QUALITY AND TREATMENT OF FARM POND WATER FOR DOMESTIC USE

A Thesis

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by

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I. INTRODUCTION

A) Water Problems

Water is essential to life. It is the primary solvent in plants and animals. The importance of water has been known since the beginning of man. Villages, cities, and societies have located near rivers, seas and oceans in order to have an adequate supply of water. Early in man's history it was found that water must be treated to make it fit for human use. In the medical lore in Sanskrit dating 2000 B.C., this passage was found, "It is good to keep water in copper vessels, to expose it to sunlight and filter through charcoal ..... it is directed to heat foul water by boiling and exposing to sunlight and by dipping seven times into it a piece of hot copper, then to filter and cool in an earthen vessel" (1, p. 1).*

The treatment of water for domestic use has progressed vastly from that time. Very few towns and cities in the United States today do not have treatment plants that produce a superior quality of water. But what of those persons who are not supplied by these plants? This is a large problem area.

The early farmer and rural person drew his water from the nearby stream or river. If the stream was not near, he dug a well, a cistern, or developed a spring. Today, as in the past, these are the rural sources of water: springs, cisterns, wells, and surface water.

Two large problems face these people---quality and quantity. The vast increase in our population quickly lead to the contamination of the surface water with wastes from humans, animals and industries. It

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* Numbers in parenthesis refer to references listed at the end of this paper.

has been said of the Delaware River that it is "too thick to drink and too thin to plow" (2). This is true of many of our rivers and streams. Surface water was not the only sources struck by this condition. Willrich (3, p. 1) reported, "that 65 to 75 percent of the wells (in Iowa) produce water of unsatisfactory or unsafe bacteriological quality". Springs and cisterns are not any safer. Besides bacteriological contamination, wells and springs contain iron, sulfur, salt and other material which makes the water undesirable.

The quantity of water used from individual water supplies for farms, rural homes and suburban fringe homes was estimated to be 43 gallons per person per day in 1900, 100 in 1955, and is predicted to be 125 in 1975. This includes livestock water (4).

This increase in use has been brought about by the ease that water can be attained and higher water using processes. Electricity was found on 93% of the farms in 1954 as compared to 7% in 1920 (5). With electricity came the farm pump. Now the rural family had water for the bathroom, kitchen, livestock and milk house with a turn of a faucet. Water consumption increased. The family wash once done by hand now is done in a washer that uses 40 gallons of water per load. The dishwasher (10 gallons per load), the bulk milk tank and many other modern conveniences have increased water usage.

This increased demand has left the cistern dry and the old well struggling to produce enough flow. A family of four in Ohio using 100 gallons per day per person would require a roof area of 8,850 sq. ft. or two-tenths of an acre (6). This much roof area is not available.

The lack of water because of poor quality and quantity has caused

the farmer to look for sources of water. It is estimated that there are 1½ million farm ponds averaging two acre-feet storage in the United States (13). The farm pond has shown to be a promising source of water. This report deals with farm ponds as water supply.

B) Water Sources in Ohio

The average rainfall in Ohio is 38 inches. Most of the state is dependent on this directly or indirectly (surface and ground water) for water. The exception being those that derive there water from Lake Erie or the Ohio River. Of this 38 inches of rainfall, 13 inches finds its way down the streams. It has been estimated that 25 inches per year return to the atmosphere through evaporation and transpiration (7). Ohio must obtain its water from 13 inches of rainfall per year which may be found as surface water or ground water. These are interconnected in that ground water discharges into streams.

Many rural areas of Ohio do not have adequate water supply because (a) geological formations are such that ground water is not available or of poor quality and (b) streams are not available.

A study by the Ohio Water Resources Board showed that 45 of the 88 counties in Ohio had small ground water supplies. A number of the other counties had water with high salt, sulfur and iron content (7).

Eleven farmers in seven counties representing four different regions of Ohio were asked why they were using pond water instead of well or cistern water. As shown in Tables I and II, the most common reply was that the well went dry or had salt water. The quantity of water in the cistern was the largest problem in that area.

TABLE I

Reasons for Using Pond Water Instead of Well*

Sulfur Water in Well	Salt Water in Well	Sand in Well	Well goes Dry	No Well
1**	4	1	5	2

* Some farmers gave more than one reason.
** Number of replies

TABLE II

Reason for Using Pond Water Instead of Cistern

Quantity of Water in Cistern	Quality of Water in Cistern	No Cistern
7*	0	4

* Number of replies.

Due to this critical water supply problem, many rural families are turning to farm ponds as a source of water. A survey of county agents in 1956 (44 of 88 counties reporting) showed that 9,000 farmers had a critical water problem and that 300 farmers were using pond water for domestic or milk house use. Farm ponds are being built in an ever increasing number. The Federal Government through its cost-sharing program partly accounts for this growth. In 1959, 977 ponds were constructed in Ohio under the supervision of the Soil Conservation Service. It is estimated that this is about half of the ponds built annually in Ohio. The Soil Conservation Service has constructed 12,586 ponds in Ohio since this program began. It is easily formulated from this that farm ponds are becoming an important source of water in Ohio.

II. LITERATURE REVIEW

As mentioned earlier in this report, treating water for human use is not new. A great deal of research has been carried on in the municipal purification of water. Baker (1) has traced this development in his book.

Sponges were used in France from 1500 to as late as 1800 to filter water. The Boule-Rouge plant in Paris in 1821 used sponges, pulverized sandstone, charcoal and coarse sand in that order to filter water. Settling basins were, also, employed about that time. The slow sand filter gained a small foot-hold toward the end of the 19th century.

England made use of the slow sand filter earlier than this. The "Lancashire Filter" (1790) was one of the first used to treat industrial water. The slow sand filter is still common in Europe, whereas, the rapid sand filter is popular in the United States.

The first filtration of water was attempted in the United States at Richmond, Virginia, in 1832. This unit failed. The first successful unit was at Elizabeth, New Jersey, in 1855. Up to the end of 1860, there had been constructed only 136 water works in the United States. The rapid sand filter was introduced in 1880 and chlorination in the early twentieth century to revolutionize water treatment in America.

Except for the work done in the 18th century, the major developments have been concerned with the municipal water works and not with small individual water plants. Much attention has been focused in this area in the past ten years as ponds have increased as a source of water. The large plant has highly controlled equipment under the supervision of trained personnel. This a small plant inherently does not have.

Tempel (18) conducted one of the early studies on farm pond water. During 1950 he studied twenty farm ponds in Missouri for chemical, physical and bacteriological quality. He found no significant effect of the watershed on alkalinity, pH, nitrogen or bacteria. In studying the seasonal variations, it was noted in one year that the rainfall decreased as the season progressed and the turbidity increased. Tempel formulated that this was due to the turn over in the pond keeping the sediment in suspension. He, also, noted that wind was an important factor in raising the turbidity in a pond. Watershed type and turbidity could not be correlated. Tempel ran some tests on using a vertical slow sand filter. It was his feeling that this type filter is best fitted to pond water treatment.

Baumann (19) made a preliminary survey of farm water supplies in Southern Iowa in 1954. He found eight different types of treatment facilities (19, p. 48):

"1. Natural filtration through soil into existing wells.
2. Soft-brick, beehive filters.
3. Perforated barrel inlets followed by subsequent sand filters.
4. Floating intakes followed by sand filters.
5. Bottom-of-pond filter and underdrain.
6. Sand filled trench filters.
7. Slow-sand filters.
8. Rapid-sand filters."

Natural filtration through soil into existing wells proved to provide a continuous supply of water, but in most cases produced contaminated water. No reference was made to quality. Perforated barrel inlets had sediment settle on them and the flow reduced. This sediment was drawn into the water discharge resulting in the water having a higher turbidity leaving the inlet then when entering.

In five installations soft-brick inlets were employed. The settled sediment reduced the capacity excessively in a matter of months. Ice, also, broke these filters almost every winter. A floating inlet was tried at one installation and proved successful. No freezing problems were encountered.

The bottom-of-pond filter performed poorly. Thick layers of sediment formed on top of them and was drawn into the water system. Sand-filled trench filters built into the side of ponds required extensive maintenance. They removed turbidity from the water, but at times produced water that "smelled". The one installation that had a rapid-sand filter worked satisfactorily.

Only 4 of 49 installations investigated by Baumann provided for chlorination. On two of these installations, the chlorinators were maintained and functioned properly. The other two chlorinators were never found operating.

From this information, Baumann made these recommendations: (a) floating intakes are essential, (b) a separate constructed slow sand filter should be used, (c) storage for 2 or 3 days in order to maintain a slow filter rate and have sufficient storage is needed to control bacteria.

Baumann felt that the largest problem area was that of disinfection. He felt that superchlorination and dechlorination was a possible answer to this problem. With this in mind, he studied three installation using such systems. As part of this study, he ran tests on the quality of the water in the ponds. His conclusions were that: (1) new ponds and ungrassed ponds had higher turbidities, (b) nitrates

were high in ponds that fertilized the drainage area heavily, (c) color of water from old ponds with well grassed drainage areas was in the range of 10 to 35 ppm, (d) hardness was in the range of 25 to 120 ppm, (e) turbidity was in the range of 2 to 20 in old ponds with grassed watersheds, (f) iron content was negligible, and (g) pH was in the range for good chlorination.

In Baumann's bacterial studies he found that all ponds were grossly polluted. The superchlorination system at one installation operated poorly because of poor maintenance of the chlorinator. Coliform counts were found even with chlorine residuals as high as 1.5 ppm. Dechlorinated water showed increased counts over the chlorinated water indicating that the carbon was serving as a breeding ground for some bacteria.

Willrich and Baumann (3) reported later results of the studies in Iowa in 1957 (revised 1959). Turbidity in a newly constructed pond fell in the range of 165 to 260 units. After treatment with gypsum, color and turbidity were lowered. An old pond contained water that had color in the range of 5 to 50 units and turbidity of 2 to 35 units. The pH varied from 6.5 to 8.2. Water color, turbidity, hardness and bacterial concentration were lowest near the pond surface. Therefore, it was felt that an inlet near the surface was best. From their studies of filters, they came to the conclusion that a slow sand filter as a separate structure was the easiest to operate and maintain. A filtering rate of 50 gallons per day per square foot of filter area was recommended. Slow sand filters were found to lower the bacterial count, but would not produce a safe water.

The studies on superchlorination showed that a safe water may be produced. A 3 mg/l residual chlorine seemed to do an effective job. Maintenance of the chlorinators by the owners was a major problem area.

Hodges (20) reported the results of a study in Missouri on a slow sand filter system in 1959. His conclusions were that (20, p.6):

"(a) A properly constructed and maintained slow sand filter will provide a clear water (usually less than 5 turbidity units when the turbidity of the pond is less than 30 units).

(b) Only an uncertain fraction of the bacteria in raw water is removed by slow sand filtration.

(c) Proper chlorination (about 0.4 ppm residual) should be maintained in the storage reservoir to insure safe water bacteriologically.

(d) Scraping of the filter surface should not be too frequent if the unit is properly sized and the turbidity of the pond water is maintained below about 30 turbidity units.

(e) Good management and proper maintenance of all components of the system are necessary to insure a high quality water."

Daniel (21) reported on the work performed in Oklahoma on pond water treatment. He found that the average turbidity in thirty ponds was 247.4 units, the pH 8.32 and the hardness 14.19 ppm. Four methods were mentioned as successful in pond water treatment: 1) treatment of water as removed from pond, 2) treat pond with flocculation agent, 3) store water in earthen reservoirs and then filter in a slow-sand filter and 4) a slow sand filter built in the side of the pond. A surface type inlet was recommended because of less taste, odor and turbidity in the upper levels.

Amerman (11) in his thesis gave the results of work he had done at Purdue in treating farm pond water with a slow sand and diatomaceous earth filter. His results showed that the turbidity ranged from 1 to 100 units, color 5 to 25 units, pH 7 to 9.5, hardness 50 to 98 ppm,

alkalinity 50 to 75 ppm as $CaCO_3$, iron 0.1 to 1.0 ppm, and manganese 0 to 1.4 ppm in pond water. In these treatment plants the water was removed from the ponds by a floating inlet and each system was supplied with one week's storage. It was thought that high turbidities in the pond would not last longer than a week and during this period no water would be treated. This proved to be wrong as high turbidities lasted for several weeks.

Amerman's conclusions were that the slow sand and diatomaceous earth filters were equally effective in removing bacteria and turbidity. The pond water had to have a turbidity of below 30 to 40 units before either filter produced acceptable water. It must be noted that the sand used in the slow sand filter was ordinary mortar sand with an effective size of 0.24 millimeters and a uniformity coefficient of 1.92. Both systems produced water with high turbidities during the winter months when the turbidity in the ponds ranged from 60 to 100 units. Turbidity in the treated water never exceeded 20 units. It was felt that the slow-sand system was best suited for a family sized installation and the ditomaceous earth filter for large systems.

Additional results showed that gypsum applied as recommended by Missouri did nothing in lowering the turbidity in the ponds. Floating inlets proved to be the best.

Kentucky (14), Oklahoma (15), Illinois (16), and Ohio (17) have circulars on the construction of pond water treatment systems. Table III summarizes the information in these publications. From the foregoing discussion, it can be seen that Oklahoma recommends flocculation and sedimentation because of high turbidity.

TABLE III

Pond Water Treatment Recommendations for Various States

State	Kentucky(14)	Oklahoma(15)	Illinois(16)	Ohio(17)
Agency	Extension	Extension	Health	Health
Intake	Surface	Surface	Surface	Surface
Flocculation	Add Alum	Add Alum	None	None
Sedimentation	Yes	Yes	None	None
Filtration	Slow-Sand	Slow-Sand	Slow-Sand	Slow-Sand
Depth of Filter	4' 6"	4' - 4'6"	7'6"	5'6"
Depth of Sand	27"	30"	36"	30"-36"
Flow Rate (Gallons per Day per Sq. Ft. Surface Area)	72	25	67	56
Storage	Yes	Yes	Yes	Yes
Amount	2½ days	1½ days	2 days	1 day
Chlorination	Yes	Yes	Yes	Yes
Location of Chlorine Injection	Storage Basin	At Pump	Storage Basin	Between Filter & Storage
Type	Positive-Feed	-----	Electrical	Electrical
Controlled by	-----	-----	Pump	Pump
Chlorine Residual (p.p.m.)	-----	-----	0.3 - 0.5	0.2

III. PURPOSE OF THE STUDY

In order to develop an effective system for pond water, more information was needed as to the quality of water in ponds and the effectiveness of treatment systems presently found at farm ponds. With this information, an experimental treatment plant was developed and tested. The objectives of this study were as follows:

1) To determine the quality of water in farm ponds by measuring the turbidity, color, odor, bacteria and chemical content and to determine the effect of the location of the inlet on the quality of water removed.

2) To evaluate the effect of present farmer operated treatment facilities, such as filters, chlorinators and other treatments, on water quality.

3) To test an experimental slow sand and rapid sand filter system.

IV. PROCEDURE

This study was made by collecting samples of water from existing farm ponds and from an experimental laboratory. These samples were taken to the laboratory at Columbus for analysis.

A) Water Analysis

1) Definitions and Equipment

Terms used in describing water quality and test equipment used are as follows:

Turbidity. The turbidity of water is caused by the presence of suspended matter, such as clay, silt, finely divided organic matter plankton and microscopic organisms. Turbidity is an expression of the optical property of a sample which causes light rays to be scattered and absorbed rather than transmitted in straight lines through the sample (8). A Hellige turbidimeter precalibrated by the Jackson candle method was used for making these determinations. The values for turbidity are expressed as turbidity units.

Color (apparent). Whenever color is mentioned in this report, apparent color is implied. The apparent color shall include not only the color due to substances in solution, but also that due to suspended matter. Apparent color was determined on the original sample without filtration or centrifugation(8). The color was determined by comparing the sample with colored glass discs in a Hellige Aqua Tester. The glass discs are precalibrated. This is known as the U. S. Geological Survey method and the units are in parts per million (ppm) (see Figure 1).

Odor. Samples were given one of three classifications: 1) no odor, 2) perceptible, and 3) objectionable during the first year and a half

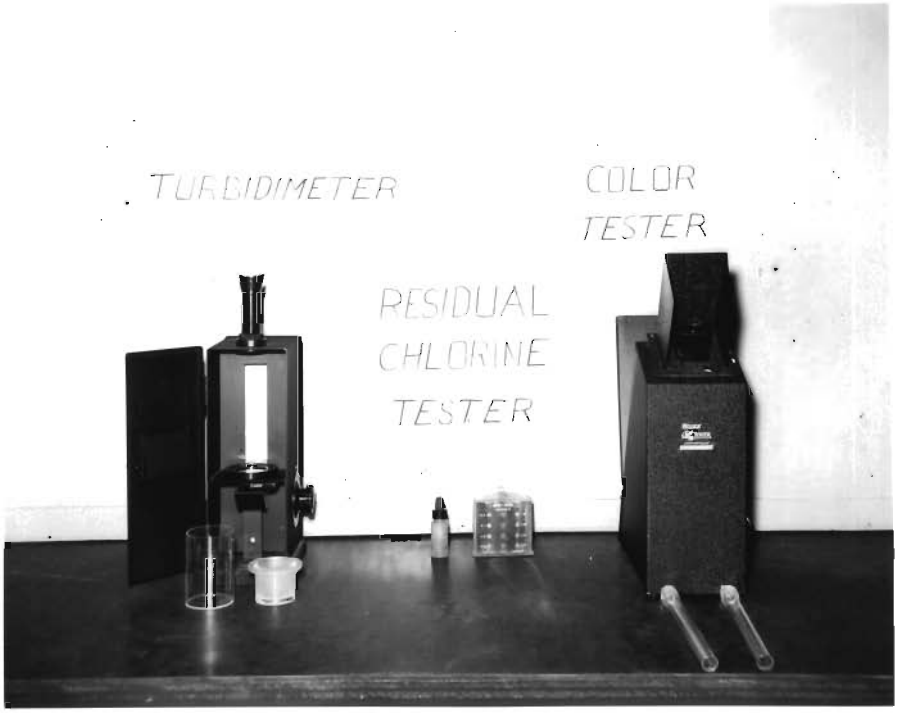

Figure 1. TESTING EQUIPMENT
(a) Turbidimeter to measure turbidity, (b) field residual chlorine tester and (c) laboratory color and residual chlorine tester.

of this study. A sample having a faint odor, but not considered objectionable was classified as perceptible. Any sample having a strong odor or an objectionalbe odor was classified as objectionable. Starting in 1960, the threshold odor was used. The procedure for this test is given in Standard Methods (8).

Bacteria (coliform group). The coliform group method does not provide for the detection, isolation or enumeration of pathogenic bacteria in water. It is intended only to indicate the degree of contamination of the water with wastes from human and animal sources. No attempt was made in differentiating fecal contamination from nonfecal contamination. The Membrane Filter Method (MF) was used during the first three months of this study. The change to the Most Probable Numbers (MPN) method was made because of the poor agreement between the MF and MPN results. Ninety-four comparisons were made during that period and only 30.8% were in agreement. See reference (9) for a complete description of these tests. For a description of the MF and MPN methods used see reference (8). Only the presumptive and confirmed tests were used on the MPN samples. The coliform group count is in coliform colonies per 100 ml. This work was performed at the Bacteriology Department, Ohio State University.

