PHYSICO-CHEMICAL ASPECTS OF CLAY TURBIDITY WITH SPECIAL REFERENCE TO CLARIFICATION AND PRODUCTIVITY OF IMPOUNDED WATERS

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INTRODUCTION

This paper concerns the nature of clay turbidity and the effectiveness of vegetation in the precipitation of suspended clay in turbid waters. The purpose of this investigation was to provide additional information and data on clay turbidity as it exists in central Oklahoma.

Welch (1935) divides turbidity-producing substances into two groups, viz., the settling suspended matters and the non-settling suspended matters. The first group represents a class of substances that is temporary and fluctuates in quantity with certain inherent and environmental factors. The second group is by far the more troublesome. Most of the turbid waters in central Oklahoma are essentially non-settling colloidal suspensions of a montmorillonite type of clay in a water medium, the clay particles having been introduced and dispersed into the water by winds and the hydraulic erosive action of run-off water.

The writer is concerned with turbidities due to inorganic soil particles suspended in water and not to those turbidities caused by plankton and particulate organic matter. The term silt is used in this paper to designate the clay that is held in suspension in the water. This soil is not true silt but consists mainly of clay particles so finely divided as to be colloidal.

A few preliminary laboratory studies were made with clay as a colloid and have been included and employed only in so far as they relate to the reaction of colloidal clay to certain precipitating agents. The principal data represent the results of a limnological study of small impoundments in Payne County, Oklahoma, which exhibited different degrees of turbidity due to suspended clay. Some impoundments were studied in an attempt to correlate chemical properties of the water with their existing turbidity. Others were investigated to learn the physical and chemical changes induced when plant material was added to the water and to find the effect of this vegetation upon the biological productivity.

The factors that determine or are indicative of the potential productivity of fresh waters have long interested limnologists. Factors responsible for the productivity of any group of aquatic organisms are complex and incompletely understood. Emphasis has been placed on the relationship between chemical quality of waters and food production whereas other factors such as turbidity and light penetration have received comparatively little attention. Pure water, although transparent, absorbs some energy as sunlight passes through it, while water containing suspended matter impedes its passage.

Relatively large amounts of suspended materials in water limit the penetration of light, therefore the direct effect of such turbidity upon biological productivity is of importance. Ellis (1931, 1937, 1944) stresses the influence of erosion silt as a pollutant in impounded waters and its effect on light penetration. Prescott (1939) regards phytoplankton production to be retarded by the presence of suspended inorganic matter. Year round plankton studies by Chandler (1940, 1942a, 1942b, 1944) and Chandler and Weeks (1945) on Lake Erie have indicated that phytoplankton pulses occur when turbidity is relatively low and smaller populations exist during high turbidity. Irwin (1945) emphasizes that turbidity due to silt decreases the total food production and affects the general economy of an impoundment. Langlois (1948) mentioned the presence of erosion silt in waters of Ohio as producing a turbidity which excludes sunlight to the extent that nutrient salts present cannot be synthesized into plant tissues.

The principal factors contributing to the existence of turbid waters in an impoundment are the type of soils, shape, size, and vegetal cover of watershed, turbulence on the bottom and margins, and the character of the rainfall preceding run-off. The rate, quantity, and occurrence of rain are beyond man's control. However, a degree of control can be exercised over its subsequent behavior after the rain reaches the land surface.

When the various conditions which affect erosion are considered, it becomes evident that surface water retained in reservoirs, is likely to have varying quantities and sizes of clay particles in suspension. Fortunately, this suspended colloidal soil in water needs not be considered a permanent evil as methods of precipitating it from impounded waters have been demonstrated and successfully used without harming aquatic life.

Irwin (1945) has shown that the addition of organic matter to water decreases this turbidity and permits increased light penetration. Thus the treatment of muddy water with the proper applications of organic matter aids in precipitating soil particles and increases the fertility of the water. When lake productivity is considered, it is logical to believe that unfavorable turbidities can be corrected by artificial means and a cycle of organic matter synthesis and subsequent decomposition can be activated within the reservoir to lengthen the period of productivity. Therefore, the investigation of necessity concerns biological, physical, and chemical factors.

The writer makes no claim for an exhaustive or complete treatment, yet it is felt that in limnological studies all the above factors must be correlated. The problem was divided into parts, each part was studied separately and the results were analyzed with respect to the whole.

METHODS

Analyses of hydrogen-ion concentration, carbon dioxide, dissolved oxygen, phenolphthalein alkalinity, methyl orange alkalinity, biochemical oxygen demand, and oxygen consumed were made according to the techniques described in "Standard Methods for the Examination of Water and Sewage", 1946.

Hydrogen-ion Concentration

A Hellige comparator was used for all tests of hydrogen-ion concentrations. Indicators which covered the range were chlorphenol red, phenol red, and thymol blue. The colorimetric method was used instead of the more accurate electrometric determinations because it could be used in the field with greater ease and it provided an accuracy of 0.1 pH units.

Free Carbon Dioxide

The determinations of free carbon dioxide were made: (1) to learn the correlation between pH and CO_2 and (2) to observe the relation between the production of H_2CO_3 and reduction of turbidity. If the hydrogen-ion concentration in the water studied was due largely to the presence of CO_2, then the pH values and the values for CO_2 should be in an inverse ratio; that is, as the CO_2 increases the pH should decrease. When water, at zero degrees C. is saturated with CO_2 gas, it will retain approximately 3,300 parts per million. The CO_2 is held in solution partly in combination with water as H_2CO_3 and partly as the gas. The reaction of a saturated solution of CO_2 is approximately pH 4.0, but such a low pH is not necessary for clay flocculation.

Dissolved Oxygen

The dissolved oxygen determinations were made for the following reasons: (1) to determine its abundance and fluctuation, (2) to detect the approach of oxygen depletion, and (3) as an index to biochemical oxygen demand from added organic matter.

Alkalinity

The determination of alkalinity was of importance in detecting the availability of carbon dioxide as combined to form carbonates and bicarbonates of potassium, sodium, calcium, and magnesium. Carbonates hydrolyze into the hydroxide and carbonic acid, the alkalinity of the hydroxide overbalancing the acidity of the weaker carbonic acid. Waters giving an alkaline reaction to phenolphthalein contain no free CO_2 but do contain normal or mono-carbonates. Titration with 0.02N H_2SO_4 indicates the amount of free CO_2 which would be necessary to convert all of the mono-carbonate to the bicarbonate. Waters giving a neutral or acid reaction to phenolphthalein contain free CO_2 in solution.

Phenolphthalein, with an end point of pH 8.3, indicates the presence of carbonate or hydroxide alkalinity. Methyl orange, with an end point of pH 4.4, indicates the value where "alkalinity" due to bicarbonates is eliminated by H_2SO_4. There are actually three zones on the pH scale into which the range of "acidity" and "alkalinity" can be subdivided: (1) the zone below pH 4.4 due to mineral acids; (2) the zone between pH 4.4 and 8.3 when the water is "alkaline" due entirely to bicarbonates in the presence of free CO_2; (3) the zone above 8.3 representing the water devoid of CO_2 but containing carbonates, bicarbonates, and hydroxides.

Turbidity

Measurements of turbidity were made with a Jackson turbidimeter. The range of this instrument is limited to turbidities above 25 parts per million. When the terms "clear water" or "clearing" are used in this paper, reference is made to turbidities due to soil particles that read less than 25 ppm. Turbidity due to soil particles was in most cases distinguishable from other suspended matter. A lumetron photoelectric colorimeter was used to learn the relative percentage of light transmission.

Temperature

Temperature readings were taken with an H•B reversing thermometer. Both air and water temperatures were recorded.

Biochemical Oxygen Demand

Biochemical oxygen demand analyses were made to evaluate the intensity of oxidizable matter occurring within the reservoir. It was thought that fluctuations in the available oxidizable matter, as measured by these tests, might serve as an index for the potential clarity of the water. Cognizance has been taken of the fact that this analysis does not measure the total dissolved organic matter but represents the biochemical activity and thus is an indirect indication of the available dissolved organic matter.

Oxygen Consumed

Oxygen consumed determinations give a convenient relative measure of the dissolved organic matter. This test has been effective when B. O. D. determinations were too low to be significant.

FACTORS THAT ATTRIBUTE TO TURBIDITY DUE TO SOIL

Siltation is subject to numerous contributing factors. It was necessary to consider all known suggestive causes of siltation, both preventive and corrective. Attention is invited to the difference between the soil particles that settle to the bottom soon after the rate of flow is decreased and those much smaller clay particles that remain suspended in the water for long periods of time. Rapidly flowing water can carry rock particles of all sizes including rubble, gravel, sand, silt, and clay. When the rate of flow is decreased the capacity to carry larger particles is likewise decreased. Deposition of the various sized particles follows in accordance with decreased water velocity. In this manner the bulk of the erodible soil is soon deposited in reservoirs near the point of water inflow, but the extremely small colloidal clay particles tend to remain suspended and can be carried in the water to all parts of the impoundment. Variations of this phenomenon have been illustrated in an explanation of density currents (Wiebe 1939). Often the aggregated volume of this colloidal clay is small in comparison to the total siltation of the reservoir but its effect upon light penetration and general appearance of the water is profound. The presence of dispersed colloidal clay on the eroding part of the watershed is the prime factor in producing soil turbidities that persist.

Turbulence

It has been the opinion of many people, including some biologist (Clements and Shelford, 1939), that the chief cause for muddy waters is agitation of bottom materials, as produced by activity of bottom feeding organisms, such as, carp, catfish, and crayfish. They have maintained that clear waters can be had by their elimination. Discrepancies in this argument are: (1) there are impoundments possessing clear water which harbor these organisms; (2) turbid water in a laboratory aquarium (with no soil on the bottom) in the absence of turbulence and bottom feeding organisms, maintains its turbidity for months; (3) impounded waters, when cleared with vegetation, have remained clear in spite of winds, carp, catfish, and crayfish. An abundance of these forms may lead to some turbidity because of their wallowing and burrowing activities. However, deep-water impoundments such as the T. V. A. reservoirs and "catfish lakes", for example, Spavinaw and Grand Lake, clear-water lakes in Oklahoma, certainly are little affected by these agents. Lake Carl Blackwell, in Payne County, Oklahoma was clear, when first impounded, in spite of crayfish and catfish.

Another factor which exemplifies the same type of agitation of bottom materials is the trampling of impounded areas by farm animals. This produces a muddiness that can often be eliminated by fencing the pond and allowing the livestock to drink from a tank below the dam.

The wind frequently creates a wave action which causes erosion on the outer area and shoreline of shallow impoundments. Proper construction of the pond, wind-breaks, and fencing permit the development of shoreline vegetation which decreases wave wash and erosion.

Mineral Content of Water

Low total mineral content of the water has been cited as the chief cause of permanent turbidity. Other observations tend to disprove this statement. Table 1 contains unpublished data from U. S. Geological Survey analyses of samples collected from both clear and turbid sources. The muddy waters, in general, show a high rather than a low mineral content. However, little difference was observed in the mineral content of Rutter Settling Pond which maintains a high turbidity and Rutter Fish Pond, a clear impoundment which receives its water supply from the settling pond. It would seem that the dissolved minerals in water are not necessarily related to turbidity.

The calcium content has been offered as a causative factor for high or low turbidities. Low calcium content (less than 65 ppm.) has been regarded as the cause of turbid waters and high calcium content (more than 65 ppm.) as the factor producing clear waters. Analysis of data as presented in Table 1, shows no correlation.

The use of calcium has resulted in great improvements in the permeability and granulation of certain types of soil, and since it is known to be a coagulating agent for dispersed

TABLE 1

Dissolved Inorganic Solids and Calcium Content in Relation to Turbidity Condition in Some Oklahoma Waters

Unpublished Data From U. S. Geol. Survey

Station	Date	Ca ppm.	Dissol. inorg. solids, ppm.	Condition regarding turbidity
Arkansas River at Sand Springs	2/8/49	74	1350	muddy
Arkansas River at Sand Springs	9/1-5/49	132	2110	muddy
Canadian River near Whitefield	2/21-25/48	132	1930	muddy
Canadian River near Whitefield	9/1-10/49	209	3370	muddy
Lake Carl Blackwell, Payne County	4/30/47	17	198	muddy
Rutter Settling Pond, Payne County	1/16/50	26	209	muddy
Salt Fork of Red River at Mangum	8/11-12/48	514	2670	muddy
Washita River near Tabler	2/1-6/49	204	1030	muddy
Washita River near Tabler	9/1-7/49	104	996	muddy
Greenleaf Lake near Braggs	3/8/49	17	88	clear
Kiamichi River near Belzoni	2/1-10/49	2.7	64	clear
Kiamichi River near Belzoni	9/1-10-49	3.2	62	clear

TABLE 1 (Continued)

Station	Date	Ca ppm.	Dissol. inorg. solids, ppm.	Condition regarding turbidity
Mountain Fork near Eagletown	9/20-30/48	7.0	41	clear
Neosho River near Commerce	9/19-22/49	23	164	clear
Poteau River near Wister	6/21-30/47	5.7	98	clear
Rutter Fish Pond, Payne County	1/16/50	33	234	clear

clay particles in soils, its importance in the maintenance of clear water in impoundments has been overestimated. Mineral analyses, as reported in this paper, show the mineral content and the turbidity to vary independently. Thus, it seems that while the chemical quality of the water may play an important part in the transportation and stability of colloidal clay, it is impossible to predict, from mineral analyses, which waters will retain this material in suspension.

