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Treatment of Surface Water Supplies for The Farm Home

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COLUMBIA, MISSOURI

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USE IN THE FARM HOME

The old conventional sources of water supply for farm homes are becoming inadequate. Modernization of farm homes with the accompanying greater water requirements has made cisterns inadequate in quantity. Springs and shallow wells that were depended upon in the past have become fewer during the recent dry years as they are very sensitive to drouth conditions. Deep well water is not obtainable in many parts of Missouri and in some other places where it is obtainable, the water is highly mineralized. Financial limitations make it impossible in some cases to obtain deep well waters. The conservation and treatment of surface water supplies for domestic use remains one of the most favorable prospects for farm families in many parts of Missouri as well as in the North Central Region.

A study of the supply of ground water in Missouri emphasizes this problem of water supply for farm homes. Figure 1 is a map of Missouri reproduced from information gathered by the State Geological Survey. The state is divided into four areas based on the presence of ground waters. Area 1, covering most of northwest Missouri is underlain with salt water in the bed rock. Municipalities in this area for the most part use reservoirs. The topography of this area has been influenced by glaciers and in places the deposit or drift is as much as two or three hundred feet deep. In these areas many farm wells are sunk into the drift but they are somewhat sensitive to drought conditions. Area 2 is a border area where fresh water may be obtained from relatively shallow wells in the bed rock. Deeper wells generally produce highly mineralized water. Considerable water is available in this area, however, along major streams in alluvial deposits. Area 3 has an abundant water supply at shallow depths. Area 4, consisting of the Ozark Hill regions is underlain with abundant fresh waters deep in the bed rock. Most cities in this area use deep wells for municipal water supplies but it is not always economically feasible for individual farmers to go to the necessary depths for this water.

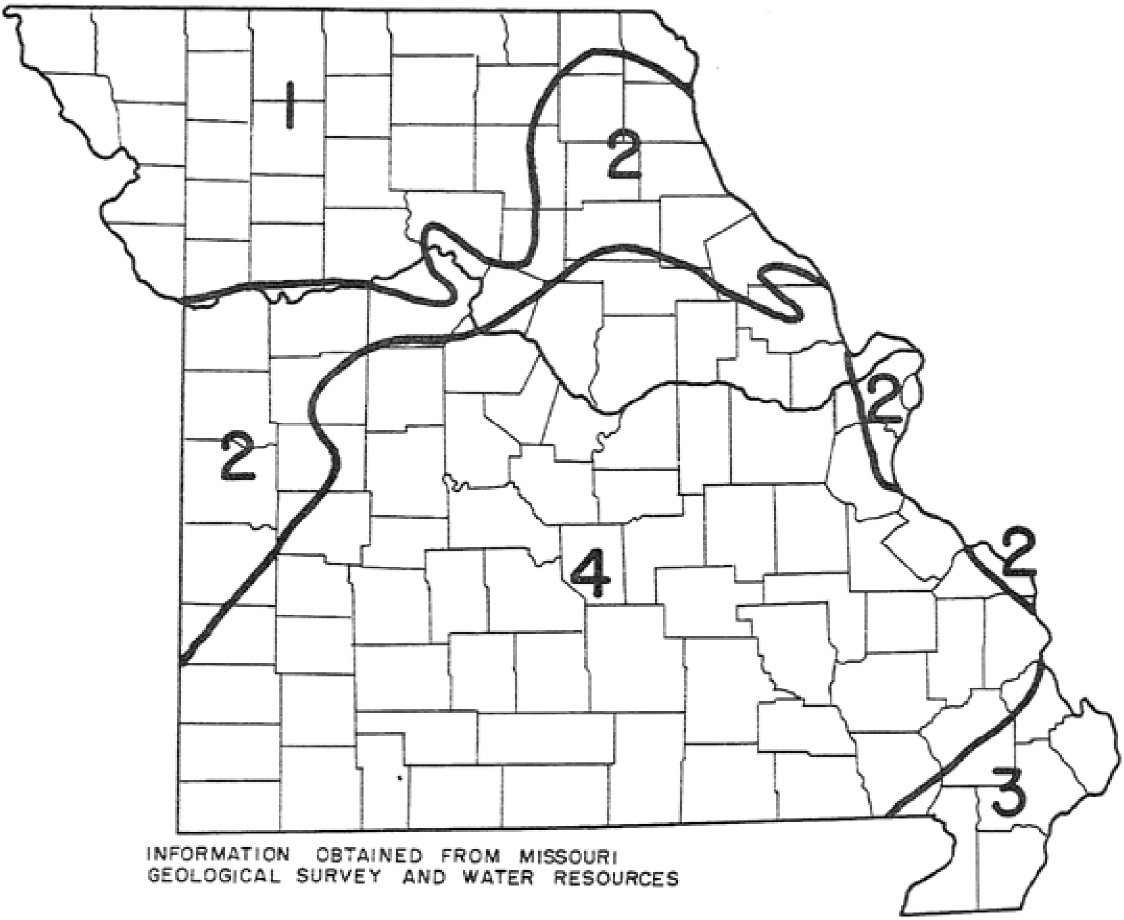

Fig. 1—Availability of ground water supplies in Missouri.

FARM PONDS FOR DOMESTIC WATER SUPPLIES

Farm ponds have become popular for livestock water, and with today's heavy earth moving equipment, the contruction of new ponds specifically designed and located for domestic water supplies is not a major problem.

Comparison of Ground and Surface Waters

Suspended impurities and bacteria, in general, are not found in ground water, but are found in varying degrees in surface water supplies. The degree to which suspended impurities are found in surface water depends to a large extent upon the condition and care given the runoff area and the reservoir itself. There is also some variation in the purity of ground water, depending upon the type of underlying strata the water comes from. In limestone, which has a tendency to fissure and crack, surface bacteria may enter and flow with the underground current for great distances to enter a spring or well. Where there are underlying materials that do not crack or fissure, the filtering action of the material itself is often sufficient to remove suspended impurities and bacteria. Poorly constructed wells and covers are the source of much contamination found in deep well waters.

Salts of calcium, magnesium and sodium, iron-oxide and magnesium, and hydrogen sulfide are found in both surface and ground waters, but concentration of these impurities is usually much greater in ground waters. These chemical impurities are in solution rather than in suspension. Chemical concentration depends on time of contact. Surface waters run off rapidly and usually over short distances, thereby allowing only a little chemical action.

Vegetable dyes are found only in surface water while oxygen, carbon dioxide, and nitrogen may be found in both surface and underground water. The concentration of these impurities in surface waters may be controlled to a large extent by care and maintenance of the water shed and reservoir. If a large amount of organic matter is allowed in the reservoir, carbon dioxide will be found in large amounts as a result of decay and undesirable tastes and odors may result.

Water Borne Diseases and Their Causes

Typhoid fever, dysentery (both amoebic and bacillary), gastroenteritis and asiatic cholera are the important water borne diseases. All of these diseases are transmitted by the intestinal and urinary discharges of sick persons and carriers. This source of contamination, prevalent in surface waters, must be controlled with disinfection. Cisterns as used for years are, in general, quite contaminated. They not only receive impurities and bacteria from the roof but many are poorly constructed with the result that surface pollution enters through cracks in the walls or through faulty covers. Faulty construction is also a common cause of contamination of many wells that would otherwise produce pure water. Improper installation of plumbing may also bring about contamination.

Care and Maintenance of Watersheds and Reservoirs

Certain basic principles have been used for years in connection with watersheds used for municipal water supplies, and no doubt most of them can be applied to watersheds for farm reservoirs as well. Water draining from any known source of pollution obviously should be diverted from the watershed .

The Quality of Farm Pond Waters

The first step of this study in diagnosing the problem of utilizing surface runoff water for domestics purposes was to determine the characteristics of the runoff water from different types of watersheds under varying conditions.

Twenty farm ponds in the vicinity of Columbia, Mo., having five different types of watersheds handled under different conditions, were selected for this study. Water samples were taken regularly every two weeks from these ponds over a period of months so that the findings might be representative of conditions throughout the various seasons. Two separate samples were taken in each case, one for the bacteriological analysis and the other for the chemical analysis.

Seasonal Fluctuations

The analyses made, other than bacteriological, were for hardness, alkalinity, nitrate content, and turbidity. Figure 2 presents, graphically, the results from these analyses. For an indication of seasonal effects or trends the test results from all ponds were averaged together. In examining the plotted data it will be noted that all of the characteristics tested were low during the summer months followed with the tendency to increase in the early fall until peaks were reached in the October-November period. After December all values began to decline and it is anticipated that they would again peak during the spring months.

It is significant that the quantity of nitrates present was found to be very low. No measurable quantities were found until late fall after the ponds had begun to freeze. The amount of rainfall is also plotted on this graph to show any relation between rainfall and the other factors. No relationship was apparent.

The turbidity of the waters in the various ponds throughout this seasonal check averaged a little above 20 parts per million (ppm), which is a satisfactory level for filtration treatment.

Bacteria as Affected by Watershed and Seasons

Bacterial tests were made on raw pond waters to establish the level of bacterial concentration in various ponds during various seasons, rather than to determine its suitability for drinking. The tests made were of the type which confirm the presence of bacteria of the E. coli group. This type of bacteria has the characteristic of forming gas during growth in a suitable medium. Gas formation in the medium does not necessarily mean that disease bacteria are present, since some members of this gas forming group are harmless. However, gas formation does cast suspicion upon the water because it establishes the possibility of the presence of harmful types. No attempt was made in the first phase of this study to isolate any specific bacteria.

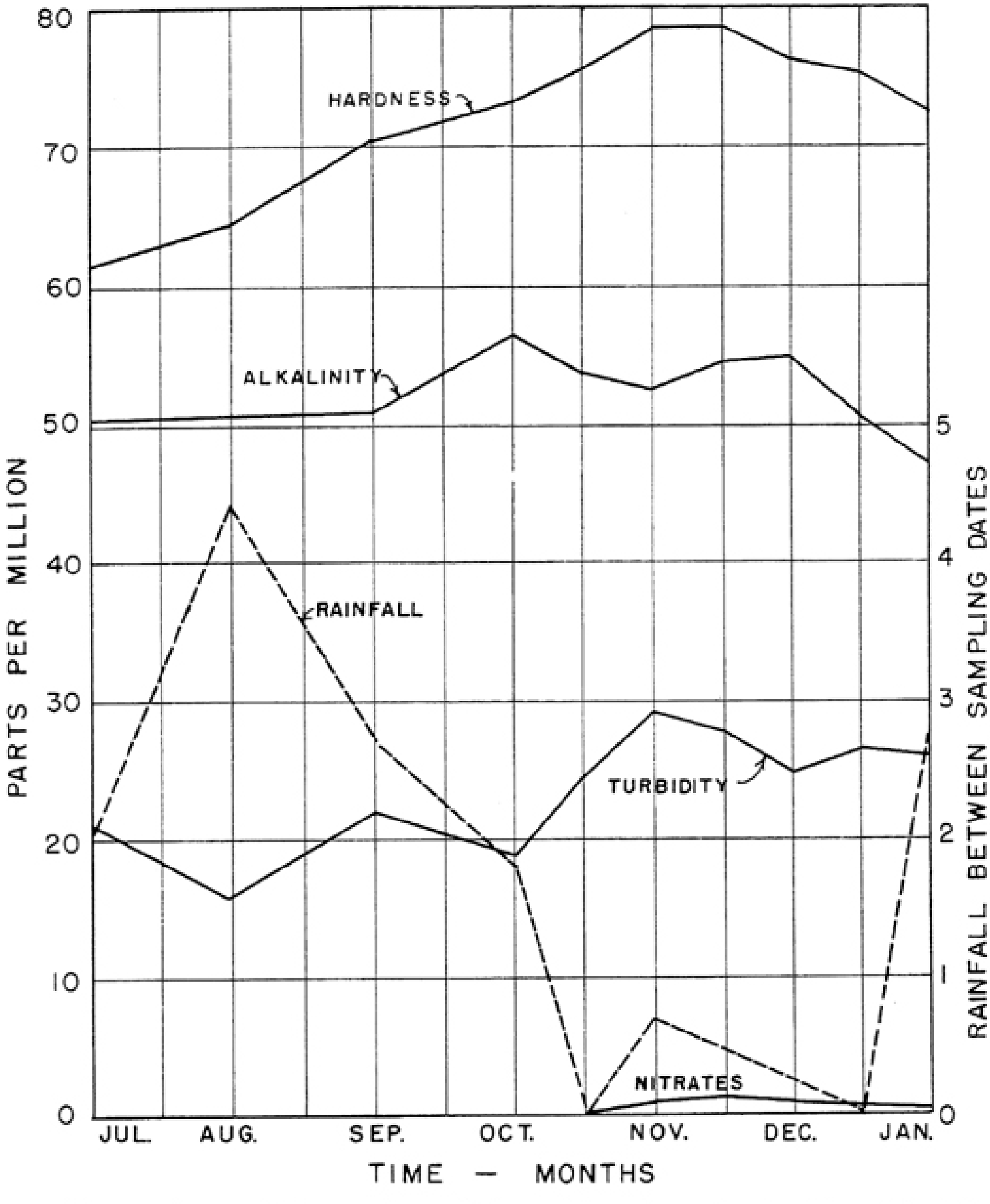

Fig. 2—Seasonal fluctuations of the quality of pond water from all types of water sheds.