Chemical Analyses. The following chemical analyses were made on one sample from each pond during the summer of 1958 and 1959. Volatile solids, total solids, total alkalinity, total hardness, pH, total iron, chloride, fluoride, nitrate nitrogen and sulphate were measured in parts per million. Radiation count was also made. Ponds in which Sodium Arsenite had been used to control weeds were tested for arsenic. After January 1960, chemical samples were taken monthly at pond 60.

See reference (8) for methods used in determination. This work was done by the Ohio Department of Health laboratory.

Chlorine Residual. As used in this report, chlorine residual shall include free or combined available chlorine as determined by orthotolidine tests as described in reference (8). The units are parts per million. The chlorine content was determined with the tester shown in Figure 1.

Particle Size Determination. Turbidity does not give an indication of the size of the particles in suspension. Baver (10) lists six methods for determining the distribution of particle size in soil samples. The two most common methods are the pipette and hydrometer. The centrifuge has also been used in a number of cases. The accuracy of these methods are poor for the small-sized particles. They, also, do not lend themselves readily to water samples where the amount of material in suspension is small. Amerman (11) in his thesis suggested using the coefficient of fineness. Coefficient of fineness is defined as the ratio of suspended solids to turbidity. Suspended solids is a measurement of the suspended matter that settles out in 45 minutes in an Imhoff cone. A low coefficient would indicate that small particles were present. Amerman (11, p. 116) gives this limitation to this method.

"When turbidity is very low, suspended sediment is probably also very low, and since the methods for measuring suspended sediment require the physical manipulation of the material, very small amounts may not be measurable. Very small amounts of turbidity are measurable..... It is possible, then, to obtain zero coefficients, when actually they may well be nearly unity. Hence, coefficients of fineness of zero must be meaningless unless turbidity is fairly high."

A different method was attempted in this study. A turbidity reading was taken of a 125 ml sample before and after it was passed through a filter with a known pore size. From these readings, it could be

deduced that a certain percentage of the turbidity was composed of a size equal to or greater than the filter's pores. A series of filters were used to obtain some indication of particle size distribution. Membrane filters of pore sizes 5 u ± 1.2 u, 1.2 u ± .3 u, and 100 mu ± 8 mu were employed.* It was assumed that none of the suspended material would pass the 100 mu filter. Some error can be expected in filtering the highly turbid samples. The suspended matter would tend to clog the pores in the filter and cause it to filter smaller-sized particles than indicated by the pore size. Figure 2 shows the filter apparatus.

2) Significance of Tests

The U. S. Public Health Service has set up certain quality standards for drinking water. Those standards that are pertinent to this report are listed in Table IV.

Typhoid fever, dysentery, gastronenteristis and asiatic cholera are the important water born diseases. All of these are transmitted by the intestinal and urinary discharges of sick persons and carriers. The coliform group indicates wastes from human and animal sources. For this reason the coliform groups are used as an indicator for possible contamination of water born diseases.

Total solids give an indication of the amount of foreign matter in the water. Volatile solids gives an indication as to the amount of organic matter.

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* Pore size as given by the Millipore Filter Corp., Bedford, Mass.

The total hardness of water is the sum of the concentrations of all metallic cations other than cations of the alkali metals. The tolerance range and classifications of hardness are 0-51 ppm -- Relatively Soft Water, 52-120 ppm -- Moderately Hard Water and 120-340 ppm -- Hard Water(12).

A radiation count was taken to determine the radiation level of pond water. The count was broken down into two parts: 1) suspension, and 2) filtrate. Although no standard has been set for a maximum level for radiation, 1.00×10^{-7} microcuries per ml is considered by many as the maximum allowable.

TABLE IV

Drinking Water Standards *

Factor	Maximum Allowed	Minimum
Turbidity	10 units	- -
Color	20 ppm	- -
Taste	not objectionable	- -
Fluoride	1.5 ppm	- -
Arsenic	0.05 ppm	- -
Iron & Mangenese(together)	0.3 ppm	- -
Chloride	250 ppm	- -
Sulfate	250 ppm	- -
Total Solids	500 ppm	- -
pH	10.6 @ 15°C.	6
Residual Chlorine	- - -	0.4 ppm
Odor	not objectionable	

Total Alkalinity:

pH range	Limits for Total Alkalinity (ppm)
8.0 - 9.6	400
9.7	340
9.8	300
9.9	260
10.0	230
10.1	210
10.2	190
10.3	180
10.4	170
10.5 - 10.6	100

Bacteria: Occasionally all of the (5) equal one hundred milliliter portions constituting a single standard sample may show the presence of organisms of the coliform group, provided that this shall not be allowable if it occurs in consecutive samples or in more than one standard sample when less than five samples have been examined per month.

* Information taken from Public Health Service Drinking Water Standards 1946, by U. S. Department of Health, Education and Welfare except for residual chlorine.

ppm = Parts per million

Figure 2. MEMBRANE FILTER APPARATUS AND FILTERS

B) Field Sampling

1) Sampling Procedure and Equipment

A specially designed sampler was constructed to take the samples from the pond. This equipment is shown in Figure 3. A 250 ml. sterile, ground glass stoppered sample bottle was placed in the tube section of the sampler. The upper part then swiveled to lock the bottle in place. A mechanism connected to the stopper of the bottle was constructed so that the bottle could be opened and closed at any time by pulling a small nylon rope. The sampler was lowered into the water by means of a chain. To take a bottom sample, the sampler was lowered carefully into the water so that only a small amount of disturbance would occur when the sampler touched the bottom. By pulling the rope the stopper was pulled. When the bottle was full, bubbles stopped appearing at the surface of the water. The string was then released and the spring above the stopper closed the bottle. A thermometer was fastened to the sampler to record the temperature. All samples were taken in a similiar way by holding the mouth of the bottle the desired depth below the surface.

Water samples were taken from faucets after they had been allowed to run for five minutes as prescribed in the Standard Methods (8). All samples were placed on ice in a portable chest immediately after being taken. The samples remained under refrigeration till they were analyzed for bacteria. No more than 12 hours ever elapsed between the time the sample was taken and analyzed.

A rubber raft was used to transport the person taking the samples. When the pond was frozen over, a hole was punched in the ice and the

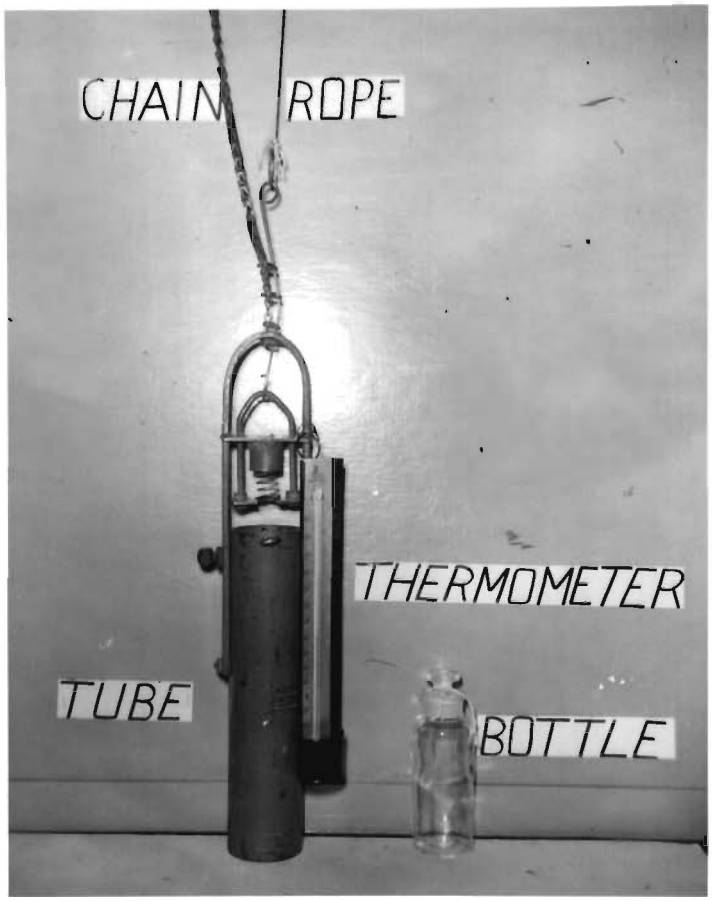

Figure 3. WATER SAMPLER

sample taken.

2) Location of Samples

Samples were taken one foot above the bottom at the deepest point of the pond (this sample will be called "bottom" throughout this report); one foot below the surface at the deepest point of the pond (called "top" sample); and if different from one of these two points, at the inlet into the filtering system. An attempt was made to take a sample before and after each treatment facility. Table V gives a description of the location where samples were taken for each pond. Starting in January 1960, samples were taken at each one foot depth intervals.

3) Number of Samples

Fourteen ponds located in eight different counties in Ohio were studied for two years. At least 10 samples and as high as 36 samples were taken during this period from each pond. Nearly all samples were tested for turbidity, color, odor, and coliform group bacteria. Where chlorinators were used chlorine residual was taken. Temperatures were taken of the water at the time of sampling. Once during each summer a sample for chemical analysis was taken, and starting in 1960 monthly samples were taken at pond 60. All chemical analyses were made by the Ohio Department of Health Laboratory.

TABLE V.

Location of Sampling Points***

Pond Number	
1	a) Top*, b) Bottom**, c) Cold water in house or milk house after water passed through slow sand filter and had been chlorinated, d) House-after chlorinated water had been dechlorinated.
5	a) Top, b) Bottom, c) Floating inlet, d) Cold water in house.
6	a) Top, b) Bottom, c) Cold water in house after chlorination, d) cattle waterer.
8	a) Top, b) Bottom, c) Cold water in house before filtration and after chlorination
23	a) Top, b) Bottom, c) Cold water in house after chlorination, d) House after chlorinated water had been dechlorinated.
25	a) Top, b) Bottom, c) Before slow sand filter, d) After slow sand filter and before storage basin, e) Storage basin, f) Cold water in milk house after chlorination.
26	a) Top, b) Bottom, c) Storage basin after slow sand filter, d) Cold water in house after chlorination.
60	a) Top, b) Bottom, c) Floating Inlet, d) Outlet from floating inlet, e) Outlet from barrel inlet, f) Outlet from buried pipe inlet, g) A top sample was also taken from an old pond near pond being studied.
62	a) Top, b) Bottom, c) Inside and at bottom of concrete block inlet, d) Cold water in house after chlorination.
86	a) Top, b) Bottom, c) Inlet, d) Cold water in house after chlorination.
87	a) Top, b) Bottom, c) Inlet, d) Cold water in house after chlorination.
88	a) Top, b) Bottom, c) Inlet, d) Cold water in house after chlorination, e) House after dechlorination.
89	a) Top, b) Bottom, c) Cold water in house after slow sand filter.
90	a) Top, b) Bottom, c) After chlorination, d) After chlorination and filter, e) After chlorination and filter and dechlorination.

* Top - one foot below surface at deepest point of pond.
** Bottom - one foot above bottom at deepest point of pond.
*** After January 1960 samples were taken at one foot depth intervals in all ponds.

V. DESCRIPTION OF INSTALLATIONS

A) Field Installations

1) Location

The fourteen ponds were divided into four groups according to their geographic location. Five ponds were located in north central Ohio in Lorain and Crawford counties, four in central Ohio in Delaware county, three in southeastern Ohio in Washington, Vinton and Jackson counties, and two in the southwestern part of the state in Highland and Brown counties.

The ponds were selected so that each of the three major soil regions in Ohio were represented (see Table VI.).

TABLE VI.

Location of Ponds by Soil Regions

Soil Region	Pond Number	Soil Series No.
Glacial Limestone	1	6B2, 6B3, 6B8
	60	752, 753
	62	753, 754
Glacial Sandstone and Shale	5	602
	6	693, 694
	8	703
	86	703
	87	703
	88	702
	89	702, 703
	90	103, 602, 603
Residual Sandstone and Shale	23	374
	25	733
	26	406

2) Treatment Facilities

All ponds selected had some type of treatment facility. This was done so that treatment facilities already in use could be studied and evaluated. Table VII presents the treatment facilities at each pond installation.

TABLE VII.

Type of Facilities at Each Installation

Installation Number	County	Intake in Pond	Type of Filter	Type of Chlor.	Storage Before Chlor.	Storage After Chlor.	Other Treatment	Water Use
1	Delaware	gravel trench	Slow Sand*	Everclor	None	200 gal.	Dechlorinator Everpure	Household, Drink, Livestock, Milk house
5	Delaware	Floating	None	None	None	None	None	Household, Livestock
6	Delaware	30 and 50 gal. barrels filled with sand and gravel	None	Sureclor Removed 7/7/58	None	40 gal. pressure tank	None	Household, Drink, Livestock, after 7/7/58 livestock only
8	Delaware	55 gal. barrel filled with sand and gravel-7/26/59 Installed Floating inlet (a rapid sand filter system was installed in 1960)	None	Sureclor 7/9/59- Installed Proportioneer	None	pressure tank on pump	None	Household, Drink, Livestock
23	Washington	Two-50 gal. barrels filled with sand	Slow Sand*	Everclor	None	82 gal. pressure storage tank	Dechlorinator Everpure	Household, Drink, Livestock, Milk house

* Flow rate was greater than that recommended for slow sand filters.

TABLE VII. (Cont'd.)

Type of Facilities at Each Installation

Installation Number	County	Intake in Pond	Type of Filter	Type of Chlor.	Storage Before Chlor.	Storage After Chlor.	Other Treatment	Water Use
25	Jackson	50 gal. barrel	Slow Sand	Batch in storage basin 9/59 Installed Everclor	None	Storage basin 12,000 gal.	None	Household, Drink, Livestock, Milk house
26	Vinton	Barrel two-50 gal.	Slow Sand	Batch in cistern	None	Storage basin	None	Household, Drink, Livestock, Milk house
60	Brown	(1) Floating (2) Barrel (3) Buried	None	None (Two treatment systems installed March, 1960)	None	None	None	None
62	Highland	Cinder block box	None	Sureclor	None	Pressure tank on pump	None	Household, Drink
86	Lorain	Cinder block box filled with sand 7/12/59-Floating inlet installed	None	Sureclor	None	Pressure tank on pump	None	Household, Drink, Livestock

TABLE VII. (Cont'd.)

Type of Facilities at Each Installation

Installation Number	County	Intake in Pond	Type of Filter	Type of Chlor.	Storage Before Chlor.	Storage After Chlor.	Other Treatment	Water Use
87	Lorain	Box filled with gravel - bottom of pond	None	Everclor	Cistern	Pressure tank	None	Household, Drink, Livestock, Milk house
88	Lorain	Block box filled with gravel-bottom of pond	Diamond filter (Commercial) rapid sand	Everclor	Cistern	Pressure tank	Dechlorinator Everpure	Household, Drink, Livestock, Milk house
89	Lorain	Cinder block box filled with gravel 7/12/59 - Floating inlet installed	Myers Commercial fast sand	None	None	None	None	Household, Livestock
90	Crawford	Gravel trench in pond 8/59 - Floating inlet installed	Duro commercial fast sand	Wallace-Tiernan 8/59 - Installed Proportioneer	None	42 gal. pressure tank and 42 gal. storage tank	Monovalve Charcoal filter	Household, Livestock, Drink

B) Experimental Laboratory

From the results obtained during the first seventeen months of study on the field installations, plans were formulated for an experimental laboratory to test pond water treatment systems. This laboratory was constructed below pond 60 at the Southern Substation of the Ohio Agricultural Experiment Station, Ripley, Ohio (Figure 4). It consisted of a building 18' by 20' with two 900-gallon storage tanks below the floor. Three types of inlets from the pond supplied water by gravity to the building.

A slow sand and rapid sand filter system was designed for initial research.

1) Slow Sand Treatment System

Most investigators have recommended some form of a slow sand filter system to treat pond water. A slow sand filter was used in this research for two reasons: a) to evaluate a slow sand filter under Ohio's conditions, and b) to use the slow sand filter as a control to compare other treatment systems. Figure 5 shows a diagram of this installation.

As seen in Figure 6 the slow sand filter was connected to the three inlets from the pond in such a manner that water from any one of the three could be applied to the filter by turning a valve. From April 4, 1960, to June 28, 1960, water from 500 feet of perforated one-inch plastic pipe buried in the bottom of the pond was used, because it contained the poorest quality water. After this series of tests, the barrel inlet was used so that water from the same source could be used in both the rapid and slow sand filter.

Figure 4. WATER TREATMENT LABORATORY
Pond is to the right of building.

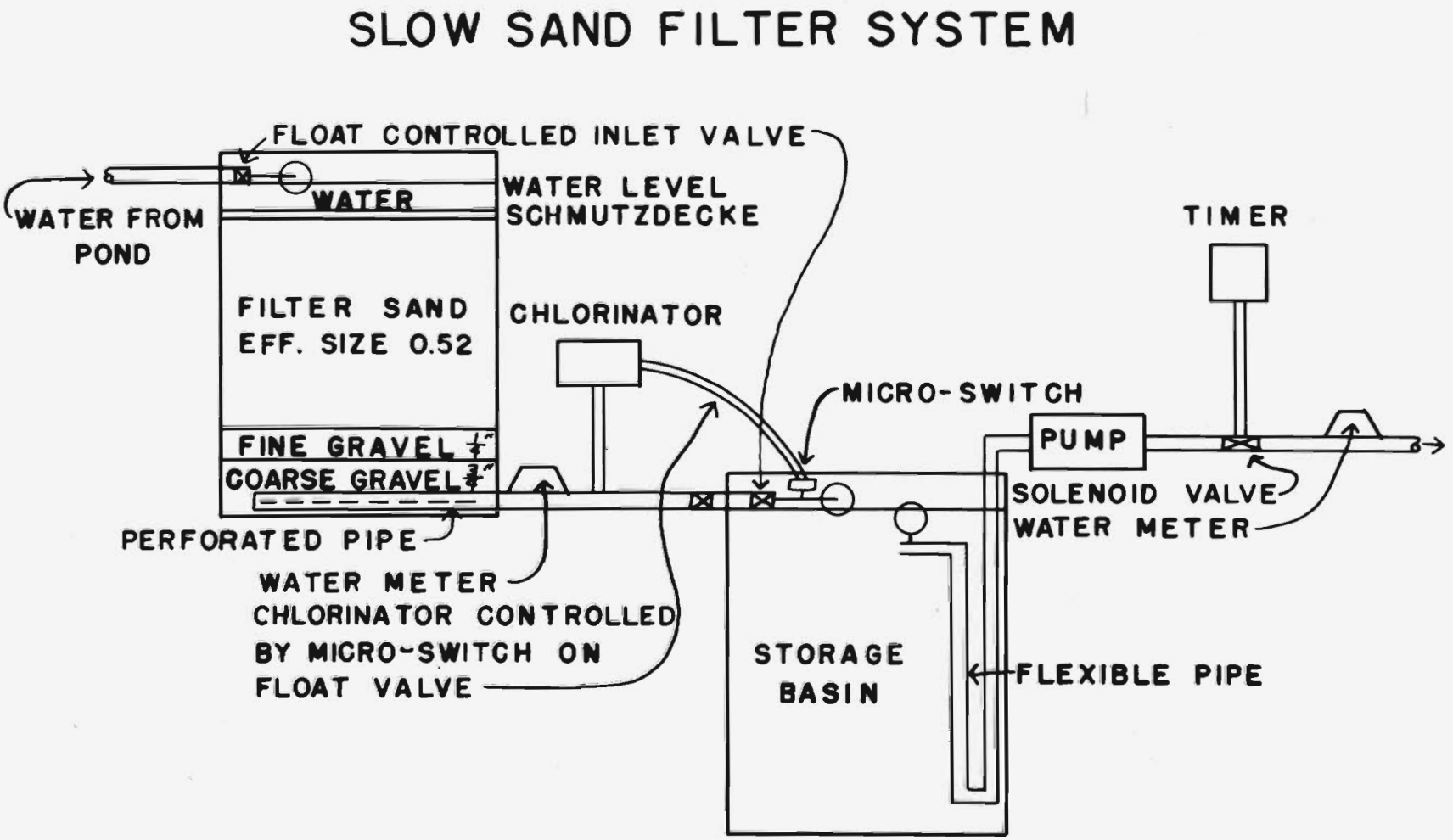

Figure 5. SLOW SAND FILTER SYSTEM

Figure 6. INLETS FROM POND
(a) Floating inlet, (b) buried pipe inlet, (c) barrel inlet, (d) rapid sand filter pump, (e) rapid sand filter 120 gallon pressure tank and (f) slow sand filter tank.

