DESIGN OF A LIME-SODA WATER SOFTENING PLANT FOR MICHIGAN STATE COLLEGE

Thesis for the Degree of M. S.

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Marshall Hines

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This is to certify that the

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Design of a Lime-Soda Water Softening Plant

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C L Allen
Major professor

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DESIGN OF A LIME-SODA WATER SOFTENING PLANT FOR MICHIGAN STATE COLLEGE

By

MARSHALL HINES

A THESIS

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

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HISTORICAL SKETCH

Since the beginning of time man has realized the importance of a safe water supply. A knowledge of the development of waterworks is of importance in emphasizing the changes in practice and the relatively recent development of present-day methods.

No doubt the earliest method of artificially obtaining a water-supply was by digging wells. At first these were shallow cavities scooped out in low and moist places. As necessity arose and man's tools improved, wells were made deeper to increase the supply. Joseph'S well at Cairo is indeed a great engineering achievement. It is excavated in solid rock to a depth of 297 feet and consists of two lifts; one is 18 by 24 feet and 165 feet deep; the other is 9 by 15 feet and is 130 feet deep.[1] The deepest wells were dug by the Chinese. Depths of over 1500 feet were reached.

The greatest water supply undertakings of the ancients were primarily for irrigation. The most remarkable was Lake Moeris, in Egypt, constructed about 2000 B.C. It was of sufficient size to regulate the annual inundation of the Nile, and supply the deficiency of water during low flow. This, with other large reservoirs, enabled the Nile valley to support 20,000,000 people. Only one-fourth that many people live there today.[2] In ancient times the Assyrians built similar

reservoirs for controlling the flood waters of the Tigris and Euphrates. One of the distributing canals, the Nahrawan Canal, was some four hundred miles long and from two hundred to four hundred feet wide, with depth great enough for navigation of vessels of the time.

In India, the English found at the time of their occupation about 50,000 reservoirs for irrigation purposes, the construction of which had involved the building of 30,000 miles of earth embankment.[1]

Wyckoff states that "Evidences exist in New Mexico and Arizona that in pre historic times a race now extinct had extensive irrigation works and cultivated large areas."[2]

Drinking water for ancient Carthage was supplied from a spring in the Zaghoun Mountains some 65 miles to the south. The channel which conducted the water to the city was ten inches square in section. It contoured the hillsides for many miles, was underground in places, and was carried on arches over low sections near the coast. The water was stored in great cisterns, eighteen in number, each about one hundred feet long, twenty feet wide and twenty feet deep. They were originally covered with earth. They are in a very good state of preservation to this day.

The Romans were perhaps the greatest water-supply engineers of the past. The waterworks constructed by the Romans are the best known of the ancients. Previous to about 312 B.C. Rome obtained its water from the Tiber and from springs and wells in the immediate vicinity. As the population increased the supply became polluted and inadequate, so water had to be obtained from springs some distance away. It was necessary to build long conduits and aqueducts to convey the water from these new sources. These conduits often led through hills in tunnels and were carried over valleys on long lines of arches. The principle of the inverted siphon was well understood, and one of the siphons built by the Romans in Lyons, France, was nine miles long, constructed of twelve and eighteen inch lead pipe, and working under a head of about two hundred feet. Iron pipes were unknown; the only materials used were stone, lead, and pottery.

The first aqueduct built to supply Rome was called the Aqua Appia, constructed in 312 B.C. It was eleven miles in length. The Claudia aqueduct built in 50 A.D. is the most interesting because of its long line of imposing arches. The cost of construction of this 45 mile aqueduct was equivalent to about $12,700,000. In all, nineteen aqueducts were built between 321 B.C. and 305 A.D. The aggregate length waw 381 miles and the length of arches was 50 miles. In cross-section the aqueducts of Rome varied from 3 to 8 feet in height and 2½ to 5 feet in width. The interior was finished with great care to secure imperviousness but constant repair was necessary. One half of the Roman aqueduct at Metz, Germany is in use to this day.

Much of the detail concerning the history of the water supply of Rome is presented in " Frontinus, and the Water Supply of Rome," translated by Clemens Herschel.[3] Frentinus was water commissioner of Rome about 100 A.D. His records deal not only with the history of Rome's water supply, but also with the intimacies of the Romans and his difficulties with people tapping the aqueducts illegally. It is believed that Frontinus was responsible for the construction of the famous Roman baths at Bath, England in the first century A.D.[4] He was govenor of England before being appointed water cammissioner of Rome.

The various aqueducts serving Rome carried water of different degrees of purity. The least clear and most loaded with sand was used for public baths and street watering; the clearer waters were used for tanks, fountains, and washing troughs; while the best water was used for drinking purposes.[5] The water from the aqueducts first passed into large cisterns. From these it was distributed through lead pipes to other cisterns, to the fountains, baths, and various public buildings, and to private consumers. Only the rich could afford private service; most of the people were obliged to carry water from public fountains.

The quantity of water supplied to Rome is not known exactly. Estimates range as high as 400,000,000 gallons per day. No doubt the many aqueducts could carry this amount, but generally not all the aqueducts were in capacity use at one time. A more conservative estimate and one which is more generally accepted, is 50,000,000 gallons per day as estimated by Herschel. This is a per capita supply of 50 gallons for the 1,000,000 inhabitants of Rome.

The ancients had certain conceptions concerning the quality of water supplies. As was mentioned above the defferent qualities of water delivered to Rome were used for different purposes. In some cases water was passed thru artificial reservoirs to purify it by sedimentation. Four hundred years befor the beginning of the Christian era Hippocrates advised boiling and filtering a polluted water before drinking it.[2] During the Middle Ages it was recognized that water distributed in lead pipes became poisonous.

In the Middle Ages the great aqueducts of Rome were either destroyed or fell into disuse. Public water supply in these times an any scale were practically nil except for the works of the Moors in Spain.

Until 1183 Paris obtained its entire supply of water from the River Seine. Up to 1550 the Paris supply was only one quart per capita. This increased to only 2½ quarts as late as the end of the seventeenth century. Such meager quantities attest to the sanitary conditions of the day.

London was first supplied with small amounts of spring water by lead pipes and masonry conduits. In 1582 the first pump was installed on London Bridge to take water from the Thames River and deliver it to the city through lead pipes. The pump was operated by the river current. In Germany water-works were constructed as early as 1412, and pumps were installed at Hanover in 1527.

By the invention of the steam engine in the 18th century machinery of adequate capacity and power was made possible. It might be said that the growth of water-works plants dates from this time, however, slow progress was made until the latter part of the nineteenth century. Cast iron pipe began to replace wood and lead in the year 1800.

Water treatment got its start in Europe. The water supplied to European cities was of better quality than that supplied in the United States, but the quantities were much smaller. This condition changed about 1900 with the rapid growth of plants in this country. American cities still are supplied much larger amounts than cities of Europe.

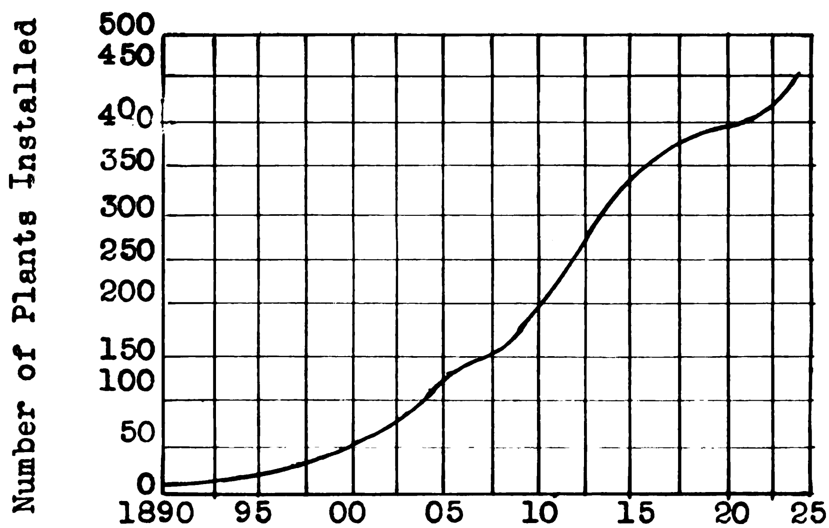
The principle of supplying each house with water started on 1619 in London. In that year the New River Company was incorporated. This company still supplies a part of London. At first it was believed impracticable to furnish a continuous supply to homes. The water was turned on for a few hours each day at which time the consumers had to draw their supply for the day. As late as 1891, 35 per cent of the London supply was still on the intermittent system.

The first filtration of water on a large scale was by the Chelsea Company in London. This was in 1829. This method of water purification spread rapidly. It was the slow type filter.

The first works in America were those that supplied Boston. They were built in 1652 and served to bring water by gravity from springs. Machinery was first used at Bethlehem, Pa. in 1754. The steam engine was first used at Philadelphia in 1800 and in New York in 1804.

The great advances of water plant design in the United States have taken place since 1850. The improvements that made possible these great advances include the perfection of cast iron pipe, improved pumps, particularly the perfection of smaller sizes, the adaption of direct pumping systems for small towns, and the development of ground and artesian water-supplies.

The first application of alum as a coagulant was at Sumerville, N.J., in 1884. Alpheus Hyatt patented the process. Perhaps the greatest advance since the construction of sand filters in London was that of rapid sand filtration. The first rapid sand filter was completed in 1897 at Louisville, Ky. by Hermany and Fuller. The principles they established have served as the basis for the design of mechanical filters that have since been constructed in the U.S. The rapid sand filter has almost completely replaced the slow sand filter. The graph below shows the fast growth in the number of rapid sand filter plants in the United States.



Number of water-filtration plants installed by years.
Jour. A.W.W.A., Vol. 14, p. 123, 1924.

Water as a disease germ carrying medium has long been recognized. A great many plants now sterilze the water as a safeguard against a water-borne epidemic. Chlorine is used almost universally for this purpose. It is used either in the gas state or as hypochlorite of lime. The first application of chlorine to a public water supply for the purpose killing bacteria was in Belguim in 1902. Sterilization usually requires complicated mechanisms which need the attention of skilled operators to avoid breakdown and incorrect dosage. In 1916 an attendant at the Milwaukee waterworks stopped the chlorinator for eight hours. It so happened that the water was badly polluted that day, and there resulted 50,000 to 60,000 cases of enteritis, 400 to 500 cases of typhoid, and 40 to 50 deaths.[7]

The existance of great concentrations of population in present day cities and the many activities pursued therin would be impossible without the availability of water. A city with a resticted water supply is a city of resticted growth.

HISTORY AND ECONOMICS OF WATER SOFTENING

The art of water softening with lime dates back to 1776 when Cavendish discovered that the addition of lime to natural water caused calcium and magnesium carbonates to precipitate out. In 1800 Thomas Henry of England proposed using lime to soften water on a plant scale. It was 1841 before water softening on a large scale was developed by Clark in Scotland. About 1865 Porter of London used soda ash for removing iron-carbonate hardness. For years this lime-soda process was called the Clark-Porter process. The increasing number of industrial plants employing steam made the demand for soft water great, and during the last half of the 19th century about fifty softening plants were constructed in England.

Before the turn of the century a number of plants were built to soften boiler and laundry water, but it was not until 1903 that the first municipal plant was constructed. This was at Oberlin, Ohio. In 1908 a large plant was built at Columbus, Ohio to soften 30 million gallons per day. This plant was later enlarged to treat 54 million gallons.

