12-1959

A surface water treatment system for rural homes and farmsteads

Edward B. Hale

To the Graduate Council:

I am submitting herewith a thesis written by Edward B. Hale entitled "A surface water treatment system for rural homes and farmsteads." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

C. W. Bockhop, Major Professor

We have read this thesis and recommend its acceptance:

C. H. Shelton, Henry Andrew

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

December 9, 1959

To the Graduate Council:

I am submitting herewith a thesis written by Edward B. Hale entitled "A Surface Water Treatment System For Rural Homes and Farmsteads". I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

C W Bockhop
Major Professor

We have read this thesis
and recommend its acceptance:

C. H. Shelton

Henry Andrews

Accepted for the Council:

Dale Wantling
Dean of the Graduate School

2r
33

A SURFACE WATER TREATMENT SYSTEM FOR RURAL HOMES AND FARMSTEADS

A THESIS

Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

by

Edward B. Hale

December 1959

ACKNOWLEDGEMENT

The author wishes to express appreciation to Dr. C. W. Bockhop, Head of the Agricultural Engineering Department and Major Professor for his untiring support, guidance and encouragement.

The guidance and counciling of the other committee members, C. H. Shelton, Assistant Professor, Agricultural Engineering and Henry Andrews, Assistant Professor, Agronomy, were extremely helpful in the development of the project and thesis.

The author thanks E. J. Chapman, Superintendent of the Middle Tennessee Agricultural Experiment Station, and his staff for their cooperation in providing facilities and assistance in building and testing the experimental water supply unit.

The excellent cooperation of the Sanitary Engineering Division of the Tennessee Department of Public Health through its director, Julian Fleming and his staff in the development and testing of this water treatment system is wholeheartedly appreciated.

The author thanks Dr. Webster Pendergrass, Dean of the College of Agriculture, Dr. Vernon W. Darter, Director and Mr. E. C. McReynolds, Associate Director, respectively of the Agricultural Extension Service, for allowing the time to complete these studies.

Appreciation is expressed to the many other staff members of the Agricultural Engineering Department, The College of Agriculture and The University of Tennessee for their guidance and support.

Miss Bonnie Estes' diligent efforts in typing this thesis are appreciated.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

CHAPTER I

INTRODUCTION

A. General

The demand for larger supplies of potable water for farms and rural homes has increased considerably in recent years. Wells and springs with low flows, and cisterns no longer are able to meet the daily requirements of modern farms and households. Many rural residents in Tennessee haul water, sometimes many miles, during drought periods and have to ration themselves even in periods of greater than average rainfall.

Increased household use of water has been brought about by benefits and uses derived from having an automatic water system which must supply bathrooms, automatic washing machines, dishwashers and many other household needs and equipment.

Modern technology in farm operation has necessitated increased quantities and quality of water. Modern Grade A dairies require relatively large quantities of clean water for washing equipment, caring for cows and cleaning the milking barn. Large scale integrated poultry and hog enterprises are requiring quantities of clean water for production and for prevention of disease. Many farmers are now processing their products on the farm, thus requiring safe water in varying quantities depending on their operation.

B. Statement of the Problem

The only objective of research work upon which this thesis is based was to design, construct, and test a water treatment system to utilize surface water sources to meet the demands for rural domestic and farmstead water. The system would provide an adequate supply of potable water for a family of five and maintain sanitary conditions for milking a herd of thirty cows. It is anticipated that the cows could be supplied water for drinking. The daily family needs would be fifty gallons per person or a total of two-hundred-fifty gallons (20). Approximately four-hundred-fifty gallons of water would meet the daily needs for cleaning the dairy utensils and the milking barn.

The initial investment in the water treatment system should be reasonable. For any given situation, the justification would depend upon the need and the availability of other sources or methods of obtaining potable water.

Operating costs should be in line with other methods of obtaining potable water.

The amount of attention necessary to keep this system in operation should be held to a minimum. No more than weekly visits to the system with a total attention time of not more than one and one-half hours per month should be necessary.

C. Importance of the Study

Many of the present sources of water are inadequate to meet the needs. Many more will become inadequate in the future as these and other needs increase.

Ground water from wells and springs has been our major source of rural domestic water since Tennessee was settled by the white men. The only physiographic region in Tennessee where a dependable supply of good ground water may almost always be found is West Tennessee extending as far east as the western Highland Rim (30). The only other region which approaches this quantity is the East Tennessee Valley where adequate supplies of domestic water may be secured from springs and wells in most areas (23). Figure 1 shows these regions and their relative availability of ground water.

The area of most critical ground water supply is the central basin where many wells cease to produce during drought conditions (28, 19). The water is usually located in limestone fissures and drilling may produce no water at all or yields of less than five gallons per minute. If water is not found near the surface, some wells have been drilled into the Knox dolomite formation lying from 400 to 1200 feet below the surface. This aquifer usually yields less than ten gallons per minute for any one well. A good example is the well drilled in 1956, on the Middle Tennessee Agricultural Experiment Station, Spring Hill, Tennessee, which yielded two gallons per minute at the bottom of the 1142 foot well.

Another area of deficient water supply is the Cumberland Plateau where wells are relatively shallow but produce little water, many of which will not yield more than fifty gallons at one pumping (1, 17). Farm ponds provide the major source of livestock water in this area.

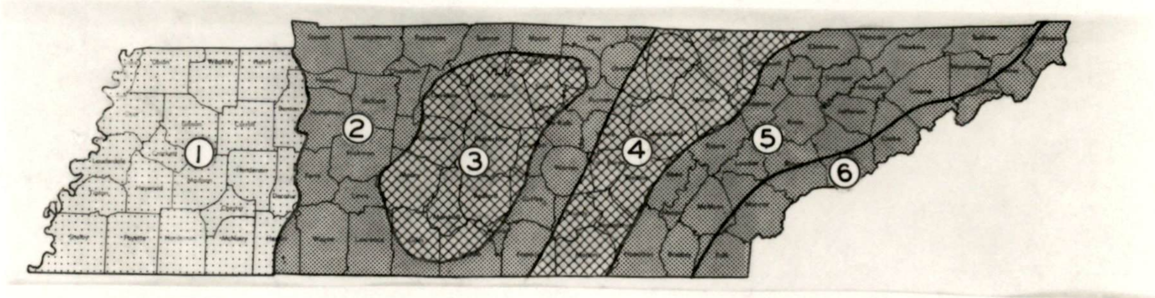
The Highland Rim area produces fair quantities of domestic water from wells but often high sulfur or iron content makes the water undesirable. Farm ponds are also a major source of livestock water in this area. Cisterns are used extensively in the high mineral content areas (28, 19, 1, 17).

The 1954 Census of Agriculture showed that only 36 per cent of Tennessee farms had piped running water (29). Estimates, as of 1959, indicate that not more than 50 per cent of Tennessee farm families have running water. It is felt that these low percentages are due in part to the lack of development of adequate potable water sources in areas of ground water deficiency.

It is evident that sources other than ground water need to be developed for farmstead and domestic use. Surface water appears to offer the best future source since Tennessee is located in an area of comparatively high rainfall. Average annual rainfall for the state is 51.4 inches with station averages ranging from 42.21 inches to 60.48 inches (5, 22). The average annual rainfall for the Central Basin and the Cumberland Plateau is about the same as the state average.

Figure 1. AVAILABILITY OF GROUND WATER IN TENNESSEE

(1) GULF COASTAL PLAIN	(4) CUMBERLAND PLATEAU
(2) HIGHLAND RIM	(5) EAST TENNESSEE VALLEY
(3) CENTRAL BASIN	(6) BLUE RIDGE



LEGEND

- LARGE QUANTITIES, GENERALLY AVAILABLE
- MODEST QUANTITIES, SOME AREAS
- SMALL QUANTITIES, USUALLY UNCERTAIN

Since there are no streams flowing in dry weather in many of the water deficient areas, ponds depending primarily on surface runoff offer the best water source.

The driest year on record in Tennessee was 1941, when an average of only 37.86 inches of rainfall was recorded (5, 22). The town of Halls, located in West Tennessee near the Mississippi River recorded only 25.23 inches of rainfall that year and had a period of seven consecutive months beginning in the Fall of 1940 in which no appreciable runoff could be expected. Other stations in Tennessee had periods of ten consecutive months when no large runoff could be expected.

Storage in farm ponds would have to be provided to cover any period of insufficient runoff. For example, a family using 250 gallons of water daily would require 75,000 gallons in a ten month period. Most farms would require at least twice that amount to meet minimum needs. Storage capacity in a farm pond should be more than twice the average annual water use to offset losses such as evaporation and seepage.

D. Definition of Terms (Used in a Particular Sense)

Aquifer - A water-bearing strata in the earth.

Coagulation - The formation of an insoluble gelatinous flocculent precipitate which entrains suspended and colloidal matter (2).

Coliform Bacteria - A bacteria present in the intestinal tract of man and animals which is closely related to the intestinal pathogens; typhoid and dysentery.

Droughts - Periods during which precipitation is less than 85 per cent of mean (2).

Effective Size of Sand- The size of grain in a sample of sand such that ten per cent, by weight, of the sample has grains smaller than this size (2).

Flocculation - The agglomeration of the particles of floc into masses of sufficient weight and bulk in order that they may settle readily.

Manometer - A device for measuring the difference in pressure head.

Orifice - A small opening or aperture which may be used to control the rate of flow of a fluid.

Prechlorination - The addition of a relatively large dosage of chlorine to untreated water to kill algae and bacteria and oxidize minerals in order that the precipitates may be removed by filtration.

Rapid Sand Filter - A device for the purification of water consisting of a layer of sand through which water is filtered at a more rapid rate than the slow sand filter, the filter being cleaned by reversing the flow of water through the sand.

Schmutzdecke - The surface layer of a filter containing a zoogloeal jelly which is largely responsible for bacteria removal in a slow sand filter.

Slow Sand Filter - A device for the purification of water consisting of a layer of sand through which water is filtered at a relatively slow rate, the filter being cleaned by scraping a thin layer of dirty sand from the surface (2).

Uniformity Coefficient of Sand - The ratio of the size of grain in the sample such that sixty per cent, by weight, of the sand has smaller grains, to the effective size (2).

E. Scope of the Study

It was decided to design, construct and test a single type of water treatment system to determine its effectiveness in meeting the objectives previously mentioned. It was anticipated that, from the results of testing this system, recommendations for improvements in equipment, methods and procedures could be made.

Since it was anticipated that approximately two months time would be required to test each treatment, it was decided to test only those treatments which are commonly used in commercial or municipal water treatment systems and compare them with minimum treatments.

Since the primary objective of the study was to develop a method of providing an adequate supply of potable water from surface sources for rural homes and farmsteads, tests were conducted on water samples to determine whether the treated water met the specifications for safe water as set forth by the Tennessee Department of Public Health.

Since minimum attention to the system is necessary where individual domestic water supplies are concerned, tests were set up to determine the operating time of the filter prior to its need for cleaning.

This study will represent only the results of testing one type of system at one location using a limited number of treatments. However, the results should be applicable to water supplies under similar conditions.

CHAPTER II

REVIEW OF LITERATURE

A. General

A limited number of studies have been made on the treatment of pond water for domestic purposes. Esmay et al. (10), Sorrels (25) and Daniels (6) seem to be the only ones to have made detail studies of the problem. Several others including Baumann (3), Brakensiek (4) and Hodges (13) have made investigations of special phases of the problem. Others have approached the problem in terms of municipal types of systems (21).

B. Domestic and Farmstead Water Demands

Many authors have established recommendations on the water in the home and around the farmstead (20, 3, 13, 21, 14, 24, 12). The general consensus of this group indicated that the daily use of water where adequate supplies are available under pressure should be estimated on the following basis:

50 gallons per person

35 gallons per milking cow

12 gallons per dry cow, beef cow or horse

4 gallons per hog

2 gallons per sheep

4 gallons per one hundred hens

C. Ponds

Farm ponds are generally classified into three groups (11):

(a) Spring-fed. - This type of pond receives water continuously from above or in the pond.

(b) Surface runoff-fed. - This type of pond receives practically all of its water from surface runoff from its watershed.

(c) By-pass-fed. - This type of pond receives water diverted from the main flow of the stream.

Storage capacity in the pond should be sufficient to supply the farm and home needs for at least four months (11) and preferably up to ten months (5) without appreciable replenishment from run off. Brakensiek (4) indicated that most watersheds can be expected to produce no runoff when the annual precipitation falls below approximately twenty-two inches. Thirty inches of annual rainfall would be expected to yield six inches of runoff and fifty inches annually would yield twenty-two inches of runoff (11, 4). Using this as a basis, it could be expected that a watershed in Tennessee would yield a minimum of 150,000 gallons of water per acre per year. The pond should be at least eight feet deep over at least one third of its area so that evaporation losses may be held at a minimum (3). The losses by evaporation and seepage should be considered greater than the quantity of water retained in storage.

Plant and algae growth are problems in many ponds which may be overcome by various methods of treatment (27).

D. Water Purification Methods

Rapid-sand filters are successful for filtering pond water if proper flocculation and coagulation are obtained prior to filtration (3). However, the need for constant attention makes them of little value to rural users with water sources having turbid water conditions. The problems in maintaining this type of unit are the need for chemical coagulation and frequent backwashing.

Slow-sand filters of various types are recommended by various state extension services, experiment stations, health departments and others (13, 21, 18, 26, 7, 16, 8, 24). Apparently none of these recommendations is based on controlled experiments. One type of filter consists of a sand trench leading from the bottom of the pond to a cistern at the edge of the pond (10, 18, 3). The problem involved with this type of filter system is the difficulty of removing the layer of sediment which forms over the surface of the filter in the pond. Another difficulty is the lack of control of the filtration rate which might be excessive if the cistern were pumped too low, thus pulling turbidity into the cistern.

The recommended filtering rate for slow sand filters varies considerably, ranging principally from twenty-five to seven gallons per square foot per day (21, 10, 14, 13, 2). Babbitt *et al.* (2) suggest satisfactory filtering up to one-hundred-seventy gallons per square foot per day, however, Esmay et al. (10) state that their tests indicate the maximum rate for pond water to be sixty-nine gallons per square foot per day.

The effective sand size and its coefficient of uniformity are of apparent importance in slow sand filters. Recommendations for effective sand size range from 0.20 to 0.50 millimeters (10, 13, 14). Esmay (10) reported that excessive turbidity was run through the filter sand when the size exceeded 0.35 millimeters. The recommended coefficient of uniformity should not be more than 2.5 according to Hodges (13) or 3.0 according to Esmay (10). Recommended sand thickness ranged from twelve inches (28) to thirty inches (21).

When the surface of the slow sand filter becomes clogged with sediment, the filter must be cleaned by removing the layer of dirty sand. The filter operating time ranges from that which will allow from five-hundred to thirty-five-hundred gallons of water per square foot of filter surface to pass through the filter between cleanings (3) depending upon turbidity and algae in the raw water.

Slow sand filters which are operated properly may be expected to remove 98 per cent or more of the total bacteria in the water (2, 3). However, slow sand filters do not always consistently produce water which is safe (31, 3); hence, the need for additional treatment such as chlorination as a method of disinfection exists.

Turbidity removal is one of the major problems involved in treating pond water. New ponds have high turbidity before a good vegetative cover can be established. Hodges (13) indicated that water which has twenty to twenty-five parts per million turbidity is satisfactory for filtering; thus, requiring some pretreatment for new ponds or ponds whose turbidity exceeded these figures. Esmay (10) reports the results of a study of twenty ponds whose turbidities ranged from eleven to forty-one parts per million turbidity. He also reports that highly turbid ponds were treated with twelve pounds of gypsum per 1000 cubic feet of water to reduce the turbidity level to below twenty parts per million.

CHAPTER III

SELECTION OF WATER TREATMENT SYSTEMS

A number of different designs have been developed for farm pond water treatment systems. Each of these designs appeared to have limitations which would make them somewhat less desirable than might be expected.

A slow sand filter has been selected in most instances by state colleges and health departments as the most practical method of filtering surface water for individual farm or home use. This type of filtration was selected for this study because of several factors. Babbitt and Doland (2) said that a slow sand filter is highly efficient in the removal of bacteria; being reliable for the removal of 98 to 99 per cent of the bacteria in raw water. They also pointed out that slow sand filters require less attention and less skilled operators. The slow, sand filter is also suppose to remove suspended and settleable matter not collected in the settling basin.

Since most septic tanks are now precast and delivered to the user ready for installation, it was felt that there was a good possibility of using these tanks as the basic units of the farm water treatment system. If the demand for these filtering systems should increase to a point where it would be feasable, manufacturers of septic tanks could develop forms for precasting the water treatment tanks since there is no basic difference except the location and size of holes for pipe connections. These tanks could be delivered to the farm for probably less than the farmer could make his own cast-in-place system. All that would be required would be that the user have a foundation on which to set the tanks.

An objection to most cast-in-place systems is the common walls between the various units of the system having different levels of cleanliness. This objection is overcome by the use of separate pre-cast tanks. Since septic tanks are usually available in only two sizes, it may become necessary to use multiple units for some of the operations.

There is a possibility of standardization of the plan whereby complete kits of the necessary materials could be made available to the user. Pipes could be pre-cut and threaded, proper pipe fittings, control devices, intake pump, pressure tank, raw water intake, chlorinator and other necessary equipment could be included in the complete kit. The user would have to provide a foundation which is constructed to specifications and an enclosing structure. It is, of course, possible that the entire unit could be installed by a contractor.

CHAPTER IV

FACILITIES

A. Selection and Description of Site

The Middle Tennessee Agricultural Experiment Station was selected as the site for testing the water treatment system due to its location in an area of ground water deficiency, its relative proximity to facilities of the Tennessee Department of Public Health in Nashville and the availability of ponds on the station. The 8.6 acre pond was selected because there was little chance that it would go dry, it had sources of contamination, electricity was available, and a pipeline to stock watering troughs was near.

The 8.6 acre pond, show in figures 2 and 3, contains approximately forty one acre feet of water when full and depends upon surface runoff and a spring for maintaining its water level. The spring presently supplies the office, dwellings and barns on the station with drinking water. Although there is no record of the springs going dry, its flow has been reported to be small during extended drought periods. The normal flow of the spring is estimated at approximately ten gallons per minute. This represents approximately fifteen acre feet annually.

The pond's surface watershed consists of approximately 153 acres of gently rolling land. Roughly ninety per cent of the watershed is in permanent pasture or hay crops. Only a small area of watershed, consisting of small experimental test plots and gardens, is cultivated. A four-lane

Figure 2. View of 8.6 Acre Pond Facing Dam.

Figure 3. View of 8.6 Acre Pond Facing Away From Dam

divided highway crosses the watershed for a distance of about 2,000 feet. Four dwellings, a large beef cattle barn with silo, and a tobacco barn are located in the watershed.

The principal soil types found in the watershed are Maury silt loam, Maury silty clay loam, and Maury rocky silt loam. Small areas of the phosphatic phases of Linside, Burgin, and Huntington silt loams are found in the drainage area.

Dairy heifers and sheep grazed in the field in which the pond was located. The heifers were observed wading in the pond and generally disturbing the water in the shallow areas. It was felt that the conditions existing in this pond would approach the worst ones to be found on most farms.

Sanitary engineers from the Tennessee Department of Public Health were consulted prior to the final choice of locations.

One of the two smaller ponds previously mentioned was selected to compare conditions of raw water with the test pond.

The water treatment systen was located where there was access to water at least five feet deep in the pond. The location was also close to the livestock watering pipeline and the electric line.

B. Description of Water Treatment Plant

1. <u>General</u>

The component parts necessary for a small slow sand filter water treatment system were selected and located on a plan of the plant as shown in figure 4.

Since it was decided to use pre-cast concrete septic tanks as basic elements of the water treatment system, a local manufacturer of tanks was contacted and arrangements were made for their construction and delivery. The tanks for the settling, filtering, and storage units were cast in standard 750 gallon septic tank steel forms.

