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The Honorable
Board of County Commissioners
RAMSEY COUNTY, MINNESOTA

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John Leinen
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STANDING COMMITTEE ON
LAKE IMPROVEMENT

John Leinen
Leo F. Groos
Herbert P. Keller

FOREWORD

Prior to the Spring of 1923, Lake Improvement in Ramsey County had been conducted without any comprehensive program pointing to a final goal.

A Lake Improvement fund had been established from which appropriations were made, from time to time, for miscellaneous improvements considered of necessity and for the best interests of the taxpayers and the public at large.

During the expenditure of these funds so many questions were raised in regard to the advisability of different phases of the work, that the necessity of a thorough study of the conditions governing such work became obvious. No connected records existed at that time in regard to the action of the elements and the natural phenomena so vital to the existence and development of our lakes.

The following report is the result of the first step taken by the Board of County Commissioners to establish a firm foundation on which a comprehensive plan of lake improvement can be developed.

It is hoped that this report will answer a great many questions that have heretofore been the cause of argument, dissatisfaction, and hesitation on the part of those most desiring to protect and develop the lakes. The data that has been collected is of great value in spite of the fact that it extends over such a short period of time. The value of this data will increase as it is supplemented by future records, and will be the source of deductions on which will depend all future improvement.

TO THE HONORABLE BOARD OF
COUNTY COMMISSIONERS
Ramsey County,
Saint Paul, Minnesota.

Gentlemen:

I have the honor to transmit herewith, the Special Report on Lake Improvement, which has been made possible by your vision, in recognizing the necessity of gathering and correlating data in regard to the natural phenomena, effecting our lakes.

This report treats mainly the general fundamental causes of lake deficiency, excessive weed growth, and mud deposits, and suggests a remedy for improving the conditions resulting from these causes.

It is hoped that the information presented will be of assistance to you in your endeavor to outline a progressive policy of preservation and improvement of our lakes.

Respectfully,

PAUL N. COATES,
County Engineer.

LAKE IMPROVEMENT

PERSONNEL

Lynn J. Lubins, Assistant Engineer

In charge of surveys, investigation, and experimentation.

Algot W. Lindahl	Topographer
Roy O. Glockner	Dredging Supt.
Rudolph Hess	Mechanic

To these men we owe an acknowledgment of thanks and a word of praise. They sacrificed individual recognition in a public service to the end that their respective efforts have blended together to attain the result desired.

PAUL N. COATES,
County Engineer.

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GENERAL FEATURES

Ramsey County is located in the east central part of Minnesota, and was one of the first counties to be organized in the state, being one of the nine counties created by the first legislature in 1849. It is bounded on the north, east, south and west, respectively, by Anoka, Washington, Dakota and Hennepin Counties. It is about twelve miles wide, east and west, and its greatest length, north and south is about sixteen miles. The southern boundary for the most part, is the Mississippi River. The county has an area of one hundred and sixty-one square miles, or approximately one hundred and three thousand acres.

In 1850, when the county included a larger area, the total population was but two thousand one hundred ninety-seven. The present population of Ramsey County is estimated at two hundred and seventy-two thousand, having increased eighteen (18%) percent during the last fourteen years. Ramsey County is by far the most densely populated in the state, and leads also in the density of rural population, with approximately sixty persons to the square mile.

Situated in the extreme southern portion of the county is the city of St. Paul, the capital of the state, and the county seat. Saint Paul, commonly known as the "Gateway City Of The Northwest," is the second largest city in the state. The estimated present population of Saint Paul is two hundred and sixty-two thousand, representing about ninety-five (95%) per cent of the population of the county., Saint Paul not only provides exceptional markets for every variety of farm product, but has extensive industries that utilize these products, including creameries, packing plants and canneries.

Approximately ninety-three (93%) per cent of the area of Ramsey County is upland, the remainder being about equally divided between terraces and low bottom lands along the Mississippi River. The upland surface of Ramsey County is that of a drift plain, holding one general altitude, presenting minor relief features such as, morainic hills and ridges with intervening depressions. The range in elevation is from eight hundred and sixty to one thousand and eighty feet above sea level, the greater part of the county lying between the nine hundred and thousand foot contours. In the northeastern and northwestern portions of the county, are large areas of flat to gently undulating land, much of which is poorly drained and interspersed with lakes and swampy tracts. The Mississippi river has an "S" shaped course along the southern border of the county. Above Fort Snelling, the river flows in a deep channel with an abrupt break of more than one hundred feet from the plain to the river channel.

Drainage is incompletely established over a large part of the county. Two streams, Rice Creek in the northwestern corner, and Phalen Creek, entering the Mississippi at Saint Paul, give the only surface drainage for the entire county. A chain of lakes through the central and northwestern part of the county have natural overflow or drainage channels, but the system is not active except for extreme high lakes stages. The chain of lakes in the north central part of the county (Fig. 2) is extensively drawn upon by the city of Saint Paul as a source of water supply and these lakes are not open for public use for reasons of sanitation. Over most of the county, the runoff finds its way by swales, and shallow indefinite valleys to the lakes and depressions.

Climate

Ramsey county lies in the northern part of the north temperate zone. The climate is characterized by moderate precipitation, cold winters and warm summers. In summer, the days are sometimes hot but the nights are usually cool. The mean annual temperature is about 44° F. Freezing weather has occurred in every month, except June, July and August, but the average growing season is one hundred and sixty days, which is sufficient to permit the production of a good range of crops. The rainfall is well distributed for agriculture and approximately three-fourths of the precipitation falls during the growing season or from April to September, inclusive.

The State of Minnesota is receiving considerable publicity through the use of the well known slogan—"Minnesota, the Land of Ten Thousand Lakes" and "The Playground of a Nation." The slogans truly depict what nature has provided for those who seek diversion from their daily routine.

It is obvious that the lakes and streams and the natural scenery and recreational facilities afforded by them in such abundance in our state, have particularly, since the advent of the automobile and the good roads, become a great factor in the development of the state. The recreation craved by the great "Out-of-Door" public is generally found at or near bodies of water, and by maintaining and preserving our natural advantages in regard to these attractions still further development can be expected and present investments and improvements will be safe-guarded.

What has been said concerning the state, can be truly applied to Ramsey county, which should feel justly proud of its generous allotment of "Minnesota's Ten Thousand Lakes." The county has, wholly or partly within its boundaries, some thirty-five lakes of which a large percentage are accessible to, and used by the public for recreational and home building purposes.

To the county as a whole, the true value of its lakes can be classified as one of the many great assets which have a bearing, or depend, on one another for their proper development. The two factors that go hand in hand in the development of the county are its lakes and roads, for one without the other could not function to its fullest extent in affording the possibilities and realization of its true significance. Let us assume Ramsey county to be a rolling stretch of land without lakes. Then the well developed net work of roads throughout the county such as we have today, would serve the public only as routes between destinations, with little or no attractions for travel outside of business use. The present generation of pleasure seeking "Out-of-doors" people, who have no objection to distance since the automobile came into use, would leave or pass through this county en route to portions of this state where fishing, outing and home building sites are available on many lakes. On the other hand, let us assume that Ramsey county had but a few good roads for travel. Then the existing lakes would naturally be of a wilder nature and would not receive the development and serve the public to their fullest extent for they then could not be approached with the rapidity and comfort desired by those who leave their city or country homes to enjoy the lakes in conjunction with their business. It is true that with such conditions existing, there would be more fish in the waters and a greater possibility of enjoying an outing by those who are able and inclined to seek solitude.

Evaporation

Precipitation and evaporation are two stages in a cycle of phenomena which have neither beginning nor end but which may possibly be experiencing a small progressive increase or decrease.

Under conditions of constant temperature, relative humidity and wind, evaporation from lakes of uniform size and depth should be the same, but in Ramsey County where such conditions are adverse, it is an impossibility to precisely compute the amount of evaporation taking place on each body of water unless stations were established and maintained on each or representative bodies of water. The depth of a lake has considerable to do with the amount of evaporation that takes place. Deep lakes which have a lower water temperature, during the summer months when evaporation is the greatest, are not subject to as much evaporation as the shallow lakes with a higher water temperature.

From experience and actual tests of evaporation made throughout the United States, formulas and curves have been worked out which enable us to compute with some degree of accuracy the amount of evaporation taking place from Ramesy County lakes by using the atmospheric temperature and relative humidity as recorded at the St. Paul and Minneapolis Stations. Following is a tabulation of annual and monthly mean temperatures for various periods as recorded at St. Paul and Minneapolis:

MONTHLY AND ANNUAL MEAN TEMPERATURE AT ST. PAUL AND MINNEAPOLIS

	1820-1923	1871-1923	1890-1923		1907-1923		1924
	St. Paul	St. Paul	St. Paul	Mpls.	St. Paul	Mpls.	*
Jan.	12.4	12.1	13.0	13.5	12.5	12.7	7.5
Feb.	16.1	15.5	14.7	15.0	15.5	15.5	21.3
Mar.	28.9	28.7	29.2	29.6	30.8	30.5	29.4
April	45.4	45.8	46.0	41.6	45.3	45.4	44.1
May	58.2	57.8	57.4	57.5	57.0	57.4	50.2
June	66.6	67.3	67.4	67.5	67.2	67.8	64.3
July	72.4	72.0	72.0	72.3	72.0	72.6	69.4
Aug.	69.3	69.5	69.3	69.6	69.0	69.5	67.5
Sept.	59.7	60.7	61.4	62.1	61.3	62.0	5.73
Oct.	47.6	48.4	49.1	49.6	48.8	49.2	56.3
Nov.	31.7	31.8	32.8	33.3	34.0	34.5	32.5
Dec.	17.8	19.0	19.8	20.0	20.0	20.2	21.5
Annual	43.9	44.1	44.4	44.7	44.4	44.7	43.5

*St. Paul and Minneapolis Mean.

Evaporation constitutes the largest of all natural losses from our lakes. This loss occurs directly from the water area and indirectly from the land area by reducing runoff into the lakes. Transpiration which is the process of vaporization of water from the breathing pores of leaf and other vegetable surfaces, also reduces runoff and has its effect as a loss.

The losses from the land and water area in form of evaporation and transpiration are the only elements counteracting precipitation under normal conditions. The average annual precipitation provided by nature would nearly balance the average annual losses from our lakes, and runoff would supply the deficiencies or cause a rise in lake levels, if there were no other losses.

Computations have been made to determine the evaporation from various county lakes by using the atmospheric conditions as recorded at St. Paul. The evaporation is not uniform on all lakes due to the lakes having various depths. The tabulation following is of the computations made for individual lakes for the twelve month-period beginning December 1st, 1923, to December 1st, 1924, also the recorded precipitation and evaporation loss in inches:

Lake.	Recorded Precipitation Inches	Computed Evaporation Inches	Precipitation Minus Evaporation (Loss in Inches)
White Bear	25.0	29.0	—4.0
Turtle	27.3	30.5	—3.2
Snail	26.6	31.6	—5.0
Johanna	28.5	30.8	—2.3
Josephine	28.5	30.8	—2.3
Owasso	30.6	31.6	—1.0
Kohlman, Gervais, Keller, Phalen	29.8	29.5	+0.3
Island	24.3	33.3	—9.5
Birch	26.5	34.3	—7.8
Round	27.5	31.6	—4.0
Bald Eagle	27.6	30.6	—3.0

Runoff and Drainage Areas

Runoff is the technical name applied to that portion of precipitation which is carried off from the land area into the lakes through surface channels after evaporation, transpiration and deep seepage losses are subtracted. Given rates of precipitation cause different amounts of runoff from drainage areas varying in character and condition. For any given rainfall, the total surface runoff from a pervious sandy drainage area will necessarily be less than from other drainage areas with heavier soils, due to the more rapid absorption of water by the soil. Drainage areas with steep slopes and inclined to be rugged furnish more runoff than those more flat and rolling.