For a long time there were several distinct disadvantages of lime treatment. Difficulties arose in operating sand filters due to incrustation of the sand with calcium carbonate. Water mains, service pipes, and meters became clogged with deposits. At times there was excess causticity which made the water unpalatable. These difficulties were overcome with the development of the recarbonation process by Archbutt and Deely in England. Practically all plants are now equipped with recarbonation devices.

The chemistry of water softening is now well understood. Improvements in design and equipment for applying chemicals and removing sludge have greatly simplified operation; as a result, the trend has been toward softening. At the present time more than 350 municipal water softening plants are in operation in the United States using lime or lime-soda. Many more plants employ the zeolite method for softening.

The consumer normally judges the degree of hardness of a water by the amount of soap necessary to make a good lather. Hard water causes scale in boilers and pipes which is very objectionable. It is cheaper to soften all the water for a city at a central plant than to have small softening units in hundreds of homes. Softening units in the home make necessary extra plumbing. The units are not well cared for and results from them are seldom satisfactory. The nuisance to the home-owner is objectionable. Softened water costs more to the consumer, but the saving to him in plumbing and soap waste more than offset the increase in his water bill.

The softening of water with soap is not only expensive but is objectionable because of the curd formed when the soap combines with the hardness producing compounds. Curd adheres to clothes, combines with grease on dishes, produces deposits on basins and bathtubs, and irritates the skin. The cleansing action of soap is not realized until the soap has actually softened the water and then lathers. The extravagance of removing hardness with soap can be appreciated when it is realized that a pound of lime costing about half a cent will neutrilize as much hardness as 20 pounds of soap costing $3.00.

A number of investigations have been made to determine the amount of water softened per capita per day by soap by users of hard water. Some of the estimates are as follows;[7]

Foulk	0.9 gallons
Report of Special Committee For Madison, Wis.	1.7
City of St. Louis	1.0
Average	1.2 gallons

The amount of soap required to reduce the hardness of 1,000 gallons of water one part per million has been determined as being 0.2 of a pound (Foulk's formula); Pounds of soap consumed per 1,000 gallons = 2- 0.2H.

Based on these assumptions, the loss per family of five using water of varying degrees of hardness is shown in the following table:

Raw Water Hardness P.P.M.	Hardness Reduced to	Loss Lbs. Soap per Family of Five per yr.	Amount of Loss at 12¢ lb.
150	85	28.5	$ 3.40
200	85	50.0	6.00
250	85	72.5	8.70
300	85	94.0	11.30
350	85	116.0	13.90
400	85	138.0	16.55
450	85	160.0	19.20
500	85	182.0	21.85

H. W. Hudson of the University of Illinois[7] has made an interesting sur vey of the relation between water hardness and retail soap sales. Four cities were included in the survey; Superior, Wisconsin, Bloomington, Champaign-Urbana, and Chicago Heights, Illinois. The results are tabulated in the following tables:

Total Soap Sales

City	Annual Soap Sales pounds	Annual Soap Sales Dollars
Superior	1,530,314	$196,133
Bloomington	1,517,658	215,528
Champaign-Urbana	2,093,381	307,732
Chicago Heights	1,009,503	159,910

Per Capita Consumption For Different Hardness

	Hardness, p.p.m.	Per Capita Soap Consumption	Per Capita Cost of Soap
Superior	45	29.23 lbs	$3.75
Bloomington	70	32. 13	4.48
Champaign-Urbana	298	39.89	5.93
Chicago Heights	555	45.78	7.50

It is readily seen that for an increase in the hardness of the water supply, the soap consumption also increases. The saving of this large loss in soap to the consumer would more than offset the increased cost of softened water, not to mention the convenience of soft water.

The hardness of a water supply is proportional to its content of calcium and magnesium salts. The salts, in order of their relative average abundance in various water supplies are (1) bicarbonates, (2) sulfates, (3) chlorides and (4) nitrates. The calcium salts are about twice as abundant as the magnesium salts. The averages may vary considerably in different supplies. Iron and aluminum also are hardness producers, but are generally present in such very small quantities as to be insignificant in hardness determinations. For this reason they are neglected in connection with hardness and calcium and magnesium hardness only will be considered.

The hardness caused by the bicarbonates was formerly termed "temporary hardness" because it was thought to be removed entirely by boiling, but since only a variable amount is so removed the term "carbonate hardness" is now used. The hardness caused by sulfates and compounds other than the bicarbonates, formerly called "permanent hardness," is now called "non-carbonate hardness."

In the United States and the British Empire, the standard of hardness measurement is the calcium carbonate ($CaCO_3$) equivalent. Alkalinity is also expressed in terms of calcium carbonate.

The most accurate method for determining total hardness is by a gravimetric analysis of calcium and magnesium and calculating their $CaCO_3$ equivalents. Other methods used for hardness determinations are the soap method and soda-reagent method. Both are approximate; the latter being preferred to the standard soap test.

Carbonate hardness is found by calculation from the results of the normal carbonate and bicarbonate alkalinity determinations which are express as $CaCO_3$ as indicated above. If the normal carbonate and bicarbonate alkalinity is greater than the total hardness, normal carbonates or bicarbonates of sodium and potassium are present. These compounds do not cause hardness, so the carbonate hardness would be equal to the total hardness. If the sum of the normal carbonate and bicarbonate alkalinities is equal to the total hardness, the carbonate hardness equals total hardness. If the sum of the normal carbonate and bicarbonate alkalinities is less than the total hardness, this sum is equal to the carbonate hardness and the difference between this sum and the total hardness is the non-carbonate hardness.

The degree of hardness in a water at which softening is desirable or necessary presents a question. Theroux, Eldridge, and Mallmann state that " water having less than 50 to 75 ppm of hardness is generally considered as sufficiently soft for the ordinary uses of a public water supply. Water having 75 to 150 p.p.m. of hardness may be considered as moderately hard but still not sufficiently hard to interfere seriously with its use for most purposes or to cause much public demand for water softening. Hardness above 150 p.p.m. is noticed by most persons and if the hardness is above 200 p.p.m. many homes will be provided with household softeners or cisterns."[8]

The lime-soda process is most commonly used in the larger municipal water softening plants. The following reactions occur when softening chemicals are added to hard water.

(1) $CaO + 2H_2CO_3 = Ca(HCO_3)_2 + H_2O$

(2) $Ca(HCO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$

(3) $Mg(HCO_3)_2 + Ca(OH)_2 = MgCO_3 + CaCO_3 + 2H_2O$

(4) $MgCO_3 + Ca(OH)_2 = Mg(OH)_2 + CaCO_2$

(5) $CO_2 + Ca(OH)_2 = CaCO_3 + H_2O$

(6) $CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$

(7) $MgSO_4 + Ca(OH)_2 = Mg(OH)_2 + CaSO_4$

$CaSO4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$

(8) $CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$

(9) $MgCl_2 + Ca(OH)_2 = Mg(OH)_2 + CaCl_2$

$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$

Reaction (1) expresses the conditions that occur in nature to cause hardness. The calcium carbonate in the limestone is dissolved by water containing dissolved carbon dioxide. Reaction (2) shows the formation of insoluble normal carbonate by the reaction between calcium bicarbonate and lime. The removal is not complete because calcium carbonate is soluble to about 15 p.p.m. The third and fourth equations show the removal of magnesium bicarbonate. Sufficient lime must be added to arrive at (4) or else soluble magnesium carbonate will be formed as in (3). Equation (5) is the reaction of lime with any carbon dioxide that may be present.

Noncarbonate hardness is removed with soda ash (Na_2CO_3) and lime as shown in (6-9). Calcium non-carbonate hardness requires soda ash only as is shown in (6) and (8). Magnesium non-carbonate hardness requires both lime and ~~soda~~ ash as is shown in (7) and (9).

The computations for the amounts of chemicals needed for the water in question are given on page . The factors in the table are derived by ratio of the molecular weights of the reacting substances and adjusted to the units indicated.

CHEMICALS REQUIRED

The following is an analysis of College water as reported by the National Aluminate Corporation.

	p.p.m.
Total Hardness (as $CaCO_3$)	315.0
Non-carbonate Hardness (as $CaCO_3$)	3.4
Ca Hardness (as $CaCO_3$)	206.0
Mg Hardness (as Mg)	26.6
Total Alk. M.O. (as Co_2)	311.6
Free CO_2 (as CO_2)	9.0
Chlorides (as NaCl)	8.6
Sulfates (as Na_2SO_4)	13.7
Silica (as SiO_2)	8.6

In determining the amount of chemicals required certain tests are used. The tests needed are (1) free carbon dioxide (CO_2), (2) alkalinity, (3) non-carbonate (incrustant) hardness and (4) magnesium.

The non-carbonate hardness is negligible, so no soda ash will be required and no provision will be made for its use. When present, non-carbonate hardness is reduced to 30-35 p.p.m.

The following table gives the factors by which to multiply values in the first column to obtain the required amounts of pure calcium hydroxide and calcium oxide.

Item determined, in p.p.m.	$Ca(OH)_2$ Lb. per 1,000 gal.	CaO Lb. per 1,000 gal.
CO_2 (as CO_2)	0.01403	0.01062
Bicarbonate Alk. (as $CaCO_3$)	0.006169	0.00467
Mg (as Mg)	0.02539	0.01922

Calculationa; (Using factors from table)

Free CO_2:

$9 \times 0.01062 = 0.098$ lb. CaO per 1,000 gal.

Alkalinity:

$311.6 \times 0.00467 = 1.454$ lb. CaO per 1,000 gal.

Magnesium:

$26.6 \times 0.01922 = \underline{0.51 \text{ lb. CaO per 1,000 gal.}}$

Total 2.06 lb.

Commercial lime is not pure CaO. The purity is usually about 90 per cent. The amount of chemical required is $\frac{2.06}{0.90} = 2.29$ lb. CaO per 1,000 gal. or 274 p.p.m. This is the amount of chemical theoretically required to reduce the hardness to zero. It is desired to reduce the hardness only to 70-80 p.p.m. or approximately one-fourth of the total hardness. This would necessitate the use of about 206 p.p.m. of CaO. In the operation of a softening plant it is customary to carry excess lime to the extent of 10 to 50 p.p.m. because the chemical reaction is not complete. Assuming 30 p.p.m. excess lime, the total amount needed is 236 p.p.m. This value is an estimation; only by actual operation of the plant can the exact amount be determined that will give the desired final product.

It is desired to have storage capacity for one month. Calcium oxide weighs 55 lb. per cu. ft.

Storage capacity =

$$\frac{236}{1,000,000} \times 3,000,000 \times 8,34, \frac{30}{55} = 3,220 \text{ cu. ft.}$$

A flocculating agent is generally required in the softening process.

Alum will be used here;

Alum required - (Assume 20 p.p.m. needed)
20 x 8.34 x 3 = 500.4 #/day

Alum weighs 65 #/cu. ft.

$$\frac{500 \times 30}{65} = 230 \text{ cu. ft.}$$

Lime bins:

$V = 11 \times 15 \times 9 + 1/3 \times 7 \times 11 \times 15$

$= 1485 + 385$

$V = 1840$ cu. ft. per bin

2 bins - 3740 cu. ft.

Alum bins:

$V = 4 \times 7.5 \times 9 + 1/3 \times 7 \times 4 \times 7.5$

$= 270 + 70$

$V = 340$ cu. ft. per bin

2 bins = 680 cu. ft.

POPULATION STUDY AND WATER DEMAND

An estimate of the number of people to be served is always an important consideration in the design of a waterworks. In the case of cities and towns an estimate can be arrived at by any one of several conventional methods and with favorable accuracy.

The author takes the liberty of reproducing a predicted enrollment graph for Michigan State College made by Professor F. R. Theroux in 1944. Professor Theroux's prediction is based on the following population statistics of the college for fall terms.