Figure 3 shows graphically the heavy concentration of bacteria found in the ponds during the fall and early winter. Where pond water is to be used during all seasons for domestic supply, additional care must be exercised during these months. The increased amount of bacteria in the ponds during the fall season was no doubt due to more favorable living conditions within the pond and the decreased amounts during the summer months due

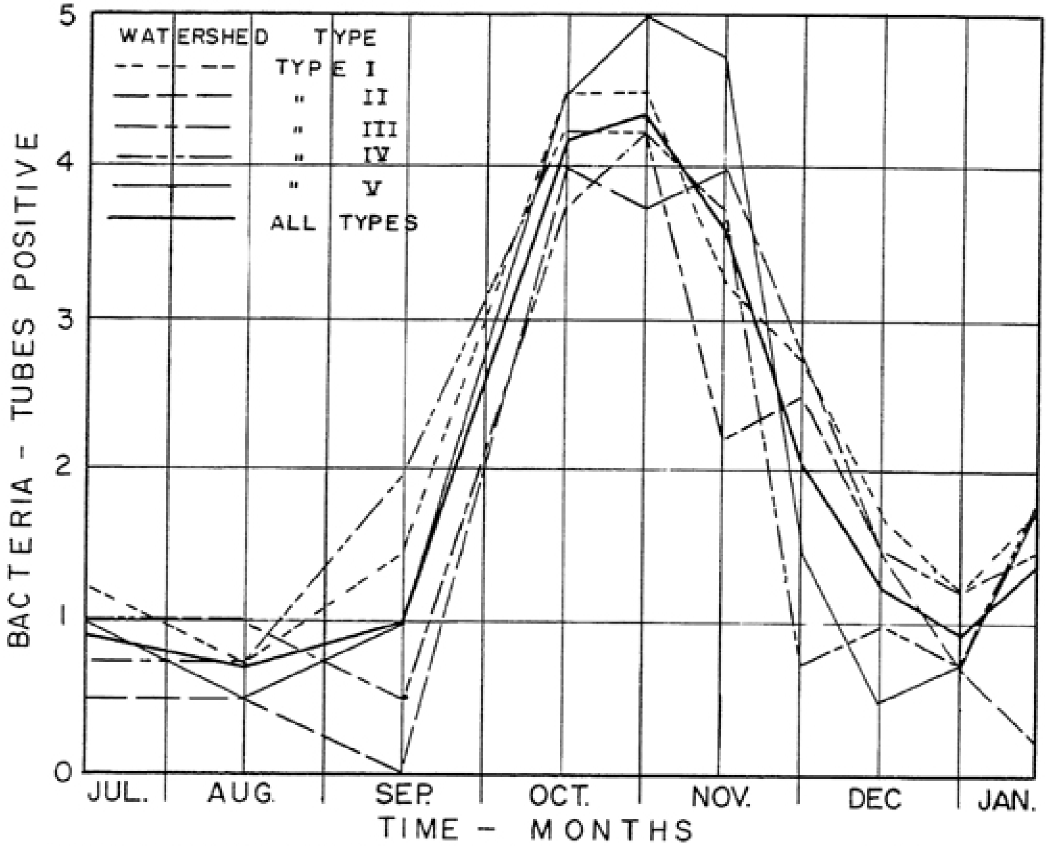

Fig. 3—Seasonal fluctuations of bacteria with respect to watershed type.

to the intense sunshine which is toxic to the growth of bacteria. In late fall and early winter the temperature of the water lowers and again unfavorable conditions for the growth of bacteria are set up. The low bacteria counts during the summer months reflect quite directly the effect of sunshine on the water as the samples were all taken within the top 6 inches of pond water. This toxic effect of sunshine, however, would be expected to decrease at greater depths.

Although the seasonal effect on bacterial concentration in pond waters was significant as indicated by Figure 3, there was little appreciable variation between the five watershed types. The five watershed types are defined as follows:

Type 1. Small, well-grassed watershed used only for the collection of water.
Type 2. Large, grassed watershed supplying more water than necessary to fill the pond, and used for grazing.
Type 3. Small well-grassed watershed used for grazing.
Type 4. Terraced, grassed watershed used for grazing.
Type 5. Cultivated watershed.

Turbidity Level as Affected by Watershed and Seasons

The turbidity of water is important in considering it for treatment with slow sand filters. Observations in general indicate that there is a great variation in the turbidity of water in different ponds and considerable fluctuation within the same pond throughout the various seasons. Turbidity analyses were made from 20 ponds with five different types of watersheds in an attempt to explain these variations.

The curves shown in Figure 4 indicate that the quality of water in ponds is determined by other factors than the type of watershed. It will be noted that most turbid waters in this test were produced by ponds having small, well-grassed watersheds used only for the collection of water. The cultivated watershed produced pond water having about average turbidity throughout the test and the small, well-grassed watersheds used for grazing produced water with the lowest turbidity. It is evident from these findings that there are other more dominate factors that affect the turbidity of pond waters.

Although there appeared to be no correlation between watershed type and the turbidity of pond waters in this test, there was general seasonal trend followed by all ponds. The quality of farm pond water might be expected to be at its lowest ebb during the spring and fall rainy seasons. This was borne out by this test, although the experiment covered a period with below normal rainfall. The high turbidity during these two seasons is no doubt due to convection currents in the water rather than to runoff. As the surface water is cooled, it settles or sinks to a lower level, and as cooling continues, the water is in constant motion. This motion tends to keep material entering the pond in suspension and to bring settled material up from the bottom.

Surface area and volume of ponds might also affect the turbidity of the water but no correlation was found in this experiment.

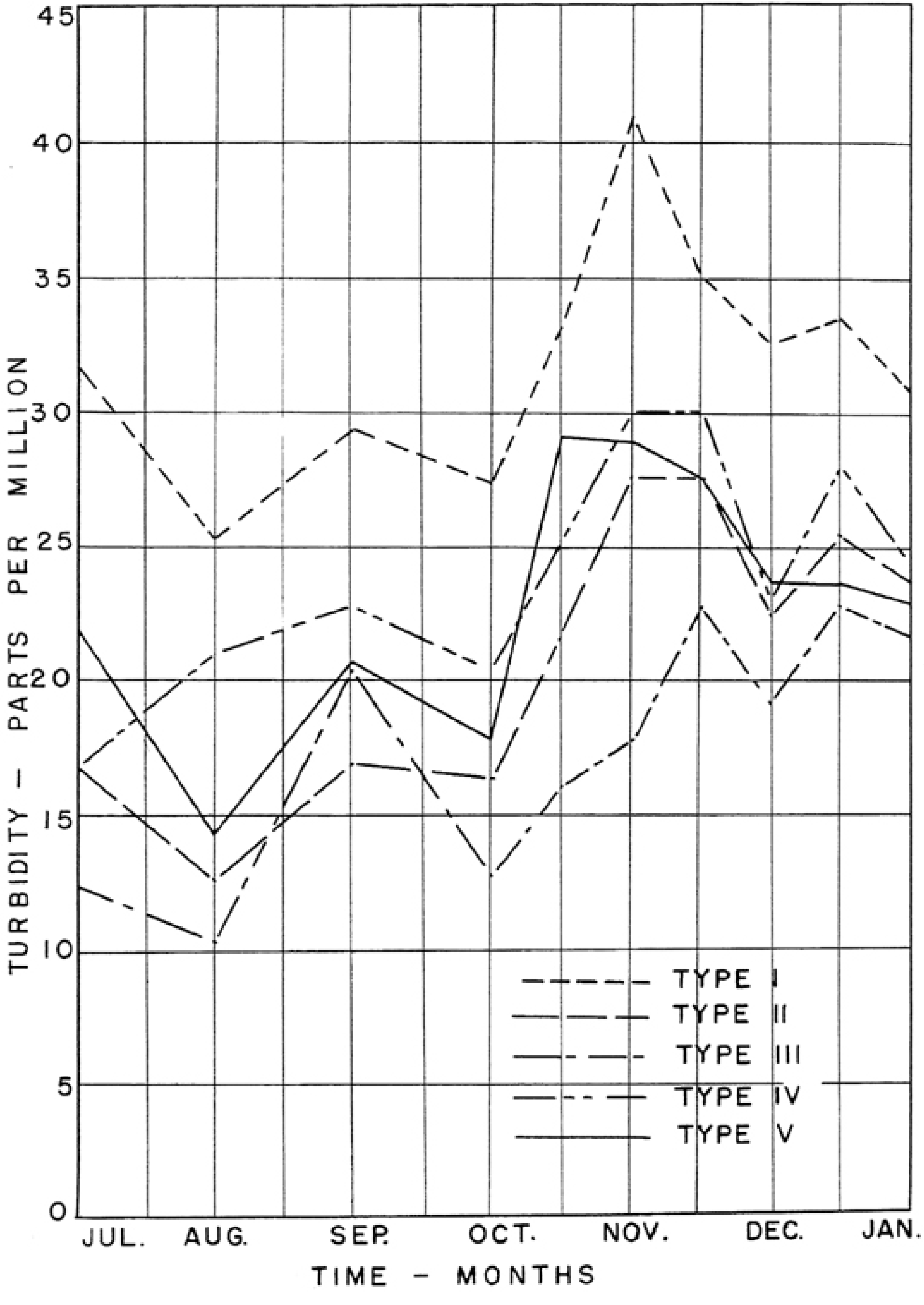

Fig. 4—Seasonal fluctuations of turbidity with respect to watershed type.

Turbidity Level as Related to Water Conductivity

Observations indicate that some ponds tend to remain in a highly turbid condition throughout all seasons. One factor which seemed likely to affect the rate of settling of suspended particles is the conductivity of the water as caused by the amount of salts in solution. If colloidal particles in suspension in water are to coagulate by electrolytic action into larger particles of sufficient weight to settle, they must then be surrounded by a medium which will conduct electricity.