Watershed

Watershed control has long been emphasized as a corrective as well as preventive means to insure clear water impoundments. An unprotected watershed is obviously vulnerable to severe erosion, although a well grassed drainage area will not exclude colloidal clay soil from entering the impoundment and muddying the water. In Oklahoma, this is due to two reasons: (1) rainfall often occurs in intense downpours, and (2) the soils of many watersheds are largely composed of fine clays.

Water flowing over land surface is likely to carry away soil in three ways: by dissolution, by carrying it in suspension, or merely by rolling it along the surface of a substratum. These are natural processes that are characteristic of erosion and deposition, and where the surface cover has been disturbed (by man or other agents), the erosive power of water is greatly magnified. The silt-carrying capacity of water as it moves over sloping land depends upon the size of the particles available for suspension as well as upon the velocity of the water.

Soil and water conservation methods aid immensely in control of the turbidity in impounded waters as will be seen from the explanation. When drops of rain strike the earth's densely vegetated surface, they do not strike the soil directly nor dislodge soil grains, but break into a spray of clear water which normally finds its way into the innumerable soil interstices. When rain drops strike bare soil, the force of the drops moves soil particles and stirs the finer ones into suspension and forms drops of muddy water. As this water sinks into the soil the fine particles of clay remain at the surface to form a thick film which occludes the surface pores of the soil. Then, only a portion of the drops filter into the soil and the remainder is left unabsorbed and flows over the surface, carrying suspended soil particles with it. Important effects of vegetation are to increase the permeability and absorptive capacity of the soil as well as to reduce the velocity of surface movement. Even then, the intensity of rainfall in prairie areas, together with the quantity and quality of dispersed colloidal clay of some soils, results in considerable erosion though the ground is covered with plant growth. Kelley (1942) has stated that the extent of dispersion of the clay particles and the stability of the clay aggregates greatly influence the erodibility of soils. It is apparent that the presence of slick or alkali spots (Harper and Plice, 1949) on watersheds, in which the soil is already dispersed and impermeable to the water, contribute to the muddy condition of surface water.

Breazeale (1926), in a study of the Colorado River silt, stated that the non-settling property of silt is inherent in the character of soils before they were eroded. He further maintains that the suspended colloidal clay, as it appears in standing water, is definitely dispersed and this condition has been brought about by the following factors: (1) the soil from which the silt is derived was colloidal and dispersed, no changes having been brought about in its condition, by the water, in the course of its transportation; (2) the soil was originally flocculated but at times the quality of the water is such as to bring about deflocculation. He assumes that small amounts of sodium ions in water, will cause the finely divided clay fraction of the eroded soil to remain dispersed.

The silt derived from such dispersed soils will not settle readily unless activated by some flocculating agent.

NATURE OF CLAY DISPERSION AND FLOCCULATION

Attention must be given to the complexities of the clay system, in any attempt to correlate the flocculation of certain soil particles with the established facts of soil chemistry. Clays show pronounced physical properties due to the great surface activity of the colloidal particles. Most turbid waters, of the non-clearing type, are suspensions of colloidal clay in a water medium. The colloidal portion is composed primarily of alumino-silicates. According to Sigmond (1938), colloidal particles owe their existence to two factors: (1) the electric charge on their surface, which may prevent the coagulation of similarly charged particles, and (2) the hydrated layer on the surface, that surrounds the particles like an elastic protective sheath and also prevents their coagulation.

Structure of the Colloidal Particle

Soil physics (Baver, 1948) teaches that one colloidal-clay particle or micelle may be conceived as a negatively charged nucleus surrounded by positively charged ions. Fixed anions have a position at the surface of the core and constitute the inner part of a double layer. The outer layer consists of an envelope of oscillating cations which diffuse into the surrounding water medium. If the negative potential is sufficiently great, the clay particles will repel each other in the suspension when they collide during Brownian movement. The force of repulsion is due to the charge on the particle. If the electric potential is small, there will be little tendency for repulsion and the particles will coalesce following a collision and thus attain mass sufficient to settle as an aggregate.

The cations common in the outer layer are Na, K, Ca, Mg, and H with Na and K predominating in highly dispersed soil. These cations are commonly designated "adsorbed", "replaceable", or exchangeable".

Various effects of added or substituted cations, on soil colloids, are ascribed to differences produced in the structure of the colloidal micelles and specifically to changes in the double layer. According to Anderson (1929), the colloidal soil material falls in the category of those comparatively insoluble substances that have a tendency to dissociate into ions. According to the theory, such substances dissociate at the surface of the nucleus and give rise to negative and positive ions. The negative ions are insoluble and remain at the surface. The positive ions are soluble and are dissolved in water surrounding the nucleus, but held in position by electrical attraction. The density and diffuseness of the outer layer of ions depend on the degree of colloidal ionization. The chief ions remaining in the periphery of the nucleus, appear to be some form of silicate anions. The outer layer is composed of cations that can be exchanged for cations in the surrounding medium. Thus many of the physical properties of soils are affected by the nature of the adsorbed ion.

Electrical Charge of Clay Particles

Fixed negatively charged silicate anions, which comprise the inner part of the double layer, reside at the surface of the core. The inner layer is part of the core wall of the particle and, according to Baver (1948), this ionized wall determines the sign of the charge on the particle. The ionized particle behaves like the negative radical of an acid. When exposed to the action of an electric current the negatively charged nuclei move toward the positive electrode. If the charge is reduced to a sufficiently low potential, aggregation of the particles occurs. Therefore, the electrical charge maintains the stability of the suspensoid.

Hydration

A clay particle in a dilute suspension can, therefore, be pictured as consisting of a central core surrounded by a negatively charged layer. An envelope of water molecules surrounds the negative charges. The cations, outside this layer, also possess envelopes of water molecules. Hydration varies with the nature and number of adsorbed cations. Therefore, the electric double layer can be considered as a diffused hydrated shell comprised of ions and bound water molecules. Since water films occupy space, any force attracting clay particles must act through a greater distance, so that the force is reduced. Consequently, any factor that tends to reduce the water hull, aids in the aggregation of clay particles.

Flocculation by Organic Substances

It has long been recognized that organic matter serves as an aggregating agent in soils. At present, the exact nature of the effects of organic matter on soil aggregation cannot be fully explained.

Williams (1935) proposed a theory that attributes aggregate formation in some soils to ulmic acid, which is secreted by anaerobic bacteria during the decomposition of root residues. The ulmic acid is supposed to produce a water stable cement that causes aggregation of soil particles.

Sideri (1936) has suggested that humus is adsorbed by clay, which causes a binding effect between the organic and inorganic constituents of the soil. The soil humus, according to Sideri, is adsorbed by the clay through a physical orientation of the organic molecules on the surface of the clay particles. He visualized the organic colloidal material as an amorphous jelly-like mass which envelops the solid mineral grains and adds the necessary weight for precipitation.

Myers (1937) suggested that the mutual effects of organic and inorganic colloids can best be explained on the basis of polar adsorption. He indicated that humic compounds are polar and are therefore capable of being oriented on an inorganic surface possessing electrical properties. Since the soil colloids are electro-negative, they attract toward their surfaces the positive end of a polar compound. This adsorption results in a close packing of the organic colloid particles on the surfaces of the clay, thus aiding in neutralization and cementing of the clay particles.

Peele (1940) maintained that physical and chemical factors were responsible for the increased aggregation of soil with which organic matter was mixed, and divided the organic binding forces into two groups. One group comprised colloids of the decomposition products of plant residues. The other consisted of the cells of microorganisms and their secretory products such as mucus, slime, or gum.

Several investigators have observed that an increased growth of microorganisms in the soil lead to greater soil aggregation. Meyers _et al_. (1940) reasoned that bacteria acting on organic matter, are associated with, and responsible for, the aggregation of soils solely on the basis of accumulated metabolic products in the soil that function as cementing agents. Peele and Beale (1943) used crimson clover, in a soil, and measured CO_2 evolution and degree of aggregation and demonstrated that the peak in microbial activity, which occurred on the sixth day, coincided with the high point in aggregation. McHenry and Russell (1944) found two peaks in CO_2 evolution and these also were correlated with maximum points in the degree of soil aggregation. The first peak was attributed to products released during the decomposition of the readily available materials, whereas, the second originated from products of the more resistant compounds. Microbial products were included, in the aggregating effect, in both instances. McCalla (1945) substantiated the importance of organic decomposition products on soil aggregation by showing that cellulose, hemicellulose, simple carbohydrates, and waxes bring about an increased aggregation of soil particles. His results also indicated that inorganic salts, when added to soil, do not exert a flocculation effect but that strong acids increase aggregate stability. Gilmour (1949) in a study of biological factors on soil aggregation, showed that molds and bacteria are quite effective aggregating agents. This effect was shown to be due to forces involving physical and chemical factors, which included orientation of fine clay particles on the surface of microbial cells and the influence of products secreted by the cell. An increase in titrable acidity was indicated as a chemical factor causing the more rapid flocculation, while capsular material secreted by the cells aided in causing a binding effect of suspended particles.

Ensminger and Gieseking (1939) have proposed an additional factor which apparently aids in neutralizing the negative charge on colloidal clay. They state that, since tissues of plants and animals contain most of their protein and protein derivatives in a basic form, or in a form that becomes basic upon hydrolysis, these products are capable of reacting like basic compounds. This makes possible an attraction between the basic or positive spots of the organic matter and the negative spots on the crystal lattice of the clay. Individual particles of soil organic matter will have a great number of positive spots resulting from free amino groups. Likewise, individual clay particles, having a cation-exchange capacity, will have a great number of negative spots. If the two particles should orient themselves in such a manner that there was a mutual attraction between these spots, a stable combination would be formed. Consequently, the clay crystal might become covered by a "network" of organic material. This increases its size, and makes precipitation possible.

OBSERVATIONS ON IMPOUNDMENTS HAVING VARIOUS TURBIDITIES

General Physical and Chemical Data

Physical and chemical analyses were made on impounded waters, in Payne County, Oklahoma, to determine if a relationship existed between these factors and the turbidity of the water. These observations were made during the time when the major portion of the experimental field work on clay precipitation was being conducted. It was recognized that impounded waters may vary one from another, physically and chemically, in the same area and that all bodies of water vary with changing seasons and environmental factors.

It is necessary to present data concerning a few of the many impoundments, both large and small that exist in this area, to show variations in properties. Examples, as listed (Table 2), illustrate some factors involved in these numerous bodies of water. Many features such as the character of watershed, nature of shoreline, extent of aquatic vegetation, water exchange, etc., must be considered as factors contributing to the general characteristics of the pond or lake. These features showed enough variation to indicate that they did not constitute the complete explanation for the existing status of turbidity. Keyes Pond, for example, had a barren shoreline and an overgrazed watershed, yet it was clear and produced a rich growth of filamentous algae. By way of contrast, Denney Pond, an old stock tank, drained a well covered watershed, had a fairly well shaded shoreline and was continuously muddy. Rutter's two ponds presented an excellent

TABLE 2

Physico-chemical Data from Miscellaneous Ponds of Various Turbidities in Payne County, Okla.

Impoundment	Location From Stillwater	Date	Water Temp. deg.C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
Berry Pond A	1 mi. S. (By house)	11/7/49	14.0	8.6	0.0	7.2	32.0	197	clear
College Barn Pond	1.5 mi. W.	11/10/49	14.6	8.6	0.0	6.9	26.0	228	clear
Hesser Spring Pond	4 mi. E. 2.5 mi. N.	11/8/49	8.0	7.6	8.4	7.6	0.0	198	clear
Keyes Pond	3.5 mi. E.	11/4/49	16.2	8.3	0.0	8.1	5.0	109	clear
Rutter Fish Pond	6 mi. E. 6 mi. S.	1/14/50	5.0	7.8	6.0	8.6	0.0	159	clear
Wilson Pond	1 mi. E.	11/4/49	14.6	8.4	0.0	8.0	11.0	118	clear
Berry Pond B	1 mi. S. (By office)	11/7/49	14.8	8.4	0.0	9.2	16.0	126	30
Fisher Pond	7.5 mi. E.	11/3/49	10.2	8.4	0.0	8.6	4.0	162	38
Lake Carl Blackwell	12 mi. W.	9/3/49	25.0	8.3	0.0	5.9	2.5	122	45
Boomer Lake	1 mi. N.	12/3/49	12.2	8.8	0.0	8.9	22.0	66	74

TABLE 2 (Continued)

Impoundment	Location From Stillwater	Date	Water Temp. deg. C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
Cross Pond	6.5 mi. E. 2 mi. S.	11/4/49	14.5	7.8	2.8	8.6	0.0	82	87
Creech Pond	0.5 mi. E. 0.5 mi. N.	12/3/49	11.0	8.0	1.4	8.2	0.0	81	138
Swank Pond	1 mi. S.	12/10/49	9.2	8.5	0.0	9.2	16.0	64	156
Swank Pond	(Same)	10/4/49	22.0	8.4	0.0	7.8	12.0	72	168
Denney Pond	6 mi. N.	8/14/49	28.8	8.0	2.4	7.2	0.0	74	234
Denney Pond	(Same)	1/13/50	5.2	8.2	0.0	9.1	2.0	68	260
Rutter Settling Pond	6 mi. E. 6 mi. S.	1/14/50	6.2	7.8	5.6	8.9	0.0	78	270
Hesser Pond	4 mi. E. 2.5 mi. N.	11/8/49	15.4	8.2	0.0	9.0	1.0	94	315
Smith Pond	1.5 mi. E. 1 mi. N.	11/1/49	10.8	8.4	0.0	8.3	5.0	68	740

example of the application of good conservation measures, in the construction and maintenance of productive impoundments. The settling pond, located directly above the fish pond, contained approximately one surface acre and received all the surrounding run-off water. Little vegetation grew around the margin, and no filamentous algae was detected in the water. This water constantly retained a large quantity of colloidal clay in suspension. The fish pond, immediately below, had an area of five surface acres and received all its water, through a pipe, from the settling pond. Diversion ditches had been constructed around the fish pond to prevent the entrance of run-off water. As a result of this construction, strict control has been exercised over incoming and outgoing water. This pond was clear. Copious amounts of submerged and emergent plants and filamentous algae grew in the shallow margins of the basin. Tests made on the waters of these two contrasting ponds showed that the only detectable difference, besides turbidity, was an increase of bicarbonates in the clear water.