Figure 7 shows the steel tank used as a slow sand filter. This tank was five feet high and five feet in diameter. Down one side of the tank, faucets were placed at one-foot intervals, starting at the top, so that samples could be taken from a number of places in the filter itself. Connected to these faucets on the inside of the tank were sections of perforated pipe packed in gravel to keep out sand. The tank contained six inches of 3/4" coarse gravel on the bottom, three inches of fine gravel above this and four feet of filter sand. A sieve analysis of this sand is shown in Figure 8. A float valve controlled the water level in the tank.

Water was removed by an underdrain composed of 25 ft. of plastic pipe perforated on the bottom. The pipe was spiraled in the coarse gravel. From the filter, the water passed through a water meter. A "Proportioneer" positive-feed chlorinator injected chlorine as the water left the water meter. The chlorinator was controlled by a float valve and microswitch (Figure 9). This same float valve controlled the level of the water in the storage basin. Just before the float valve, a globe valve was located to regulate the flow through the slow sand filter. The storage basin contained 900 gallons of water. The water was removed from the storage basin by a small pump. The water was taken from about three inches below the surface. The pump was controlled by a time clock and a solenoid valve. Twelve times during the day the solenoid valve was actuated by the clock which opened the line for five minutes (Figure 9). The flow was approximately 500 gallons per day. The water was allowed to go to waste.

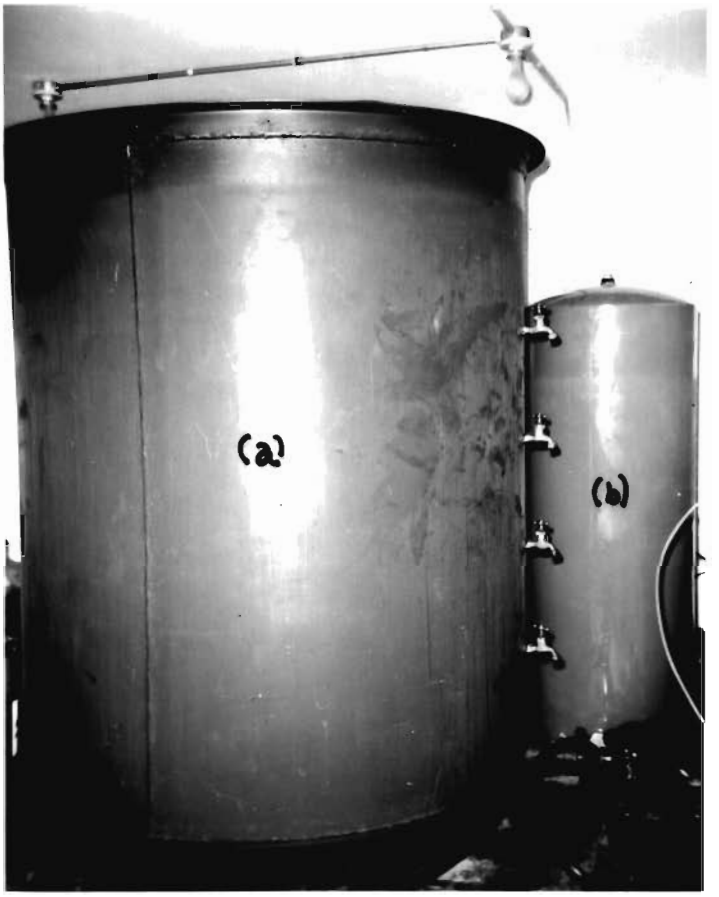

Figure 7. SLOW SAND FILTER TANK
(a) Slow sand filter tank, (b) rapid sand filter pressure tank and (c) water meter.

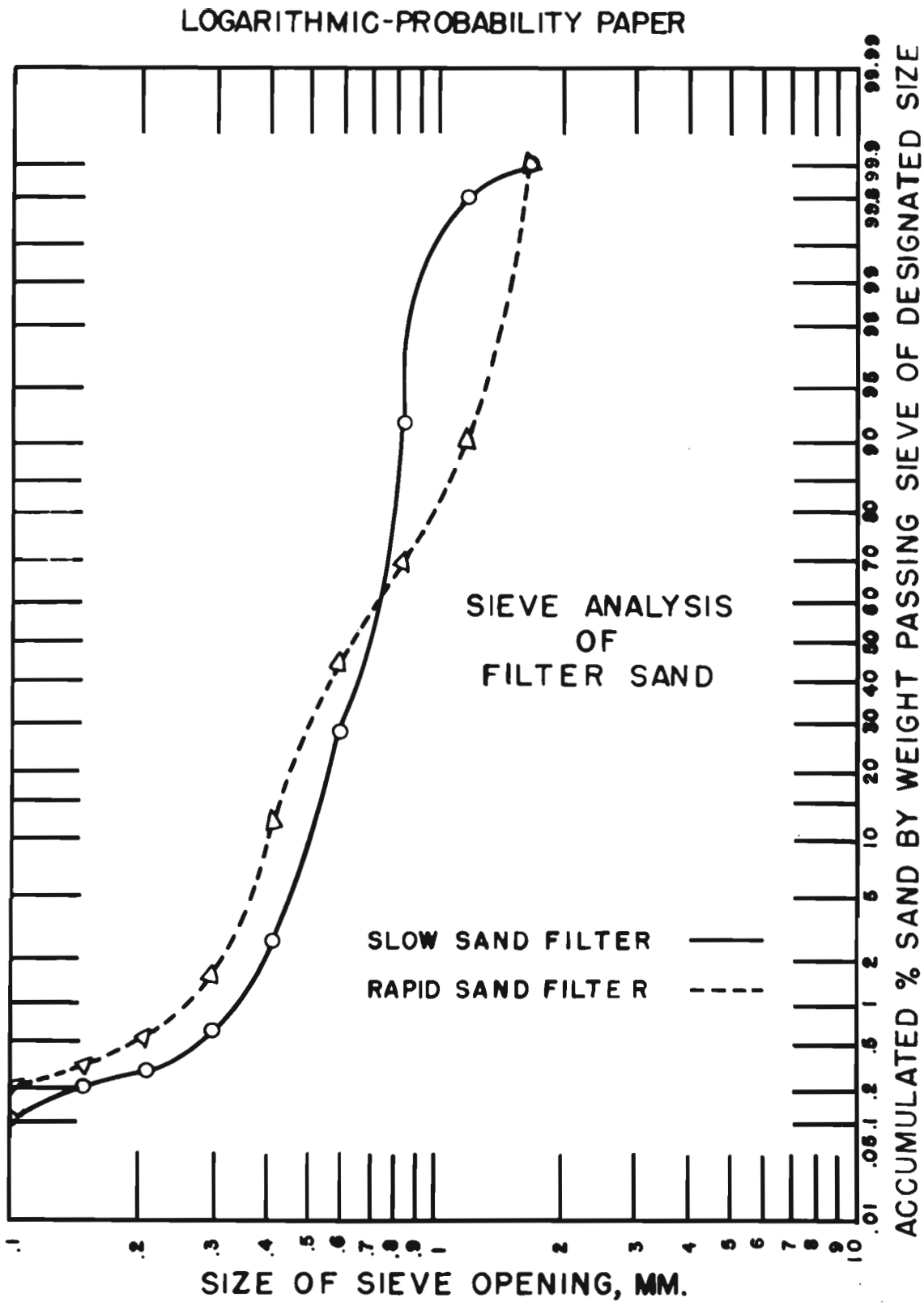

Figure 8, SIEVE ANALYSIS OF FILTER SAND

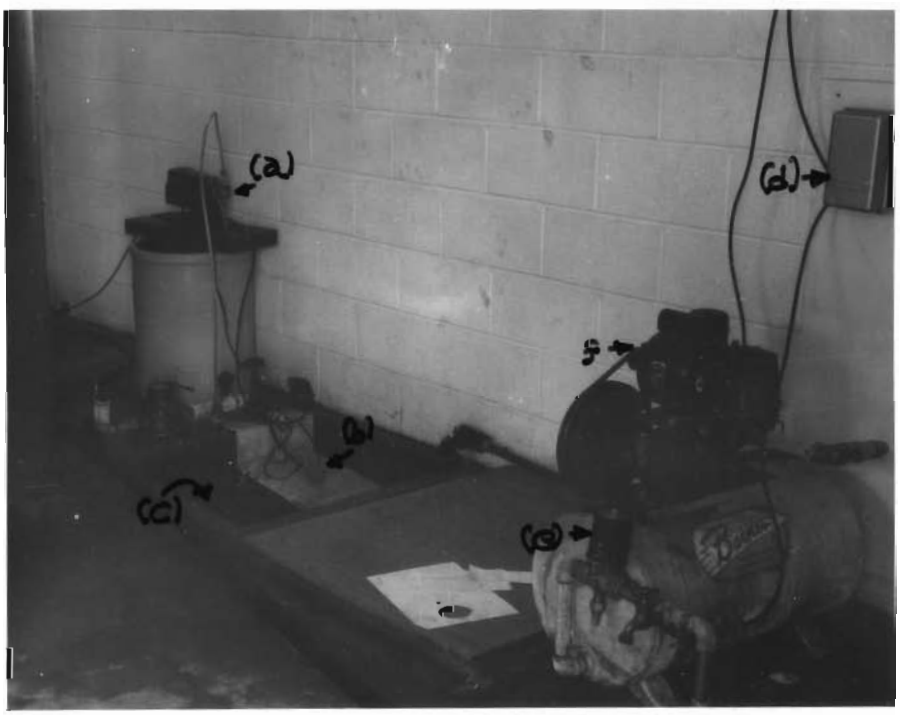

Figure 9. CHLORINATOR AND PUMP CONTROLS
(a) Chlorinator, (b) microswitch which controlled chlorinator, (c) sump, (d) time clock, (e) solenoid valve controlled by time clock and (f) slow sand filter pump.

2) Rapid Sand System

A rapid sand system was tested for three reasons: a) this is the type filter used by most municipal plants, b) this type filter can be easily obtained on the market, and c) no research has been reported on this type filters. Figure 10 shows a diagram of this installation.

Water was pumped from the pond through the barrel inlet. The water was chlorinated before the pump with a "Everclor" chlorinator from April 18, 1960 to June 6, 1960. After this time the water was chlorinated as it left the pump by a "Clayton Mark Electraclor". Both of these chlorinators operated when the pump operated. A 120-gallon pressure tank followed the pump.

A "Myers" rapid sand filter was used. This filter was 18 inches in diameter and contained 100 pounds of gravel and 70 pounds of filter sand. A sieve analysis of this sand can be seen in Figure 8. As seen in Figure 11, provision was made so that this filter could be backwashed and rinsed. From this filter the water passed through a "Cuno" cellulose fiber filter. Its purpose was to act as a finishing filter. The water then passed through a water meter. This system was controlled in the same manner as the slow sand filter. Five hundred gallons were allowed to pass per day by a time clock and a solenoid valve.

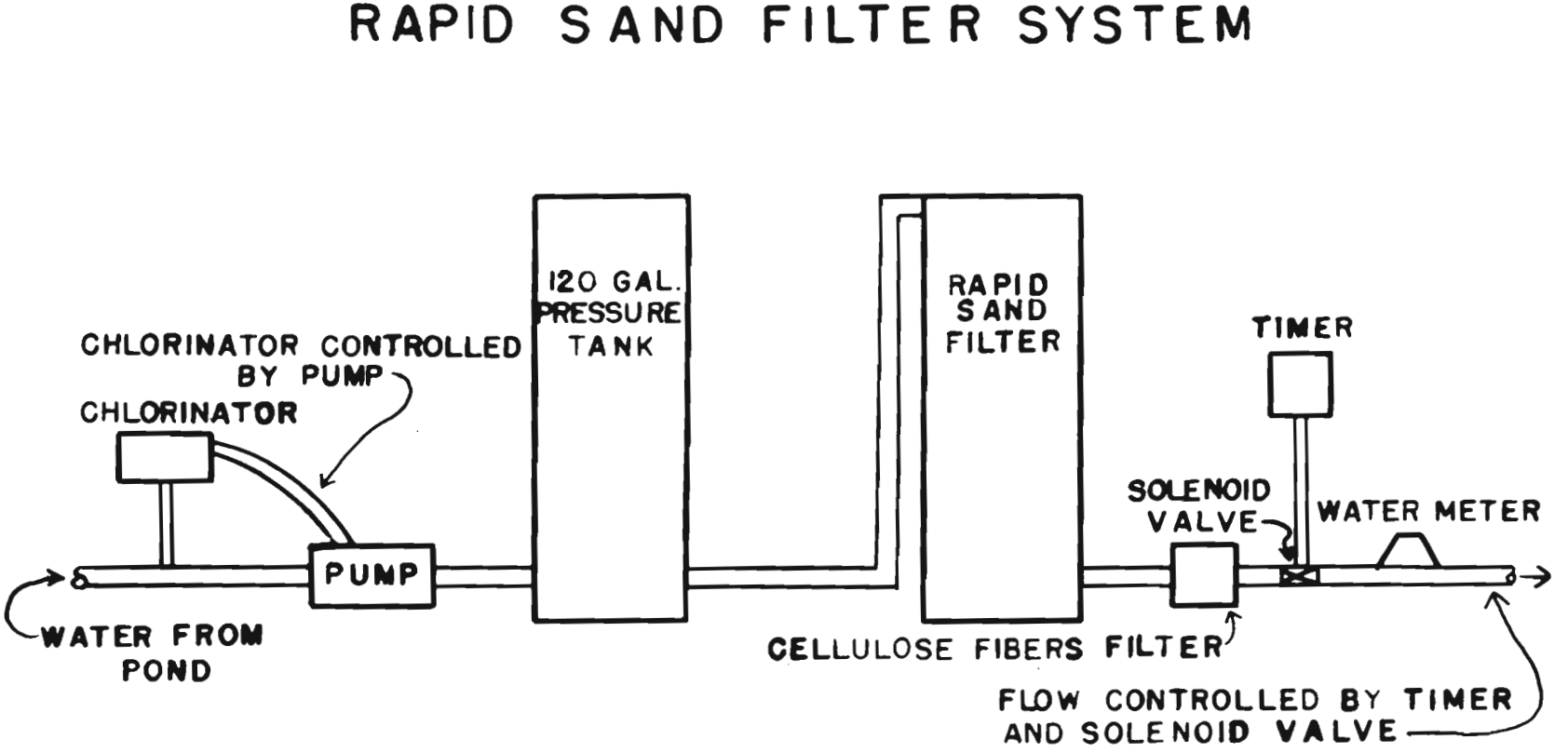

Figure 10. RAPID SAND FILTER SYSTEM

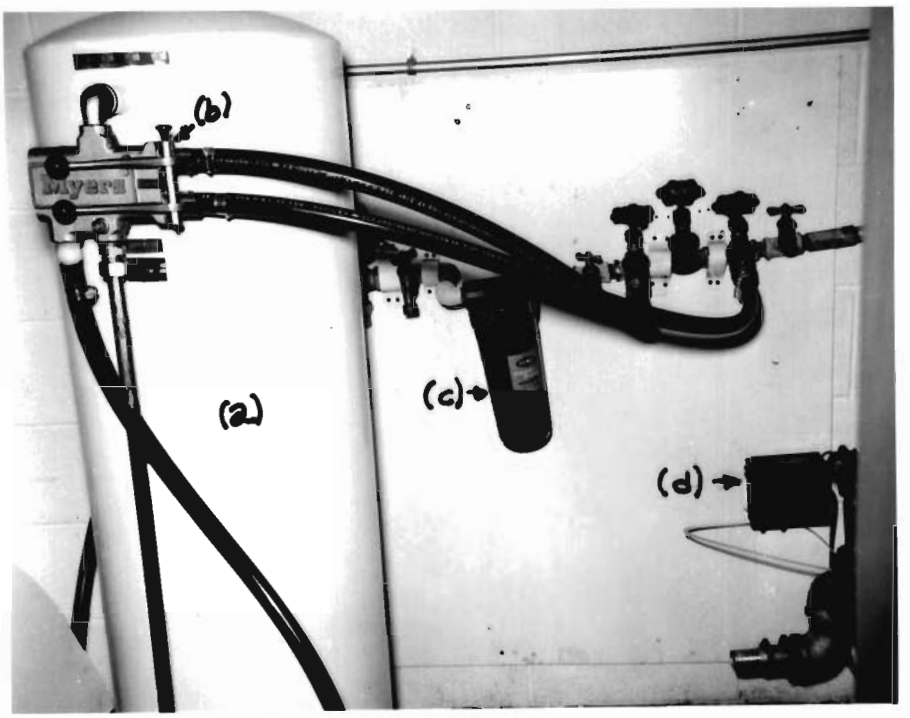

Figure 11. RAPID SAND FILTER
(a) Rapid sand filter, (b) backwash mechanism, (c) cellulose fiber filter and (d) chlorinator.

VI. RESULTS

A) Quality of Pond Water

1) Turbidity

Turbidity in the 14 farm ponds during the period of study was found to fall within the range of 1 to 78 units for the top samples and 5 to 153 units for the bottom samples. The mean of 261 top samples was 21.2 and of the bottom samples 40.1. Table VIII gives the maximum, minimum and mean turbidity for each pond.

In comparing these results with those obtained by Iowa, Missouri, Oklahoma and Indiana some interesting observations can be made. Oklahoma (21) had the highest average turbidity of 247 units. The other states, in general, had much lower turbidities. Iowa's (3) results showed turbidities of 165 to 260 units for new ponds and 5 to 50 units for old ponds. The older ponds were close to the values found in Ohio, but the newer ponds were higher than any pond found. Indiana's (11) turbidities fell in the range of 1 to 100 units (2 ponds) with an approximate average of 30 units. Missouri (20) in one pond found the turbidity to be in the range of 1 to 32 with an approximate average of 15 units. The location of the sampling points in the ponds from other states were not reported.