To determine if there was any correlation between pond water turbidity and water conductivity, tests were made on the 20 ponds in this study. The results were somewhat erratic but several characteristics are noteworthy. In general, as the conductivity of the water increased, the turbidity decreased. A majority of the points as plotted in Figure 5 fall fairly closely into one general pattern. A few ponds showed a definitely higher turbidity with a given

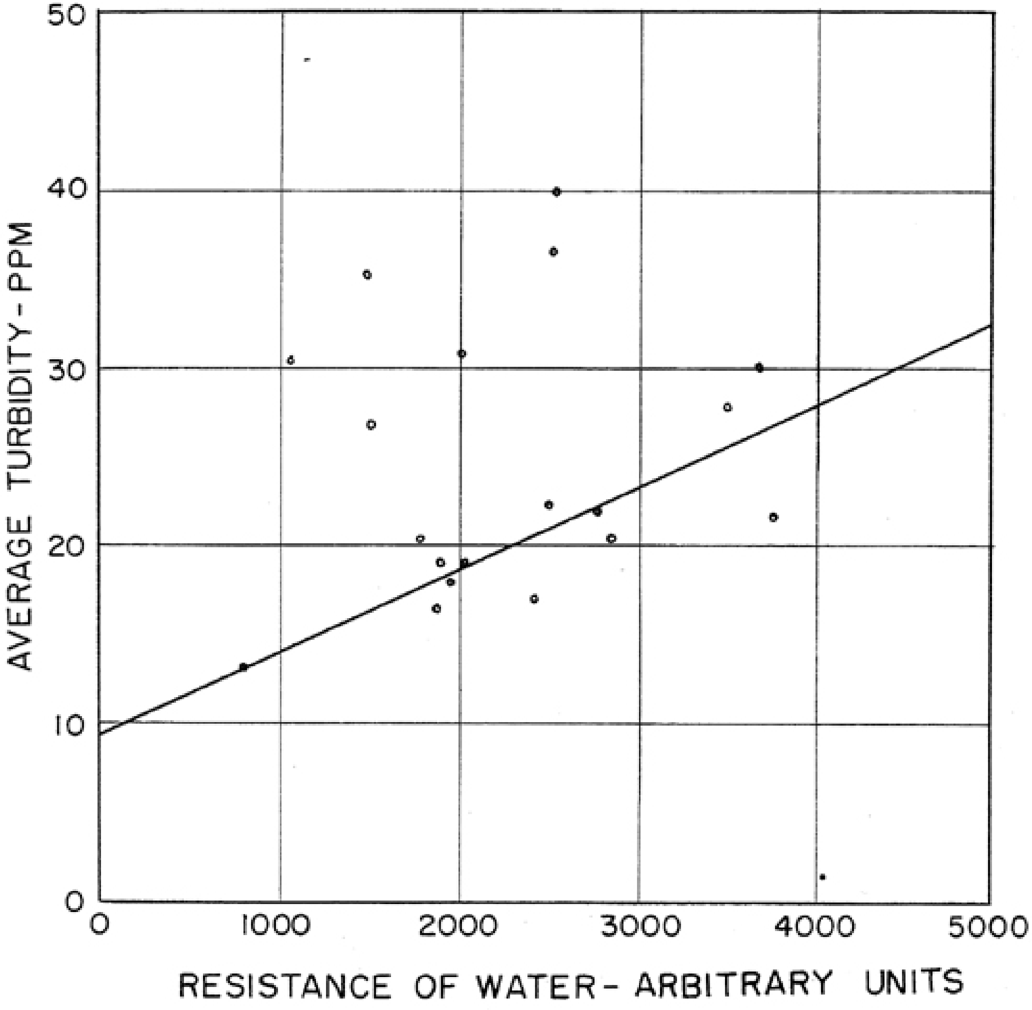

Fig. 5—Relation between pond water conductivity and turbidity level.

conductivity. This might be explained by the quality of the runoff water entering the pond. Water from a few water sheds might carry a larger load of finely divided, suspended particles produced by an easily dispersed soil, thereby allowing a somewhat higher turbidity in relation to a given water conductivity.

The most logical source of salts in pond waters is from the watershed soils. In order to check this, six soil samples were taken from each watershed and tested. A highly significant correlation between the conductivity of the soil and the conductivity of pond waters was evident (Figure 6).

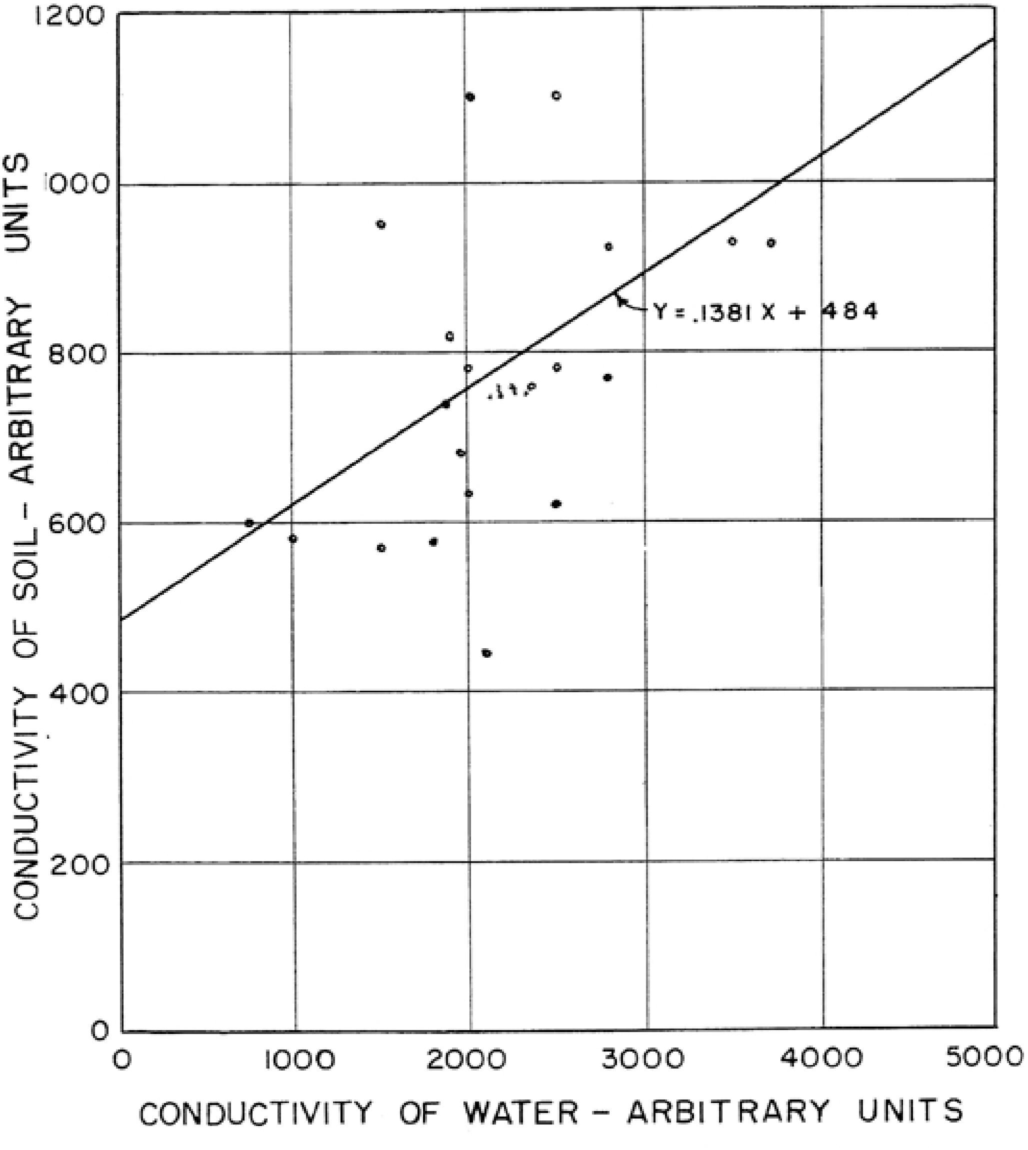

Fig. 6—Correlation between conductivity of watershed soil and runoff water.

Pond Management

A study made by a soils specialist and an agricultural engineer, on two ponds located close together and with almost identical watersheds showed that one was consistently turbid and the other quite clear. An analysis of the water from each pond showed the only difference to be in the conductivity of the water. The clear sample was a much better conductor than the turbid sample which had little more conductivity than distilled water.

In another case study during the spring of 1951, the amount of gypsum necessary to flocculate all of the suspended clay in a pond near Columbia, Mo., was calculated. In a trial application, the gypsum was put in the pond one-third at a time. One week after the first third was applied no effect was discernible. At the end of the week following application of the second portion the pond had cleared noticeably. The remainder of the flocculent was then applied with further clearing. The water from this pond, after going through a horizontal filter, was sparkling clear within a week, but it was not until considerable filamentous algae had grown up and died out later in the summer that the pond itself became sparkling clear. A year later the pond was still clear and the gypsum content in the water was negligible.

Since that time, a number of turbid ponds over the state have been treated similarly. The recommended dosage for the average pond is 12 pounds of gypsum for each 1000 [redacted] of water. The full dosage is scattered over the surface of the pond in one application and the turbidity is usually reduced to 10 or 20 ppm within a week or two. Other chemicals that will flocculate suspended clay particles can be used but they usually go into solution too rapidly, causing an immediate heavy floc and endangering the fish life of the pond. This is true of aluminum sulfate, which is widely used as a flocculent in municipal water treatment plants. Hydrated lime and portland cement will flocculate the clay but may be toxic to fish. Gypsum goes into solution very slowly and the floc does not form rapidly enough to endanger the fish. The addition of gypsum, however, caused a noticeable increase in hardness of the water. This hardness gradually lessens and the ponds, once clear, give evidence of being able to maintain their clarity with the addition of but a small quantity of gypsum every year or two.

In many clear water ponds the growth of algae and other plant life may become a problem. A heavy concentration of algae can clog a sand filter as quickly as the clay it replaces, and in addition, decaying plant life imparts tastes and odors to the water that no amount of filtering will remove. Plant life can be controlled effectively by the judicious application of copper sulfate to the water. It can be applied at the end of the pond containing the filter intake, and the remainder of the pond left free to grow the aquatic plant life beneficial to fish.

A clear water pond will not only look cleaner, but will have fewer bacteria. Turbidity protects disease bacteria from the disinfecting effect of the sunlight. Algae growths, if not heavy enough to be detrimental otherwise, are beneficial in that they emit large amounts of dissolved oxygen, which is extremely toxic to bacteria.

Summary

The average hardness of pond waters as sampled over a seven-month period was 72.9 ppm. This is not too hard for most uses in the home. Most municipal plants do not soften water which is below 70 ppm. It was found that the amounts of turbidity, hardness, alkalinity, pH, nitrates, and bacteria were somewhat higher in the early fall months than during the summer season. The amount of rainfall did not appear to be related directly to the quality of the pond waters. The presence of nitrate was not found in measurable quantities until late fall when the ponds began to freeze. The turbidity of the pond waters tested averaged a little above 20 ppm, which is a satisfactory level for filtration purposes. The seasonal affect on bacterial concentration was quite pronounced, inasmuch as many samples taken during the summer months were quite free of bacteria. Little variation in bacteria was found between the various types of watersheds.

No significant correlation was found between type of watershed and turbidity of the water, which indicates that the quality of water in farm ponds is determined by other factors. The pond waters were tested for their ability to conduct electricity and in general it was found that as the conductivity of the water increased the turbidity decreased. As the watershed soils seemed to be the most logical source of salts in pond waters, the pond waters and watersheds were further checked to determine any correlation. A highly significant correlation between the conductivity of the soil and pond waters was found.

Tests with turbid pond waters showed that they could be cleared successfully with an application of 12 pounds of gypsum to each one thousand gallons of water in the pond.

EFFECTIVENESS OF HORIZONTAL SLOW SAND FILTERS

The lack of water for domestic purposes led many farmers during the last few years to choose the farm pond as a new source. Sand filters of various types were installed. Due to the immediate demand for information, a horizontal trench-type slow sand filter was devised. By the spring of 1953 an extension service survey indicated that there were some 200 systems of the type shown in Figure 7 in operation in Missouri. Although the filtering systems varied in respect to the location and construction of the entrance

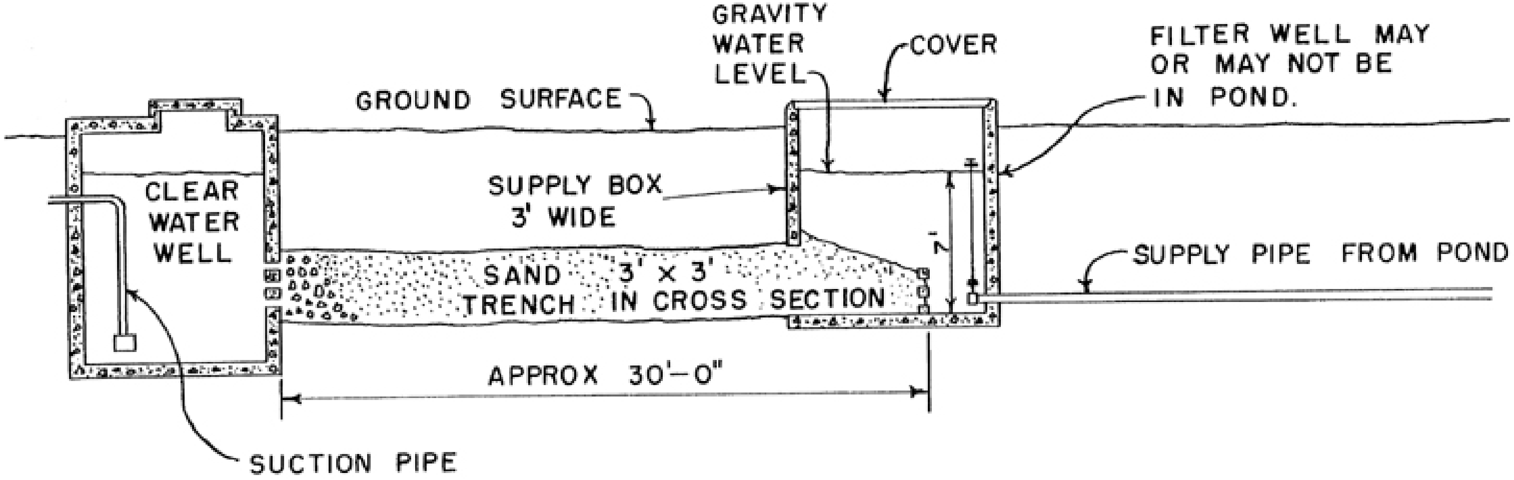

Fig. 7—Filter (horizontal) with influent well outside of pond.

well and the storage cistern, they were all made up essentially of a trench of sand 3 feet square in cross section and 30 feet in length. Many of the filters were constructed with the entrance well in the pond and the sand trench extending through the dam.

