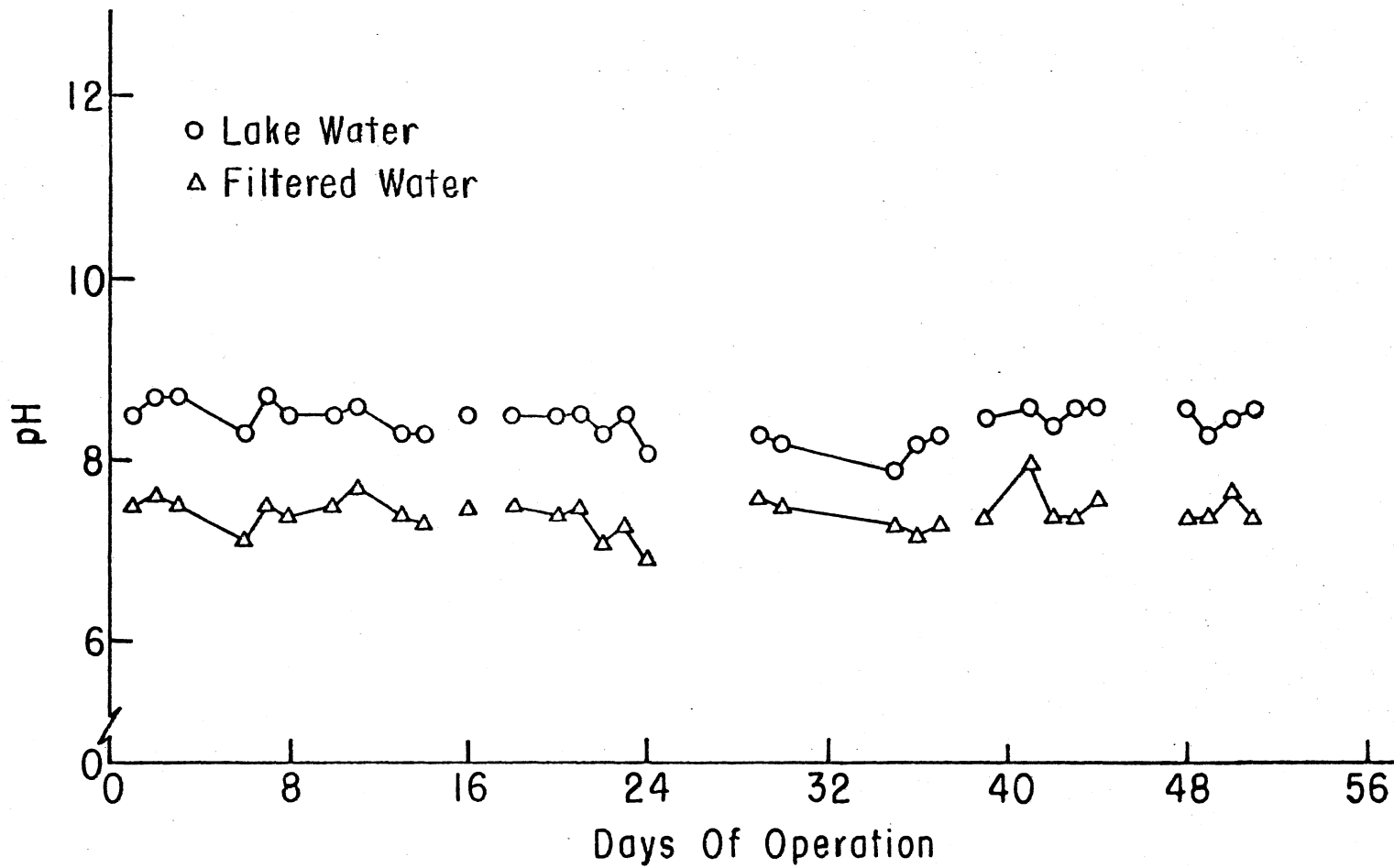


Figure 16. pH Versus Days of Operation

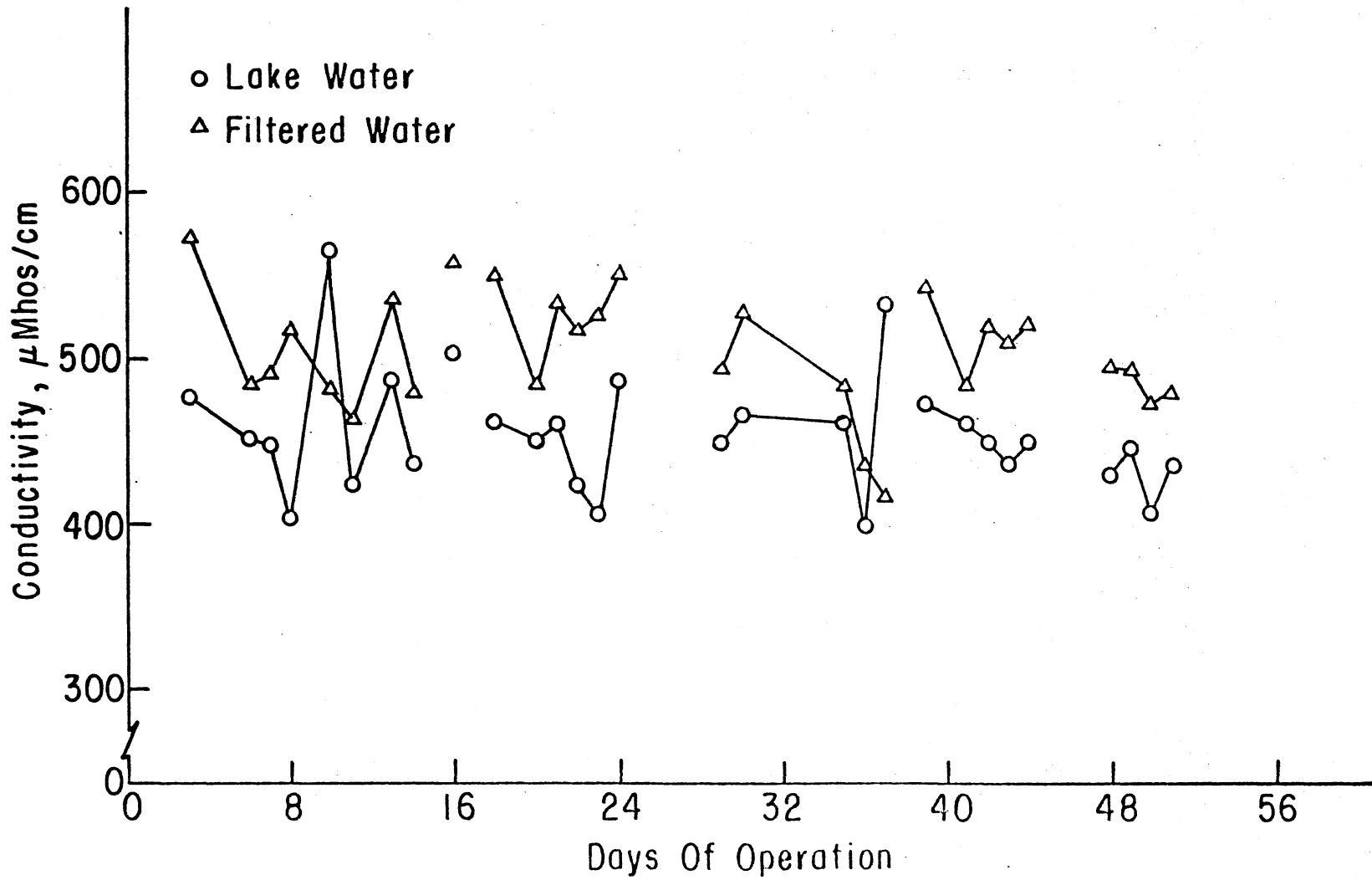


Figure 17. Conductivity Versus Days of Operation

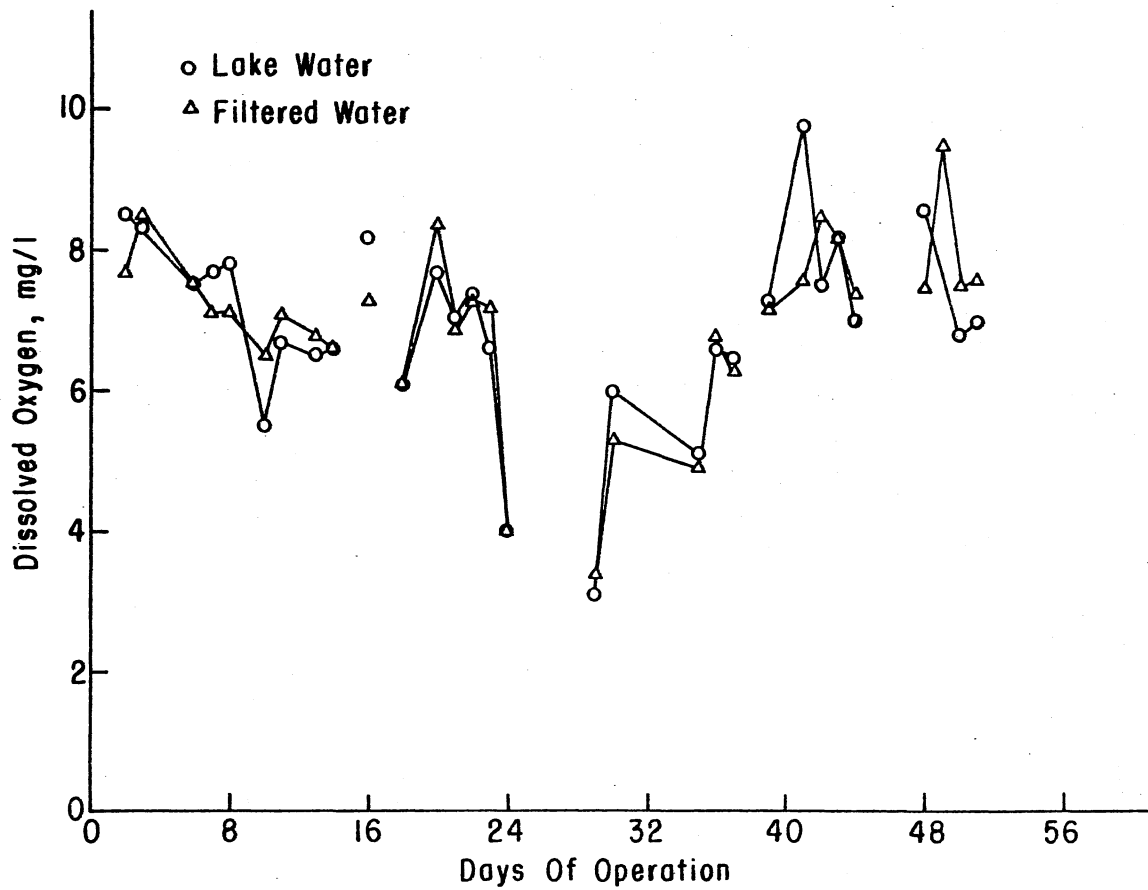


Figure 18. Dissolved Oxygen Versus Days of Operation

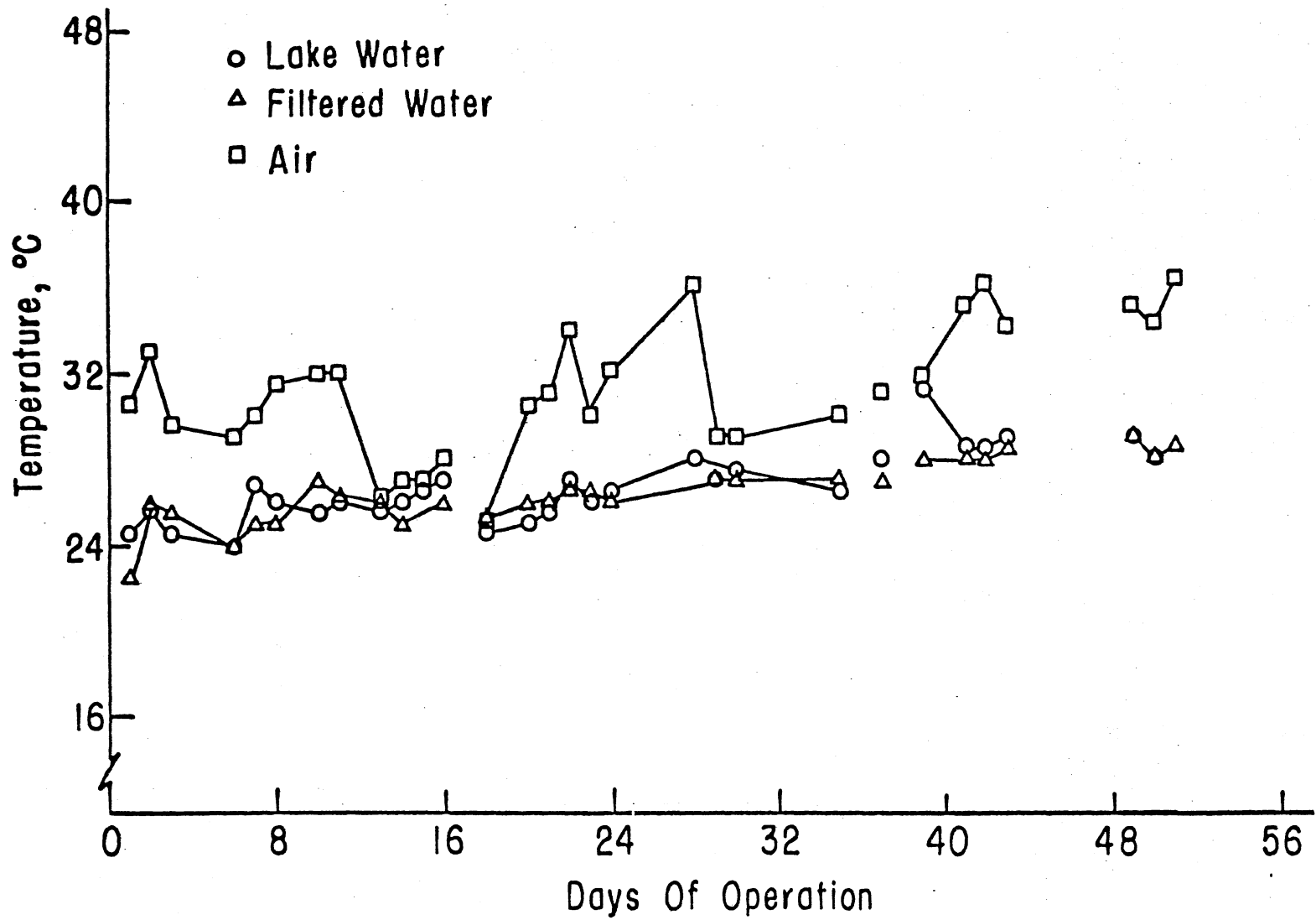


Figure 19. Temperature Versus Days of Operation

high of 11.0 NTU to a low of 1.1 NTU for the filtered water and from a high of 12.0 NTU to a low of 4.0 NTU for the raw water.

The pH of the lake water was consistently more basic than the pH of the filtered water. Values of pH ranged between 8.0 and 6.9 for the filtered water and between 8.7 and 7.9 for the raw water. The recommended range for pH is 7.0 to 10.6.