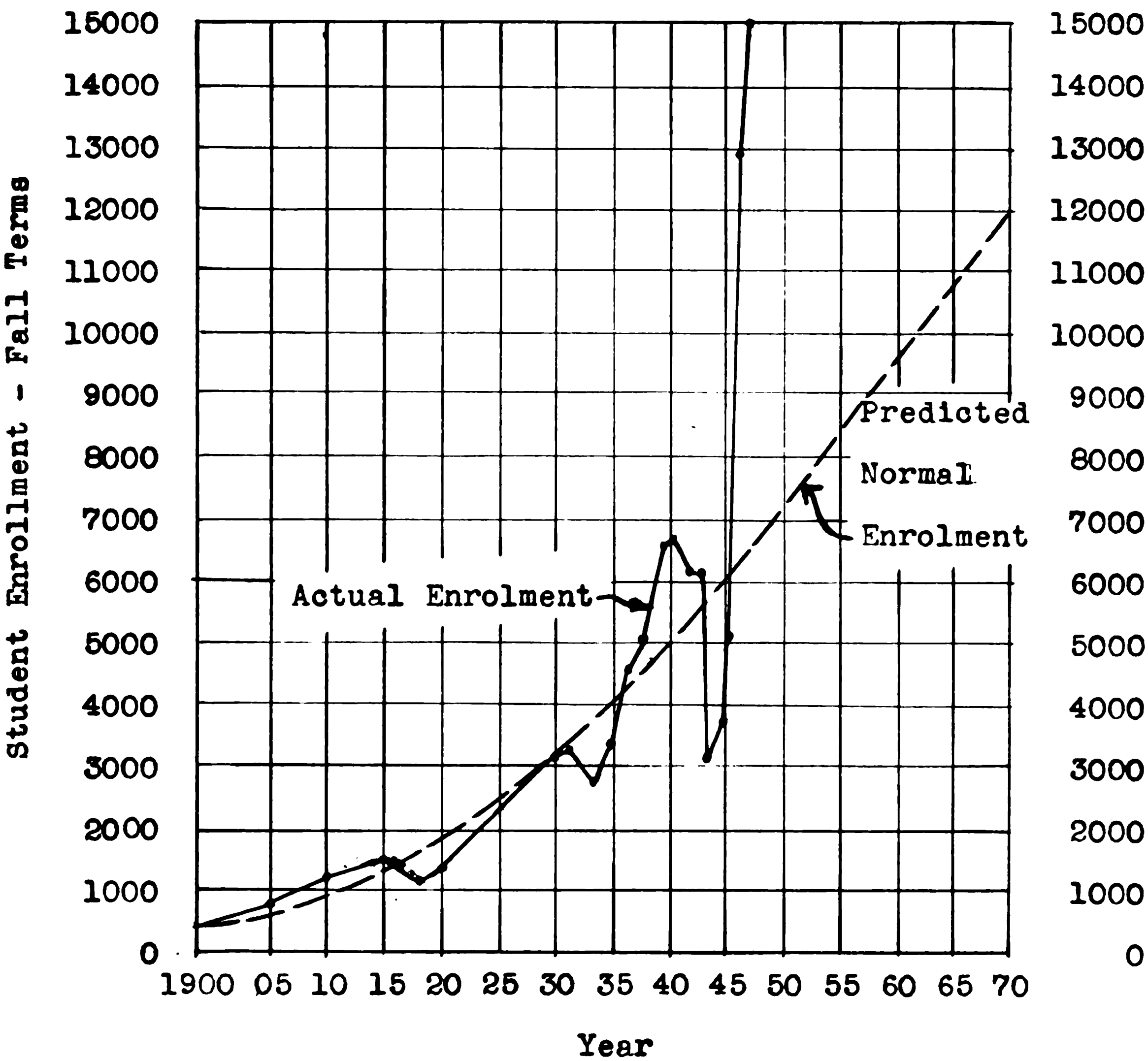
Year	Enrollment	Year	Enrollment
1900	463	1938	5835
1905	757	1939	6650
1910	1174	1940	6676
1915	1499	1941	6356
1920	1411	1942	6331
1925	2314	1943	3484
1930	3211	1944	3821
1935	4006	1945	5284
1936	4627	1946	12965
1937	5218	1947	14979

Registrar Linton estimates that the fall enrollment in 1948 will top 16,000. The question of when the maximum post-war enrollment peak will be reached and how

MICHIGAN STATE COLLEGE

STUDENT ENROLLMENT

Past Values And Predicted Future



Prof. Frank R. Theroux

great the enrollment will be is the big problem. The Council of State College Presidents in Michigan in a report to the Michigan Legislature[9] estimates the peak will be reached in 1950. The figure reached then will decline until 1960 when the normal growth will again assume a normal upward trend. This report does not estimate how many students will be enrolled in each college, but rather the total number in the state. At the time the report was published (January 22, 1947) the number of students enrolled in state colleges was in excess of 83,000. The estimate for 1950 is put at 200,000 to 210,000 students. This figure would indicate an enrollment at Michigan State approaching 20,000.

On July 13, 1946[10] the President of the United States appointed a Commission on Higher Education. The commission was made up of twenty-eight members including educators and civic leaders. Their voluminous six volume report to the President was completed in February 1948.

The President's commission, after evaluating the evidence available, reports that the American colleges and universities face an unprecedented era of expansion. Instead of declining or remaining stationary, the present record student body is expected to double. Thus, by 1960, the commission predicts, the college enrollment will reach 4,600,000. The present figure is 2,500,000 which is 1,000,000 greater than pre-war enrollments. Considerable of this increase will be on the junior college level in many cities, taking some of the load off the present colleges. The Commission recommends that the Federal Government provide direct aid to students and money for building.

All indications are that federal aid in education will be continued. The G.I. Bill is a starting point. The Congress has not acted on any proposals for grants to colleges so no definite statements can be made.

Mr Denison, assistant to President Hannah, told the author that the enrollment of the college will level of at about 15,000 and that figure will be maintained. This figure is the size enrollment the administration would like to maintain.

The type of population to be served is very subject to change. A few years ago only students in dormitories lived on campus with the exception of a few houses. At present there are some four thousand people in non-dormitory housing on campus. This number will very likely drop when the married student enrollment drops. The breakdown on the above figure is as follows (Fall 1947):

Permanent apartments	535
Faculty village (Quonsets and British prefabs)	172
Barracks apartments	2636
Trailers	928

Most of these housing units will be in use for several years. With the demand for advanced degrees on the increase, the number of married students may be expected to remain much higher than formerly, but of course considerably lower than at present. No figures on this particular aspect of the problem are available.

The total number of people residing on campus in January 1948 was 10,530. Two more dormitories, one for men and one for women, to be built in the near future are now in the planning stage. They are to be built with the intention of reducing the overcrowding in the other dormitories and to take the place of the temporay Quonset Dorm. Other proposed buildings include an animal industries building, bacteriology building, greenhouses, library, hotel, a Memorial Chapel and International Center, and others in the more distant future. Buildings now under construction and to be ready for occupancy during the 1948-1949 school year include the Natural Science Building, new Union Bldg, Physics Bldg, Gilchrest Hall for women and the Electrical Engineering Bldg.

The following table gives the water consumption for various types of buildings.

Water Consumption In Gallons Per Month

Building	October 1947
Field House	1,401,900
Dairy Barn	451,700

Campbell Hall	825,200
Union	2,172,200
Hospital	393,700
Chemistry	747,300
Abbott Hall	361,800
Berkey Hall	122,400

The buildings to be completed in the next year will add considerably to the water demand. In comparing these buildings with the same type of old building and the water demand of the old buildings, it is safe to say that the water demand will be in excess of 100,000 gallons per day.

Considerable water is used for irrigation on campus and in the prefab area. The latter will be of limited duration. A sizable portion of the campus lawn watering is river water pumped for condensing return steam at the Power Plant. This pipe line extends from the Power Plant to the Beaumont Tower-Library area and over to the Horticulture Gheenhouse. For greenhouse purposes this warm river water is preferred to the well water. The Landscape Dept. believes it more desirable to extend this line rather than to use the service water system. The season when the greatest amount of water is used for lawn sprinkling is in the summer when the enrollment is small and the water demand small.

The following table gives the water consumption statistics for the 1947-1948 school year. This year has been a record year for the amount of water pumped on campus.

Month	Daily Ave. gpm	Maximum gpm	Minimum gpm
Sept.	1,066,300	1,255,000	757,000
Oct.	1,176,700	1,235,900	1,091,100
Nov.	1,046,800	1,272,300	622,300
Dec.	896,100	1,202,900	324,100
Jan.	1,083,600	1,254,100	634,500
Feb.	1,085,100	1,236,000	820,000
March	983,700	1,264,100	594,700
April	1,073,500	1,236,700	703,300
May	1,220,400	2,562,400	833,100

The reason for the extreme high in May was the use of water for flushing hydrants and mains. The daily averages of the higher demand months is seen to be about 1,200,000 gallons. Basing this in terms of gallons per capita, the figures would be 120 gallons per capita for the 10,000 people living on campus and 80 gallons per capita for the 15,000 students.

The hourly rate of pumping is not recorded, however, the demand at night is very small. The rate of pumping remains constantly high from 7:00 A.M. to 8:00 P.M. The proposed reservoir, which is to be built in the near future, is to have a capacity of 1,250,000 gallons. This capacity is well large enough to supply the night demand and still retain sufficient reserve to make softening unnecessary at night. For this reason the conditioning plant will be designed to operate 16 hours a day.

For design purposes the quantity of water to be softened will be 150% of the present demand. This will take care of the immediate forseeable increases and peak load days.

The design quantity is as follows:

150% of present demand	1,800,000 gal.
Wash water-5½%	100.000
Waste with sludge - 5½%	100,000
Total	2,000,000, gal.

The rate of operation is 3,000,000 gallons per day based on operation for 16 hours a day. This gives the plant an ultimate capacity of 3,000,000 gallons per day.

EXISTING WATER SUPPLY FACILITIES

The tremendous increase in water demand at Michigan State College has made it mandatory to increase water supply facilities. The College has 12 wells, four of which were dug during the current building program. Of the others, only four are still in use. One of the new ones is not on the line yet. It produces 220 gallons per minute. The total production of the wells in use is 2100 gpm. This figure could be upped about 600 gpm if the older wells were cleaned. One well has an air lift pump; the others are electric motor driven multi-stage pumps. The new wells in use, which have a capacity of 930 gpm are hooked onto the line directly, they do not feed to the reservoir as do the older wells. This water then, is not chlorinated.

The existing reservoir has a capacity of 250,000 gallons. This is woefully inadequate for the size of the consuming population and the large area served. Claud R. Erickson, who is consulting engineer for the college, has just completed the design for a new reservoir. It is to have a capacity of 1,250,000 gallons. Building plans call for the construction of this reservoir in the very near future.

Three of the new wells are located near the Grand Trunk Railroad tracks. They are hooked into a 14" main. This main passes by the site of the proposed reservoir. This location is between the Piggery and Shaw Lane.

It is planned also to have a zeolite softening plant and pumping station in connection with the reservoir. These units will not be built in the immediate future because of lack of funds.

A central water conditioning plant is a great need on campus. At present there are over 50 separate zeolite softeners in the various buildings. Most buildings have two units, but some have only ane and others have three. The capacities of these various tanks ranges from 1000 gallons to 35,500 gallons. It is a full time job for one man to rejuvenate the softeners regularly.

In the past 12 months the college has used 75 tons of salt for the softeners at a cost of $10.50 a ton. The salt is purchased in 100 pound bags and is delivered to the Power Plant. From there it is distributed to the various buildings as needed.