From this data, it can be formulated that there is a greater need for settling out the turbidity in both Oklahoma and newer Iowa ponds. The additional treating processes of flocculation and sedimentation will probably have to be integrated into the water plant.

The highest turbidities in Ohio were recorded in February, March and April. Another peak came in July, August and October for the

TABLE VIII

Turbidity Values for Each Pond

Pond Number	Maximum Turbidity	Minimum Turbidity	Mean Turbidity	Number Samples
samples one foot below surface (top)				
1	46.5	4.4	23.4	36
5	47	6	22.9	29
6	44	3.3	20.8	24
8	54	1	21	36
23	50	8	26.2	11
25	19	5	12	10
26	26.5	7	13.1	11
60	36.5	4	15.9	28
62	55	1	17.5	20
86	50	4	20.3	11
87	78	7	41.8	11
88	35	5	14.5	10
89	61	15	32.1	11
90	33	7	18.4	13
Avg.	--	--	21.2	--
samples one foot above bottom				
1	150	4.4	37.8	35
5	150	8	43.2	27
6	112.5	4.4	37.8	24
8	143	4	43.9	36
23	121	18	45	12
25	55	13	26.1	9
26	73	11	35.1	11
60	90	4.8	30.5	27
62	134	2.6	29.5	21
86	145	7	60	11
87	153	11	58.7	11
88	81	7	35.3	11
89	99	10	46.3	11
90	92.5	10	46.2	13
Avg.	--	--	40.1	--

bottom samples (see Figure 12). At no time of the year did the monthly average of either the top or bottom samples meet the Public Health Service standard for drinking water (8). However, individual ponds occasionally met the standard. Table IX shows the monthly variation in the turbidities for 1958, 1959, and 1960.

TABLE IX

Turbidity by Months for the Years 1958, 1959, 1960
(Top Samples)

Month	1958	1959	1960
January	----	14.6	20.2
February	----	----	30.8
March	----	32.8	28.1
April	----	29.2	25.9
May	28.8	15.9	11.3
June	----	14.3	8.9
July	25.7	21.2	----
August	17.8	28.5	----
September	15.3	22.2	----
October	15.7	17.6	----
November	8.5	26.1	----
December	11.4	31.5	----

Figure 13 shows the seasonal variation of pond 15 in Indiana (11) for June, 1957 to February, 1958 and the pond in Missouri for July, 1957 to May, 1958 as compared to the average top values for Ohio for the twenty-five-month period starting May, 1958. Indiana had the highest turbidity values during the period between January and March. Missouri had the lowest. During May and June, both states had higher values than the Ohio average. However, from July through October, this reversed and Ohio had the highest values. November and December were high months for Indiana with Ohio and Missouri having about the same values.

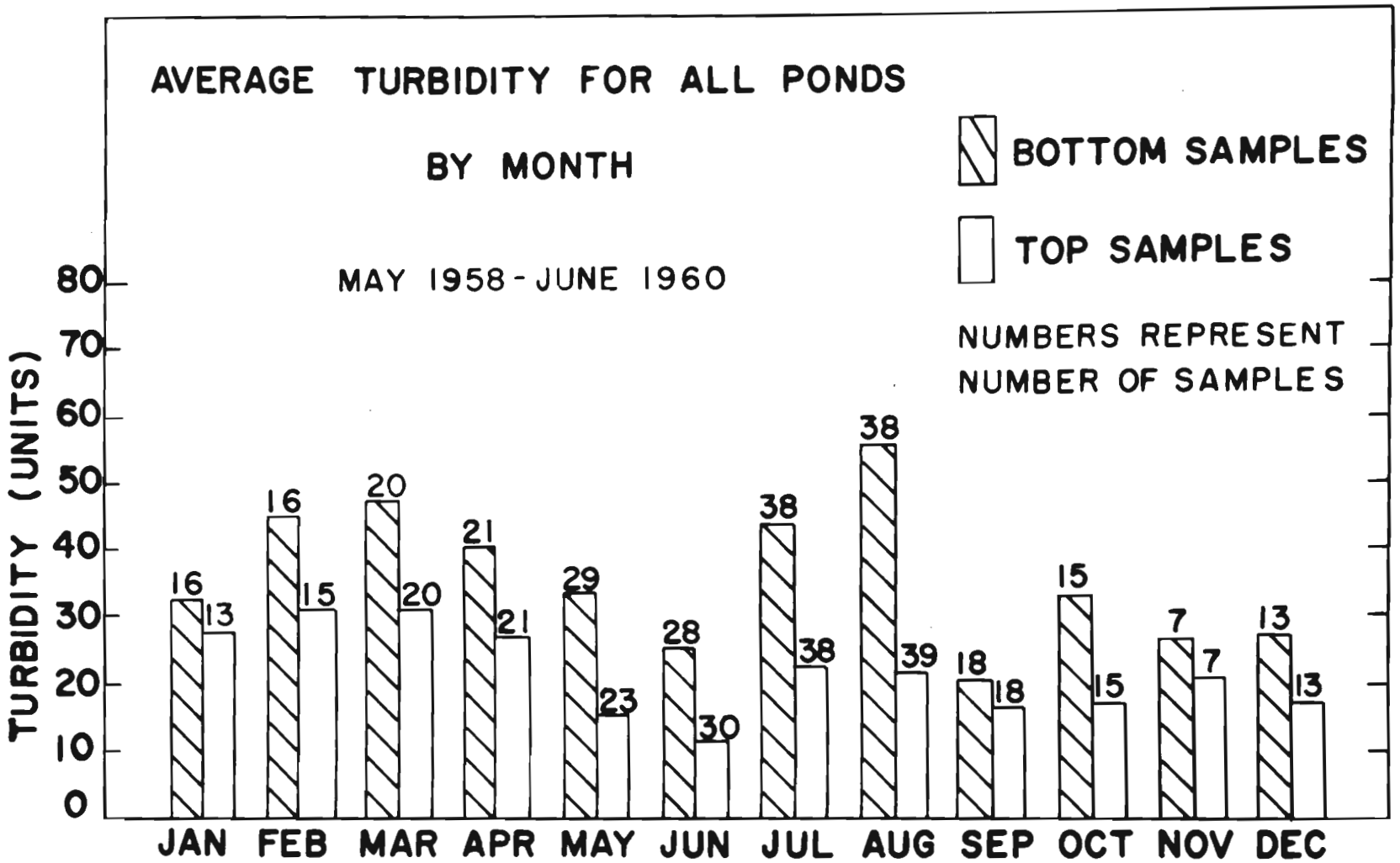

Figure 12. AVERAGE TURBIDITY FOR ALL PONDS BY MONTH

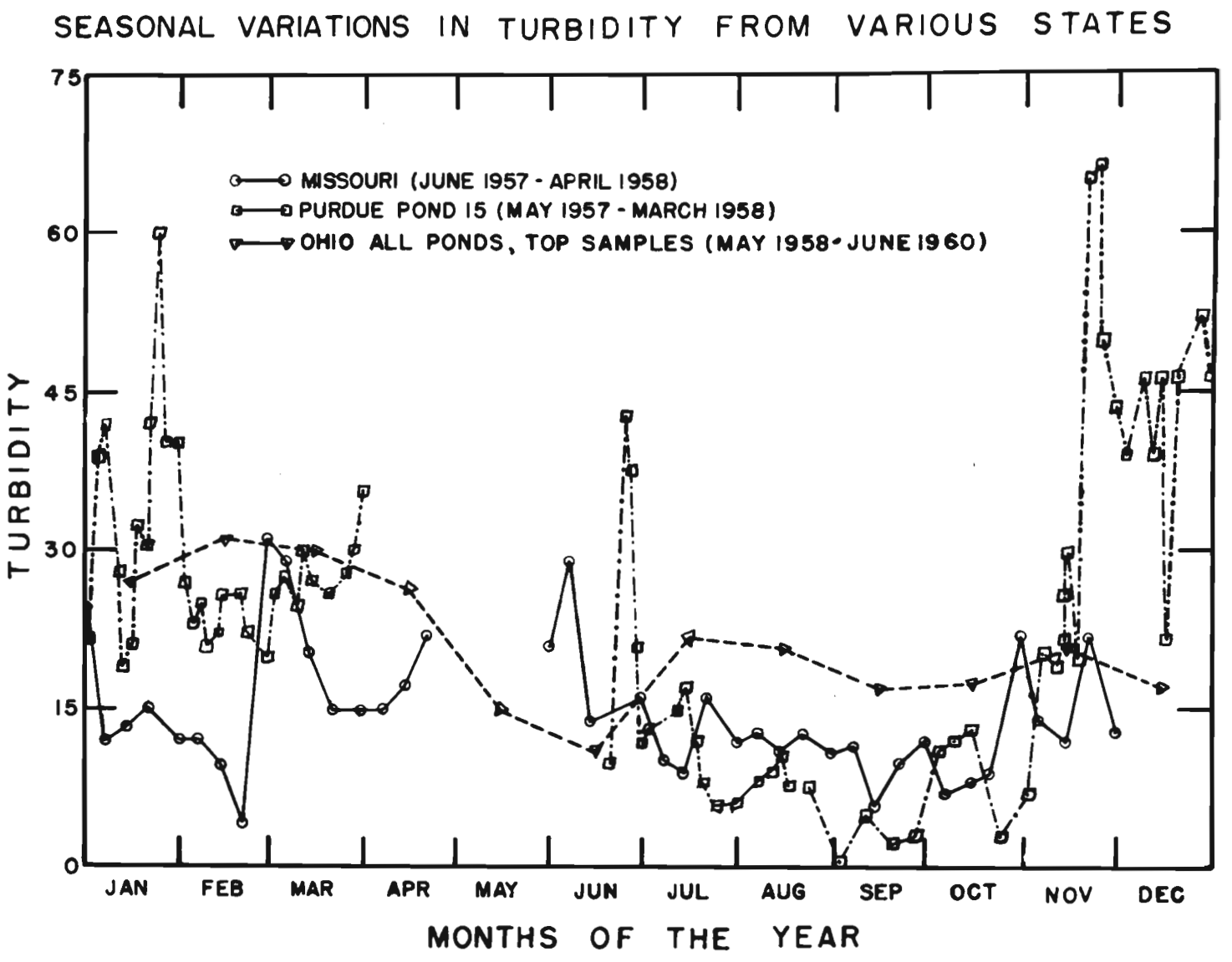

Figure 13. SEASONAL VARIATIONS IN TURBIDITY FROM VARIOUS STATES

In every month the bottom samples had a higher turbidity than the top samples. In three months the bottom samples had approximately 100% higher values. The correlation coefficient (Snedecor 22, p. 138) between all the top and all the bottom samples was 0.489. This value is highly significant, that is, 99% or more of the time the top samples will vary proportionally with the bottom samples or vice versa.

Ponds in the Glacial Sandstone and Shale Soils region were found to have an average top sample value of 19.0 and bottom of 40.8 and the Residual Sandstone and Shale Soils had an average top sample value of 16.9 and bottom of 37.4. It is felt that the lower values in the Residual Sandstone and Shale Soils may be due more to the fact that two of the three ponds in this region are spring fed, rather than due to differences in soil. The spring-fed ponds had from 29 to 50% less turbidity than all the nonspring-fed ponds.

The highest turbidity values were obtained in pond 87. This high turbidity was most likely due to the poor cover on the banks of the pond and to the ducks in the pond. High turbidities were also found in pond 23 where the cover was poor just around the pond. Pond 87 had lower turbidities in 1960 after the banks of the pond had better cover and the ducks removed.

The size of the drainage area (0.86 to 51 acres) had little effect on the turbidity. The correlation coefficient for the average turbidity of all the top samples and the drainage area in acres was +0.176. Compared to the correlation coefficient of 0.497 at the 95% level this value was far from being significant. Since averages tend to vary less than individual observations, the correlation coefficient would have

been less than the above values if individual turbidity samples had been compared. Because the turbidity of the bottom samples tends to vary with the top samples, the results would be about the same for the bottom samples. Therefore, the data show no relationship between turbidity and size of drainage area. The presence of bare soil immediately around the pond had more effect than the size of the drainage area.

Wind played an important part in the turbidity. The turbidity would increase from 50 to 100 percent on a windy day as compared to a calm day. This condition was noted more on ponds that had bare banks.

2) Color

The color of the water in farm ponds was found to fall within the range of 0 to 200 ppm for the top samples and 0 to 520 ppm for the bottom samples. The over-all average for top samples was 40 ppm and 74 ppm for bottom samples.

Maximum color for bottom samples was found during a period from February to September. The remainder of the year the top and bottom samples had approximately the same color or 40 ppm. The top samples had approximately 40 ppm of color throughout the year except for February, March, and May. Figure 14 shows the seasonal variation of color. The correlation coefficient between top and bottom samples was found to be 0.443. This value is highly significant at the 99% level.

Individual ponds varied considerably in color. Ponds 26 and 88 had the lowest color. This low level can be traced partly to the absence of large amounts of algae. Pond 89, which at one time had a bad algae problem, had one of the highest color values. Table X gives the maximum, minimum and mean color for each pond.

The size of the drainage area and soil region in which the pond was located had no apparent effect on the color content.

TABLE X

Color Values for Each Pond

Pond Number	Maximum Color	Minimum Color	Mean Color	Number Samples
	Samples one foot below surface			
1	130	10	34.5	34
5	200	0	60.2	27
6	80	10	40.9	22
8	90	0	38.9	35
23	130	10	56.8	11
25	60	10	31.5	10
26	40	0	20	10
60	60	10	25.7	29
62	80	0	27.8	20
86	70	10	33.6	11
87	110	10	50	11
88	70	0	20.9	11
89	160	20	75.1	11
90	100	10	48.8	13
Avg.	---	--	39.6	--
	Samples one foot above bottom			
1	165	10	54.4	34
5	240	10	75	25
6	190	20	74.1	23
8	160	10	61.7	35
23	200	20	94.1	11
25	400	35	200.	9
26	70	0	34.5	11
60	520	10	80.2	28
62	120	0	37.5	21
86	180	20	73.6	11
87	150	20	65.5	11
88	110	20	47.7	11
89	360	40	162.4	11
90	200	10	84.6	13
Avg.	---	--	73.9	--

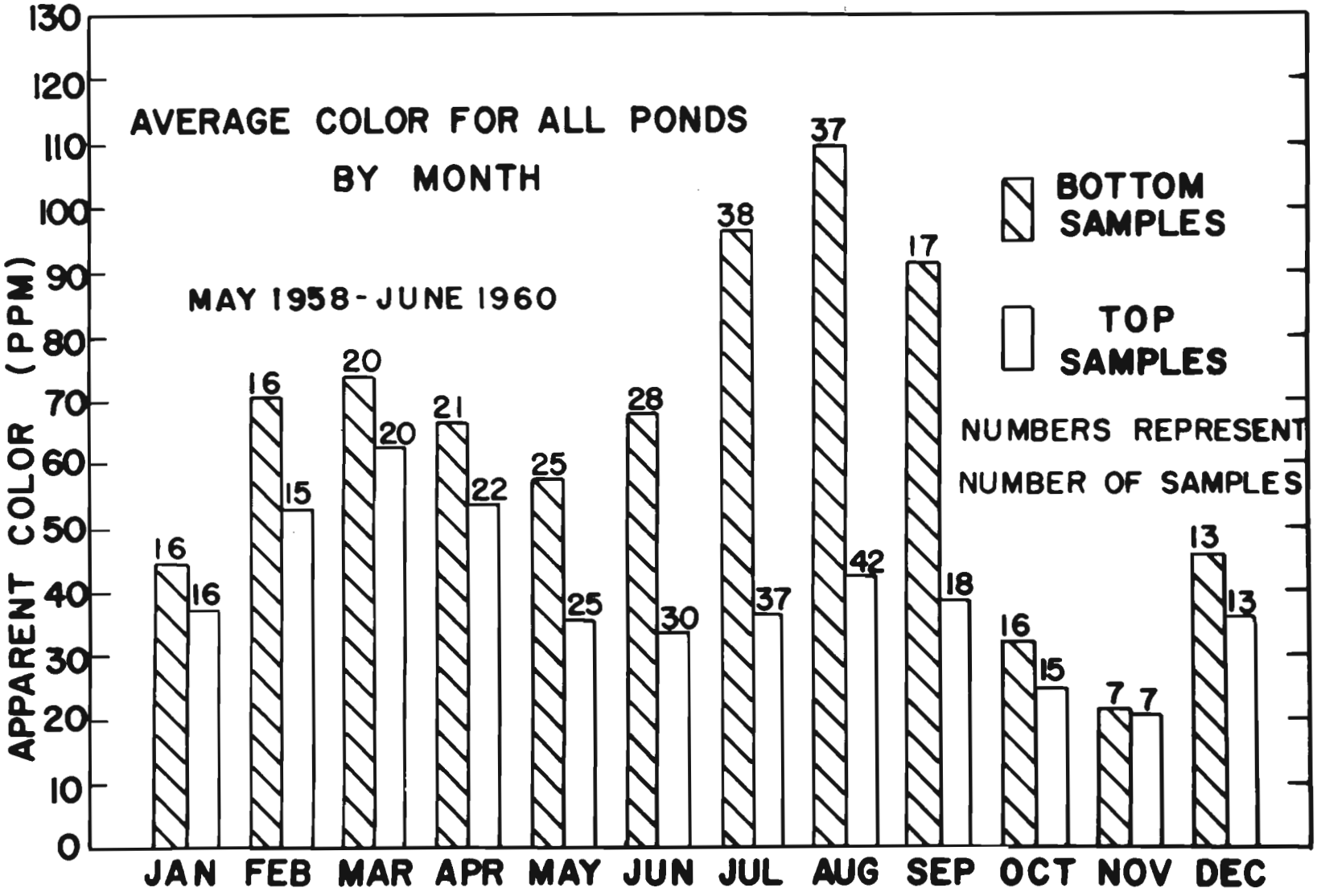

Figure 14. AVERAGE COLOR FOR ALL PONDS BY MONTH

3) Odor

As high as 64% of all the bottom samples from an individual pond had an odor (Table XI). The average percentage of bottom samples having an odor was 27% as compared to 8% for the top samples. In all ponds the percentage of bottom samples with an odor was greater than the percentage of top samples.

TABLE XI

Percent of Samples Having An Odor For Individual Ponds

Pond Number	% Top Samples Having Odor	% Bottom Samples Having Odor
1	3	11
5	15	21
6	5	35
8	6	20
23	18	33
25	10	60
26	0	9
60	0	25
62	10	14
86	9	45
87	0	8
88	8	27
89	27	64
90	8	54
All Ponds	8	27

The presence of odor in pond water depends largely on the season of the year. As shown in Figure 15 the bottom samples did not have an odor during February and November. The top samples showed no odor in January, September and October as well as in the above two months.