Values for conductivity were from 572 to 418  $\mu$ Mhos/cm for lake water.

Dissolved oxygen ranged between 9.5 and 3.4 mg/l for the filtered water and between 9.8 and 3.1 mg/l for the lake water at the time during the day the samples were taken.

Temperature of the filtered water, lake water, and air were between 22.5 and 29.0, 24.0 and 31.2, 25.0 and 36.0  $^{\circ}$ C, respectively, at the time during the day when the samples were collected. Samples were collected at approximately three o'clock in the afternoon.

Alkalinity was measured but due to the technique of analysis the validity of many of the values is questionable. The approximate values in which confidence is given for hydroxide, carbonate, and bicarbonate are 0, 0, 79-119 and 0, 0-6, 94-117 mg/l, respectively, for filtered and lake water.

The depth of water in Ham's Lake measured at the principle spillway varied between 3.4 and 3.1 meters (11.2 and 10.2 ft).

The filtered water was not analyzed for chlorine residual until the twenty-first day of operation because the chlorine comparator was not obtained until that time. After tests were started the total chlorine residual ranged between 2.4 and 4.8 mg/l and the free chlorine residual ranged between 0.1 and 0.2 mg/l.

On the seventh day of operation, water samples were collected and taken to the Soil and Water Service Laboratory in the Agronomy Department, Oklahoma State University, and to the County Health Department for their analysis. The results from the Soil and Water Service Laboratory are presented in Table III and results from the Department of Health in Table IV. Also, the Department of Health reported their finds on the bacteria samples. The total coliform found in the raw water was over 200 coliform/100 ml. This was the limit which was actually counted and an indication was given that there were more than this. In the filtered water, the total coliform found was 65 coliform /100 ml. This was with a chlorine treatment of two mg/l, but equipment was not yet available to determine the chlorine residuals. Once this result was found, the chlorine treatment was increased although no more bacterial analysis was made.