The pipe openings in the septic tanks were not in the desired locations, thus new holes were prepared by the manufacturer in the tank walls after the forms were removed but before the concrete cured to its high strength.

The foundation for the water treatment plant consisted of a five inch slab of reinforced concrete with a drain, raw water inlet pipe, and treated water discharge pipe cast in place. When the foundation concrete had cured, the tanks were delivered and set in place (Figure 5). A concrete block building was constructed to enclose the tanks and work area.

2. Raw Water Intake

Previous studies (3, 2) have indicated that pond water with the least mineral and bacterial contamination is usually found near the water surface where the water depth is at least four feet. The raw water intake for this system is floated by two one-gallon glass jugs (Figure 6) and is anchored approximately sixty feet from shore where the water is normally more than five feet deep. Experience showed that the glass jugs did not break as a result of the pond's surface freezing. The intake consists of a screen and foot valve connected to a one-inch plastic pipe which delivers the water to the treatment plant.

LEGEND

1. Raw Water Intake Pipe
2. Raw Water Pump
3. Raw Water Pipe
4. Chemical Injection Point
5. Mixer and Diffuser
6. Float Switch
7. Settling Tank Discharge Pipe
8. Filter Tank Discharge Pipe
9. Storage Tank Cover
10. Storage Tank Inspection Lid
11. Storage Tank Discharge Pipe
12. Discharge Pump
13. Chlorinator
14. Chlorine Solution Jar
15. Pressure Tank
16. Discharge Water Meter
17. Pipe to Distribution System
18. Manometer
19. Flow Rate Meter

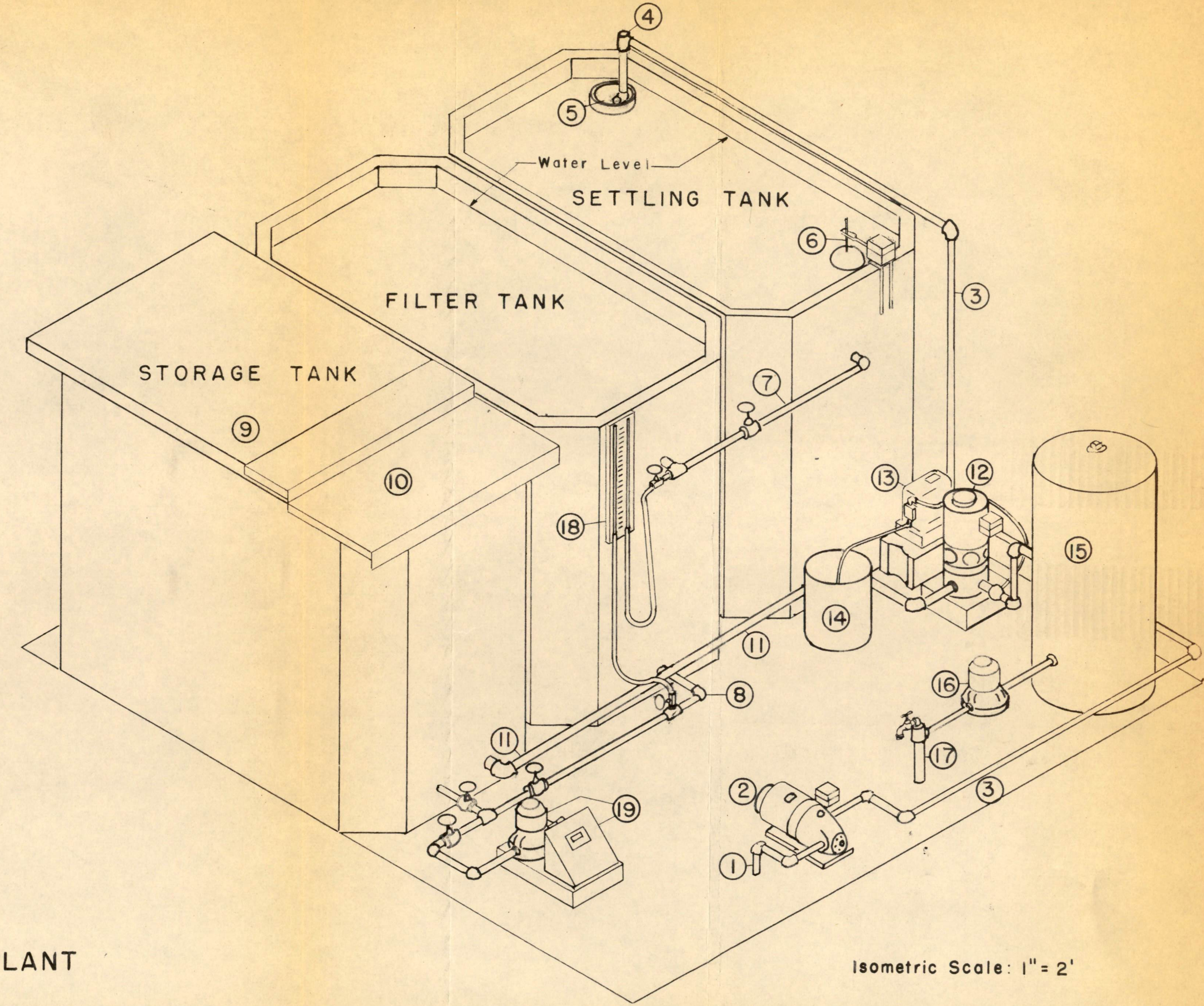


Figure 4.

WATER TREATMENT PLANT

Isometric Scale: 1" = 2'

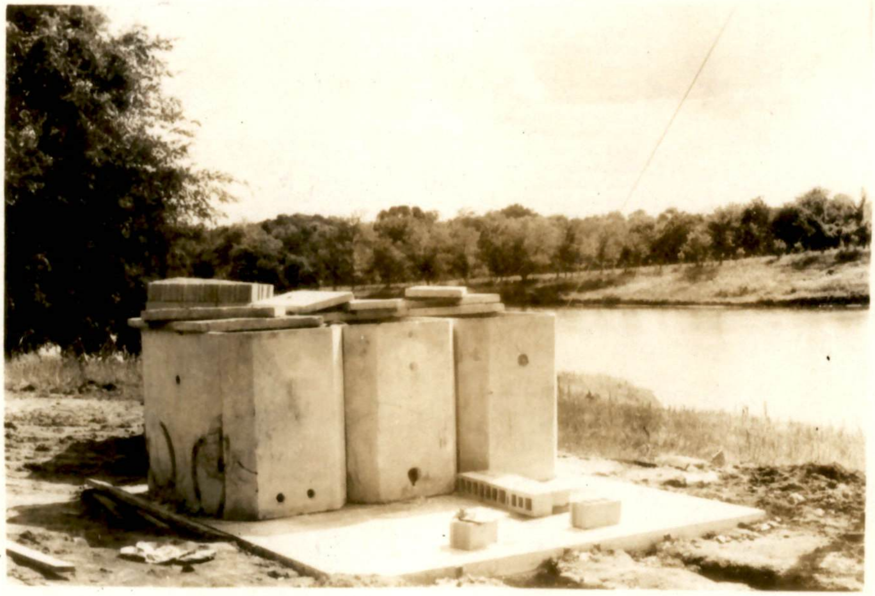


Figure 5. Foundation and Precast Septic Tanks Set in Position Prior to Construction of Building.

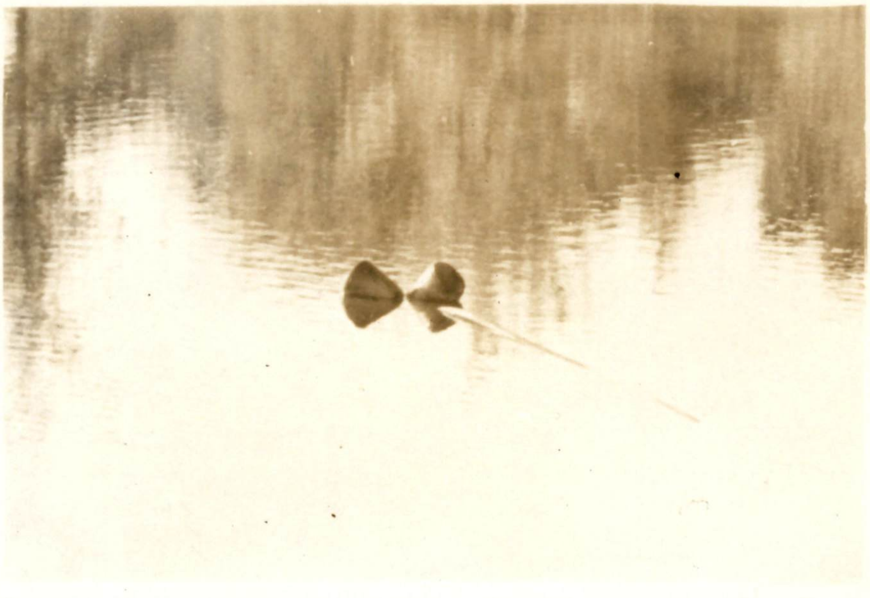


Figure 6. Raw Water Intake Showing Two One-gallon Jugs Used As Floats.

3. Raw Water Pump

Since the rate of flow through the filter is relatively slow, a one-quarter horsepower, shallow-well centrifugal jet pump was utilized to pump the raw water (Figure 7). The pump which was selected had a capacity of approximately 300 gallons per hour at forty pounds per square inch head or 600 gallons per hour at five pounds per square inch. This pump is controlled by a movable float switch located on the wall of the settling tank for all the tests except the one which did not include settling at which time the float switch was transfered to the filter tank, (Figure 8).

4. Coagulant Feeder and Mixers

A coagulation agent was introduced into the raw water line between the raw water pump and the settling tank in two of the tests, hence the description of the feeder and mixer will be included at this point. Good mixing of the coagulant with the raw water is necessary for proper flocculation. The coagulant solution was pumped from a large container by a high pressure chemical feeder (Figure 9) into the raw water pipe then into the mixer. The coagulant feeder used in these tests was a Proportioneer's "Midget Chloro-feeder" which was on loan from the Tennessee Department of Public Health.

The mixing device used in the initial coagulation test consisted of a five foot high six-inch diameter pipe made from two thirty-inch lengths of bell tile standing on end in the settling tank (Figure 10). The coagulant solution was introduced into the raw water line which in turn discharged the raw water-coagulant mixture into the top of

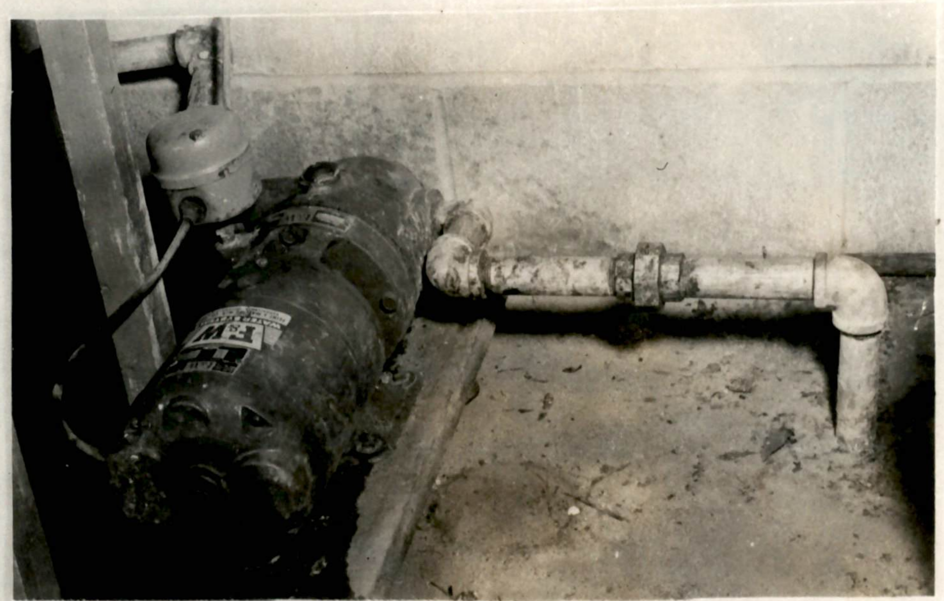


Figure 7. Raw Water Pump.

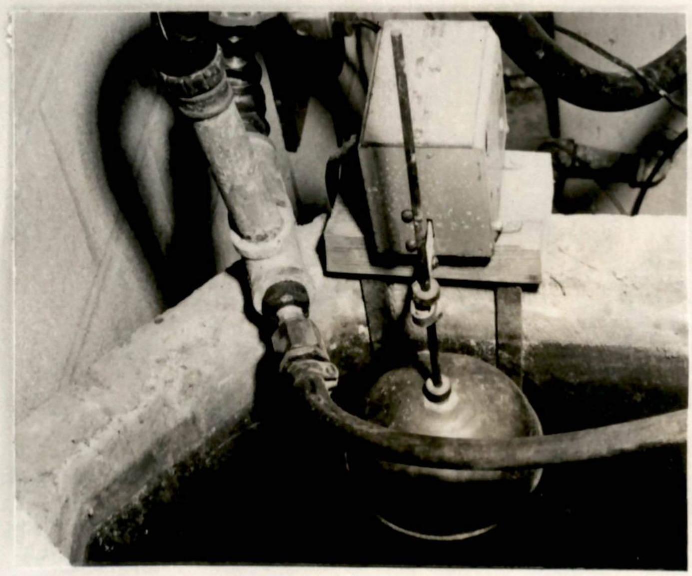


Figure 8. Float Switch and Coagulant Injection in Raw Water Line Prior to Mixing.

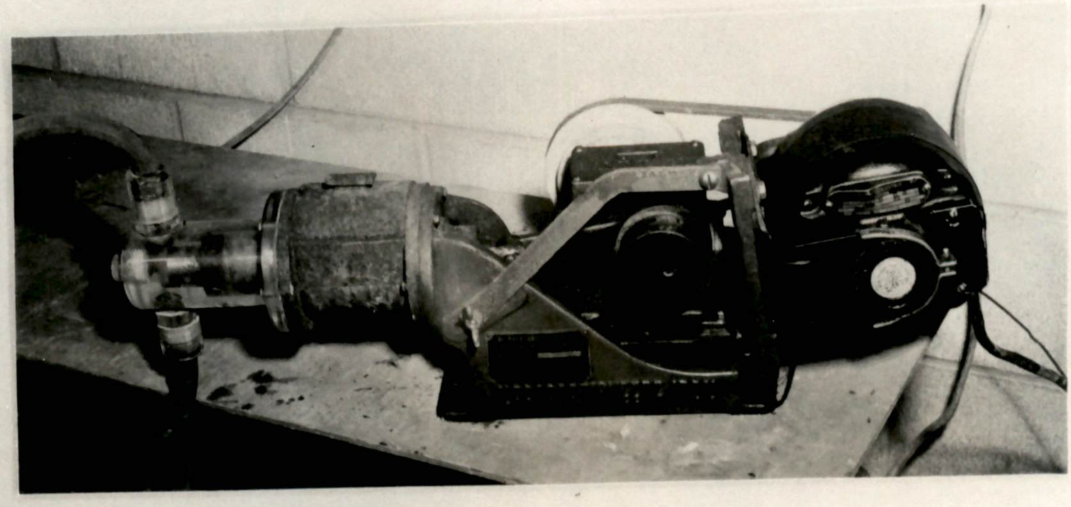


Figure 9. Coagulant Feeder.

Figure 10. Six-inch Bell Tile Coagulant Mixer.

the tile near its edge in such a manner as to cause a swirling action of the water. This mixture discharged from the bottom of the tile into the settling tank proper.

The mechanical mixer which was developed as a possible improvement of the pipe mixing method is described in the chapter on Description of Tests.

5. Settling Tank

The settling tank is the first of three 750 gallon size pre-cast septic tanks used in the plant. Since the tank was delivered with holes in the ends for inserting the pipes and also the openings normally needed for septic tanks operation, it was necessary to seal the pipes in place and close the other openings. At first, a rapid curing cement with a trade name of "Por-rock" was used as a sealant (Figure 11). This material was easy to apply and solidified in about fifteen minutes; but it was found that contact with water caused its structure to deteriorate. It was necessary to cover this material with a waterproofing cement called "Sta-dri" Patching Cement. After all the holes were filled and the pipes were firmly held in place, the entire enterior of the tank was painted with a waterproofing paint "Sta-dri". This paint has proved to be very effective since there has been no evidence of seepage through the concrete. However, failures have occured around pipes where the cement was apparently applied improperly.

A two-inch drain was provided at the floor level of the tank to facilitate the removal of sediment. The tank provided at least ten

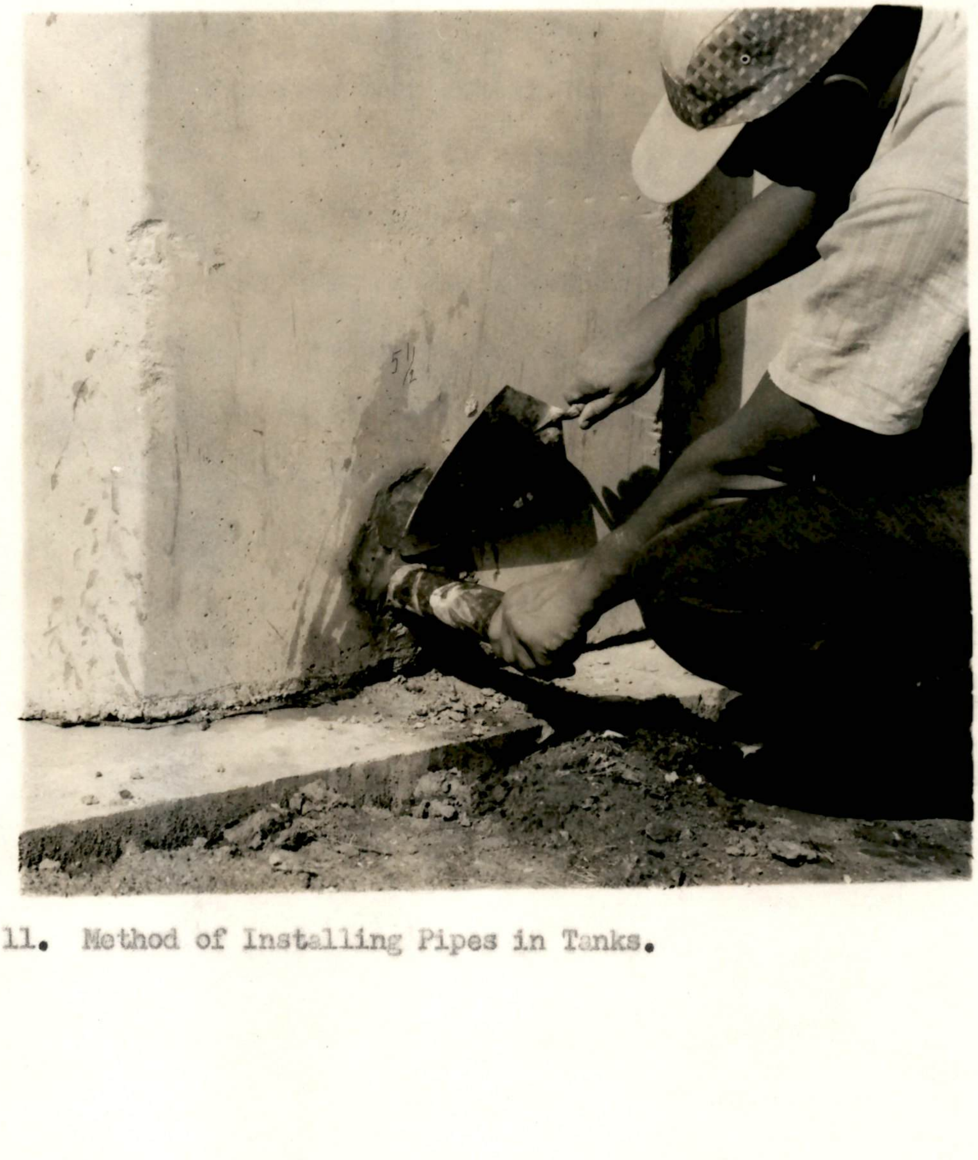


Figure 11. Method of Installing Pipes in Tanks.

hours of settling time for the raw water prior to entering the filter. There was some question as to the effectiveness of the tank for settling very small particles due to currents caused by the incoming water. Two vertical baffles made from galvanized sheet metal were placed in the tank so as to cause the water to travel farther before reaching the outlet and would dampen any current which might develop from the inlet. A small skimmer was placed over the outlet to prevent currents from developing and to remove the water from the top three to six inches. The outlet through which the water passes from the settling tank onto the filter was a one-inch pipe located sixteen inches below the top of the tank.