Starting in 1960, a threshold odor test was run on samples that had an odor. In 1960 the first odors were recorded in May. Pond 5, which had a bad algae problem and ducks in it, showed an odor of 2 at the top and 8 at the bottom. All of the samples taken from the pond

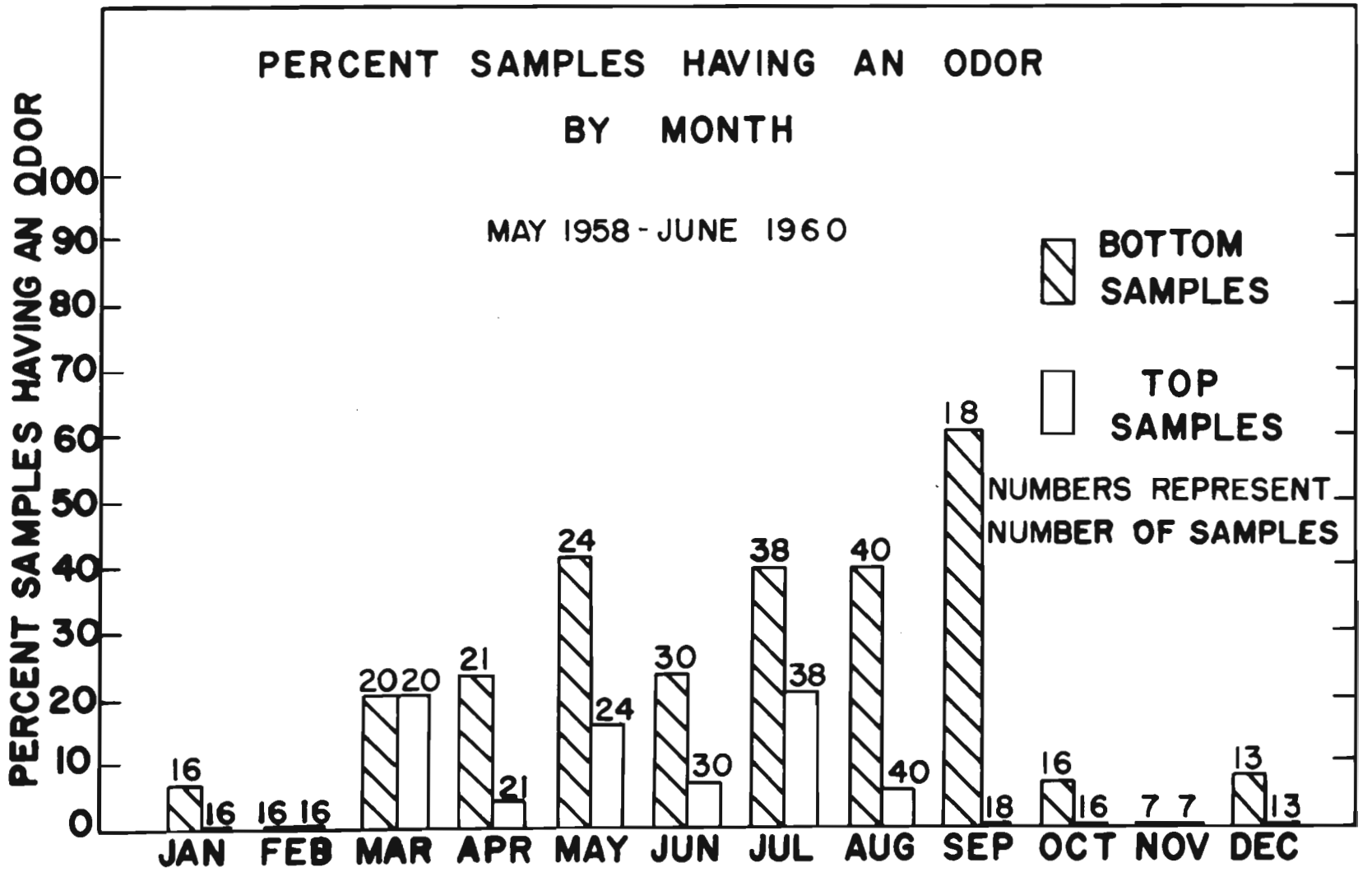

Figure 15. PERCENT SAMPLES HAVING AN ODOR BY MONTH

had odors in that range. This problem lasted through June when the peak odor of 64 was recorded for a bottom sample. A sample two weeks after this showed no odor. Ponds 23 and 25 had bottom samples with odor of 32 and 8, respectively, the first part of July. Pond 86 water samples contained odors between 8 and 16 at the 11-, 12-, and 13-feet levels where the depth was 14 feet. The odor in these last three cases were probably due to anerobic decomposition of dead weeds and algae.

Odor was noticed in a number of ponds after large quantities of algae had died. The odor types were classified as fishy, musty and grassy based on descriptions in Standard Methods (8, p. 202).

4) Bacteria

In In only two samples of 289 taken for bacterial analysis was the coliform group count at a safe level. The data indicate that all pond water is contaminated and needs treatment before it can be used for domestic purposes.

The maximum bacterial counts for all ponds occurred during the summer months of July, August and September (Table XII). The temperature of the pond water was a factor affecting the bacterial count. The correlation coefficient between bacteria count for 117 bottom samples and temperature was 0.64. The corresponding coefficient at the 99% level is 0.237 (Snedecor 9, p. 149). Therefore, the correlation is highly significant.

TABLE XII

Maximum Bacteria* Counts and Month of Occurrence

Pond Number	Top Sample: Max. Bacteria Count - Coliform groups per 100 ml	Top Sample: Month Occurring	Bottom Sample: Max. Bacteria Count - Coliform groups per 100 ml	Bottom Sample: Month Occurring
1	330	July	260	Aug.
5	5,400	July	9,200	July
6	>2,400	July	>24,000	July
8	>2,400	July	7,900	Aug.
23	5,400	Sept.	1,700	Sept.
25	9,200	July	1,100	July
26	790	July	490	Sept.
60	330	Aug.	920	Aug.
62	1,400	July	9,200	Aug.
86	>2,400	July	9,200	Sept.
87	16,000	Aug.	>24,000	Aug.
88	2,200	Sept.	5,400	Sept.
89	2,400	Aug.-Sept.	5,400	Aug.
90	>24,000	Aug.	16,000	Aug.

* Coliform Group

In six of ten months that data were available the bottom samples had greater bacterial counts than the top samples. As seen in Table XIV the percentage of samples that the bottom samples were greater than the top occurred in all months except February, May and July, but the number was the same in January. In 54% of all the samples the bacteria count in the bottom samples was greater than in the top samples. This relationship, however, varied widely from pond to pond (Table XIII).

TABLE XIII.

Comparison of Bacteria* in Top and Bottom Samples

Pond Number	Samples Compared	No. Bottom Samples Having Higher Bacteria Counts Than Top Samples	No. Samples Having Same Bacteria Count	Samples % (Bottom Greater Than Top)
1	15	8	3	53
5	12	6	2	50
6	9	6	1	67
8	15	11	1	73
23	10	3	1	30
25	9	4	0	44
26	11	6	1	55
60	16	12	0	75
62	13	7	1	54
86	8	4	1	50
87	8	2	2	25
88	8	5	1	63
89	7	3	1	43
90	8	3	0	38
Total	149	80	15	54

* Coliform Group

TABLE XIV.

Comparison of Bacteria* in Top and Bottom Samples by Months

Month	Total Samples	No. Bottom Samples Having Higher Bacteria Counts Than Top Samples	No. Samples Having Same Bacteria Count	% Samples (Bottom Greater Than Top)
Jan.	8	4	1	50
Feb.	2	0	1	0
Mar.	13	8	2	61
Apr.	11	7	0	64
May	15	7	3	47
June	7	6	0	86
July	31	12	4	39
Aug.	35	19	1	54
Sept.	13	8	1	62
Oct.	0	0	0	--
Nov.	0	0	0	--
Dec.	9	6	1	67
Total	144	77	14	53

* Coliform Group

The correlation coefficient between bacterial count and turbidity was 0.216 for 133 top samples and 0.095 for 135 bottom samples. The correlation was significant for the top samples at the 99% level, but was not significant for the bottom samples at the 95% level.

The Bacteriological Department of the Ohio State University ran further studies on bacteria in pond water. Table XV shows the results of some of this work. The standard plate count, which is a measure of the total bacteria population, ranged from "too numerous to count" to 40 colonies per milliliter. Thermoduric bacteria are important in that they are not killed by pasteurization. This is vital when the water is used in the milk house. These are not pathogentic bacteria, but spoilage types. In pond water this group ranged from less than ten to as high as 4100 colonies per milliliter. Thermophilic bacteria grow best at high temperatures (50-55° C.) and psychrophilic at low temperatures (15-20° C. or below). These groups showed a very low count in the water.

TABLE XV.

Bacteriological Analyses of Pond Water

Sample Location Pond	Depth	Date 1960	S.P.C. per ml 1)	Thermo-duric 2) per ml	Thermo-philic 3) per ml 50-55°C.	Psychro-philic 4) per ml 15-20°C.	MPN 5) per 100 ml
60	top	5/2	40	50	<1	<10	3
	bottom		190	170	1	<10	3
1	top	5/6	TNTC6	4100	1	10	23
	bottom		100	70	--	<10	23
5	top	5/6	TNTC	140	2	<10	15
	bottom		120	50	2	10	43
8	top	5/6	TNTC	110	1	<10	9.1
	bottom		610	480	36	<10	93
60	top	5/16	600	--	2	<10	23
	bottom		510	60	--	20	3
62	top	5/16	110	140	<1	<10	15
	bottom		250	190	<1	20	11
1	top	5/20	110	--	<1	10	23
	bottom		--	--	15	70	9.1
60	top	5/23	320	<10	<10	2	93
	bottom		8700	60	30	25	1100
62	top	5/23	290	40	1	<1	39
	bottom		880	120	--	7	19
1	top	5/26	350	190	<1	8	9.1
	bottom		490	50	<1	2	43
5	top	5/26	230	60	5	4	150
	bottom		--	300	3	5	150
8	top	5/27	150	90	<1	1	14
	bottom		--	150	<1	<1	15
8	top	6/2	490	40	<1	--	460
	bottom		--	170	4	--	93

1) Standard Plate Count
2) Thermoduric - bacteria that are resistant to the Pasteurization process.
3) Thermophilic - bacteria that grow well at temperatures of 50-55° C.
4) Psychrophilic - bacteria that grow well at temperatures of 15-20° C. and will grow at lower temperature
5) Most Probable Number
6) TNTC - Too numerous to count

5) Chemical Analysis of Pond Water

One sample from each pond was taken in the summers of 1958 and 1959 for chemical analysis. This sample was obtained one foot below the surface near the inlet into the water system. Table XVI presents the maximum, minimum and average value for each chemical test performed for Ohio ponds and rivers, Indiana ponds and Oklahoma ponds.

TABLE XVI.

Results of Chemical Analysis From All Ohio Farm Ponds, Ohio Rivers, Indiana Ponds, Oklahoma Ponds

	Ohio Farm Ponds			Ohio Rivers		Ind. Ponds (11)		Okla.(21) Ponds
	Max.	Min.	Avg.	Max.	Min.	Max.	Min.	Avg.
Total solids ppm	464	60	184	--	--	--	--	--
Volatile solids ppm	106	6	45	--	--	--	--	--
Dissolved solids ppm	--	--	--	20,000	49	--	--	--
Alkalinity, total ppm	145	10	79	--	--	75	50	--
Hardness, total ppm	212	0	95	1,710	23	98	50	14.19
pH	9.3	5.2	8.0	8.5	2.9	9.5	7	8.32
Iron, total ppm	1.55	.05	.38	4.1	.01	1.0	0.1	--
Chloride ppm	110	0	16	12,000	1.8	--	--	--
Fluoride ppm	0.5	0	.29	3.2	0	--	--	--
Nitrate ppm	5.9	0	.48	111	.1	--	--	--
Sulfate ppm	110	48	36	1,360	15	--	--	--
Radiation (microcuries per ml x 10^{-7})								
Suspension	0.82	0.10	0.26					
Filtrate	0.64	0.00	0.32					

Pond water in Ohio was of better quality than that found in the rivers. Ohio pond water seemed to be harder and have higher alkalinity than Indiana. Oklahoma pond water was the softest.

a) Total Solids

The total solids in farm ponds could be traced to the soil region in which the pond was located. The Glacial Limestone Soils and Glacial Sandstone and Shale Soils Region had approximately the same average total solids of 211 ppm. The Residual Sandstone and Shale Soils Region had 67 ppm. In all cases the ponds in this region had a lower value for total solids than the other ponds.

In eleven samples out of seventeen the total solids increased from 4 to 63% from the summer of 1958 to summer 1959. The average increase was 25%. The highest decrease was 16% and the average decrease for the six remaining samples was 9%. This increase may have been due to the dry summer of 1959 as compared to the wet summer of 1958. The samples would be diluted by the rain and therefore, show less total solids.

b) Volatile Solids

Volatile solids are an indication of the amount of organic matter. In the Glacial Limestone Soils Region the volatile solids were 30% of the total solids. In the Glacial Sandstone and Shale Soils Region and the Residual Sandstone and Shale Soils Region the volatile solids were 26 and 39% of the total solids, respectively. All ponds except those in Delaware County had a decrease in volatile solids from 1958 to 1959. The average decrease was 50%. Delaware County, however, had an average increase of 204%.

The decrease in volatile solids may be due to the ideal conditions during the summer of 1959 for decomposition of organic materials. No reason can be given for the increase of the volatile solids in Delaware County.

c) Total Alkalinity

The total alkalinity in all samples was below the maximum as set up by the drinking water standards (8). As shown by Table XVII the Residual Sandstone and Shale Soils Region had the lowest average alkalinity and the Glacial Limestone Soils Region the highest average value. Total alkalinity was not a problem in farm pond water.

TABLE XVII.

Chemical Analyses of Pond Water by Soil Regions

	Glacial Limestone Soils Ponds 5,6,8 80,87,88,89	Glacial Sandstone and Shale Soils Ponds 1,60,62	Residual Sandstone and Shale Soils Ponds 23,25,26
Total Solids (ppm)	212	211	67
Volatile Solids (ppm)	63	54	26
Alkalinity (ppm)	91	85	27
Hardness (ppm)	118	104	21
pH	8.33	7.75	6.6
Iron (ppm)	.44	.46	.3
Chloride (ppm)	12.3	30.7	1.67
Fluoride (ppm)	.49	.20	.22
N. Nitrogen (ppm)	.07	1.54	.03
Sulfate (ppm)	44.4	31.8	17.1

d) Total Hardness

The total hardness for pond water was within the range of 0 to 212 ppm. Ponds 23, 25, 26 in the Residual Sandstone and Shale Soils Region had relatively soft water (Table XVII). As shown in

Table XVIII, the remaining ponds were in the moderately hard to hard water class. The water in ponds 6 and 8 increased in hardness in 1959, but there was no change in water class for the other ponds.

TABLE XVIII.

Total Hardness of Pond Water

Year	Soft Water 0-51 ppm	Moderately Hard Water 52-120 ppm	Hard Water 121-340 ppm
1958	*23,25,26	5,6,8,60,62,88,89	1,86,87,90
1959	23,25,26	5,60,62,88,89	1,6,8,86,87,90

* Numbers indicate pond number.

e) Total Iron

The drinking water standard for maximum total iron and manganese is 0.3 ppm. The average total iron in the ponds was 0.38 ppm. Nine of the fourteen ponds would not meet the above standards. However, the highest value was 1.55 ppm or five times greater than the standard.

f) pH

The pH for ponds varied widely from 5.2 to 9.3. A low pH value is an indication that the water may have corrosive properties. Most ponds have basic pH values near neutral. However, pond 23 had values below 7.0 or in the acidic range. All ponds in the Residual Sandstone and Shale Soils Region had lower pH values than those of the other regions.

g) Chloride, Fluoride, Nitrate Nitrogen, Sulfate and Radiation

In no case was chloride, fluoride, nitrate nitrogen, sulfate or radiation found at a value greater than the maximum allowable by drinking water standards. These values were usually much lower than the standard.

6) Particle Size

The use of membrane filters in determining particle size is somewhat of a new concept. The size of filters to be used were chosen for these reasons. The 5 u (0.005 mm) filter has pore spaces the same size as the upper clay limit as set up by the U. S. Bureau of Soils (10). This same organization considers any particle smaller than 1.0 u to be colloidal in nature. The 1.2 u (0.0012 mm) filter closely approximates this size. It was assumed that no sediment could pass the 100 mu (0.0001 mm) filter.

Turbidity measurements were taken of the sample before and after it passed through this series of filters. Table XIX presents typical results from these filter runs and Figure 16 shows typical filters. It can be noted that the 5 u filter lowered the turbidity to approximately one unit. From this data, it can be reasoned that the majority of the particles in suspension in pond water are greater than 5 u. Therefore, a filter with an effective pore size of 5 u would be expected to be a good pond water filter.

Turbidities of greater than one unit after the 5 u filter always came from samples with a turbidity of 18 units or higher except in one case. In this particular sample the turbidity was reduced from 2.55 to 1.1 units. The sediment in this sample must have been very fine as only

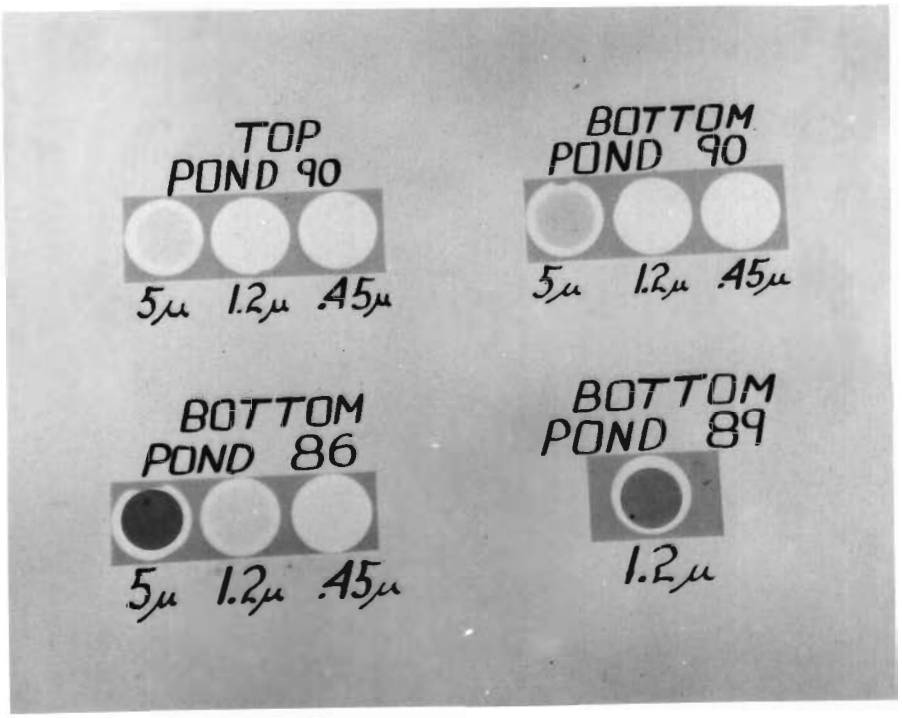

Figure 16. MEMBRANE FILTERS
(a) Sediment on 5 u filter for bottom pond 86 was due to clay and silt and (b) sediment on 1.2 u filter bottom pond 89 due to algae.

a very small portion of the turbidity was taken out by the 1.2 u filter. The 1.2 u filter in almost all cases reduced the turbidity to a value of 0.5 or less.