TABLE III  
HOUSEHOLD WATER ANALYSIS REPORT

Constituents	Filtered Water (mg/l)	Lake Water (mg/l)
Calcium	32.5	31.9
Magnesium	21.5	21.5
Sodium	27.0	23.0
Chlorides	24.9	30.2
Sulphates	66.0	36.0
Nitrates	4.4	4.4
Total Dissolved Solids	330.0	293.7
pH	8.2	8.5
Hardness expressed as $\text{CaCO}_3$	170.0	170.0

TABLE IV  
OKLAHOMA STATE DEPARTMENT OF HEALTH  
WATER SUPPLY ANALYSIS REPORT

Constituents	Filtered Water (mg/l)	Lake Water (mg/l)
Calcium Hardness as $\text{CaCO}_3$	84	101
Total Hardness as $\text{CaCO}_3$	241	226
Chloride	35	35
Sulfate as $\text{SO}_4$	35	45
Nitrate as N	0.28	0.13
pH	7.70	8.00
Total Alkalinity	124	147
Total Iron	0.05	0.01

## CHAPTER VI

### SUMMARY AND CONCLUSIONS

#### Summary

This project was initiated to develop an outdoor pond water treatment unit and evaluate the performance of the unit on a typical household using pond or lake water as the source.

An automated pond water treatment unit was designed, constructed, and evaluated. The testing was performed at Ham's Lake, a Soil Conservation Service flood prevention structure located west of Stillwater, Oklahoma. Initial operation of the unit showed that modifications were needed to improve the performance of the unit. These modifications were made and operation continued. A major problem encountered in this research was the channeling action of the sand filler. This problem greatly affected the turbidity of the finished water. For a short period of operation, the problem of channeling did not occur, but complications arose which degraded this performance and the channeling continued.

While the unit was operating, several water samples were taken and analyzed. These defined the water quality parameters. The effectiveness of the system was then determined from results of these analyses.



## Conclusions

1. Effects of chemical treatment of the water were evident from observing floc particles and the reduction of coliform bacteria in the water analysis.

2. Although some effectiveness was noted by the chlorine, coliform bacteria were present in the treated water which made it unfit for consumption. Other bacterial tests were needed after the chlorine rate was increased.

3. Channeling of the filter media increased the turbidity of the finished water.

4. The system provided water at the rate of 4.3 liters/min or 6100 liters/day, which will supply 90% of the demand of 12 people.

5. Leaking occurred from the wooden water chamber at a rate of 0.2 liters/min.

6. The globe type valve in the water chamber drain caused an unsatisfactory backflushing operation.

7. The injecting of pressurized water into the drain line to aid in backflushing proved unsatisfactory.

## Suggestions for Future Research

1. Modify the design so that the lower portion of the water chamber is accessible without removal of the filter media.

2. Test the system on a lake which has higher turbidity.

3. Operate the system with an artificial filter material in place of the sand.

4. Use a metal or plastic tank for the water chamber.

5. Slope the bottom of the water chamber to aid the backflushing.
6. Adjust the chlorine metering rate to obtain a free chlorine residual.
7. Vary the outflow from the system to more closely simulate household use patterns.