These existing slow sand filters provided an opportunity to test the effectiveness of this type of a filtering system under actual farm operating conditions. Thirty installations in north central Missouri were chosen for this investigation. Each installation was found to differ from the others in at least one respect. In order to properly analyze the systems a complete physical description was made of each. The description included a listing of the dimensions of the cistern, sand trench, influent well, and pond. Various uses, of the water and the number of people the system supplied were also listed to furnish an estimate of the average daily flow of water through the filters. Other items included in each description were a schematic sketch of the system, a brief history of the filter, and, finally, a summary of costs.

Sand Samples

The sand used in the individual sand trenches came from a number of sources. Many farmers used washed river sand from the Mississippi or the Missouri River; others used unwashed creek sand or purchased their sand from a lumber yard. In order to attempt a correlation between filtering effectiveness and the sand used, sand samples were secured, where possible, from each filter. The filtering sands were then classified through tests to determine sizes and uniformity coefficients.

Water Samples

The yardstick by which the effectiveness of a filtration system is ultimately measured is the production of a clear safe water. To measure the bacterial reduction brought about by the filters, samples were collected monthly from both the influent and effluent of each filter. The samples were collected in sterile 200 cc. bottles with foil protected tops, and immediately placed in ice boxes for transportation to the laboratory for analysis. The water samples were tested in the laboratory for the presence of typical *Escherichia* and *Aerobacter* colonies of bacteria and for turbidity.

Turbidity of Influent and Effluent With Respect to Season

The average turbidities of the influents and effluents are shown in Figure 8, as plotted against time. The average influent turbidity through the months of May to October shows a decreasing trend. The month of November indicates some possible upturn in turbidity of pond waters for the winter season. This same trend was indicated in the study of a separate group of ponds (Figure 2).

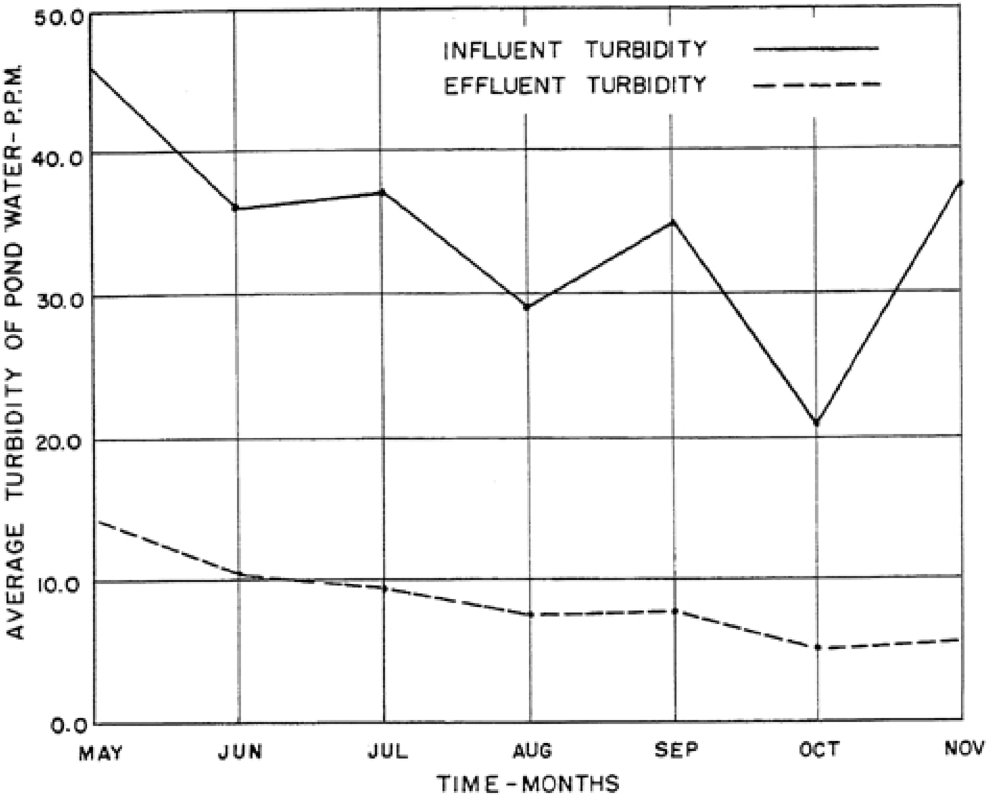

Fig. 8—Seasonal fluctuation of influent and effluent turbidities.

Although some seasonal fluctuation in the turbidity of pond waters is indicated, the important aspect of this study is the lack of seasonal fluctuation of the turbidity of the effluent. While the monthly variations in the effluent turbidity are not nearly as great as those of the influent, they follow the same general trend, decreasing from May until October and then rising slightly. The fact that the effluent turbidity varies relatively little in comparison to the influent turbidity, indicates that the filters do not tend to reduce the influent turbidity by a fixed ratio, but rather, to a constant level of near 10 ppm.

A study of the turbidity reduction characteristics as compared to the influent turbidity shows a significant correlation. This fundamental relationship is shown by Figure 9. A second degree parabola was determined to be the curve of best fit for the data. From the correlation it is shown that the efficiency (based on percentage turbidity reduction), of the sand filters studied increased with increased influent turbidity up to a maximum average reduction of 88 percent for influent turbidities of up to 75 ppm. The turbidity reduction was downward for pond waters with higher than 75 ppm turbidity, indicating that a desirable low turbidity effluent cannot be expected with pond water turbidities above that level.

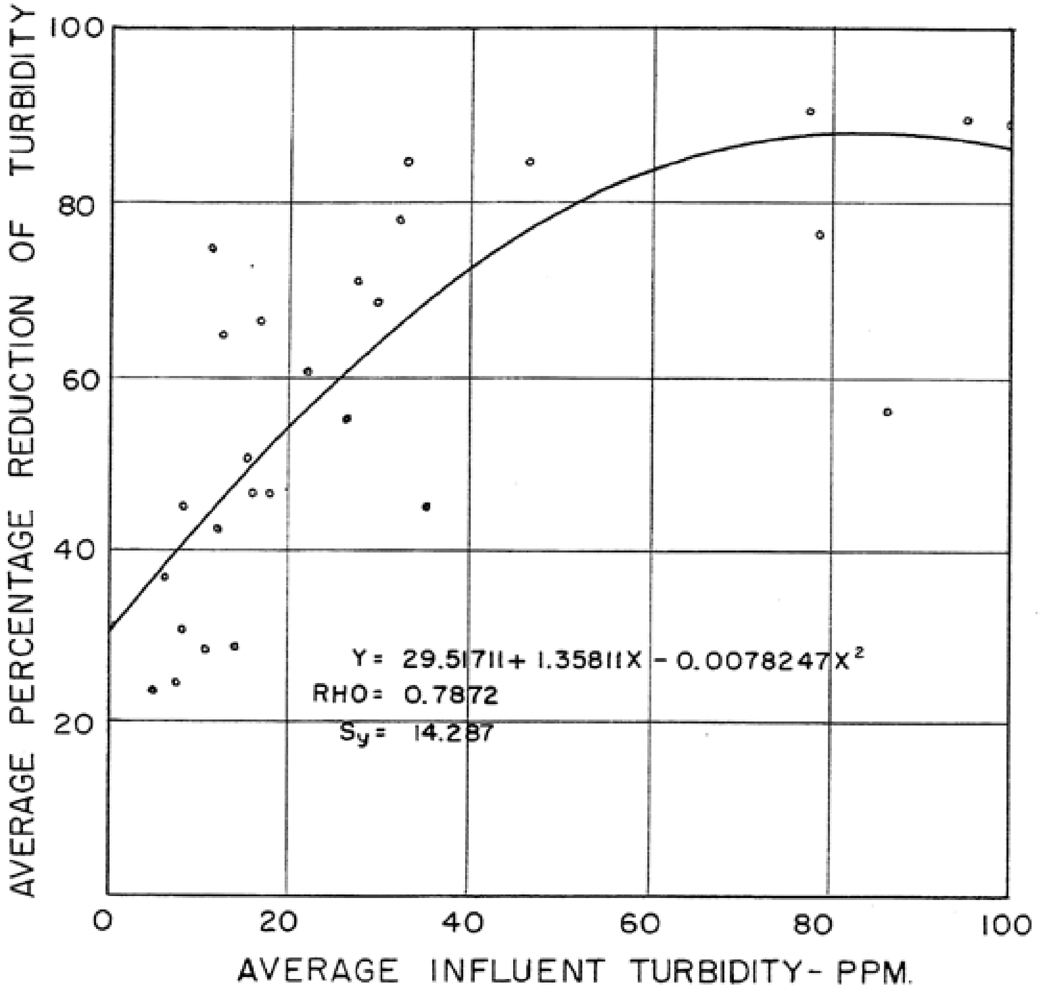

Fig. 9—Turbidity reduction with respect to influent turbidity.

Bacterial Reduction

Figure 10 shows graphically the percentage reduction in bacteria as produced by the filters under test. It will be noted that the average percentage reduction of bacteria increased during the summer months and paralleled quite closely the mean monthly temperature. As shown previously by Figure 3, high concentrations of bacteria can be expected in farm ponds during the fall months and minimum amounts during the summer months. It is, therefore, significant that the least bacterial reduction by the filters tested was during the seasons when the bacteria counts are expected to be the highest. It will be further noted that the percent of bacteria reduction is quite low on the average.

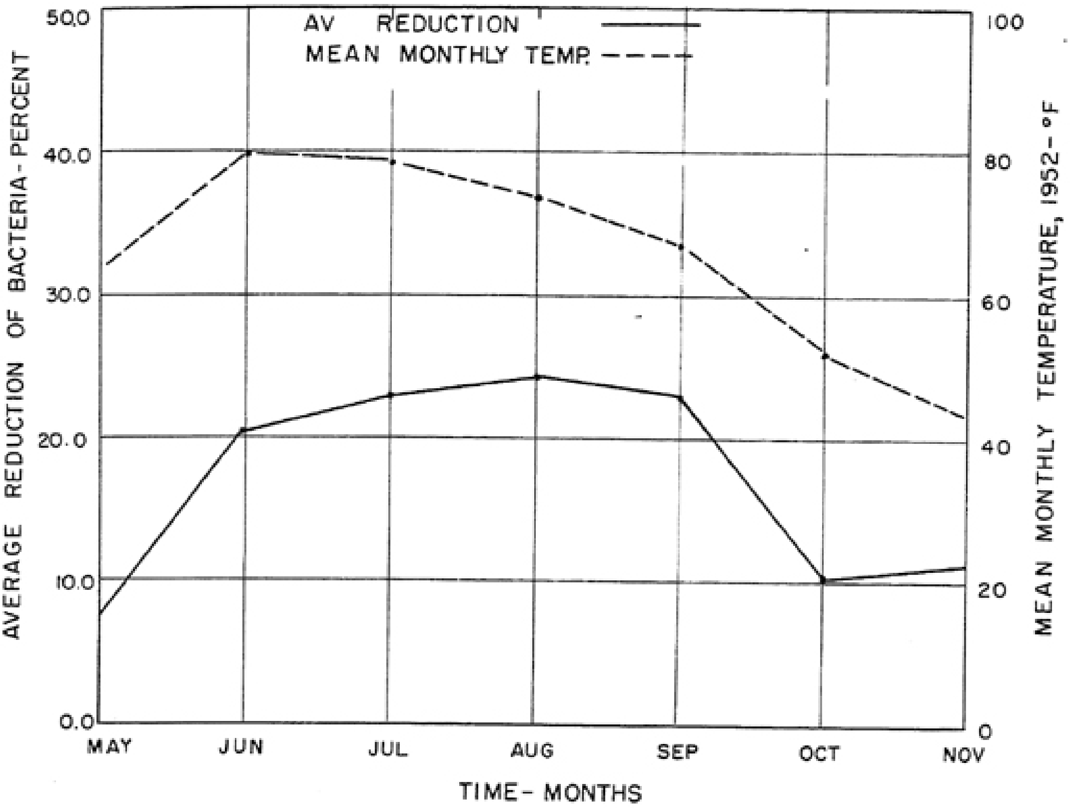

Fig. 10—Seasonal variation of bacterial reduction.