TABLE XIX.

Turbidity Reduction Due to Filtration Through Membrane Filters

Pond	Date 1960	Sample Location	Turbidity Before Filter	After 5u Filter	After 1.2u Filter	After 100mu Filter
1	6/27	Top	5.7	.41	.35	.35
		Bottom	6.5	.69	.61	.35
5	6/27	Top	19.5	1.01	.69	.41
		Bottom	32.5	1.19	.69	.61
8	6/27	Top	2.55	.61	.47	.35
		Bottom	26.5	1.01	.47	.29
8	6/29	Top	2.55	1.1	.69	.27
		Bottom	64.5	1.1	.92	.41
23	7/3	Top	25.	1.39	.41	.41
		Bottom	82.	1.39	.92	.41
25	7/4	Top	5.25	.69	.47	.35
		Bottom	18.	1.19	.47	.41
26	7/4	Top	5.7	.69	.54	.41
		Bottom	14.5	.61	.41	.35
60	6/8	Top	11.5	.41	.20	.20
		Bottom	19.5	.35	.29	.23
62	6/8	Top	1.01	.41	.29	.18
		Bottom	2.55	.29	.23	.13
62	6/22	Top	5.25	.35	.29	.29
		Bottom	28.	.92	.54	.47
62	6/28	Top	7.9	.92	.84	.29
		Bottom	36.5	1.19	.84	.47

7) Spraying Ponds for Vegetative Control

Stockdale (24) and Lawrence (25) recommend the use of copper sulfate to control algae in ponds and sodium arsenite for control of submerged weeds. A number of ponds in the study used copper sulfate to control algae. The copper level in these ponds never reached a dangerous level. Secondary reactions due to dead algae, however,

increased color and odor. Pond 87 which was sprayed in the spring of 1959 had an increase of 60 ppm in color and developed an objectionable odor shortly after the algae died. Similar situations were observed in ponds 1, 6, 89 and 90.

In three ponds sodium arsenite was used to control submerged weeds. In these ponds dangerous levels of arsenic were found in samples of water taken near the inlet into the filtration system. The Public Health Service's standard for arsenic is a maximum of 0.05 ppm. Routine sampling in 1958 showed the level to be 1.2 ppm in pond 8. This level was found three months after the pond had been sprayed. In 1960 a residual of 1.4 was found in pond 86 three weeks after spraying. Because of the high arsenic value found in 1958, further studies were made in pond 88 in 1959. On June 5, 1959, this pond was sprayed with sodium arsenic at the rate of 3 gal. per acre-foot of water as recommended by Stockdale (24). Five days after spraying a chemical test for arsenic showed 1.00 ppm residual. Additional tests were then taken and the results are shown in Table XX. The arsenic content three months after the pond was sprayed was approximately the same as after five days. The increase in arsenic from August to September is probably due to the lowering of the water level in the pond. The arsenic content of the cold water in the home was taken in September. This sample contained 0.60 ppm arsenic as compared to 1.00 ppm in the pond. This difference is due to the water being pumped from the pond into a cistern and then used. The water in the cistern was from the lower arsenic level of August. Tests of this same pond showed that after fourteen months the arsenic level was still above that recommended by the Health Service.

TABLE XX.

Arsenic Content in Farm Pond Water*

Date of Sampling	Arsenic Content (ppm)	Location of Sample
June 5, 1959	Pond Sprayed with Sodium Arsenite	
June 10, 1959	1.00	top near inlet
July 12, 1959	0.60	" " "
Aug. 4, 1959	0.60	" " "
Sept. 1, 1959	1.00	" " "
Sept. 1, 1959	0.60	cold water in house
Feb. 20, 1960	0.20	bottom near inlet
July 16, 1960	0.4	bottom near inlet
July 16, 1960	0.4	top near inlet
July 16, 1960	0.4	cold water in house

* Pond 88

Arsenic is a stable element and does not combine readily with other elements. There is apparently no easy method of removing arsenic from ponds. James Kneale*, Sanitary Engineer, Ohio Department of Health made this statement concerning arsenic in ponds, "It is reasonable to assume that high concentrations of arsenic will cause a chronic arsenoisis, the result of which may not be apparent for several years". Jack H. Russel**, Veterinary Epidemiologist, Ohio Department of Health, stated that, "Since arsenic accumulates in the tissues there would be a slow build-up of toxicity. The symptoms would, in general, be the same as acute poisoning but the onset is more insidious and the slow development of the symptoms is frequently misleading. As the arsenic is ingested and exerts its effect on the body, some of it is excreted by the kidneys and some of it is retained by certain tissues (skin, hair, bones, and bone marrow). Any time that an acidosis condition develops in the blood, this arsenic could be re-absorbed and produce an acute, fatal attack by adding its toxicity to an already chronic condition". No effect has been noted by the persons using the pond water containing arsenic.

* Letter to W. E. Stuckey, Ext. Specialist in Safety, dated Oct. 1, 1959
** Letter to W. E. Stuckey, Ext. Specialist in Safety, dated Sept. 17, 1959

8) Animals In and Around Ponds

The majority of the ponds in this study were fenced to keep farm livestock from getting near or in the pond. On two occasions animals were noted in and around the pond after they had gotten through the fence. At two pond installations ducks were in the pond a majority of the time.

In July 1959 it was observed that cows had broken through the fence at pond 25 and were in the pond. The bacteria count for the sample taken that day was 9,200 coliform per 100 ml as compared to 1,100 taken twenty days before. The cows were kept out of the pond after that time and the bacteria count was reduced to 240 eleven days later. The closest pond to pond 25 had a change of only 287 counts in this same period.

Horses have been observed near pond 5, but were never in it. The horses pasturing in the drainage area caused no noticeable increase of bacteria in the pond water as compared to sampling days when no horses were in the area. In 1960 two ducks were placed in this pond. The turbidity doubled over that of 1959 while the other three ponds in the same county had a decrease in turbidity.

In July 1959 nine ducks were found in pond 87. The bacteria count was higher in all but one set of samples during the period that ducks were in the pond. Table XXI shows a comparison of pond 87 which had ducks and pond 88 which did not. These two ponds are approximately 300 yards apart and have similar drainage areas as to soil type and topography. As shown in Table XXI, the water samples from pond 87 had a higher bacteria count than those from pond 88 for both top and bottom

samples except for the sample on July 12, 1959. In 1960 the ducks were removed from this pond. The turbidity was reduced by 75% in 1960 as compared to 1959.

TABLE XXI.

Effect of Ducks on the Bacteria Count in Pond Water

	Pond With Ducks Pond 87		Pond No Ducks Pond 88	
	Top	Bottom	Top	Bottom
7/11/58	2,400	2,400	920	1,600
8/21/58	2,800	370	170	78
9/17/58	4,900	7,900	2,200	5,400
7/12/59	70	81	490	240
8/14/59	16,000	3,500	1,100	2,400
9/1/59	9,200	9,200	170	330

9) Algae and Weeds in Farm Ponds

Algae seemed to have an effect on the odor and color found in water samples. This effect was noticed in most cases after the algae had died. Ponds that were observed to have a black layer of decaying organic matter (dead algae) on the bottom always indicated color and odor. The bottom samples did not always show this effect because they were taken one foot above the bottom which was above this layer. However, samples taken in the water system at times showed higher color and odor than the water in the pond. These higher values were due to the dead algae settling into the barrel or the concrete block gravel inlets at the bottom of the pond. The odor and color produced by the decaying organic matter were drawn into the water system.

An illustration of this effect is pond 1. After the algae died, the color of the bottom samples increased from 35 to 165 ppm. A month

later the bottom sample decreased in color to 45 ppm. In this same month period the sample taken in the house had an increase from 125 to 440 ppm. After this time, the house sample was higher than the bottom sample. A floating inlet was installed later which decreased the color to 20 ppm.

Weeds seemed to have little or no direct effect on water quality. No cases were observed where weeds increased the color, odor, or turbidity of the water.

10) Effectiveness of Different Inlets

Based on test results obtained on turbidity, color, odor and bacteria, better quality water is found near the surface than near the bottom. Several different types of inlets (entrance at outlet water pipe from the pond) were evaluated. At the initiation of this project three of the fourteen ponds had a pipe buried at the bottom of the pond as an inlet, two had a floating inlet, six had a barrel filled with gravel, one had a concrete block box inlet and four had a concrete block box filled with gravel. Three types of inlets were installed in pond 60 at the Southern Substation for this study.

Buried pipe. Two types of buried pipe inlets were studied. In pond 60 a perforated 1-inch plastic pipe 500 feet long was buried in soil about 18 inches deep at the bottom of the pond. In ponds 1 and 90 a perforated plastic pipe had been placed inside a small diameter drain tile which was covered with about 18 inches of gravel. The purpose of the soil or gravel was to filter the water.

Eight of 11 samples of water from the buried pipe in pond 60 had a lower turbidity than the bottom samples, 9 of 11 had lower color. The

turbidity was reduced by 41% and the color by 40%. The water coming out of the inlet had a greater concentration of odor than the water one foot above the bottom of the pond. Of the bottom samples 54% had an odor as compared to 67% of those taken from the pipe. The bacteria count was reduced by the inlet in 66% of the samples, but not to a safe level.

In pond 90 the turbidity was 13% higher after passing through the buried pipe than at one foot above the bottom of the pond. Color was reduced by 9% and less odor was found after passing through the buried pipe inlet. In pond 1 the color was increased 100% after passing through the buried pipe inlet. The other quality tests could not be evaluated at this pond.

With a buried pipe inlet, the color and odor may be increased by the water passing through the soil or gravel. This increase may be due to the water picking up soluble organic material. Some filtration of the turbidity may take place. In some cases of high head it could be possible for piping action to take place and the water would not be filtered. The results of these tests show that a buried pipe is a very poor method of removing water from a pond.

Concrete block box inlet. Pond 62 had a concrete block box 5' square by 9' deep in the pond. The blocks were the only filter material as the box was hollow.

The turbidity was reduced 29% by passing through the concrete blocks. A reduction of turbidity was even found after it was noted that the mortar was missing between a number of the blocks. The decrease in turbidity may be due more to the stilling effect of the box than to filtering by the blocks. None of the samples taken inside the block

box had an odor. The bacteria count was not reduced by this inlet.

Concrete block box filled with sand and gravel. These inlets were approximately 4' square by 3' deep and were located at the bottom of the pond. The box was made with concrete blocks and filled with sand and gravel. Because of the pipe connection in the water systems, the effectiveness of this type inlet could be evalueated for turbidity only in pond 86. The reduction in turbidity was 17%.

Barrel Inlets. Barrel inlets are usually made with two 50-gallon steel drums, one on top of the other. The drums are perforated and filled with sand and gravel. The average turbidity was reduced in ponds 6, 8, 25, and 60 by 32, 57, 44 and 60%, respectively. Baumann (19) reported that water drawn through a barrel inlet always had a higher turbidity than the water in the pond. This condition was not found in the above ponds. The water drawn from the inlet always had a lower turbidity than the bottom sample and in a few cases lower than the top sample.

Floating Inlets. The floating inlets in this study were of two types: (a) commercially built fiber glass inlet (Figure 17) and (b) "homemade" type which consisted of a section of perforated steel pipe wrapped with fiber glass and wire. The inlets were connected to a float and suspended 1½ to 2 feet below the surface.

At the start of this project, two ponds had floating inlets, but by September 1959, the number had increased to seven or 50% of the ponds. Ponds 1, 8, 86, 89 and 90 developed color and odor problems during the period of study. Since the data showed that water near the surface of the pond was of higher quality, these pond owners were

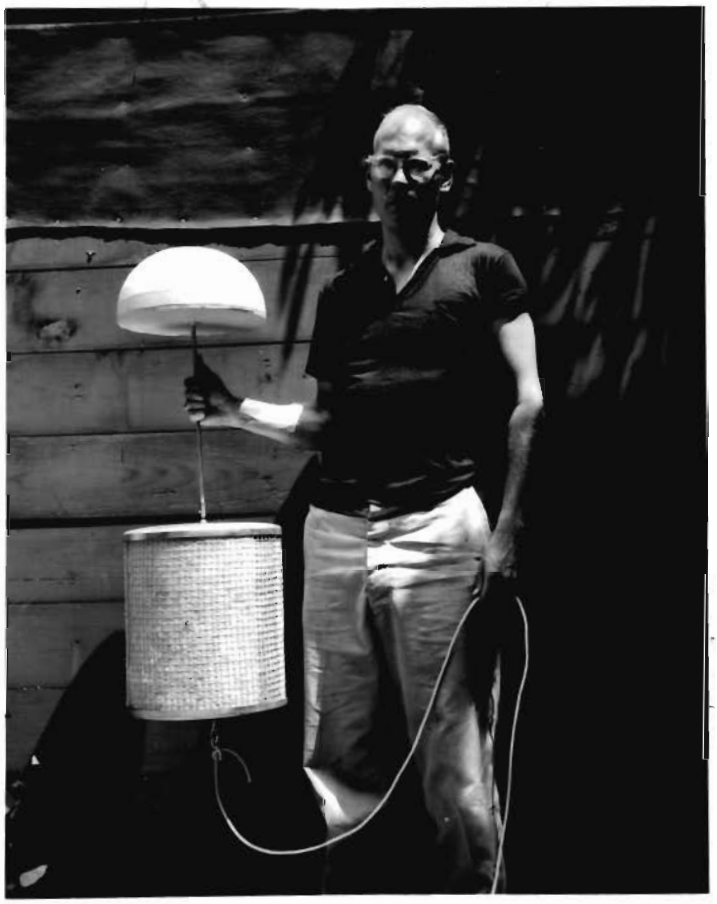

Figure 17. FLOATING INLET

advised to install floating inlets. In every case the water quality was improved. As seen in Table XXII, the floating inlet lowered the turbidity, color and odor in all five ponds, except in pond 1 where the odor remained the same. The owner of pond 90 reported that the fouling of his automatic water cups due to sediment had ceased.

TABLE XXII.

Effect of Floating Inlet on Water Quality

Type Inlet	Turbidity units	Color in ppm	Odor
	Pond # 1		
Buried pipe	24	240	None
Floating	18	20	None
	Pond # 8		
Barrel	18	20	Perceptible
Floating	9	0	None
	Pond #86		
Concrete block	25	120	Objectionable
Floating	20	20	None
	Pond #89		
Concrete block	26	200	Perceptible
Floating	21	20	None
	Pond #90		
Buried pipe	150	40	Perceptible
Floating	9	0	None

A comparison of three different inlets operating at the same time and in the same pond was made in pond 60. As seen in Table XXIII, the water quality from the buried pipe was the poorest and the water from the floating inlet the best.

Fiber glass was used on the floating inlets as a filtering material. The commercial type inlet has a fiber glass cylinder 12 inches in

diameter, 12 inches high and 5/8 inch thick (Figure 17). This inlet reduced the turbidity by 34%. Of the 16 samples taken before and after this inlet the turbidity was reduced in 75% of them. The fiberglas lasted seven months at one pond before being changed. The units at the other ponds were still in use after 11 months. No freezing problems were encountered in the 1958-59 or 1959-60 winters.

Fiber glass was wrapped around a section of pipe in the "homemade" type inlet. This type inlet reduced the turbidity an average of 25%. The turbidity was reduced in 87% of 15 samples taken before and after this inlet. The "homemade" type inlet had the disadvantage of clogging up quicker because of the smaller surface area.

TABLE XXIII.

Effectiveness of Different Inlets at Pond 60*

	Floating Inlet	Barrel Inlet	Buried Pipe Inlet
Avg. Turbidity (units)	10.2	13.0	32.4
Avg. Color (ppm)	25.9	42.5	78.4
% Samples Having Odor (%)	12.5	37.5	56.2
Avg. Bacteria (Coliform/100 ml)	22.0	40.0	166.0

* Average of 15 samples.

11) Depth of Inlets

Starting in the fall of 1959, samples were taken at one foot depth intervals in all ponds. This data was obtained so that better recommendations could be made as to the proper depth an inlet should be placed.

Figure 18 and 19 shows the varieties of turbidity and color as a function of depth for seven different depth of ponds. In all but a