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APPENDIX A

CONSTRUCTION PLANS FOR FILTER UNIT

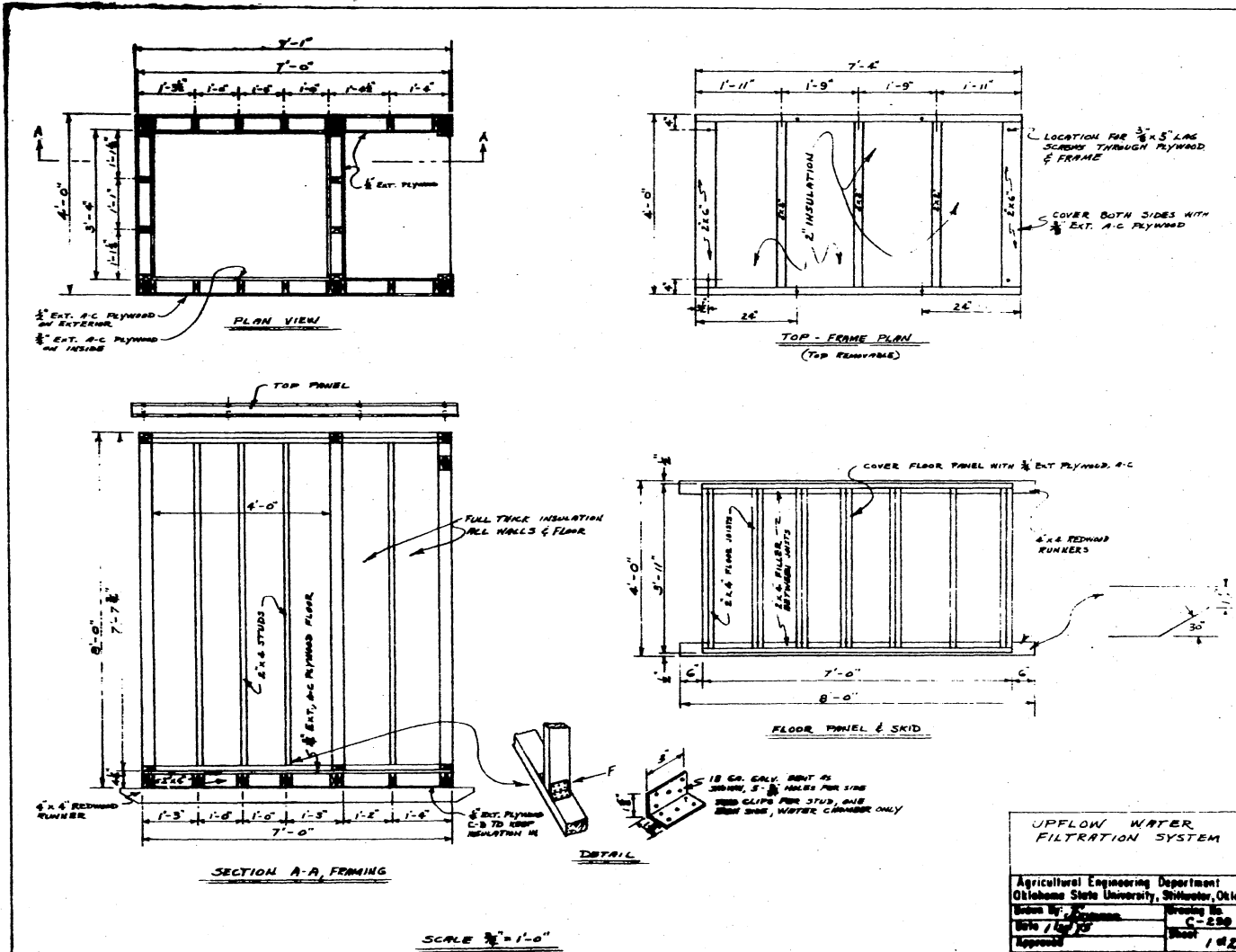


Figure 20. Construction Drawing for Water Treatment Unit



**APPENDIX B**

**WATER ANALYSIS DATA**

TABLE V  
 WATER ANALYSIS DATA OBTAINED AT THE AGRICULTURAL  
 ENGINEERING LABORATORY

Days of Operation (Days)	Conductivity ( $\mu$ mhos/cm)		Dissolved Oxygen (mg/l)		pH		Turbidity (NTU)		Temperature (°C)		
	Lake	Filter	Lake	Filter	Lake	Filter	Lake	Filter	Lake	Filter	Air
1	---	---	---	---	8.5	7.5	7.0	6.7	24.5	22.5	30.5
2	---	---	8.5	7.7	8.7	7.6	6.1	1.1	25.6	26.0	33.0
3	477.0	572.0	8.3	8.5	8.7	7.5	8.4	2.8	24.5	25.5	29.5
6	452.0	485.0	7.5	7.5	8.3	7.1	7.0	3.4	24.0	24.0	29.0
7	448.0	491.0	7.7	7.1	8.7	7.5	4.0	2.5	26.8	25.0	30.0
8	403.0	518.0	7.8	7.1	8.5	7.4	4.8	3.6	26.0	25.0	31.5
10	565.0	482.0	5.5	6.5	8.5	7.5	7.1	4.1	25.5	27.0	32.0
11	424.0	464.0	6.7	7.1	8.6	7.7	7.5	3.3	26.0	26.3	32.0
13	488.0	537.0	6.5	6.8	8.3	7.4	8.0	4.8	25.5	26.0	26.0
14	437.0	480.0	6.6	6.6	8.3	7.3	7.3	4.6	26.0	25.0	27.0
15	---	---	---	---	---	---	---	---	26.5	---	27.0
16	504.0	558.0	8.2	7.3	8.5	7.5	7.4	4.9	27.0	26.0	28.0
17	---	---	---	---	---	---	---	---	---	---	---
18	463.0	552.0	6.1	6.2	8.5	7.5	8.3	3.4	24.5	25.2	25.0
20	451.0	485.0	7.7	8.4	8.5	7.4	7.2	5.1	25.0	26.0	30.5
21	462.0	535.0	7.0	6.9	8.5	7.5	8.4	4.9	25.5	26.0	31.0
22	424.0	518.0	7.4	7.3	8.3	7.1	7.9	5.0	27.0	26.5	34.0
23	406.0	527.0	6.6	7.2	8.5	7.3	8.1	4.5	26.0	26.5	30.0
24	488.0	551.0	4.0	4.0	8.1	6.9	7.1	5.0	26.5	26.0	32.0
28	---	---	---	---	---	---	---	---	28.0	---	36.0
29	450.0	495.0	3.1	3.4	8.3	7.6	9.3	6.4	27.0	27.0	29.0
30	467.0	528.0	6.0	5.3	8.2	7.5	12.0	11.0	27.5	27.0	29.0
35	462.0	484.0	5.1	4.9	7.9	7.3	12.0	3.3	26.5	27.0	30.0
36	399.0	436.0	6.6	6.8	8.2	7.2	7.7	6.7	---	---	---
37	534.0	418.0	6.5	6.3	8.3	7.3	8.4	7.4	28.0	27.0	31.0
38	---	---	---	---	---	---	---	---	---	---	---
39	474.0	544.0	7.3	7.2	8.5	7.4	7.3	2.5	31.2	28.0	31.8
41	462.0	484.0	9.8	7.6	8.6	8.0	7.7	6.8	28.5	28.0	35.0
42	450.0	521.0	7.5	8.5	8.4	7.4	6.6	4.9	28.5	28.0	36.0
43	437.0	510.0	8.2	8.2	8.6	7.4	5.6	4.3	29.0	28.5	34.0
44	450.0	521.0	7.0	7.4	8.6	7.6	5.5	3.5	---	---	---
45	---	---	---	---	---	---	---	---	---	---	---
48	430.0	495.0	8.6	7.5	8.6	7.4	4.1	2.5	---	---	---
49	447.0	493.0	---	9.5	8.3	7.4	5.5	1.8	29.0	29.0	35.0
50	407.0	474.0	6.8	7.5	8.5	7.7	7.6	4.8	28.0	28.0	34.0
51	437.0	480.0	7.0	7.6	8.6	7.4	6.0	2.6	---	28.5	36.0