Land under cultivation will, in the spring and fall, absorb considerable rain and reduce the surface runoff, and vegetation will retard the runoff somewhat but its effect is soon lost in case of heavy rains. Runoff from drainage areas in Ramsey County has undoubtedly been reduced by extensive cultivation, but to offset this reduction artificial drainage has enlarged the drainage areas and made possible a better and more speedy runoff from remote parts of the tributary areas.

Surface runoff is usually given a value in the form of percentage, that is, the per cent of the inches of precipitation falling on the drainage area that reaches the lake as runoff. To determine this percentage, it is necessary to know the relative proportion or ratio, of the lake and land areas, also the effect in inches on the lake, that a given amount of precipitation caused. For example, we will assume a lake area of one square mile with a drainage area of four square miles, and a given amount of precipitation over the entire area as four inches, occurring within a few hours. The recorded rise in lake level as a result of this precipitation, we will assume as being six inches. We know that four of the six inches fell directly on the lake, therefore, the two inches represents runoff. The drainage area being four times the size of the lakes would naturally receive four times the amount of precipitation falling on the lake which would amount to the equivalent of sixteen additional inches on the lake, if all the water falling on the drainage area had run off into the lake, but, of a possible sixteen inches, only two inches were recorded as runoff, which in this case, amounts to twelve and one-half per cent runoff.

In making a study of runoff from Ramsey County drainage areas, it was found necessary to make watershed surveys, in addition to lake surveys, to determine the ratio of each lake to its drainage area as illustrated by Fig. 30.

The per cent of runoff from Ramsey County drainage areas during individual storms has been computed by using the measured amount of precipitation falling on the lakes and drainage areas, and the recorded rise in lake levels caused by a single rainfall. The variation in percentages as tabulated below, appears to be too great for a series of lakes with relatively small tributary land areas such as Ramsey County lakes.

OBSERVED RUNOFF OF VARIOUS DRAINAGE AREAS

Lake	Watershed Ratio Land to Water	Snowfall March 30, 1924		Rainfall Aug. 21, 1924, Wet Week Preceding		Rainfall Sept 21, 1924, Dry Week Preceding	
		†	‡	†	‡	†	‡
Bald Eagle	4.6-1	City Pumps Operating				1.23	6¼
Island	2.6-1	2.25	36	3.11	49	0.82	5
Johanna	4.6-1	3.25	23	3.20	11	1.13	7
Josephine	1.1-1	3.25	29	3.20	32	1.13	25
Gervais, Keller, Phalen	9.5-1	3.00	29	2.60	19	1.13	1¼
Long	42.6-1	Overflow		3.11	30	1.03	2½
McCarrons	4.3-1	3.00	37	3.20	22	1.22	21
Owasso	2.9-1	3.00	29	3.59	13	1.54	2¼
Snail	4.4-1	2.25	19	No Record		1.25	1½
Turtle	0.9-1	3.00	63	2.85	68	1.15	58
White Bear	0.95-1	3.75	50	2.74	16	1.06	14

†Precipitation in Inches
‡Observed Percent of Runoff.

CHART SHOWING LAKE AND DRAINAGE AREAS OF VARIOUS RAMSEY COUNTY LAKES

RAMSEY CO. | LAKE ELEV. | LAKE AREA | WATERSHED AREA

CHART SHOWING LAKE AND DRAINAGE AREAS OF VARIOUS RAMSEY COUNTY LAKES

RAMSEY CO. LAKES	LAKE ELEV. Sea Level	LAKE AREA ACRES	LAKE AREA SQ. MILES	WATERSHED AREA ACRES	WATERSHED AREA SQ. MILES	BASIN AREA ACRES	BASIN AREA SQ. MILES	ELEV. OF OVERFLOW	RATIO Water to Land
WHITE BEAR	921.5	2,372.4	3.707	2,261.2	3.533	4,633.6	7.24	ʊ 926.24	1 to .953
BALD EAGLE	909.0	1,069.02	1.67	4,910.92	7.673	5,979.94	9.343	ʊ 910.48	1 to 4.59
ISLAND	943.0	57.11	.09	149.61	.23	206.72	.32	945.8	1 to 2.62
ROUND	889.5	128.00	.20	394.49	.616	522.49	.816	890.4	1 to 3.08
VALONTINE	876.4	(58.88)	(.092)	Lake Area	is included	in Long Lake	Area.	876.5	
LONG	864.3	343.97	.537	14,642.95	22.88	14,986.92	23.417	865.0	1 to 42.61
JOHANNA	874.7	201.58	.315	934.64	1.46	1,136.22	1.775	● 878.30	1 to 4.64
JOSEPHINE	882.95	116.75	.182	125.0	.195	341.75	3.77	ʊ 885.1	1 to 1.07
LITTLE "	883.75	9.255	.015	40.0	.063	49.255	.078	● 883.9	1 to 4.32
BENNET	888.28	38.04	.06	355.21	.555	393.25	.615	891.7	1 to 9.34
OWASSO	885.12	353.75	.552	1,046.24	1.635	1,399.99	2.187	● 888.42	1 to 2.93
LITTLE BASS	884.62	42.85	.067	190.21	.297	233.06	.364	888.1	1 to 4.44
GRASS	879.61	109.807	.171	521.478	.815	631.285	.986	● 879.40	1 to 4.77
SNAIL	881.3	156.25	.244	684.20	1.070	840.45	1.314	No Outlet	1 to 4.39
TURTLE	890.4	438.40	.685	392.32	.613	830.72	1.298	892.7	1 to .895
KOHLMAN	857.27	79.08	.959	5,804.0	9.069	6,417.5	10.028	ʊ 859.0	1 to 9.459
GERVAIS		228.40							
KELLER		80.64							
* PHALEN		225.49							
McCARRONS	839.23	75.12	.12	319.09	.50	394.21	.62	840.80	1 to 4.26
BIRCH	916.36	105.12	.164	366.65	.573	471.77	.737		1 to 3.49
GOOSE	920.0	95.023	.1484	161.689	.2526	256.712	.4010	No Outlet	1 to 1.70

* Includes small Round Lake and canals. ʊ = Spillway ● = Culvert If no sign is shown outlet is natural.

Fig. 30

It is possible for a vast variation in runoff percentages resulting from a slight unavoidable misinterpretation of the lake elevation before and after the rainfall. There is bound to be some surge in lake levels due to wind action, and, unless the lake has been perfectly calm for two or three hours prior to the time the elevation was recorded, there is a possibility for a slight error which would cause a variation in the observed per cent of runoff. Let us take for example, the rainfall of August 21, 1924, when 2.74 inches of precipitation was recorded at White Bear. The recorded effect on the lake level for this rainfall was 3.0 inches. The observed per cent of runoff in this case, considering slight evaporation from the lake between gauge readings, was 16 per cent. Should the readings of the lake elevation taken before and after the rainfall vary but one-fourth of an inch, each, there would be a possibility for a total discrepancy of one-half inch, which if taken positively could cause the percentage of runoff to be increased from 16 per cent to 35 per cent, whereas taken negatively, it would reduce the 16 per cent to nil.

The variation and high percentage of runoff on the White Bear, Turtle and Island Lake drainage areas as tabulated on page 60, is possibly due to an unavoidable error in taking the lake elevations and will be subject to correction when further records of rainstorms are made.

The shape and location of a drainage area relative to the lake has a considerable effect on the amount of surface runoff. Well equalized tributary areas generally contribute more surface runoff than the elongated areas with the lake located near one end. The White Bear-Turtle-Josephine and Island lake drainage areas, altho relatively small in proportion to the lake area, are far more equalized than those of Johanna, Long and the Phalen group of lakes. (See Fig. 27) The abundance of surface runoff received in Long lake, due to its large tributary drainage area, would possibly be even greater if the lake was more equi-distant from all watershed extremities.

Ordinary surface runoff caused by moderate rains, is retarded and to some extent diminished by small ponds or pot holes. These depressions no matter how small, have some retarding effect on runoff and, may, to some extent, increase percolation. Small ponds of permanent nature usually exist because percolation is exceedingly slow. They greatly increase evaporation losses from a drainage area and consequently reduce the total available surface runoff.

Swamps caused by a high watertable elevation or by impervious bottoms which retain surface runoff, not only cause large evaporation losses but add to transpiration losses by sustaining a luxuriant growth of vegetation or trees.

When precipitation is not sufficient to keep the ground saturated, as is usually the case, runoff from the drainage area, as a whole, is greatly reduced until the ground is 100% saturated and all small depressions filled to a point of overflow.

To arrive at the amount of runoff from a drainage area during a single year or several years, consideration must be given to the moisture content of the soil at the beginning of the runoff period. The conditions brought about by the preceding year must be carried forward in all cases. Hydrological computations have been made which treat a thirty-one year (1893-1923) period in Ramsey County. The annual runoff from a single watershed over this period varies considerably due to variation in precipitation, evaporation and transpiration. For the year December 1st, 1923, to December 1st, 1924, runoff has been computed for the White Bear watershed as tabulated at the top of the following page.

COMPUTED RUNOFF FOR WHITE BEAR DRAINAGE AREA FOR PERIOD DEC. 1, 1923 TO DEC. 1, 1924

Month	Mean Monthly Temperature	Recorded Mean Monthly Precipitation	Loss From Water Area (Evaporation)	Loss From Land Area		Total Loss From Land Area	Precipitation minus Losses
				Transpir-ation	Evapor-ation		
	Deg. F.	Inches	Inches	Inches	Inches	Inches	Inches
Dec. 1923	29.6	0.54	1.08		0.17	0.17	+ 0.37
Jan. 1924	7.5	0.81	0.19		0.17	0.17	+ 0.64
Feb.	21.4	0.57	0.76		0.46	0.46	+ 0.11
Mar.	30.1	3.86	1.56		0.69	0.69	+ 3.17
April	43.9	3.71	1.87	0.30	1.72	2.02	+ 1.69
May	50.1	1.27	2.42	0.75	0.80	1.55	- 0.28
June	64.1	3.38	3.85	1.54	2.07	3.61	- 0.23
July	69.4	0.94	4.69	1.80	0.80	2.60	- 1.66
Aug.	67.5	5.70	4.52	1.54	3.00	4.54	+ 1.16
Sept.	57.1	3.08	3.41	0.90	1.50	2.40	+ 0.68
Oct.	56.1	0.38	3.36	0.79	0.35	1.14	- 0.76
Nov.	32.6	0.76	1.29		0.23	0.23	+ 0.53
Total		25.0	29.0	7.62	11.96	19.58	+ 5.42

No run-off occured during November so 0.53 is deducted from the last column total leaving 4.89 inches of run-off from land area or the equivalent to 4.6 inches on the lake. (Water to land ratio = 1 to .95)

Using the White Bear computations as a basis similar computations have been made for various lakes covering the same period. The following tabulation shows the recorded precipitation and computed runoff in inches, for various Ramsey County lakes covering the twelve month period, December 1st, 1923 to December 1st, 1924.

Lake.	Observed Precipitation. Inches.	Computed Runoff Equivalent on Lake. Inches.
White Bear	25.0	4.6
Turtle	27.3	3.6
Snail	26.6	10.0
Johanna	28.5	9.0
Josephine	28.5	5.0
Owasso	30.6	7.0
Kohlman, Gervais, Keller, Phalen	29.8	12.0
Island	24.3	15.0
Birch	26.5	9.0
Round	27.5	9.0
Bald Eagle	27.6	8.0

The runoff during the twelve month period December 1st, 1923, to December 1st, 1924, as previously tabulated in inches, was sufficient to balance or exceed the loss from the lakes due to evaporation. In all cases there should have been a rise in lake levels for the period instead of a drop. Following is a tabulation showing the net runoff yield or gain in lake levels that should have taken place during the twelve month-period.