6. Filter Tank

Initially, the filter tank was similar to the settling tank except for the pipe locations in the walls. The unwanted openings and pipes were sealed in the same manner as in the previous tank. A filter effluent collecting pipe (Figure 12) was installed length-wise along the center of the tank to collect the filtered water and convey it to the storage tank. This one-and-one-half inch pipe had one quarter inch holes drilled three inches apart on both sides for its full length and was capped on the end.

A nine inch layer of pea gravel was placed in the bottom of the filter to act as a collecting area for the filtered water and to support the sand thus preventing it from entering the storage tank (Figure 12). This pea gravel was obtained from a local building supply dealer and visual inspection indicated practically no gravel derived from calcium

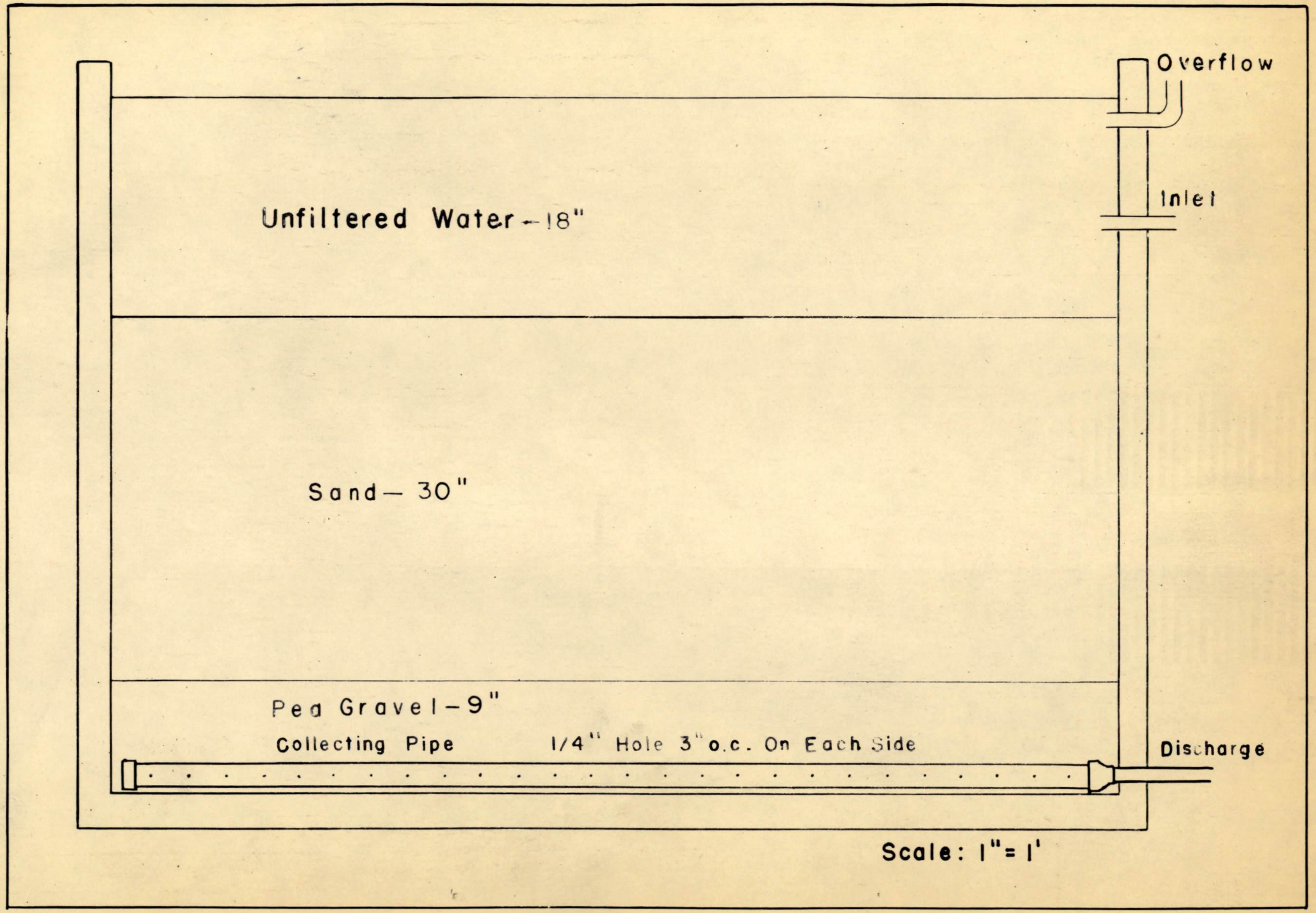


Figure 12. CROSS SECTION OF FILTER TANK

carbonate sources. This gravel covered the effluent pipe to at least a six inch depth.

A thirty inch layer of filter sand was placed on top of the pea gravel. This sand was obtained from the Monteagle Silica Sand Company, Monteagle, Tennessee. An analysis of the sand (Appendix A) showed that its average size was 0.45 millimeters with a coefficient of uniformity of 1.5. This is somewhat larger than is considered most desirable for a slow sand filter; however, it was within the specified range. The surface area of the sand was determined to be 23.23 square feet.

A one inch pipe and valve located sixteen inches below the tank tops connected the filter and settling tanks and was so located that the pipe would always be above the filter sand yet would be below the water surface to prevent cavitation of the sand surface due to the incoming water velocity.

An overflow pipe was located near the top of this tank to prevent damage to testing equipment should the float switch fail to operate properly.

The filter was heavily chlorinated prior to conducting the test to remove all sources of contamination in the filter.

7. <u>Storage Tank</u>

The water leaving the filter tank normally goes directly into the storage tank but was discharged at intervals for test purposes through a flow rate meter. This discharge route is also used to drain the filter for cleaning.

The device which controled the rate of flow through the slow sand filter was located in the storage tank. At first, a pipe whose outlet could be raised or lowered was used to regulate the filter flow rate. The swivel point on the pipe was located above the highest sand level of the filter so as not to allow the water to fall below the top of the sand. The increasing head losses in the filter necessitated changing the outlet level at frequent intervals. At each change, the flow had to be checked by filling a calibrated container in a specified time. This required entirely too much attention, particularly for inexperienced operators.

It was decided to use an orifice (Figure 13) to control the filter water flow rate since the discharge from an orifice varies directly with the square root of the head.

$$Q = K A \sqrt{2 g h}$$

where Q = Rate of flow

K = Coefficient of discharge

A = Orifice area

g = Acceleration due to gravity

h = Head

It was determined through calculations and tests that a five-sixteenth inch nozzle would serve for this installation. At fifteen inches head, which was maximum, the orifice delivered 1.28 gallons per minute which is well within the limits of a slow sand filter. It also delivered 0.81 gallons per minute at six inches head which meant that it maintained much of its capacity even when the filter became increasingly clogged.

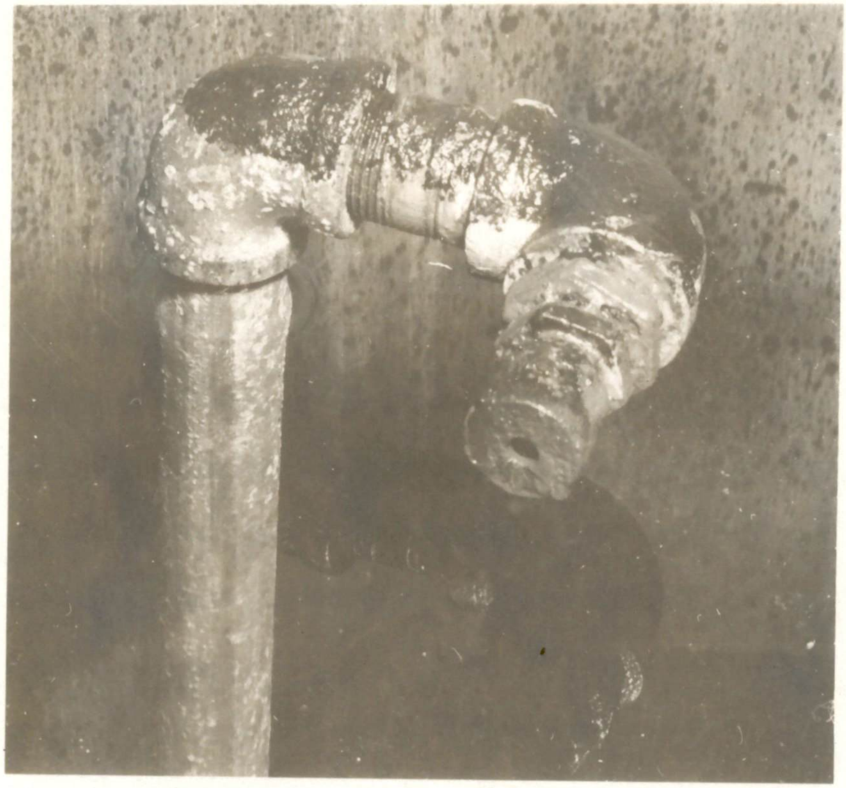


Figure 13. Filter Flow Control Orifice.

The storage tank was similar to the other tanks initially, and the same methods were used to seal the openings. However, a top was placed on this tank using septic tank cover sections which were placed over the rear three-fourths of the tank. These sections were sealed from the underside with 'Sta-dri' patching cement and painted with 'Sta-dri' waterproofing paint. The remaining opening was covered with a removable close fitting galvanized metal cover to prevent contamination by rodents. The discharge intake which has a screen and horizontal foot valve is located near the bottom of the tank. The storage tank was also thoroughly chlorinated prior to testing the system.

8. Discharge Pump

The discharge pump (Figure 14) was a one-third horsepower shallow well centrifugal jet pump which drew the water from the storage tank and delivered it under pressure to the farmstead. It was controlled by a pressure switch on the discharge line.

9. Chlorination Equipment

The chlorine solution was prepared in a large plastic container, (Figure 14) according to the water needs. A readily available laundry bleach containing 5.25 per cent sodium hypochlorite was used during the tests.

A Wallace and Tiernan 'Clorinet', a positive acting chlorinator, (Figure 14), was used to inject the chlorine solution into the water line between the discharge pump and the pressure tank. The chlorinator

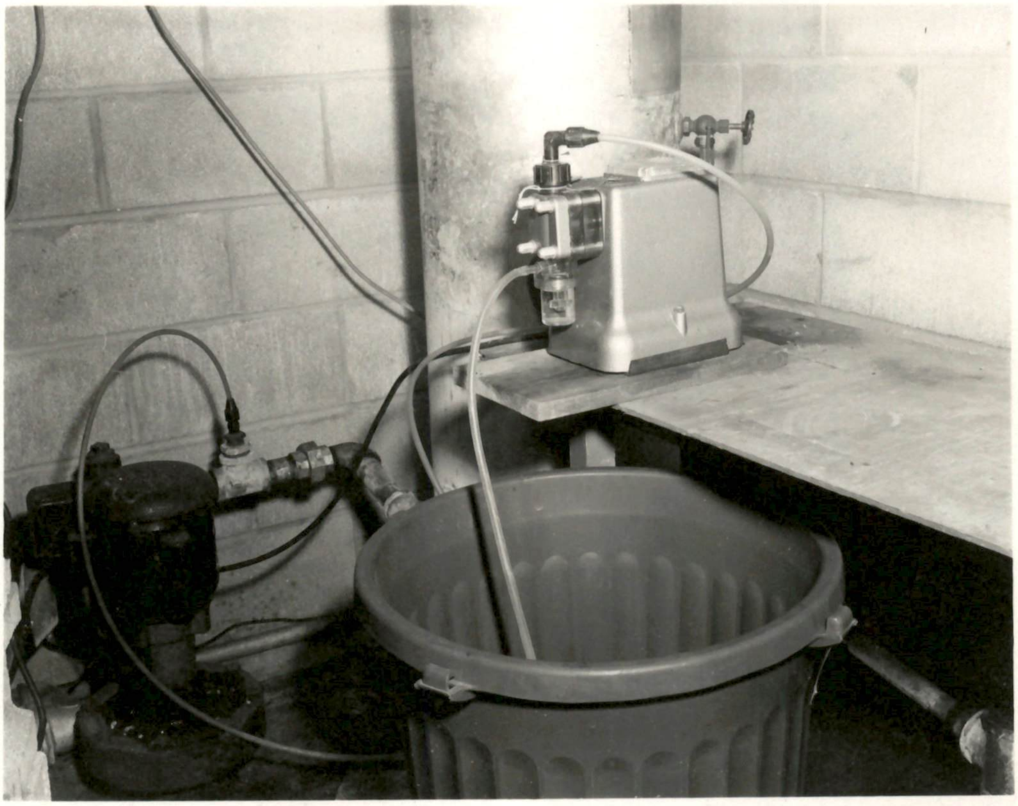


Figure 14. Chlorinator, Chlorine Solution Jar, Chlorine Injection Terminal, Discharge Pump, and Pressure Tank.

was connected so as to operate only when the discharge pump operated.

During the tests using prechlorination as a treatment, the chlorine was injected into the raw water line and the chlorinator connected so as to operate only when the raw water pump was operating.

10. Pressure Tank

The pressure tank (Figure 14) maintained its normal function in the farm water systems. It also provided a short retention period for the chlorine to perform its killing action on bacteria in the water. Water was delivered to the farmstead upon demand.

C. Instrumentation

1. Measuring Total Flow Through Treatment System

The quantity of water which passed through the treatment plant was measured by two Niagara one-inch nutating disk type of water meters, (Figure 15). One meter was located in the discharge pipeline between the pressure tank and the farmstead distribution system, Figure 4, number 16, and measured the quantity treated water which is discharged through the faucet in the building or was delivered to the farmstead. The other meter, which is called the flow rate meter, measured the quantity of water discharged from the filter effluent pipe without its passing through the storage tank, (Figure 15). Readings were taken at regular intervals during the test.

2. Measuring Head Loss Through Filter

In order to determine filter head losses, predetermined rates of flow through the filter had to be established. The flow rate meter (Figure 15) used in these tests, was a one-inch Niagara nutating disk type of meter with a small generator attached to the dial actuating shaft. A millimeter was connected to the generator and was calibrated to read the rate of flow directly. A glass tube manometer (Figure 16) connected to the filter inlet and filter effluent pipes, measured the pressure head loss through the filter at predetermined flow rates established through the flow rate meter. These flow rates through the filter were controlled by valves in the line with the flow rate meter (Figure 15). It was necessary to close the valve on the line from the settling tank to the filter tank in order to get accurate readings on the manometer.

Head loss readings were determined for flow rate readings of one, two and three gallons per minute until the manometer could no longer be read due to excessive head loss. The higher flow rates served the purpose of checking the accuracy of the initial readings since there were no recording instruments used.

3. Facilities For Testing Water Samples

The Division of Sanitary Engineering, Tennessee Department of Public Health, cooperated in conducting the tests to determine the effectiveness of the water treatment plant. Sanitary engineers from the state office were responsible for collecting the water samples at weekly intervals during each test. Physical, chemical and

Figure 15. Flow Rate Meter, Control Valves, and Storage Tank.

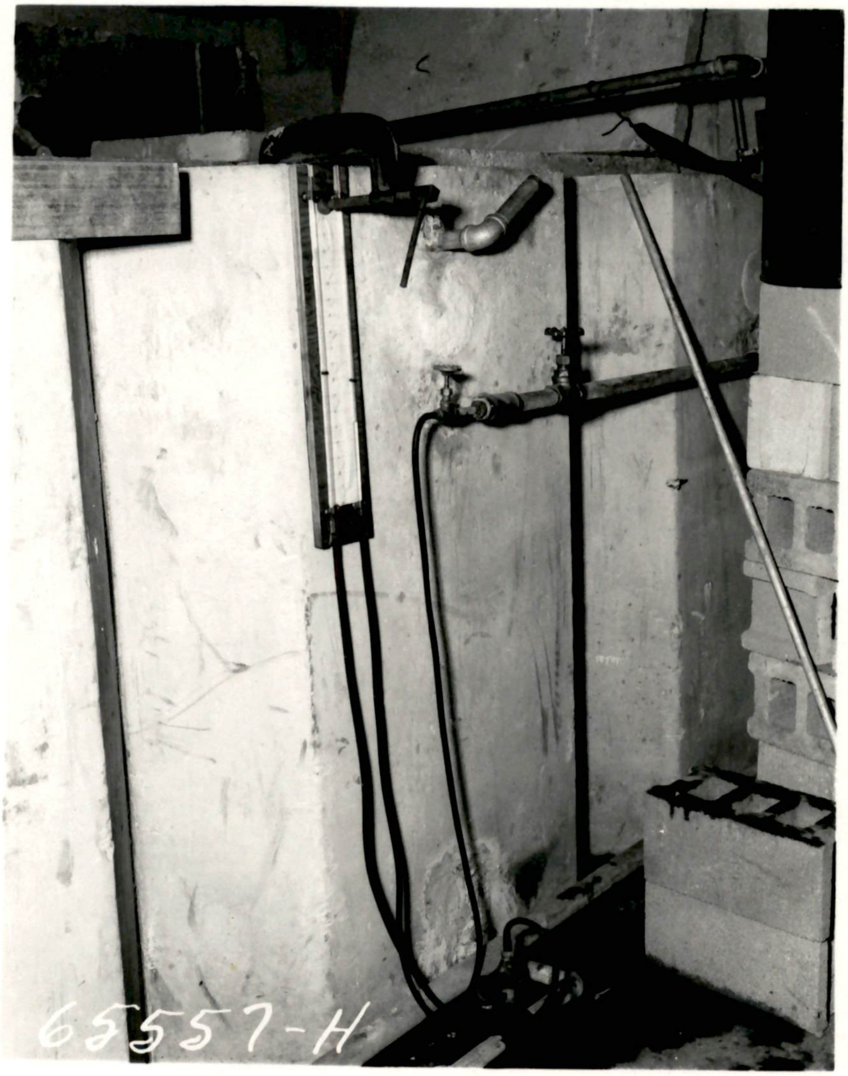


Figure 16. Glass Tube Manometer and Connection to Filter Intake and Discharge.

bacteriological tests on these samples were made in the Tennessee Health Department's Nashville laboratory using their normal methods and procedures.

CHAPTER V

PROCEDURES

A. Selection of Treatments

1. General

Four basic treatments were decided upon in cooperation with the Sanitary Engineering Division of the Tennessee Department of Public Health. These represented the most common water treatments used in commercial and municipal plants as compared to minimum treatments.

Since the water treatment system was primarily in the development stage, alterations and improvements were made on the equipment and procedures as the tests proceeded. It was impractical to get sufficient replications of tests for statistical analyses due to the length of the individual tests, the limited time available and the Health Department's limited personnel time for sampling. Considering these factors, it was felt that randomization of the order of treatments would be of no particular advantage.

2. Treatment I

Conditions were selected for the initial test so as to provide a basis for comparing the succeeding tests. Since settling and filtering would be the only treatments common to all the other tests except the one to determine the relative effectiveness of the settling tank, it was decided to conduct the first test to include only these treatments as comparisons with those which followed.

