# THE DESIGN OF AN ELECTRICALLY OPERATED PUMPING STATION

BY

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THESIS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED BY

Joseph Ferdinand Chinlund

ENTITLED The Design of an Electrically Operated Pumping Station.

BE ACCEPTED AS FULFILLING THIS PART ON THE REQUIREMENTS FOR THE PROFESSIONAL DEGREE OF Electrical Engineer

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# THE DESIGN OF AN ELECTRICALLY OPERATED PUMPING STATION.

## OBJECT.

The object of this thesis is to present a design of an electrically operated pumping station, together with an estimate of the cost of installation, operation and maintenance of such a station as compared to those of a similar station operated by steam.

A detailed description of the two most recently completed pumping stations of the City of Chicago, which are steam operated, will be given, in addition to a description and drawings of the electrically operated station.

Comparison will then be made of the two types, in all features, with the idea in view of determining the type which is the more economical.

The subject of a source of power for a system of motor driven pumping stations in the City of Chicago, as well as for municipal street lighting and other municipal light and power needs, will be gone into thoroughly, and an endeavor made to ascertain the most economical method of securing this power.

## HISTORY.

The water pumping system of the City of Chicago had its beginning in 1840, when the Chicago Hydraulic Company was granted a franchise. A 25 H.P. pumping engine was installed, with an elevated reservoir, and about two miles of logs, with holes bored through their centers, were laid in the streets of the City, to serve as water mains.

In 1851 the City took over the above mentioned company, and in 1853 erected a pumping engine with a capacity of 8,000,000 gallons per day on the site of the present Chicago Avenue station. In 1856 a second unit, with a capacity of 13,000,000 gallons per day, was installed.

The first lake tunnel, five feet in diameter and running two miles out under the lake, terminating in the Two Mile Crib, was completed in 1867, and thereafter fed the Chicago Avenue station.

The next step was the erection of the present Twenty-Second Street station, and the building of a seven foot tunnel to the Two Mile crib. This was completed, and two 15,000,000 gallon pumping engines installed in the station, in 1876. An additional unit, with a daily capacity of 36,000,000 gallons, was also installed in the Chicago Avenue station.

Two stations, known as the Harrison Street and the Fourteenth Street stations, with a tunnel extending four miles out into the lake and terminating at the so-called Four Mile Crib were completed in 1891. Two 15,000,000 gallon pumps were installed in the Harrison Street station and three 15,000,000 gallon pumps were installed in the Fourteenth Street station. In 1898 an additional 30,000,000 gal. pump was installed in the Fourteenth Street Station.

In 1889 the towns of Lake View, Hyde Park and Lake were annexed to the City. Each of these towns had its own station, Lake View's being on the site of the present Lake View Station, and those for Hyde Park and Lake being the present Sixty-eighth Street station. The two latter stations adjoined, being both fed from the Sixty-eighth Street Crib.

In 1900 and 1901 the Central Park avenue and Springfield avenue stations, located about four miles inland, were completed, the capacity of each being 100,000,000 gallons per day. The tunnel for these two stations extends three miles out into the lake, terminating in the Carter H. Harrison Crib.

In December, 1911, the Roseland Station was completed, the installation being two units, the capacity of each being 25,000,000 gallons per day. The tunnel for this station extends to the Edward F. Dunne Crib, which adjoins the Sixty-eighth Street Crib.

In 1912 the two motor driven pumps were installed in the Twenty-second Street station.

In 1913 the old Lake View station was demolished and a new station with a capacity of 100,000,000 gallons per day is being erected.

In 1913, one 25,000,000 gallon turbine driven centrifugal pump was installed in each of the following stations: Fourteenth Street, Harrison Street, Central Park Avenue and Springfield Avenue.

The stations to be built in the near future are the following:

Mayfair, located at Wilson Avenue and 49th Avenue.

Thirty-fifth Street, located near Western Avenue and 35th Street.

Sixty-eighth Street, to replace present Sixty-eighth Street station.

The water system of Chicago has been a gradual development as made necessary by the growth of the City.

At the present time there are nine major stations pumping water into the mains of the system, as follows:

| | | |
|---|---|---|
| Roseland, | located at | 104th St. and Stewart Ave. |
| 68th Street, | " " | 68th St. and Oglesby Ave. |
| 14th Street, | " " | 14th St. and Indiana Ave. |
| Harrison Street | " | Harrison St. nr. Desplaines St. |
| 22nd Street | " | Ashland Ave. and 22nd St. |
| Chicago Avenue | " | Chicago Ave. and Lincoln Parkway. |
| Lake View | " | Montrose Blvd. and Clarendon Ave. |
| Springfield Ave. | " | Springfield Ave. nr. North Ave. |
| Central Park Ave. | " | Central Park Ave. nr. 12th St. |

There are four minor pumping stations, located as follows:

Edison Park, located in Edison Park, supplying the territory from artesian wells.

Norwood Park, located in Norwood Park, supplying that section from artesian wells.

Rogers Park, located at Kenilworth Avenue and the lake, fed by a short steel shell running out into the lake.

Jefferson Park, located on 47th Avenue near Montrose Boulevard, and boosting the water from Lake View to the higher territory lying in the northwest corner of the City. This station is fed by a 24 inch main from the Lake View Pumping station. More will be said of this station later.

The nine major stations are all fed by tunnels which run out into the lake and terminate in cribs. They are also interconnected by 36 inch mains, as shown on the accompanying map, the idea being that, in case of the shut-down of any one station, the stations nearest to it would furnish water supply necessary to take care of the first station's territory.

Prior to 1911 no thought had evidently been given to the subject of operating pumping stations by electrical power. In the fall of that year two motor driven centrifugal pumps were installed in pits of the Twenty-second Street Pumping Station, these pits being located between the foundations of the steam driven pumps. These two pumps were started up in January, 1912, and have been in continuous operation since that time, with the exception of the time necessary to shut down for repairs and the intervals when the power supply has failed.

In the summer of 1912, the Jefferson Park Pumping station was built. Three gas engine driven direct-acting pumps were installed here to boost the water from the Lake View station. The suction pressure at this station varies from plus fifteen to plus twenty pounds, depending upon the pressure at Lake View and the amount of water used east of the station. A great deal of objection was raised by the citizens near this station to the noise of the exhaust, and the dirt and soot when kerosene was used as an explosive. In the summer of 1913, therefore, a motor driven centrifugal pump was installed at this station, to take the place of the three gas engine driven pumps. This pump was started up July 30, 1913 and has been in successful and continuous operation since then with the exception of the short intervals when the power supply has failed. The cost of operation of this pump is practically one fifth that of the three gas engine driven pumps using gasoline as an explosive. It also pumps more water, and the discharge pressure is maintained at 60 pounds, whereas 40 pounds was the best that could be obtained with the three gas engine driven pumps.

Both the Twenty-second Street pumps and the Jefferson Park pump are supplied by power from the Lockport plant of the Sanitary District of Chicago.

## DESCRIPTION OF STEAM DRIVEN PLANT.

The following description of the two latest pumping stations is given for the purpose of later comparison with the proposed electrical driven plant.

### ROSELAND PUMPING STATION.

The Roseland Pumping station is located at 104th Street and Stewart avenue, near the southern end of the City.

When completed the plant will have four pumping units each with a daily capacity of 25,000,000 gallons per twenty four hours against a head of 140 feet. At present two units are installed and in operation. The other two will be installed and in operation by July 1st, 1914.

The building is in two sections. The boiler room occupies the southern section, with wings at the west and east ends reppectively for coal receiving room and repair shops. The engine room occupies the northern section. The building faces north, the central entrance portico fronting on 104th Street, opposite Harvard Avenue. On either side of this entrance are the offices of operating engineers, the engineer in charge of the station having his office on the west side of the entrance, and the engineers on watch on the east side.

The engine room, 130 feet square in size, is located centrally over the tunnel shaft and the 100-foot circular engine pit. The clear inside height from the engine pit floor, which is at -5 feet, Chicago city datum, to the horizontal lower chord of the roof, is 74.29 feet.

The four engines in the engine pit are grouped around the central circular suction well and are located in the diagonals of the square engine room. The suction well is situated centrally over the tunnel shaft. This shaft, 10 feet in internal diameter, extends from the tunnel, the center line of which is at -90 feet to elevation -29 feet, where the wet, or suction, well proper begins, with an inside diameter of 23 feet. The floor of the well is a flat concrete slab 2 feet thick. The concrete wall of the well is 2 feet thick, from elevation -29 to elevation -8. From this elevation the well is enclosed in a shell of structural steel plates and angles, lined with 12 inches of reinforced concrete extending to the top of the well, at elevation plus 11.5, which is even with the basement floor of the engine room. In the wall of the well are four cast-iron suction glands with split packing rings, through which pass the 42 inch suction pipes of the pumping engines. The suctions, with 90° elbows, extend down to elevation -19 feet, where the ends flare to a 48 inch diameter.

The two south pumps and accessories were erected under a contract with the Allis-Chalmers Company, and the two north pumps by the Bethlehem Steel Company.

The following is a tabulation of the essential data as to the design of the engines:

Capacity - 25,000,000 U.S. gallons per 24 hours.
Head - Total normal - 140 feet.
Head - Total maximum - 200 feet.
Steam pressure at throttle - 170 pounds gage.
Rotative speed at rated capacity - 25 r.p.m.
Plunger speed at rated capacity - 250 feet per minute.
High pressure cylinder - 24 in. diam. x 60 in. stroke.
Intermediate pressure cylinder - 46 in. x 60 in.
Low pressure cylinder - 70 in. x 60 in.
Pump plungers - 34 in. diam. x 60 in. stroke.
Surface condenser - 1000 square feet cooling surface.
Air pump - single, 22 in. diam. x 60 in. stroke.
Diameter of suction pipe - 42 inches.
Diameter of discharge pipe - 42 inches.