Lake	Precepitation Minus Evaporation (Losses in Inches)	Computed Runoff Inches	Net Runoff Yield Inches	Observed Drop in Lake Level Inches
White Bear	—4.0	4.6	+ 0.6	6.6
Turtle	—3.2	3.6	+ 0.4	3.7
Sail	—5.0	10.0	+ 5.0	18.3
Johanna	—2.3	9.0	+ 6.7	9.0
Josephine	—2.3	5.0	+ 2.7	3.0
Owasso	—1.0	7.0	+ 6.0	4.2
Kohlman, Gervais, Keller, Phalen	+0.3	12.0	+11.7	3.6
Island	—9.5	15.0	+ 5.5	6.7
Birch	—7.8	9.0	+ 5.5	6.7
Round	—4.1	9.0	+ 4.9	1.2
Bald Eagle	—3.0	8.0	+ 5.0	1.0

With sufficient runoff to balance the loss due to evaporation, the actual loss or drop in lake levels during the past year can be attributed to an invisible underground loss termed as seepage.

Watertable and Seepage

Ramsey County is underlain with nearly horizontal layers of sandstone, of great depth, interspersed with layers of limestone, and shale, and the whole is overlaid with glacial drift that varies in thickness from thirty to two hundred feet due to a pre-glacial stream valley which crosses the county from the north and joins this Mississippi river at Saint Paul. There is a slight gradual slope to the south in these stratas, to where the Mississippi river has cut a channel approximately two hundred feet deep.

In localities where an unbroken impervious stratum separates the drift from the pervious water-bearing strata below, the rain that is absorbed by the drift forms a ground water supply that is local and independent of the deep underground reservoir. This, however, is not true in Ramsey County, where, in places, this impervious layer is broken or does not exist. The underground water supplies in this case, are united and function as a single underground reservoir, the upper level of which is commonly known as the watertable.

The underground water supply, for the region in which Ramsey county is located, is mainly derived from the Potsdam and St. Peter sandstone. About 15,000 square miles of this sandstone outcrop occurs in central Wisconsin and eastern Minnesota. These sandstone strata dip below impervious limestone and slope to the south and west. Precipitation percolates into these pervious sandstone outcrops, the process being relatively slow, and supplies the underground reservoir of this region. The elevation of this reservoir, or watertable, depends upon precipitation, percolation and the amount taken for domestic use.

A study of the watertable elevation has been made and it is evident that it has been dropping for the past fifteen or twenty years, due to the lack of precipitation, and percolation and the increased demand for underground water used for domestic purposes in the vicinity of Saint Paul. The amount of water pumped and used in Saint Paul, during the past years, has exceeded nature's supply, and the watertable has been artificially lowered.

It is many years ago since deep wells were first drilled at Saint Paul, and the water was drawn for various purposes. These early wells were flowing wells due to the hydraulic head caused by the slope, to the south, of the pervious waterbearing strata. The flow from these wells was reduced as more wells were drilled and the dropping water level, resulting from this increased use, soon caused the flowing wells to cease flowing and pumping machinery to be installed to bring the water to the surface. As the city of Saint Paul expanded and developed, numerous deep wells were drilled to meet the increasing demand for water, which has resulted in a general lowering of the watertable throughout Ramsey county.

The lowering of the watertable has, for the past twenty years, been more noticeable at or nearer Saint Paul than at the northern extremity of the county. In the loop district of Saint Paul, the watertable has lowered from forty-five to fifty feet in the past twenty-five years, whereas at Centerville, which is fifteen miles north of the Saint Paul loop district, the lowering has amounted to approximately ten feet. The extensive lowering at Saint Paul, has been caused by nature's inability to supply, by percolation, the vast quantities pumped from the watertable. The hydraulic slope, to the south, of the watertable today, as compared to the slope some years ago, being determined by the elevation at which the water stands in deep wells, is, as herewith tabulated.

Location of Well.	Distance No. of the Mississippi	Present Elevation of water level.	Old Elevation of water level.	Drop in feet.
Centerville ------	15.5 mi.	885	897 in 1892	12
Vadnais --------	6.5 mi.	860	878 in 1892	18
McCarrons -----	3.3 mi.	794	830 in 1910	36
N. P. Office Bldg.	0.25 mi.	682	727 in 1892	45
Mississippi River-	---	690	690	45

The present hydraulic slope of the watertable, to the south as above tabulated, shows a drop from Centerville to Vadnais of approximately three feet per mile, from Vadnais to McCarrons, a drop of twenty feet per mile and from McCarrons to the Mississippi River, a drop of thirty-one feet per mile. (See Fig. 32, Page 68.)

It is apparent that the watertable in Ramsey county is much lower than it was years ago. Investigations and studies have been conducted in the hope of determining a relation between a low watertable and the level of Ramsey county lakes. As a result of these investigations and studies, a clue to the present low lake levels has been found.

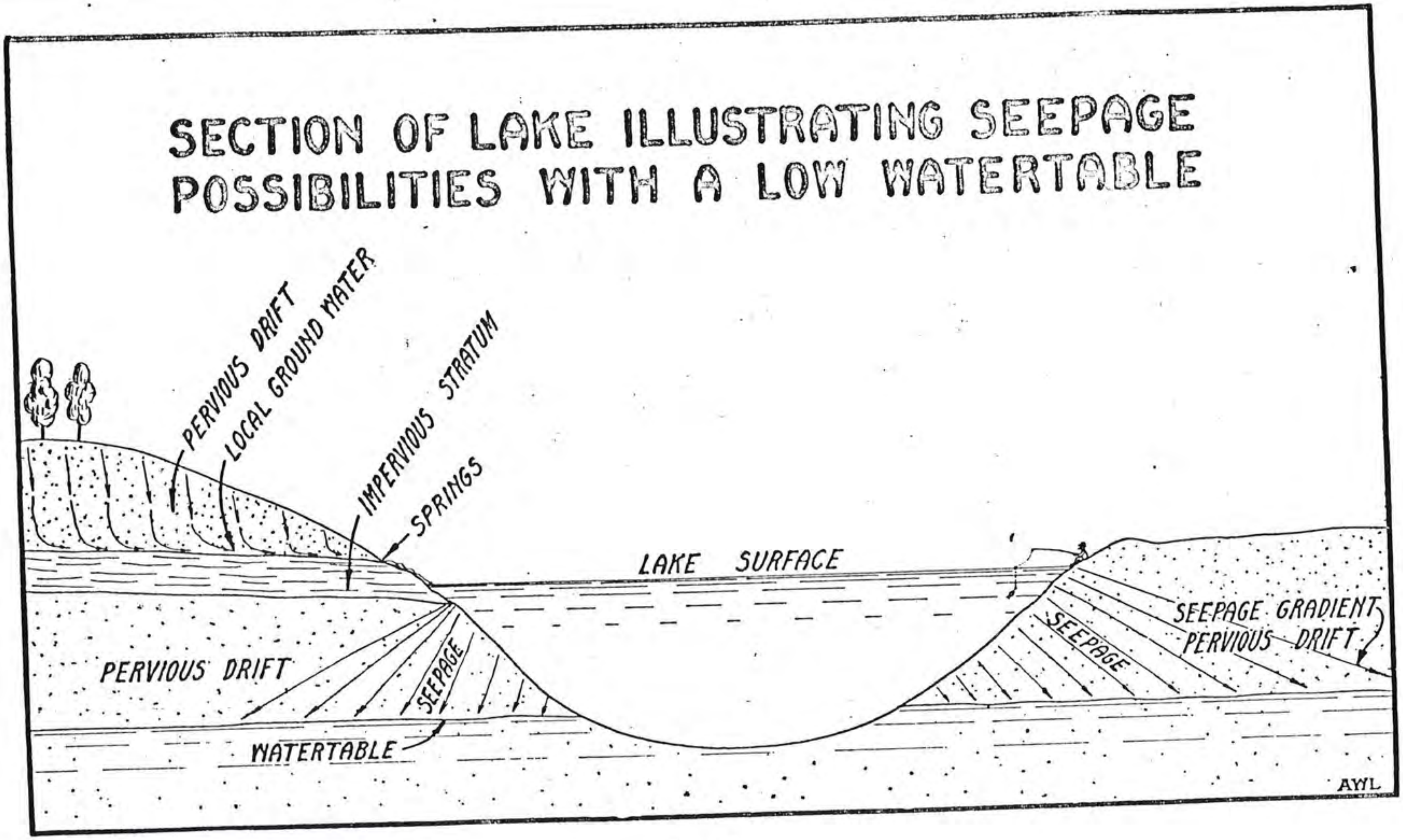

SECTION OF LAKE ILLUSTRATING SEEPAGE
POSSIBILITIES WITH A LOW WATERTABLE
PERVIOUS DRIFT
LOCAL GROUND WATER
IMPERVIOUS STRATUM
SPRINGS
LAKE SURFACE
PERVIOUS DRIFT
SEEPAGE
WATERTABLE
SEEPAGE
SEEPAGE GRADIENT
PERVIOUS DRIFT
AYL

Fig. 31

When the level of a watertable just reaches the surface of the ground, it causes swamps, and when it stands above the level of a depression or valley, it forms lakes and ponds. Lakes thus formed are dependent upon the watertable elevation for their existence. When the watertable drops below the level of the depression or valley, it leaves the lakes in a situation that might best be explained by comparing the lake to a porous cup set in a pan of water. The fluctuations within the cup are determined by the fluctuations within the pan. Similarly, the water in our lakes is seeking the level of the lowering watertable by seepage as illustrated by Fig. 31.

We are at loss to know when the watertable started lowering and caused seepage from our lakes or what the increase in seepage from year to year has been, but we can arrive at an average annual seepage loss over a period, for which we have records of lake stages, and also the seepage loss that occurred during the past year when special provisions were made to obtain this loss on various lakes in Ramsey County.

It is obvious that the lowering of the watertable is a factor in the acceleration of seepage and we can expect greater seepage from our lakes today than occurred years ago when the watertable was much higher. The average annual seepage loss that has taken place in the past, has no bearing whatever, on the present and future seepage losses.

If all our lakes were leak proof, we would not be concerned with the elevation of the watertable and precipitation would maintain the lakes at high and overflowing levels. However, with seepage existing, the watertable elevation is a seepage factor until it lowers below the level of the lake bottom and exposes the entire lake area to seepage possibilities. Once the watertable is below the lake bottom, seepage is limited only by the ability of the porous stratum below, to absorb the water.

The acceleration of this loss, is not proportional to the lowering of the watertable, but largely depends upon the porosity of the glacial drift underlying the lakes. Lakes in the southern part of the county, where the watertable is far below the level of the lake would naturally be subject to greater seepage if the porosity of the glacial drift was uniform throughout the county, but the condition of the lake bottom and underlying strata whether pervious or impervious governs the rate and amount of seepage from our lakes.

During the winter of 1923, and 1924, when the lakes were frozen over and very little evaporation took place, a loss was very noticeable over the shallow portions of the lakes where slightly submerged shoals and bars existed. The falling lake level caused the ice to rest on the shoals or bars and formed humps or irregularities in the ice surface which became more noticeable as the general lake level dropped during the winter. This observed drop is concrete evidence that seepage is taking place.

To confirm our ideas regarding seepage, surveys were made on several lakes in Ramsey County, during the latter part of March, 1924, to determine the seepage gradient from the lakes. Water leaving the lakes in the form of seepage does not wholly percolate or pass straight down to seek the level of the watertable, but spreads over an area considerably larger than that exposed to seepage. The porous ground acts as a blotter and the seepage water in the process of lowering and spreading, forms the seepage gradient as illustrated by Fig. 31, Page 66.

To determine the seepage gradient in the vicinity of the lakes, test pits were dug and during a period of no surface runoff or precipitation, were allowed to collect all the water that would seep into them during a reasonable length of time. The elevation of the seepage water thus determined was recorded and plotted as contours showing the seepage gradient as illustrated by Fig. 32, Page 68.