The water softening problem would be vastly simplified if a central conditioning plant were built. If this were done, the cold water as well as the hot water would be soft. All of the new permanent buildings on campus have two softening tanks. The money spent to buy these 26 softeners would have gone a long way on financing a central plant.

The boiler water is conditioned at the Power Plant. This conditioning plant will be continued in use even

though a central plant is built.

The pumps at the new wells are capable of pumping the water directly to the mains. The water from the reservoir is moved by four pumps in the Power Plant. There are two 1000 gpm pumps, one electric and one steam, and two 300 gpm units, also one electric and one steam. These ratings are for a pressure of 80 pounds.

The chlorinating unit is in the Power Plant.

The college has a connection with the city of East Lansing in case more water is needed than can be supplied by the college system. Considerable water has been bought from the city in the past year.

SOFTENING UNIT

The type of softening unit to be used is the Permutit (Spaulding) Precipitator. This type of unit has several advantages over the standard coagulation - sedimentation type unit, the most important of which is the saving in space. In a cold climate coagulation and sedimentation must be accomplished under cover. The holding time of a precipitator is only slightly over an hour as compared to 2 to 4 hours for standard basins. Less chemicals are required; savings vary from 10% to 40%. This is particularly true when softening cold water.

In the precipitator the sludge is not settled to the bottom, but by mechanical agitation and upward flow, is kept suspended. The water passes thru this sludge blanket, leaving the precipitates behind and flows from the top of the device as a clear liquid.

The raw water and chemicals are admitted to the top of the inverted cone as indicated in the diagram below. In this zone the chemicals and water are mixed and coagulation takes place. The water then passes under the inverted cone and into the upright cone where the water flows up thru the sludge blanket, emerging as clear water to be drawn off the top of the tank.

Other advantages of the precipitator are the elimination of sludge removal equipment and adaptability to variable rates of flow. A sludge outlet from some convenient point as indicated in the illustration is all that is required. The sloping sides of the sludge filter zone cause a continuously increasing rate of change of area. Therefore, at the normal operating level of the top of the sludge filter a very stable condition exists, and even large changes in the rate of flow will result in relatively small changes in the elevation of the top of the sludge filter. As the rate of flow decreases, the top of the sludge filter drops until a level is reached where there is the proper area to correspond to the new lower rate.

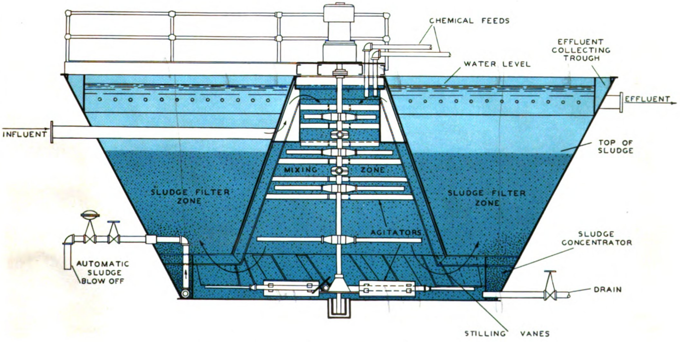


Fig. 1—*Schematic Diagram of principle of the Permutit Precipitator.*

The suspended matter in the precipitator effluent is lower than standard settling tank effluents. This makes longer filter runs possible.

Precipitator units are designed by the Permutit Company to meet certain requirements and specifications. The tank size will be figured here in order to determine the size of the room necessary to house the units.

The basic detention time is considered as the time that the water being treated is in actual contact with the sludge. When the clear water leaves the sludge filter zone the chemical reactions have ceased and the remaining upflow portion serves as storage space, or space to take up fluctuations in flow rates. Two units will be used; each to soften 1,500,000 gallons per day.

Detention time - One hour plus 15 min. storage

$$V = \frac{1.25}{24} \times \frac{1,500,000}{7.48} = 10,430 \text{ cu. ft.}$$

Depth of tank - 14 feet

Top diameter - 38 feet

Bottom diameter - 24 feet

$V = 1/3(A_1 + A_2 + \sqrt{A_1 \times A_2})h$

$= 1/3(1,140 + 454 + \sqrt{1,140 \times 454})14$

$V = 10,800$ cu. ft.

Pipes from Precipitators to Filters

Use 12" pipe from each precipitator.

Use 18" pipe for combined flow to filters.

Flow in 12" (A = 0.7854 sq. ft.

$Q = 1.547 \times 1.5 - 2.32$ c.f.s.

$v = Q/A = 2.95$ '/s.

$v^2/2g = 0.135$ ft.

Flow in 18" (A = 1.77 sq. ft.

$Q = 1.547 \times 3 = 4.64$ c.f.s.

$v = 2.62$ '/s.

$v^2/2g = 0.107$ ft.

Head losses in 12"

Entrance	$0.5\ v^2/2g$
2 Elbows	1.0 "
1 Valve	0.1 "
20' Pipe - F x L/D	0.4 "
	$2.0\ V^2/2g = 1.27$ ft.

Head losses in 18"

18" Y	$0.25\ V^2/2g$
2 Elbows	1.0 "
2 Valves	0.20 "
1 Tee	1.50 "
45 feet. pipe	0.60 "
	$3.55\ V^2/2g = 0.39$ ft.

12" - 18" Enlarger

$0.25(V_1^2/2g - V_2^2/2g = 0.01$ ft.

"Homomix" Recarbonator	1.0 ft.
Total Head Loss	1.67 ft.

Place bottom of effluent trough 2.0' above water level in filters.

Specifications for Precipitator:[12]

A treating plant consisting of 2 units shall be provided as shown on the drawings. Each unit shall meet the following specifications.

The maximum diameter shall be 38'.

The total detention time in the treating tank shall be not less than 75 minutes at designed rate of flow.

The unit shall be constructed to include a centrally located mixing compartment. Raw water and chemicals shall be introduced into the top of this chamber. The water being treated shall pass in a downward direction through the mixing zone so that one complete change of direction of flow will take place before the water enters the upflow sludge filter compartment.

The sludge filter compartment shall have a restricted entrance port above which the horizontal area shall gradually increase, thus insuring uniform distribution of the treated water and stability of the sludge filter.

The agitator shall consist of paddles, rotating about a shaft and driven through suitable speed reducers by an open motor and suitable equipment to give a speed variation of at least 2 to 1. Manual starting equipment of the cross-the-lime type shall be provided. The tip speed of the agitator blades shall not exceed 10 feet per minute at the highest speed of the motor.

Provisions shall be made for intermittent sludge removal operating automatically on an adjustable time cycle. A drain connection and an overflow connection shall also be provided.

Walkway and railings shall be provided as indicated on plans. All structural steelwork shall be given a shop coat of priming paint to within two inches of any edges prepared for field welding.

The inner structure shall be of steel at least 3/16" thick. Necessary structural steel members shall be provided to insure rigidity and properly support the inner sections, baffles and agitator.

The inner structure shall be shipped in sections designed for field welding.

The outer tank shall be constructed of steel plate at least ¼" thick, shipped in sections designed for field welding.

The agitator shall be mounted on a vertical shaft and its driving mechanism shall be carried by a bearing located above the water. A corrosion-resisting water-lubricated guide bearing shall be provided for the lower end of the agitator shaft.

As part of the treating tank, there shall be furnished a straight raw water conduit of welded steel or cast iron construction from a point one (1) foot outside the tank wall and similar outlet conduit to a point one (1) foot outside the tank wall.

SAND FILTERS

Babbitt and Doland suggest that at least three units be used. Here two are being used because of large storage capacity, the plant is not large, and since well water is being used the raw water can be pumped directly to the reservoir in case of extreme emergency.

Number of units - 2

Rate of filtration - 125 m.g.a.d. = 2 gal. per min per sq. ft.

Quantity - 1,500,000 gal. per day per filter

$$\text{Area} = \frac{1.5 \times 43,560}{125} = 522 \text{ sq. ft.}$$

Length = 1.25b

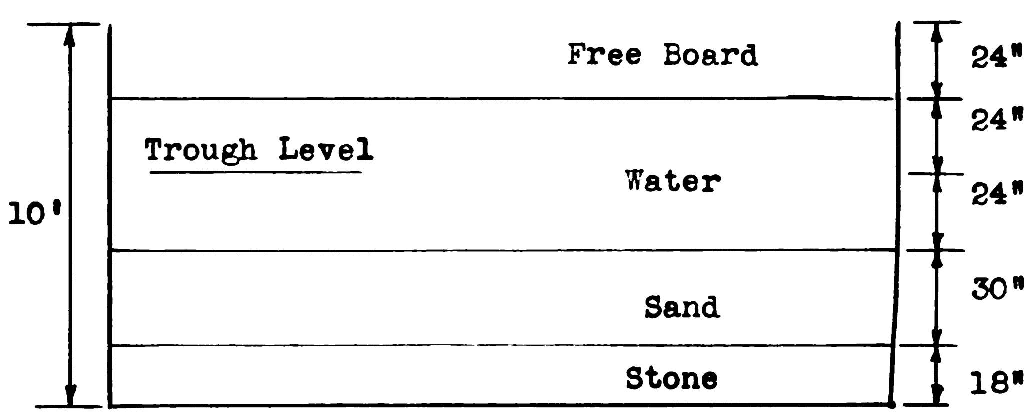
$$1.25b^2 = 522$$

$$b = 20.5 \text{ ft.}$$

$$l = 1.25\, b = 25.6 \text{ ft.}$$

Make tank 20' x 26' = 520 sq. ft.

Cross section of filter



Wash water gutters

Rate of wash - 2 ft. rise per minute

$Q = 2 \times 520 = 1040$ c.f.m.

for each trough $Q = \frac{1040 \times 7.48}{3} = 2600$ gpm.

(Trough size determined by method explained in in Engineering New-Record, Vol. 90, p. 882)

Let $S = 0.02$

$z = 1.58'$

y_1 = depth of water at shallow end.

$y_1 = Z - LS = 1.58 - 26 \times 0.02 = 1.06$ ft.

y_2 = depth at deep end

$y_2 = 2/3\ (y_1 - Ls)$

$= 2/3\ (1.06 - 26 \times 0.02)$

$y_2 = 1.05$ ft.

Make shallow end 16" deep - allowing 3½" fall over weir.

See Detail Sheet 1 for cross-section of troughs

Underdrains-

Manifold cross-section - 1¾ - 2 times total lateral area.

Lateral area 2 x orifice area

Orifice area to bed area - 0.3% to 0.4%

Lateral spacing - 6" c/c

Orifices - 3/8" @ 6" c/c (Area 3/8" orifice = 0.11 sq. in.)

Orifice to bed area: (4 orifices per sq. ft.)

$$\% = \frac{4 \times 0.11}{144} = 0.31$$

Rate of wash - 2 ft. rise per min.

Vel. thru orifice

$$v = \frac{2 \times 144}{60 \times 4 \times 0.11} = 10.9 \text{ l/s}$$

$$\text{vel. head} = \frac{V^2}{2g} = 1.84 \text{ ft.}$$

Lateral size - 2½"

$$A = (2.5)^2 \times 0.7854 = 4.91 \text{ sq. in}$$ 2 x orifice area.

Area taken by one lateral = 10 x 0.5 = 5 sq. ft.

$$\text{Vel. in lateral} = \frac{5 \times 2 \times 144}{60 \times 4.91} = 4.88 \text{ l/s}$$

$$\frac{V^2}{2g} = 0.37 \text{ ft.}$$

Total number of laterals - 104

Area of laterals = 104 x 4.91 = 510 sq. in.