The steam cylinders of the pumping engines are steam jacketed, and there is a reheating receiver between the high and the intermediate and also between the intermediate and the low pressure cylinders. The condenser is a surface condenser of the Wheeler type, and is designed to maintain a vacuum within two mercurial inches of the barometer. The condenser is located in the suction pipe, between the hydraulic valve and the pump cylinder. In this way the suction of the pump passes through the condenser, furnishing the cooling water for the same. The exhaust of the condenser is so arranged that it may be by-passed through a primary feed-water heater. There is an oil separator in the exhaust steam line before it reaches the primary heater and the condenser, which removes practically all the oil, the balance being removed by the feed-water heater and purifier in the boiler room.

Each engine is provided with a direct-driven air pump, direct-driven feed pump and direct-driven air compressor.

There is also an independent air compressor and an independent air pump, for use in starting the engines.

There is an automatic oiling system provided, so arranged that it is unnecessary to handle any oil in the plant after it has been deposited in the tanks of the oil room.

The station throughout is electric lighted, and all the auxiliary power, such as is necessary for operating bilge pumps, cranes, coal conveyor, repair shop, etc.,is also electrical. Electric current for power and light is furnished by two General Electric Company's 75 kilowatt, 125 volts, direct current generators, direct-connected to two Curtis horizontal impulse turbines, running at 3300 r.p.m. In the summer the exhaust from these turbines goes to the feed water heater in the boiler room, or they may be run condensing, as desired. In the winter the exhaust steam is used in the heating system of the station.

The discharge pipes from the pumping engines lie in shallow trenches in the basement floor, with center lines at elevation plus 11.5 feet, and pass through cast iron thimbles in the north foundation wall of the engine room, into the discharge pipe vault.

North of, and adjacent to, the north foundation wall of the engine room and under the roadway of 104th Street is constructed a discharge pipe vault. In plan this vault is 161 feet east and west, and 70 feet north and south. It is U-shaped, with the base of the U extending east and west in 104th Street. The four discharge lines from the station lie in the short arme extending to the building. These discharge lines are connected to two main feeder lines, 48 inches in diameter, running east and west in 104th Street. Nine 36 inch and two 42 inch hydraulically operated gate valves are so placed in the discharge pipes in the vault as to control the flow from any or all discharge pipes to any or all of the feeders. A Venturi meter tube is placed in each discharge pipe in the vault, between the feeder main and the pumping engine. A check valve is mounted in each discharge line between the venturi meter tube and the Pump.

South of, and adjacent to, the engine room, extending its entire width, is the boiler room, 55 feet wide, at either end of which are the wings previously mentioned. The west wing contains the locker and toilet rooms, and the coal receiving and ash hoppers. The east wing contains various repair shops and storage rooms. The smokestack, eight feet inside diameter and 180 feet high, above the grates, is immediately south of the station, on an independent foundation.

The steam supply for the eventual capacity of 100,000,000 gallons pumpage per day is to be furnished by a complete plant of six 300 horse power boilers. The present equipment consists of two batteries of two Edgemoor water tube boilers.

The boilers are fitted with Illinois Stoker Company's chain grate stokers, of the horizontal continuous feed type with interlocking grates. The feeding of the four stokers is operated by eccentrics on two shafts mounted above each, driven by either if two stoker engines.

The boiler room floor is of reinforced concrete slabs, supported by enclosed steel beams on steel columns. The floor is designed for a uniform live load of 200 pounds per square foot, and for the concentrated loads of boilers and stokers. The beams are supported by steel columns resting on piers in the basement. The coal bunkers are supported on steel columns passing through holes in the boiler room floor and resting on independent piers. The flat reinforced concrete roof is supported by steel trusses, six in number, which span the entire room and also carry the coal conveyor.

Coal is received from cars on tracks of the Chicago & Western Indiana Railroad. The side track, running south from a trailing switch north of 104th Street, passes through the conveyor house, which forms the major part of the west wing of the station. This conveyor house contains a square elevated structural steel, concrete lined ash bunker, mounted on two steel columns with piers inside of but independent of the building. The hopper is adjacent to the track, and is fitted with a compound spout, so ashes can be emptied into cars on the track or into wagons, which can be backed into the building from the south. There is a receiving hopper under the track, about twenty feet square, which is supported on two 20-inch I-beams. Under the outlet of this hopper is a motor driven coal crusher, designed to crush bituminous coal from run of mine to 1 1/4 inch size, or to give a clear opening for direct feeding into a continuous pivoted bucket conveyor. The continuous carrier runs east and west around the boiler and conveyor rooms, in a vertical plane about four feet south of the south front of the boilers. An apron feed moves the coal from the hopper, east into the crusher, thence down into the buckets with center line at elevation plus 7.67 feet, thence west and upward to the roof, where the motor drive is mounted, thence on a slight up-grade over the ash hopper into the lower part of the boiler room roof trusses with center line at elevation plus 73.76 feet, thence east on a horizontal line over the coal bunkers to the east wall of the boiler room, thence down to the basement to a line just below the boiler room basement floor with center line at plus 10.42 feet in a trench which passes the ash pit doors, thence to the west end of the boiler room where it dips on a slope into the crusher pit. Both vertical runs are enclosed by steel casings, and an ash guard protects the chain in the trench. The carrier conveys both coal and ashes. A stationary dumper or bucket trip is provided over the ash hopper, and two traveling dumpers are located over the coal hoppers. The dumpers can be operated from below. The ashes are fed into the conveyor through removable aprons, which slope from the ash pit doors to the conveyor.

There are at present four bunkers, in pairs of two, or one for each boiler at present installed. Space is provided for two single bunkers for the two boilers required for the eventual capacity of the station.

Each pair of bunkers has a capacity of 170 tons of coal. The single bunkers are to be designed for a capacity of 90 tons. The ash hopper is designed to hold sixty tons of wet ashes. The conveyor carries forty tons per minute, when traveling at a speed of forty feet per minute.

## LAKE VIEW PUMPING STATION.

The Lake View Pumping Station is located at Montrose Boulevard and Clarendon avenue, near the lake shore.

This station has four engine driven pumps, the capacity of each being 25,000,000 gallons per day at a head of 140 feet.

The engine room is rectangular in plan, the outside dimensions of the building being 71 feet by 175 feet. The pumping engines are of the vertical triple expansion, crank and fly wheel condensing type with Riedler type valves and are placed side by side on the north and south centerline of the building. Each engine has an air pump which is located just to the west of each engine.

A short tunnel runs to each pair of engines from a shaft located east of the station. These short tunnels terminate in shafts into which the suction pipe for each engine extends. Each suction pipe is controlled by a 42 inch hydraulically operated gate valve set horizontally.

Four 30-inch discharge pipes are provided for each engine, each pipe controlled by a hydraulically operated gate valve. Two of these connect to the east discharge main, and two to the west discharge main. These mains run the length of the station and out into a discharge vault located in Montrose Boulevard, where they are cross-connected by a 48 inch hydraulically operated valve. In each of the discharge mains, which are 48 inches in diameter, is located a Venturi meter tube which is connected to a recording Venturi meter located in the engine room.

The boiler house is 59 feet by 175 feet and is located to the west of the engine room. In the south end of the boiler house are located the offices, locker rooms, wash rooms, etc.

In the boiler room are located five 320 H.P. Sederholm type fire tube boilers and one separately fired superheater, each boiler being provided with a vertical feed pump, the five pumps being located in the center of the room.

A chain grate stoker is provided for each boiler and for the superheater, fed from coal hoppers above by spouts. A bucket conveyor feeds the hoppers from the coal storage house, which is located north of the boiler and engine rooms. This building is 32 feet by 222 feet and is three stories high, being provided with thirteen bunkers, the capacity of each bunker being 250 tons of coal. At the west end of the coal storage house are located the shops.

Coal is brought to the station by wagon, weighed and dumped into a hopper located between the storage and boiler houses. From this hopper the coal may be run to the coal crusher, or to the north and south conveyor which feed into the bunkers in the boiler house, or into the east and west conveyor which feed into the storage bunkers. From the crusher the coal can be run either into the north and south conveyor or into the east and west conveyor.

## DESCRIPTION OF ELECTRICAL PLANT.

### TWENTY-SECOND STREET PUMPING STATION.

At the Twenty-second Street Pumping Station there are, in addition to the four steam driven units, at present installed two motor driven centrifugal pumps, each with a capacity of 25,000,000 gallons against a head of 120 feet. Each unit is installed in a pit between two of the steam driven pumps.

The pumps are of the single stage turbine type made by the Platt Iron Works. The motors are rated at 1000 H.P. and are of the inducto-synchronous type, operating on 440 volts, 60 cycles, three phase alternating current, starting as slip ring induction motors and may be operated as induction motors or as synchronous motors. Closing the last starting switch cuts out all starting resistance and connects the exciter to the rotor circuit, which is so wound that fixed poles are formed and the machine operates as a synchronous motor. The exciter armature is mounted on the rotor shaft.

The incoming lines, of which there are two, are 12,000 volt lines direct from the Thirty-ninth Street sub-station of the Sanitary District. The oil switches and high tension bus work are located in the basement. Two three-pole oil switches connect the 12,000 volt busses to six single-phase, oil insulated, water cooled transformers, which are located on the engine room floor. These transformers are rated at 275 KVA, 60 cycles, single-phase and step down from 12,000 volts to 440 volts. Three pole oil switches connect the low tension busses to the motors and starting panels. The oil switches are all remote controlled, lever operated, provided with no voltage and overload release, the operating handles being located on the switchboard in the engine room. The following instruments are provided for each motor: Ammeter; Wattmeter; Power factor indicator; Graphic recording wattmeter, Watt-hour meter. Two volt meters are provided connected to voltmeter receptacles.