Results of all tests, from these heterogenous bodies of water, fall within the normal range limits for productive waters. The chemical tests revealed no obvious factors (except possibly bicarbonates) which could be used to explain the difference in turbidities.

Specific Conductance and Turbidity

Specific conductance is often used in industrial water analyses. It offers a quick and convenient method to indicate the presence or absence of ionized substances, but it gives no indication of the relative quantities of each constituent of a solution. Natural waters usually contain various quantities of acids, alkalies, or dissolved salts. The main salts are the chlorides, sulfates, carbonates, nitrates, and phosphates of solium, potassium, calcium and magnesium. Total conductivity is equal to the sum of the capacities for electric conductance of each ionizable substance present.

"Other things being equal, the richer a body of water in electrolytes, the greater its biological productivity" (Welch, 1935). Decomposition of organic matter in the water and in the bottom deposits, results in the production of carbonic and various organic acids. Respiration of aquatic organisms supplements the carbonic acid content of the water. Rooted aquatic plants, through growth and decomposition, tend to recirculate compounds from the bottom and, therefore, increase the dissolved mineral content. All of these factors, resulting from biological activity, should increase the number of free ions in the water and should reflect higher specific conductance values. The work of Ellis (1936) indicates the importance of conductivity test on pollution studies, but shows little difference between clear water and that containing erosion silt. He stated that the average specific conductance of relatively unpolluted river waters carrying silt varied from 133 to 388 micromhos, the usual value for the larger streams being 290 micromhos. The conductance of the river water, carrying erosion silt, was essentially the same as the conductance of the same sample of water after the erosion silt was removed by a colloidal filter.

Specific conductance measurements were not made on all of the impoundments or with all chemical analyses. Values are given (Table 3) for the purpose of comparing the conductivity with other properties. Little significance has been attributed to specific conductance as an index of the biological activity and corresponding turbidity in the water because of the limited number of tests, yet a slight correlation is shown by these values. As will be given in detail later in the report, Yost Lake and six ponds had been treated with vegetation and were either clear, or in the process of clearing at the time conductivity tests were made. Smith Pond maintained a high turbidity during the entire course of the investigation, contained no aquatic plants, and had a low specific conductance. Its organic matter content was low (Tables 15, 16). The other bodies of water (Table 3) to which vegetation had been added showed higher conductivity. Low bicarbonate content and a lack of carbonic acid may have resulted in a low specific conductance of Smith's pond water. The higher conductivity values of the other waters may have been due to the organic matter that was added. There seemed to be little consistency, however, between specific conductance and other properties exhibited by the waters tested.

TABLE 3

Specific Conductance and Other Physico-chemical Data in Relation to Turbidity from Some Impoundments in Payne County, Okla.

Pond Sampled	Water Temp. deg.C.	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.	Specific Conductance Micromhos
Smith Pond	10.8	8.4	0.0	8.3	5.0	68	650	120
Pond #6	13.6	7.8	4.2	6.8	0.0	96	104	203
Pond #5	14.4	7.8	5.6	6.9	0.0	138	95	315
Pond #4	13.2	7.8	6.4	4.8	0.0	132	70	284
Pond #3	12.8	7.6	7.0	3.2	0.0	104	64	196
Pond #1	12.2	7.6	4.6	7.0	0.0	125	42	256
Pond #2	13.0	7.6	3.2	7.2	0.0	132	38	245
Yost Lake	15.6	7.8	2.4	8.9	0.0	112	clear	210

SUSPENDED CLAY AGGREGATION UNDER LABORATORY CONDITIONS

Laboratory experiments were conducted, with clay suspensions, to determine some of the conditions under which clay particles could be aggregated and precipitated. Water used was taken from ponds, in Payne County, in which the colloidal suspensions were stable.

These experiments differed in important respects from field operations since interference from external forces, such as winds and other agitating agencies, were minimized. Nevertheless, basic coagulating principles, as determined under laboratory conditions, could be utilized in impoundment projects.

Coagulation is a term used to explain changes that occur when substances, in colloidal state, flocculate or aggregate into particles that eventually become heavy enough to precipitate. Alum has long been used by sanitary engineers as a coagulant in the process of clarification of turbid waters. Substances such as aluminum and iron salts are excellent clarifying agents, due to the nature of the floc formed upon hydrolysis.

By using various neutralizing and coagulating agents, it was evident that results of the following experiments had an important bearing on field problems, and should be discussed here because they affect the conclusions to be drawn from the field data.

Inorganic Materials

Tests were made in order to learn the relative effects of increased and decreased hydrogen-ion concentration on the precipitation of suspended clay. Normal solutions of HCl and NaOH were prepared and from these the dilutions were obtained for the experiment (Table 4). Five cc. of the acid or base, as indicated, were added to flasks, each containing one liter of water from Smith's pond (turbidity 440 ppm.). These suspensions were stirred and then left to stand for observation. Test samples were carefully withdrawn from one inch below the surface by means of pipette. Initial and final pH readings and turbidity measurements at significant intervals were made. Final observation was made 24 hours after mixing the electrolyte with the clay suspension. Thus the minimum electrolyte requirement, for precipitating this suspended clay, was determined.

As indicated in Table 4, an increase in hydrogen-ion concentration by ten times (i.e. reducing the pH from 8.0 to approximately 7.0) was effective in clearing the suspension in the 24 hour period. Lower pH values resulted in more rapid precipitation. At the end of 24 hours observation, the pH value was slightly higher in suspensions to which acid had been added. It is indicated that free hydrogen ions had been removed. These ions had apparently been adsorbed by the colloidal clay. The suspended colloidal clay seemed to exhibit a buffer action comparable in effect to certain dissolved substances.

Several experiments similar to the preceding one, were performed on suspensions of various turbidities and corresponding results were obtained. However, an increased quantity

TABLE 4

Effect of Hydrogen-ion Concentrations in Precipitating Colloidal Clay

	0 min.		30 min.	60 min.	90 min.	2 hrs.	18 hrs.	24 hrs.	
Electrolyte	pH	Turb. ppm.	Turb. ppm.	Turb. ppm.	Turb. ppm.	Turb. ppm.	Turb. ppm.	pH	Turb. ppm.
Control	8.0	440	440	440	440	440	440	8.0	440
1 N HCl	6.6	440	260	100	60	clear	clear	6.8	clear
0.5 N HCl	6.8	440	400	390	380	350	40	7.0	clear
0.25 N HCl	6.9	440	420	420	410	400	110	7.0	clear
0.125 N HCl	7.1	440	440	440	440	440	290	7.3	130
0.063 N HCl	7.5	440	440	440	440	440	320	7.6	310
0.031 N HCl	7.8	440	440	440	440	440	420	7.8	420
0.125 N NaOH	8.6	440	440	440	440	440	440	8.6	440
0.25 N NaOH	8.9	440	440	440	440	440	410	8.9	390
0.5 N NaOH	9.4	440	440	440	440	430	390	9.4	310
1 N NaOH	9.8	440	320	190	80	40	clear	9.8	clear

of acid was required to effect a change in pH of water taken from the same pond when the water held more suspended clay. These observations indicated that more hydrogen ions were adsorbed when the colloidal particles were increased. Therefore, the quantity of a coagulant necessary for clearing was directly related to the turbidity of the suspension.

The hydrogen ion, which is the smallest ion, has long been known to be an effective flocculant for colloidal clay. Wolkoff (1916) has shown that acids are better flocculating agent than their salts. According to Bradfield (1924), Kelley (1929), and Jenny (1932), the hydrogen ion is the most strongly adsorbed ion. Sigmond (1939) reasoned that the adsorbing energy of hydrogen is four times as great as that of the calcium ion. Any treatment, that will increase the hydrogen-ion concentration of a soil, will lower that soil's capacity for holding bases, because the metallic ions are replaced by hydrogen ions. It is possible to substitute most of the replaceable bases and flocculate dispersed clay by hydrogen, upon treating soil with an acid. Kelley (1929) has presented data which supports the idea that hydrogen ions, formed in soils by biochemical action or introduced by carbonated water, replace many of the replaceable bases. Acid soils represent the result of this condition.

Sodium hydroxide caused complete flocculation in 24 hours at a pH value of 9.8 because of some influence of the sodium ion. Smaller amounts of this alkali tend to stabilize clay suspensions. To study this influence, a similar clay suspension was titrated carefully with sodium hydroxide until complete coagulation was effected, care being taken not to add more sodium hydroxide than was necessary to produce visible aggregates. The resultant mixture was treated with an equivalent amount of hydrochloric acid and shaken into a suspension. The suspension so prepared remained stable and did not coagulate on long standing. This experiment points to the adsorbing and replacing power of hydrogen ions, and with an increase in hydrogen ions (Table 4), their effective neutralizing power can be seen. The addition of sufficient amounts of any electrolyte will cause the clay system to flocculate and settle. This seems definitely related to the law of mass action.

No two colloidal clay suspensions seem to possess exactly the same properties toward the action of an electrolyte. The relation of one colloidal substance to another, in such a mixture, must vary with different soils and different waters. This suggests that the suspension is a mixture of several colloids. If coagulation is accomplished by the process of neutralization with positive ions, the presence of these in sufficient numbers should precipitate the clay. The above experiment with an acid and a base suggested the action of replaceable positive ions in coagulation.

One liter of water from the same pond in each of a series of jars was used and five cc. of a compound added. These suspensions were stirred and allowed to stand for 24 hours. Initial and final pH and turbidity measurements were recorded. The type of substance added to the clay suspensions and its effect upon the turbidity during the 24 hour period is shown (Table 5). All the compounds that ionized, except KCl, cleared the water when mixed with the suspension. Since KCl is a neutral salt, it has little influence on pH, however, when added in sufficient quantities it will precipitate the clay due to the increased number of positive ions. Jenny and Reitemeier (1935) stated that the addition of proper amounts of any electrolyte will cause the system to settle, however, the magnitude of the flocculation value is a function of the properties of the coagulating cation. According to Baver and Hall (1937), the flocculating power of certain cations follow the order: Na, K, Mg, Ca, H. Hydrogen ions are therefore considered by them to be the most effective flocculating agents. The results obtained with the various acids (Table 5) seem to show the importance of the positive ion, since clearing was effected at approximately the same pH value.

The next coagulant used in an experiment, although of no practical value, does emphasize a basic principle of neutralization. A basic dye, methylene blue, was added to a clay suspension in a concentration of one hundred parts per million. The clay particles were aggregated and precipitated although the water remained strongly colored. Ludwig (1942) stated that flocculation with methylene blue is the result of neutralization of the negatively charged clay particles by the positively charged dye colloid. The phenomenon is purely physical, in that the finely divided powder carries a charge which causes the oppositely charged clay particles to flocculate and settle

TABLE 5

Effect of Various Compounds in Precipitating Colloidal Clay

0.25 N Solution	0 Hours pH	0 Hours Turbidity ppm.	24 Hours pH	24 Hours Turbidity ppm.
Control	8.0	440	8.0	430
HCl	6.9	440	7.0	clear
H_2SO_4	6.8	440	6.9	clear
HNO_3	6.8	440	6.9	clear
$CaSO_4$	7.8	440	7.8	clear
$CuSO_4$	7.0	440	7.0	clear
$HC_2H_3O_2$	7.2	440	7.3	clear
$C_2H_2O_4$	6.9	440	7.0	clear
$HC_3H_5O_3$	7.1	440	7.2	clear
$C_{12}H_{22}O_{11}$	8.0	440	8.0	430
KCl	8.0	440	8.0	430
*H_2CO_3	6.6	440	7.6	clear

* CO_2 was bubbled into suspension before initial reading

to the bottom by the action of gravity.

Organic Materials

A major objective in this investigation was to study readily available non-toxic materials for clearing waters of their suspended clay. Inasmuch as organic matter is accessible, particularly vegetation (grass or weeds), and has been shown to clear turbid water (Irwin, 1945) the question of the quantity necessary was studied. Various ratios have been devised such as the vegetation from an acre of ground applied to a surface acre of water, or a ton of vegetation to a surface acre of water. It was felt that these quantities were not applicable to all bodies of water since water volume, degree of turbidity, and amount of vegetation obtainable per unit area were not constant. It seemed more practical to calculate the actual weight of suspended clay in a unit volume of water and use an equivalent weight of vegetation or multiple of this value.

This procedure was followed in experiments conducted in the laboratory with pond water using native vegetation which would be available to any land owner. Bermuda grass, Johnson grass, Indian grass, little blue-stem, alfalfa, smartweed, sunflower, wheat, and grain sorghum plants were used. A known weight of each kind of plant was added to a glass container with 1500 cc. of pond water. Ten jars, one for each of nine kinds of vegetation and a control, were provided. The turbidity of the water used measured 690 ppm. The calculated weight of suspended clay in 1500 cc. was 1.035

grams. A quantity (6.21 grams) of each kind of vegetation equal to six times the weight of the suspended clay was added to each of the nine jars for the first test. At the end of 60 hours, the clay had been precipitated in all nine jars but the control remained muddy.

The experiment was repeated in like manner using four times the weight of suspended clay or 4.14 grams of vegetation, to each 1500 cc. of the suspension. Clarification in the treated jars took place in five days following this treatment.