None of the filters investigated yielded a bacteria free effluent for the entire test period. In most cases, the filters were extremely erratic in reducing the bacteria of the influent. In a few cases there was actually an increase in the bacteria concentration in the effluent over that of the influent previous to passing through the filter.

Effective Sizes and Uniformity Coefficients of Sand Samples

The accepted limits for filtering media are an effective size of 0.35 mm. and a uniformity coefficient not to exceed three. The *effective size* is the theoretical sieve size through which 10 percent, by weight, of the sample will pass. The *uniformity coefficient* is the ratio of the theoretical sieve size through which 60 percent, by weight, of the sample will pass to the effective size. Sand samples were obtained from 26 of the filters investigated. Of these, seven or 26.9 percent were found to be within the specified limits. However, if the uniformity coefficient is disregarded, 15 or 57.8 percent of the samples were within the effective size limits of 0.35 mm. This would indicate that the removal of the coarser fraction of the sand would bring a much larger percentage of the Missouri sands within the acceptable limits. Due to the many other variables in the filters studied, such as filter construction, pond waters, storage cisterns, and maintenance, no correlation between sand and filtration effectiveness was apparent.

Summary

Some seasonal fluctuations in pond water turbidities were found as in the previous study. The filter effluent turbidities did not show significant seasonal fluctuations. This indicates that the filters do not tend to reduce the influent turbidity by a fixed ratio, but rather to constant level of near 10 ppm. The efficiency of the sand filters studied, based on percentage turbidity reduction, increased with increased influent turbidity up to a maximum average reduction of 88 percent for influent turbidities of up to 75 ppm. The turbidity reduction was downward for pond waters with higher than 75 ppm turbidity, indicating that a desirable low turbidity effluent can not be expected from highly turbid pond waters.

None of the filters investigated yielded a bacteria free effluent for the entire test period. In most cases the filters were extremely erratic in reducing the bacteria of the influent.

Tests of the sand samples from the horizontal filters studied showed only 26.9 percent were within the accepted limits for slow sand filters of an effective size of 0.35 mm and a uniformity coefficient of three. However, 57.8 percent met the effective size requirement. This would indicate that the removal of the coarser fraction of sand would make these Missouri river sands acceptable.

DESIGN, CONSTRUCTION, AND TESTING OF EXPERIMENTAL FILTERS

In the initial design of experimental slow sand filters for farm use, heavy reliance was placed upon the past experience of municipalities in treating water. Although municipalities now, in most cases, use rapid sand filters, the slow sand filter seemed the most desirable for farm filtration. As pointed out by Ernest W. Steel (9) in his text, slow sand filters require less skilled operation, operating costs are less, little or possibly no wash water is required, and the efficiencies of the two filters are similar.

The most common method of filtration is a system which allows water to pass downward by the force of gravity through a bed of sand. There are many details involved in the process of treating water by slow sand filtration; however, the schematic diagram in Figure 11 shows the conventional type of system used by municipalities. Some of the critical specifications for slow sand filters as established by the experiences of municipalities through the years are as follows:

1. Rate of flow should be limited to less than 3,000,000 gallons per acre per day, or 69 gallons per square foot per day.

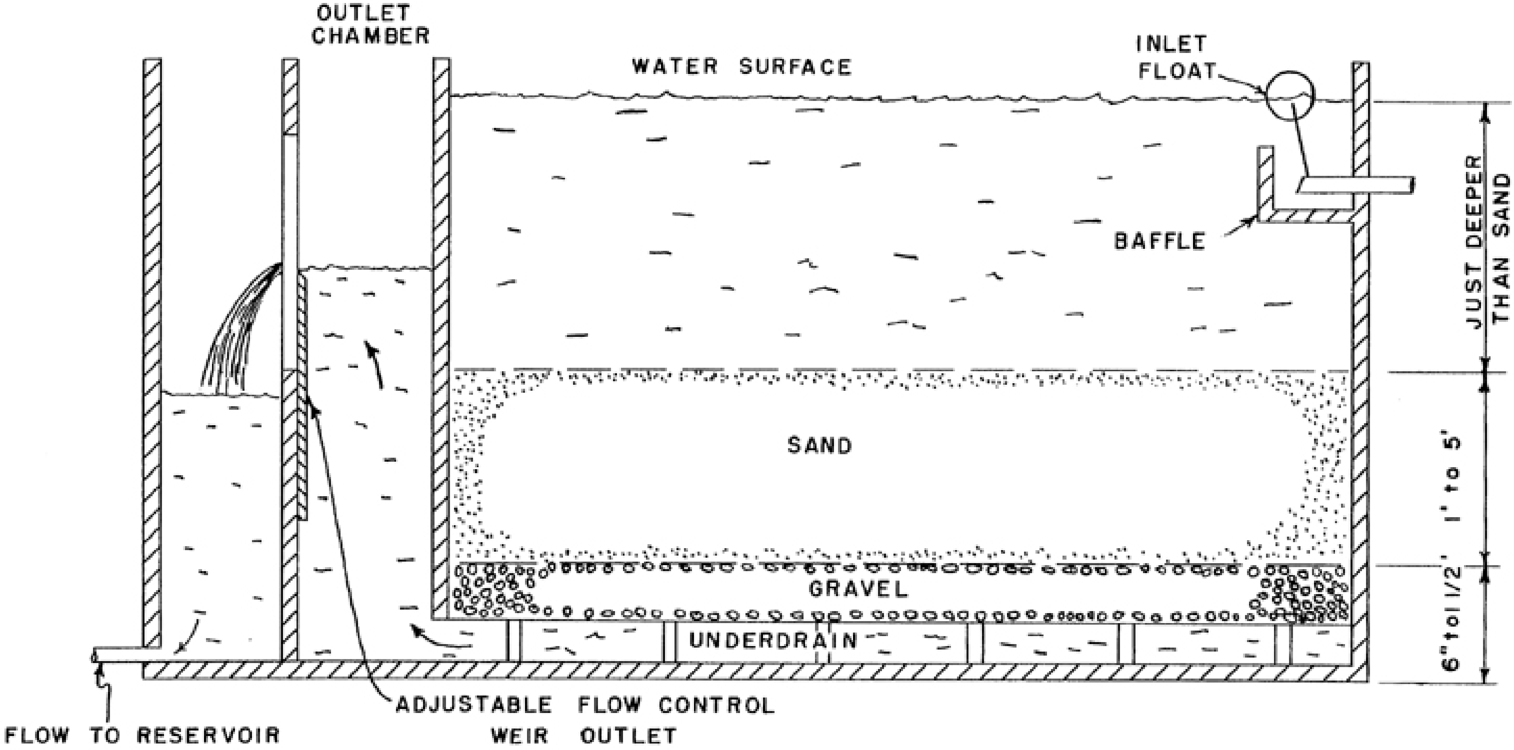

Fig. 11—Schematic drawing showing the features of a municipal slow sand filter.

2. The head of water above the filter sand should be constant and at least equal to the depth of the filter sand.

3. The underdrain system must be designed to receive water uniformly from all parts of the sand bed without clogging with filter sand.

4. The filter media, most commonly sand, should have a uniformity coefficient of 1.75 or less and an effective size of not over 0.3 millimeters.

Experimental Filter Design

The first experimental filter was constructed during the spring of 1950. A portable filter was desired and one that was relatively full scale. A vertical type steel metal filter box (Figure 12) was designed and constructed. The 6-foot depth was adequate for a full scale depth of sand; however, the 4-foot square area was somewhat less than would be required for an ordinary family. The center of the underdrain system was placed 2 inches above the bottom of the filter and surrounded by a 3-inch layer of ¾-inch gravel. Above this a 3-inch layer of ¼-inch gravel was used to keep out the filter sand. This filter allowed for a maximum of 2½ feet of sand with nearly an equal depth of water above the sand.

During the summer of 1953 one additional vertical type filter and one horizontal filter were constructed. The vertical filter (Figure 13) was similar to the first vertical filter except that it was round instead of square. A second filter similar to the first was desired for operation as a control during tests to establish the significance of different variables. The flow rates were to be controlled on the basis of square feet of filter sand so it was felt that the shape and relative size would not be significant.

To test, experimentally, the comparative effectiveness of horizontal filters, a third filter was constructed. This filter was 18 feet long and 3 feet in diameter as illustrated in Figure 14. The filter was constructed similar to the two vertical ones insofar as possible, although it differed in sand depth and direction of flow. The specifications were the same for the underdrain systems in all the filters, and the sand sizes, water depth, and flow rates could be adjusted similarly. The horizontal filter had the underdrain system in a vertical position and the filtering sand surface was sloping as illustrated. One tower, 2 feet in diameter, was placed at the influent end for the purpose of maintaining a head of water equal to the other filters. A second tower, 18 inches square, was welded over a hole about mid-length and filled with sand to prevent channeling along the top of the filter in the case of sand settlement.

Filtering Tests

Test No. 1. The first test with the vertical square filter was started July 13, 1950. This test was designed to explore the possibilites of such a filter clarifying water under extremely turbid conditions and to check the effective-

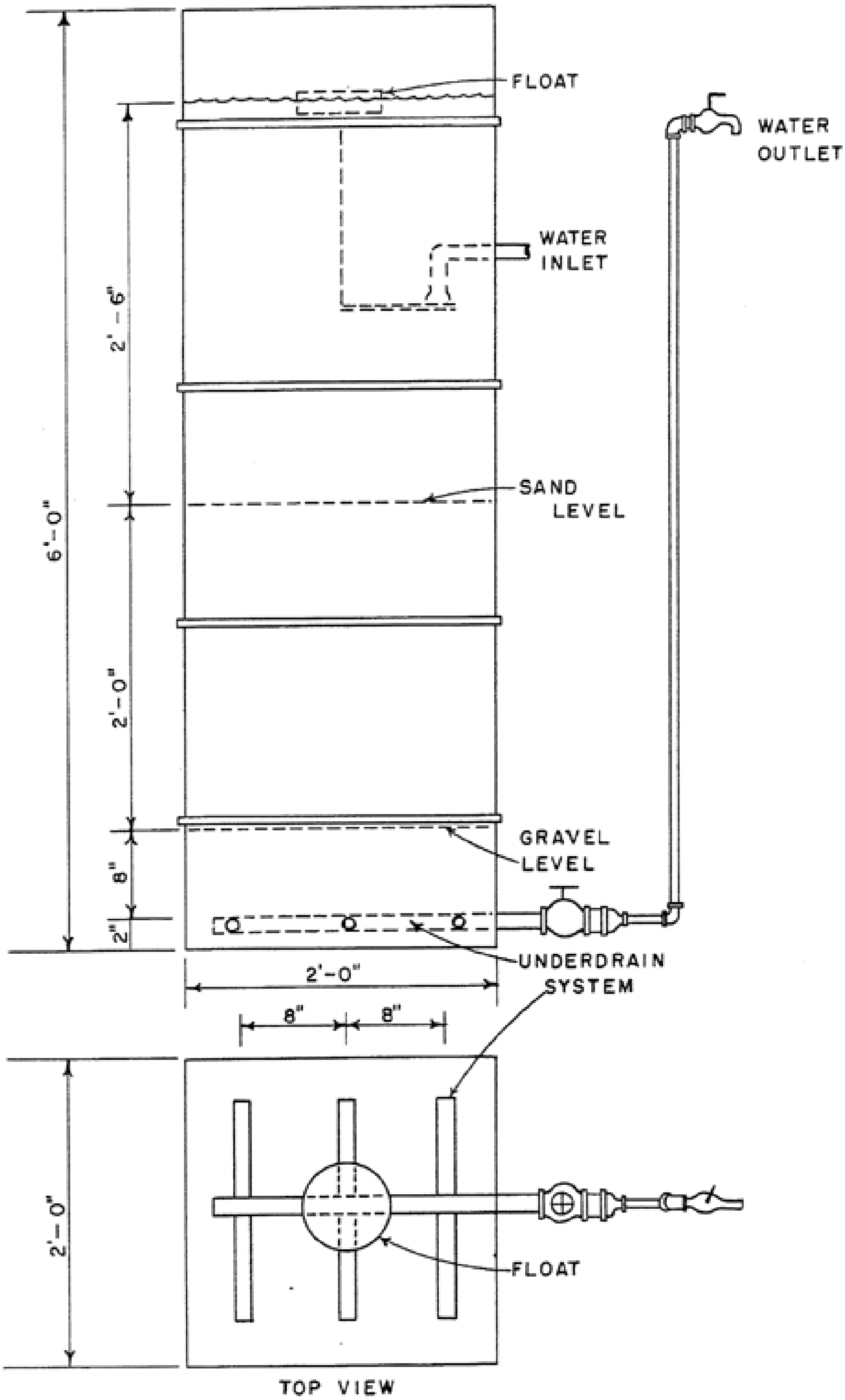

Fig. 12—Details of square vertical experimental filter.