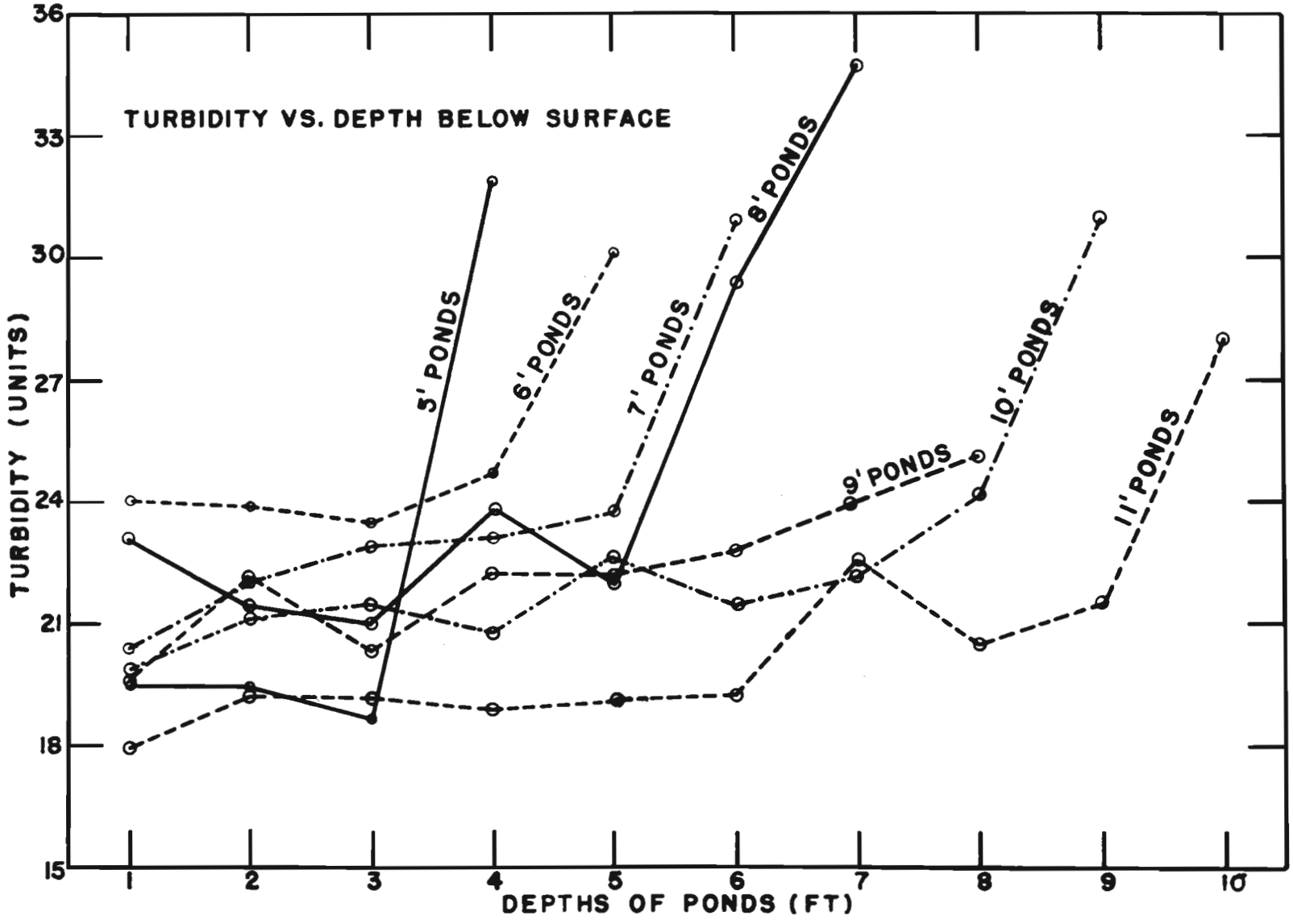

Figure 18. TURBIDITY AS A FUNCTION OF DEPTH

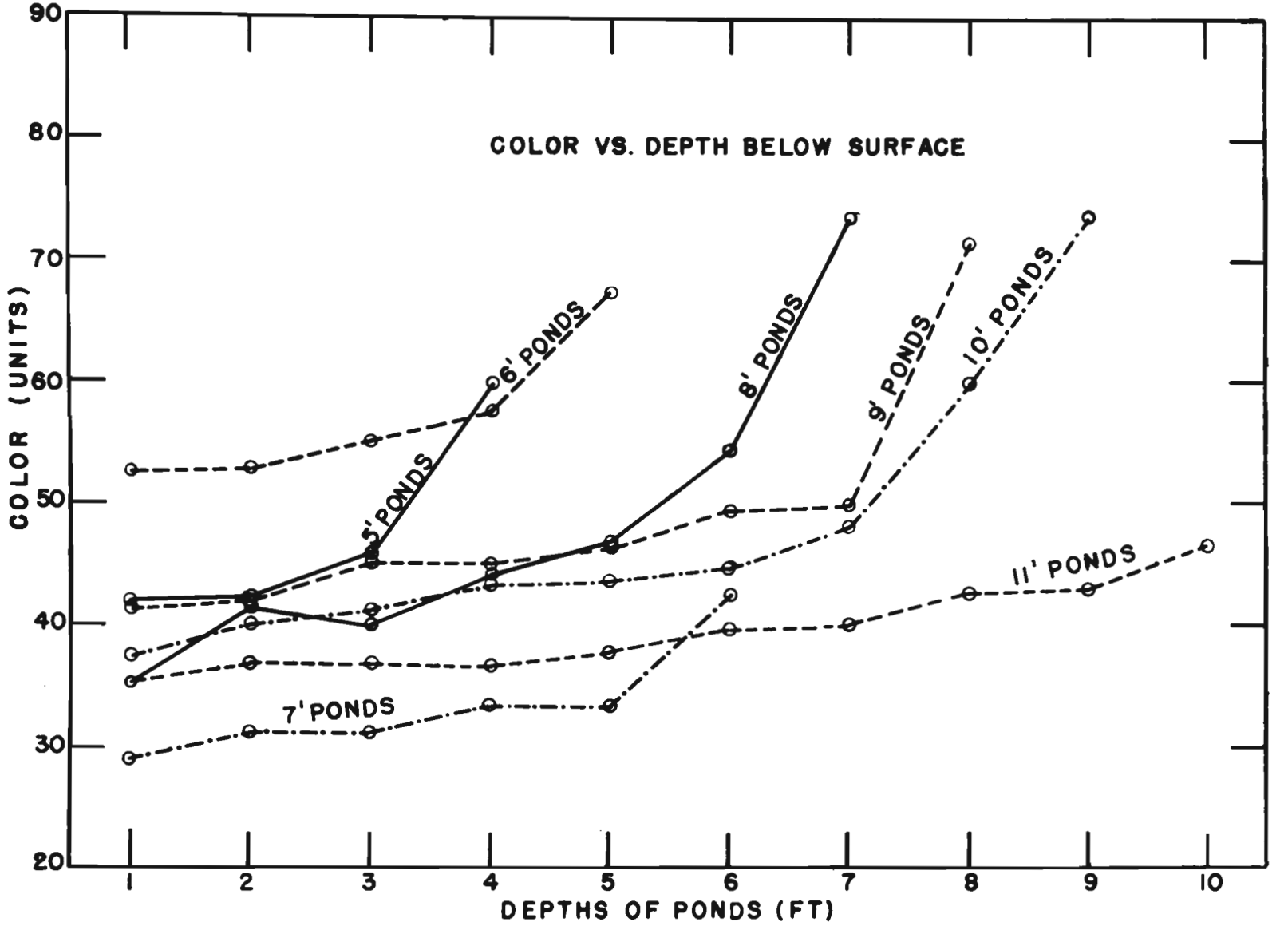

Figure 19. COLOR AS A FUNCTION OF DEPTH

few cases the turbidity and color of the water increased as the depth increased. This confirms the trend as seen in the results from the top and bottom samples. There appears to be no relationship between the total depth and the turbidity and color for comparable depths above the bottom of the pond.

The best water appears to be one foot below the surface in all the ponds. However, it is felt that an inlet should be placed at least 18 inches deep and not more than 3 feet. An inlet less than 18 inches deep would have a tendancy to pick up algae, leaves, and other floating material on the surface. Most of the curves show a gradual increase in turbidity and color below the three feet level. An inlet above this level would pick up a better quality water.

B) Field Water Treatment Installations

In order to better understand the problems in treating pond water with small individual plants, a study was made of eleven such installations. These plants were constructed by the farmer himself with what information he could find. They ranged from chlorination alone to systems with filtration, storage, chlorination and dechlorination. Each treatment plant is analyzed individually.

1) Pond 1

Pond 1 was an up-ground pond in which water was pumped from a small wet-weather stream. The water was removed by a buried pipe inlet and flowed by gravity to a supposedly slow sand filter. No storage was supplied and, therefore, when the pump ran water was pulled through the filter. The flow through the 12 square feet surface area filter was approximately 360 gallons per day per square foot surface area. This

is at least 500% of that recommended for slow sand filters. The water was chlorinated at the pump with an "Everclor"* chlorinator. The water passed through a 60 gallon pressure tank and a 60 gallon storage tank before being used in the house and milk house. The drinking water in the kitchen was dechlorinated with an "Everpure"* activated carbon filter.

The combination of the buried pipe and the sand filter reduced the turbidity on the average from 40.4 to 14.8 units. Half of the samples taken after treatment did not meet the standard of 10 units. The color in this system increased from 66 ppm in the pond to 132 ppm in the effluent. Only one sample met the standard of 20 ppm. In June, 1959, the owner stopped using pond water and started hauling water because of the bad color. He tried increasing the chlorine residual in the water, but this only increased the color. In July, 1959, a floating inlet was installed in the pond. This solved the color problem. The combination of the float inlet and the sand filter reduced the turbidity on the average from 24.3 to 16.6 units. Only 37% of the samples met the standard for turbidity. The cause of this poor filtration was probably due to the excess filter rate.

Twenty-four samples were tested for Coliform Group bacteria. Sixteen of these were contaminated. Seven of these were found when the chlorine residual was zero. The lack of chlorine in the water was due to chlorination break-downs and poor owner maintenance.

The dechlorinator was effective in removal of the taste and odor of chlorine. It, also, reduced the color and turbidity to an acceptable

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* Everpure, Inc., 2627 Nineteenth Street, Chicago 8, Illinois

level. In one sample the water entering the dechlorinator was uncontaminated and the effluent contaminated.

2) Pond 8

At the start of this study, pond 8 had a treatment system consisting of a barrel inlet and chlorination ("Sureclor"*). The average turbidity in the house was 22.5 units and the color 70.5. None of the samples met the standard for turbidity and only three for color. In July, 1959, a floating inlet was installed. The average turbidity in the house was then 23 units and the color 37 ppm. Only 16% of the samples met the standard for turbidity and 58% for color. It was obvious that a floating inlet alone could not treat the water.

In May, 1960, a 42-gallon storage tank, a pressure-type rapid sand filter and a dechlorinator was added to the system. The effluent from the sand filter had an average turbidity of 2.9 units and color of 8.9 ppm. All samples met the drinking water standards for color and turbidity. The filter reduced the turbidity by 67%. It should be mentioned that the average turbidity and color of the water near the inlet in the pond was 4 units and 21 ppm, respectively.

Before the storage tank and sand filter had been added 63% of the samples had been contaminated. The chlorine residual in the water ranged from 0.2 to 3.0 in the contaminated samples. The cause of this contamination was lack of contact time between the bacteria and chlorine. After the storage tank and sand filter had been added, none of the samples were contaminated.

There was some reduction of color, and turbidity in the dechlorin-

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* Clayton Mark & Company, 1900 Dempster Street, Evanston, Illinois

ator. The chlorine taste and odor were eliminated from the water. However, in 50% of the samples, the effluent from this unit were contaminated, whereas, the influent was not. It appears that the bacteria might be living in the filter.

3) Pond 23

A barrel inlet, supposedly slow sand filter, chlorinator and dechlorinator comprised the system at pond 23. The slow sand filter was much like the one at pond 1. No storage was supplied after filtration, and the water was drawn through the filter at a much higher rate than recommended.

It was found that the barrel inlet and sand filter produced water with a turbidity of 22.5 units and a color of 78 ppm. Only 8% of the samples met the turbidity standard and 15% the color standard. Contaminated samples were found 33% of the time in the effluent. The contaminated samples were found at residual chlorine levels of 0.2 to 5.5 ppm. The two major problems with this system was lack of storage after filtration and contact time.

The dechlorinator did an excellent job in removing the chlorine, turbidity and color. In all cases these were found at an acceptable level.

4) Pond 25

Pond 25 was located about a quarter of a mile from the buildings. Water was pumped from the pond to a slow sand filter near the buildings. The slow sand filter was made in two compartments both filled with sand. The water entered one compartment and passed down through it and up through the second compartment. The flow was control-

led by the pump at the pond. The flow rate through the filter was approximately 600 gallons per day per square foot of surface area. The water flowed by gravity to a 12,000 gallons storage basin. At regular intervals 50% available chlorine solution was poured into the basin for batch chlorinator. The water was pumped from the basin to three houses, a milk house and barns.

The sand filter reduced the turbidity from an average of 13 to 9.6 units. Eighty percent of the filtered water samples met the drinking water standards. The filter performed poorly when the turbidity of the influent was greater than 20 units. Color was not reduced appreciably. Bacteria was reduced in 80% of the samples, but not to a safe level.

Batch chlorination was ineffective. Sixty percent of the samples showed no residual chlorine and 40% of the samples were contaminated.

5) Pond 26

Pond 26 was equipped with a barrel inlet, a slow sand filter and storage. The flow rate through the sand filter was 20 gallons per day per square foot of surface area. The water was batch chlorinated in the storage basin.

The average turbidity after the combined treatment of the barrel inlet and sand filter was 16 units. Fifty percent of the samples met the drinking water standard. The highest turbidities were found when the pond had turbidity values greater than 25 units. The color after treatment was greater than the color found in the pond. This is due to dead vegetation settling in the inlet and soluble organic compounds being picked up by the water.

Fifty percent of the samples in the house showed no residual chlorine and 64% were contaminated. Batch chlorination is definitely

a poor method of chlorination.

6) Pond 62

At pond 62 the water passed through a hollow concrete block box inlet and was chlorinated with an asperator type unit. The average turbidity in the house was 15 units. Seventy-one percent of the samples met the standard for turbidity. Whenever the turbidity was greater than 25 units in the pond, the water would not meet the standards. Some reduction in color was noted between the samples from the pond and the house.

Twenty-four percent of the house samples were contaminated. All of the contaminated samples were found when the chlorine residual was zero. Between a 1 and 3 ppm residual was effective in controlling bacteria.

7) Pond 86

The water was removed by a block-box-filled-with-sand inlet and chlorinated at pond 86. The average turbidity in the house was 9.9 units and color was 39 ppm. In June 1959 the turbidity in the house had risen to 25 units and the color to 110 ppm. At this time a floating inlet was installed. Since then the average turbidity and color have been 19 units and 30 ppm. The floating inlet cleared up the color problem.

8) Pond 87

Pond 87 had a system consisting of a block-box-filled-with-sand inlet, storage and chlorination. The water was pumped from the pond and into a cistern. Another pump supplied water to the house, milk house and barns from the basin. The water was chlorinated at the

second pump. The combination of inlet and storage produced water with an average turbidity of 18 units and that met the standard only 36% of the time. The average color was 29 units and 55% of the samples met the standard.

Fifty percent of the samples were contaminated in the house. Forty percent of the contaminated samples were at times when no chlorine residual was found. The other 60% had chlorine residuals between 1 and 5 ppm.

9) Pond 88

Pond 88 had the same system as pond 87 except that the drinking water in the kitchen was dechlorinated. The average turbidity in the house was 10 units. All but two samples had met the drinking water standard for turbidity and color.

Seventeen percent of the samples in the house were contaminated. The contaminated samples were found at chlorine residuals of 3 and 8 ppm. The remainder of the samples were safe when 2.4 to 8 ppm residual chlorine was found.

The dechlorinator reduced the turbidity and color to an acceptable level and eliminated the chlorine. In three samples the water was safe before and contaminated after the dechlorinator.

10) Pond 89

At pond 89 the water was removed by a block-box-filled-with-gravel inlet and passed through a pressure-type rapid sand filter. The water was not chlorinated. The average color and turbidity in the house was 136 ppm and 21 units, respectively. The water, also, had a bad odor. In July, 1959, a floating inlet was installed. After this date the average color was 30 ppm, the turbidity was 25 units, and the odor

problem was eliminated. The rapid sand filter was ineffective in filtering the water.

11) Pond 90

The treatment system at pond 90 was composed of a buried pipe inlet, a rapid sand filter, a carbon filter and a positive-feed chlorinator.

The average turbidity after the inlet and sand filter was 44 units. None of the samples had met the drinking water standard. The color averaged 100 ppm. In August, 1959, a floating inlet was installed. The floating inlet and sand filter produced water with an average turbidity of 12 units and color of 10 ppm. The change in location of the inlet resulted in most of the reduction. The rapid sand filter on an average of all samples reduced the turbidity 12%.

The carbon filter was used to remove the chlorine from the drinking water. This filter, however, lowered the turbidity to ten or less units in all but two samples. It also reduced the color as well as the chlorine.

The "Wallace & Tierman"* chlorinator was an old model and performed poorly. Forty-three percent of the chlorinated samples were contaminated. The chlorine residual in these samples ranged from 0.3 to 3.0 ppm. In August, 1959, a "Proportioneer"** chlorinator was installed. Fifty percent of the samples after this chlorinator were contaminated. A chlorine residual of 3 and 0.2 ppm were found in the contaminated samples. Lack of contact time was the major reason for this contamination. The type of chlorinator seemed to have no effect.

* Wallace & Tiernan, Inc., 25 Main Street, Belleville, New Jersey
** Proportioneers, Inc., Division of B-I-F Industries, Providence, R. I.

C) Experimental Treatment Systems

1) Slow sand filter system

The experimental slow sand filter system consisted of filtration by a slow sand filter, chlorination, and storage. The flow rate through the filter was adjusted such that the maximum rate was 72 gallons per day per square foot of surface area. The maximum flow was not often encountered due to the low capacity of the float valve.

Figure 20 shows the turbidity before and after filtration. The effluent from the filter ranged between 2 and 7 units while the influent varied between 8 and 112 units. The slow sand filter was effective in lowering turbidity to an acceptable level.

The average color of the influent to the filter was 49.5 ppm and the effluent 21.7 ppm. This shows an overall reduction of 56% in color. During the first 42 days of the filter run (17,077 gallons filtered) the effluent color was never greater than 5 ppm. On the 47th day the color was 15 ppm and ranged from 25 to 70 during the next 50 days. A build up of dead vegetation had been taking place on the surface of the filter. The color was probably coming from this material.

In seven samples that were taken before and after filtration, four showed a reduction in coliform group bacteria. The average reduction in these four samples was 88%. However, the other three samples showed an increase of the coliform group by 268%. The overall average was a 2% decrease in coliform bacteria. The effluent never had a coliform group count that was considered safe. These results definitely point out that other treatment in addition to filtration is needed to control bacteria.

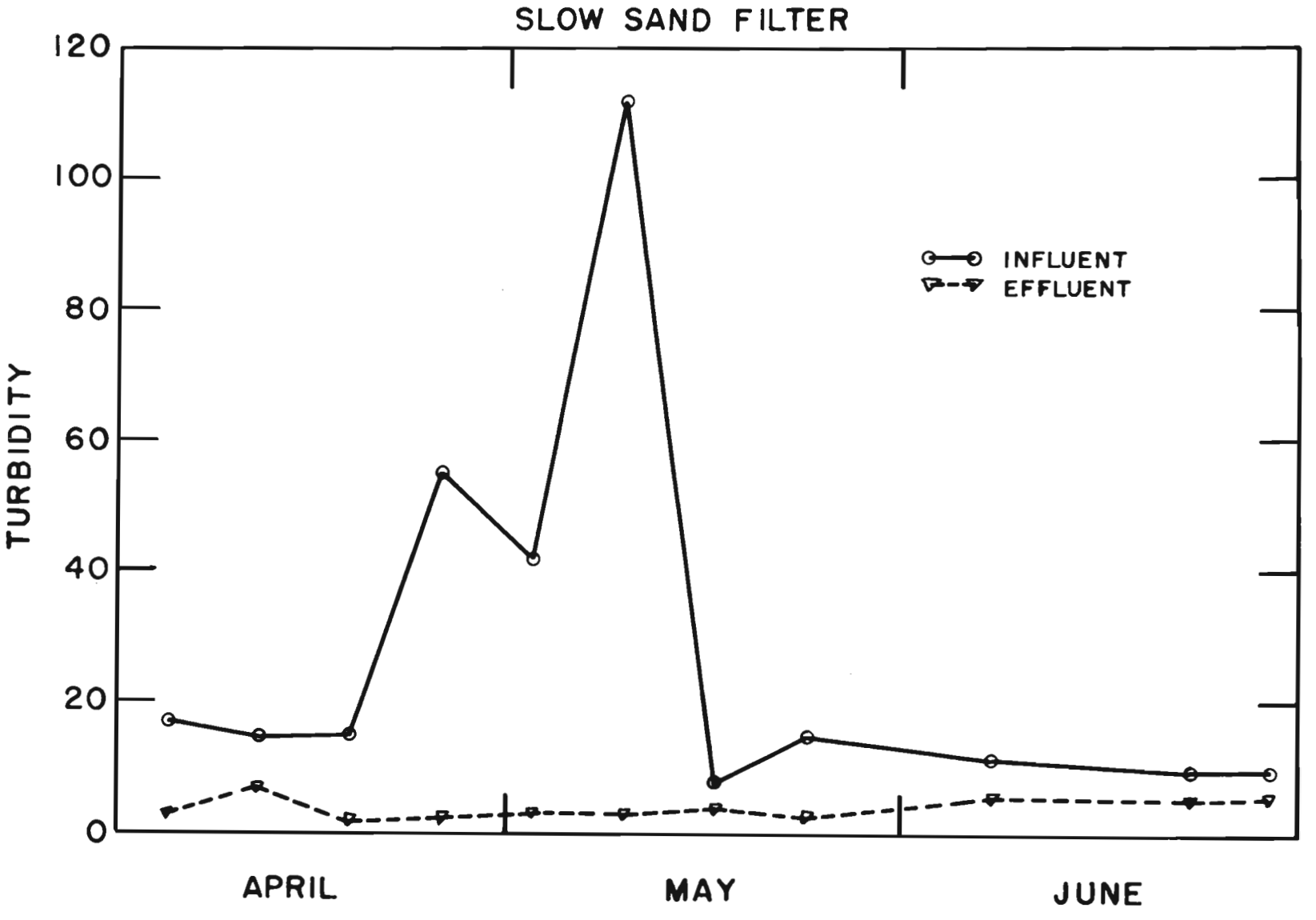

Figure 20. FILTRATION DUE TO THE SLOW SAND FILTER

After filtration the water was chlorinated with a "Proportioneer" chlorinator. Two feet from the injection of chlorine a sample was taken. This sample showed a reduction of 99.5% in coliform bacteria. Table XXIV shows the residual chlorine in the water and the coliform group (MPN) bacteria found in the water at four points in the treatment system. The after chlorination sample was taken just before the water entered the sump. The sump sample was taken one foot below the surface in the sump and three feet from the discharge from the sand filter. The after pump sample was taken at the effluent of the whole system. In only two of eight samples of the water entering the sump was the bacteria level safe. All the counts at this point were very low. The chlorine residual did not seem to affect this to any great degree. Approximately the same count was found in all samples and the residual chlorine varied from 0.3 to 4.0 ppm.