Further reduction in quantity of vegetation was tried in the third experiment, by adding twice the weight of suspended clay, or 2.07 grams, to each 1500 cc. of the original suspension. Precipitation of the clay in all jars, except the control, was effected in eight days.

Still another test was performed using a weight of vegetation, 1.035 grams, equal to the weight of suspended clay. Precipitation of the clay occurred very slowly and at the end of two weeks the turbidity had been reduced only about one-fourth.

The small quantity of vegetation used in the last experiment was effective in precipitating the suspended clay but was insufficient to completely clear the water. Clarification of the clay suspension was accomplished by using a weight of vegetation equal to twice the quantity of suspended clay. Larger quantities resulted in more rapid clearing.

It was expected that at least one kind of plant would be more effective than the others because of their difference in chemical composition and the difference in weight of plants at early and late growth stages. However, the end result in each series of tests was the same. Thus, the calculation of weight from soil turbidity in parts per million provides a practical measure for determining the amount of vegetation needed for clearing impounded water.

An experiment was conducted to determine the rate of turbidity decrease as a result of organic decomposition products. The fact that vegetation, when placed in water, provides an excellent medium for one-celled organisms is well known but the complexities of the products of dissolution and decomposition are not so well understood. These products, rather then the kind of vegetation, must be responsible for the reduction in the amount of suspended clay. The apparent correlation existing between organic decomposition products and the flocculation of colloidal clay was tested by using the formation of CO_2 as an end product in the metabolism of bacteria and its effect in lowering pH values. Four aquaria (Table 6), each containing 20 liters of pond water were arranged, numbered, and, to three aquaria, 90 grams of plant materials added as follows: to No. 1, green alfalfa cuttings, to No. 2, cured alfalfa hay, to No. 3, wheat straw. No. 4 was retained as a control.

It was determined from this experiment that an incubation period existed before appreciable quantities of CO_2 were liberated. This lag in CO_2 production was natural and was the time required for a large microorganism population to

TABLE 6

Effects of Vegetation upon Bacterial Growth, CO_2 Production, Hydrogen-ion Concentration and Turbidity Reduction in Muddy Water

Aquarium #1 —— Green Alfalfa

Time, Hours	pH	CO_2 ppm.	Turbidity: Lumetron % Light Trans.	Turbidity: Jackson ppm.	Bacteria no./ml. x 10^6
0	8.0	3.4	6.0	690	0.0047
2	8.0	3.6	6.0	690	0.0055
4	8.0	4.2	6.0	690	0.0196
6	7.8	10.6	6.0	690	0.0650
8	7.6	18.0	6.0	690	0.1040
10	7.2	27.2	6.4	---	1.0
12	7.1	28.8	6.4	650	1.840
14	7.1	28.8	6.5	---	6.80
16	7.1	28.6	6.5	650	24.70
18	7.1	28.8	6.5	---	213.50
22	7.0	32.4	7.0	640	-----
24	7.0	34.6	8.0	---	-----
32	7.0	35.0	17.0	410	1,264.0
44	6.8	64.0	37.0	200	680.0
50	5.8	84.0	62.0	145	-----
68	5.4	164.0	80.0	88	-----
72	5.2	202.0	88.0	84	-----

Aquarium #2 —— Alfalfa Hay

Time, Hours	pH	CO_2 ppm.	Turbidity: Lumetron % Light Trans.	Turbidity: Jackson ppm.	Bacteria no./ml. x 10^6
0	8.0	3.4	6.0	690	0.0049
2	8.0	3.6	6.0	690	0.0088
4	8.0	6.2	6.0	690	0.0191
6	7.6	14.4	7.5	620	0.1620
8	7.4	37.6	11.0	470	0.2020
10	6.8	47.6	14.0	---	1.20
12	6.8	52.0	16.0	430	2.780
14	6.8	52.8	16.0	---	15.20
16	6.9	56.8	16.0	430	56.0
18	6.9	59.0	16.0	---	562.40
22	6.8	118.4	20.0	390	-----
24	7.0	124.2	21.0	---	-----
32	6.1	156.0	57.0	165	410.0
44	5.6	182.0	73.0	142	520.0
50	5.4	212.0	76.0	150	-----
68	5.0	382.0	73.0	165	-----
72	5.0	396.0	73.0	167	-----

TABLE 6 (Continued)

Effects of Vegetation upon Bacterial Growth, CO_2 Production, Hydrogen-ion Concentration and Turbidity Reduction in Muddy Water

Aquarium #3 —— Wheat Straw

Time, Hours	pH	CO_2 ppm.	Turbidity: Lumetron % Light Trans.	Turbidity: Jackson ppm.	Bacteria no./ml. x 10^6
0	8.0	3.4	6.0	690	0.0047
2	8.0	3.6	6.0	690	0.0135
4	8.0	4.0	6.0	690	0.0310
6	8.0	4.8	6.0	690	0.0320
8	7.8	11.2	6.4	680	0.0890
10	6.8	17.6	6.4	---	0.1520
12	7.2	20.0	6.5	650	0.880
14	7.1	20.0	7.0	---	1.4160
16	7.2	20.0	7.0	630	5.120
18	7.2	20.8	7.0	---	7.940
22	7.2	21.0	7.5	600	-----
24	7.2	22.0	8.0	---	-----
32	7.2	22.8	9.0	525	68.0
44	7.2	24.0	15.0	440	126.0
50	7.0	29.6	21.0	310	-----
68	6.4	34.4	44.0	205	-----
72	6.2	35.4	51.0	170	-----

Aquarium #4 —— Control

Time, Hours	pH	CO_2 ppm.	Turbidity: Lumetron % Light Trans.	Turbidity: Jackson ppm.	Bacteria no./ml. x 10^6
0	8.0	3.4	6.0	690	0.0048
2	8.0	3.4	6.0	690	-----
4	8.0	3.4	6.0	690	-----
6	8.0	3.8	6.0	690	-----
8	8.0	4.0	6.0	690	-----
10	8.0	4.0	6.0	---	-----
12	8.0	4.4	6.0	690	0.0560
14	8.0	4.4	6.0	---	-----
16	8.0	4.8	6.0	690	-----
18	8.0	4.4	6.0	---	-----
22	8.0	4.8	6.5	660	-----
24	8.0	4.6	6.5	---	-----
32	8.0	4.2	7.0	650	0.060
44	8.0	4.2	7.0	640	0.0920
50	8.0	4.0	7.0	640	-----
68	8.0	4.2	7.0	640	-----
72	8.0	4.0	7.5	630	-----

develop. The initial CO_2 evolution was low but rapidly reached maximum rate. The CO_2 evolution rate, however, followed a pattern normal for biological activity in such materials. There was a definite relationship between the dissolved CO_2 and hydrogen-ion concentration although the change in pH lagged behind the increase in CO_2. The effects of other acids such as the various organic acids liberated in the water were not measured. Reduction in turbidity paralleled the increase in hydrogen-ion concentration. The rate of decomposition, as measured by CO_2 evolution, varied among the three plant materials. Dry alfalfa changed most rapidly, green alfalfa less, and wheat straw least.

Bacterial numbers increased as a result of increased available food. The peak in bacterial numbers in the aquarium containing green alfalfa was reached at the end of 32 hours (Table 6). There was a decrease in bacterial count together with a decrease in turbidity at 44 hours. Many bacteria apparently were carried to the bottom with the precipitated clay. The highest bacterial count in the aquarium containing alfalfa hay was noted at 18 hours. The next count, at 32 hours, showed a slight decrease in numbers, and again, this reduced count was correlated with a decrease in turbidity. The final count from Aquarium No. 3, containing wheat straw, made at 44 hours, gave its highest numbers. A lack of the nutrient content was evidenced in this culture. Furthermore, only slight clay precipitation was noted prior to the 44 hour period.

It will be noted from these data that there was a definite correlation between CO_2 production, increase in hydrogen-ion concentration, and precipitation of the suspended clay in all three cases. It is apparent that the presence of free oxygen and organic matter are essential for such bacterial growth. Waksman (1941) stated "Carbon dioxide production is largely a function of aerobic bacteria." It would seem that those plant materials that decompose rapidly are more effective in bringing about rapid aggregation than those that decompose slowly, however, in application the same end result is obtained.

Electrophoresis

The electrical charge ensures the stability of suspensoids as is shown by the phenomenom of electrophoresis. When positive and negative electrodes are placed in a clay suspension and kept activated, the normally negative clay particles migrate to the positive pole. When the potential of the clay particles approaches or reaches the isoelectric point the dispersion coagulates. The difference in potential within a micelle varies with the thickness of the outer ion layer and with the degree of hydration of the ions as previously discussed. Since work with precipitating agents showed that suspensions of high turbidities required a greater amount of an electrolyte to reduce the existing potential, it was thought that a comparison of the relative speed of migration of particles would be of interest.

An electrophoresis U-tube calibrated in 0.5 mm. units was used for an experiment. A constant potential of 140 volts was maintained on the electrodes by means of a direct current generator. Sufficient distilled water to cover the electrodes was admitted through a stopcock at the bottom of the tube and turbid water was carefully introduced in like manner. After filling, a definite line of demarcation between clear and muddy water was present. The velocity measurement recorded was the average of three determinations, computed as the distance over which clearing occurred at the cathode during a 25 minute period. Accuracy of the measurements required careful control of conditions. Most important were the original stability of the colloidal suspension and the sharpness of the line of demarcation dividing the muddy and the distilled water.

Samples A, C, D, E, and F (Table 7) represented suspensions taken directly from the ponds and used in the electrophoresis tube. Sample B was a suspension prepared by diluting A with distilled water. Sample G was a suspension taken from the same source as A but which had previously been treated with Bermuda grass for 12 hours. The turbidity reading of Sample G had been reduced from 620 to 540 ppm while in contact with the Bermuda grass. Data are presented showing turbidity of the suspensions and relative speed of migration of the suspended particles.

From the data (Table 7) it is evident that suspensions with lower turbidity cleared faster than those with a greater number of particles but not in the relative rate expected.

Sample B, for example, which presumably contained half the

TABLE 7

Relative Migration Velocities of Clay Particles in Colloidal Suspensions of Various Turbidities by Electrophoresis

Water Sample	Turbidity ppm.	Rel. Velocity in grad. units	Time Minutes
A (Smith Pond)	620	0.9	25
B (Smith Pond)	310	1.2	25
C (Swank Pond)	156	1.7	25
D (Creech Pond)	148	1.6	25
E (Boomer Lake)	74	2.0	25
F (Fisher Pond)	70	1.7	25
G (Smith Pond treated)	540	precipitated	22

number of particles as A, did not clear at twice the rate. Sample C and Sample D, with approximately equal turbidities, cleared at about the same rate. Sample E, with approximately the same turbidity as F, cleared at a more rapid rate. Sample G resulted in coagulation.

The lack of a ratio between turbidity and the migration rate of particles, as found in Samples A and B, may have been due to changes in the dispersing medium. Another influencing factor could be the increased space between particles which may have retarded their union into an aggregate large enough to slow Brownian movement. This increased space would provide less chance for particles to collide. Obviously the migration velocity is affected by several factors among which are the size, charge, and hydration of the suspended particles. Samples E and F had similar turbidities; however, particles in E exhibited a higher migration velocity. This would seem to indicate that particles in E carried a higher negative charge. Therefore, it would be more difficult to neutralize these highly charged and highly dispersed particles with a flocculating agent. Sample G, which had previously been treated with vegetation for 12 hours, was an unstable suspension. The behavior may be explained by the assumption that the charge on these particles had been reduced by agents from the vegetation, and under the influence of the current, rapid flocculation and precipitation resulted.

The effects of substituted cations on migration velocity in descending order are Na, K, Ca, Mg, and H, according to

Anderson (1929). The colloids with these different replaceable cations may be assumed to have a decreasing tendency to ionize in the above order and consequently a decreasing diffuseness of the double layer. Anderson further stated that the migration velocity, which varies directly with the electrical charge of the particle, is an indirect measure of differences in the density and diffuseness of the double layer.

Conclusions drawn from this experiment would seem to indicate that, other factors being equal, the greater the speed of migration of particles in suspensions of equal turbidity, the greater is their negative charge. This is borne out by observations on muddy impoundments which have revealed that it is often easier to reduce the turbidity of some waters than of others. One explanation for this condition could be a difference in the size and charge of the suspended clay particles.

SUSPENDED CLAY AGGREGATION UNDER FIELD CONDITIONS

Observations on small impoundments in Payne County, both before and after treatment with vegetation, were made to determine changes induced by organic matter. Field observations extended from June 20, 1949 to January 29, 1950. Each pond was tested at least twice before and at regular intervals following treatment. Samples of water and temperature readings were taken at approximately two feet below the surface. Most determinations were made between 8:00 and 12:00 A. M.

These bodies of water were artificial impoundments receiving their water supply from watersheds of various types. Factors such as accessibility, interest and cooperation from the property owner, construction and size were considered in selecting these bodies of water. Several small bodies of water used experimentally can provide more limnological data in a given period of time than a single large lake, since conditions affecting them can be more easily modified and treatments varied.

Effects Produced in Several Impoundments by the Addition of Vegetation

I. Yost Lake, located six miles north and three east of Stillwater, had a surface area of about 30 acres and an average depth of 6 feet. This lake was leased by the Yost Lake Country Club and used primarily for recreational purposes. Prior to 1941, the lake contained a good growth of aquatic plants and remained clear except for a few weeks each year during the rainy seasons. In 1941, the plants were eliminated by cutting and copper sulfate treatments. Subsequently, the water did not attain its previous clarity even though an increasing number of submerged and emergent aquatic plants established themselves in the shallow margins of the lake.