3. Treatment II

The basis for Treatment II was the possibility for elimination of the settling tank as a unit of the water treatment system. If settling in this tank proved to be relatively ineffective, its elimination would materially reduce the cost of the system. Therefore Treatment II was conducted with the raw water being introduced directly on the filter by passing the settling tank. Comparison of the results with the test including the settling tank would determine its effectiveness.

4. Treatment III

Since most commercial and municipal water treatment systems utilize coagulation with alum as a method for removing turbidity and color from raw water, Treatment III was tested to determine its effectiveness under the conditions existing at the test plant.

5. Treatment IV

Several advantages are claimed for prechlorination according to Babbitt et al. (2) which should prove effective in treating pond water. These were (a) reduction of bacterial load on the filter (b) better color removal in certain instances (c) increased filter runs (d) control of plankton in basins and filters and (e) eliminations of tastes and odor. These possible advantages were the basis for testing Treatment IV using prechlorination, settling and filtering as the principal elements in the system.

B. Selection of Sample Tests and Data

1. Filter Head Loss and Total Flow

Since long filter life is important in a system requiring minimum operator attention, the loss of pressure head in the filter was measured at regular intervals and compared with the quantity of water filtered. Data for three filter flow rates were collected to determine the head loss. The one-gallon-per-minute rate (62 gallons per square foot per day) was considered standard for operating the filter because it represented the optimum rate as reported by several authors (2, 3, 10). This rate of flow was not exceeded greatly in the general operation of the filter. Head loss readings were taken at two and three gallons-per-minute flow to provide a check of the accuracy of the one gallon per minute readings since no automatic data recording devices were used in taking head loss readings. It was hoped that the data from the higher flow rates would also provide information for predicting filter life before completion of the test. The total quantity of water filtered prior to filter stoppage indicated the life of the filter.

C. Tests of Water Samples

All of the water samples were collected by the Sanitary Engineering Division of the Tennessee Department of Public Health and the samples were tested in their Nashville laboratory using standard laboratory procedures. The significance of these tests are reported in the following paragraphs.

1. Turbidity

Turbidity is a measure of the suspended and colloidal matter in water. Visible turbidity which produces sediment is ordinarily composed of fine particles of silt and clay and as such is not particularly detrimental to the potability of water. The indication of surface runoff suggests the possibility of pollution from surface sources. Larger particles may conceal and prevent bacteria from being killed by normal levels of chlorine treatment. Higher levels of turbidity require higher rates of chlorination for effective treatment. The United States Public Health Service standards limit the permissible turbidity to ten parts per million and suggest that it should not exceed five. The Tennessee Department of Public Health limits the permissible turbidity to five parts per million. The colorimetric method of testing for turbidity was used in the laboratory.

2. Color

Color in water has little sanitary significance, however, its presence is esthetically undesirable as it may stain materials with which it comes in contact. The United States Public Health Service standards limit the permissible color in acceptable water to twenty parts per million and preferably less than ten. The Tennessee standards are the same except that higher levels of color may be allowed under special circumstances since sanitation is not effected. The colorimetric method was used to test for color also.

3. Alkalinity

Alkalinity of natural water represents its content of carbonates, bicarbonates and hydroxides. Caustic alkalinity, caused by hydroxides, is undesirable but is seldom found in natural waters. Titration using phenolphthalein and methyl orange determined the quantities of each alkalinity source. Neither alkalinity nor acidity has sanitary significance in natural waters.

4. Hardness

Hardness is primarily the solution in the water of the carbonates and sulphates of calcium and magnesium. Its effect is to inhibit lathering by soap and the formation of scale in boilers; however, it has no sanitary significance in itself. The United States Geologic Survey classifies water of various hardnesses as follows:

0 to 55 parts per million	Soft
56 to 100 parts per million	Slightly hard
101 to 200 parts per million	Moderately hard
201 to 500 parts per million	Very hard

The test for hardness was conducted by titration.

5. Free CO_2

Carbon dioxide is of importance in a water supply because of the desirable taste it imparts, its effect of increasing the solubility of many minerals in water, and the corrosiveness resulting from its presence. No standards are established for its concentration in water but a desirable balance between the concentration of calcium carbonate and carbon dioxide should be maintained.

6. Iron and Maganese

Iron and manganese are objectionable in water supplies because they cause stain on plumbing fixtures and in clothing in the laundry and they may cause tastes and odors. The United States Public Health Service standards state that the combined concentration of iron and manganese shall not exceed 0.3 parts per million if more suitable water supplies are available. The colorimetric method was used in tests for these minerals.

7. Chloride

Chlorides found in natural waters are usually salts of sodium and indicate salinity of water. Drinking water should contain less than 250 parts per million of chlorides for palatability. Titration was used in the laboratory tests to determine the level of chlorides.

8. Fluorides

Concentrations of fluorides higher than one part per million may cause mottling of infant's teeth. Small quantities of flourine, however, are used in public water supplies to inhibit tooth decay. The colorimetric method was used for the fluoride tests.

9. pH

The significance of pH in water treatment is primarily in the control of chemicals used in the purification process. The pH level of most natural waters ranges from 7.0 to 8.5. Coagulation with alum is adversely affected by a pH in excess of 8.0; however, other coagulants have different ranges of pH in which they operate satisfactorily. The colorimetric method was used for pH determination.

10. Nitrates

The presence of nitrates indicates an organic contact sufficiently remote to permit oxidizing action. Levels in excess of 0.5 parts per million remaining for long periods of time are considered suspicious. Colorimetric tests were made for nitrates.

11. Calcium and Magnesium

The carbonates and sulphates of calcium and magnesium are the usual causes of hardness in water but have no sanitary significance. Levels of magnesium should not exceed 125 parts per million if a better water source is available.

12. Coliform Bacteria

The bacteriological analysis of water is for one purpose only, namely, to determine the potability of water. Since coliform organisms are closely related to the intestinal pathogens such as typhoid and dysentery, they are used as an indication of fecal matter in the water supply. The lactose broth method was used in these tests to determine the level of *E. Coli*, a member of the coliform family, in the water. The United States Public Health Service standards state that not more than ten per cent of all the 10 milliliter samples examined per month shall show the presence of organisms of the coliform group. Of all the 100 milliliter portions examined per month not more than 60 per cent shall show the presence of the coliform group. The coliform bacteria count in these tests were determined by the Most Probable Number (M. P. N.) method. Baumann *et al.* (3) suggests the following classification for nonchlorinated water supplies:

	M. P. N. coliform count per 100 ml.
Highly satisfactory	0 - 1
Satisfactory	1 - 2
Suspicious	3 - 10
Unsatisfactory	greater than 10

D. Describing Tests of Treatments

1. General

Upon completing the construction of the water treatment plant, water was pumped from the pond into the settling tank and allowed to flow onto the filter until water covered the top layer of sand. A half-gallon of laundry bleach was poured into the water on the filter and allowed to pass through the filter into the storage tank, thus sterilizing the filter. Laundry bleach was used to sterilize the storage tank when it filled with filtered water.

2. Treatment I, Settling and Filtering

A test to determine the effectiveness of the filter using settling as the only pretreatment was conducted upon completion of the water treatment plant and sterilization of the filter. A flow rate of one gallon per minute was established through the filter by regulating the level of the filter discharge pipe in the storage tank. This flow rate represented an average rate of sixty two gallons per square foot per day, or 2,700,000 gallons per acre per day. Had the filter been operated at this capacity for a twenty four hour period, it would have filtered approximately 1440 gallons of water. Since normal usage would not require this period of operation, a solenoid valve controlled by a time clock allowed the system to operate only eight to ten hours per day.

In order to maintain the one gallon per minute rate of flow through the filter, the discharge pipe which rotated on a swivel connection, had to be lowered during each regular inspection of the system to compensate for the increase in filter head loss. Each time the pipe was moved, the flow rate had to be re-established by timing its discharge into a standard size container.

Samples of the raw and filtered water were collected and filter head loss readings were recorded at one week intervals by sanitary engineers of the Tennessee Department of Public Health.

Figure 17 shows the flow diagram for Treatment I. The test of this treatment extended over a longer period of time than planned due to an equipment failure.

At the conclusion of the test, the top layer of filter sand was scratched with a rake and the remaining water allowed to drain through the filter until the water level was below the top layer of sand. The dirty layer of sand was then removed by skimming with a shovel. The top layer of sand was then leveled by raking. Water from the

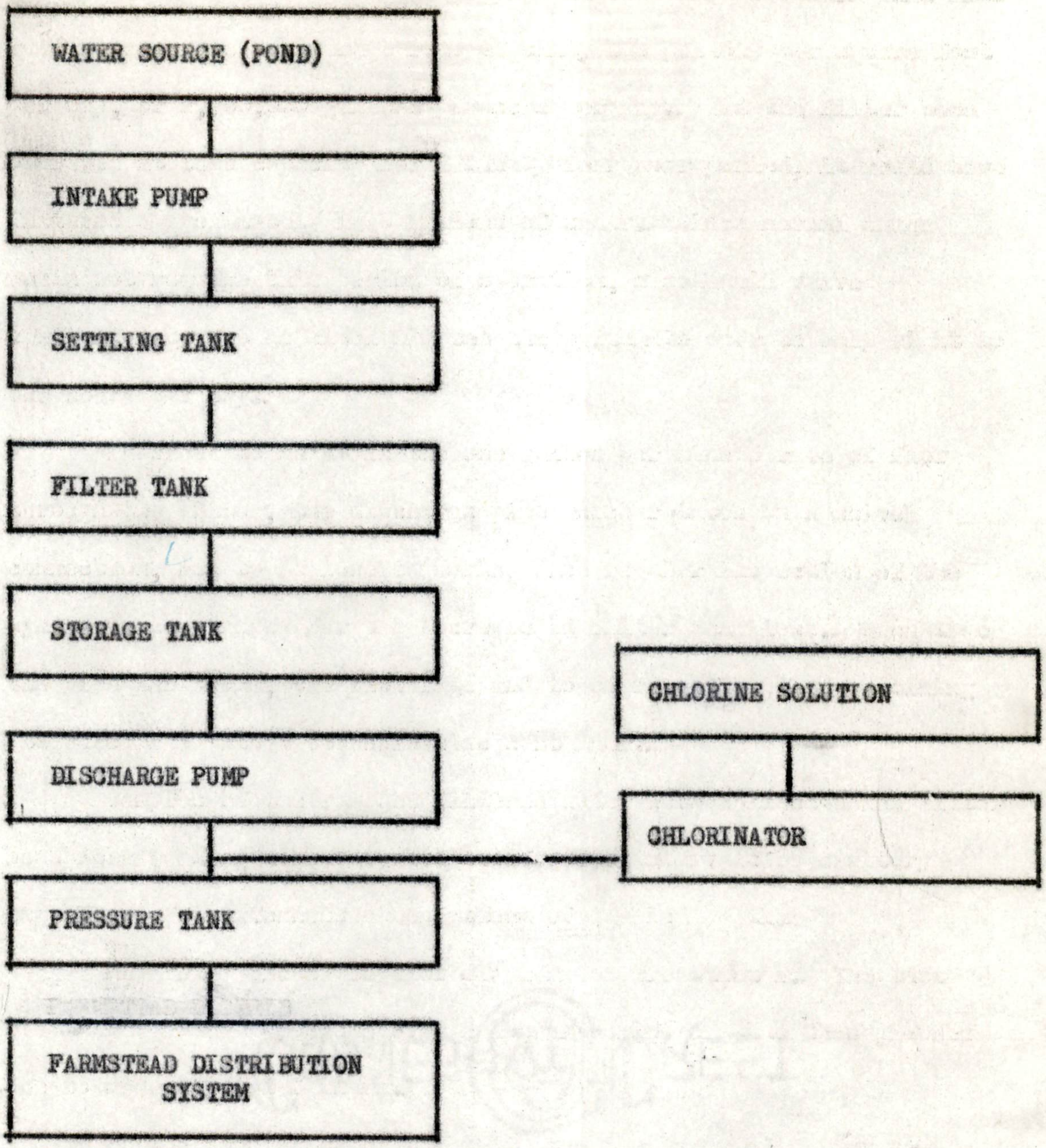


Figure 17. Flow Diagram for Treatment I, Settling and Filtering

clear storage tank was allowed to flow by gravity through the filter in the reverse direction to prevent a large depression from being formed in the sand due to the incoming raw water having nothing to counteract its fall onto the sand. If the water level in the clear storage tank was below the filter sand level, a hose was connected from the system discharge pump to the filter effluent pipe forcing water up through the filter. Once the water level over the sand reached approximately three inches, the raw water was allowed to flow onto the filter. This problem indicated the need for a better method of controlling the flow of the water onto the top of the filter.

3. Treatment II, Filtering

A test was conducted to determine the need for a settling tank under the conditions existing at the test site. This was done by operating the filter without prior settling and comparing the results with tests including the settling tank. Treatment II was the test of the system without settling.

The float switch and the raw water discharge pipe were transferred to the filter tank to allow the raw water from the pond to be introduced directly onto the filter without passing through the settling tank as indicated in the flow diagram, Figure 18. The rate of flow through the filter was established at approximately one gallon per minute as in the previous test. This flow rate was interrupted by the time clock and adjustments were made in the outlet level of the filter discharge pipe to compensate for head loss in the filter as in the previous test. Samples of the raw and treated water were

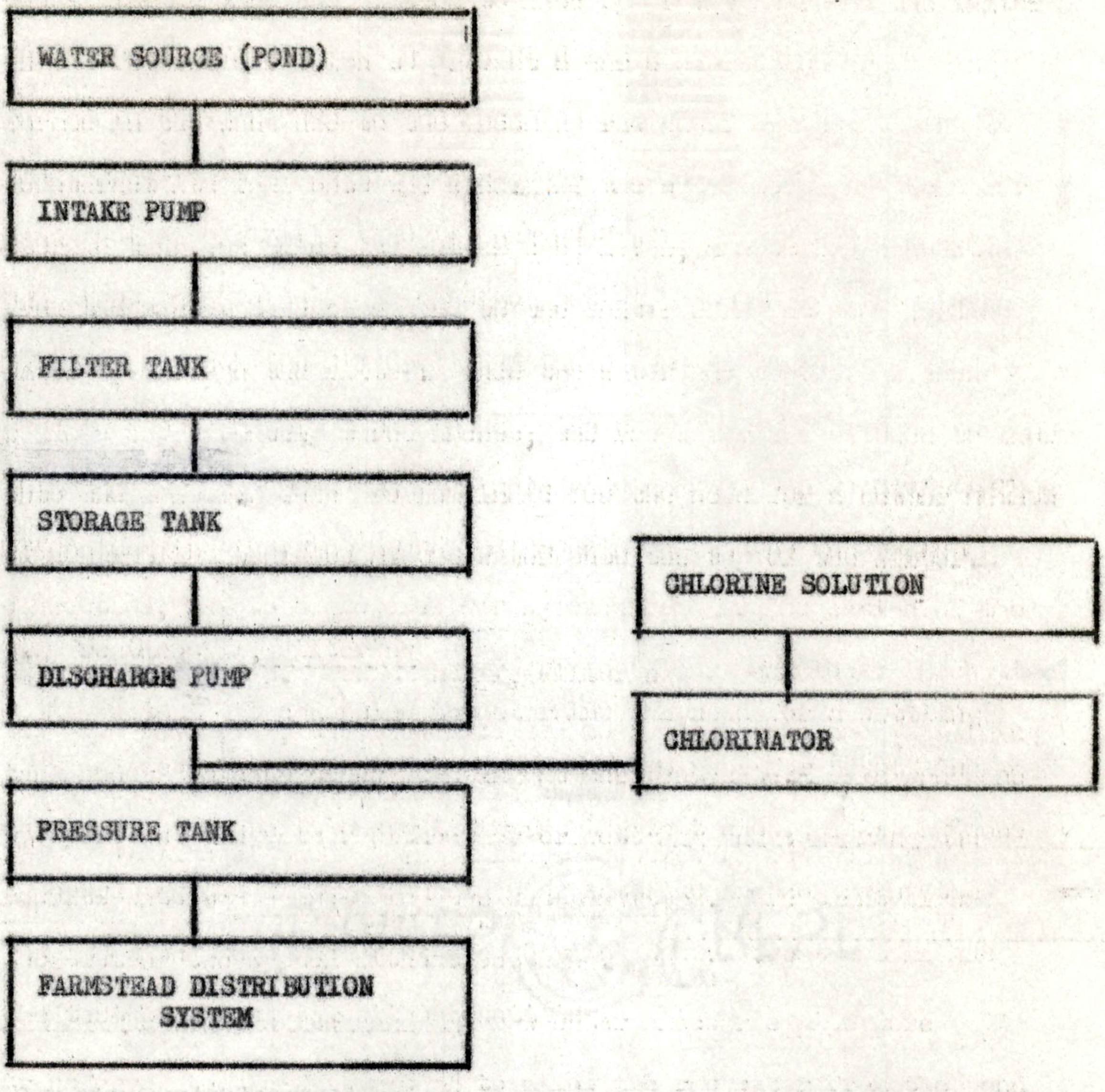


Figure 18. Flow Diagram for Treatment II, Filtering

collected and filter head losses were determined as in the previous test.

4. Treatment III (First Test): Coagulation, Settlings and Filtering

The first test using coagulation as a pretreatment was conducted from October 14, 1958, to November 5, 1958, following the steps shown in the flow diagram, Figure 19. Alum, being the most commonly used and available coagulant, was secured in granulated form for this test. Two pounds of the granulated alum were dissolved in ten gallons of water and fed at the rate of fifty milliliters per minute into the influent raw water pipe having a flow of approximately ten gallons per minute. Mixing was accomplished by introducing the alum solution into the influent pipe prior to its discharge into the top of a six-inch diameter, five foot vertical tile located in the settling tank. The velocity of the water as it was ejected near the outer rim of the tile maintained a circular motion of the water until it exhausted into the settling tank through an opening in the bottom of the tile.

The alum treated water had an average minimum settling time in excess of ten hours prior to its entry into the filter tank. The rate of flow through the filter was controlled by raising or lowering the filter effluent pipe as in the previous tests. The time clock was used to control the quantity of water treated each day, and samples of the water were taken as indicated previously.