TABLE XXIV.

Coliform Group Bacteria (MPN) and Residual Chlorine in the Slow Sand Filter System

Date	Before Chlorination		After Chlorination		Sump		After Pump	
	MPN	Chlorine ppm	MPN	Chlorine ppm	MPN	Chlorine ppm	MPN	Chlorine ppm
4/18/60			11	2.4	7.3	4.8	460	5.0
5/2/60			3.6	2.0	<3	1.0	<3	1.0
5/9/60			3.6	2.0	<3	.35	<3	0.8
5/16/60	15	0	3	0.3	<3	.25	<3	0.4
5/23/60	150	0	<3	0.7	<3	0.6	<3	0.5
6/7/60	14	0	<3	1.2	<3	0.0	3.6	.15
6/22/60	210	0	3	1.0	3.6	.15	9.1	0.1
6/28/60	2,400	0	3.6	4.0	15	0.0	240	0.0

This table also shows that five out of eight samples in the sump had a safe coliform bacteria count. Two of the contaminated samples were found when the chlorine residual was 0.15 and 0.0 ppm. These contaminated samples were all found after a break-down in the chlorinator system. The turbidity did not change in the sump. However, on an average the color increased 7% in the sump. This was probably due to a reaction between the chlorine and soluble organic compounds.

The chlorination system in this plant operated unsatisfactorily. The chlorinator was controlled by a float valve and a micro-switch. The float valve's flow was regulated by the level of the water in the sump. As the water level raised, the flow into the sump decreased. This resulted in the valve taking a great length of time to close completely. The chlorinator, therefore, ran for a long period of time. As much as 15 gallons of chlorine solution was being used every two days. At times the chlorine solution crock went dry and no chlorine was fed for as long as two days. The chlorinator control needed revision. No trouble was encountered with the chlorinator.

2) Rapid sand filter system

The experimental rapid sand filter plant consisted of chlorination and filtration by a pressure type rapid sand filter ("Myers"*), and by a cellulose fiber filter. The flow rate through the two filters was approximately 5 gallons per minute or 5,350 gallons per day per square foot of surface area for the rapid sand filter. The rapid sand filter was backwashed before samples were taken.

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* F. E. Myers & Bro. Co., Ashland, Ohio

Figure 21 shows the results of rapid sand filtration on turbidity. In the first test the turbidity was only lowered a small amount. After this time, the turbidity was always lower than the maximum allowable under the drinking water standards. At times only a very small reduction was found in turbitiy.

The average influent color of the filter was 28.5 ppm, and the effluent color was 19.5 ppm. Very little color reduction took place at influent values of 15 to 25 ppm. The filter could not be evaluated for bacteria removed because the water was chlorinated.

In Figure 22 it can be seen that effluent from the cellulose fiber filter ("Cuno"**) had greater turbidity than the influent in all but three samples. It appears that the material that collected on the surface of the filter after a time may be moving through the filter. The cellulose unit was never changed. It probably should have been after 8,048 gallons had been filtered. The turbidity at this time was greater after filtration than before. The filter had no effect on color. In most cases the coliform bacteria were not reduced by this filter. In one case the influent to the filter has less than three MPN and the effluent had 43 MPN.

An "Everclor" chlorinator was used during the first phase of these tests. This chlorinator fed chlorine into the water before the pump and operated at the same time as the pump. A 120-gallon pressure tank was connected to the pump. Even when this chlorinator was adjusted to feed at its highest rate, a low chlorine residual was normally found in the water. This was due to the high capacity of the pump. The flow

** Cuno Engineering Corp., Meriden, Connecticut

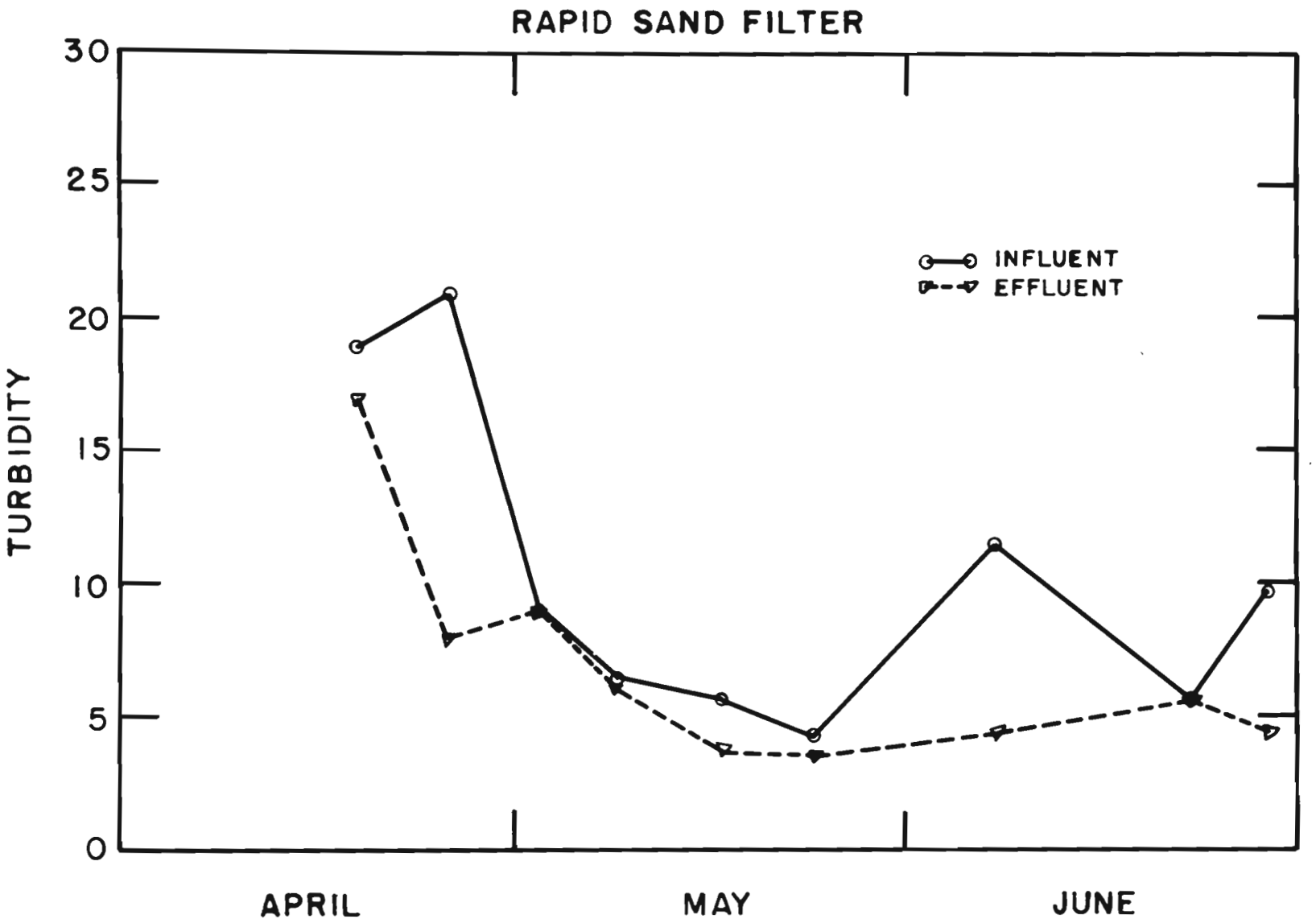

Figure 21. FILTRATION DUE TO THE RAPID SAND FILTER

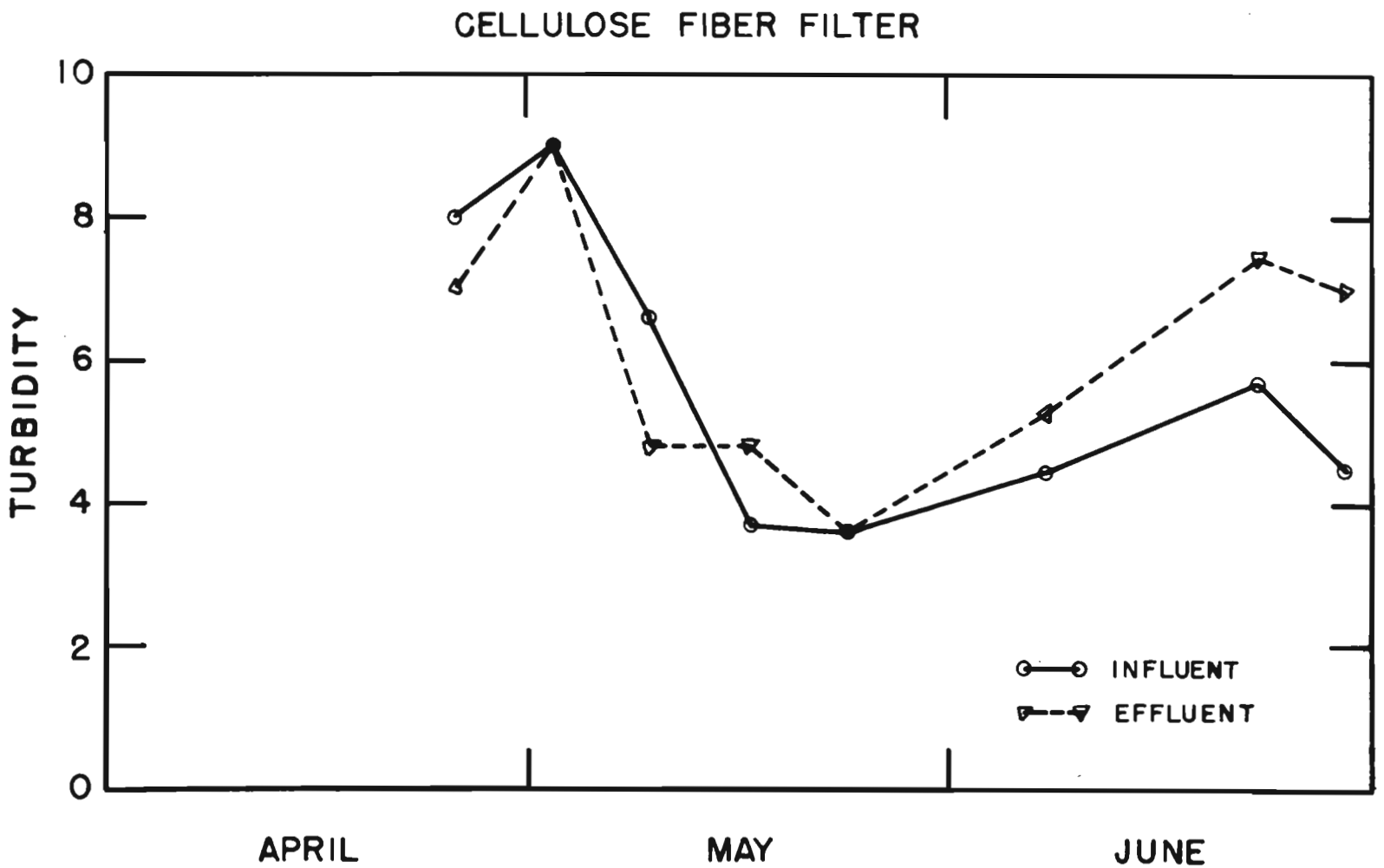

Figure 22. FILTRATION DUE TO THE CELLULOSE FIBER FILTER

rate of the pump was 12 gpm. At this rate, the pump only ran for a short period. Table XXV shows the coliform bacteria counts and residuals chlorine in the water at different points in the system. The first two sample sets were contaminated due to the bacteria initially in the system. After this time the bacteria count was at a desirable level. A chlorine residual of approximately 0.35 ppm seemed to be sufficient. After June 22, 1960, a "Clayton Mark Electroclor" chlorinator was used. This chlorinator fed chlorine into the water line between the pump and the pressure tank and was controlled by the pump. A low chlorine residual was found in the water for the same reason as the "Everclor".

TABLE XXV.

Coliform Group Bacteria (MPN) and Residual Chlorine in the Rapid Sand Filter System

Date	Before Sand Filter		After Sand Filter		After Cellulose Filter	
	MPN	Chlorine ppm	MPN	Chlorine ppm	MPN	Chlorine ppm
4/18/60	--	0.1	29	0.0	29	0.0
4/25/60	--	2.4	210	1.0	29	0.4
5/2/60	--	0.6	<3	0.3	43	0.2
5/9/60	--	0.1	<3	0.1	3.6	0.0
5/16/60	<3	1.1	<3	.35	<3	.35
5/23/60	<3	1.0	<3	.35	<3	0.8
6/7/60	<3	0.6	<3	0.2	<3	0.1
6/22/60	3.6	0.8	9.1	0.2	9.1	.25
6/28/60	15	0.4	73	0.1	150	0.0

VII. SUMMARY

A field study of existing farm ponds and water treatment systems was made at fourteen installations in eight counties during the period April, 1958, to July, 1960. The purpose of the study was to gather information for the development of an individual farm water treatment system. At least 10, and as high as 35 samples sets, were taken from each installation. The amount of color, odor, bacteria (coliform group) and turbidity at different levels in the pond and at other locations in the water system was determined. Chemical tests were also taken during each summer. From information collected from the field installations, a water treatment laboratory was constructed and tests on a slow sand filter and a pressure-type rapid sand filter were made.

It was found that water near the surface was of the best quality. For this reason the floating inlet removed the best quality of water. All pond water was contaminated. Chemical tests of pond water showed that only hardness and iron did not meet drinking water standards. Ponds sprayed with sodium arsenite were found to have dangerous levels of arsenic.

No field treatment system was completely adequate. Slow sand filters did a good job when the flow rate was kept near the recommended amount. When higher rates were used, very little filtration took place. Pressure-type rapid sand filters lowered the turbidity to an acceptable level when the influent to the filter was less than 20 units of turbidity. Dechlorinators and carbon filters reduced turbidity, color, chlorine and odor. However, it appeared that bacteria grew in these filters and re-contaminated the water. Between 14 and 67% of the

samples from an individual installation were contaminated after being chlorinated. The two reasons for this contamination were lack of contact time and poor maintenance of the chlorinator.

The laboratory tests showed that the slow sand filter did an excellent job in removing turbidity. However, the filter was ineffective in removing bacteria. The chlorination system was effective in removing bacteria when operating properly. The rapid sand filter (pressure type) performed well when the influent had a low turbidity. The chlorination system was the major problem in this system. A constant chlorine residual could not be maintained. The cellulose fiber filter seemed to have no application in this type of system.

VIII. CONCLUSIONS

The data collected in this study indicate the following conclusions:

(A) Turbidity in pond water was the least near the surface and increased with depth. The highest turbidities in the top samples (one foot below the surface) were found in the spring months and in the bottom samples (one foot above the bottom) during the winter and spring. The average turbidity for all top samples was 21.2 units and the bottom samples 40.1 units.

(B) Size of drainage area (0.86 to 51 acres) had little, if any, effect on water quality. The turbidity was increased a great deal by poor cover immediately around the pond. A strong wind and animals in the pond caused the turbidity to increase. Animals were also a source of contamination.

(C) Color in pond water increased with depth. Highest color in the top samples was found between February and April and in the bottom samples between February and September. The average color was 40 ppm for all top samples and 74 ppm for all bottom samples.

(D) Odor was found in 27% of all the bottom samples and 8% of the top samples. The threshold odor ranged from 0 to 64.

(E) All pond water was contaminated. Maximum coliform group bacteria counts occurred during the summer. The higher the pond water temperature was the higher the bacterial count.

(F) Pond water was chemically good for domestic use. The major problems were the removal of turbidity, color, odor and bacteria. The average total solids of pond water was 184 ppm. Volatile solids (a measure of

organic matter) varied from 26 to 39% of the total solids. Hardness in pond water ranged from 0 to 212 ppm. Some ponds had water with a total iron content greater than 0.3 ppm, the maximum by drinking water standards.

(G) Ponds sprayed with sodium arsenite had dangerous levels of arsenic as long as fourteen months after treatment.

(H) The floating inlet was the best method of removing water from a pond. This type inlet removed the best quality of water and thus reduced filtering problems. The inlet should be placed at least 18 inches below the surface and not deeper than 3 feet.

(I) Farmer constructed and operated slow sand filters were ineffective due to poor maintenance and poor control of flow rate. Slow sand filters that were designed and operated properly produced a satisfactory water.

(J) Pressure-type rapid sand filters did a fair job of reducing turbidity when the influent had a turbidity less than 20 units. Commercial cellulose fiber filters were not suitable for pond water filtration.

(K) Dechlorinators and carbon filters did perform well in removing chlorine, color, odor and some bacteria. Bacteria grew in some of these filters and caused contamination.

(L) A vital process, but one that was performed poorly was disinfection. None of the chlorination systems studied did a reliable job. The major problem was shortage of contact time. Poor maintenance of the chlorinator system often lead to low or no chlorine residuals in the water.

IX. RECOMMENDATIONS FOR FURTHER RESEARCH

The data collected in this project revealed a number of problems that need further research. The following recommendations include the most critical areas.

(A) Investigation of other disinfection methods, such as ultraviolet and pasteurization.

(B) Development of a better method of control in a slow sand filter so that the effluent is always chlorinated.

(C) Development of a reliable method of obtaining contact time in a pressurized rapid sand filter system.

(D) Control for the chlorinator so that when the chlorine supply gets low, the pump will not operate.

(E) Improvement of the rapid sand filter such as flocculation and sedimentation before filtration.

(F) Research into other methods of filtering water.

(G) A study on the sprays used in and around ponds and their effect on the water with respect to human and livestock consumption.

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