The condition still prevailed in 1948 and, early in the summer, approximately 20 tons of gypsum were piled in the shallow water in the belief that, upon increasing the calcium content, the suspended clay would be precipitated. The objectionable turbidity persisted however, and in the spring of 1949, the Board of Trustees authorized the planting of 30 acres of adjoining land to grain sorghum for the purpose of using the green fodder to clear the water.

Tests were made weekly by the writer, beginning June 20, on the water preceding the time when vegetation was put into the lake. Based on 180 acre feet of water, calculations showed that 19,440 pounds or approximately 10 tons of clay were suspended in the lake water. The average turbidity value at this time was 40 ppm. An attempt was made to add a measured amount of vegetation based on calculations from turbidity readings.

The original plan was to add only the grain sorghum, however, on July 26 an estimated quantity of 10 tons of prairie grass, cut from a field bordering the lake, was piled in the water. Thirty tons of the green sorghum were added on August 5. The total weight of green vegetation constituted 40 tons which approximated four times the weight of the suspended clay.

Table 8 summarizes the physical and chemical data recorded from analysis of this water. The data show that turbidity readings varied around 40 ppm. during the period previous to the introduction of prairie grass. The free CO_2 determination obtained on August 5 showed a slight increase from the previous average. At this same time there was noted an increase in hydrogen-ion concentration, an increase in bicarbonates, and a decrease in turbidity. Since this set of tests was taken ten days after the prairie grass had been hauled into the water, it was assumed that these changes were due to this vegetation. There was a definite increase in transparency of the water after August 5, with the exception of a few times following rains, when it became temporarily cloudy. The hydrogen-ion concentration was definitely correlated with the free CO_2 in the water. The range of free CO_2 extended from 0 to 4.8 ppm. and the increase seemed to be associated with the decomposition of the vegetation. Carbonates were not found except on June 27. Bicarbonates ranged from 65 to 112 ppm. with the first slight increase noted following the first addition of vegetation. Dissolved oxygen content never became critically low even though it was evident that the decomposing organic matter decreased it. The percent saturation of dissolved oxygen ranged from 52.5 to 98.6, and on five occasions only, was the percent saturation less than 60. It would seem from the trend shown in the data that the addition of the sorghum fodder was unnecessary from the standpoint of increasing the transparency. Since it did not seriously deplete the dissolved oxygen, it was beneficial in that it increased the

TABLE 8

Physico-chemical Data Showing the Effects of Organic Matter Added to Yost Lake

Date		Air Temp. deg.C	Water Temp. deg.C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
June	20	30.8	29.6	8.0	1.2	7.60	0.0	68	40
	27	29.8	29.4	8.2	0.0	7.08	2.0	70	38
July	5*	30.4	29.0	8.0	1.0	6.60	0.0	66	45
	13	33.2	30.6	8.0	1.0	6.19	0.0	65	37
	19	34.1	29.4	8.0	1.4	6.34	0.0	73	38
	25***	33.0	29.6	8.0	1.2	6.26	0.0	73	38
Aug.	2*	31.2	30.4	8.0	1.4	5.94	0.0	76	35
	5****	32.8	29.6	7.8	2.0	6.14	0.0	78	27
	6	34.4	29.0	7.8	2.0	6.23	0.0	78	30
	7	35.6	28.4	7.8	1.8	5.64	0.0	83	25
	8	32.8	27.8	7.8	2.6	6.38	0.0	81	25-**
	9	31.2	27.6	7.8	3.4	6.08	0.0	79	25-
	10*	32.6	27.2	7.8	4.0	5.98	0.0	72	25
	11	30.2	27.0	7.6	4.8	5.34	0.0	74	25-
	12	34.2	28.8	7.6	4.0	6.16	0.0	85	27
	13	36.0	29.6	7.8	3.6	5.88	0.0	89	25-
	14*	30.8	29.2	7.6	3.2	5.26	0.0	88	25-
	15	31.6	29.4	7.6	3.4	5.64	0.0	82	25-
	16	36.0	30.6	7.7	2.8	4.97	0.0	84	25-
	17	33.8	31.2	7.6	3.0	4.46	0.0	81	25-
	19	32.4	28.8	7.8	2.8	4.72	0.0	84	25-
	21	26.8	27.0	7.8	2.8	4.24	0.0	77	25-
	23	30.8	26.6	7.8	3.0	4.82	0.0	86	25-
	31*	23.0	25.0	7.7	2.8	5.50	0.0	91	25-
Sept.	6*	31.4	25.5	7.8	3.2	5.24	0.0	88	25-
	10	22.8	23.0	7.8	2.8	5.94	0.0	86	25-
	21	20.2	22.4	7.8	2.8	6.30	0.0	92	25-

TABLE 8 (Continued)

Date	Air Temp. deg.C	Water Temp. deg.C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
Sept. 26	18.8	21.2	7.9	2.4	6.14	0.0	93	25-
Oct. 7*	20.8	20.0	7.8	2.0	7.52	0.0	102	25-
12	30.2	21.6	7.8	2.6	7.40	0.0	104	25-
28	23.6	15.6	7.9	1.8	8.98	0.0	112	25-
Nov. 6	4.0	10.8	7.8	2.4	8.80	0.0	108	25-
20	14.2	9.0	7.8	2.4	7.94	0.0	107	25-
Dec. 3	23.8	8.6	8.0	1.6	9.78	0.0	109	25-

* Rains occurred within previous 24 hours
** Less than 25 ppm.
*** Ten tons prairie grass added (July 26)
**** Thirty tons grain sorghum added (Aug. 5)

organic matter content and fish food in the water.

Information obtained from the Soil Conservation Service showed that Yost Lake drained 470 acres of medium sloping land. There were 160 acres of this watershed under cultivation, 140 of which were terraced. The remaining 310 acres consisted of pasture land moderately grazed. Classified according to type of soil, 425 acres consisted of medium-textured slowly permeable soil, 20 acres of medium-textured permeable soil, and 25 acres of very shallow fine-textured soil. Two miles of dirt and gravel roads also were included in the watershed.

Erosion silt was carried into the lake with every run-off. When precipitating agents were present in the water, the finely suspended colloidal clay no longer persisted as an impediment to light penetration but settled to the bottom. The vegetation added to this lake undoubtedly altered the physical and chemical properties of the water. The addition of organic matter apparently resulted in the precipitation of suspended colloidal clay. It should be remembered, however, in this connection that water will not remain clear unless all incoming clay can be precipitated and this may be difficult unless erosion is decreased.

II. Pond No. 1, located on the south end of the Yost Lake Country Club golf course, had 0.59 surface acres and an average depth of 3.5 feet. According to reports from club members, this pond had persisted in a muddy condition for several years. An attempt was made, however, in the summer of 1946, to clear the water by the use of gypsum. It cleared as a result of this treatment but muddied again following a rain and remained in that condition. Consequently, this method of temporary clearing was abandoned.

The drainage area, which was part of the golf course, consisted of five acres of medium-sloping land covered by closely cut grass. The soil was classified by the Soil Conservation Service as a very shallow, fine-textured soil, not recommended for cultivation. During heavy rains, run-off water from about 400 feet of the road adjacent the golf course, emptied on the drainage area. It was evident from the nature of this watershed that fine particles of clay were carried into the pond by the run-off water.

Beginning on July 5, preliminary tests were made on the water to determine some of its physical and chemical properties. The turbidity leveled-off and presented a fairly constant average of 150 ppm. Considering the volume of water as two acre-feet, calculations showed that 810 lbs. of clay were suspended in the water. It was decided to add the equivalent of three times this weight in sorghum fodder, and on August 5, 2430 lbs. were applied.

Table 9 summarizes and presents the data obtained over a five month period. It shows that two days after the sorghum was added (August 7) there was a change in properties comparable to that in Yost Lake. There was an increase in free CO_2 and bicarbonates, a decrease in pH, dissolved oxygen, and turbidity. The free CO_2 increased from practically 0 to a maximum of 12 ppm. two weeks after the vegetation had been

TABLE 9

Physico-chemical Data Showing the Effects of Organic Matter Added to Pond No. 1

Date		Air Temp. deg. C	Water Temp. deg. C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
July	5*	30.4	29.4	8.0	1.6	5.17	0.0	75	192
	13	33.3	31.0	8.2	0.0	5.08	1.0	74	198
	19	34.1	33.2	8.2	0.0	5.90	1.5	75	152
	25	33.0	30.0	8.0	1.4	5.85	0.0	72	150
Aug.	2*	31.2	31.0	8.2	0.0	7.23	2.0	78	162
	5**	32.8	30.0	8.2	0.0	7.33	2.0	75	148
	6	34.4	28.8	8.2	0.0	6.54	2.0	80	155
	7	35.6	28.0	7.8	4.0	5.95	0.0	72	144
	8	32.8	28.2	7.8	8.0	5.34	0.0	78	152
	9	31.2	27.0	7.6	6.4	5.15	0.0	88	146
	10*	32.6	26.0	7.7	4.0	4.95	0.0	92	158
	11	30.2	26.4	7.8	5.6	4.46	0.0	94	136
	12	34.2	31.2	7.8	7.2	3.86	0.0	97	112
	13	36.0	30.2	7.6	6.8	4.06	0.0	102	100
	14*	30.8	28.4	7.8	4.8	4.16	0.0	100	124
	15	31.6	28.0	7.6	8.2	3.18	0.0	98	96
	16	36.0	31.1	7.4	9.2	2.80	0.0	102	75
	17	33.8	31.9	7.6	9.0	2.48	0.0	106	60
	19	32.4	26.6	7.5	12.0	2.30	0.0	102	58
	21	26.8	25.0	7.5	9.6	2.38	0.0	106	53
	23	30.8	24.0	7.6	9.2	2.40	0.0	112	48
	31*	23.0	24.5	7.7	7.2	2.80	0.0	119	67
Sept.	6*	31.4	26.4	7.7	5.6	3.40	0.0	107	63
	10	22.8	21.0	7.7	6.0	5.40	0.0	109	48
	21	20.2	21.6	7.6	4.6	5.20	0.0	111	53
	26**	18.8	20.2	7.8	4.4	4.95	0.0	118	54
	28	20.4	18.2	7.8	5.2	6.32	0.0	122	54

TABLE 9 (Continued)

Date		Air Temp. deg.C	Water Temp. deg.C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
Oct.	1	23.6	18.8	7.6	4.8	5.90	0.0	124	57
	4	21.0	20.8	7.8	6.8	4.63	0.0	126	68
	7*	20.8	20.2	7.6	7.2	3.40	0.0	125	52
	12	30.2	19.8	7.7	6.4	5.00	0.0	132	56
	28	23.6	18.2	7.6	5.6	7.20	0.0	125	42
Nov.	6	4.0	9.4	7.6	5.6	6.72	0.0	132	45
	20	14.2	8.6	7.8	4.4	7.80	0.0	136	38
Dec.	3	23.8	9.4	7.8	4.8	8.26	0.0	128	32

* Rains occurred within previous 24 hours
** Grain sorghum added (Aug. 5, Sept. 26)

added. The pH value decreased from a maximum of 8.2 to a minimum of 7.4, which correlated with the increase in free CO_2. Dissolved oxygen content was lowered considerably for almost a week, paralleling the time when free CO_2 values were high. The minimum dissolved oxygen value on August 19, showed the water to contain 2.30 ppm. or to be 28.2 per cent saturated. Initially, carbonates were low, then disappeared and bicarbonates were increased to a maximum of 136 ppm., almost double the initial value. Turbidity readings began to drop noticeable on August 11. Precipitation lagged behind the increase in free CO_2 and hydrogen-ion concentration, and seemed to be the result of their increase.

According to Ellis (1944), a dissolved oxygen level of 5 ppm. is the lowest value which may reasonable be expected to maintain a varied warm water fish fauna at a water temperature of 20° C. or above. Bullheads were known to be present in the pond and there was no evidence of asphyxiation of any aquatic organisms present.

Decrease in turbidity continued and leveled-off between 50 and 60 ppm. during the month of September. Thinking that insufficient vegetation was present to clear the water, 810 lbs. of sorghum were added to the pond on September 26. The turbidity showed a slight increase. The water was examined under the oil immersion lens of a microscope and no evidence of clay particles of any size could be found but zooplanktors were observed in great abundance. It was obvious that these organisms were producing the turbidity. The turbidity readings dropped later with the decrease in plankton. The general results obtained in this pond were quite in accord with those produced in Yost Lake.

III. Pond No. 2, with 0.6 surface acres and averaging 3.5 feet deep, was located 450 feet north of Pond No. 1 on the above mentioned golf course. Since this pond was situated in the same general drainage basin but on a lower level, it was somewhat protected from excess run-off water and siltation by Pond No. 1. Pond No. 2 got its water supply primarily from surface run-off, but any overflow that took place at the south pond spillway went directly into it. Turbidity had never remained as high in this pond as in No. 1, and a few aquatic plants had become established.

The immediate watershed was composed of six acres of land, one acre of which was covered by undisturbed blue-stem and the remainder by closely mowed buffalo grass. Three acres were classified as a soil type having deep medium-textured, very slowly permeable soil and the remaining three acres as very shallow fine-textured soil. It was apparent that some fine clay particles were carried into the pond from the fine-textured soil.

The same principles and techniques were used in the treatment of this pond. Preliminary tests were made on six occasions prior to treatment. Turbidity readings remained fairly stable at approximately 105 ppm. Vegetation equal to twice the weight of the suspended clay was used for the initial trial application in order to check the effectiveness of adding a smaller relative quantity of vegetation. The pond received 1134 lbs. of the sorghum on August 5.