## ELECTRICALLY OPERATED PUMPING STATION.

The following is a brief description of the proposed pumping station, drawings of which are attached hereto.

The building is 94 feet 9 inches wide and 207 feet 4 inches long. The pumping units, of which there are six, will each have a capacity of 25,000,000 gallons per day against a head of 140 feet. They will be located in the basement at an elevation of -12.0 feet. The pumps are of the turbine type, with double suction so arranged as to draw water from either of the two tunnels. A hydraulically operated gate valve will control each suction tube. The discharge will also be double, with hydraulic valves, so that either discharge main may be fed.

The two 48-inch discharge mains will traverse the length of the station to discharge into the mains running both north and south from the station.

The motors will be rated at 900 H.P., 440 volts, 60 cycles, three phase, 1200 R.P.M. They will be of the slip ring induction type, with secondary resistance, of sufficient capacity to operate continuously at 10 per cent below full load speed, mounted to the west of each motor. Two synchronous condensers will then be installed, each of sufficient capacity to make up for the wattless current in all six motors and provide unity power factor on the lines.

As an alternative, inducto-synchronous may be installed of a type similar to those at the Twenty-second Street station.

The transformers will be three-phase, 60 cycles, oil insulated self-cooling, rated at 750 KVA. Seven transformers will be installed to provide one spare for emergency. The transformers will be installed in concrete compartments at an elevation of plus 10.5 feet. Each transformer will be set on a steel truck and a runway and transfer truck will be provided west of the transformer compartments for facility in cleaning, and interchanging transformers. In a passageway east of the transformers will be provided three oil pumps to keep oil circulating through the transformers. An oil dryer and filter will also be provided in this passageway. Oil piping will be run on the west wall of this passageway, proper connections and valves being provided to transformers, pumps and dryer. For emergency purposes a quick opening valve will be installed on each transformer with connections to the sewer, to provide for quick draining of transformers.

On a platform above the transformer compartments will be installed the switchboard with all necessary instruments. All oil switches, disconnective switches, current and potential transformers, and high and low tension bus work will be installed in compartments in back of the switchboard.

The high tension bus work will be installed in alberene troughs above the switches. Slabs will be laid on top of the troughs, so all repairs will be made from above.

All bus bars and connections will be in duplicate and properly sectionalized, as shown on wiring diagram, to insure reliability of service. Four 12,000 volt lines will be brought in from two sources. Only two of these lines will be in service at one time, the other two running to some separate source of power for emergency service.

In the basement will be located the following apparatus, all motor driven:

Ventilating fan, for transformer compartments.

Fire pump, with capacity of 500 gallons per minute at a head of 200 feet.

Vacuum cleaner.

Air compressor.

Oil pump, for pumps and motors.

For heating the station two 66" x 16' 0" return tubular low pressure boilers will be installed at the south end of the basement.

Coal storage space will be provided in the basement below the transformer runway, with a motor-driven coal handling crane. Coal will be received in cars and dumped into a hopper on the west side of the station. From the hopper the coal will run into the basement where it will be handled by the crane.

Above the transformer runway, at the same elevation as the switchboard gallery, will be provided offices, locker rooms and storage rooms.

A machine shop is provided above the boiler room, and public toilet rooms at the opposite end of the station.

## COMPARISON OF STEAM AND ELECTRIC PLANTS.

It will be at once noted that the chief differences between the steam plant and the electrical plant are those of size and amount of machinery.

The electrical plant takes up approximately 20,000 square feet of ground and a steam plant of the same capacity with the necessary coal storage space would occupy approximately 45,000 square feet at a minimum of actual ground covered. Actually, nearly 60,000 square feet would be necessary, owing to the irregular shape of the buildings. That is, the steam plant requires almost three times as much ground as an electric plant of the same capacity.

The steam plant, too, has an immense amount of machinery, moving parts which require attention and frequent repairs. These factors are shown in the operating costs which will be gone into later.

The valve gear on a vertical, triple-expansion engine is an intricate mechanism, and requires expert attention to secure the best results. A large pumping engine, such as those at the Roseland and Lake View stations, is not economical unless it receives the proper care. A large number of oilers are required to see that all moving parts are properly lubricated, and machinists' services are frequently required to repair and readjust the machinery. The air pumps, air compressors, oil pumps, etc., add considerably to the total to increase the attendance and repair accounts.

In the boiler room we also find a large amount of machinery, moving parts which require attention and repairs. Boiler feed pumps, stoker engines, conveyor systems, chain grates, etc., all need oiling, adjustment and frequent renewals of moving parts. Boilers and furnaces require replacement of tubes and fire brick. Steam piping from boilers to engines and feed water piping require renewal of packing in joints and re-covering with non-conducting material.

In the electrical station the moving parts are few and not subject to breakage or damage, as they can be made large and rugged. Only four bearings on each unit require oiling and the only renewal which would be necessary would be the impeller on the centrifugal pumps.

At the most, only seven men are required on each watch in an electrical station, whereas seventeen are required in a steam station. This, of course, means that a smaller payroll would be necessary for an electrically operated station than for one operated by steam. Also the first cost of a steam station is far in excess of that of an electrical station. These factors are shown in detail in the following pages.

## COST OF AN ELECTRICALLY OPERATED STATION.

The first cost of an electrically operated pumping station containing six motor-driven centrifugal pumps, the daily capacity of each unit being 25,000,000 gallons at a head of 140 feet, such as that described above and shown in drawings attached hereto, is itemized as follows:

| | |
|---|---|
| 6 - 25,000,000 gal. pumps with 900 H.P. motors ..... at $15000.00 each........ | $90,000.00 |
| 7 - 750 KVA 12000/440 volts, OISC transformers, 60 cycles, 3 phase..at $1900... | 13,300.00 |
| Switchboard................................ | 4,500.00 |
| Instruments and meters..................... | 6,350.00 |
| 22 - 300 amp. 12000 volts oil switches...... | 5,500.00 |
| 12 - 2000 amp. 4500 volts oil switches...... | 6,600.00 |
| 440 volt bus bars.......................... | 2,000.00 |
| 12,000 volt bus bars....................... | 3,000.00 |
| Potential transformers..................... | 1,440.00 |
| Current transformers....................... | 1,330.00 |
| Oil pumps, piping, etc..................... | 2,000.00 |
| Wiring, switchboard to motors.............. | 5,000.00 |
| Ventilating fan and ducts.................. | 2,000.00 |
| Fire pump, 500 gal. per min. 200 ft. head... | 3,000.00 |
| Vacuum cleaning system..................... | 2,000.00 |
| Air compressor and piping.................. | 1,000.00 |
| Oiling system.............................. | 500.00 |
| Illumination of station.................... | 6,000.00 |
| Foundations for pumps and motors........... | 6,000.00 |
| Installing motors and pumps................ | 3,000.00 |
| Installing transformers.................... | 1,800.00 |
| Installing switchboard..................... | 500.00 |
| Installing H.T.busses and compartments...... | 3,000.00 |
| 2 - 100 H.P. return tubular boilers......... | 3,000.00 |
| Heating system............................. | 3,000.00 |
| Building................................... | 100,000.00 |
| Land....................................... | 5,000.00 |
| Suction and discharge piping............... | 30,000.00 |
| Miscellaneous expense...................... | 19,180.00 |
| Overhead charges........................... | 30,000.00 |
| Total cost of station...................... | $360,000.00 |

Hence, it is seen that the first cost of a station of this size will be $360,000.00. Assuming interest at 4% and depreciation at 3%, the fixed charges on this plant will be $25,200.00 per annum.

The above estimated costs of apparatus were obtained, in most cases, from manufacturers; others, including labor costs, being made from unit costs obtained in previous installations of apparatus in generating stations and substations.

## COST OF A STEAM OPERATED STATION.

The largest pumping station at present installed in the city has a daily capacity of 100,000,000 gallons per day. The two most recent stations are those at Roseland and at Lake View. The total cost of the Roseland Station was approximately $1,000,000, and this station has no provision for coal storage. The total cost of the Lake View Station, when completed, will be approximately $1,100,000, not including extra costs due to removal of old plant.

The estimated cost of a steam operated pumping station containing six vertical direct-acting pumping units, each with a daily capacity of 25,000,000 gallons at a head of 140 feet, and the necessary boiler equipment, steam piping, auxiliaries, coal bunkers, etc. is as follows:

| | |
|---|---|
| 6 - pumping engines at $80,000 each....... | $480,000.00 |
| 7 - 320 H. P. boilers and 1 superheater... | 76,000.00 |
| Steam piping............................ | 30,000.00 |
| Breeching............................... | 6,000.00 |
| Pipe covering........................... | 4,000.00 |
| Suction and discharge piping............ | 40,000.00 |
| Buildings - Engine house) Including plumb- | 200,000.00 |
| Boiler house( ing, lighting | 240,000.00 |
| Coal Storage) and heating. | 100,000.00 |
| Conveyor system......................... | 45,000.00 |
| Air compressor.......................... | 3,000.00 |
| Oiling system........................... | 3,000.00 |
| Boiler feed pumps....................... | 7,000.00 |
| Turbo-generators and switchboard......... | 10,000.00 |
| Miscellaneous........................... | 46,000.00 |
| Engineering and inspection.............. | 130,000.00 |
| Total cost of station | $1,430,000.00 |

That is, the first cost of a pumping station of this capacity, operated by steam, would be $1,430,000.00. Assuming interest at 4% and depreciation at 4%, the fixed charges on this station would be $114,400.00 per annum.

The costs presented in the above table were obtained in part from bids on apparatus in stations now erected, and in part from costs of apparatus installed in stations by contract and by city labor.