Where steep inclines from the lake shore to high land adjoining the lakes, exist, the ground water was found at an elevation above the lakes. In this case, the impervious layers of hard pan and clay that are disjointed and found here and there in the glacial drift, likely have collected the water that has percolated through the overlying porous strata and formed local ground water supplies that are independent of the watertable. Many of these impervious strata are found terminating on a hillside or in a valley and the local ground water that has been collected escapes, forming springs and marshes.

Although ground water stands above the level of the lake in many places, it does not necessarily indicate that no seepage from the lake is taking place. Possibly the impervious strata holding the ground water at this high elevation are very thin and seepage is taking place in the pervious earth below.

The seepage gradient was determined from test pits dug in draws and on low areas adjoining the lake where no local ground water interfered and the gradient undoubtedly could have been traced to where it reached the level of the watertable below if it had been thought necessary. To locate the places where maximum and minimum seepage occurs, would require an unlimited amount of time and money. Knowing that seepage from the lakes is taking place and preventing it would be to large an undertaking, but care must be taken not to stimulate the loss by unnecessarily interfering with the lake bottoms.

With the exact amount of precipitation recorded at the various Ramsey County Lake Stations, established December 1st, 1923, (Fig. 27), and the recorded drop in lake levels (losses) during a twelve month period beginning December 1st, 1923, and ending November 30th, 1924, we are able to apportion the loss on each lake in the study and arrive at the annual amount of seepage from our lakes today.

There having been no overflow or appreciable domestic use of water from our lakes during the past year, with the exception of Bald Eagle Lake, where water was taken for St. Paul water supply purposes, we can classify the recorded losses for the twelve month period, used for this study, as evaporation, seepage from the lakes, the negligible amount of water replacement for earth removed by dredging and that used for domestic consumption and overflow of which there was none. The only counteraction on the losses for this period are precipitation on the lake area, runoff from the tributary land area and the negligible amount of water received from local springs where they occur with the exception of the water pumped into White Bear lake during October and November, 1924.

With the total natural supply and losses determined from data and hydrological computations covering the twelve month period ending December 1st, 1924, the unaccounted for loss (seepage) from various County Lakes is given values as shown by the following tabulation:

SEEPAGE LOSS FROM RAMSEY COUNTY LAKES DETERMINED FROM HYDROLOGICAL DATA FOR PERIOD DECEMBER 1st, 1923 to DECEMBER 1st, 1924

RAMSEY COUNTY LAKES	Observed Precipitation	Computed Runoff	Total Natural Supply	Observed Drop In Lake Level	Total Water Loss	Distribution of Loss: Computed Evaporation	Distribution of Loss: Seepage and Consumption
	Inches	Inches	Inches	Inches	Inches	Inches	Inches
White Bear	25.0	4.6	29.6	6.6*	36.2	29.0	7.2
Turtle	27.3	3.6	30.9	3.7	34.6	30.5	4.1
Snail	26.6	10.0	36.6	18.3	54.9	31.6	23.3
Johanna	28.5	9.0	37.5	9.0	46.5	30.8	15.7
Josephine	28.5	5.0	33.5	3.0	36.5	30.8	5.7
Owasso	30.6	7.0	37.6	4.2	41.8	31.6	10.2
Kohlman, Gervais, Keller, Phalen	29.8	12.0	41.8	3.6	45.4	29.5	15.9
Island	24.3	15.0	39.3	6.7	46.0	33.8	12.2
Birch	26.5	9.0	35.5	5.5	41.0	34.3	6.7
Round	27.5	9.0	36.5	1.2	37.7	31.6	6.1
Bald Eagle	27.6	8.0	35.6	1.0*	36.6	30.6	6.0
Long	28.2	Overflow occured due to heavy runoff					
Mc Carrons	30.2	"		"	" "	"	"

* Corrected for Pumping

The loss recorded during the winter months, December 1st, 1923, to March 24th, 1924, when preciptation nearly balanced the evaporation and there was no appreciable runoff, is proof in itself that seepage is taking place. The following is a tabulation of seepage loss determined from hydrological data for the winter period:

SEEPAGE LOSS FROM RAMSEY COUNTY LAKES DETERMINED FROM HYDROLOGICAL DATA FOR PERIOD—DECEMBER 1, 1924-MARCH 24, 1924

Ramsey County Lake	Precipitation Dec. 1 - Mar. 24	Observed Drop in Lake Level Dec. 1 - Mar. 24	Computed Evaporation Dec. 1 - Mar. 24	Seepage and Consumption Dec. 1 - Mar. 24	Equivalent Annual Seepage Loss
	Inches	Inches	Inches	Inches	Inches
White Bear	2.0	3.4	3.5	1.9	5.7
Turtle	2.4	1.8	3.5	0.7	2.1
Snail	2.3	11.0	3.5	9.8	29.4
Johanna	2.0	5.2	3.5	3.7	11.1
Josephine	2.0	4.8	3.5	3.3	9.9
Owasso	2.2	3.6	3.5	2.3	6.9
Kohlmans, Gervais, Keller, Phalen	2.3	4.8	3.5	3.6	10.8
Island	2.1	11.4	3.5	10.0	30.0
Birch	2.1	3.3	3.5	1.9	5.7
Round	2.2	4.4	3.5	3.1	9.3

Note,- There was practically no surface run-off into the lake during this period and only a negligible amount of inflow from springs.

The annual seepage determined from the four month period is in some cases greater than directly determined from the twelve month period. This increase must be given consideration, however, and by taking a mean of the two periods, we feel that the seepage loss thus determined is as close to the correct amount as can be computed from the data available.

The seepage loss as herewith tabulated is a mean of the losses determined by two sets of computations and the amounts stand, not as final conclusions, but as figures indicating what is actually taking place.

SUMMARY OF ANNUAL SEEPAGE LOSS FROM RAMSEY COUNTY LAKES.

Lake	Seepage Loss Determined from Twelve month period Inches on Lake	1924 Seepage loss Determined from four month period Inches on Lake	Probable Seepage Loss—1924 Inches on Lake
White Bear	7.2	5.7	6.5
Turtle	4.0	2.1	3.1
Snail	23.3	29.4	26.6
Johanna	15.7	11.1	13.4
Josephine	5.7	9.9	7.8
Owasso	10.2	6.9	8.5
Kohlmans, Gervais, Keller, Phalen	15.9	10.8	13.4
Island	12.2	30.0	20.0
Birch	6.7	5.7	6.2
Round	6.1	9.3	7.7
Bald Eagle	6.0	*	5.0

Note: St. Paul waterworks pumped continuously from Bald Eagle during the four month period.

With normal lake elevations and less evaporation taking place from the lakes due to less shallow water along the shores, and the average annual precipitation of 27.5 inches, the total annual losses including seepage would be somewhat less than that recorded in 1924.

The probable mean drop in lake levels in normal years (consumption and seepage loss), and the equivalent in gallons per minute are as follows:

Lake.	Probable Mean Annual Drop in Lake Levels in Inches	Gallons per Minute Equivalent to mean annual drop or loss G.P.M.
White Bear	4.5	550
Turtle	3.0	72
Snail	17.5	146
Johanna	12.0	132
Josephine	4.5	31
Owasso	6.0	128
Kohlmans, Gervais, Keller, Phalen	7.0	225
Birch	4.0	26
Island	10.5	32
Round	3.5	25
Bald Eagle	3.5	200

The losses that will undoubtedly occur, even in normal years, must be offset or the majority of the lakes in Ramsey County which are dependent upon natural supply for their maintenance will, in the future, be subject to the same irregularities caused by low lake stages, as in the past.

The following is a set of summarized hydrologic computations which deal with the precipitation yield on White Bear lake and from its tributary land area. The computations show the distribution of the yield and the cumulative natural yield with and without seepage deduction.

HYDROLOGICAL DATA AND COMPUTATION

WHITE BEAR WATERSHED

Lake Area

Year	Precipitation (Inches)	Evaporation (Inches)	Precipitation Minus Evaporation (Yield) (Inches)	Cumulative Difference between Precipitation and Evaporation (Inches)
1893	24.1	27.9	— 3.8	— 3.8
1894	22.6	29.9	— 7.3	—11.1
1895	25.4	30.1	— 4.7	—15.8
1896	34.4	29.2	+ 5.2	—10.6
1897	31.0	27.3	+ 3.7	— 6.9
1898	25.4	30.6	— 5.2	—12.1
1899	26.3	30.4	— 4.1	—16.2
1900	34.9	32.0	+ 2.9	—13.3
1901	25.7	31.5	— 5.8	—19.1
1902	29.8	30.2	— 0.4	—19.5
1903	39.7	29.0	+ 9.7	— 9.8
1904	34.0	28.2	+ 5.8	— 4.0
1905	31.5	29.8	+ 1.7	— 2.3
1906	32.5	31.0	+ 1.5	— 0.8
1907	23.4	28.3	— 4.9	— 5.7
1908	30.8	30.8	0.0	— 5.7
1909	31.6	29.9	+ 1.7	— 4.0
1910	11.4	30.9	—19.5	—23.5
1911	39.2	30.1	+ 9.1	—14.4
1912	21.1	28.9	— 7.8	—22.2
1913	25.6	30.2	— 4.6	—26.8
1914	24.1	31.5	— 5.4	—32.2
1915	30.8	28.9	+ 1.9	—30.3
1916	23.8	29.5	— 5.7	—36.0
1917	25.6	26.7	— 1.1	—37.1
1918	28.7	29.6	— 0.9	—38.0
1919	31.8	30.8	+ 1.0	—37.0
1920	24.5	30.2	— 5.7	—42.7
1921	25.4	33.5	— 8.1	—50.8
1922	25.1	31.8	— 6.7	—57.5
1923	19.8	29.7	— 9.9	—67.4
1924	25.0	29.0	— 4.0	—71.4

HYDROLOGICAL DATA AND COMPUTATIONS
WHITE BEAR WATERSHED

Land Area

Year	Precipitation (Inches)	Transpiration (Inches)	Evaporation (Inches)	Total Loss (Inches)	Precipitation Minus Losses (Yield) (Inches)
1893	24.1	8.0	11.3	19.3	4.8
1894	22.6	7.0	10.4	17.4	5.2
1895	25.4	8.7	13.9	22.6	2.8
1896	34.4	8.4	15.5	23.9	10.5
1897	31.0	8.8	14.9	23.7	7.3
1898	25.4	8.6	13.4	22.0	3.4
1899	26.3	9.0	13.2	22.2	4.1
1900	34.9	10.2	17.2	27.4	7.5
1901	25.7	9.6	14.1	23.7	2.0
1902	29.8	7.9	16.0	23.9	5.9
1903	39.7	7.9	18.2	26.1	13.6
1904	34.0	7.6	15.9	23.5	10.5
1905	31.5	8.8	15.2	24.0	7.5
1906	32.5	8.8	16.4	25.2	7.3
1907	23.4	7.0	13.1	20.1	3.3
1908	30.8	8.6	16.0	24.6	6.2
1909	31.6	7.9	15.7	23.6	8.0
1910	11.4	5.0	7.0	12.0	—0.6
1911	39.2	8.4	19.6	28.0	11.2
1912	21.1	7.3	14.3	21.6	—0.5
1913	25.6	8.5	14.1	22.6	3.0
1914	24.1	8.8	13.0	21.8	2.3
1915	30.8	8.1	15.1	23.2	7.6
1916	23.8	7.2	11.5	18.7	5.1
1917	25.6	7.1	12.1	19.2	6.4
1918	28.7	8.0	15.0	23.0	5.7
1919	31.8	8.5	15.6	24.1	7.7
1920	24.5	7.6	12.1	19.7	4.8
1921	25.4	9.8	14.8	24.6	0.8
1922	25.1	9.2	11.4	20.6	4.5
1923	19.8	7.4	11.7	19.1	0.7
1924	25.0	7.6	12.0	19.6	5.4