Data are presented (Table 10) covering the same testing dates as given for the previous pond. The same general correlations were observed. Initial pH readings were slightly lower. Bicarbonates increased following treatment as in Pond No. 1. Since the free CO_2 and hydrogen-ion concentration did not increase to the extent found in the other pond, it was apparent that these values were directly dependent upon the quantity of organic matter introduced. This was followed by a drop in turbidity. Less oxygen depletion was encountered as the minimum value showed 3.37 ppm. or 41.3 percent saturation.

A disturbing condition, concerning the turbidity measurements, comparable to that observed in Pond No. 1, was likewise found in this pond. Toward the latter part of August the turbidity had dropped to 42 ppm. Following a rain on August 30, the turbidity increased and after two weeks it had not returned to its previous low level. More sorghum (567 lbs.) was added, as in No. 1, but after five days no great decrease in turbidity reading took place. Water checked with the microscope showed no clay particles but an abundance of zooplanktors. Apparently a pulse of plankton was occurring at this time and had been intensified by the additional organic matter in the water. After the plankton decreased, transparency of the water increased greatly and the final turbidity reading showed the water to be practically clear.

IV. Pond No. 3, located one mile south of Stillwater on the Berry farm west of Highway 40, was selected for

TABLE 10

Physico-chemical Data Showing the Effects of Organic Matter Added to Pond No. 2

Date		Air Temp. deg.C	Water Temp. deg.C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
July	5*	30.4	29.4	8.0	1.0	5.92	0.0	76	142
	13	33.2	31.2	7.9	2.2	6.32	0.0	75	112
	19	34.1	33.2	8.0	0.8	6.12	0.0	74	90
	25	33.0	30.2	8.0	1.2	6.36	0.0	75	108
Aug.	2*	31.2	31.0	8.0	1.4	6.44	0.0	70	112
	5**	32.8	30.2	8.0	0.8	7.23	0.0	78	106
	6	34.4	29.0	8.0	1.4	6.15	0.0	78	100
	7	35.6	28.2	7.8	4.6	5.06	0.0	80	102
	8	32.8	28.4	7.8	7.2	4.46	0.0	93	110
	9	31.2	27.8	7.6	7.6	3.66	0.0	95	112
	10*	32.6	26.2	7.6	6.0	3.78	0.0	94	114
	11	30.2	26.6	7.4	8.0	3.37	0.0	96	100
	12	34.2	31.2	7.6	6.4	4.46	0.0	108	92
	13	36.0	31.6	7.6	7.2	5.04	0.0	109	90
	14*	30.8	28.3	7.9	6.8	5.34	0.0	102	112
	15	31.6	28.8	7.6	8.4	4.08	0.0	108	68
	16	36.0	32.2	7.7	6.4	5.05	0.0	103	68
	17	33.8	32.8	7.8	7.6	4.86	0.0	113	62
	19	32.4	26.4	7.6	6.8	3.89	0.0	115	50
	21	26.8	26.4	7.6	10.2	4.85	0.0	118	42
	23	30.8	24.2	7.6	9.4	3.78	0.0	123	44
	31*	23.0	24.5	7.8	7.0	4.50	0.0	95	92
Sept.	6*	31.4	26.4	7.8	6.0	4.32	0.0	106	94
	10	22.8	20.4	7.8	6.2	3.80	0.0	114	80
	21	20.2	21.6	7.9	4.6	4.30	0.0	112	72
	26**	18.8	20.4	8.0	3.2	4.60	0.0	121	60
	28	20.4	17.8	7.8	4.8	3.54	0.0	115	58

TABLE 10 (Continued)

Date		Air Temp. deg. C	Water Temp. deg. C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
Oct.	1	23.6	19.2	7.6	8.4	4.72	0.0	127	62
	4	21.0	21.0	7.8	6.4	4.26	0.0	122	66
	7*	20.8	20.4	7.6	8.2	3.94	0.0	128	82
	12	30.2	17.4	7.8	6.0	6.30	0.0	133	64
	28	23.6	17.9	7.6	4.2	7.22	0.0	132	52
Nov.	6	4.0	9.2	7.6	4.2	6.84	0.0	129	46
	20	14.2	8.0	7.8	3.6	7.86	0.0	128	28
Dec.	3	23.8	10.0	7.9	3.2	8.72	0.0	142	30

* Rains occurred within previous 24 hours
** Grain sorghum added (Aug. 5, Sept. 26)

experimental treatment on account of the high turbidity which it had maintained since its construction. The pond consisted of 0.11 surface acres and had an average depth of 2.75 feet which presented a volume of 3.025 acre-feet of water.

Pond No. 3 was not a very desirable pond from the standpoint of construction and location, in which to expect to maintain permanently clear water. The watershed comprised four acres of medium sloping land, of which 2.5 acres were covered with ungrazed blue-stem and the rest was exposed soil. The unprotected part of the watershed lay adjoining the road and a part of the roadside was included in the drainage area. A considerable amount of siltation occurred with every run-off rain and many fine particles of clay remained suspended in the water. These conditions accounted for the high turbidity existing at the outset of testing.

Preliminary tests were made, September 25 and 28, to record the normal properties of the water (Table 11). The pond water maintained a turbidity of 520 ppm., which was higher than the average pond, and had a suspended clay weight of 425 lbs. vegetation equal to three times the calculated weight of suspended clay was added in the form of grass cut from the watershed.

Approximately 1275 lbs. of grass, mostly blue-stem, were hauled into the water on September 29. Tests were made at frequent intervals for the following three weeks in order to evaluate the effect of this vegetation upon the properties of the water. Free CO_2 reached a maximum concentration of 17.4

TABLE 11

Physico-chemical Data Showing the Effects of Organic Matter Added to Pond No. 3

Date		Air Temp. deg. C	Water Temp. deg. C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
Sept.	25	29.2	21.2	8.0	1.2	5.8	0.0	84	520
	28**	22.6	18.6	8.0	1.6	6.2	0.0	82	520
Oct.	1	19.6	16.0	8.0	1.2	4.9	0.0	90	530
	2	30.8	19.4	7.8	5.2	1.4	0.0	106	390
	3	30.2	19.8	7.6	9.2	1.4	0.0	98	360
	4	22.2	20.0	7.4	14.8	1.1	0.0	102	290
	6	30.8	22.4	7.2	16.8	0.5	0.0	92	130
	8	30.4	25.2	7.0	17.4	0.0	0.0	94	90
	9	32.0	27.2	7.2	13.8	0.0	0.0	98	65
	10	24.4	21.8	7.4	11.6	0.6	0.0	100	72
	12	19.8	15.8	7.1	16.8	1.0	0.0	89	60
	14	10.2	13.6	7.1	15.6	0.6	0.0	108	66
	16	27.2	17.4	7.2	15.2	1.8	0.0	112	55
	18	17.4	16.2	7.2	13.4	0.8	0.0	111	48
	20	23.4	21.0	7.2	15.6	0.6	0.0	116	34
	26*	19.8	15.8	7.6	7.0	3.2	0.0	100	42
Nov.	1	8.0	9.4	7.3	8.4	3.0	0.0	100	50
	3	9.4	10.2	7.3	8.0	3.9	0.0	91	58
	7	27.2	13.8	7.4	8.4	4.2	0.0	98	47
	10	26.8	17.0	7.4	8.4	4.6	0.0	108	48
	14	25.2	16.0	7.5	8.0	4.2	0.0	118	46
	18	14.4	9.4	7.4	8.0	4.6	0.0	134	34
	22	18.2	10.4	7.4	7.6	5.1	0.0	130	28
	27	24.6	14.2	7.4	6.4	5.5	0.0	125	30
Dec.	5	21.6	9.2	7.7	3.6	7.6	0.0	130	32
	12	8.0	5.4	7.6	4.0	7.8	0.0	136	28

* Rains occurred within previous 24 hours

** Vegetation added (Sept. 29)

ppm. Hydrogen-ion concentration increased ten times the initial quantity, changing from a pH value of 8.0 to 7.0 ten days following the application. The low pH determination correlated with the high CO_2 content.

Reduction of dissolved oxygen began on the second day, with a decided drop on the third. Total depletion of dissolved oxygen occurred October 8, nine days after treatment. Bullheads could be seen at the surface showing great discomfort from lack of oxygen, but no evidence of a "fish kill" was seen. On October 26, oxygen was being restored again.

No carbonates were present. Bicarbonates increased from a minimum of 82 ppm. to a maximum of 136 ppm.

Turbidity was reduced from 520 ppm. on September 28 to 390 ppm on October 2. On October 20, three weeks after vegetation had been introduced, the turbidity measured 54 ppm. Readings fluctuated between 40-60 ppm. for the next month. The final reading on December 12 was a low of 28 ppm. The lack of lower turbidity readings was not due to the presence of clay particles in suspension but to the dissolved colored material from the vegetation.

Precipitation of suspended clay was accomplished but practical usage was offset by a severe loss in oxygen. It seems that less vegetation should have been used in a single treatment in this pond.

V. Pond No. 4, was located one mile south of Stillwater on the Berry farm across the highway opposite Pond No. 3. This pond was likewise selected for its high turbidity as well as to evaluate data from the use of a smaller relative quantity of vegetation. Measurements showed this pond to contain 0.19 surface acres and possess an average depth of 2.5 feet. The total volume of water in the basin equaled 0.475 acre-feet.

Since the pond was situated in a depression on the top of a rise, the drainage area was comparatively small, consisting of approximately one acre. The immediate watershed was poorly protected, covered only by a sparse growth of smartweed, and mainly constituted the drainage area. During extremely heavy rains, water drained also from a slow sloping area of well grassed land. The muddy condition was maintained by run-off water from the raw clay watershed and by wave action on the barren shore margin.

Turbidity measurements in the preliminary tests showed an average of 475 ppm. (Table 12). The pond received 1218 lbs. of grass, September 30, which was cut, weighed and dumped into the pond from an adjoining field. This quantity represented twice the equivalent weight of suspended clay.

The CO_2 content and hydrogen-ion concentration increased and the turbidity decreased as in the preceding ponds. Hydrogen-ion concentration increased to a pH value of 7.4 at which point the free CO_2 had reached a maximum of 14.4 ppm. Since some clay still remained in suspension, more vegetation was added. A quantity (256 lbs.) of baled alfalfa hay, equivalent to twice the existing weight of suspended clay, was added to the water on November 4. Changes in free CO_2,

TABLE 12

Physico-chemical Data Showing the Effects of Organic Matter Added to Pond No. 4

Date	Air Temp. deg. C	Water Temp. deg. C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
Sept. 28	20.2	18.0	8.2	0.0	6.0	1.0	96	480
29	22.4	17.4	8.2	0.0	5.8	1.0	94	470
Oct. 1**	19.6	15.2	8.2	0.0	6.4	1.0	94	480
2	30.8	23.2	8.0	2.0	4.9	0.0	90	460
3	30.2	22.6	8.0	4.8	4.9	0.0	101	430
4	22.2	21.2	7.7	8.4	3.2	0.0	104	390
6	30.8	23.2	7.8	7.8	3.4	0.0	124	310
8	30.4	24.6	7.4	6.8	4.5	0.0	127	255
9	32.0	27.0	7.4	7.6	4.3	0.0	132	200
10	24.4	21.0	7.7	6.0	5.3	0.0	119	190
12	19.8	16.2	7.6	10.4	3.0	0.0	130	170
14	10.2	13.8	7.6	14.4	3.2	0.0	134	135
16	27.2	19.6	7.4	13.6	3.2	0.0	138	128
18	17.4	16.4	7.4	12.4	3.4	0.0	144	96
20	23.4	20.6	7.4	14.4	3.4	0.0	156	90
26*	19.8	17.6	7.8	6.4	4.8	0.0	132	110
Nov. 1	8.0	9.2	7.5	8.0	5.1	0.0	118	115
3	9.4	11.0	7.6	5.6	4.1	0.0	127	105
7**	27.2	14.6	7.6	7.6	4.0	0.0	139	122
10	26.8	16.8	7.7	8.0	4.1	0.0	148	114
14	25.2	15.6	7.6	7.4	3.4	0.0	152	110
18	14.4	8.2	7.4	12.4	3.6	0.0	170	56
22	18.2	10.8	7.4	13.0	3.7	0.0	162	38
27	24.6	14.8	7.5	13.8	3.9	0.0	174	40
Dec. 5	21.6	9.6	7.4	12.4	3.5	0.0	212	32
10	18.0	8.8	7.5	13.6	4.2	0.0	234	36
Jan. 8	9.2	3.4	7.6	13.4	6.8	0.0	221	26

* Rains occurred within previous 24 hours

** Vegetation added (Sept. 30, Nov. 4)

pH, and dissolved oxygen values again occurred following the addition of this organic matter. Turbidity readings dropped to a minimum of 26 ppm. A considerable increase in bicarbonates was manifested since the range increased from 90 to 234 ppm.

Clearing of this pond was effected by the use of vegetation on two different applications. There is the possibility that the clay would have been precipitated as a result of the first application but an additional amount expedited clearing without seriously affecting the chemical properties.

VI. Pond No. 5, was located one mile south of Stillwater on the Berry farm immediately north of the section line road. This pond measured 0.305 surface acres with an average depth of 3.5 feet and had a total water volume of 1.07 acre-feet.

This pond had been constructed for use as a settling basin for a fish pond which was located 500 feet north. The basin drained approximately six acres of well grassed watershed, however, run-off water from 500 feet of road bed also emptied into it. According to the owner, an estimated two tons of prairie hay had been put into the water, in the spring of 1948. This cleared the water which remained clear until after the spring rains of 1949. Bluegill and bass had been stocked in the pond in 1948 and one year later showed excellent growth. The water remained dingy (turbidity 100 ppm.) during the summer of 1949, but the pond contained a fair growth of filamentous algae in the shallow margins. This pond was treated with a quantity of vegetation equal in weight to the suspended clay.