Area of manifold = 1.75 x 510 = 893 sq. in.

Use 36" pipe - A = 1020 sq. in.

Wash water drain pipe

$$Q = \frac{520 \times 2}{60} = 17.3 \text{ c.f.s.}$$

Try 18" pipe A = 1.77 sq. ft.

Pipe losses:

3 Elbows	$1.50\, V^2/2g$
1 Valve	0.10 "
1 Tee	1.50 "
Entrance	0.50 "
30' Pipe f x L/D	0.38 "
	$3.98\, V^2/2g = 6.17$ ft. (6.6' available)

Wash water tank

Rate of wash 2 ft. rise per min. per sq. ft.

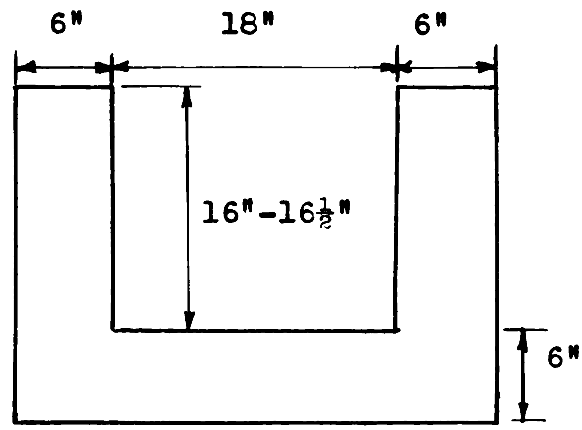
Wash period 6 min.

$$Q = 2 \times 520 \times 6 = 6{,}240 \text{ cu. ft.}$$

Try tank of 20' diameter

$$h = \frac{6{,}240}{0.7854 \times 400} = 19.8' \qquad \text{Use } 20' \text{ d \& } 20' \text{ h}$$

Make sides and bottom 6".



Cross-section of Wash Water Trough

Dead load = 5.3 x 0.5 x 150 = 398 #/1

Live load = 1.5 x 133 x 62.4= 117 #/1

Total load= 515 #/1

Each side is a beam carrying half the load.

Moment equations for fixed - end beam.

$$M_a = M_b = \frac{wl^2}{12} = \frac{25.0 \times 26^2 \times 12}{12} = 152,400\#".$$

$$M_c = \frac{wl^2}{24} = 76,200 \#"$$

Inflection point

$x = 0.211L = 5.5'$.

f_s = 20,000 p.s.i.

f_c = 1350 p.s.i.

n = 10

$$x = d\left(\frac{f_c}{f_s/n - f_c}\right) = 19.5 \left(\frac{1350}{3350}\right) = 7.87''$$

$$M_R = \tfrac{1}{2} f_c \times b \times X \times a$$

$$= \tfrac{1}{2} \times 1350 \times 6 \times 7.87 \times 16.88 = 537{,}000 \ \#''.$$

$$A_s = \frac{M}{f_s\, j\, d} = \frac{152{,}400}{20{,}000 \times 0.83 \times 19.5} = 0.44 \text{ sq. in.}$$

Use 2 - $\frac{3}{4}'' \phi$. As = 0.66 sq. in.

Shear:

$$V = \frac{26}{2} \times 500 = 6{,}500 \ \#.$$

$$v = \frac{V}{bjd} = \frac{6{,}500}{6 \times 0.83 \times 195} = 55.7 \text{ p.s.i.}$$

Bond:

$$u = \frac{vb}{\Sigma o} = \frac{55.7 \times 6}{3.5} = 95.5 \text{ p.s.i.}$$

Use hooked bars.

To give support to the bottom place $\frac{1}{2}'' \phi$ hangers in trough as shown on Detail Sheet 1.

FILTER WALL DESIGN

Pressure on wall:

4.5' water @ 62.4 #/cu. ft.

4.0' sand and stone @ 115#/cu. ft.

Water – P = $wh^2/2 = \frac{62.4 \times 8.5^2}{2}$ = 2,256#

Sand – P = $\frac{60 \times 4^2}{2}$ = 480#

Total 2,736#

Average weight of sand, stone, and water over whole depth = 75.8 #/cu.ft.

Ma:

Total Pressure =	2,736# x 3.66	=	10,050#'
W_1 = 10.5 x 1 x 150	= 1,575# x 0.5	=	786#'
W_2 = 12 x 2/3 x 150	= 1,200# x 0.5	=	600#'
W_3 = 1.25 x 12 x 150	= 2,250# x 4	=	-6,000#'
W_4 = 10 x 8.5 x 75.8	= 6,440# x 5	=	-32,200#'
	10,715#		-26,763#'
			- 2,51

Resultant falls within middle third.

$$f = \frac{P}{A}\left(1 \pm \frac{6e}{b}\right)$$

$$= \frac{10,715}{12}\left(1 \pm \frac{6 \times 1.5}{12}\right)$$

f = 1565 #/sq.ft. @ toe

= 225 #/sq.ft. @ heel.

Wall Steel

M = 2736 x 2.84 = 7,750 #'.

$$d = \sqrt{\frac{M}{Rb}} = \sqrt{\frac{7,750 \times 12}{236 \times 12}} = 5.74''$$

$P_V = 10,715 \quad x\ 5 \quad = -53,575$

$P_E = \underline{6,580} \quad x\ 3.35 = \underline{22,100}$

$V = 4,135. \qquad M = 31,475\#'$

$d = \frac{V}{vjb} = 6.7" \quad d = \sqrt{M/Rb} = 11.5$

Use 15" slab - d = 12".

$A_S = \frac{M}{fsjd} = \frac{31,475 \times 12}{20,000 \times 0.87 \times 12} = 1.80$ sq. in.

Use 1"ϕ @ 5"c/c. $A_S = 1.90$ sq. in.

$u = \frac{V}{\Sigma ojd} = \frac{4,135}{7.5 \times 0.87 \times 12} = 75.5$ p.s.i.

Toe:

$M_{B-B} = 1450 \times 1 \times 0.5 - 112 \times 0.5 \times 2/3$

$M_{B-B} = 762\ \#'$ Very small.

Place steel as shown on Detail Sheet 1.

Filter gallery floor

Free span - 13' Design as simple beam.

Try 6" slab; d = 4"

L.L. = 150 #/'

D.L. = 75 #/'

T.L. = 225 #/'

$M = \frac{wl^2}{8} = \frac{225 \times 13^2}{8} = 4760\#' = 57,120\#".$

$A_S = \frac{M}{fsjd} = \frac{57,120}{20,000 \times 0.87 \times 4} = 0.82$ sq. in. per ft.

Use $\frac{3}{4}$"ϕ @ 6" c/c. $A_S = 0.88$ sq. in.

Shear:

$v = \frac{V}{bjd} = \frac{1460}{12 \times 0.87 \times 4} = 34.8$ p.s.i.

Bond:

$u = \frac{vb}{\Sigma o} = \frac{34.8 \times 12}{4.7} = 88.9$ p.s.i.

d being used is 9.5" for a 12" wall

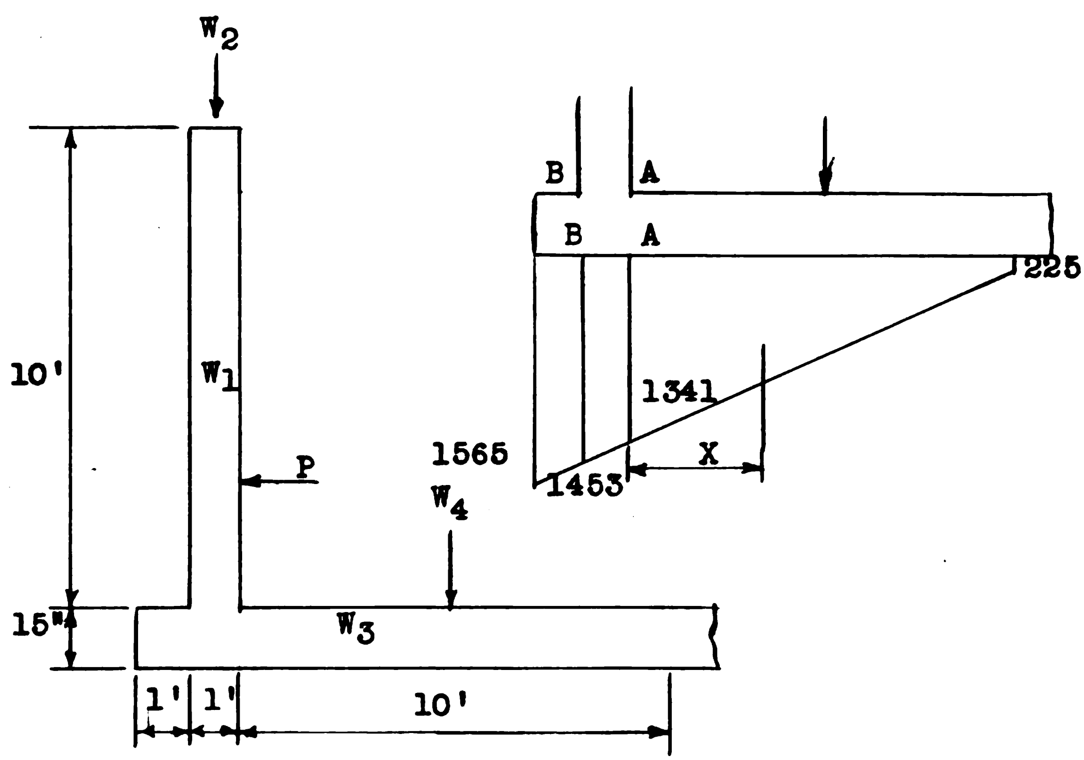
$$A_s = \frac{M}{f_s j d} = \frac{7,750 \times 12}{20,000 \times 0.87 \times 9.5} = 0.563 \text{ sq. in.}$$

Use $\frac{3}{4}$" ϕ @ 8" c/c. $A_s = 0.66$ sq. in.

On wall that is common to both units this steel to be placed on both sides of wall.

Temperature Steel

Use $\frac{1}{2}$" ϕ @ 8" c/c.