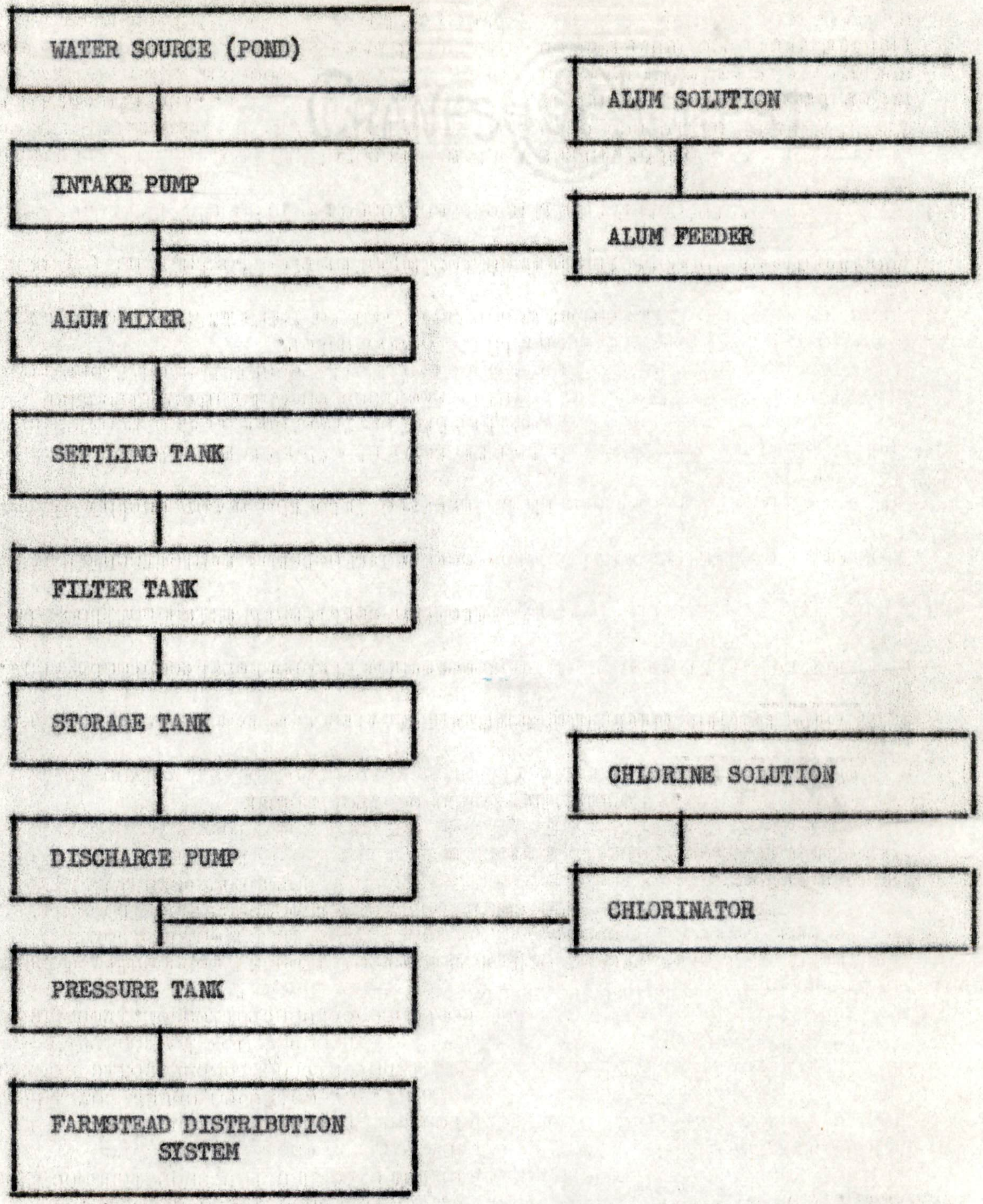


Figure 19. Flow Diagram for Treatment III, Coagulation, Settling and Filtering

5. Treatment IV (First Test): Prechlorination, Settling and Filtering

A test to determine the effectiveness of prechlorination as a method of producing potable water under the test conditions was conducted from December 3, 1958, to December 14, 1958. Equipment was set up similar to the coagulant test except that a chlorine solution was introduced into the system where the alum had been previously used (Figure 23). The chlorine solution, using a common household bleach containing 5.25 per cent sodium hypochlorite, was fed into the raw water at a rate which would provide ten ppm of chlorine.

The chlorinated raw water was allowed to remain in the settling tank for periods averaging not less than ten hours. This time was determined by the filter flow rate and the size of tank and was much longer than normally considered necessary. The chlorine residual varied from 0.1 to 0.3 ppm., free and combined, as measured in the filtered water and on top of the filter.

Due to a failure of the time-clock operated valve, the rate of flow through the filter was controlled by the valve operated in conjunction with the flow rate meter. The filtered water was disposed of through the floor drain of the building. This method of control did not utilize the storage tank nor the discharge pump. The filter operated continuously until it became clogged instead of intermittently as in previous tests. Filter head loss, gallonage and chlorine residual readings were taken every day during this test by experiment station personnel. Health Department personnel were the only able to visit the unit once during the test to secure samples for chemical, physical and bacteriological analysis; hence, there is only one sample of these data for this test.

6. Treatment III (Second Test): Coagulant (Mechanical Mixing), Settling and Filtering

The low gallonage which passed through the filter during the first test using a coagulant presented a serious problem of maintenance if coagulation were used to assist in the removal of color and turbidity. The percentage removal of color and turbidity was also below the average of the other tests. It was thought that there was a possibility of insufficient mixing of the alum with the water. A hydraulically operated mechanical mixer was constructed to use in another test of coagulation.

The mixer (Figure 20) consisted of eight small paddles (Figure 21) approximately eight inches long and one inch wide mounted on a shaft which was driven by the water discharging through a nozzle located approximately eight inches from the shaft and pointed at right angles to the radial line (Figure 22). The water discharged on top of a separating disk mounted two thirds of the distance from the bottom of a fifty five gallon drum. The water passed through the shaft opening into the lower section of the drum where the paddles acted as a mechanical mixer. The alum solution was introduced into the pipe immediately before the water was discharged through the driving nozzle. Flash mixing was accomplished at this point. The paddles were driven at approximately ten RPM which should be sufficient to accomplish slow mixing with a retention time averaging seven minutes.

Water was discharged from the mixing drum (Figure 20) by gravity

Figure 20. Mechanical Coagulant Mixer Showing Drum, Top Intake, and Side Discharge.

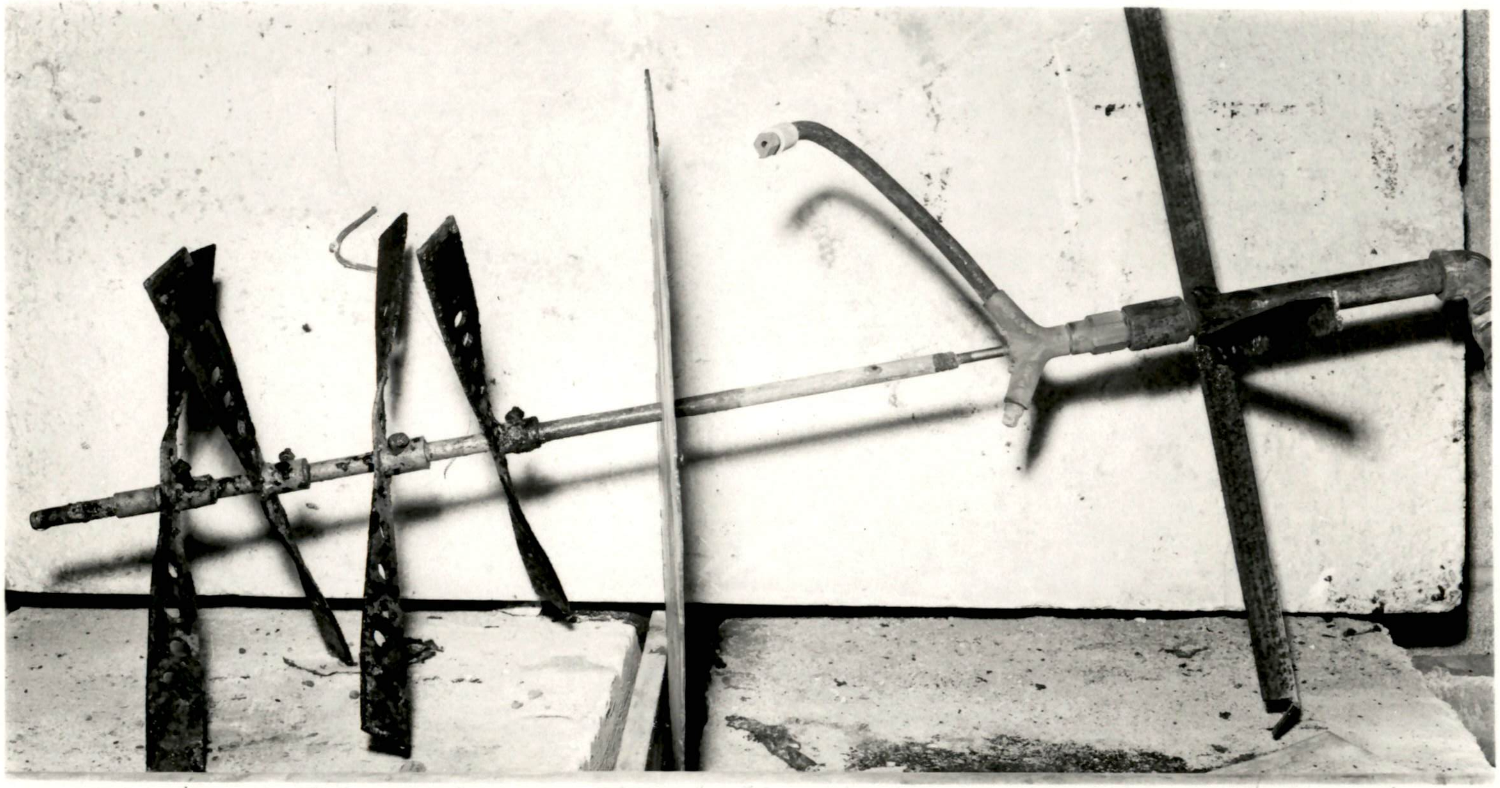


Figure 21. Mechanical Coagulant Mixer Showing Paddles, Baffle, and Impelling Nozzle.

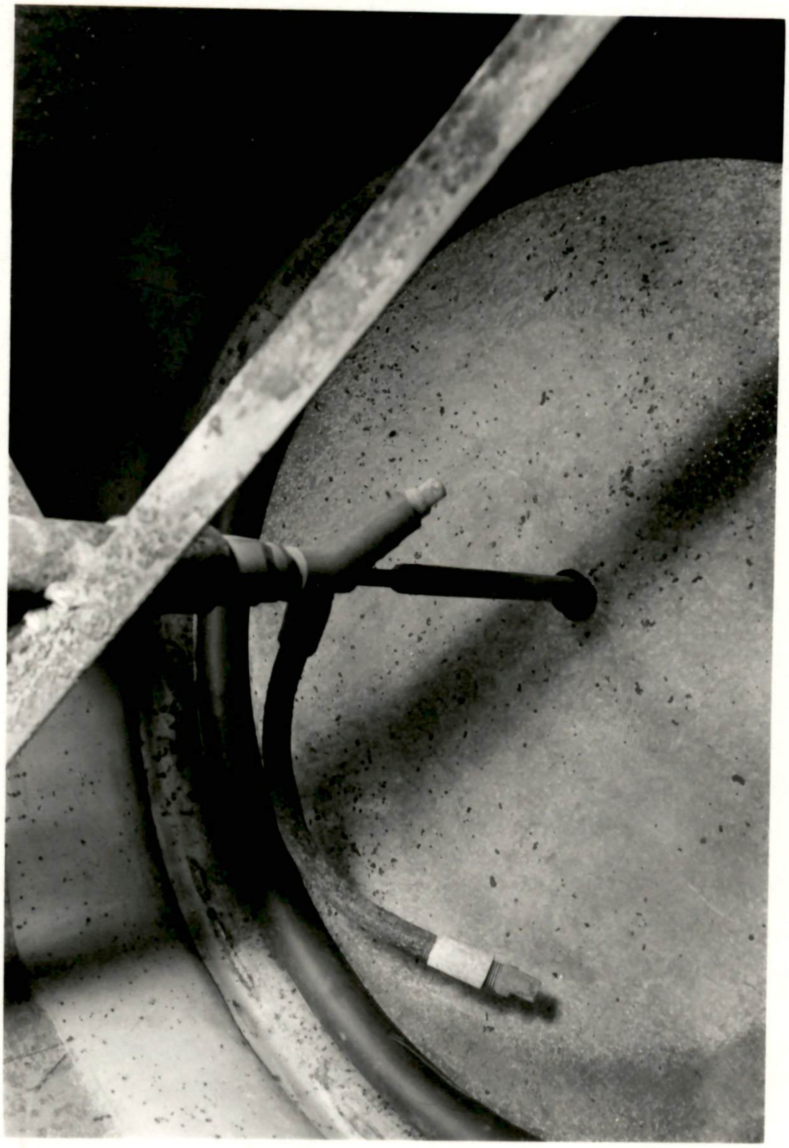


Figure 22. Mechanical Coagulant Mixer Showing Impelling Nozzle and Baffle in Operating Position.

through a pipe having its intake within one inch of the bottom of the drum. Pipes connected the mixing drum with the six-inch vertical tile located in the settling tank where the coagulant treated water was allowed to discharge into the tank.

The rate of flow through the filter was controlled by a valve regulated according to the flow rate meter. A solution consisting of two pounds of granulated alum mixed with ten gallons of water was introduced at a rate of fifty milliliters per minute. Head loss readings were recorded each day the unit was operated; however, water samples were collected only once due to the short period of operation.

7. <u>Treatment IV (Second Test): Prechlorination, Settling and Filtering</u>

Since prechlorination as a pretreatment of the raw water showed some promise in the first test, it was decided to conduct another test with this treatment. The equipment set-up, procedures, and facilities were the same as those reported for the previous test of this treatment. However, no one from the health department was able to visit the plant to collect water samples during this test; hence, no comparison can be made with previous tests where water quality is involved.

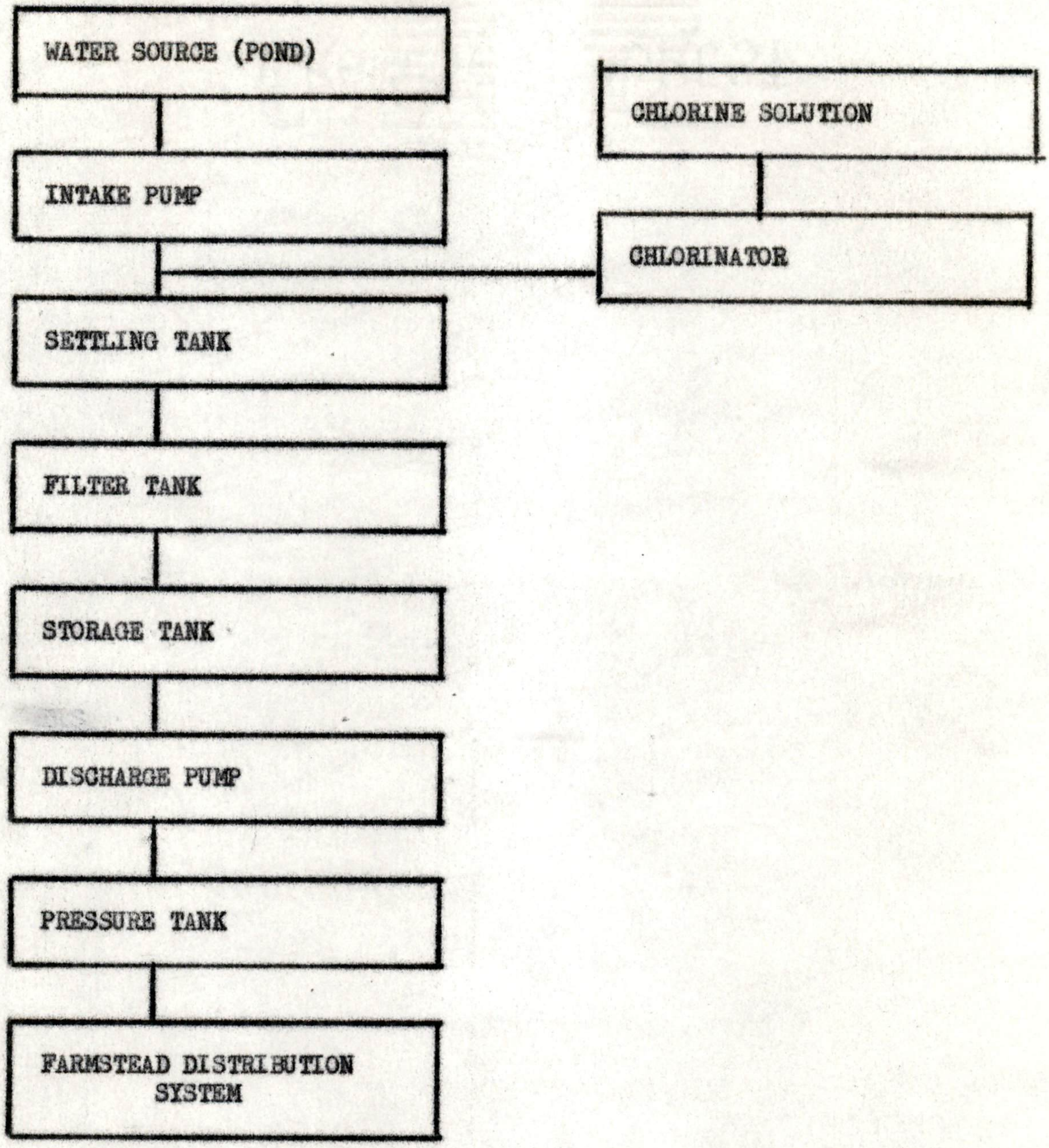


Figure 23. Flow Diagram For Treatment IV, Prechlorination, Settling and Filtering

CHAPTER VI

RESULTS

A. General

The limited number of tests and the limited observations for each test eliminates the possibility of extensive statistical analysis. The small quantity of data is primarily due to the location of the experimental unit at the Middle Tennessee Agricultural Experiment Station which is approximately 230 miles from headquarters. Also, the schedule arranged with the Sanitary Engineering Division of the Tennessee Department of Public Health was such that only weekly observation could be recorded and samples collected. Some of the tests were extended over a two month period which did not permit many tests to be conducted during the limited time available. All of the water samples were collected by experienced Sanitary Engineers who also recorded all of the head loss data prior to the prechlorination test. Filter head loss data was collected daily by an experiment station employee during the prechlorination and coagulation with mechanical mixing tests.

When the tests were completed, the flow rate meter was removed from the installation and taken to the Knoxville Utility Board to check its accuracy. It was found that the meter recorded only 88 per cent of the water at a rate of one gallon per minute, 89 per cent at two gallons per minute and 97 per cent at five gallons per minute.

Since most of the water passing through this meter did so at rates less than two gallons per minute, it was decided to correct the readings for this meter by the 88 per cent figure.

The generator-ammeter portion of the flow rate meter was calibrated in the Agricultural Engineering Laboratory at the University of Tennessee before being installed in the water treatment system. However, when this portion of the meter was checked by the Knoxville Utilities Board following completion of the test, the ammeter readings required correction as follows:

Meter Readings	Tested Rate
0.5 gpm	1.0 gpm
1 gpm	2.0 gpm
2.9 gpm	5. gpm

The flow rate meter was used to measure part of the water passing through the filter in all of the tests, hence the corrections were made on only that portion which passed through this meter.

Since it was desirable to determine the filter head loss at one gallon per minute flow, and since there were no readings taken at this level due to inaccuracies in the flow rate meter, two reference sources were found which were helpful in calculating the one gallon flow rate figures from the higher flow rate head losses.

Ellms (9) reported that Hazen's formula developed through experiments on filter sands, is adaptable to slow sand filters. It is as follows:

$$V = c\, d^2 \left(\frac{h}{L}\right)\left(\frac{t + 10^\circ}{60}\right)$$

where V = velocity of water in meters daily
c = a coefficient
d = effective size of sand
h = head of water
L = depth of sand layer
t = temperature of water, degrees F

Since c, d, L, and t are constant at any given instant, the velocity V varies directly with the head loss.

also q = VA
where q = rate of flow
V = Velocity
A = cross section area of pores

Since A is constant at any given instant, the rate of flow q may be substituted for velocity V thus showing the rate of flow q varies directly with the head.

Jacob (15) reported that Darcy investigated the flow of water through filter beds and found that the discharge through a filter varies directly with the loss of head at low flow rates.

Since both Hazen and Darcy found that filter rates vary directly with the head loss, the head losses for the one gallon per minute flow rate were calculated from the two gallon per minute head loss readings.

B. Treatment I, Settling and Filtering

Approximately 19,150 gallons of water were filtered during this test (Table I). However, a breakdown of equipment may have affected the results somewhat. This gallonage represented the largest amount of water filtered in any of the tests and is equivalent to 823 gallons per square foot of filter surface.

It is apparent from Table I that the filter head loss began to increase rapidly as the filter approached clogging. Insufficient data are available from this test to determine any rate of increase in head loss.

The turbidity of the raw water during this test ranged from fifteen to forty nine parts per million (p.p.m.) and averaged thirty five parts per million (p.p.m.), Table II. Turbidity of the filter effluent ranged from three to ten p.p.m. and averaged six p.p.m. Two of the five samples of filtered water had more turbidity than is considered acceptable by the Tennessee Department of Public Health. Average reduction of turbidity in this test amounted to 83 per cent.