## SOURCE OF POWER FOR ELECTRICAL STATION.

Electrical power for operating pumping stations, as well as for street lighting and other lighting and power requirements of the City of Chicago may be obtained from three sources, viz.-

Sanitary District of Chicago.

Commonwealth Edison Company.

Municipal Power Station.

Power from the Sanitary District is generated at the Lockport hydroelectric plant, transmitted on overhead lines at 44,000 volts to the terminal station at 31st Street and Western Avenue, and from there underground to the lighting substations and consumers.

The rate for power to the City is $15.00 per H.P. year maximum demand for street lighting and $2.20 per H.P. month maximum demand for power, metered at the terminal station. The power available from this source is limited to the flow of water through the Drainage Canal allowed by the Federal Government. At the present time practically the limit of capacity has been reached, and no additional load can be taken on until the Government permits an increased flow.

The connected street lighting load at the present time is approximately 13,000 K.W. The City has a contract with the Sanitary District whereby this should be increased to 15,000 K.W. in the near future. This increase will be met, it is expected, either by increasing the flow of water through the Canal or by erecting an auxiliary steam station to take the peak load.

The second source of power available is the Commonwealth Edison Company's power stations. An unlimited amount of power may be obtained from this source, at rates which are fixed by contract ordinances with the City. Recently a contract ordinance was passed fixing the maximum rates for the next five years. These rates are given below. They are, however, only maximum rates, and may be reduced from time to time as is seen fit.

The third source of power is a municipal power plant. If such a plant were erected it would provide for all the electrical requirements of the City, such as street lighting, lighting and power in the City Hall and other municipal buildings, and light and power in pumping stations. The total maximum load of the city at the present time is approximately 15,000 K.W. This would be increased to about 20,000 K.W. if an electrically operated pumping station were built.

Hence, if a power plant were built, five 5,000 KVA units would be the initial installation, together with the necessary auxiliaries, boilers, transformers, control apparatus, etc. The cost of this plant would be approximately $2,250,000, the fixed charges, at 8%, being $180,000 per year. The labor cost, based on the present cost of labor to the City, would be $88,500.00 per annum, and the cost of supplies and repairs, including coal, would be $410,000.00 per annum. Hence, the total cost of production would be $678,500.00 per year.

The total power output per year would be approximately 100,000,000 kilowatt hours per year, made up as follows:

| | | |
|---|---|---|
| Street lighting........... | 64,000,000 | KW hours. |
| Pumping load.............. | 26,000,000 | " |
| City Hall and Misc. load.. | 10,000,000 | " |
| Total..................... | 100,000,000 | KW hours. |

Hence, the average cost of power generated would be practically $0.007 per kilowatt hour, not including any transmission losses.

OPERATING COSTS OF AN ELECTRICALLY OPERATED STATION.

The annual operating costs of an electrically operated pumping station, estimated from unit costs of operation of steam stations and electrical sub-stations, are given in the following pages.

The attached load curve was adapted from those of the past two years for the present 68th Street station, as published in the annual reports of the Department of Public Works of the City of Chicago. Practically the same shaped curve was used, the maximum demand being increased from about 90 million gallons to 150 million gallons.

In making the calculations for the power demands, given in the following table, the overall efficiency of the pumping units was taken at 70%, since this efficiency was obtained on the 22nd Street pumps, and a higher efficiency than this is guaranteed by the manufacturers.

The monthly load factor is assumed as being 85%, as calculations showed that load factors of from 85% to 95% are obtained at the present steam operated stations of the City.

The charge of the Sanitary District is based upon a cost of $2.20 per H.P. per month maximum demand, with an added charge of 5% of the total for transmission and transformer losses and $8400.00 per annum for fixed charges on transmission lines.

The cost of power from the Commonwealth Edison Company is based upon the following costs, as determined in the above mentioned contract ordinance between the company and the City;

Primary charge:

First 200 K.W. at $23.00 per K.W. per year.

Next 800 K.W. at $17.00 per K.W. per year.

Over 1000 K.W. at $15.00 per K.W. per year.

Secondary charge:

First 5,000 K.W.H. at $0.025 per K.W.H.

Next 95,000 K.W.H. at $0.0075 per K.W.H.

Next 900,000 K.W.H. at $0.0055 per K.W.H.

Over 1,000,000 K.W.H. at $0.0045 per K.W.H.

In addition, 2% is added to the total for transformer losses, since power is to be metered on the high tension side of the transformers.

# COST OF POWER FOR ELECTRICALLY OPERATED PUMPING STATION.

| MONTH | MAXIMUM DEMAND MILLION GALLONS PER DAY. | K.W. MAXIMUM DEMAND | H.P. MAXIMUM DEMAND | TOTAL PUMPAGE MILLION FOOT GALLONS. | POWER CONSUMPTION KILOWATT HOURS | COST OF POWER COMMONWEALTH EDISON COMPANY | COST OF POWER SANITARY DISTRICT OF CHICAGO. |
|---|---|---|---|---|---|---|---|
| JAN. | 150 | 3910 | 5250 | 536,000 | 2,390,000 | $12,047.50 | $11,550.00 |
| FEB. | 140 | 3650 | 4900 | 500,000 | 2,230,000 | 11,327.50 | 10,780.00 |
| MAR. | 140 | 3650 | 4900 | 500,000 | 2,230,000 | 11,327.50 | 10,780.00 |
| APR. | 130 | 3390 | 4540 | 464,000 | 2,074,000 | 10,627.50 | 9,988.00 |
| MAY. | 125 | 3260 | 4370 | 446,000 | 1,990,000 | 10,237.50 | 9,610.00 |
| JUNE | 125 | 3260 | 4370 | 446,000 | 1,990,000 | 10,237.50 | 9,610.00 |
| JULY | 135 | 3520 | 4720 | 482,000 | 2,150,000 | 10,957.50 | 10,400.00 |
| AUG. | 150 | 3910 | 5250 | 536,000 | 2,390,000 | 12,047.50 | 11,550.00 |
| SEPT. | 140 | 3650 | 4900 | 500,000 | 2,230,000 | 11,327.50 | 10,780.00 |
| OCT. | 125 | 3260 | 4370 | 446,000 | 1,990,000 | 10,237.50 | 9,610.00 |
| NOV. | 125 | 3260 | 4370 | 446,000 | 1,990,000 | 10,237.50 | 9,610.00 |
| DEC. | 125 | 3260 | 4370 | 446,000 | 1,990,000 | 10,237.50 | 9,610.00 |
| TOTAL | | | | 5,748,000 | 25,644,000 | 130,850.00 | 123,878.00 |
| | | | | | | 61,850.00[1] | 6,194.00[3] |
| | | | | | | 192,700.00 | 8,400.00[4] |
| | | | | | | 3,854.00[2] | |
| TOTAL COST OF POWER PER ANNUM. | | | | | | 196,554.00 | 138,472.00 |

1- PRIMARY CHARGE.
2- 2% TRANSFORMER LOSSES.
3- 5% TRANSMISSION AND TRANSFORMER LOSSES.
4- FIXED CHARGES ON LINES.

As shown in the above table, the maximum demand is 3910 K.W. and the total power consumption is 25,644,000 kilowatt hours. This indicates an annual load factor of 76%.

The Commonwealth Edison Company will also furnish emergy at the terminal sub-station, located at 31st Street and Western Avenue, at a primary charge of $15.00 per K.W. per year, and a secondary charge of $0.004 per kilowatt hour. Adding 5% for losses and $8400.00 per year for fixed charges on transmission lines, the cost of power from this source is as follows:

| | |
|---|---|
| Primary charge-3910 K.W. at $15.00.... | $ 58,650.00 |
| Secondary charge- 25,644,000 K.W.Hrs. at $0.004 per K.W. hr....... | 102,576.00 |
| Total.................................. | 161,226.00 |
| Five per cent. losses................... | 8,061.00 |
| Fixed charges on lines................ | 8,400.00 |
| Total cost of power.................... | $177,687.00 |

The following table gives the estimated cost of labor, supplies and repairs in a station of this capacity. These are estimated from the cost of operating the present steam stations of the City.

LABOR.

| | |
|---|---|
| Chief operating engineer (1)......... | $2,500.00 |
| Assistant operating engineers (3).... | 6,000.00 |
| Motor tenders (6).................... | 6,480.00 |
| Janitor (1).......................... | 960.00 |
| Laborers (3)......................... | 2,700.00 |
| Extra labor during winter a/c heating | 1,200.00 |
| Total cost of labor per annum....... | $19,840.00 |

## SUPPLIES AND REPAIRS

| | |
|---|---|
| Coal for heating.............. | $1,200.00 |
| Oil, waste, etc............... | 800.00 |
| Office supplies............... | 200.00 |
| Telephone..................... | 125.00 |
| Motor and electrical repairs.. | 4,000.00 |
| Pump repairs.................. | 1,000.00 |
| Hauling ashes................. | 100.00 |
| Building repairs.............. | 300.00 |
| Total supplies and repairs.... | $7,725.00 |

As shown above, the fixed charges on a station of this description amount to $25,200.00 per annum. Hence, the total annual cost of operation of a plant of this sort would be $191,237.00 using Sanitary District power, or $249,319.00 using Commonwealth Edison power, direct from the generating station.

OPERATING COSTS OF A STEAM OPERATED STATION.

The following table of costs of labor, supplies, repairs and fuel are taken from the operating costs of the present pumping stations of the City, properly proportioned to a station of this size. The majority of the costs are taken from the Roseland Station, as this is the most modern station and shows the lowest operating costs.