TABLE V (Continued)

Days of Operation (Days)	Chemical Feeder Setting		Faucet Setting (Notch)	Change in Value Over Operation Interval					Chemical Feed Rate		Percent of Time Pumps Operate	
				Actual Time (min)	Pressure Pump (min)	Submersible Pump (min)	Alum Level (cm)	Chlorine Level (cm)	Alum (ml/min)	Chlorine (ml/min)	Pressure	Submers.
1	8.5	4.5	4.0	1414.0	35.0	75.0	3.5	1.9	76.7	41.7	2.5	5.3
2	8.5	4.5	4.0	1424.0	60.0	130.0	5.7	3.2	72.2	40.1	4.2	9.1
3	8.5	4.5	4.0	4405.0	269.0	579.0	26.4	14.9	74.8	42.3	6.1	13.1
6	8.5	4.5	4.0	1432.0	69.0	153.0	6.0	3.8	64.9	40.9	4.8	10.7
7	8.5	4.5	4.0	---	---	---	---	---	---	---	---	---
8	8.5	4.5	4.0	---	---	---	---	---	---	---	---	---
10	8.5	4.5	4.0	1441.0	163.0	218.0	8.9	5.7	66.9	43.0	11.3	15.1
11	8.5	4.5	4.0	1466.0	240.0	530.0	24.1	14.9	74.7	46.3	16.4	36.2
13	8.5	4.5	4.0	1405.0	147.0	300.0	13.3	---	73.0	---	10.5	21.4
14	8.5	4.5	4.0	---	---	---	---	---	---	---	---	---
15	8.5	8.5	---	1440.0	210.0	442.0	19.4	20.3	72.0	75.5	14.6	30.7
16	8.5	8.5	4.0	---	---	---	---	---	---	---	---	---
17	8.5	8.5	4.0	1219.0	95.0	246.0	10.8	10.8	72.0	72.0	7.8	20.2
18	8.5	8.5	4.0	1541.0	225.0	490.0	21.0	21.6	70.2	72.3	14.6	31.8
20	8.5	8.5	4.0	---	---	---	---	---	---	---	---	---
21	8.5	8.5	4.0	1440.0	130.0	275.0	12.4	12.7	74.0	75.8	9.0	19.1
22	8.5	8.5	4.0	1410.0	95.0	235.0	10.2	10.2	71.0	71.0	6.7	16.7
23	8.5	8.5	4.0	1425.0	160.0	320.0	14.6	14.6	74.9	74.9	11.2	22.5
24	8.5	8.5	4.0	---	---	---	---	---	---	---	---	---
28	8.5	10.0	4.0	1383.0	125.0	265.0	11.1	12.1	68.9	74.7	9.0	19.2
29	8.5	10.0	4.0	---	---	---	---	---	---	---	---	---
30	8.5	10.0	4.0	2541.0	267.0	548.0	18.4	26.0	55.2	78.0	10.5	21.6
35	8.5	10.0	4.0	1350.0	165.0	360.0	17.8	16.8	81.1	76.8	12.2	26.7
36	8.5	10.0	4.0	1410.0	175.0	370.0	14.6	17.8	64.8	78.9	12.4	26.2
37	8.5	10.0	4.0	---	---	---	---	---	---	---	---	---
38	---	---	---	1206.0	95.0	245.0	9.2	11.1	61.8	74.5	7.9	20.3
39	8.5	10.0	4.0	---	---	---	---	---	---	---	---	---
41	8.5	10.0	4.0	1395.0	130.0	290.0	10.2	14.3	57.5	81.0	9.3	20.8
42	8.5	10.0	4.0	1440.0	130.0	285.0	12.7	12.7	73.2	73.2	9.0	19.8
43	8.5	10.0	4.0	1440.0	135.0	285.0	12.4	13.3	71.4	76.8	9.4	19.8
44	8.5	10.0	4.0	---	---	---	---	---	---	---	---	---
45	5.0	5.0	3.0	4335.0	135.0	330.0	10.8	7.6	53.7	37.9	3.1	7.6
48	5.0	5.0	2.0	1395.0	15.0	50.0	1.9	2.5	62.5	83.4	1.1	3.6
49	5.0	5.0	4.0	1450.0	130.0	300.0	8.9	11.4	48.6	62.5	9.0	20.7
50	5.0	5.0	4.0	1460.0	60.0	165.0	5.7	4.8	56.9	47.5	4.1	11.3
51	5.0	5.0	3.0	---	---	---	---	---	---	---	---	---