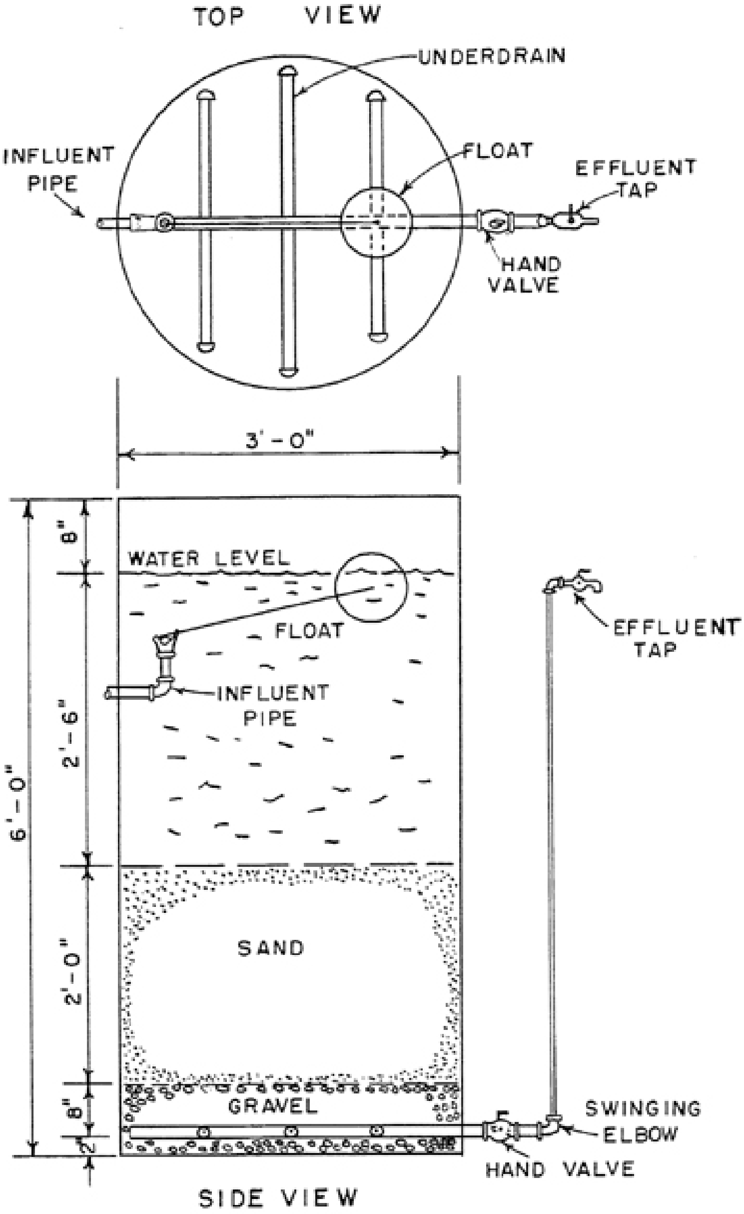

Fig. 13—Design details of experimental round vertical filter.

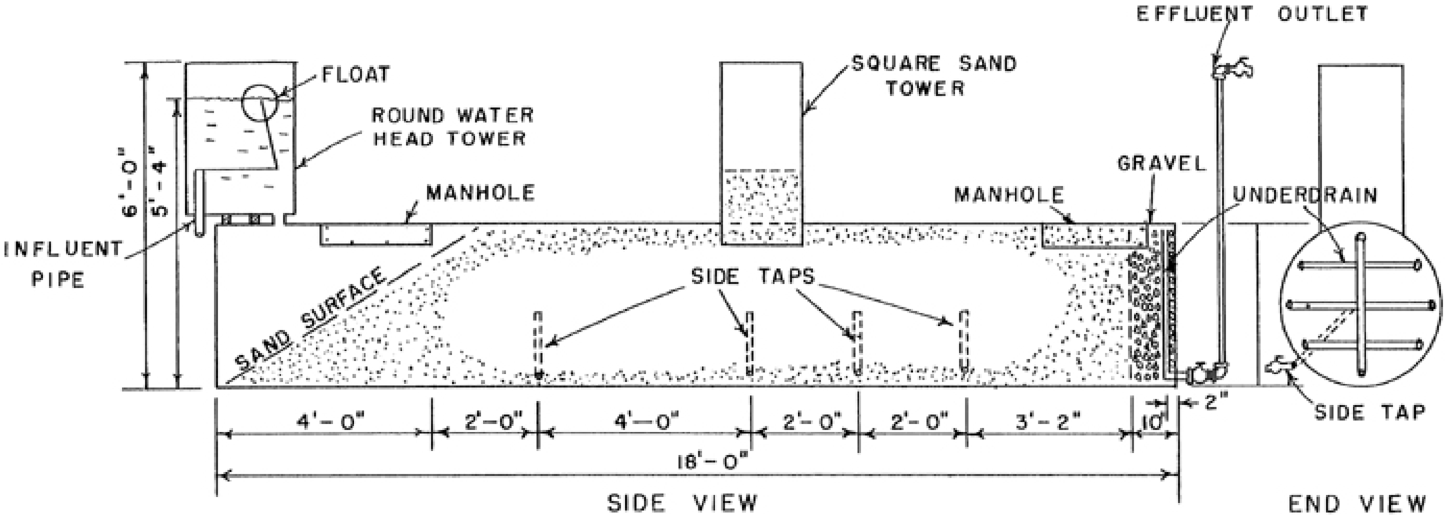

Fig. 14—Design details of experimental horizontal filter.

ness of available ungraded Missouri River sand. The flow of the filter was controlled at 1 gallon per minute, which is approximately 15 million gallons per acre per day and considerably above the limits of a slow sand filter.

During a 14-day period, approximately 14,000 gallons of water were filtered. The average turbidity reduction was from 60 ppm to 31 ppm. This water was still too turbid for domestic purposes. Due to the coarse filter sand, the high rate of filtration and the extremely turbid water, the filter soon clogged. The normal flow of the filter could not be restored by scraping the top surface of the sand, indicating that the high flow rate had forced the colloidal particles down into the coarse sand instead of allowing an accumulation on the surface.

Test No. 2. On October 18, 1950, the vertical square filter was placed in operation in a new location and allowed to flow continuously until November 6. A pond having a heavy growth of algae was chosen to test its effect on the rate of filtration. The sand used in this experiment was graded to a uniformity coefficient of three and an effective size of 0.3 mm. The filter flow was decreased to 0.5 gallon per minute which is still fast for a slow sand filter.

The large amount of algae in the water caused the rate of flow to decrease rapidly. However, it was found that the rate of flow could be fully restored by removing the top 0.25 to 0.5 inches of sand. During three complete tests the filter was entirely clogged at the end of six days operation. The average turbidity of the water entering the filter was 14 ppm and for the effluent it was 6 ppm. The average total flow prior to clogging was 3,000 gallons or a 12-day supply for an average family. This rapid rate of clogging emphasizes the importance of algae treatment of the pond water, as cleaning a filter this often would not be practical.

Test No. 3. The vertical square filter was placed in operation in a new pond on April 5, 1951, and continued in operation in that location until May 5, 1951. The rate of flow was adjusted daily, so that the total daily flow was 250 gallons. The rate was well within the slow sand filter flow rate of 3,000,000 gallons per acre per day, and sufficient for an average family.

The average turbidity of the water entering the filter was 20.3 ppm, and the average turbidity of the filter effluent was 11.8 ppm. The turbidity of the filter effluent decreased with the length of operation of the filter, even though the turbidity of the pond water increased.

This test was made under conditions similar to those that might be found on a farm. The flow rate was adjusted to the estimated requirements of an average family and the pond was one having average quality water. After one month's operation the filter was still furnishing the required amount of water without scraping the top layer of sand. This would indicate that if a filter 3 feet by 3 feet was installed for the average family it would not require cleaning more often than once every two months.

The effectiveness of this filter in removing bacteria was also checked. Although an initial sterilization of the filter was made, no reduction in bacteria was found during the first eight days. In fact, more bacteria were found in the filter effluent than in the raw pond water. It was believed that the filter was improperly sterilized so a stronger chlorine solution was used in repeating the sterilization and the purification effected by the filter immediately improved. After the first eight days the filter produced water from which less than 10 percent of the total number of 10 milliliter portions examined showed the presence of organisms of the coliform group, and no single samples contained three or more portions which showed the presence of coliform organisms. Samples were taken every other day for these tests and the water met the standards for drinking water, as specified by the United States Public Health Service (6) which states that: of all the 10-milliliter portions examined per month, not more than 10 percent shall show the presence of organisms of the coliform group.

Test No. 4. During the fall of 1953 both the square and the round vertical filters were in operation for a period of ten weeks and the horizontal filter for seven weeks. The three filters were operated and controlled in exactly the same manner in all possible respects. The maximum rate of flow through the filters was controlled at 3,000,000 gallons per day. This rate of flow is equivalent to 69 gallons per square foot per day. The average rate of flow for the ten-week period was estimated at 2,100,000 gallons per acre per day or 48 gallons per square foot per day. The sand used in all three filters for this test had an effective size of 0.5 millimeters and a uniformity coefficient of 2.8. The depth of sand in the vertical filters was 2 feet. The average length of sand in the horizontal filter was 15 feet. The depth of water above the sand in the vertical filters was 30 inches and as measured from the bottom of the sand slope in the horizontal filter was 64 inches. Water samples for testing turbidity and bacteria present were taken three times per week.

The vertical round filter started consistent bacterial reduction on the twenty-fourth day of operation and the square filter on the twenty-ninth day. They continued to show some reduction until the forty-fifth day, at which time the sand surface was scraped to restore the filtering flow desired. After scraping, the vertical square filter showed bacterial reduction on the fourteenth day and the round filter on the twenty-first day. At no time did these filters produce consistently for any length of time a water that would meet the Public Health Standards for drinking purposes. The horizontal filter did not reduce bacteria until the forty-fifth day of operation. These test emphasize that slow sand filters, even under fairly well-controlled conditions, cannot be expected to produce a water safe for drinking purposes.

Pond water being filtered in this test was fairly clear, having a turbidity of 13 ppm. The amount of filtration prior to clogging is related to the pond water turbidity and in this case 2,256 gallons per square foot were filtered prior to clogging in the vertical filters. At this rate, the filter would supply water for 45 days prior to clogging at a filtration rate of 50 gallons per square foot per day.