HYDROLOGICAL DATA AND COMPUTATIONS
WHITE BEAR WATERSHED

Lake Plus Land Area

Year	Yield of Lake Area (Inches)	Yield of Land Area (Inches)	Total Yield (Inches)	Cumulative Yield (Inches)		Cumulative Yield deducting for Estimated Average Annual Seepage (4.5 Inches)	
1893	— 3.8	4.6	+ 0.8	0.8		— 3.7	
1894	— 7.3	4.9	— 2.4	— 1.6		—10.6	
1895	— 4.7	2.7	— 2.0	— 3.6		—17.1	
1896	+ 5.2	10.0	+15.2	11.6		— 6.4	
1897	+ 3.7	6.9	+10.6	22.2		— 0.3	
1898	— 5.2	3.2	— 2.0	20.2		— 6.8	
1899	— 4.1	3.9	— 0.2	20.0		—11.5	
1900	+ 2.9	7.1	+10.0	30.0		— 6.0	
1901	— 5.8	1.9	— 3.9	26.1		—14.4	
1902	— 0.4	5.6	+ 5.2	31.3		—13.7	
1903	+ 9.7	12.9	+22.6	33.9		+ 4.4	
1904	+ 5.8	10.0	+15.8	69.7		+15.7	
1905	+ 1.7	7.1	+ 8.8	78.5		+20.0	
1906	+ 1.5	6.9	+ 8.4	86.9	*	+23.9	*
1907	— 4.9	3.1	— 1.8	85.1	— 1.8	+17.6	— 6.3
1908	0.0	5.9	+ 5.9	91.0	+ 4.1	+19.0	— 4.9
1909	+ 1.7	7.6	+ 9.3	100.3	+13.4	—23.8	— 0.1
1910	—19.5	—0.6	—20.1	80.2	— 6.7	— 0.8	—24.7
1911	+ 9.1	10.6	+19.7	99.9	+13.0	+14.4	— 9.5
1912	— 7.8	—0.5	— 8.3	91.6	+ 4.7	+ 1.6	—22.3
1913	— 4.6	2.9	— 1.7	89.9	+ 3.0	— 4.6	—28.5
1914	— 5.4	2.2	— 3.2	86.7	— 0.2	—12.3	—36.2
1915	+ 1.9	7.2	+ 9.1	95.8	+ 8.9	— 7.7	—31.6
1916	— 5.7	4.8	— 0.9	94.9	+ 8.0	—13.1	—37.0
1917	— 1.1	6.1	+ 5.0	99.9	+13.0	—12.6	—36.5
1918	— 0.9	5.4	+ 4.5	104.4	+17.5	—12.6	—36.5
1919	+ 1.0	7.3	+ 8.3	114.7	+25.8	— 8.8	—32.7
1920	— 5.7	4.6	— 1.1	113.6	+24.7	—14.4	—38.3
1921	— 8.1	0.8	— 7.3	106.3	+17.4	+26.2	—50.1
1922	— 6.7	4.3	— 2.4	103.9	+15.0	—33.1	—57.0
1923	— 9.9	0.7	— 9.2	92.7	+ 5.8	—46.8	—70.7
1924	— 4.0	5.1	+ 1.1	93.8	+ 6.9	—50.2	—74.1

Note: *Indicates overflow.

During the period 1907-1924 the equivalent of approximately seventeen inches of water was pumped into the lake.

White Bear Lake in the year 1906, overflowed into Bald Eagle due to the cumulative increase in precipitation from 1890 to 1906. We are at a loss to know how much the lake was lowered by this overflow, but it is estimated that at least one foot was lost due to the natural outlet being eroded or washed down by the water leaving the lake.

There being no overflow since 1906, available records show that from December 1st 1906, to December 1st, 1924 (18 years) there has been a drop in lake levels of 57.0 inches. During this period, there was the equivalent to 17.0 inches of water pumped into the lake which has offset the loss to that amount. If there had been no water pumped into the lake during this eighteen year period, it is obvious that our total loss would have been 17.0 inches more or 74.0 inches.

The hydrologic computations show that with no seepage taking place, there would have been an increase of 6.9 inches instead of the 57.0 inches recorded drop for the eighteen year period which is evidence that seepage from the lake is the root of this evil. The estimated average annual seepage loss of 4.5 inches over this period, caused a cumulative loss, due to seepage of 81.0 inches. This loss, however, was reduced to 74.0 inches by the natural yield of 6.9 inches, which is exactly in line with the recorded loss of 57.0 inches plus the 17.0 inches pumped for the period, (74.1 inches), and is further indication of seepage.

NATURAL RESTORATION.

Possibilities

Many public inquiries, concerning our lakes, have been made at this office in the past two years, but the outstanding question has been—"Will our lakes recover?" The logical answer to this question has been one of the objects of this report. Little was known prior to this investigation, concerning the possibilities of natural restoration, and it is conceded at the start, that it is a problem that depends entirely upon nature's ability to duplicate or exceed the beneficial factors of natural phenomenon as it has in the past.

All indications are that if the lake levels were normal and natural conditions prevailed with no seepage taking place, the expected yearly fluctuations in lake levels would occur on a higher plane, resulting now and then in overflow.

Natures' steady program has been disrupted by seepage losses from our lakes and this loss must in most cases be offset by a natural supply if natural restoration is to take place.

Natural restoration in this case does not mean a partial recovery to a normal elevation at which the lakes best serve the public, it means complete recovery to the elevation of overflow or high water. The lake levels fluctuate in close relation to the cycle or trend in precipitation as shown by Fig. 26, on Page 53. A normal elevation, generally speaking, is reached by a half cycle or half of a total fluctuation. The upper stage between the normal and ordinary high water elevation is the natural reserve which is drawn upon by the lower or dry half of the cycle. If our lake levels were restored to their normal elevations, it would indeed be pleasing, but nature must provide complete restoration or, with the heavy seepage losses, the levels of our lakes will, with yearly and periodical fluctuations, gradually fall to a hopeless stage.

The possibility of an increase in annual precipitation in the next ten or fifteen years is clearly illustrated by the cycle or trend as shown on Page 53, Fig. 26. All indications are that we are at or very near the bottom of a dry cycle, and if nature repeats, we can expect a cumulative increase in annual precipitation similar to that during the periods (1837-1849) (1865-1875) and (1890-1906).

During the eighty-seven year period for which we have records of precipitation at St. Paul (See Fig. 26) there have been at least five, more or less, distinct cycles. The upward trend or increase in these cycles caused by an increase in precipitation are in some cases rather abrupt with means, during these periods, that are considerably higher than the average for the entire eighty-seven year period. The means for the periods of increase are as follows:

1837-1849.	Annual mean=26.4	inches.
1865-1875.	Annual mean=32.0	inches.
1890-1906.	Annual mean=29.1	inches.
1896-1906.	Annual mean=31.5	inches.

The most rapid recovery was during the eleven year period (1865-1875) when the annual mean was 32 inches. The mean for the eleven year period (1896-1906), although part of the increase for the seventeen year period (1890-1906) is almost identical with the mean for the eleven year period (1865-1875). These means represent the most favorable increases of which we have record, and on these, we will base an assumption. From hydrological data and computations compiled for White Bear Lake and its drainage area, as tabulated on Pages 74, 75 and 76, we find that the cumulative yield or increase in lake levels during the eleven year period (1896-1906) when the annual mean precipitation was 31.5 inches, would have been 90.5 inches if seepage deductions were not considered. The probable increase for the period, assuming that the most favorable recorded conditions prevailed (32.0 inch mean) would have been 97.5 inches.

Let us assume that we are at the bottom of a dry cycle and during the next eleven years (1925-1935) the mean annual precipitation at White Bear will be 32.0 inches. The total yield or rise in lake levels for this period would be practically the same as computed for the eleven year period (1896-1906), disregarding seepage. With a natural yield of 97.5 inches during the next eleven years and deducting the cumulative annual seepage loss of 4.5 inches over an eleven year period (49.5 inches) we would have accumulated on the lake the equivalent to a 48 inch (four foot) rise which would put the lake at an elevation of approximately 925.5, within a foot of the spillway elevation in the year 1935.

With this high annual mean precipitation (32.0 inches) affecting the entire county during the next ten years, we could expect a natural recovery on all lakes with the possible exception of Johanna and Snail. The losses on these lakes are so great regardless of the large amount of runoff received, that natural restoration is even more doubtful.

We must bear in mind, however, that there is a possibility of natural recovery only under the most favorable conditions which, in the past eighty-seven years has occurred only twice. Our speculations into the future, concerning natural restoration, are limited and based entirely upon what has taken place in the past. The unexpected may happen and nature's supply exceed all previous records. This, however, is not probable, and it is safe to say that natural restoration of our lakes is more or less a gamble with heavy odds against it.

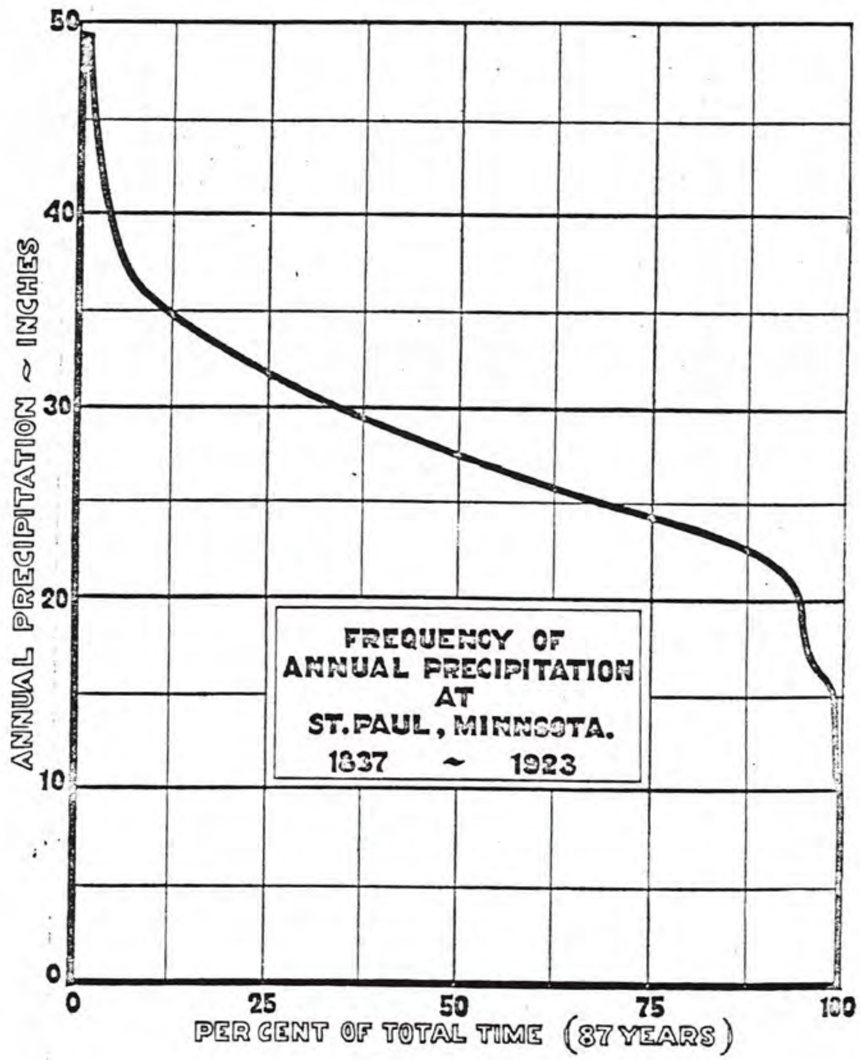
There are two lakes in the county, classified as public utility lakes, namely, McCarrons and Long, which are well maintained regardless of what seepage loss is taking place. McCarron's Lake is subject to considerable seepage loss due to its location, but any seepage loss that might occur is offset by seepage into the lake in the form of springs. It is truly a spring fed lake and subject to overflow following spring runoff. Long Lake is possibly the best maintained lake in the county. It has a tributary drainage area forty-two times the size of the water area and receives sufficient runoff to cause numerous overflows into the Mississippi river.