The raw water color ranged from 88 to 224 p.p.m. averaging 173.2 p.p.m. compared to the filter effluent color range of twenty five to sixty five p.p.m. averaging 37.8 p.p.m. Removal of 78 per cent of the color was accomplished. However, all of the filter effluent samples contained more color than is considered acceptable by the health department.

Plankton was removed completely by the filter during this test.

The concentration of all of the minerals and chemicals in the filtered water were within acceptable limits according to the Tennessee Department of Public Health.

TABLE I

EFFECT OF TREATMENT I, SETTLING AND FILTERING, ON FLOW THROUGH FILTER

	Filter Head Loss, Inches			Quantity of Filtered Water, Gallons	
		Filter Flow Rate			
Date	1 gpm*	2 gpm	5.16 gpm	Between Readings	Total
7-28-58	0.4	0.8	2.6	----	----
7-31-58	0.2	0.4	-	1552	1552
8-4-58	0.45	0.9	2.7	953	2505
8-11-58	0.7	1.4	3.8	2520	5025
8-18-58	1.8	3.6	7.7	3924	8979
8-25-58	1.1	2.2	5.3	3646	12625
9-11-58	6.7	13.4	-	6525	19150

*Calculated

TABLE II

PHYSICAL, CHEMICAL AND BACTERIOLOGICAL TESTS FOR TREATMENT I, SETTLING AND FILTERING

	Date	Raw	Treated
Turbidity, p.p.m.	7-28-58	32	5
	8-4-58	15	4
	8-11-58	49	10
	8-18-58	35	3
	8-25-58	44	8
	Average	35	6
Color, p.p.m.	7-28-58	142	25
	8-4-58	88	30
	8-11-58	224	65
	8-18-58	205	37
	8-25-58	207	32
	Average	173.2	37.8
Alkalinity ($CaCO_3$), p.p.m. Phenolphthalein	7-28-58	10	14
	8-11-58	10	0
Methyl Orange, p.p.m.	7-28-58	76	76
	8-11-58	62	72
	8-18-58	62	70

TABLE II (continued)

PHYSICAL, CHEMICAL AND BACTERIOLOGICAL TESTS FOR TREATMENT I, SETTLING AND FILTERING

	Date	Raw	Treated
Hardness, p.p.m. Betz	7-28-58	68	73
Free CO2, p.p.m.	7-28-58	0	0
Iron (Fe) p.p.m.	7-28-58	0.62	0.14
Chloride (Cl) p.p.m.	7-28-58	9	9
Fluoride (F) p.p.m.	7-28-58	0.24	0.38
pH	7-28-58	8.4	9.0
	8-11-58	8.4	8.3
	8-18-58	7.5	7.5
Nitrate, p.p.m.	7-28-58	5.5	1.3
	8-18-58	0.04	0.04
Manganese (Mn) p.p.m.	7-28-58	0.0	0.0
	8-4-58	0.0	0.0
Calcium (Ca) p.p.m.	7-28-58	62	66
Magnesium (Mg) p.p.m.	7-28-58	6	7
Coliform/100 ml (MPN)	7-28-58	91	3
	8-4-58	230	91
	8-11-58	91	62
	8-18-58	73	3
	8-25-58	430	91

Coliform bacteria averaging 183 per 100 milliliter was reduced by 73 per cent, with two of the five samples showing less than three per 100 milliliter (Most Probable Number). Chlorination would be necessary to kill the remaining bacteria following this treatment.

C. Treatment II, Filtering

During this test, 3744 gallons of water passed through the filter prior to stoppage, Table III, representing only 161 gallons per square foot of sand surface. Only four head loss readings were recorded due to the short time required to clog the filter; however, the head losses as shown in Table III, indicated rapid increases in head loss as the filter approached its stoppage point.

Due to the short duration of the test only two samples of water were collected for analysis. Raw water turbidity ranged from twenty-five to forty-nine parts per million averaging thirty-seven p.p.m. (Table IV). Filtered water turbidity ranged from 5 to 6 p.p.m. averaging 5.5 p.p.m., which represents an average turbidity according to the Health Department.

Color was reduced from an average of 261 p.p.m. to 61 p.p.m., (Table III), representing a 76 per cent removal; however, the filtered water still contained more color than is recommended by the Health Department.

The concentration of iron and manganese was higher than desirable with the possibility of causing stain on bathroom fixtures. The filter had no effect on the levels of alkalinity, pH or hardness. Coliform bacteria were reduced to less than three per 100 ml.

TABLE III

EFFECT OF TREATMENT II, FILTERING, ON FLOW THROUGH FILTER

Date	Filter Head Loss, Inches Filter Flow Rate 1 gpm*	 2 gpm	Quantity of Filtered Water, Gallons Between Readings	 Total
9-11-58	0.35	0.7	----	----
9-15-58	0.9	1.8	1,090	1,090
9-26-58	2.35	4.7	2,228	3,318
9-29-58	5.75	11.5	426	3,744

*Calculated

TABLE IV

PHYSICAL, CHEMICAL AND BACTERIOLOGICAL TESTS FOR TREATMENT II, FILTERING

	Date	Raw	Treated
Turbidity, p.p.m.	9-15-58	49	6
	9-29-58	25	5
Average		37	5.5
Color, p.p.m.	9-15-58	272	72
	9-29-58	250	50
Average		261	61
Alkalinity ($CaCO_3$) Phenolphthalein, p.p.m.	9-29-58	0	0
Methyl Orange, p.p.m.	9-29-58	90	80
Hardness ($CaCO_3$) p.p.m.	9-29-58	85.6	74.9
Iron (Fe) p.p.m.	9-29-58	1.65	2.60
pH	9-29-58	7.6	7.5
Manganese (Mn) p.p.m.	9-29-58	1.15	1.05
Coliform/100 ml (MPN)*	9-29-58	91	3

*Most Probable Number

(Most Probable Number) in both samples. It was noted that all of the sediment was collected in the top one-half inch of sand during this test as compared to the one inch depth in the preceding test.

D. Treatment III (First Test) Coagulation, Settling, and Filtering

Only 5562 gallons of water were filtered during this test before the filter became clogged (Table V). This is at the rate of 239 gallons per square foot of filter surface. Turbidity was reduced from an average of 34.3 p.p.m. to 9.3 p.p.m. None of the three filtered water samples was acceptable by the Health Department. Only 73 per cent removal of turbidity was affected by the system. Color removal averaged only 51 per cent, reducing it from an average of 149 p.p.m. to 73.3 p.p.m. with one sample showing only a 15 per cent removal of color.

The coagulant reduced the pH of the water from slightly over 8.0 to 7.4. Iron and manganese were again higher than is considered desirable. The most probable number of coliform bacteria was reduced to less than three per 100 ml. in all samples.

E. Treatment IV (First Test): Prechlorination, Settling, and Filtering

The first prechlorination test produced approximately 13,090 gallons of treated water prior to filter stoppage, Table VII. This gallonage represents a flow through the filter of 563 gallons per

TABLE V

EFFECT OF TREATMENT III (FIRST TEST) COAGULATION SETTLING AND FILTERING ON FLOW THROUGH FILTER

	Filter Head Loss, Inches				
	Filter Flow Rate			Quantity of Water Filtered	
Date	1 gpm*	2 gpm	5.16 gpm	Between Readings	Total
10-14-58	0.37	0.65	2.65	----	----
10-21-58	1.55	3.1	4.5	1839	1839
10-27-58	2.6	5.2	8.4	1096	2935
11-3-58	4.9	9.8	-	2119	5054
11-5-58	8.25	16.5	-	508	5562

*Calculated

TABLE VI

PHYSICAL, CHEMICAL AND BACTERIOLOGICAL TESTS FOR TREATMENT NO. III (FIRST TEST) COAGULATION, SETTLING AND FILTERING

	Date	Raw	Treated
Turbidity, p.p.m.	10-21-58	35	8
	10-27-58	45	10
	11-3-58	23	10
Average		34.3	9.3
Color, p.p.m.	10-21-58	159	58
	10-27-58	180	70
	11-3-58	108	92
Average		149	73.3
Alkalinity ($CaCO_3$) Phenolphthalein, p.p.m.	10-14-58	0	0
	10-21-58	0	0
	10-27-58	0	0
Methyl Orange, p.p.m.	10-14-58	62	82
	10-21-58	91	91
	10-27-58	103	103
Hardness ($CaCO_3$), p.p.m.	10-27-58	85.6	85.6

TABLE VI (continued)

PHYSICAL, CHEMICAL AND BACTERIOLOGICAL TESTS FOR TREATMENT NO. III (FIRST TEST) COAGULATION, SETTLING AND FILTERING

	Date	Raw	Treated
Iron (Fe) p.p.m.	10-21-58		0.0
	11-3-58	0.6	1.6
pH	10-14-58	8.2	7.4
	10-21-58	8.0	7.4
	10-27-58	8.0	7.4
Manganese, (Mn) p.p.m.	10-21-58		0.5
	10-27-58	1.0	1.0
	11-3-58	0.3	1.0
Bacteriological Coliform/100 ml (MPN)	10-21-58	30	3
	10-27-58	90	3
	11-3-58	3	3

TABLE VII

EFFECT OF TREATMENT IV (FIRST TEST) PRECHLORINATION SETTLING AND FILTERING ON FLOW THROUGH FILTER

	Filter Head Loss, Inches				Quantity of Filtered Water, Gallons	
	Filter Flow Rate					
Date	1 gpm*	2 gpm	3.58 gpm	5.16 gpm	Between Readings	Total
12-3-58	0.45	0.9	1.9	3.1	----	----
12-4-58	0.6	1.2	2.2	3.5	1449	1449
12-5-58	0.65	1.3	2.5	3.7	347	1796
12-6-58	1.1	2.2	3.3	4.7	415	2211
12-7-58	1.4	2.8	4.3	5.7	701	2912
12-8-58	1.9	3.8	5.5	7.1	1734	4646
12-9-58	2.85	5.7	7.6	9.4	1741	6387
12-10-58	3.1	6.2	8.4	9.9	89	6476
12-11-58	3.0	6.0	9.7	11.3	1770	8246
12-12-58	3.95	7.9	11.0	--	1638	9884
12-3-58	4.65	9.3	10.3	--	1561	11,445
12-14-58	--	-	-	--	1645	13,090

*Calculated

TABLE VIII

PHYSICAL, CHEMICAL AND BACTERIOLOGICAL TESTS FOR TREATMENT IV, (FIRST TEST) PRECHLORINATION, SETTLING AND FILTERING

	Date	Raw	Treated
Turbidity, p.p.m.	12-8-58	32	6
Color, p.p.m.	12-8-58	145	42
Iron (Fe), p.p.m.	12-8-58	0.25	0.2
Manganese (Mn), p.p.m.	12-8-58	0.0	0.0
Bacteriological Coliform/100 ml (MPN)	12-8-58	3	3

square foot of filter surface.

Samples of water were collected only once during this test due to continuous operation of the system and its relatively rapid completion. Turbidity in the one sample was reduced from 32 to 6 p.p.m. or 81 per cent, which is again not acceptable by the Health Department. Color was reduced by 71 per cent from 145 to 42 p.p.m. again being above the general level of acceptability.

Bacteriological tests showed the most probable number of coliform bacteria to be less than three per 100 milliliter sample for both raw and treated water.

F. Treatment III (Second Test) Coagulation (Mechanical Mixing), Settling and Filtering

Slightly more than 4600 gallons or 198 gallons per square foot of filter surface were treated prior to filter stoppage, (Table IX). Samples were collected only once before the filter clogged due to the tests lasting only four days. Turbidity (Table X) was reduced from fourteen to three p.p.m. or 78 per cent removal. The turbidity level in the treated water sample was acceptable according to the Tennessee Department of Public Health.

Color was reduced from 111 to 28 parts per million or 75 per cent removal.

The most probable number of coliform bacteria was less than three for both raw and treated water.

The pH of the raw water was 8.8 which is higher than is usually

TABLE X

EFFECT OF TREATMENT III (SECOND TEST) COAGULATION (MECHANICAL MIXING) SETTLING AND FILTERING ON FLOW THROUGH FILTER

	Filter Head Loss				
	Filter Flow Rate			Quantity of Water Filters	
Date	1 gpm*	2 gpm	5.16 gpm	Between Readings	Total
2-24-59	0.45	0.9	2.3	----	----
2-25-59	1.8	3.6	8.7	1409	1409
2-26-59	6.35	12.7	--	1998	3407
2-27-59	--	--	--	1204	4611

*Calculated

TABLE X

PHYSICAL, CHEMICAL AND BACTERIOLOGICAL TESTS FOR SECOND TEST OF TREATMENT III COAGULATION (MECHANICAL MIXING), SETTLING AND FILTERING

	Date	Raw	Treated
Turbidity, p.p.m.	2-24-59	14	3
Color, p.p.m.	2-24-59	111	28
Alkalinity ($CaCO_3$) Phenolphthalein, p.p.m.	2-24-59	6.2	2.1
Methyl Orange, p.p.m.	2-24-59	139	62
Hardness ($CaCO_3$), p.p.m.	2-24-59	83	30
Iron (Fe) p.p.m.	2-24-59	.72	.35
Chloride, p.p.m.	2-24-59	17	13
pH	2-24-59	8.8	8.3
Manganese (Mn), p.p.m.	2-24-59	0.01	0.0
Bacteriological Coliform/100 ml (Mn)	2-24-59	3	3

recommended when alum is used as a coagulant. This high pH was not known until the water sample was sent to the laboratory for analysis, and the test completed. This factor could have possibly been the reason for the relatively low gallonage of water treated during the test.

The hydraulically driven mechanical mixer, which was developed especially for this test, operated satisfactorily throughout the test. The level of concentration of minerals for which tests were conducted was satisfactory, (Table X).

G. Treatment IV (Second Test)
Prechlorination, Settling and Filtering

This test was conducted over a period of ten days during which the sanitary engineers from the Tennessee Department of Public Health were unable to visit the unit to collect samples; thus, no comparisons can be made of water quality. However, filter head losses and total flow readings were recorded every day. A total of 16,775 gallons or 720 gallons per square foot of filter surface was treated during the test. There appears to be sufficient data from this and the previous prechlorination test to suggest a pattern for filter head loss.

TABLE XI

EFFECT OF TREATMENT IV (SECOND TEST) PRECHLORINATION, SETTLING AND FILTERING ON FLOW THROUGH FILTER

	Filter Head Loss, Inches					
		Filter Flow Rate			Quantity of Filtered Water, Gallons	
Date	1 gpm*	2 gpm	3.58 gpm	5.16 gpm	Between Readings	Total
3-10-59	0.45	0.9	2.0	3.4	----	----
3-11-59	0.65	1.3	2.4	4.0	2328	2328
3-12-59	0.75	1.5	2.9	4.4	2155	4483
3-13-59	1.25	2.5	4.2	5.9	2152	6635
3-14-59	1.90	3.8	5.8	7.2	1529	8164
3-15-59	2.40	4.8	7.3	9.1	2321	10485
3-16-59	3.0	6.0	9.3	11.1	1993	12487
3-17-59	3.2	6.4	10.8	14.3	2074	14552
3-18-59	4.9	9.8	13.4	--	1368	15920
3-19-59	7.0	14.0	--	--	855	16775

*Calculated

CHAPTER VII

DISCUSSION OF RESULTS

A. General

Since there were insufficient replications of treatments to analyze statistically, only generalized comparisons may be drawn between the effectiveness of the various treatments. However, the results of the tests give indications of the effectiveness of the treatment system in general and are reported in the paragraphs which follow.

B. Turbidity

There seems to be no great difference between the various treatments in their ability to remove turbidity from water, Figure 24. The percentage of removal ranged from 71 to 84 per cent with the two tests using coagulation having the lowest percentages. This could be due to improper use of the coagulant rather than any difference between the treatments. According to these tests, the turbidity of the treated water depends largely on the turbidity of the raw water (Figure 25) since there seems to be a straight line correlation between the two. The correlation between the turbidity of the raw and treated water is significant at the 90 per cent level of probability (Appendix B). It appears from these tests that the filter has more effect on the removal of turbidity than the pretreatment.

All of the treatments tested had samples in which the turbidity was higher than is considered acceptable by the Tennessee Department of Public Health. However, in all cases these samples were within the maximum acceptability range according to the United States Public Health Service.

C. Color

The removal of color by the various treatments ranged from 71 to 78 per cent in all except the first coagulation treatment which removed only 51 per cent (Figure 26). This low removal rate is probably due to improper use or mixing of the coagulant rather than a difference between treatments.

The extremely high amount of color in the pond water presents a problem in treatment which this system did not overcome. The level of color in the treated water is not objectionable as far as sanitary conditions are concerned. However, there might be some esthetic objection to it. The author feels that a farm or rural family would be willing to accept and use water with this color level in areas where other sources are inadequate.

D. Minerals and Chemicals

The level of concentration of minerals and chemicals on which tests were conducted was not objectionable in most cases. Iron and manganese, combined, were higher than recommended in some cases;