Smartweed from the pond margin was cut and 289 lbs. were weighed and transferred to the pond On October 10. The effect of this small quantity of vegetation was reflected in only slight changes in properties (Table 13). Free CO_2 content reached a maximum of 7.2 ppm. and hydrogen-ion concentration increased from a pH of 8.0 to 7.6. No drastic reduction in dissolved oxygen occurred as the minimum content showed 5.6 ppm. Bicarbonate increase was negligible.

The influence of this vegetation on turbidity reduction was difficult to determine. Rainfall (total of 1.24 inches) occurred on October 23 and 24, which carried silt into the water. A pond situated above and on the opposite side of the road, was opened and drained on November 27. This pond, referred to as Swank Pond in Table 2, possessed a turbidity of 156 ppm. Owing to the condition of this water together with the fact that it drained the road, Pond No. 5 received a considerable volume of muddy water. Apparently, much of this clay was precipitated since turbidity measurements on December 5 indicated 112 ppm. and on January 8, 92 ppm.

VII. Pond No. 6, was located in a park area of the Berry Addition to the city of Stillwater. This pond contained 0.53 surface acres and had an average depth of 2.5 feet, which constituted a volume of 1.325 acre-feet.

Although seven acres of the watershed consisted of well grassed, ungrazed cover, a considerable amount of siltation occurred during rains because 300 feet of unpaved street lay

TABLE 13

Physico-chemical Data Showing the Effects of Organic Matter Added to Pond No. 5

Date	Air Temp. deg. C	Water Temp. deg. C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
Oct. 3	30.2	23.0	8.0	1.0	6.8	0.0	151	104
8	30.4	24.0	8.0	1.2	6.9	0.0	158	98
12**	19.8	16.4	8.0	2.8	6.1	0.0	156	100
14	10.2	13.6	7.9	4.0	6.3	0.0	152	110
16	27.2	18.8	7.8	4.8	6.2	0.0	157	108
20	23.4	21.2	7.8	6.4	5.8	0.0	153	98
26*	19.8	15.6	8.0	3.6	6.9	0.0	138	165
Nov. 1	8.0	9.4	7.6	5.2	7.9	0.0	150	120
3	9.4	10.4	7.8	4.3	8.2	0.0	152	107
7	27.2	14.4	7.8	3.6	6.4	0.0	155	100
10	26.8	16.2	7.8	3.6	7.1	0.0	154	92
14	25.2	14.4	7.8	3.2	8.2	0.0	160	86
18	14.4	7.8	7.8	4.4	8.4	0.0	165	84
22	18.2	11.0	7.7	4.2	8.0	0.0	160	80
27***	24.6	13.6	8.0	2.0	8.2	0.0	142	192
Dec. 5	21.6	12.2	7.8	3.4	8.4	0.0	154	112
Jan. 8	9.2	4.2	7.8	3.8	9.6	0.0	158	94

* Rains occurred within previous 24 hours
** Vegetation added (Oct. 10)
*** Received water from Swank Pond

adjacent to and drained into the pond.

The drainage area was too large for the size of the dam and the pond overflowed during rainy seasons of the year. Nevertheless, this pond was selected for study due to its accessibility and the ease with which vegetation could be obtained.

Baled prairie hay which is available all year and contains a combination of cured native grasses and weeds, was used without breaking the bales.

The water on October 10 and 16 had a turbidity of about 130 ppm. Taking the volume as 1.325 acre-feet, this turbidity measurement indicated 465 lbs of suspended materials. On October 17, twenty four bales of prairie hay totaling 1392 lbs. were dumped into the pond. This quantity was equal to three times the weight of suspended clay. Due to the lower temperature of the water because of the season and the form in which the vegetation had been introduced, it was recognized that no rapid changes in the properties of the water were to be expected.

Table 14 contains the data obtained over a four month period. In view of the slower rate of decomposition under the conditions mentioned above, free CO_2 content remained low. Similarly, pH values revealed little increase in hydrogen-ion concentration as fluctuations ranged from 7.8 to 7.6. Little effect was noted in the dissolved oxygen. A minimum of 5.8 ppm. was recorded on October 20, three days after the hay had been added but it was doubtful if this value was effected by

TABLE 14

Physico-chemical Data Showing the Effects of Organic Matter Added to Pond No. 6

Date		Air Temp. deg.C	Water Temp. deg.C	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M.O. ppm.	Turbidity ppm.
Oct.	10	25.6	20.4	7.8	3.4	6.0	0.0	92	125
	16	18.4	14.8	7.8	3.6	6.4	0.0	88	132
	18**	17.4	17.2	7.7	4.6	6.2	0.0	96	138
	20	23.4	21.8	7.7	6.6	5.8	0.0	98	132
	26*	19.8	15.4	7.8	4.2	6.4	0.0	96	144
Nov.	1	8.0	9.8	7.6	6.4	6.1	0.0	86	128
	3	9.4	10.8	7.6	4.4	8.4	0.0	92	118
	7	27.2	14.0	7.6	5.2	6.4	0.0	88	104
	10	26.8	15.8	7.7	6.0	6.5	0.0	84	95
	14	25.2	15.0	7.7	6.2	7.2	0.0	82	96
	18	14.4	8.2	7.8	5.6	7.9	0.0	86	98
	22	18.2	10.6	7.6	5.2	8.2	0.0	86	90
	27	24.6	12.2	7.6	5.6	8.0	0.0	94	86
Dec.	5	21.6	9.0	7.6	4.0	7.2	0.0	102	72
	10	18.0	8.4	7.8	3.6	8.4	0.0	98	64
Jan.	2*	8.2	7.2	7.8	4.0	8.2	0.0	100	118
	10	10.4	4.6	7.6	6.8	8.8	0.0	92	42
	29	7.6	6.2	7.6	7.4	9.2	0.0	118	36

* Rains occurred within previous 24 hours

** Vegetation added (Oct. 17)

the baled hay. Carbonates were absent and bicarbonates increased only slightly. Turbidity values were gradually reduced and, on January 29, three and one-half months after application of the hay, a reading of 36 ppm. was recorded.

While there was evidence that the addition of baled prairie hay influenced the properties of the water in this pond, it is apparent that the lower temperature of the water and the presence of hay, in the compact baled form, retarded its effect.

Oxidizable Organic Matter As Measured By B. O. D. Tests

Addition of organic matter to an impoundment increases the demand for oxygen because of greater microbial activity. It was thought desirable to use biochemical oxygen demand analyses in an attempt to determine the amount of organic matter available to microbial agents in an impoundment and to compare this with the existing turbidity.

Biochemical oxygen demand tests were made on samples of water from these and four additional impoundments to evaluate the changes that the vegetation produced. Table 15 presents data showing B. O. D. and certain other properties. These tests were made on January 27, 1950, when the temperature of the waters averaged 4.2 degrees C.

The B. O. D. data show a low range. Smith Pond and Rutter Settling Pond were definitely muddy and the B. O. D. in these waters was low. Ponds No. 5 and No. 6 still possessed some suspended clay while all others were clear or gave a low turbidity reading to dissolved or suspended organic matter.

TABLE 15

Analyses of Various Waters Showing B. O. D. and Some Other Properties

Impoundment	pH	Free CO_2 ppm.	Dissolved Oxygen ppm.	Alkalinity ph-th ppm.	Alkalinity M. O. ppm.	B.O.D. ppm.	Turbidity ppm.
Smith Pond	8.4	0.0	10.6	2.0	52	0.3	670
Rutter Settling Pond	7.8	3.2	9.2	0.0	70	0.3	240
Pond #5	8.0	2.0	10.8	0.0	160	0.7	78
Pond #6	7.6	5.8	9.7	0.0	102	3.3	45
Pond #3	7.6	6.4	9.2	0.0	126	O_2 incr.	34
Pond #1	7.9	3.2	10.8	0.0	138	O_2 incr.	30
Pond #4	7.7	7.8	9.0	0.0	245	1.7	30
Rutter Fish Pond	7.8	6.0	9.9	0.0	162	0.3	clear
Wilson Pond	8.4	0.0	11.5	1.5	118	2.8	clear
Yost Lake	7.8	2.0	10.4	0.0	106	1.5	clear
Pond #2	7.8	3.2	10.1	0.0	139	0.6	clear

Pond. No. 6 showed the highest B. O. D. requirements of 3.3 ppm. Since some baled hay, which had been added to this pond, was still present and undergoing slow disintegration, it is possible that this condition was reflected in the data. Wilson Pond, with next highest B. O. D. of 2.8 ppm. was a clear, productive body of water. Pond No. 1, which had maintained a rather high turbidity after sorghum had been applied, presented an oxygen increase rather than a deficit. This furnished evidence that there was considerable phytoplankton present. Pond No. 3 gave similar results. It was noted also that Rutter Settling Pond which was quite devoid of aquatic plants gave the same B. O. D. value of 0.3 ppm. as Rutter Fish Pond which was clear and maintained a copious growth of vegetation.

On the basis of this data, it appears that there is little correlation between the B. O. D. of the water and the turbidity. While the amount of organic matter present was certainly augmented by the vegetation added to these ponds its effect does not seem to be definitely indicated in B. O. D. analyses.

Oxidizable Organic Matter as Measured by O. C. Tests

Oxygen consumed determinations were used to determine if a relationship existed between dissolved organic matter and clear waters. On February 20, 1950, water samples were collected and determinations were made in the laboratory.

The amount of oxygen consumed in ppm. by oxidation with $KMnO_4$, together with respective turbidity measurements, are shown (Table 16). Since ferrous compounds in the waters were

TABLE 16

Oxygen Consumed Analyses and Turbidity of Various Waters

Water Sample	Oxygen Consumed ppm.	Turbidity ppm.
Berry Pond A	27	clear
Carberry Pond	12	clear
Keyes Pond	11	clear
Rutter Fish Pond	18	clear
Wilson Pond	28	clear
Yost Lake	17	clear
Pond #2	16	clear
Pond #3	20	32
Pond #4	29	42
Berry Pond B	12	42
Pond #1	12	56
Glass Pond	8.8	60
Boomer Lake	11	64
Cross Pond	9.6	84
Pond #6	9.8	86
Pond #5	11	96
Creech Pond	9.2	170
Denney Pond	8.2	170
Swenk Pond	5.6	186
Rutter Settling Pond	10	210
Smith Pond	5.6	520

low, these values roughly indicated the amount of dissolved organic matter present. The oxygen consumed values ranged from 5.6 ppm. in Smith Pond, possessing a turbidity of 520 ppm. to 29 ppm. in Pond No. 4 which had a turbidity reading of 42 ppm. attributed to dissolved colored materials in the water. Pond No. 4 had been given a moderately heavy treatment of vegetation and at the time these samples were taken, retained no apparent suspended clay although the water was slightly colored from dissolved organic matter. Swank Pond showed oxygen consumed values of 6.0 ppm. with a turbidity reading of 210 ppm. Smith Pond, Creech Pond, Denney Pond, Pond No. 5, Pond No. 6, and Rutter Settling Pond showed comparatively low oxygen consumed values and possessed turbid waters. On the other hand, Yost Lake, Pond No. 4, Wilson Pond, Rutter Fish Pond, and Berry Pond A showed comparatively high oxygen consumed values denoting a higher dissolved organic matter content. The ponds that had considerable dissolved organic matter contained no suspended clay.

Pond No. 1 gave an oxygen consumed value of 12 ppm.; the turbidity reading of this water was 56 ppm. Pond No. 2 showed an oxygen consumed value of 16 ppm. whereas this water was clear. Sorghum fodder had been added to these two ponds on August 5 and September 26 respectively. Five months had elapsed between the addition of vegetation and the time of testing and during this time additional silt had been introduced by run-off water. The water had a turbidity of 56 ppm. due to colloidal clay at the time of testing, yet the test indicated a fairly low content of dissolved organic matter. It would seem that much of the organic matter had been used in aggregation and subsequently precipitated.

Oxygen consumed values of Berry Pond B were 12 ppm. The owner had experienced difficulty in maintaining clarity of this water and it seemed that there was not a sufficient quantity of dissolved organic matter to perpetuate good transparency.

While Pond No. 6, which had been treated with baled prairie hay, had experienced a drop in turbidity during the period of testing, it had muddied again as a result of rains and on February 20 had a turbidity of 86 ppm. The low oxygen consumed value indicated that dissolved organic matter was limited by low temperatures.

The values obtained from Yost Lake showed excellent correlations. Oxygen consumed in the sample was 17 ppm. and the water was clear. This water, which had earlier been treated with hay and sorghum, gave evidence that biological activity had increased and that clear water was maintained. Wilson Pond with 28 ppm. of oxygen consumed also had clear water.

It is difficult to establish specific cause and effect relationships under uncontrolled conditions as shown by these data, yet a trend appears to exist between sizable amounts of oxidizable organic matter in the water and low turbidity due to suspended clay. In all measurements, samples taken from impoundments presenting muddy appearance revealed lower oxygen consumed values. Regardless of whether organic matter has been added or whether conditions within an impoundment are conducive to maintaining organic matter content in the water, the end result seems to be manifested in representing a condition whereby colloidal clay is precipitated when organic matter is present.

General Vegetation Requirements for Reducing Turbidities Due to Clay in Impounded Waters

It has been demonstrated, by the laboratory and field experiments presented, that vegetation added to the water will reduce turbidities due to clay. A quantity of green vegetation equal to three times the weight of suspended clay cleared the waters of impoundments without critically depleting the dissolved oxygen.