Bald Eagle Lake is abnormally low due to the fact that its water was used during the winter of 1923 and 1924 for St. Paul City Water supply. Generally speaking, there was the equivalent of three feet of water pumped from the lake for that purpose. There are reasons to believe that if this water had not been taken from the lake, there would be but a slight deficiency today.

The possibility of natural recovery, from the existing low stage, depends, as in other cases, upon the future supply. This lake, however, has greater possibilities of natural restoration than any county lake with the same deficiency. The deficiency in this case is not due to a natural loss, so with the expected cumulative increase in annual precipitation there are fair possibilities for natural restoration of Bald Eagle Lake, although it may be several years distant.

If, in the next ten or fifteen years, our deficient lakes would fully recover, the irregularities of today would soon be forgotten and there would be no cause for discontent until the downward cycle of precipitation caused the lakes to lower in their usual manner. As long as there are cycles in precipitation, there is bound to be natural fluctuations in our lake levels which is really the cause of the present irregularities and uncertainty. It is the fluctuations in lake levels that have caused the irregularities, not the low lake elevations. We can adjust ourselves to different levels providing the change from one level to another is not too sudden, but it would be unreasonable to adjust permanent improvement so as to derive the most from lakes having large fluctuations.

With no certainty concerning the extremities of the fluctuations in lake levels and the limits of seepage, we are at a point, where, for the best interests of the county and public at large, it is felt necessary to resort to artificial means in order to overcome the irregularities and uncertainty caused by these fluctuations.



ARTIFICIAL RESTORATION.

Watertable Fluctuations.

The full recovery of our lakes, if brought about by nature, would be termed natural restoration but, if by an act of man, nature is assisted, such recovery is herein referred to as artificial restoration.

To overcome the losses sustained by seepage is our chief motive. The problem has been analyzed from all possible angles. The first thought which enters our mind, is, can we right the basic wrong by acts which would enable the watertable to recover? This, however, is not comprehensive. The underground water supply is free for all who wish to make the necessary provisions for its use.

It has been estimated that the numerous privately owned deep wells in St. Paul each year pump from the underground reservoir, 3.2 billion gallons, which, generally speaking, is the equivalent of 1.1 foot on every lake in Ramsey County. In addition to this water privately pumped, there is, each year, approximately 5.3 billion gallons provided the City by the Water Works, of which a large percentage is pumped especially in dry years, from the underground reservoir. It is estimated, however, that the total average annual supply pumped in Ramsey County is not less than 6.7 billion gallons, or the equivalent of 2.4 feet on all our lakes, or, roughly speaking, 8.7 feet on White Bear Lake. With this enormous amount taken yearly from the underground reservoir, it is plain to see why the watertable has lowered and why all hopes of recovery are diminishing.

When the new city water supply system is put into effect and the bulk of the water heretofore pumped from deep wells and distributed for public use in the city, is taken from the Mississippi River, the overtaxed natural deep reservoir will be greatly relieved, but still burdened with the annual loss of 3.2 billion gallons pumped from private wells in St. Paul. Even with no future pumping taking place in Ramsey County, the natural recovery of the watertable is so far distant, that the present, or possibly the next two generations will not witness its recovery.

With little or no hope of the watertable being restored to its natural elevation, the possibility of reducing seepage by lowering our lakes to an elevation nearer that of the watertable, was given consideration. To overcome or substantially reduce seepage in this manner, it would be necessary to lower our lakes to such an extent that all efforts and money that have been spent in developing and improving our lakes would be sacrificed. The natural bathing beaches, both developed and undeveloped, which, through a course of years have been constructed by wave action, would be destroyed. In this case the existing gradual decline from the shore line to where an abrupt drop-off into deep water is found, would be exposed, and the decline from the remodeled shore line would be so abrupt that bathing under such conditions would be undesirable. The watertable today is, in most cases, so far below the surface of our lakes, that a reasonable lowering would do more harm than good.

Profiting by past experience at White Bear, it is felt that pumping water from deep wells into our deficient lakes is the only sound and economical method by which the present and future irregularities brought about by low lake elevations, can be overcome.

Although relatively little pumping from deep wells for lake improvement purposes has taken place in the county, it is beyond an experimental stage. The desirability of such pumping is often questioned by those who do not understand the situation. The equivalent to a foot of water may be pumped into a lake with no visible effect, but we must keep in mind that the water pumped has replaced a loss which would have taken place had there been no pumping. In other words, White Bear Lake would be approximately seventeen inches lower today if no pumping had taken place since the year 1907.

It would appear that to pump water from the underground reservoir to supply our deficient lakes would result in the lowering of the watertable, but to pump the equivalent of that water which has been lost through seepage is merely a process by which the seepage water is returned to the lakes with no cause whatever for the lowering of the watertable. To pump water into our lakes is not a process of robbing the underground reservoir, in its existing state, of water that rightfully belongs to it. In other words, pumping into the lakes to offset seepage will have the same effect on the watertable that the sealing the bottoms of our lakes would have. Pumping from deep wells at a greater rate than would be necessary to offset seepage loss would result in the lowering of the watertable. However, the apparent lowering of the watertable is more than offset by the fact that the City Water Works will no longer derive its main supply from the underground reservoir, but will pump directly from the Mississippi River at Fridley.

If pumping into our lakes is to be given consideration it would be advisable to make the necessary provisions for a possible increased demand in the future. With this in mind, wells with adequate diameter and capacity should be considered. The amount of water required to offset seepage today may be doubled in the future. To overcome this increased demand it would then only be necessary to replace the old pumping machinery with new having higher rates of discharge.

Where the watertable stands considerably below the level of the discharge the most desirable type of pumping machinery is the deep well turbin. This pump is suspended in the well casing and operates at its highest degree of efficiency at the elevation of the watertable. It must be conceded, however, that the highest pump efficiencies are obtained by horizontal and vertical centrifugal types and work to advantage in places where provisions are made to have the pump at or very near to the elevation of the watertable. To do this, in cases where the watertable is more than 8 or 10 feet below the ground surface or discharge, would necessitate the construction of a pit sufficient in diameter to house the pump and deep enough so that the pump would operate on or very near the watertable plane.

The diameter of a well has a direct bearing on the efficiency obtained by deep well turbines. Let us take for example the two county wells at White Bear. These wells when drilled twenty-five years ago were thought adequate in diameter and capacity to supply all future requirements. However, even if the capacity of these wells today is sufficient for the required amount of water, the small diameters limit the pump efficiency.

Had the diameter of these wells been 18 inches instead of 12 inches it would have been possible to obtain approximately 17% higher pump efficiency from the same type of pump as recently installed with a total power saving of $630.00 per year for the same amount of water delivered.

The cost of drilling wells is based more or less on a time and material basis. The additional time required to drill an 18-inch well, compared to a 12-inch well, is not great. The cost of a large well casing really constitutes the bulk of the additional cost and the permanency of a good well with a large diameter offsets this additional cost to such an extent that for future use only wells of adequate diameter are recommended.

The time required to pump at various rates of discharge, the equivalent of one foot rise in elevation on individual lakes in Ramsey County is shown in form of curves (Fig. 33, Page 84.) The size of a lake is directly proportional to the time required to pump at any given rate of discharge. Therefore, pump capacities are governed by time and water requirements.

For economical reasons it would not be advisable to select pump capacities over the amount required to offset seepage and hold our lakes at a more or less constant stage under adverse conditions. With adequate pumping facilities, the control of the pumps would be determined by foreseen requirements.

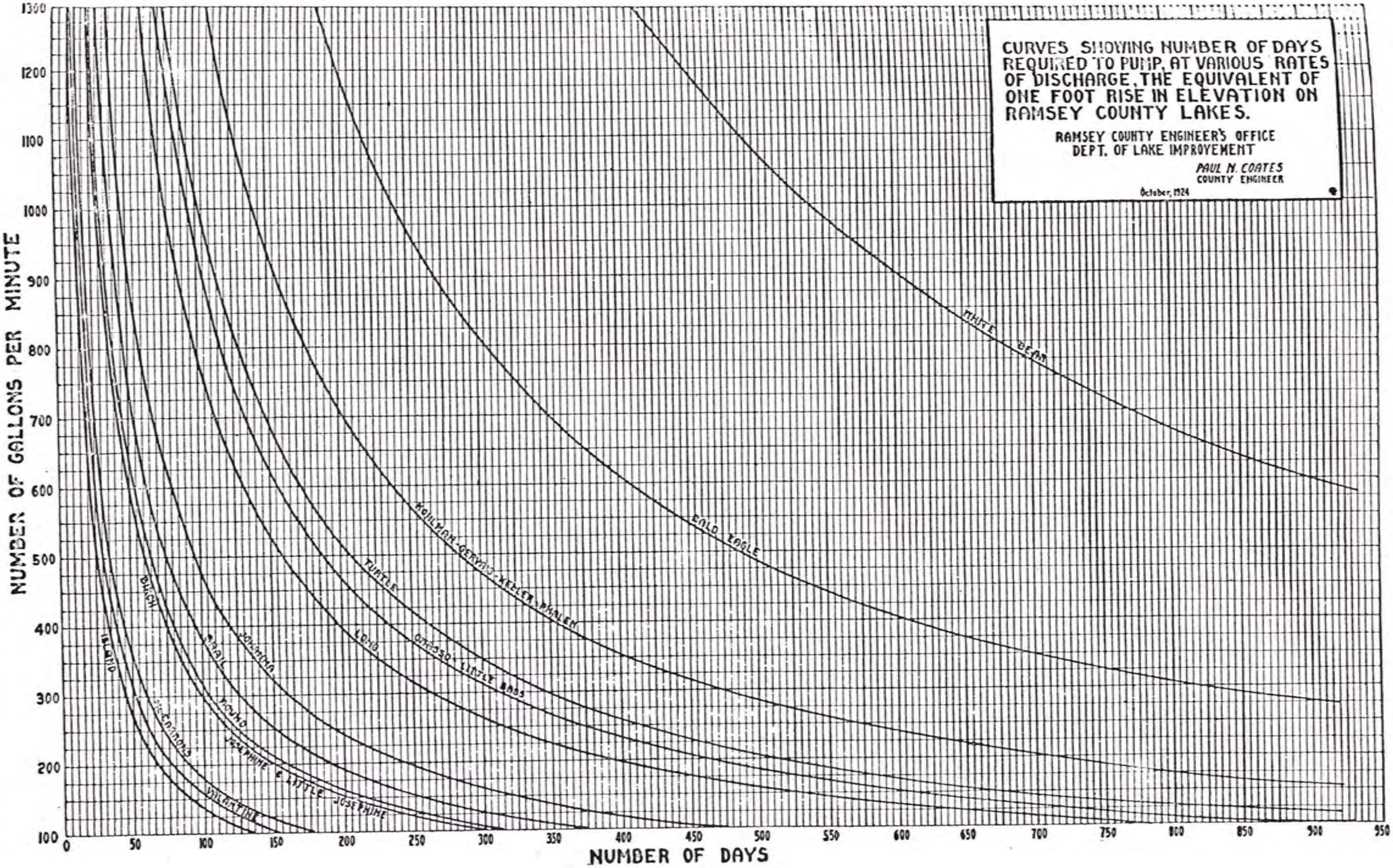
Control of Lake Levels

Frequent overflows can be expected if our lakes are restored to their normal elevations by the aid of pumps. With the watertable abnormally low, precaution must be taken so that unnecessary overflow, especially from the lower lakes of a system, will not be lost to the Mississippi River.