LABOR.

| | |
|---|---|
| Chief operating engineer (1).......... | $ 2,500.00 |
| Assistant operating engineers (3)..... | 6,000.00 |
| Oilers, 15 at $1080.00................ | 16,200.00 |
| Water tenders, 4 at $1290.00.......... | 5,040.00 |
| Coal tenders, 4 at $1000.00........... | 4,000.00 |
| Boiler washer, (1).................... | 1,260.00 |
| Janitor (1)........................... | 960.00 |
| Laborers, 6 at $2.50 per day.......... | 5,400.00 |
| Conveyor engineer (1)................. | 1,460.00 |
| Total labor........................... | $42,820.00 |

SUPPLIES AND REPAIRS.

| | |
|---|---|
| Oil, waste, etc....................... | $ 2,600.00 |
| Office supplies....................... | 200.00 |
| Illumination.......................... | 800.00 |
| Telephone............................. | 125.00 |
| Pump and engine repairs............... | 5,000.00 |
| Boiler and furnace repairs............ | 4,000.00 |
| Steam piping repairs.................. | 4,000.00 |
| Hauling ashes......................... | 3,600.00 |
| Building repairs...................... | 1,000.00 |
| Total supplies and repairs............ | $21,325.00 |

## FUEL.

At the Roseland Pumping Station the average cost of coal during the year 1912 was $1.815 per ton. At this price the cost of pumpage was $0.0121 per million foot gallons. The average cost of all pumping stations was $0.0166 per million foot gallons. Had coal cost $3.00 per ton, as it did at the Lake View Station, the average cost, taking into account the difference in B.T.U., would have been $0.019 per million foot gallons. As shown above, the total pumpage at the proposed station is 5,748,000 million foot gallons per year.

Hence, the cost of fuel on the above three bases would be as follows:

| | |
|---|---|
| At $0.0121 per M.F.G.......... | $ 69,500.00 |
| At $0.0166 per M.F.G.......... | 95,400.00 |
| At $0.0190 per M.F.G.......... | 109,200.00 |

As shown above the fixed charges on a steam station of this capacity would be $114,400.00 per annum.

Summarized, the total operating costs are as follows, omitting the cost of fuel:

| | |
|---|---|
| Labor.................... | $ 42,820.00 |
| Supplies and repairs.... | 21,325.00 |
| Fixed charges........... | 114,400.00 |
| Total..................... | $178,545.00 |

With cheap fuel, such as is obtainable at Roseland and 68th Street Stations, the total cost is $248,045.00 per year.

With average fuel the total cost is $273,945.00.

With expensive fuel, such as is used at Lake View, Chicago Avenue and Fourteenth Street Stations, the total cost of operation amounts to $287,745.00 per annum.

It should be noted that cheap fuel is obtainable at, practically, only one station in the city. This is at the Roseland pumping station, which is located on a railroad, near the southern end of the city. At all other stations coal is more expensive, the cost running up to $3.00 per ton at the stations to which it is delivered by wagon.

## RELATIVE ADVANTAGES OF STEAM AND ELECTRICAL OPERATION.

The great advantage of a steam operated pumping station is, of course, its reliability. Practically nothing short of a severe boiler explosion could throw an entire steam station out of service, whereas an electrically operated station, unless great care is taken in its design, could be eliminated from the system by any one of a number of causes.

The electrical station can, however, by proper design and by making use of public service energy, obtaining energy from at least two independent sources, be made fully as reliable as the steam operated station. For instance, if a station were to be located at 68th Street, two lines would be run from the Quarry St. station of the Commonwealth Edison Company, and two from the Blue Island plant of the Public Service Company of Northern Illinois. Quarry Street would normally feed the station, but in case of accident to the lines or at the power station, the load would be immediately transferred to the Blue Island lines.

In a similar manner, a pumping station located north of, say 35th Street, would have two lines from Quarry Street and two from the Northwest Station of the Edison Company. As a matter of fact, the chances of using the emergency lines would be very remote, as the Edison Company's service is very reliable. This is illustrated by the fact that they serve the Street Railway Companies unfailingly, and would give equally continuous service to a pumping station.

The more important advantages of the electrical station are as follows:

It requires less ground space, covering approximately one third the area of a steam station of equal capacity.

It necessitates about one fourth the capital investment that is required for a steam station.

Repairs are more easily, cheaply and quickly made than in a steam station. In fact, a spare unit could be provided at small extra cost, so that six units would at all times be ready for service.

The most important advantage of the electrical station is, however, that it can be located at the exact center of distribution of the territory which it is to serve. The benefits of this are incalculable, as it results in the following:

Permits of a lower head being carried at the station.

More nearly equal pressure at various points in the water main.

Smaller leakage in mains.

Shorter suction tunnels or discharge mains.

Smaller pumpage at the station to give the same service, owing to lower head allowable and consequent smaller leakage in mains and plumbing, and other losses.

In addition to this, the cost of electrical energy is constantly decreasing in Chicago, owing to the increasingly diversified load which the Edison Company is obtaining, whereas the cost of coal is increasing.

This means that electrical operation will become increasingly advantageous as the cost of electrical energy decreases and the cost of coal increases.

As shown above, with cheap coal, such as can be obtained at the southern end of the city where a pumping station is located on a railroad, the total cost of operation, including fixed charges, is $248,045.00 per annum. Using Commonwealth Edison Company power the annual cost of operating an electrical station is $249,319.00, a net saving per year of $1,274.00 in favor of the steam station. If Sanitary District power could be made sufficiently reliable and utilized, the cost of operation would be $191,237.00, making a net saving of $56,808.00 per year in favor of electrical operation.

At a steam station not located on a railroad track the total cost of operation would be $287,745.00. With Edison power the saving by using electrical operation would be $38,426.00, and by using Sanitary District power $96,508.00, per annum.

A legitimate comparison of the two types of stations could be made on the basis of the operating costs of a steam station located on a railroad and the operating costs of an electrical station located at the center of distribution. In the latter case a head of 100 feet at the station would suffice to give the same service that would be given by a station carrying 140 feet at the outer limit of the territory served.

The cost of power at an electrical station carrying a pressure of 100 feet and pumping the same amount of water that is given in the table on page 38 is $147,305.00 for Edison service and $101,308.00 for Sanitary District service. The total cost of operation is $200,070.00 using Edison service, and $154,073.00 using Sanitary District service. This shows a saving of $47,975.00 for Commonwealth Edison service, and $93,972.00 for Sanitary District service per annum over a steam station located at the outskirts of the territory and using the cheapest fuel.

The cost of fuel for a steam station located at the center of distribution would be $78,964.00 per annum, assuming coal at $3.00 per ton. The total cost of operation would then be $257,509.00 per annum, showing a saving in favor of electrical operation of $57,439.00 using Edison service and $103,436.00 using Sanitary District service. The probabilities are, however, very remote that it would be possible to locate a steam station at the center of distribution, as this would generally be in a residence territory.

## CONCLUSION

It is very evident from the above figures that electrical operation of pumping stations would result in large savings to the City of Chicago. Even under adverse comparisons electrical operation is shown to be cheaper, whereas under conditions which obtain at most of the stations, electrical operation shows an extremely large reduced cost of operation. It is not at all improbable that the Commonwealth Edison Company would reduce its rates to the City for a load such as this, where the annual load factor is 76%, to a point comparable with the rates of the Sanitary District of Chicago.

From the power costs calculated above it is seen that the cost of Commonwealth Edison energy is $0.0077 per kilowatt hour, and of Sanitary District energy is $0.0054 per kilowatt hour.

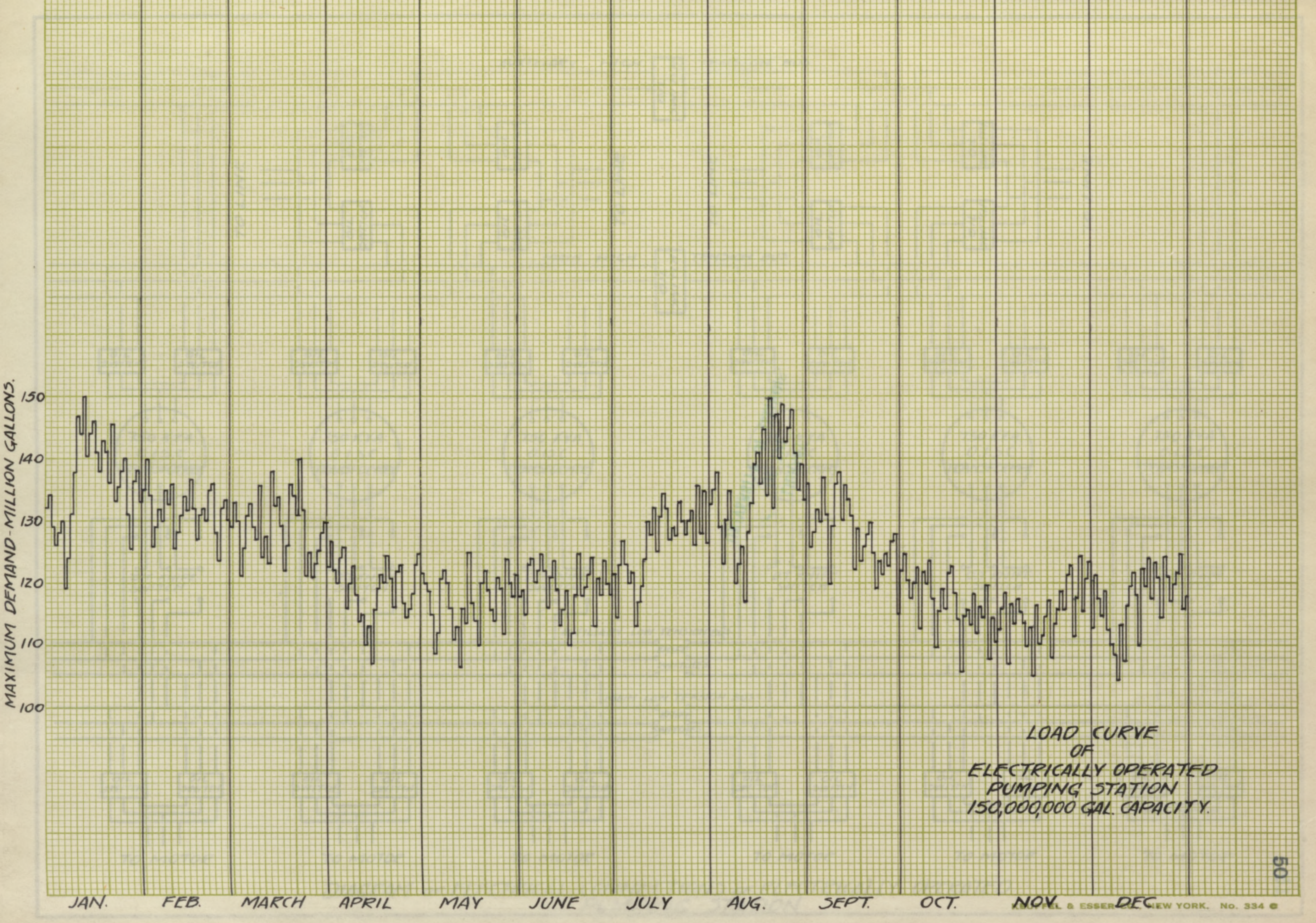
Reliability of service is the most important factor in the supply of water for municipal purposes. Protection from fire hazard necessitates the maintenance of pressure on the mains at all times, requires infallible service. This can be obtained by steam operation, as the chances of the complete shut-down of a station are extremely remote. Reliability can only be obtained with electrical operation by having all feeders underground, and by having feeders installed from at least two separate and independent sources.