Test No. 5. Three laboratory test filters were constructed of plastic cylinders 6 inches in diameter and 52 inches high. The fourth laboratory filter used was the square verticle filter used in the previous field tests. The plastic cylinders were constructed to scale as illustrated by Figure 15 and the flow rates controlled similarly to the field installations. The raw water for the filters was supplied from an elevated tank. Both the turbidity and the contamination level of the raw water were controlled artificially. Colloidal parti-

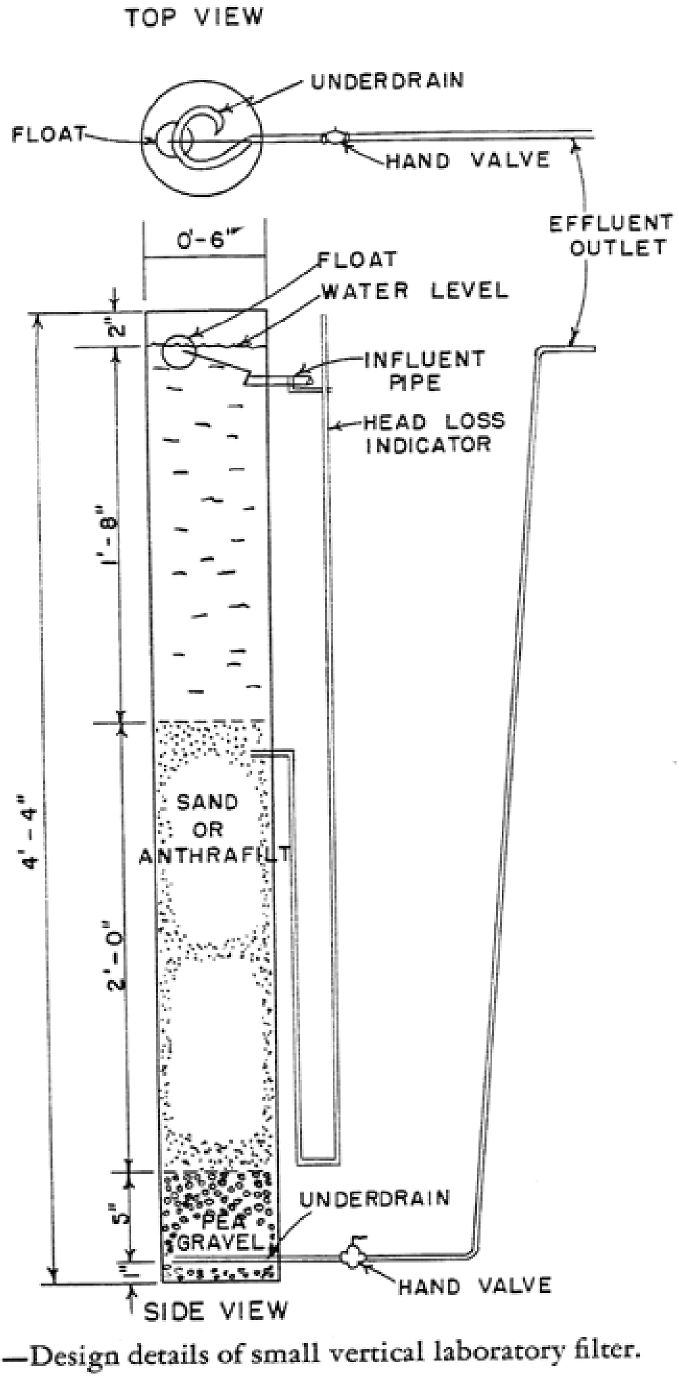

Fig. 15—Design details of small vertical laboratory filter.

cles were kept in suspension by a small electric agitator. The contamination level of the raw water was held constant by adding a calculated amount of *Escherichia coli* a few hours before the test samples were taken. The filters were operated 6 hours out of each 24 at a flow rate not to exceed 3,000,000 gallons per acre per day.

The laboratory tests were set up and operated in such a way that the effectiveness of filtering media could be investigated further. In all of the filters except one, washed Missouri River sand procured from a concrete mix company was used. The sand was first screened through a regular window screen with eighteen meshes to the inch. Figure 16 illustrates graphically

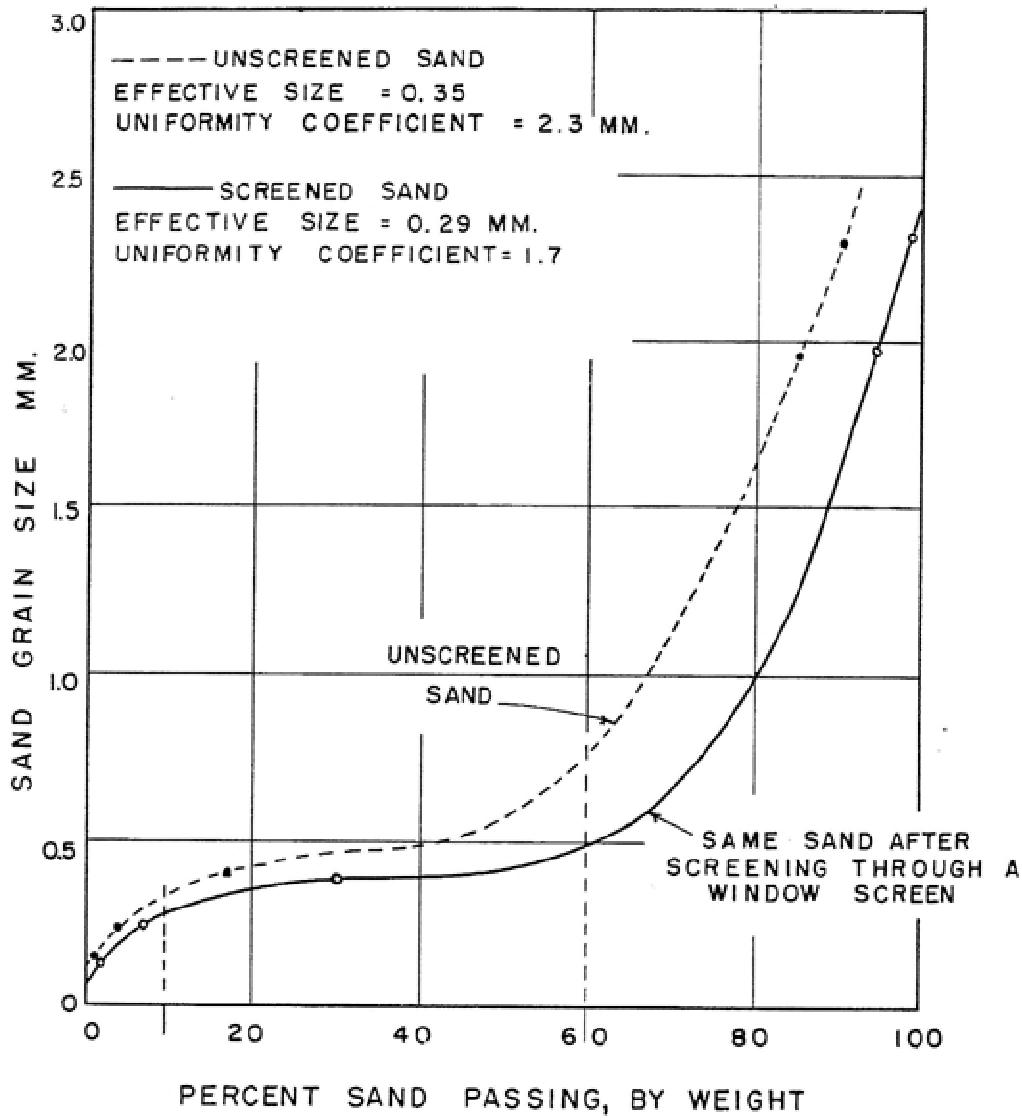

Fig. 16—Analysis of sand sample from laboratory experiment.

the change in gradation of the sand brought about by screening. It will be noticed that the effective size was reduced from 0.35 to 0.29 mm and the uniformity coefficient from 2.3 to 1.7. The screened sand met all the major requirements for a top quality filtering medium. Anthracite filter media was used as a filtering medium in the other test filter. The anthracite filter media had an effective size of 0.60 mm and a uniformity coefficient of less than 1.75. Two feet of filtering media was placed in three of the four test filters. One foot of sand was tested in one of the scale filters to compare it with the 2-foot depth.

Head loss indicators were installed 2 inches below the surface of the filtering sand (Figure 15). The filtration studies indicated that the sand produced a head loss rate of 1 inch for every 60 gallons of water filtered per square foot of filtering surface. The anthracite filter media produced in comparison, 1 inch of head loss for every 500 gallons per square foot.

Water samples for bacterial analysis were collected twice weekly during the first month of test operation and once weekly thereafter. No bacterial reduction whatever was found until the forty-first day of operation, and then bacterial reduction did not prove to be consistent.

The turbidity reduction of all four filters was excellent. The average turbidity of the raw water was 16.4 ppm and the average for the filtered effluent was 4.1 ppm. All of the filters produced water of almost equal turbidity. The average turbidity reduction of all the filtered effluent samples was 74 percent.

The vertical square filter was used in both field and laboratory tests and its effectiveness in reducing bacteria was slightly greater during the field tests than during the laboratory test. The results were not sufficient, however, in either case to produce water suitable for drinking without further disinfection. This decrease in effectiveness in the laboratory may have been due to stronger bacterial cultures used in the artificially prepared raw water. The turbidity reduction of the laboratory filters averaged 25 percent greater than the averages for the most effective field filter. Although the pond water averaged 3.4 ppm less in turbidity than that in the laboratory, the effluent from the field filters averaged 3.6 ppm more. This no doubt reflects quite directly the effectiveness of the filter sand in the laboratory filters which was screened to bring it within the limits of filter sand as set up by municipalities.

Summary

A flow rate beyond the limits for slow sand filtration, and a filter sand coarser than the maximum recommended proved to be ineffective in Test No. 1 during the summer of 1950. A fairly turbid water of 60 ppm was only reduced to 31 ppm during the test. The filter clogged in 14 days and the normal flow could not be restored by scraping the sand surface as the colloidal particles had been forced deep into the sand. Test No. 2 in the fall of 1950 was made on a pond having a high algae content. A somewhat better graded sand was used and the flow rate was reduced by one-half compared to Test No. 1. Although the flow rate was still fast for slow sand filters and the sand not entirely within the specified size, the reduction of turbidity was much better. The high algae content, however, caused the filters to clog within six days. Normal flow could be restored by scraping the sand but the need for weekly filter servicing emphasized the value of good pond water management.

A vertical filter having four square feet of filter sand surface was operated during the spring of 1951 under quite typical farm conditions. Water was filtered at the rate of three million gallons per acre per day which is the maximum for a slow sand filter. The filter sand was fair and the pond water was of average quality. The turbidity reduction was from 20.3 ppm to 11.8 ppm and after one month's operation the flow rate was still satisfactory. After the filter had been sterilized initially and again on the eighth day of operation with a stronger solution of chlorine, the filter produced water free enough from bacteria to meet the United States Public Health Specifications for the remainder of the month.

In the fall of 1953, Test No. 4 was run with two vertical and one horizontal filters. Again, an ungraded sand was used as it was the type available and most likely to be used by farm people. The reduction in turbidity was low. The filtered water had turbidity levels of from 6 to 10 ppm even though the pond water had only 13 ppm to start with. There was no significant difference between the functioning of the vertical and horizontal filters in this test. None of the three filters produced a water consistently free of bacteria. The tests emphasized further the fact that slow sand filters, even though operated under fairly controlled conditions, cannot be expected to produce a water safe for drinking purposes.

In the laboratory tests run during the winter of 1953 and 1954 a graded filter sand was used in three filters and anthracite filter media in the fourth. The turbidity reduction of all four filters was excellent. The average turbidity of the raw water was 16.4 ppm and the average for the filtered effluent was 4.1. All the filters produced water of almost equal turbidity resulting from an average turbidity reduction of 74 percent. The anthracite filter media functioned, however, with considerably less head loss than the others. No significant bacterial reductions were evidenced in this test.