A normal lake level should be agreed upon and a flood reserve established. When the lake rises to the normal level, pumping should ordinarily cease and overflow should be under control throughout the flood reserve by use of an adjustable spillway elevation, more commonly known as a "stop log system." In the spring, if excessive floods are anticipated, the lakes should be drawn down to the normal level by removing stop logs to make room for the unexpected overflow. Provisions should be made, however, to retain at least half of the flood reserve after the spring runoff had ceased, for runoff from summer rains and half for summer drought. During the discharge of water from the flood reserve, the following estimated spillway capacities should be available:

Lake.	Cubic Second Feet	Lake	Cubic Second Feet
White Bear	75	Snail	10
Bald Eagle	125	Round	10
Turtle	15	Valantine	15
Owasso	25	Long	400
Phalen Series	100	Island	5
Johanna	25	Birch	8
Josephine	5	McCarrons	10

After the flood reserve has been fully utilized, additional abnormal flood inflow must be partly stored and partly discharged at still greater rates. To determine these abnormal discharges further studies and additional hydrological observations are necessary.



CURVES SHOWING NUMBER OF DAYS REQUIRED TO PUMP, AT VARIOUS RATES OF DISCHARGE, THE EQUIVALENT OF ONE FOOT RISE IN ELEVATION ON RAMSEY COUNTY LAKES.
RAMSEY COUNTY ENGINEER'S OFFICE
DEPT. OF LAKE IMPROVEMENT
PAUL N. COATES
COUNTY ENGINEER
October, 1924
NUMBER OF GALLONS PER MINUTE
NUMBER OF DAYS
ISLAND
BIRCH
McCARRONS
SNAIL
MOUND
JOHANNA
JOSEPHINE & LITTLE JOSEPHINE
LONG
OWASSO - LITTLE BASS
TURTLE
KOHLMAN - GERVAIS - KELLER - PHALEN
BALD EAGLE
WHITE BEAR

Fig. 33

Showing Relative Lake Elevations—Natural and Recommended Flood Control Conditions.

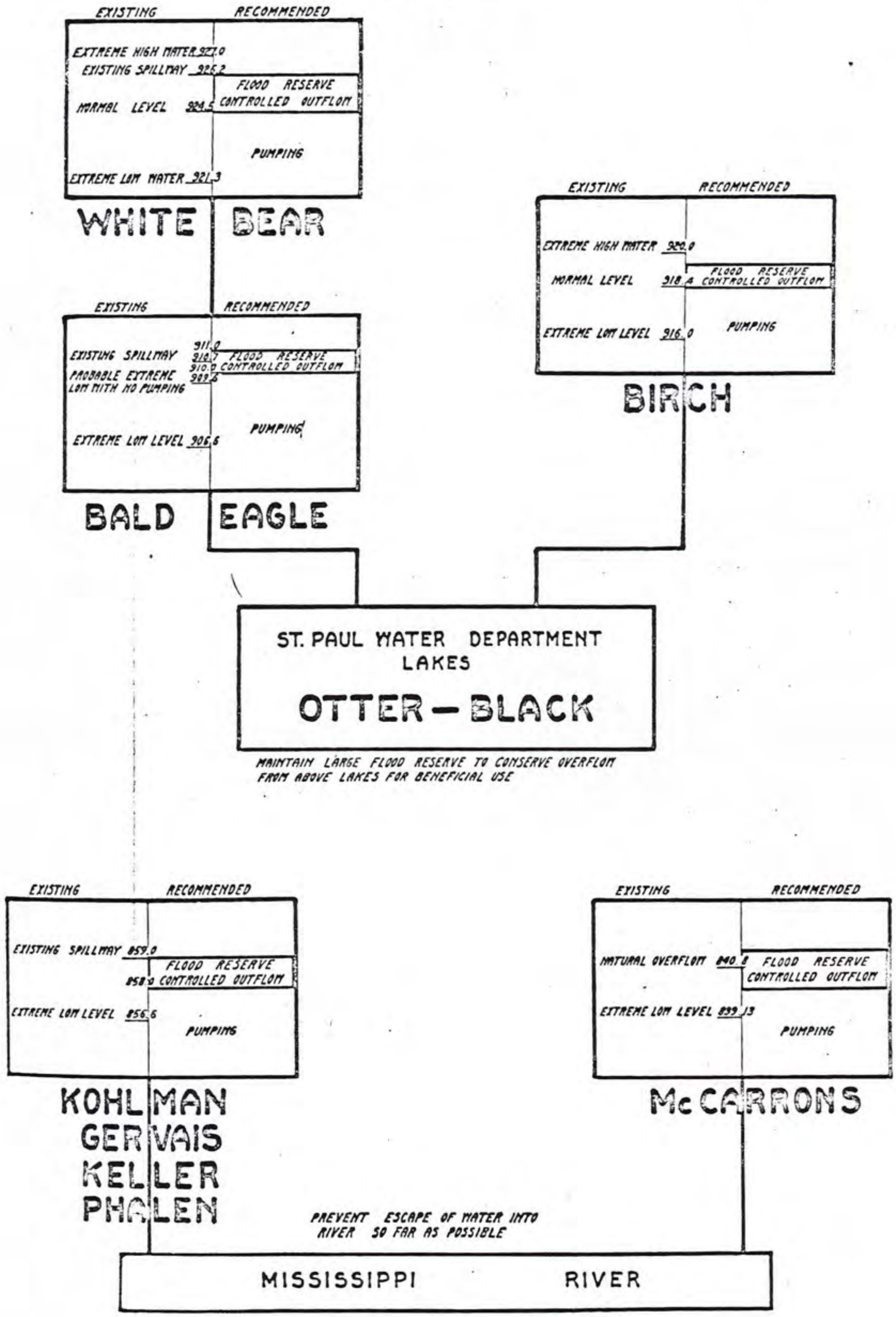


Fig. 34

Showing Relative Lake Elevations—Natural and Recommended, Flood Control Conditions.

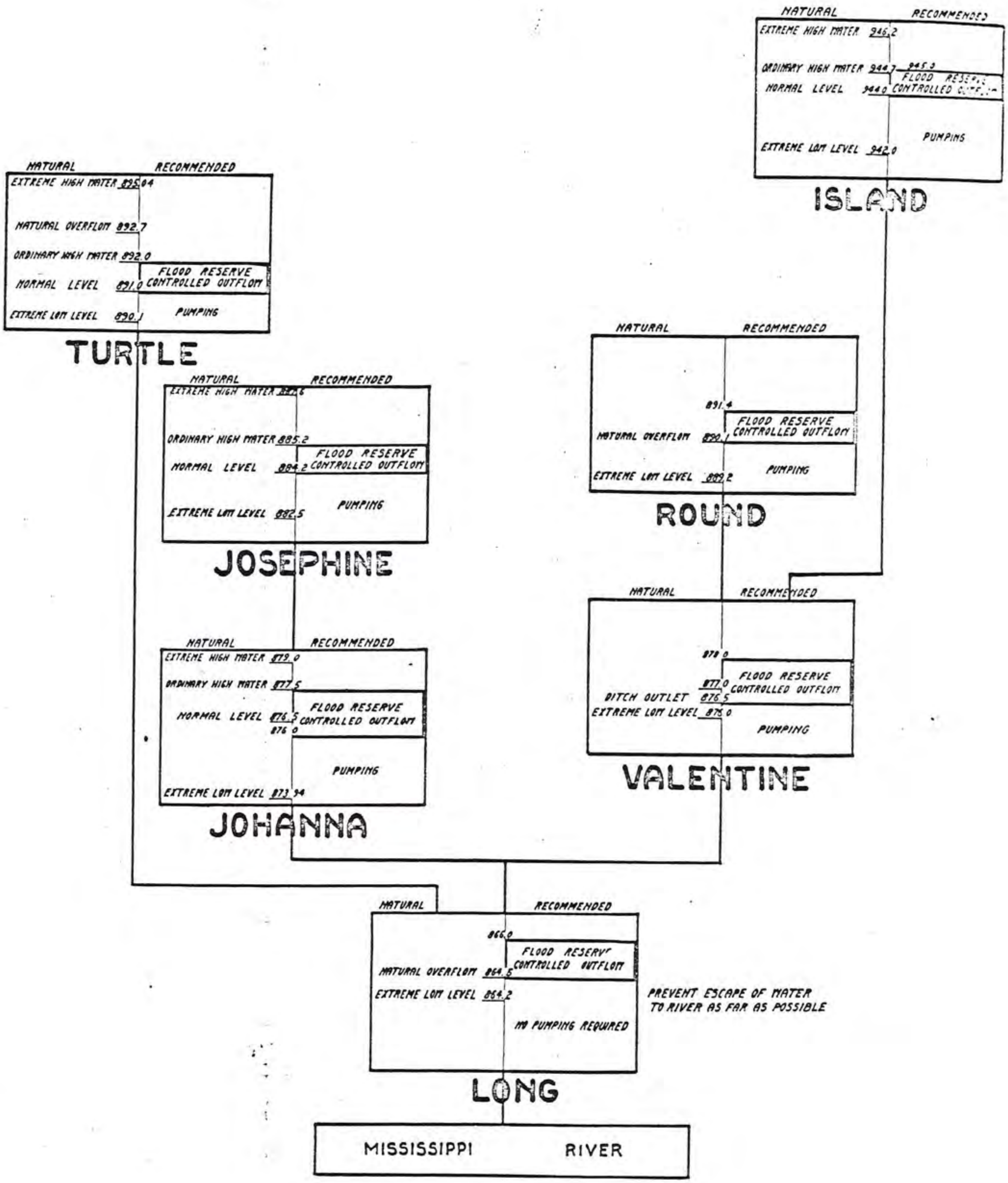


Fig. 35

Showing Relative Lake Elevations—Natural and Recommended, Flood Control Conditions.