The energy generated by the Sanitary District at the Lockport plant is transmitted on overhead lines to Chicago. This introduces a factor of unreliability, owing to the danger of interruption of service by lightning disturbances. Also, since the plant is a hydroelectric station, shutdowns are liable to occur during extremely cold weather, due to ice floating down the river and canal from the lake and choking the intakes.

As previously shown, it is very doubtful if the City can, in a municipal power station, generate and transmit power for less than $0.007 per kilowatt hour. There would, therefore, be no advantage, financially, in the City building its own plant. In addition, service of this kind would not be the best for pumping purposes, as there would be some degree of unreliability in the service.

Hence, the only practicable source of power for an electrically operated pumping station would be the public service company's plant, since the service would be continuous, and, for an extra safeguard, could be obtained from two independent sources. In addition, the cost of power from this source is at least as low as the City could itself generate and distribute the current, and in all probability could be brought lower.

In conclusion, it has been proven, in the facts and figures presented herein, that electrical operation of pumping stations is not only practicable and feasible, but that the cost is lower than that of steam operation.


MAXIMUM DEMAND-MILLION GALLONS.
150
140
130
120
110
100
JAN.
FEB.
MARCH
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
LOAD CURVE
OF
ELECTRICALLY OPERATED
PUMPING STATION
150,000,000 GAL. CAPACITY.
NEW YORK. No. 334

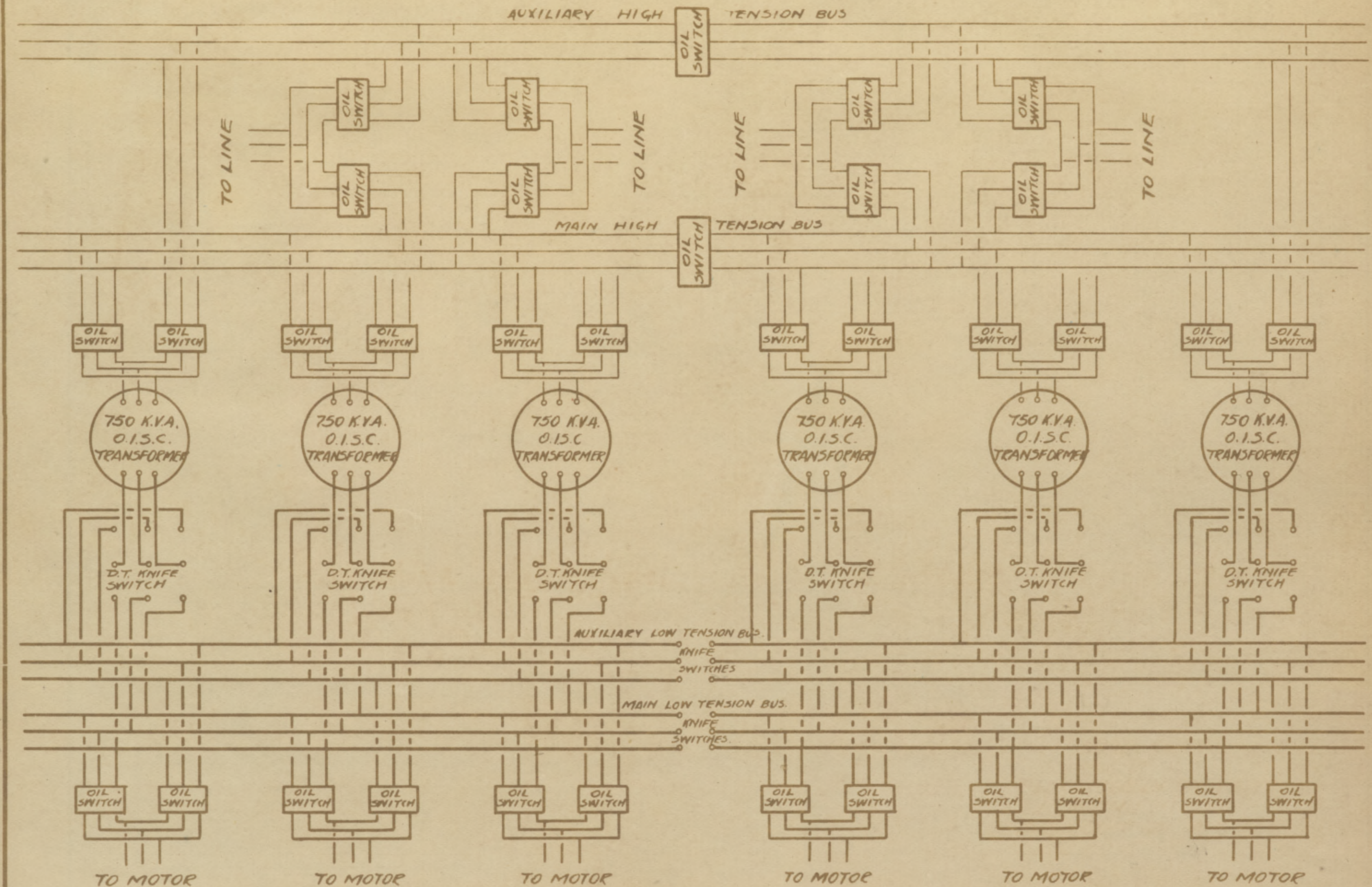
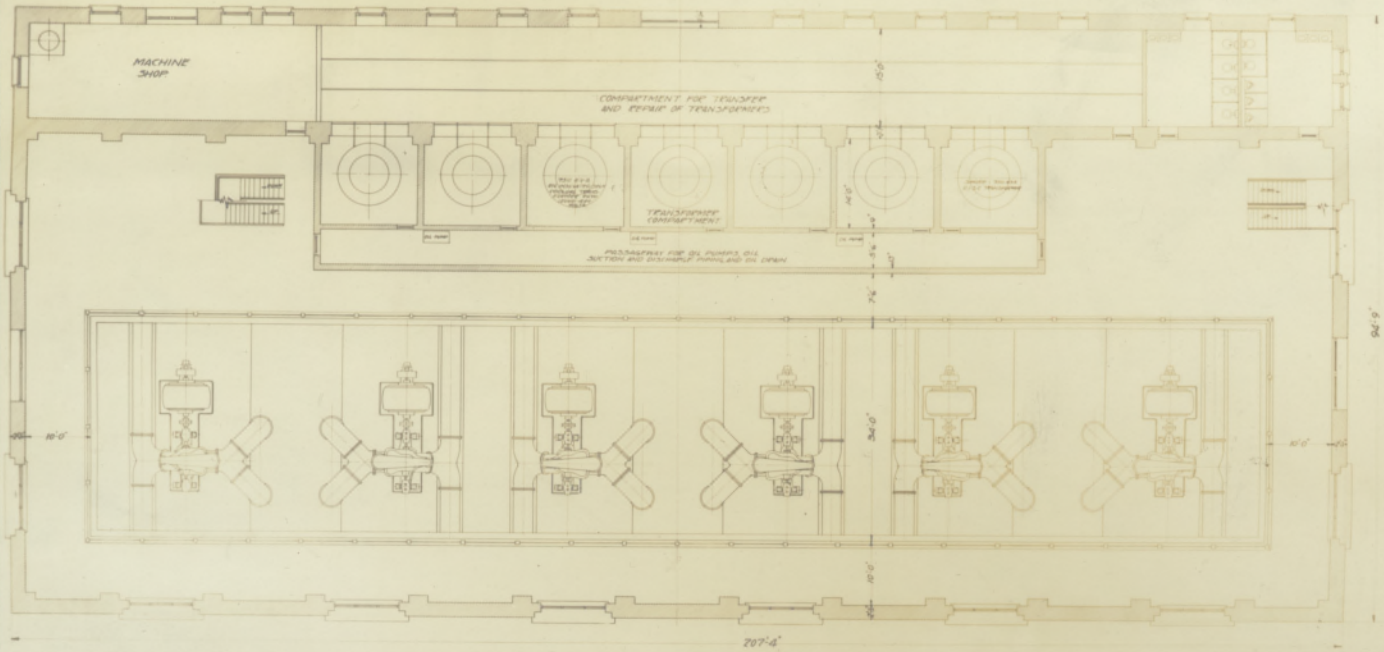
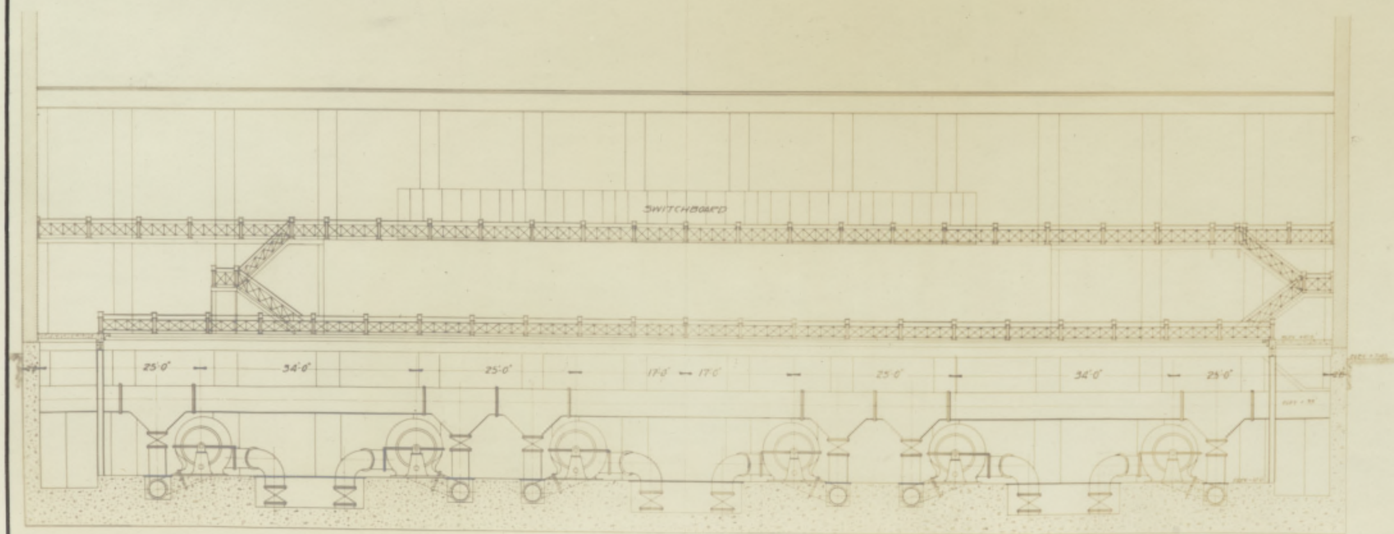