A table is presented (Table 17) showing the quantity of vegetation required to clear an acre-foot of impounded water for various turbidities. These are computed from the suspended clay present as measured in parts per million turbidity. The following method was used in making the calculations for the table. An acre-foot of water weighs about 2.7 million pounds by using the specific weight of water as a standard, 100 ppm. sustended clay would weigh about 270 lbs. or 100 x 2.7. The weight for the other turbidity measurements were computed in like manner. The weight of green vegetation listed was determined by multiplying the weight of suspended clay by 3 at intervals of 25 ppm. turbidity. Vegetation requirements of dry plant material are one-third less than for green vegetation. These differences were based on water lost

TABLE 17

General Vegetation Requirements for Reducing Turbidities Due to Clay in Impounded Waters

Turbidity ppm.	Wt. of suspended clay in lbs. per acre-ft.	Quantity of green vegetation required in lbs. per acre-ft.	Quantity of dry vegetation required in lbs. per acre-ft.
25	67.5	202.5	135.0
50	135.0	405.0	270.0
75	202.5	607.5	405.0
100	270.0	810.0	540.0
125	337.5	1012.5	675.0
150	405.0	1215.0	810.0
175	472.5	1417.5	945.0
200	536.0	1608.0	1072.0

from green vegetation during the drying process. Requirements for turbidities higher than 200 ppm. and for different volumes of water can be determined by similar computation.

DISCUSSION

The study of turbid waters has theoretical as well as practical interest because of the complexities encountered, and because of the effects that suspended soil have on water. The chief contributing factor to permanently turbid water lies in the physical nature of the soil of the watershed. Soils in certain regions possess considerable quantities of dispersed colloidal clay, which, when carried into the reservoir by run-off water, produces a permanent turbidity.

Measures for clearing impoundments permanently must be both corrective and preventive. The best procedure is to prevent silt from reaching the impoundment but it is practically impossible to eliminate siltation even from a well covered watershed. The addition of silt can be reduced by providing good vegetative cover on the entire watershed, by terracing the land, and by constructing gully plugs and settling basins. Turfing the banks at the shoreline will minimize the effects of bank-wash. The puddling effects of farm stock can be prevented by fencing the pond and watering the stock at a tank below the dam. Turbulence caused by bottom-dwelling organisms does not produce the permanently turbid condition of impoundments in Oklahoma as is evidenced by the clear water reservoirs which contain many of these forms.

One of the important properties of clay colloids of turbid waters is the fact that the particles are negatively charged. When a direct current of electricity is passed through a clay suspension; these particles move toward the cathode, and upon reaching it, are neutralized. Similarly, when any compound that releases sufficient positive ions is present in a suspension, neutralization and aggregation occur.

Many ionizable substances serve as coagulants of dispersed clay. Calcium, copper, aluminum, and iron compounds are commonly used to precipitate suspended matter in water purification plants. Aluminum and iron compounds are efficient coagulants but due to the nature of the floc formed as a result of hydrolysis, the small organisms of food chains are also carried to the bottom and are usually killed, thus retarding food production. Due to the toxicity of the copper and aluminum ions to aquatic organisms, it is impractical to use these compounds if aquatic productivity is desired. Calcium sulfate is sometimes used where it is desired to clear water and yet maintain a biota in an impoundment. As previously mentioned, the precipitate produced by the calcium ions is not stable and the bond can be broken by turbulence more easily than that formed by the smaller, less hydrated hydrogen ions. These commercial coagulants clear water only temporarily and impoundments become turbid again following each run-off or wind storm. It is apparent from the data presented that introduced organic matter provides a more practical, efficient, and lasting coagulant, and one which greatly stimulates the production of aquatic organisms.

Organic matter plays an extremely important and complex part in aggregating and precipitating suspended colloidal clay in water. Hydrogen ions, resulting from dissolution and decomposition of organic matter in the water, serve as the primary flocculating agent. Applications of organic matter, in the form of vegetation, results in precipitation of suspended clay in impoundments.

It has been demonstrated that the predetermined quantity of vegetation, necessary for clearing an impoundment, can be calculated on the basis of the suspended clay in the water. Caution must be exercised in applying large quantities of organic matter or the dissolved oxygen will be removed from the water. When a quantity of green vegetation, equivalent to three times the weight of the suspended clay, was used to treat impoundments, it proved sufficient to clear the water without serious oxygen depletion. Since a reduction in the dissolved oxygen is an important factor, it appears that double the quantity of green vegetation as calculated suspended clay would be practical in reducing the turbidity and, if necessary, a second application can be used later. Cognizance has been taken of the fact that the specific gravity of clay suspensions is greater than one and that it varies with the quantity of clay in suspension. A smaller weight of clay has been recorded than was actually present in each suspension since a specific gravity of one was used in the calculations. The relative weights of vegetation would have been adjusted in like manner if the specific gravity of clay had been used. Due to the ease of computation which this method afforded, it seemed advisable to use weight determinations that were based on a constant specific gravity value.

The most advantageous time to treat water with vegetation, in Oklahoma, seems to be during mid-summer. Green vegetation is usually available and the impoundment is not ordinarily subjected to run-off water. The summer growing season is more efficacious for the establishment of higher aquatic plants that aid in prepetuating precipitation of clays. High temperatures, pervailing in the summer months, accelerate the rate of decomposition of the organic material and thus effect more rapid clearing.

It is probable that the kind of vegetation and its condition when added to the water constitute an important variable in the aggregation of silt. Alfalfa hay, which has a high nitrogen content, reacted more rapidly than prairie hay or wheat straw. It seems that additional study of this problem might reveal new information concerning the effectiveness of kinds of vegetation and their conditions when used.

Oxygen consumed analyses seem to show that the quantity of oxidizable organic matter is a factor in regulating the turbidity of water. There is a definite relationship between these two properties. Further investigations should concern dissolved organic matter content as well as specific organic compounds in the waters. Conditions within a body of water are by no means constant; the physical, chemical, and biological properties are continuously changing. Some physical and chemical properties, at least, vary with the quantity of plant materials, with plant activity, and with the inflowing and outflowing of water. It is essential that water exchange be minimized to retain the fertility which produces the transparency.

Reservoirs obtain their organic matter from two sources, viz., that carried into them from the watershed and that synthesized within the basin. Organic matter becomes nutrients for aquatic organisms which grow, metabolize, reproduce, die, decompose, and liberate CO_2. Regardless of the source, organic matter, when present in proper amount, not only precipitates the suspended clay but also contributes to the fertility of the water thus enabling aquatic organisms to establish a cycle of organic matter synthesis and decomposition that keeps the impoundment clear.

Synthesis of organic matter in water basins is accomplished largely by chlorophyll-bearing organisms. In the presence of light, these plants produce numerous organic substances from carbon dioxide and the minerals in solution. Animals feed upon plant materials or upon smaller animals. Finally, both the plant and animal residues are decomposed by bacteria and the complex substances are again reduced to elements and simple compounds. Low turbidity, to allow light penetration, is thus essential for the synthesis of organic matter within a body of water.

No attempt has been made by the writer to determine the effect of the separate components of organic matter on aggregation, although many of these simplified or partly decomposed compounds must be coagulants. Waksman (1941) stated that bacteria do not destroy plant and animal residues in one operation but tend to decompose certain organic complexes first, and others later. The first substances destroyed are likely to be some of the carbohydrates and proteins; the lignins, other proteins, some fats and certain other constituents such as the chitins are the last to be attached. The nature and abundance of the organic matter synthesized and decomposed in water are controlled by the chemical content of it and by the season of the year.

Results by many investigators have shown the effectiveness of organic matter in producing flocculated permeable soils and the importance of the hydrogen ion in soil aggregation, but little attention has been given to this process in colloidal clay suspensions. Ellis (1937) mentioned that in the laboratory, erosion silt can be precipitated from muddy water both quickly and effectively by changing the charge of the particles in suspension or by altering the pH value of the water. Irwin (1945) attributes the precipitating effect of organic matter to the liberated hydrogen ions which neutralize the negative charges on the suspended clay particles. Dr. Minna E. Jewell (personal correspondence) reported that she has never seen a muddy acid lake and that acidifying muddy water would precipitate the clay without the use of vegetation. It seems likely that no acid waters, swamp waters, or waters with a high organic matter content remain turbid from suspended silts or clays after turbulence ceases.

It is evident from this investigation that organic matter clarifies turbid water primarily through the action of liberated hydrogen ions for the following reasons. (1) Acid waters have been recorded as clearing readily following floods. (2) Hydrogen ions, introduced by means of acids, were quite effective in neutralizing and flocculating the negatively charged colloidal clay in a suspension. (3) The hydrogen ion is the prevailing and dominant positive ion resulting from the decomposition of organic matter. It is possible that subsidiary factors may aid in precipitation. A reaction may take place between some of the intermediate decomposition products and the clay colloid. The thigmotactic tendency of certain bacteria may cause some precipitation of the clay colloids due to adsorption which forms larger and more compact structures.

There were wide variations in the hydrogen-ion concentration of the waters analyzed. These are due to differences in the quantity of inorganic substances, to varying amounts and kinds of decomposable materials, or to photosynthetic activities of the chlorphyll-bearing organisms. The analyses for CO_2 content offer some interesting suggestions in attempting an interpretation of these variations in pH since carbon dioxide content is a factor that affects this variation. The data show that a rough correlation exists between the occurrence of CO_2, whether free or as bicarbonates, and the precipitation of colloidal clay. The bicarbonate content in the miscellaneous reservoirs analyzed was often higher in clear water than in turbid water. The tendency for bicarbonates to increase was associated with the increase in free

CO_2 in the treated ponds. Since it has been established that in the absence of free CO_2, aquatic plants can break down bicarbonates and obtain CO_2 for photosynthesis, it is apparent that bicarbonates provide a reserve of utilizable CO_2. It would thus seem that bicarbonates might also constitute a reserve supply of hydrogen ions which when released could aid in precipitating colloidal clay.

Aquatic plants once established in impoundments aid in maintaining clear water. Carbon dioxide liberated into the water during respiration would increase available hydrogen ions. Certain products secreted by the plants may contribute to silt precipitation. When muddy water has inundated terrestrial plants, flocculation and precipitation rapidly occur, regardless of whether or not the plants have been killed by flooding.

Colloidal clay is precipitated in some pond waters when the pH values are sufficiently high to give an alkaline reaction. This seems to contradict the conclusion that hydrogen ions are the chief neutralizing agents. This objection becomes trivial, however, when chemical behaviors peculiar to the situation are considered. (1) Bicarbonates, even when reduced slowly in water, will release hydrogen ions. (2) Carbon dioxide, although in small quantities, will increase ionization of water and make available hydrogen ions. (3) Dissolved organic matter will allow some molecules to be present throughout the water, even in the hydrated layer of the clay micelle. As the molecules decompose, hydrogen ions are released. It should be noted that hydrogen ions are released slowly in each of the above cases. A negatively charged body would quickly attract these positive ions, because of their scarcity and proximity, and they would become adsorbed to a negatively charged clay particle before they could influence the pH value of the water. The closer the proximity of these released hydrogen ions to the negative charges, the greater would be the percentage of hydrogen ions adsorbed. The clay particles therefore act as a buffer and prevent pH change. However, when hydrogen ions are produced at a more rapid rate than can be utilized by the clay particles the pH value is decreased. The same number of positive ions would be required to saturate each clay particle whether produced slowly or rapidly. It becomes evident, then, that clarification of water is due to a continuous release of hydrogen ions and not necessarily to a low pH value.

SUMMARY

1. Properties of clay turbidity and methods of precipitating colloidal clay, as applied to impounded waters of central Oklahoma, have been investigated. An important and controlling factor in the precipitation process is the cation exchange capacity of the suspended clay.
2. Literature regarding the nature of clay turbidity and methods of aggregation was reviewed. Methods of flocculation of dispersed clay in soils by organic materials was of particular concern.
3. The most important factor which contributes to permanent turbidity is the quantity of dispersed colloidal clay in the drainage area. Watershed control can aid in minimizing siltation, while other factors, such as, turbulence and mineral content of water show little or no effect in maintaining the stable turbid condition of the water.
4. Physico-chemical analyses of several impounded waters revealed no correlation between the turbid condition of the water and other properties, with the possible exception of bicarbonates.
5. Dispersed clay colloid particles are negatively charged and any compound that releases sufficient positive ions will cause precipitation. Hydrogen ions are the most effective.
6. Transparency and fertility were increased when vegetation was added to muddy waters. Various types of plant materials were effective in precipitating suspended clay.

7. Electrophoresis experiments show that some colloidal clay particles are apparently more highly dispersed than others; therefore, such suspensions will require more of the flocculating agent to clear.
8. Seven impoundments were studied from June, 1949 through January, 1950. Physical and chemical properties were recorded before and after treatment with vegetation. Vegetation in the water caused an increase in free CO_2 and bicarbonate content, and a decrease in the dissolved oxygen, pH, and turbidity.
9. Mid-summer is an advantageous time to treat impounded water with vegetation.
10. The quantities of vegetation, necessary to clear an acre-foot of turbid water, can be based upon the weight of suspended clay as calculated from turbidity readings.
11. The turbidity of water seems to be related to the quantity of oxidizable organic matter present. Waters with a high content of oxidizable organic matter have a low clay turbidity.
12. Aquatic plants, when once established in impoundments, aid in maintaining clear and fertile water by their metabolic and decomposition products.
13. Colloidal clay particles act as a buffer in water by binding available hydrogen ions to them. An excess of hydrogen ions is reflected in a lowering of pH. It is possible that bicarbonates provide a reserve of hydrogen ions that can be used to neutralize clay particles.

14. Any process, that liberates hydrogen ions in water, tends to eliminate turbidity due to colloidal clay.

15. Water clarification processes in general, and some factors involved in particular, have been summarized and some postulations for additional research have been made.

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