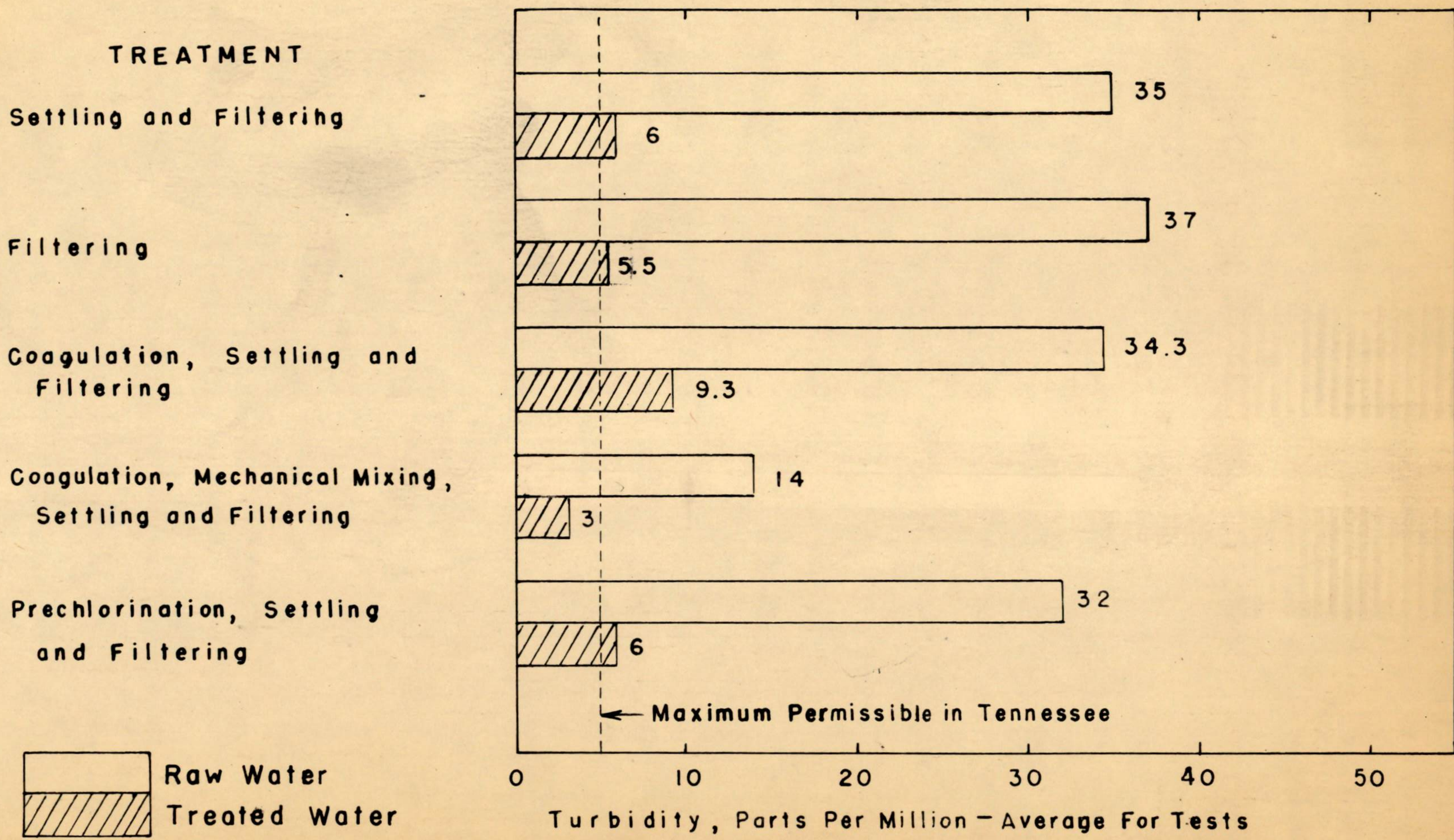


FIGURE 24. EFFECT OF TREATMENTS ON THE REMOVAL OF TURBIDITY

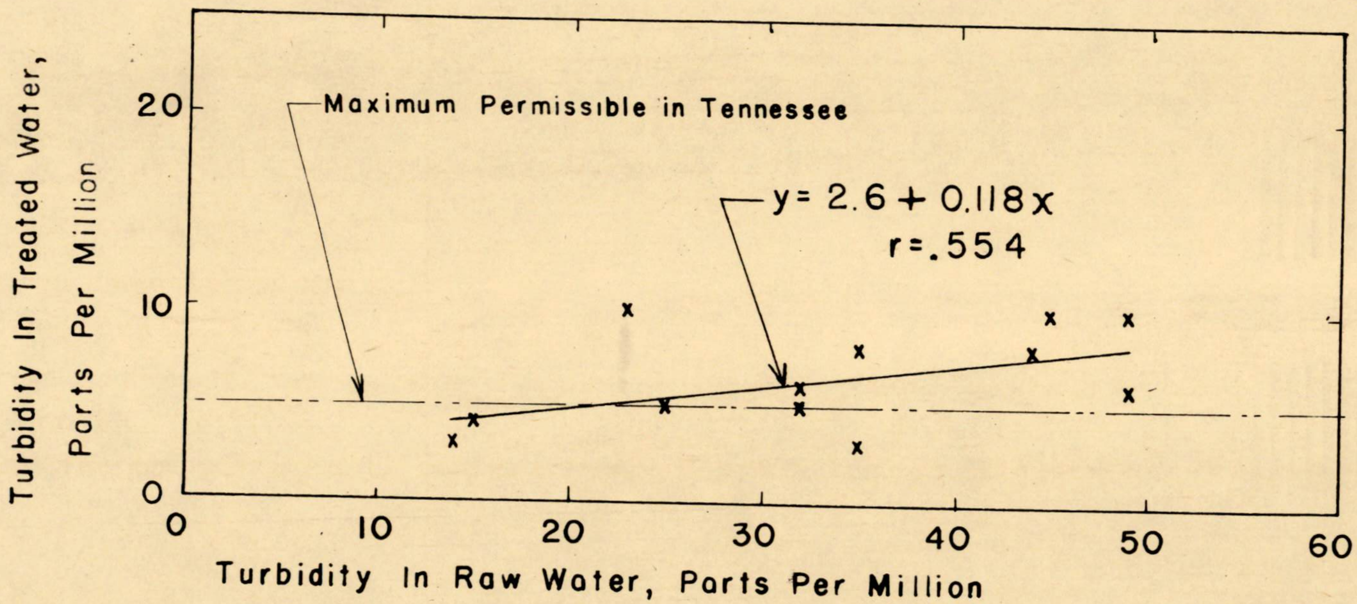


FIGURE 25. COMPARISON OF TURBIDITY IN TREATED WATER AND RAW WATER SAMPLES

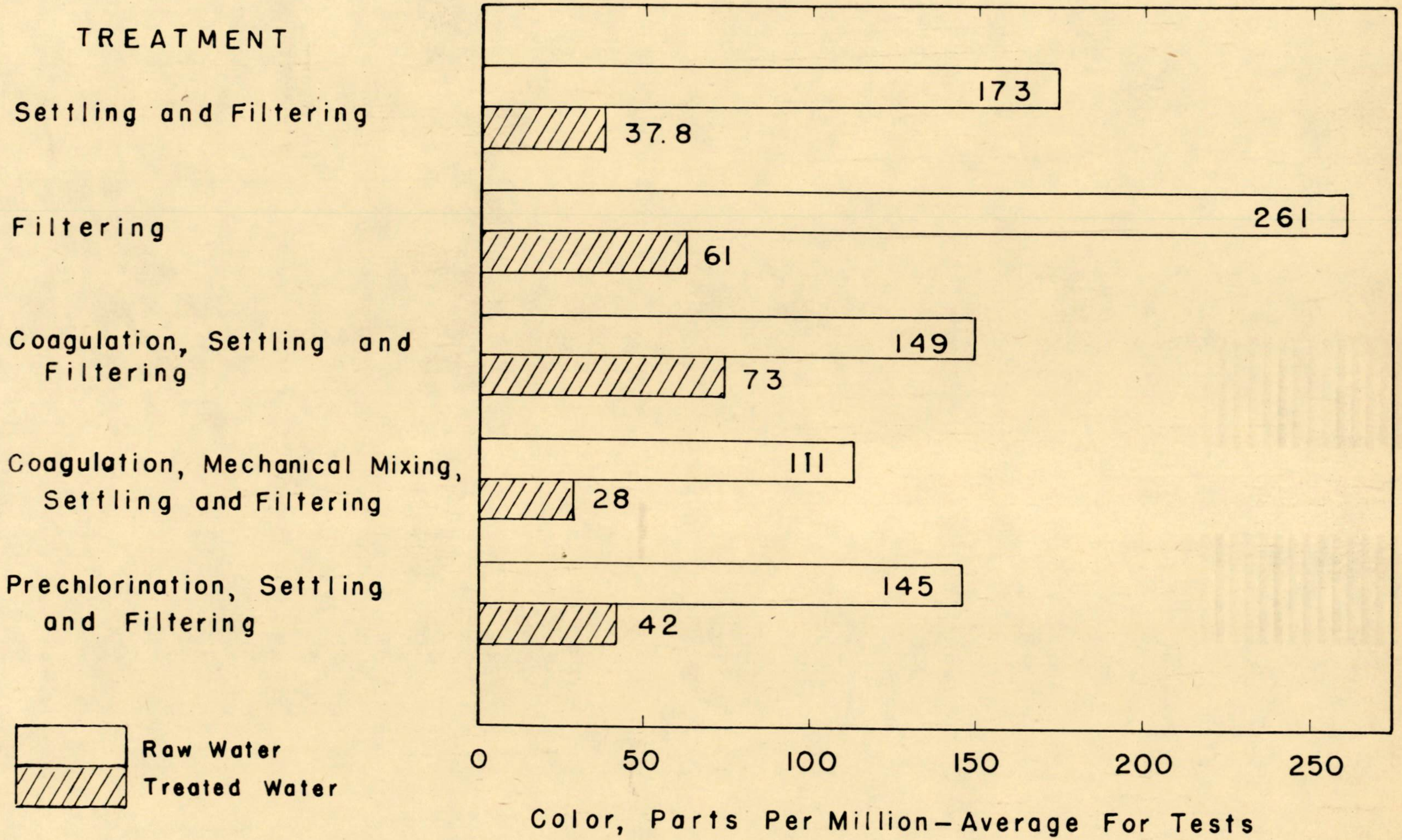


FIGURE 26. EFFECT OF TREATMENTS ON THE REMOVAL OF COLOR

however, the safety of the water for human consumption was not impaired by these minerals. Prechlorination should cause some of the iron to oxidize and settle or be filtered out.

E. Coliform Bacteria

The most probable number of coliform bacteria was less than three per 100 milliliter in the treated water before chlorination in all tests except the initial one. It is still necessary to chlorinate or sterilize the water for human consumption.

F. Taste and Odor

A musty odor was detected in the filtered water during all of the tests. The odor of deteriorated grass silage was particularly noticeable following the filling and subsequent leakage of a nearby silo into the pond. The addition of activated carbon should remove these objectionable odors and tastes.

G. Quantity of Water Filtered

The three tests (Figure 27) which included settling, with the exception of the coagulation tests, produced an average of four times as much filtered water as the test without settling. At least one-fourth inch of sediment was deposited on the bottom of the settling tank during some of the tests, thus preventing this turbid material from being deposited on and stopping the filter. It is

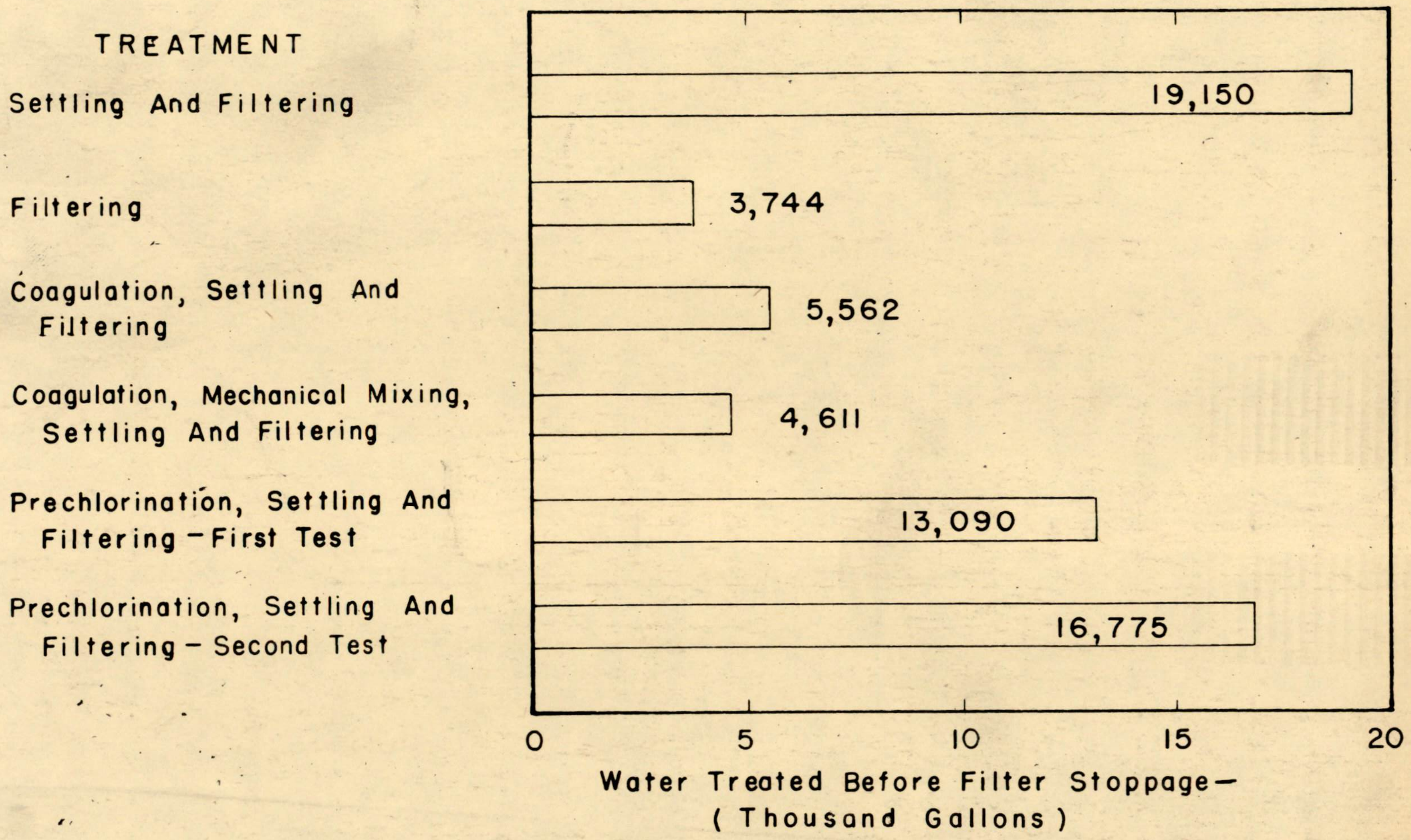


FIGURE 27. EFFECT OF TREATMENTS ON FILTER STOPPAGE

therefore evident that settling is necessary to the efficient operation of this system. No test was conducted to determine the most effective settling time. It was felt that the low gallonage recorded during the coagulation tests was due to small particles of floc clogging the surface of the filter even though most of the floc and turbid particles probably were deposited in the settling tank.

In terms of quantities of water filtered between filter skimming, there seemed to be no great difference between treatment I, settling and filtering, and treatment IV, prechlorination, settling and filtering.

H. Pattern of Filter Stoppage

Sufficient readings of filter head losses were recorded during both tests of treatment IV, prechlorination, settling and filtering, to give general indication of the pattern followed in filter stoppage, (Tables IX and XI). When the filter head losses are plotted against the cumulative quantity of water filtered (Figures 28 and 29) a definite pattern develops. There seems to be very little increase in head loss during the period when the "schmutzdecke", the surface layer on the filter, was being formed, A to B in Figures 28 and 29. It appears that the head loss increases at a more rapid, but constant, rate to the extent that a highly significant (Appendices C and D) straight line will represent the readings from point B to point C. Near point C, the head loss begins to increase at a much greater rate, C to D, and the filter becomes clogged. The most effective

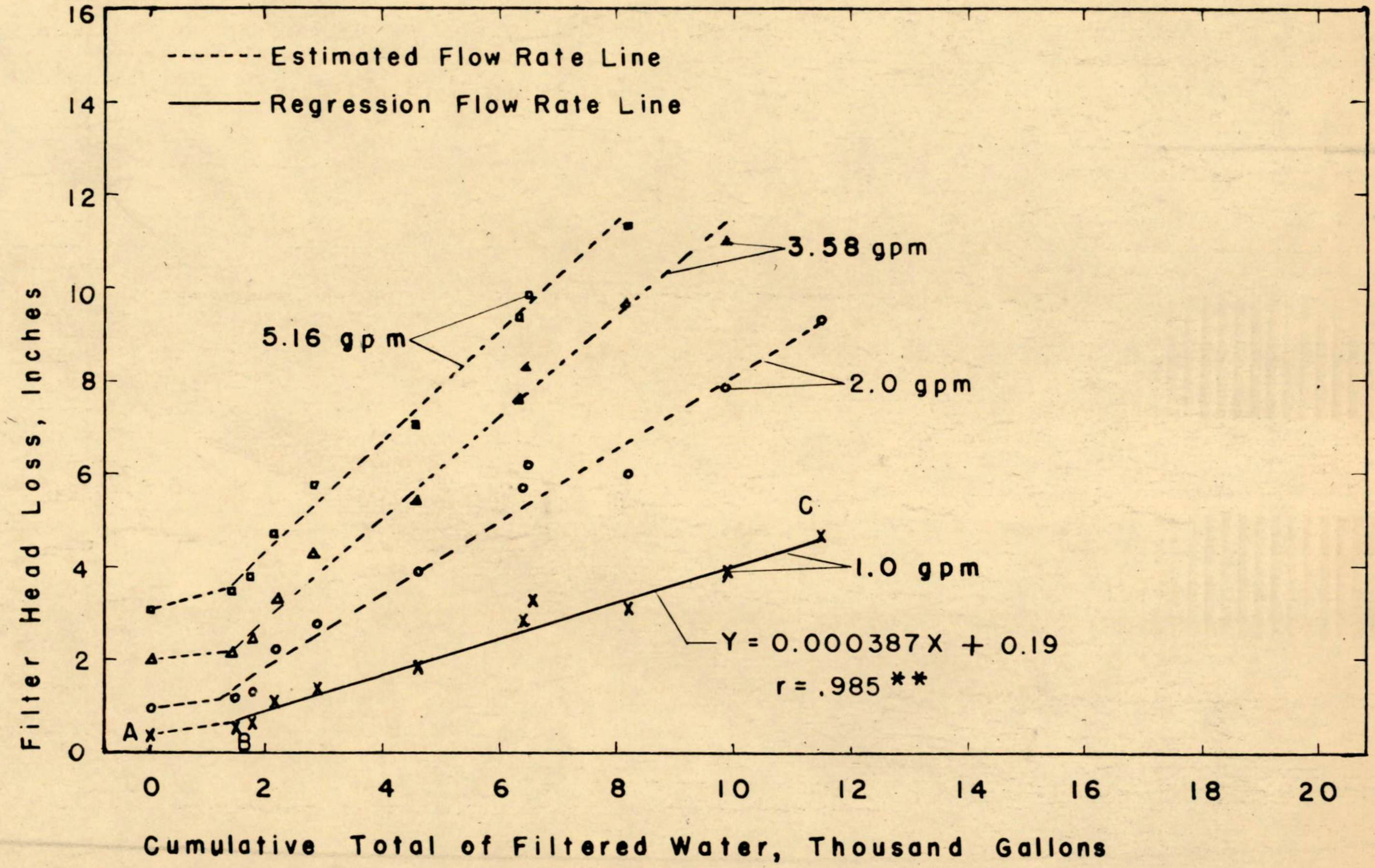


FIGURE 28. FILTER HEAD LOSS UNDER VARIOUS CONDITIONS, FIRST TEST, TREATMENT IV, PRECHLORINATION, SETTLING AND FILTERING

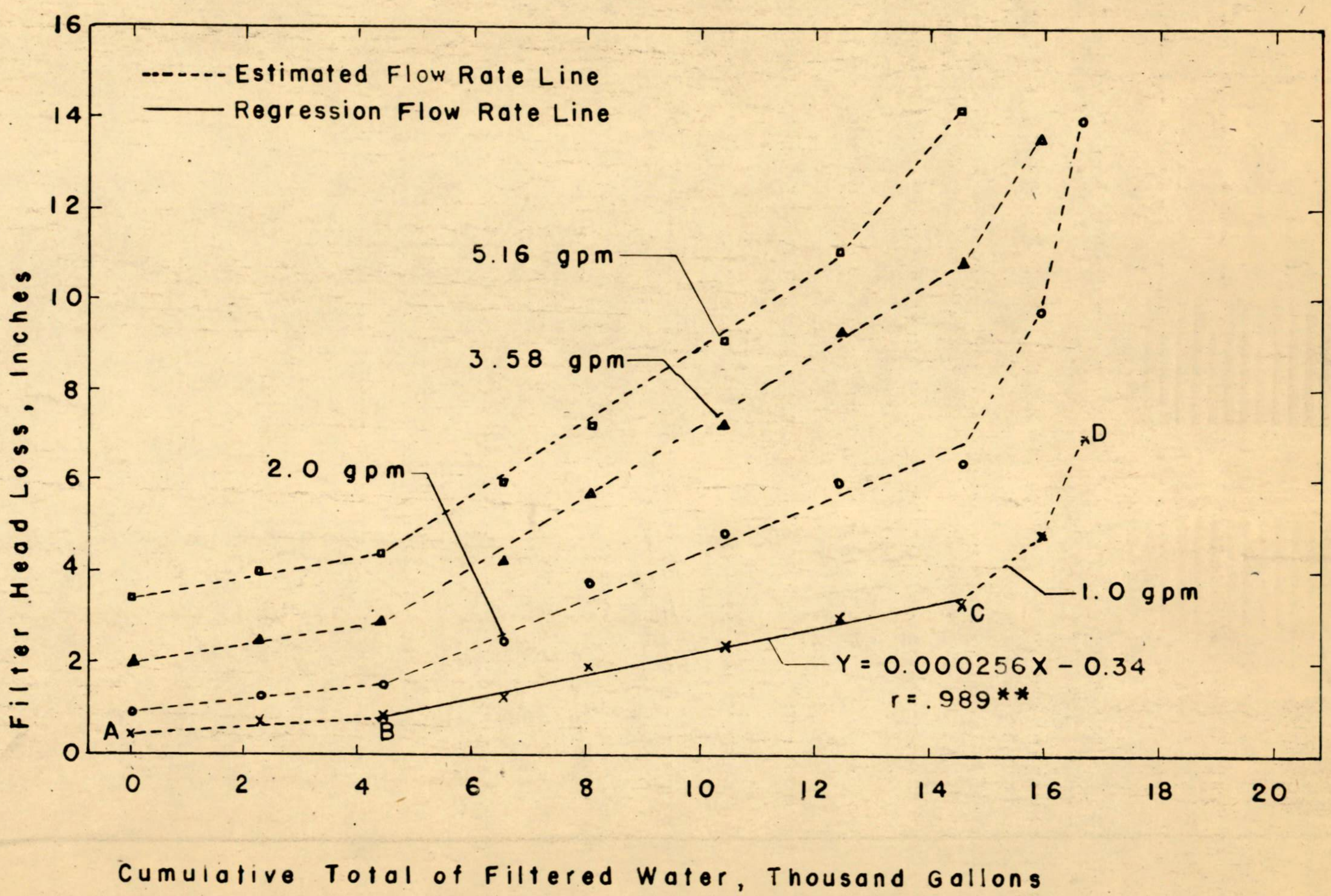


FIGURE 29. FILTER HEAD LOSS UNDER VARIOUS CONDITIONS, SECOND TEST, TREATMENT IV, PRECHLORINATION, SETTLING AND FILTERING

range of operation of the filter occurs during the period represented between points B and C.