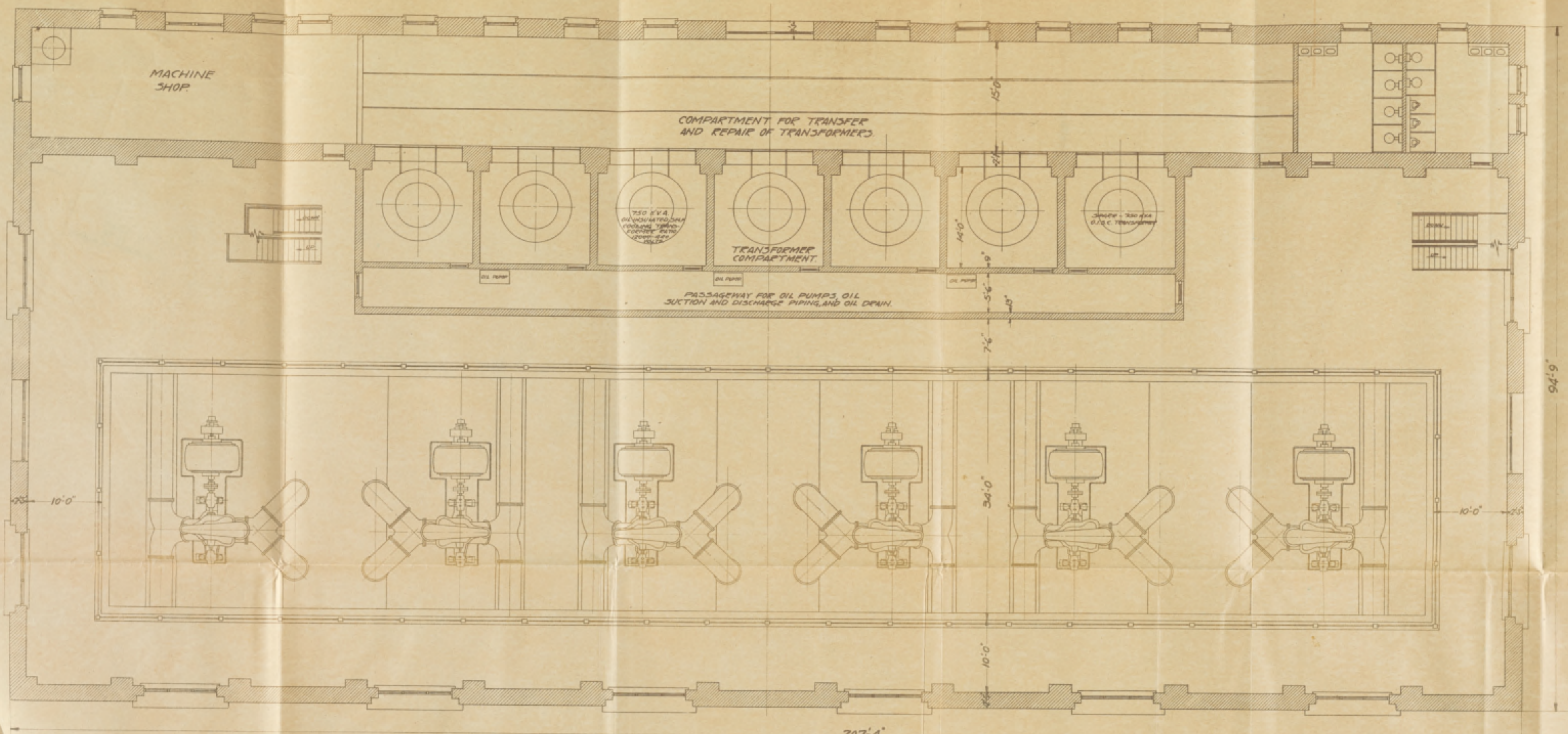

DIAGRAM OF ELECTRICAL CONNECTIONS OF ELECTRICALLY OPERATED PUMPING STATION

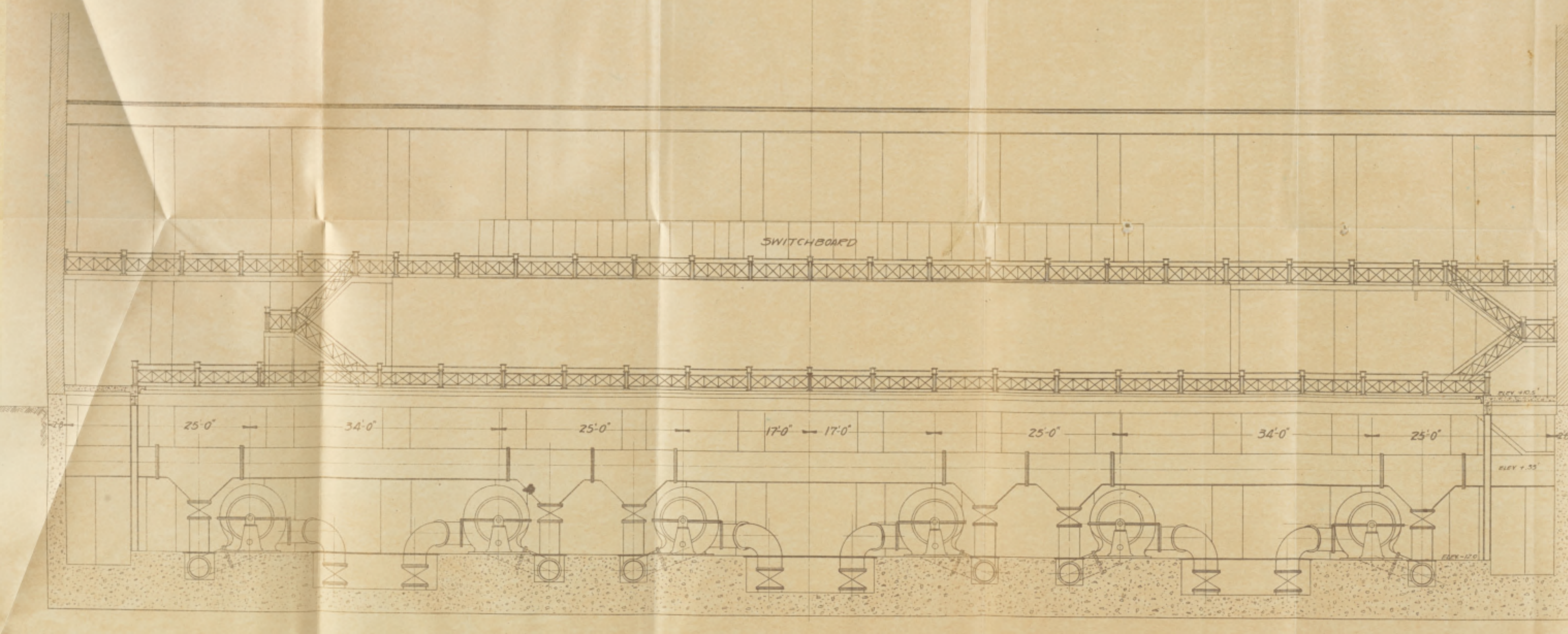


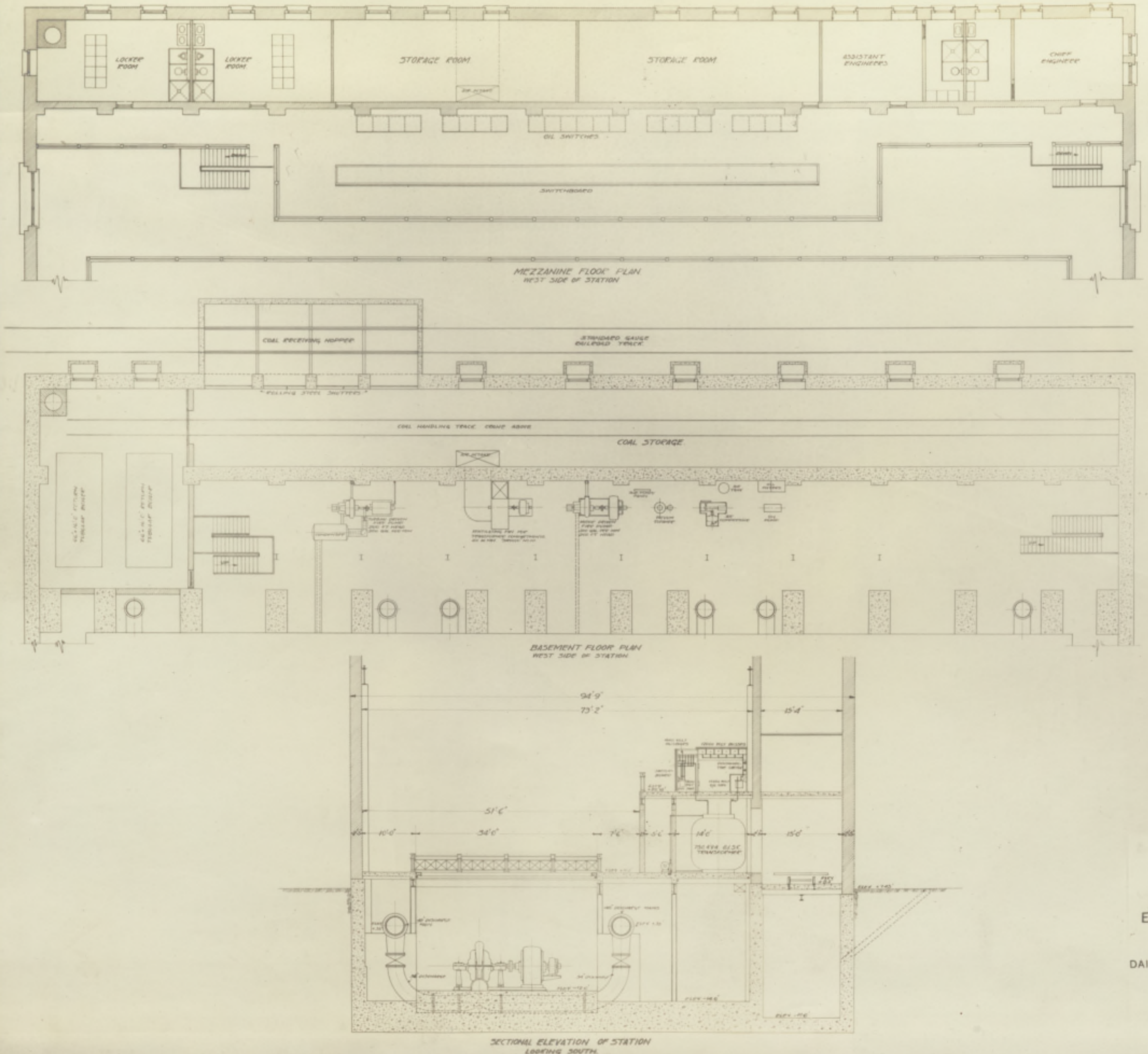

ELECTRICALLY OPERATED
PUMPING STATION

DAILY CAPACITY 150,000,000 GALLONS

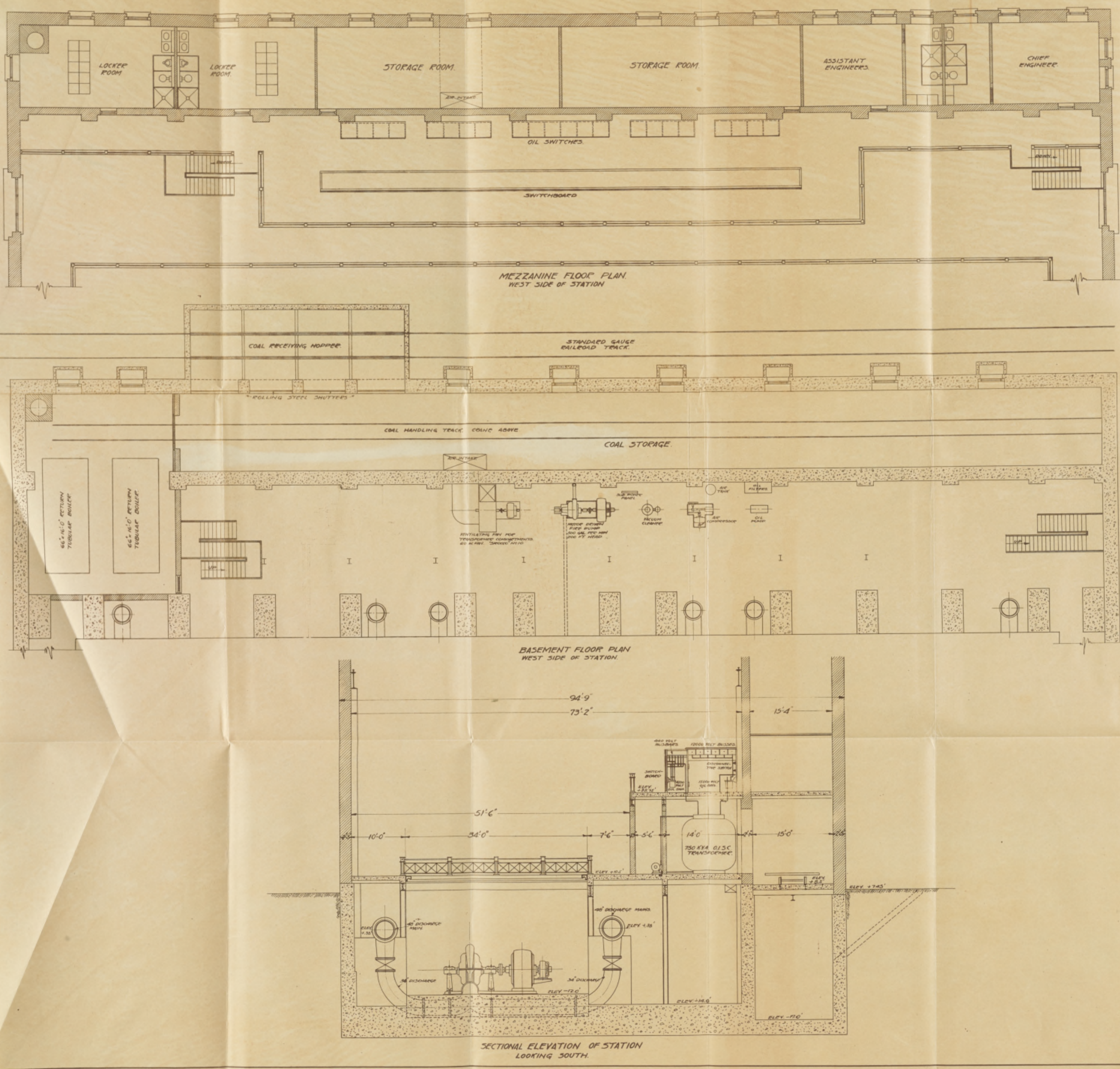



ELECTRICALLY OPERATED PUMPING STATION
DAILY CAPACITY 150,000,000 GALLONS




ELECTRICALLY OPERATED
PUMPING STATION
DAILY CAPACITY 150,000,000 GALLONS




ELECTRICALLY OPERATED
PUMPING STATION
DAILY CAPACITY 150,000,000 GALLONS


PUMPING STATION.
CITY OF CHICAGO
DEPARTMENT OF PUBLIC WORKS
BUREAU OF ENGINEERING
WATER PIPE EXTENSION DIVISION
MAP OF
CHICAGO WATER SYSTEM
SHOWING
WATER MAINS 12 IN. IN DIAM. AND LARGER
ALSO
PUMPING STATIONS, CRIBS & TUNNELS
Scale: 1 in. = 1 mile
Date, September, 191
Correct
Engineer W. P. Ext.
Approved
Assistant City Engineer
Approved
Superintendent W. P. Ext.
Approved
City Engineer
Drawn by F.H.
LAKE MICHIGAN
INDIANA
C.H. HARRISON CRIB
TWO-MILE CRIB
CHICAGO AVE. PUMP. STA.
FOUR-MILE CRIB
14TH ST. PUMP. STA.
HARRISON ST. PUMP STA.
CENTRAL PARK AVE PUMP STA.
22ND ST. PUMP. STA.
SPRINGFIELD AVE. PUMP STA.
LAKE VIEW PUMP STA.
ROGERS PARK PUMP STA.
EDISON PARK PUMP STA.
NORWOOD PARK PUMP STA.
HYDE PARK CRIB
E. F. DUNNE CRIB
PROPOSED WESTERN AVE. PUMP STA.
WASHINGTON HEIGHTS PUMP. STA.
ROSELAND PUMP STA.
LAKE CALUMET
PROPOSED CALUMET PUMP STA.
WOLF LAKE
SANITARY DISTRICT
CITY LIMITS