DISINFECTION OF SURFACE WATER SUPPLIES

Municipalities have learned through experience that surface waters must be disinfected by chlorination as well as filtered. It was a hard struggle for health organizations to convince municipal governments that money should

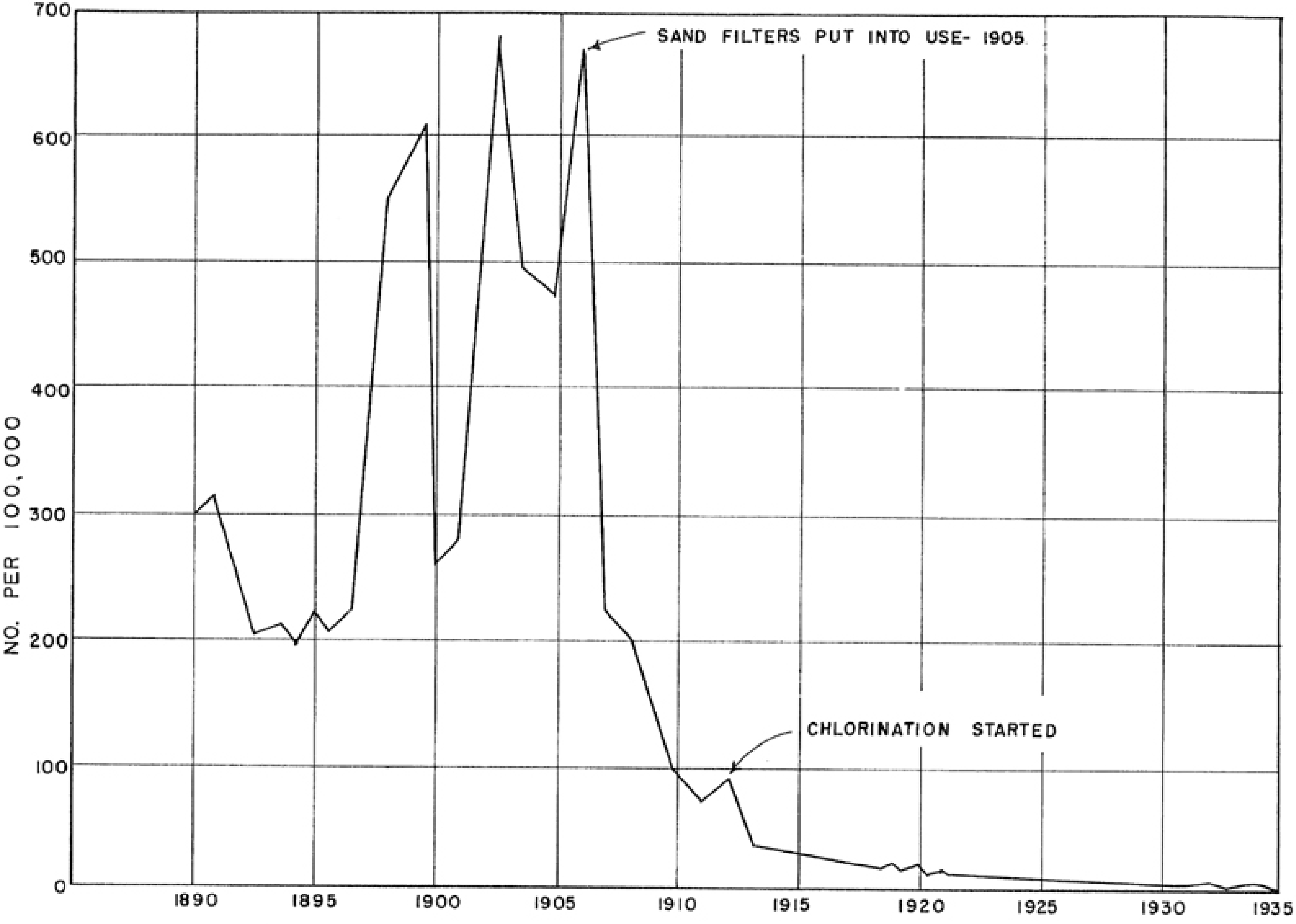

Fig. 17—Typhoid fever cases per 100,000 population, Philadelphia, Pa.

be spent in water processing in order to save lives, but once the public was shown how many lives could be saved they gradually began to change their point of view. Figure 17 shows the decline in the death rate due to typhoid fever after about 1905 for Philadelphia, Pa. The dramatic reductions occurred concurrently with the advent of filtration and later chlorination. Rural people have been less convinced that surface water needs disinfection, although the death rate in rural areas due to typhoid fever is twice as high as it is in the cities.

Chlorination

By far the most widely used disinfectant employed in treating water supplies is chlorine. Disinfection is the killing of all disease bacteria but not necessarily all the bacteria in the water. The degree of effectiveness of chlorine in killing bacteria is dependent upon the pH of the water, its organic content, and the temperature. Certain compounds, such as organic matter, sulphides, and unoxidized iron, which may be present in water will completely absorb chlorine. Chlorine which has been absorbed is not left as an available chlorine so it has no future purifying power. The more polluted a water is with organic matter and other impurities the greater is the amount of chlorine that will be needed to produce combined or free available chlorine. Any chlorine which is not absorbed and is left in excess as either combined or free available chlorine is called *residual chlorine.* All harmful bacteria will be killed in water containing residual chlorine provided sufficient contact time is allowed. It is very important when chlorinating water to know how much chlorine must be used and how long a retention time must be allowed. The difference between the amount of chlorine added to the water and the amount of residual chlorine present after a given time, is the *chlorine demand* of the water. Every water naturally has a different chlorine demand and this must be tested and determined. One of the most universally used methods of testing for the available chlorine present in the water is the orthotolidin test which any water treatment company can readily furnish.

A relatively new technique called *break-point* chlorination has been devised to control tastes and odors due to chlorophenols. As larger and larger doses of chlorine are added to water, the residual chlorine gradually increases to a point where more chlorine will cause a reduction in the residual. At this point a slight addition of more chlorine reduces the residual to practically zero. This point is called the *break-point,* because another slight addition of chlorine will cause a residual to reappear. Tastes and odors are eliminated at the break-point apparently due to a complete oxidation of all the organic matter and also of all the combined chlorine compounds that are in the water. The average dose needed to produce break-point chlorination is approximately 8 ppm and may well be more with surface water supplies. The cost of chlorine for this type of treatment is one of the limiting factors.

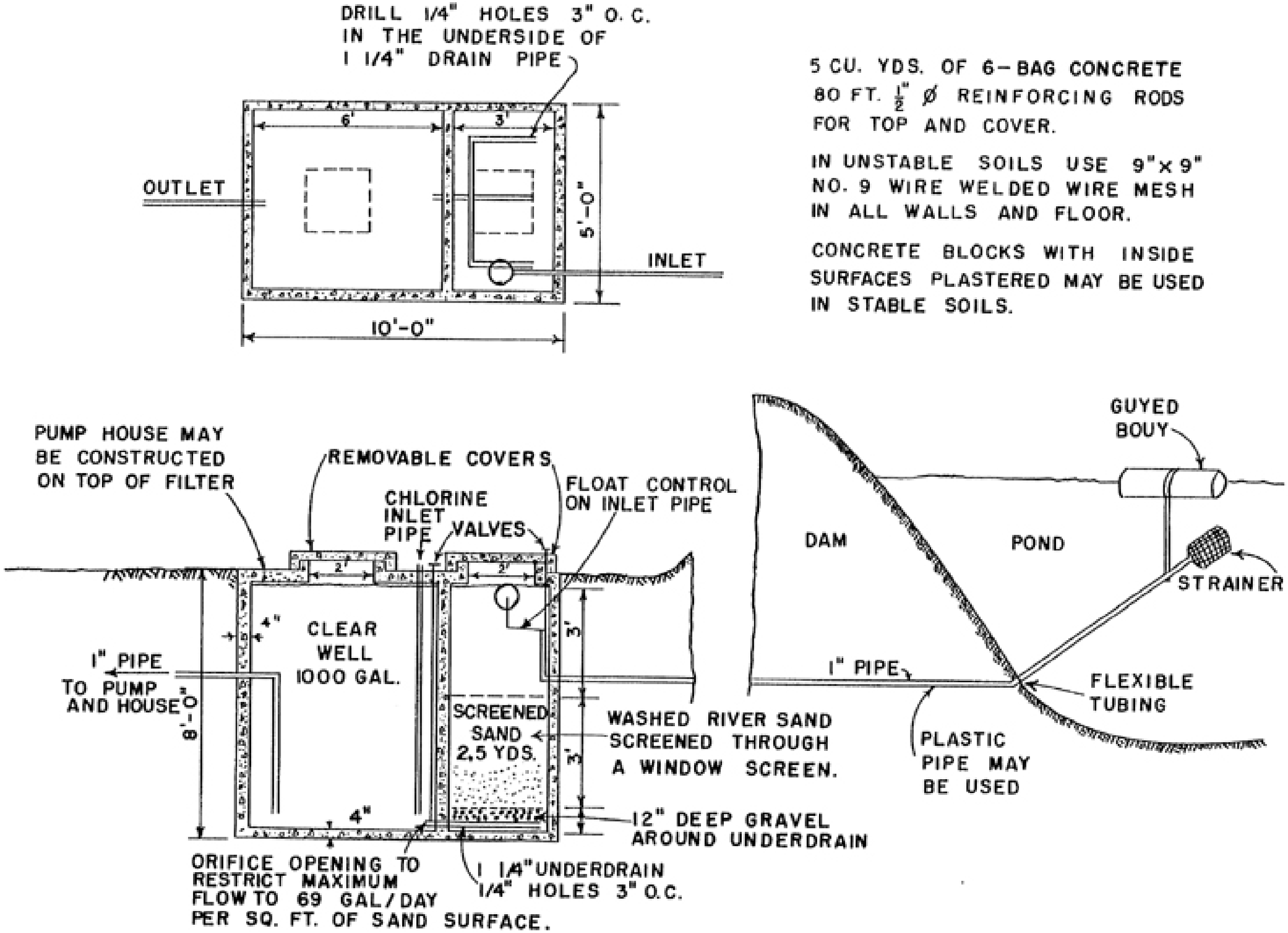

Fig. 18—Experimental slow sand filter for treating surface water supplies for the farm home.

For straight residual chlorination there is seldom need for chlorine dosages to exceed 0.2 ppm unless the organic matter content is particularly high and the pH is above seven. In general, the larger the dose needed to produce a residual, the longer the retention time should last. For this reason it is important that surface waters be chlorinated in the clear well storage cistern rather than directly in the pressure system where the retention time is possibly a minimum of a few minutes.

There are several small chlorinators on the market which are adaptable to farm pond water treating systems. The cheapest ones use the vacuum or venturi feed which must be attached to the pump so that the chlorine feeds into the water pipe on the suction side. This does not allow disinfection of the clear well cistern. Therefore, the positive feed chlorinator which will feed directly into the cistern is desired for best results. This chlorinator is operated by the control switch on the pressure system so that it introduces chlorine in a proportional amount as water is pumped out. For best results the chlorine should be introduced near the filter outlet where there is some turbulence to provide effective mixing. Chlorine is corrosive to most metals; therefore, it must be fed through either rubber or plastic tubes.

SUMMARY

These studies have shown that farm ponds can be constructed and managed adequately to produce water that is well within the limits for filtration by slow sand filters. The chemical content of the pond waters is very good, generally being better than most ground water supplies. Through adequate pond management the turbidity of the water can be maintained at a level lower than 25 ppm consistently and an effective slow sand filter will lower this on down to 5 to 10 ppm, which is acceptable for drinking.

None of the farm operated horizontal filters tested nor any of the experimental filters produced a water free of potentially harmful bacteria that would meet the requirements of the United States Public Health Service.

All of the tests made with experimental filters substantiated, essentially, the previous findings of municipalities insofar as clarifying waters with slow sand filters was concerned. Satisfactory turbidity reduction was not obtained if a flow rate greater than 3,000,000 gallons per acre per day (69 gallons per square foot per day) was maintained, if a filter sand coarser than an effective size of 0.35 mm and a uniformity coefficient larger than three was used, if highly turbid waters were run through the filter, or if high algae content waters were run through the filter. The vertical experimental filters proved to be as effective as the horizontal filters in reducing turbidity and more effective from the standpoint of controlling sanitation.

From these studies, observations, and findings, the experimental vertical filter in Figure 18 has evolved. It provides a water-tight, poured concrete filter well and clear well constructed as one integral unit. This design provides an ample supply of 1,000 gallons of filtered water. The size of the unit can, however, be altered without affecting the filtering unit materially. The minimum filter sand surface area should be 2 square feet per person for which water is to be supplied. This will provide for a maximum of somewhat over 100 gallons of water per day per person and still stay below the maximum slow sand filter rates. This design provides approximately 12 square feet of filter sand surface area, which should suffice for a good sized family.

The water is supplied to the filter by gravity and controlled by a cut-off inlet float valve. A combination of three feet of sand and three feet of water above the sand can be maintained with this unit. The underdrain of perforated pipe is surrounded with gravel to prevent fine sand from clogging the holes. A removable cover is provided above the filter sand for easy access when the sand requires scraping. Chlorination should be provided in the clearwell. Where desirable, an insulated pump house may be constructed above this filter well and storage unit, and the chlorination can be housed here with the pressure pump. A floating inlet in the pond has been found desirable as it takes water from near the surface where it is most likely to be of good quality, particularly during the summer months.

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