Base design:

Earth pressure to right of A-A (minus concrete)

$$X = \frac{100 \times 10 \times 5 + 1116 \times 10 \times 0.5 \times 3.3}{1.000 \times 10 + 1,116 \times 5} = 3.55$$

Outside walls of Precipitator room:

Assume earth pressure equivalent to liquid weighing 30 p.c.f.

$$P = \frac{wh^2}{2} = \frac{30 \times 8^2}{2} = 960\#$$

M_a:

$W_1 =$	$14 \times 150 =$	$2100\#$	$\times 0.5 =$	$1050\#'$
$W_2 =$	$=$	$1000\#$	$\times 0.5 =$	$500\#'$
$W_3 =$	$4 \times 150 =$	$600\#$	$\times 0.0 =$	0
$W_4 =$	$8 \times 100 =$	$800\#$	$\times 1.5 =$	$1200\#'$
P	$=$	$960\#$	$\times 3.67 =$	$-3530\#'$
		$4500\#$		$-1775\#'$
				$-0.39'$

$$f = \frac{P}{A}\left(1 \pm \frac{6e}{b}\right)$$

$$= \frac{4500}{4}\left(1 \pm \frac{6 \times 0.4}{4}\right)$$

$f = 1800\#$ @ toe

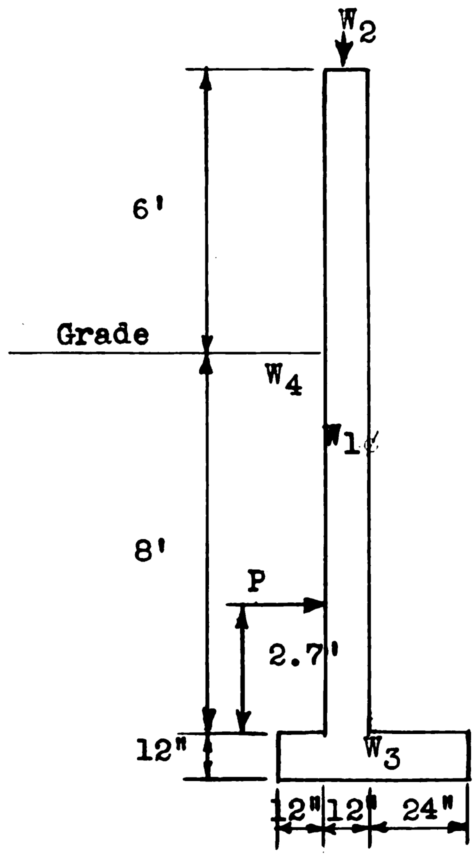
$f = 450\#$ @ heel

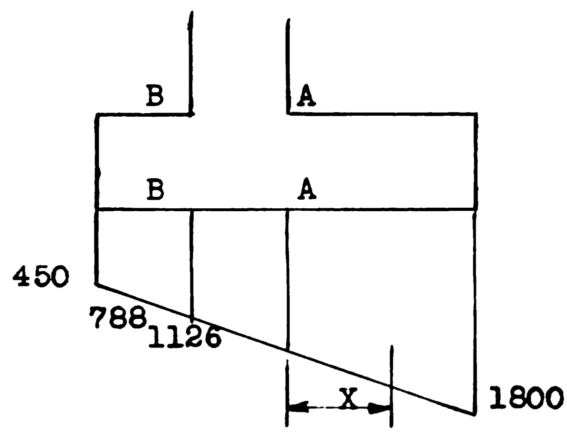
$$M = 960 \times 2.7 = 2{,}590\#'$$

$$d = \sqrt{\frac{M}{Rb}} = \sqrt{\frac{2{,}590 \times 12}{236 \times 12}} = 3.32\#$$

$$d = \frac{V}{vjb} = \frac{4500}{60 \times 0.83 \times 12} = 7.5''$$

Use 12" wall; $d = 9''$





$$A_s = \frac{M}{f_s jd} = \frac{2590 \times 12}{20{,}000 \times 0.87 \times 9.5} = 0.188 \text{ sq. in per ft.}$$

Use $\frac{1}{2}"\phi$ @ 8" c/c; $A_s = 0.30$ sq. in.

Shear:

$$v = \frac{V}{bjd} = \frac{960}{12 \times 0.87 \times 9.5} = 9.6 \text{ p.s.i.}$$

Bond:

$$u = \frac{vb}{\Sigma o} = \frac{9.6 \times 12}{2.4} = 48 \text{ p.s.i.}$$

Temperature steel:

Use $\frac{1}{2}"\phi$ @6" c/c horizontal.

$\frac{1}{2}"\phi$ @36" c/c vertical.

Base Design

Stresses at B-B are negligible.

Earth pressure to rt. of A-A. (minus concrete)

$$X = \frac{976 \times 2 \times 1 + 674 \times 2 \times 0.5 \times 1.33}{967 \times 2 + 674 \times 2 \times 0.5}$$

$X = 1.08$

$M_A = 2626 \times 1.08 = 2850\#'$

$d = \frac{V}{vjb} = \frac{2626}{60 \times 0.83 \times 12} = 4.18"$

$d = \sqrt{\frac{M}{Rb}} = \sqrt{\frac{2850 \times 12}{236 \times 12}} = 3.48"$

Use 12" base; $d = 9"$

$A_s = \frac{M}{f_s jd} = \frac{2850 \times 12}{20,000 \times 0.87 \times 9} = 0.218$ sq. in. per ft.

Use $\frac{1}{2}"\phi$ @ 8" c/c; $A_s = 0.30$ sq. in.

Shear:

$v = \frac{V}{bjd} = \frac{2626}{12 \times 0.87 \times 9.5} = 26.9$ p.s.i.

Bond:

$u = \frac{vb}{\Sigma o} = \frac{26.9 \times 12}{2.4} = 134.5$ p.s.i.

Use hooked bars.

Outside wall of pump room:

Assume earth pressure equivalent to a liquid weighing 30 p.c.f. Use 12" wall; $d = 9"$.

$P = \frac{wh^2}{2} = \frac{30 \times 12^2}{2} = 2,160\#.$

$Y = \frac{12}{3} = 4'$

$R_T = \frac{2,160 \times 4}{20} = 432\#.$

$R_B = 2,160 - 432 = 1,728\#.$

Point of zero shear:

$X_o \times 90X_o = 432$

$X_o = 2.2'$

Arm $= 8 + 2.2 = 10.2'$

$M = 432 \times 10.2 = 4,410\#'/'$

$$A_s = \frac{M}{f_s jd} = \frac{4,410 \times 12}{20,000 \times 0.87 \times 9} = 0.30 \text{ sq. in. per ft.}$$

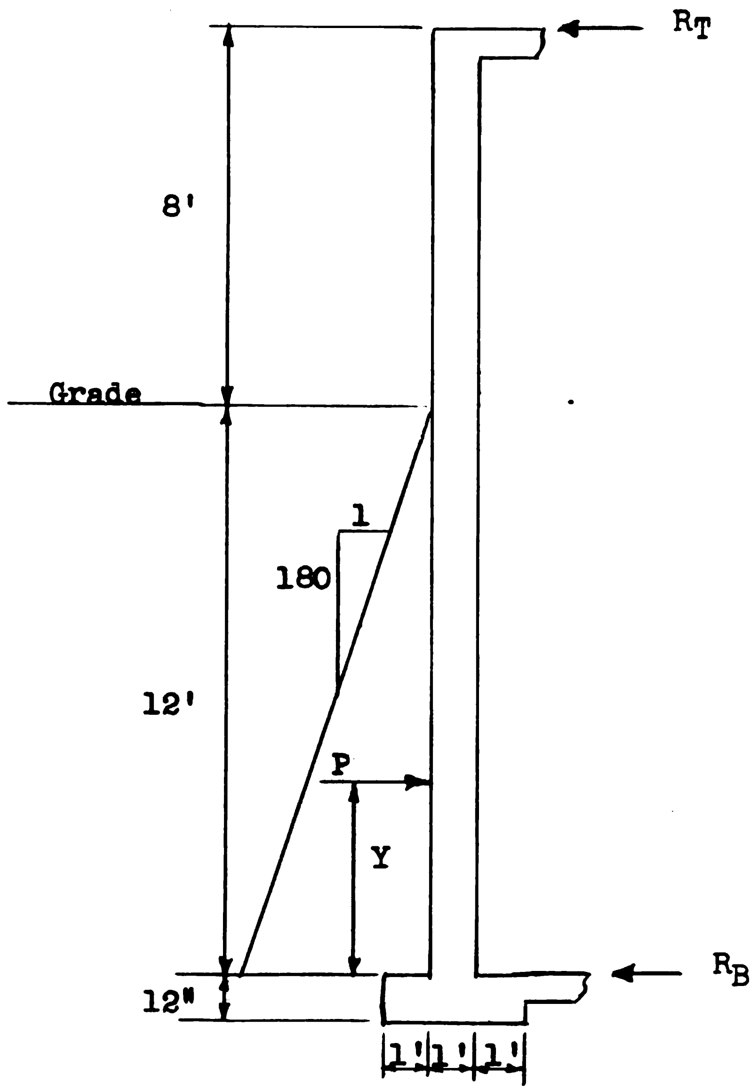
Use $\frac{1}{2}$" ϕ @8" c/c; $A_s = 0.30$ sq. in.

Shear:

$$v = \frac{V}{bjd} = \frac{1,728}{12 \times 0.87 \times 9} = 18.3 \text{ p.s.i.}$$

Bond:

$$u = \frac{5b}{\Sigma o} = \frac{18.3 \times 12}{24} = 91.5 \text{ p.s.i.}$$



COLUMN DESIGN

Filter Gallery:

Use Fink Trusses @ 10' c/c. (Top chord 6" on 1')

Vertical loads

Snow	30 #/sq.ft.
Wind	8 "
Purlins	5 "
Concrete	18 "
Slate	10 "
Ceiling	10 "
	81 #/sq.ft.

Load per ft. of top chord of truss:

$81 \times 10 \times \cos\ 26^{\circ}\ 34' = 720\ \#/'$

(From Merriman & Wiggin's "American Civil Engineers' Handbook", p 1131, the weight of a Fink Truss to carry the above load is 1650 lb.)

Load per column:

$$\frac{1650 - 81 \times 10 \times 40}{2} = 17{,}025\#.$$

Try column 12" x 12". (f_c = 540 p.s.i.)

Transformed area = 144 + (10 - 1) 0.79

A = 152 sq.in.

Allowable load

P = 152 x 540 = 82,000#

(But height of column is greater than 10 times least dimension, so by J.C. Art 858

$P_1 = P(1.3 - 0.03\ h/d)$

$P_1 = 82{,}000\ \left(1.3 - 0.03 \times \frac{144}{12}\right) = 77{,}000\#.$

Precipitator Room:

Use same size column for outside wall as used to support filter gallery roof.

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12. Bulletin No. 2204. The Permutit Company, 1942.

[redacted]

May 6 49

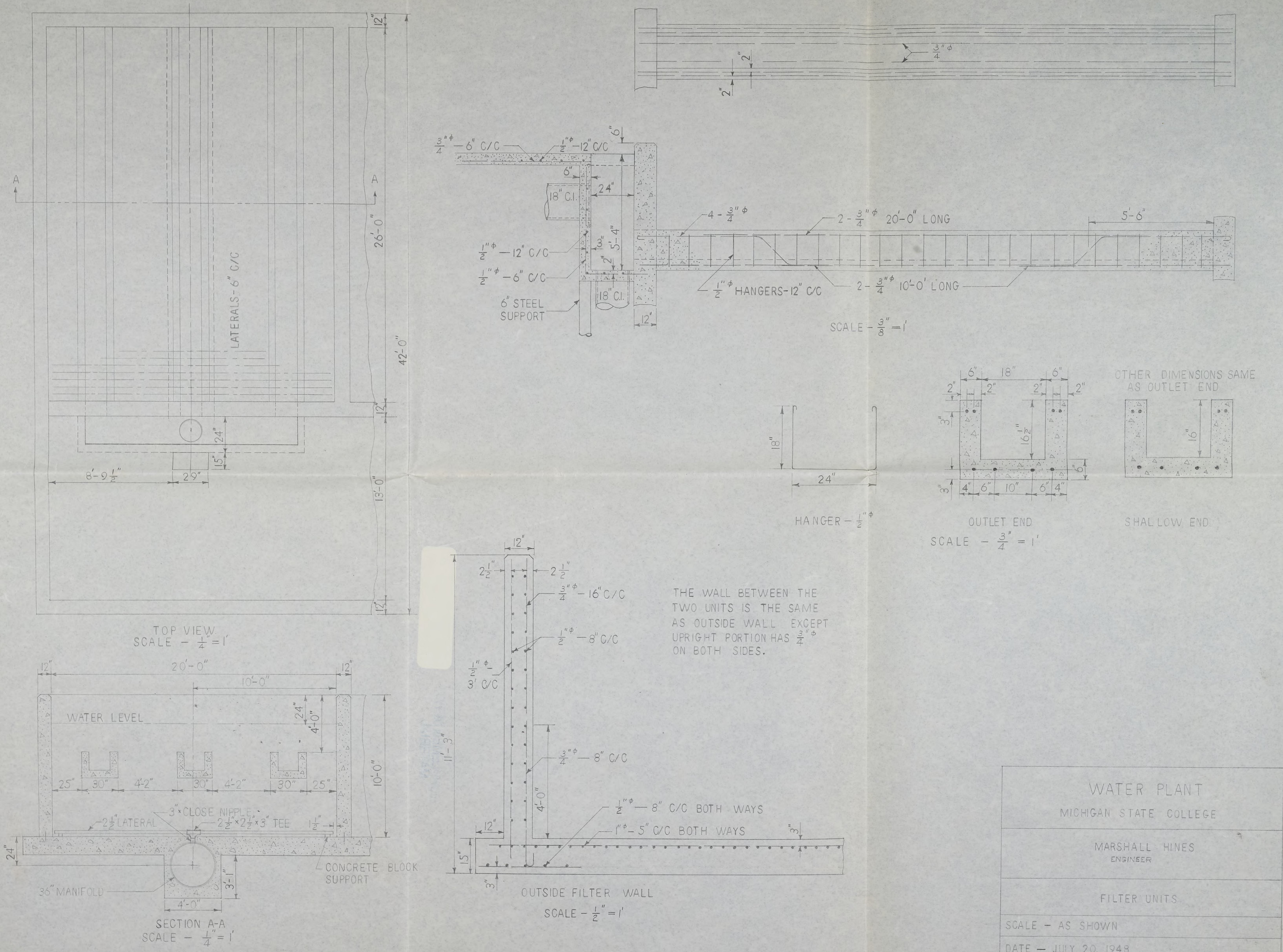
Jul 20 '5

[redacted]