TABLE V (Continued)

Days of Operation (Days)	Level Lake (M)	Chlorine Residual (mg/l)		Alkalinity (mg/l)					
		Total	Free	Hydroxide	Lake Carbonate	Bicarbonate	Hydroxide	Filter Carbonate	Bicarbonate
1	3.4	---	---	---	---	---	---	---	---
2	---	---	---	---	---	---	---	---	---
3	---	---	---	---	---	---	---	---	---
6	---	---	---	---	---	---	---	---	---
7	---	---	---	---	---	---	---	---	---
8	---	---	---	---	---	---	---	---	---
10	---	---	---	---	---	---	---	---	---
11	---	---	---	0	4	112	0	0	105
13	---	---	---	0	0	94	0	0	79
14	---	---	---	---	---	---	---	---	---
15	---	---	---	---	---	---	---	---	---
16	---	---	---	---	---	---	---	---	---
17	---	---	---	---	---	---	---	---	---
18	---	---	---	0	4	113	0	0	101
20	---	---	---	0	6	110	0	0	99
21	---	2.0	0.2	---	---	---	---	---	---
22	---	3.0	0.2	---	---	---	---	---	---
23	3.3	3.0	0.2	---	---	---	---	---	---
24	3.3	3.0	0.2	---	---	---	---	---	---
28	3.3	---	---	---	---	---	---	---	---
29	3.3	4.0	0.2	---	---	---	---	---	---
30	---	3.0	0.2	---	---	---	---	---	---
35	---	---	---	---	---	---	---	---	---
36	---	4.0	0.2	---	---	---	---	---	---
37	3.2	4.0	0.2	---	---	---	---	---	---
38	---	---	---	---	---	---	---	---	---
39	---	3.0	0.2	---	---	---	---	---	---
41	---	---	---	---	---	---	---	---	---
42	3.2	4.8	0.4	---	---	---	---	---	---
43	3.1	4.8	0.4	---	---	---	---	---	---
44	3.1	4.0	0.2	---	---	---	---	---	---
45	3.2	---	---	---	---	---	---	---	---
48	3.2	2.4	0.1	---	---	---	---	---	---
49	3.2	---	---	---	---	---	---	---	---
50	3.1	4.0	0.2	---	---	---	---	---	---
51	3.1	3.0	0.2	---	---	---	---	---	---

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VITA

Larry Don Jarrell

Candidate for the Degree of

Master of Science

Thesis: AN AUTOMATIC UPFLOW WATER FILTRATION SYSTEM

Major Field: Agricultural Engineering

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