Readings were taken at flow rates higher than that which the filter normally operated to check the accuracy of the lower readings and to see if the length of filter life could be predicted in the early stages of filtration. These readings were plotted in Figures 28 and 29 but no definite method of prediction appeared to be feasible from the limited data available.

CHAPTER VIII

NEED FOR ADDITIONAL RESEARCH

The results of the tests which are herein reported indicate the need for further research in various phases of this project. Some of the problems and possible solutions are indicated in the following paragraphs and it is felt that they justify further investigation.

1. Solving the problem of filter clogging is of utmost importance if this system is ever to be utilized by any large number of farmers. Investigation into several aspects of this problem might include the following: (a) Killing algae in pond before it reaches the treatment plant. This needs thorough testing to determine the effects of chemicals on humans, bacteria, algae, fish, livestock and plants. (b) Application of settling agents to remove algae, turbidity and color prior to filtration.

2. Study the effect of sand size on the removal of bacteria, turbidity, color, algae and other foreign material in the water. Determination of the effective rates of flow through these various sand sizes is necessary.

3. Determine the effect of other methods for the removal of algae, turbidity, color, bacteria and other objectionable materials. These methods might include centrifuging, radiation treatment, sonal treatment, pasteurization, chemical filtration and coagulation through the use of various chemicals.

CHAPTER IX

SUMMARY AND CONCLUSIONS

The increased water sonsumption in the modern home and the latest technology on farmstead operation have caused the demands for potable water to exceed that which is generally available from ground water sources in certain areas of Tennessee. It appears that surface water sources such as streams and ponds offers the most practical source of water in areas of ground water deficiency.

The major drawback to the use of surface water for rural domestic and farmstead use is the lack of a water treatment system which will provide an adequate supply of potable water, is easily and economically constructed, and requires a minimum of attention. This research study is designed to study the problems involved in the operation of an individual domestic or farm water treatment system and determine its effectiveness in meeting the requirements for safe drinkable water under conditions which may be found in Tennessee.

The design of the system incorporates elements which can be prefabricated and installed as a complete unit near a water source. Pre-cast septic tanks were used in the test unit for the settling, filtering and storage tanks. However, these tanks could be pre-cast with fittings cast in place if the demand for the system will justify the development of forms.

Plumbing elements could be pre-cut, threaded and assembled in a kit, while other elements such as the chemical feeder could fit the system without alterations.

The system as designed was constructed adjacent to a pond on the Middle Tennessee Agricultural Experiment Station. Four treatments were selected for testing which were (a) filtering only, (b) settling and filtering, (c) coagulation, settling and filtering, and (d) pre-chlorination, settling and filtering.

The tests resulted in the following conclusions:

1. The water treatment system as used during this series of tests requires too much maintenance time in relation to the quantity of water treated.
2. The turbidity level of the treated water was in all cases within the maximum limits established by the United States Public Health Service. However, the turbidity level did not always meet the standards set by the Tennessee Department of Public Health, since the Tennessee Standards are higher than those of the United States Public Health Service.
3. The color level of the treated water exceeded the standards set by both the United States Public Health Service, and the Tennessee Department of Public Health. It was felt that the degree of coloration in the water did not represent a hazard to health but might be objectionable where users require special water conditions.

4. The coliform bacteria count after filtration was less than three per 100 milliliters (MPN) for all the tests except the initial one. This is a satisfactory level when combined with chlorination.
5. The chemical tests indicated no necessity under most farm and residential conditions for additional treatment to remove any of the minerals and chemicals for which tests were conducted.
6. Although there were no specific tests made for taste and odor, these were objectionable at times. A musty odor was noted several times and a strong odor of spoiled grass silage was in evidence following the filling and subsequent leakage of a silo located in the watershed.
7. There seemed to be no apparent advantage to prechlorination and filtering as compared to filtering and post-chlorination.
8. Sedimentation prior to filtering is necessary to the extension of filter life.
9. Coagulation, using alum, was not effective under the test conditions. It also more than doubled maintenance and required additional equipment investment.

It is recommended that research studies on this project be continued with emphasis on developing more effective methods for the removal of algae, turbidity, color and undesirable taste and odor. Particular attention should be pointed toward methods for decreasing maintenance problems.

BIBLIOGRAPHY

1. Agricultural Use of Water in The Tennessee Valley, Division of Agricultural Relations, Tennessee Valley Authority, Knoxville, Tennessee: 1958.

2. Babbitt, Harold E., Doland, James J., Water Supply Engineering, Fourth Edition, McGraw-Hill Book Company, Inc., New York, 1949.

3. Bauman, E. Robert, Fowler, Eric B., A Preliminary Survey of Farm Water Supplies in Southern Iowa, Engineering Experiment Station, Industrial Science Research Institute, Iowa State College, Ames, Iowa, December, 1956.

4. Brakensiek, D. L., Selecting the Water Year Applicable to Small Agricultural Watersheds, paper presented at winter meeting, ASAE, Chicago, Ill., December, 1957.

5. Climatic Summary of the United States-Supplement for 1931 Through 1952-Tennessee, United States Department of Commerce, Climatography of The United States Number 11-35, United States Government Printing Office: 1956.

6. Daniel, Elmer, Treating Farm Pond Water for Domestic Use, Oklahoma Agricultural Experiment Station, Oklahoma A. & M. College, Stillwater, Oklahoma: 1953. Bulletin No. B-408.

7. Daniel, E. R., C. V. Phagan, "How to Treat Pond Water", Electricity on the Farm Magazine, Vol. 30, Number 5, May 1957, pages 10, 11, 32, 33.

8. "Drinking Water From Ponds", The Farm Quarterly, Volume 10, No. 3., Autumn, 1955, pages 62, 63, 82-86.

9. Ellms, Joseph W., Water Purification, McGraw-Hill Book Company, Inc., New York: 370 Seventh Avenue: 1928.

10. Esmay, Merle L., Guyer, Buford E., Shanklin, Milton D., Tempel, L. H., Treatment of Surface Water Supplies for the Farm Home, University of Missouri, College of Agriculture, Agricultural Experiment Station, Research Bulletin 589, Columbia, Missouri, July, 1955.

11. Gowder, M. T., Schwab, Delbert P., Farm Ponds, Publication 333, Agricultural Extension Service, University of Tennessee, Knoxville, Tennessee, 1953.

12. Henderson, G. E., Planning Farm Water Systems, Southern Association of Agricultural Engineering and Vocational Agriculture, Athens, Georgia., June, 1955.

13. Hodges, T. O., Shanklin, M. D., A System for Pond Water Purification, University of Missouri, Agricultural Experiment Station, Bulletin 691, Columbia, August, 1957.

14. Individual Water Supply Systems, Federal Security Agency, Public Health Service Publication No. 24, Government Printing Office, Washington: 1950.

15. Jacob, C. E., "Flow of Ground Water", Engineering Hydraulics, Rouse, Hunter, page 321, John Wiley & Sons, Inc., New York, Chapman & Hall, Limited, London, 1949.

16. Lord, Thomas H., Lipper, Ralph I., Stover, Harold E., Rural Electrification 15, Agricultural Extension Service, Kansas State College, Manhattan, Kansas,: December 1957.

17. Newcome, Roy Jr., Smith, Ollie Jr., Ground Water Resources of the Cumberland Plateau in Tennessee, The Department of Conservation, State of Tennessee, Nashville, Tennessee: 1958.

18. Phagan, C. V., Daniel, E. R., Farm Ponds for Household Water Supply, Oklahoma A. & M. College, Agricultural Extension Service, Circular 580, Stillwater, Oklahoma.

19. Piper, Arthur M., Ground Water in North-Central Tennessee, United States Department of the Interior, Geological Survey Water-Supply Paper 640, United States Government Printing Office: 1932.

20. Planning the Electric Water System and Plumbing For Your Farmstead, U. S. D. A. Miscellaneous Publication No. 674, Washington: Government Printing Office, 1949.

21. Pond Water Treatment, State of Illinois, Department of Public Health, Circular No. N820, Springfield, Illinois.

22. Precipitation in Tennessee River Basin - Annual 1954, Tennessee Valley Authority, Hydraulic Data Branch.

23. Public Water Policy in Tennessee, Public Administration Service, Chicago, Illinois, 1956.

24. Safe Water for the Farm, U.S. Department of Agriculture, Farmers Bulletin No. 1978, Government Printing Office, Washington: 1948.

25. Sorrels, J. H., Zeller, P. J. A., Disinfection of Small Surface Water Supplies with Ultraviolet Light, Texas Engineering Experiment Station, Texas A. & M. College Station, Texas: 1954. Bulletin 134.

26. Stover, Harold E., Filters and Softeners for Farm Water Supply, Rural Electrification 5, Kansas State College, Manhattan, Kansas, June, 1948.

27. Surber, Eugene W., Control of Aquatic Plants in Ponds and Lakes, United States Department of the Interior, Fishery Leaflet 344, Washington 25, D. C.: 1949.

28. Theis, Charles V., Ground Water in South-Central Tennessee, United States Department of the Interior, Geological Survey Water-Supply Paper 677, United States Government Printing Office: 1936.

29. U. S. Bureau of the Census. United States Census of Agriculture, Vol. I . (Washington: Government Printing Office, 1956.)

30. Wells, F. G., Ground Water Resources of Western Tennessee, United States Department of the Interior, Geological Survey Water-Supply Paper 656, United States Government Printing Office: 1933.

31. Winston, Joe B., A Surface Water Treatment System for the Rural Home, School of Engineering, Texas Engineering Experiment Station, Texas A. & M. College, College Station, Texas: 1945. Bulletin No. 89.

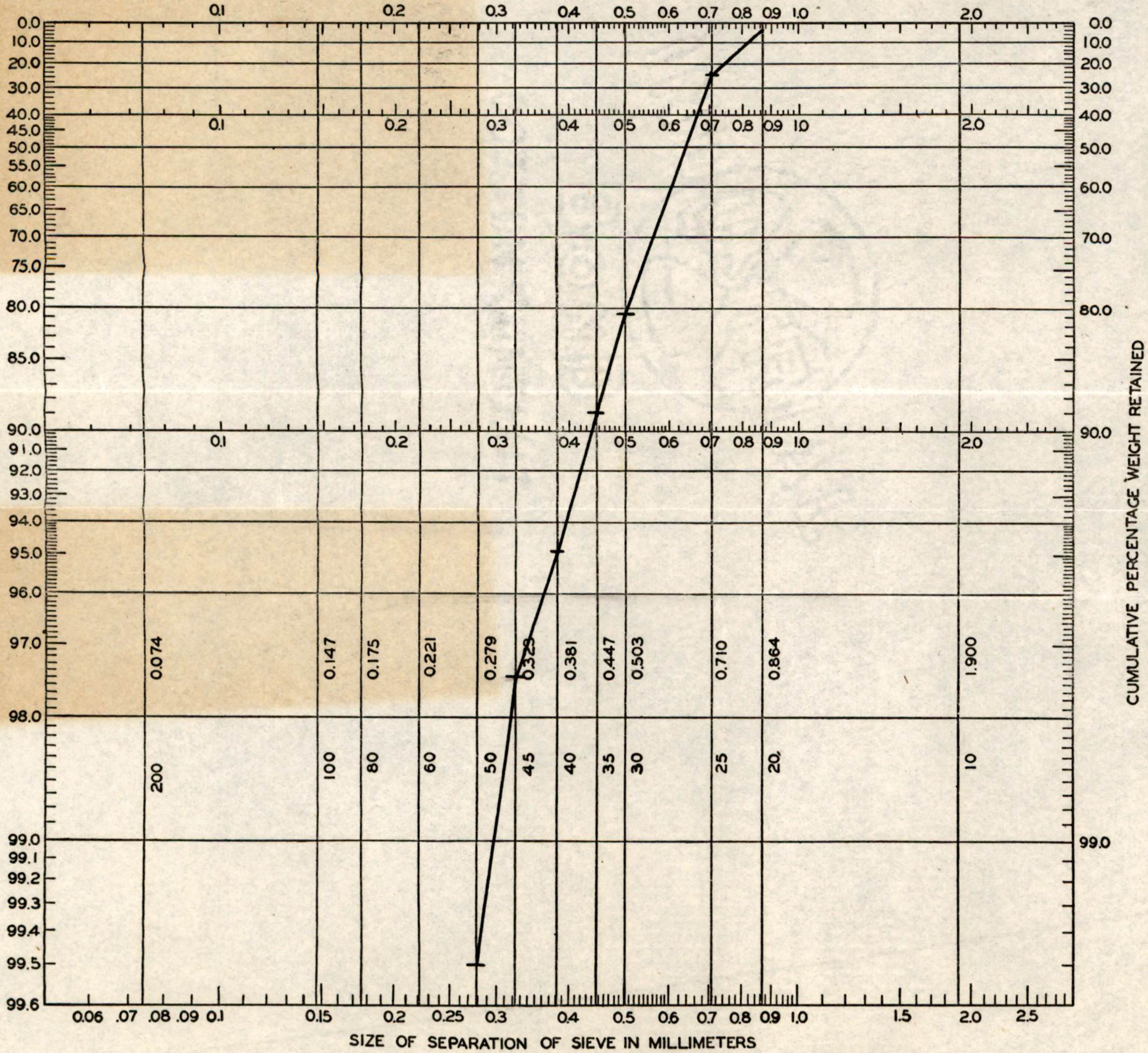
APPENDIX

APPENDIX A

STATE OF TENNESSEE

DEPARTMENT OF PUBLIC HEALTH-DIVISION OF SANITARY ENGINEERING

SIEVE ANALYSIS OF SAND



SAND FROM U. T. Experiment Sta.

FOR CITY OF Spring Hill

DATE RECEIVED ____ ANALYZED ____

BY ____ SAMPLE NO. ____

SIEVE: MESHES PER IN.	SIEVE: SIZE OF SEPARATION IN MM.	WEIGHT RETAINED IN GRAMS	PER CENT WEIGHT RETAINED	CUMULATIVE PER CENT WEIGHT RETAINED
10	1.900	0	0	0
20	0.864	10.7	2.1	2.1
25	0.710	118.9	23.8	25.9
30	0.503	273.3	54.7	80.6
35	0.447	41.5	8.3	88.9
40	0.381	30.1	6.0	94.9
45	0.323	12.9	2.6	97.5
50	0.279	10.0	2.0	99.5
60	0.221	6.7	1.3	
80	0.175	4.4	0.9	
100	0.147			
200	0.074			
PAN				
TOTALS				

AMOUNT EXAMINED 500.0 GM.

EFFECTIVE SIZE 0.45 MM.

60% FINER THAN 0.67 MM.

UNIFORMITY COEFFICIENT 1.5

REMARKS ____

APPENDIX B

REGRESSION ANALYSIS OF TURBIDITY REMOVAL

Raw Water Turbidity	Treated Water Turbidity	Deviations From Means		Squares		Products
X	Y	x	y	x^2	y^2	xy
32	5	1.2	1.5	1.44	2.25	1.80
15	4	18.2	2.5	331.24	6.25	45.50
49	10	15.8	+3.5	249.64	12.25	55.30
35	3	1.8	-3.5	3.24	12.25	-6.30
44	8	10.8	+1.5	116.64	2.25	16.20
49	6	15.8	-0.5	249.64	0.25	-7.90
25	5	-8.2	-1.5	67.24	2.25	12.30
35	8	+1.8	+1.5	3.24	2.25	2.70
45	10	+11.8	+3.5	139.24	12.25	41.30
23	10	-10.2	+3.5	104.04	12.25	-35.70
32	6	-1.2	-0.5	1.44	0.25	0.6
14	3	-19.2	-3.5	368.64	12.25	67.20
Sum 398	78	0	0	1635.68	77.00	193.00
Mean 33.2	6.5					

$$r = \frac{193}{354.9} = .544$$

$$y = 6.5 + \frac{193}{1635.68}\ x$$

$$y = 6.5 + .118\ x$$

$$Y = 2.6 + .118\ X$$

Significant at 90% level of probability

APPENDIX C

REGRESSION ANALYSIS OF FILTER STOPPAGE RATES, FOR PRECHLORINATION, SETTLING AND FILTERING TREATMENT, FIRST TEST, POINTS B TO C IN FIGURES 28 AND 29

	Cumulative Sum of Filtered Water, Gals.	Head Loss, Inches	Deviation From Means x	y	Squares x^2	y^2	Products x-y
	1796	0.65	-4204	-1.86	1767.36	3.4596	7819.44
	2211	1.1	-3789	-1.41	1435.65	1.9881	5342.49
	2912	1.4	-3088	-1.11	953.57	1.2321	3427.68
	4646	1.9	-1354	- .61	183.33	.3721	825.94
	6387	2.85	387	.34	14.98	.1156	131.58
	6476	3.1	476	.59	22.66	.3481	280.84
	8246	3.0	2246	.49	504.45	.2401	1100.54
	9884	3.95	3884	1.44	1508.55	2.0736	5592.96
	11445	4.65	5445	2.14	2964.80	4.5796	11652.30
Sum	54003	22.60			9355.35	14.4089	36173.77
Mean	6000	2.51					

$$r = \frac{36173.77}{36715.1} = .985^{**}$$

$$y = 2.51 + \frac{36173.77}{93553500}\,x$$

$$y = 2.51 + .000387\,x$$

$$y = .000387X + 0.19$$

** Significant at 99 per cent level of probability

APPENDIX D

REGRESSION ANALYSIS OF FILTER STOPPAGE RATE FOR PRECHLORINATION, SETTLING AND FILTERING TREATMENT, SECOND TEST, POINTS B TO C IN FIGURES 28 AND 29

	Cumulative Sum of Filtered Water, Gals.	Head Loss Inches	Deviation From Means		Squares		Products
			x	y	x^2	y^2	xy
	4483	0.75	-4983	-1.33	2492.83	1.7689	6627.39
	6635	1.25	-2831	-0.83	800.45	.6889	2349.73
	8164	1.90	-1302	-0.18	169.52	.0324	234.36
	10485	2.40	+1019	+ .36	103.84	.1296	366.84
	12478	3.0	+3012	+ .92	907.21	.8474	2771.04
	14552	3.2	+5086	+1.12	2586.74	1.2544	5696.32
Sum	56797	12.50			7060.59	4.7216	18045.68
Mean	9466	2.08					

$$r = \frac{18045.68}{18258.5} = .989^{**}$$

$$y = 2.08 + \frac{18045.68}{706059} x$$

$$y = 2.08 + .000256\ x$$

$$Y = .000256\ X - 0.34$$

** Significant at 99 per cent level of probability