Aug 29 '50

3 '53

~~MAR 1~~



WATER PLANT

MICHIGAN STATE COLLEGE

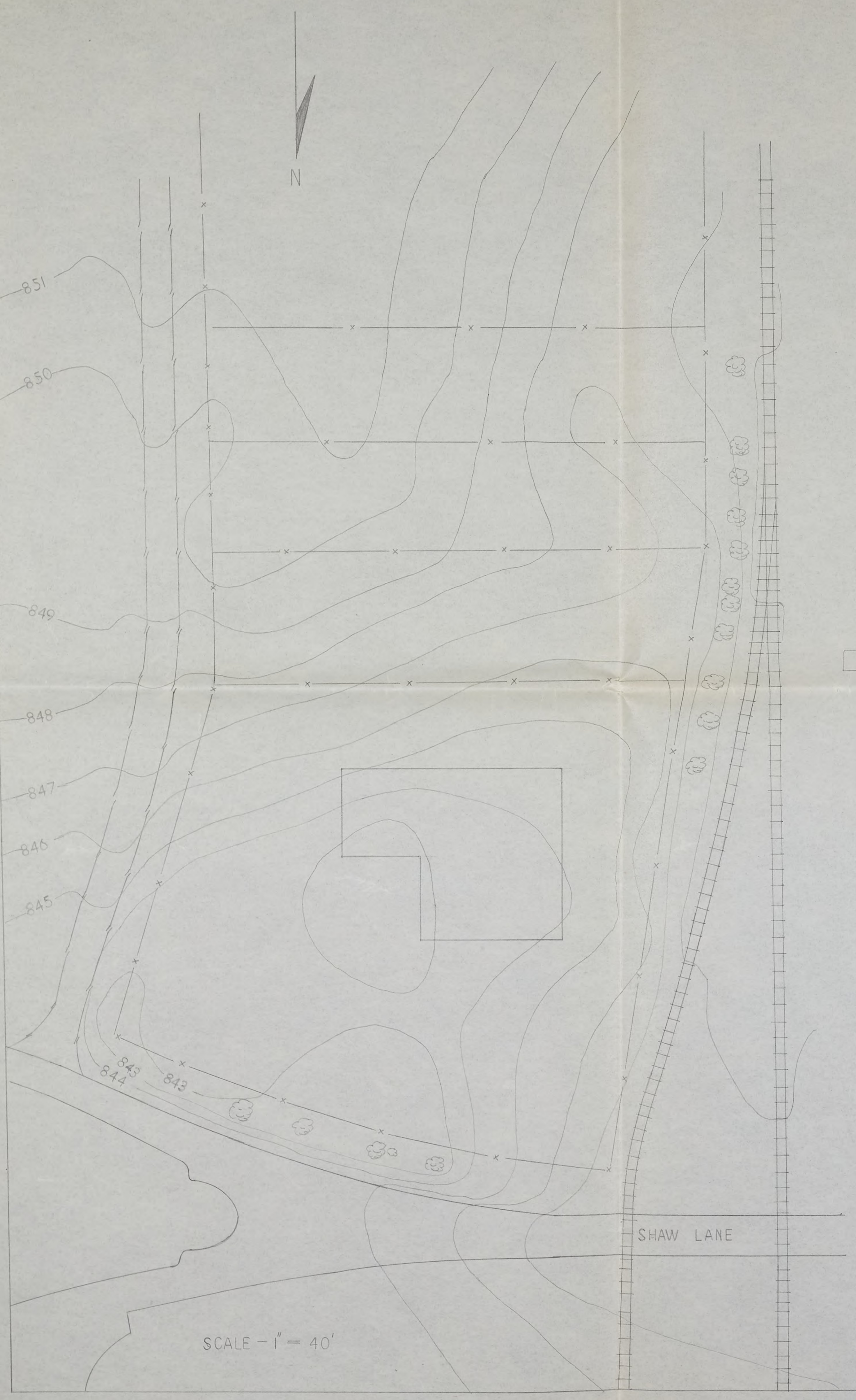
MARSHALL HINES
ENGINEER

FILTER UNITS

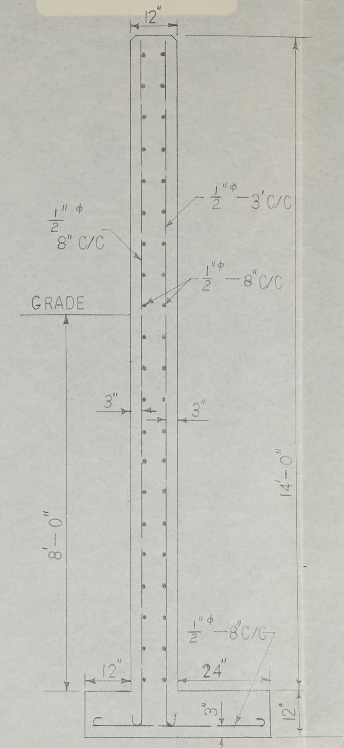
SCALE - AS SHOWN

DATE - JULY 20, 1948

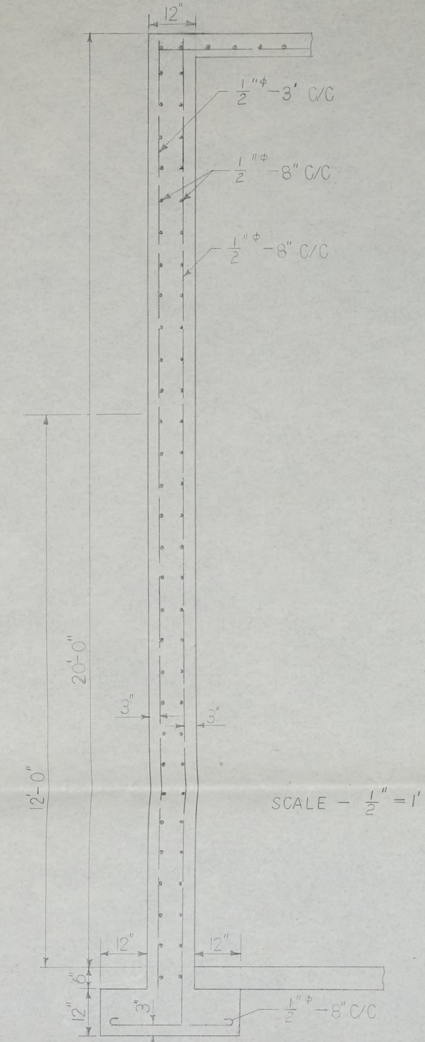
SHEET 1.



SCALE - 1" = 40'

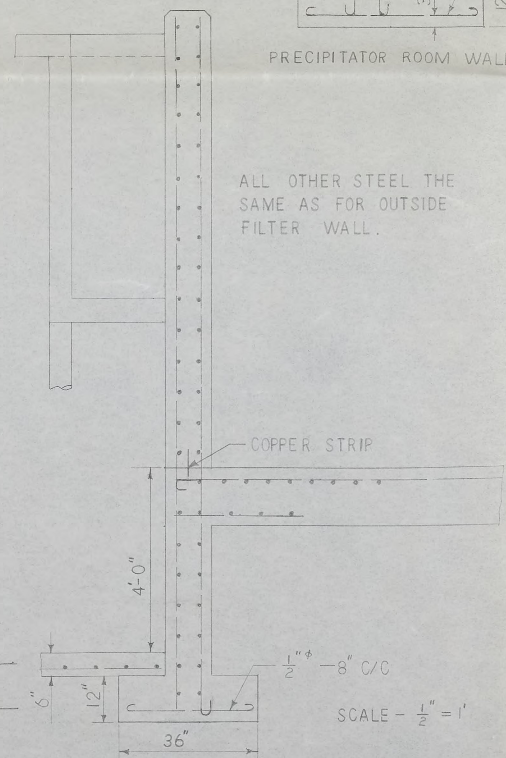


PRECIPITATOR ROOM WALLS



SCALE - 1/2" = 1'

OUTSIDE WALLS OF PUMP ROOM



SCALE - 1/2" = 1'

WALL BETWEEN PIPE GALLERY & FILTER

WATER PLANT
MICHIGAN STATE COLLEGE

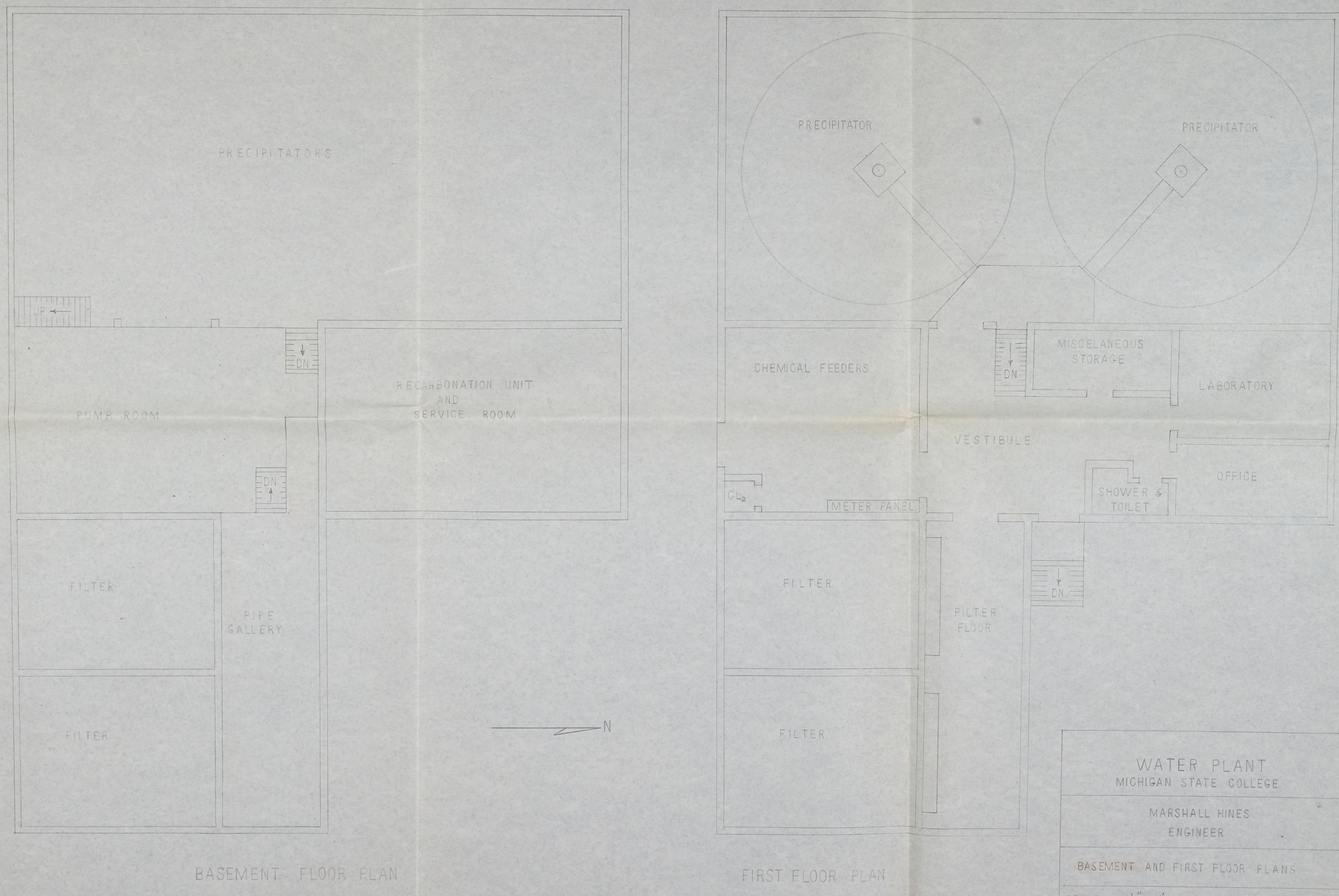
MARSHALL HINES
ENGINEER

PLOT PLAN AND WALL SECTIONS

SCALE - AS SHOWN

DATE - JULY 21, 1948

SHEET 2.



WATER PLANT
MICHIGAN STATE COLLEGE

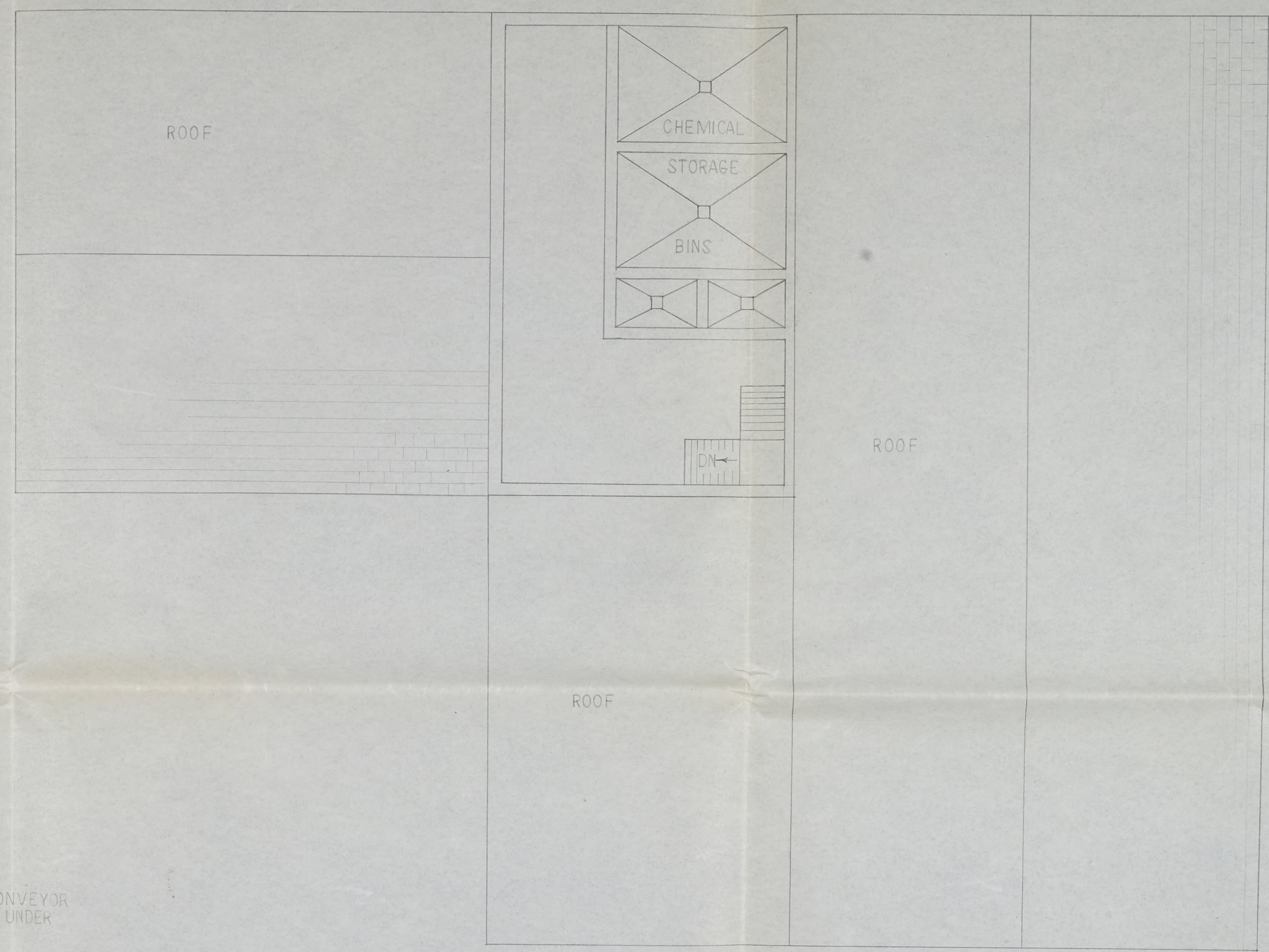
MARSHALL HINES
ENGINEER

BASEMENT AND FIRST FLOOR PLANS

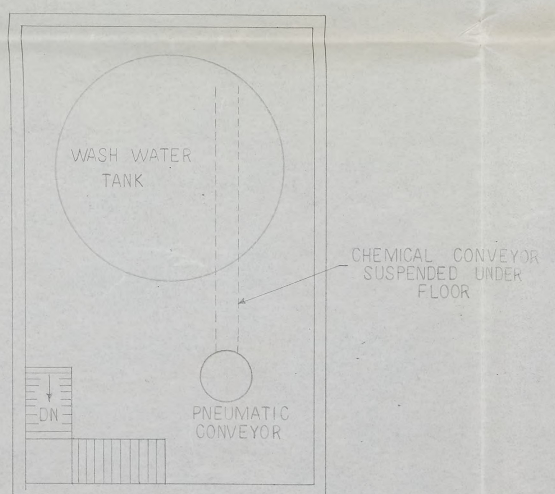
SCALE — $\frac{1}{8}'' = 1'$

DATE — JULY 21, 1948

SHEET 3.



SECOND FLOOR PLAN



THIRD FLOOR PLAN

WATER PLANT
MICHIGAN STATE COLLEGE

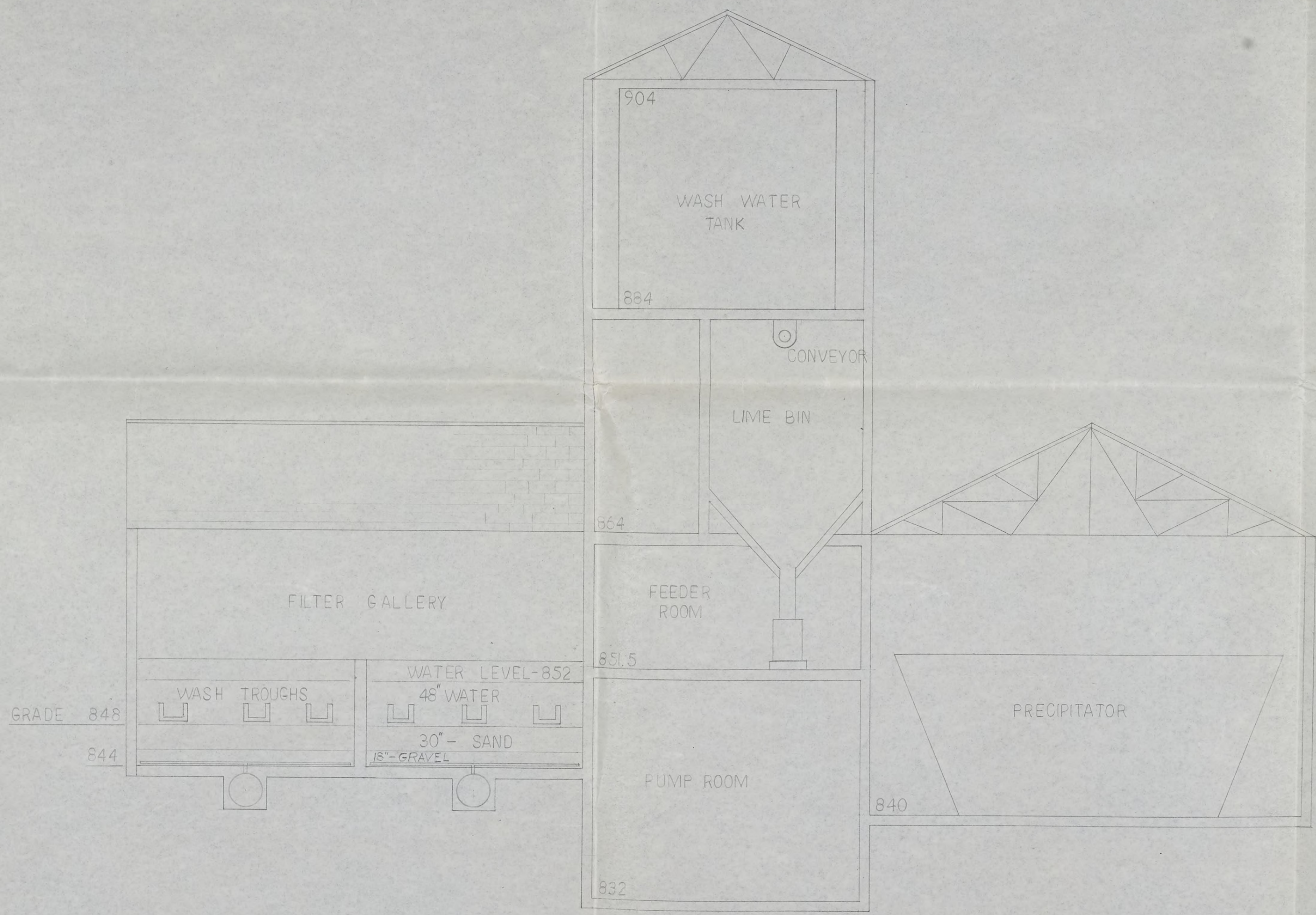
MARSHALL HINES
ENGINEER

SECOND AND THIRD FLOOR PLANS

SCALE — $\frac{1}{8}'' = 1'$

DATE — JULY 22, 1948

SHEET 4.



LONGITUDINAL SECTION

WATER PLANT
MICHIGAN STATE COLLEGE

MARSHALL HINES
ENGINEER

LONGITUDINAL SECTION

SCALE – $\frac{1}{8}'' = 1'$

DATE – JULY 22, 1948

SHEET 5