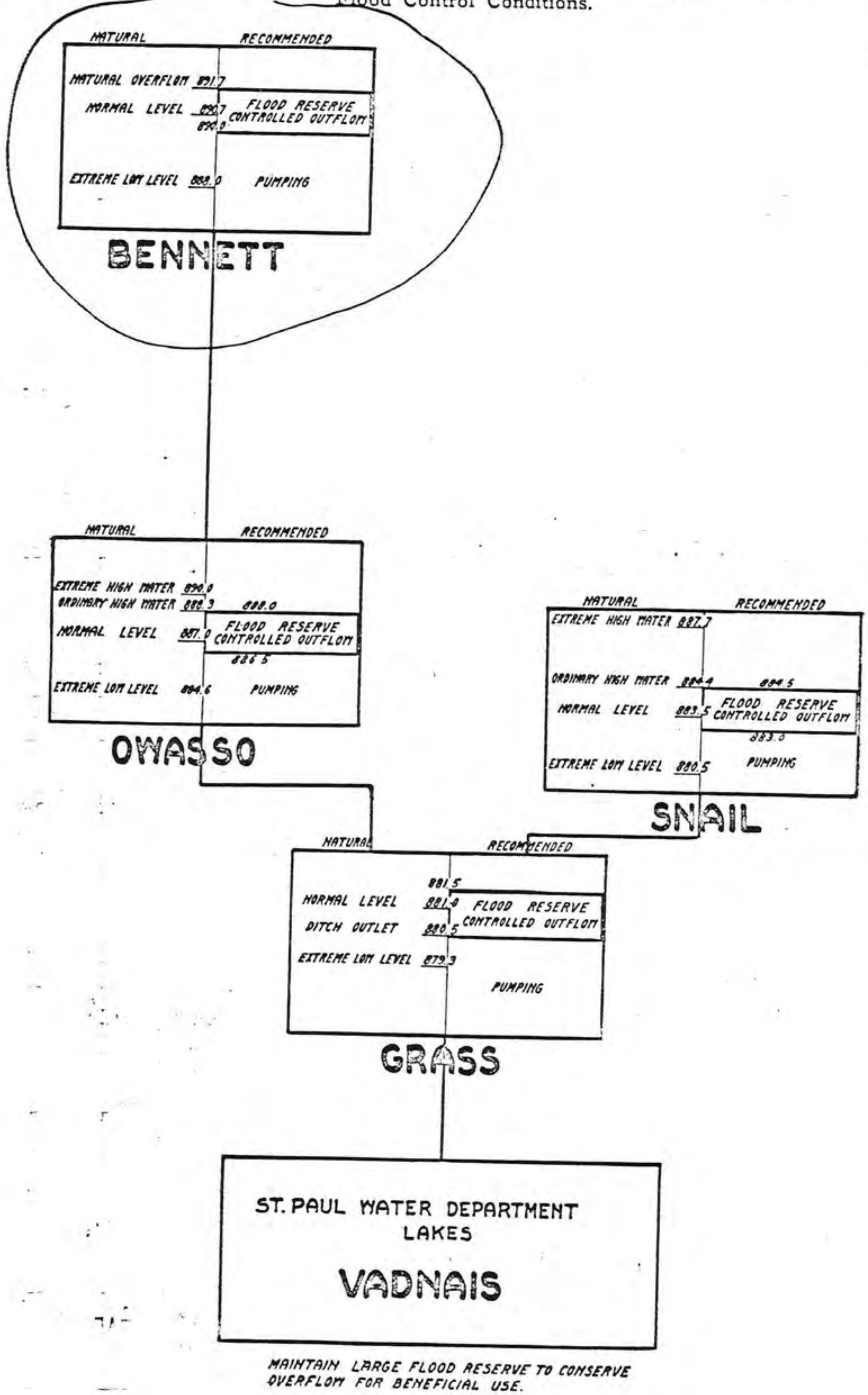


Fig. 36

Figures 33, 34 and 35 respectively, show the natural lake stages as determined in the field and the recommended flood reserve and overflow control as thought most practicable for the good of all concerned. The flood reserve and control, as shown, in all cases represents very nearly the total fluctuations to which the lake levels would be subjected with the suggested pumping program in effect. It will be noted that the lakes with the lowest altitude through which flood water from tributary lakes passes, to escape the Mississippi river, have greater flood reserves recommended for the conservation of surface runoff.

The relative elevation and natural overflow courses of all lakes, under consideration, are graphically shown by figures 33, 34, 35.

EXISTING SPILLWAYS AND OUTLETS

The necessity of adequate spillways to protect the natural outlets of our lakes can be appreciated only by personal inspection. Extreme high water marks found in some cases several feet above the existing outlet, is evident that overflow in the early days has eroded or washed away the retaining earth governing the extreme high water stages. Little has been done in the past to preserve our natural outlets, and it is felt that the construction of a proper adequate spillway is as important as the pump itself in considering a pumping program. The outlet situation on each lake is an engineering problem in itself and should be given consideration regardless of whether or not pumping is to take place. In several instances the outlet has been eroded within a few inches of the normal lake elevation. At Turtle Lake, merely a low sand ridge keeps its waters from going into the Mississippi River, and another overflow would erode the outlet so that little storage would be realized on the lake.

The existing spillways are, generally speaking, inadequate to discharge sufficient flood water so as to prevent property damage in case of an abnormal runoff.

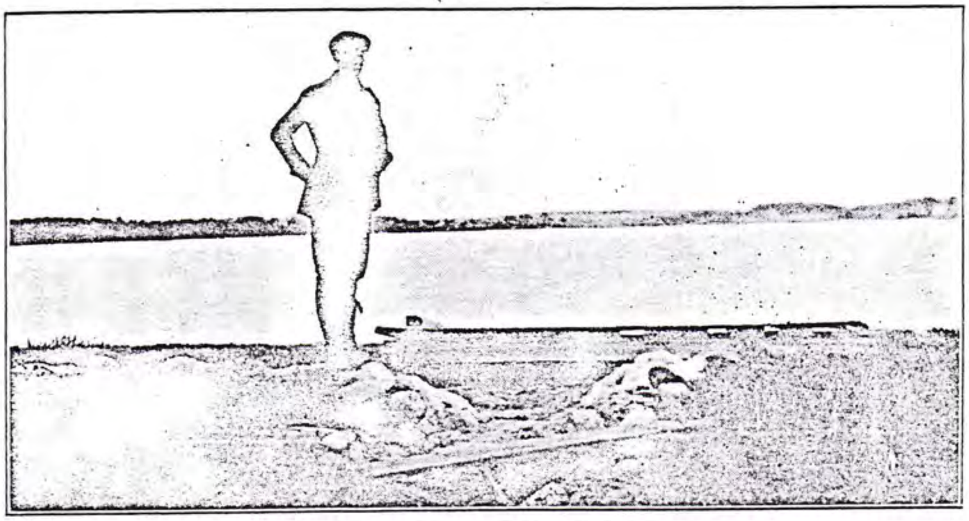
The Phalen spillway, although well constructed, is inadequate and has no provisions for flood control. The White Bear and Josephine spillways are about 75% inadequate, and water would pass around them in case of a heavy overflow.

Bald Eagle has two spillways; the one on the North end of the lake has been constructed as part of the bridge that spans the old creek bottom or natural outlet. On the west Shore the St. Paul Water Works constructed a spillway, which, when overflow occurs, discharges water into the city water supply system through Otter Lake. The combined discharge capacity of these spillways is sufficient to handle ordinary floods, but they lack control features.

Although adequate spillways, with provisions for controlling overflow, are essential and have been suggested as part of a pumping program, the immediate necessity of such improvements is not an outstanding feature.

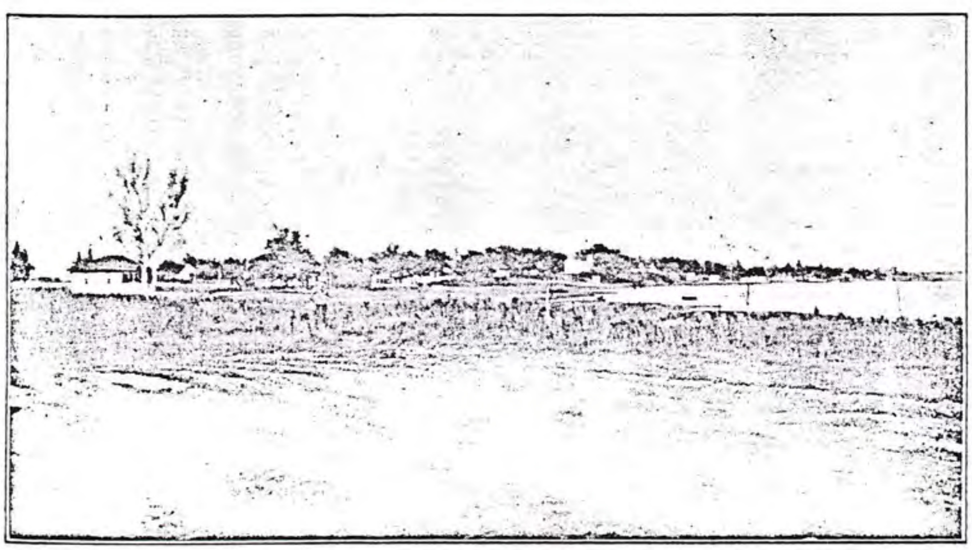
It is believed that all required spillways could be constructed in their order of importance within the next four or five years by the proper distribution of funds.

In many cases the overflow channels from one lake to another are not contracted sufficiently to prevent serious damage in case of heavy overflow. To remedy this situation, which is altogether natural, it is believed that regular ditch proceedings would be required. (Figs. 38, 39, 40.)



Existing Spillway—Lake Josephine

Outlet Culvert—Lake Owasso



Natural Outlet—Turtle Lake

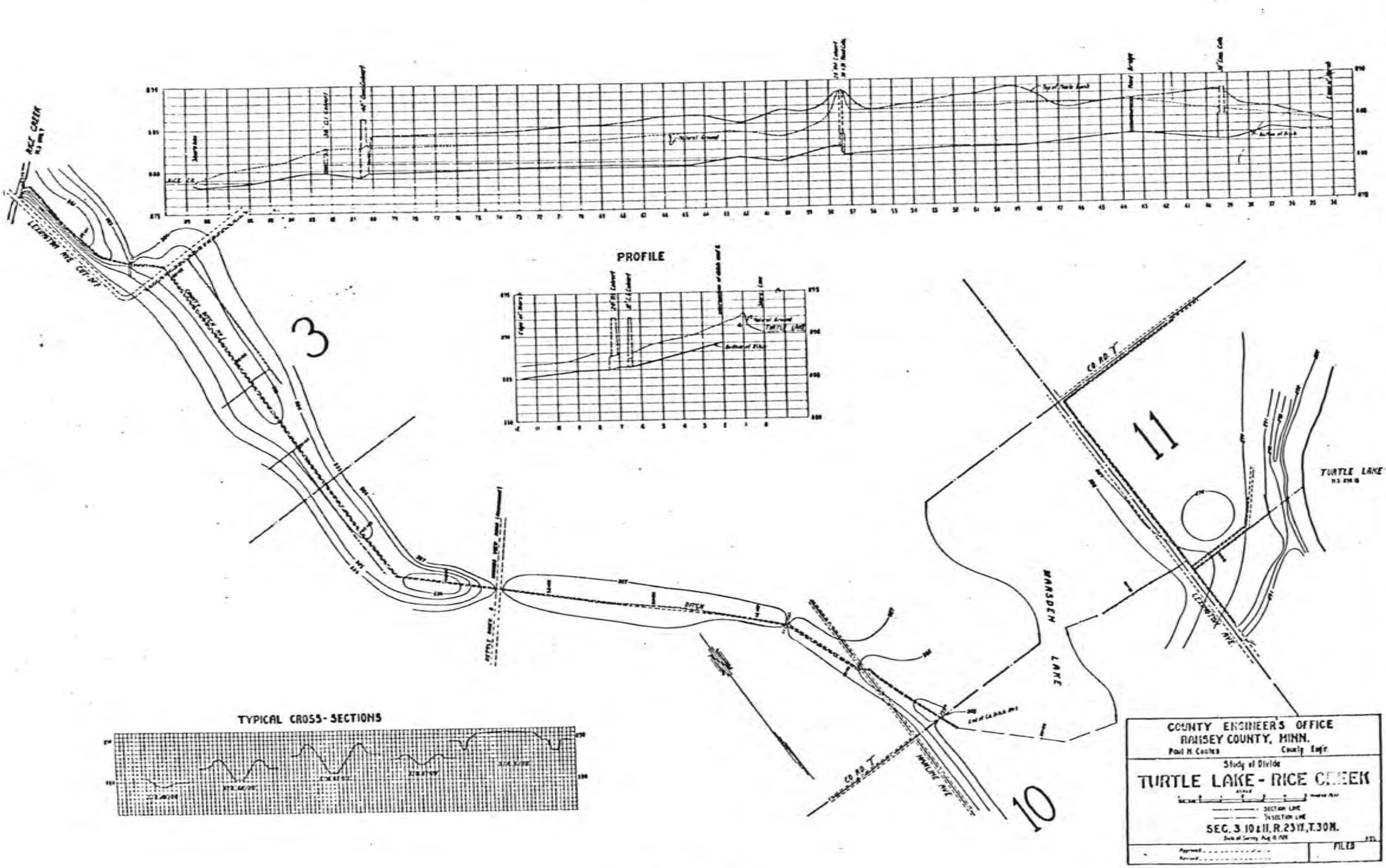
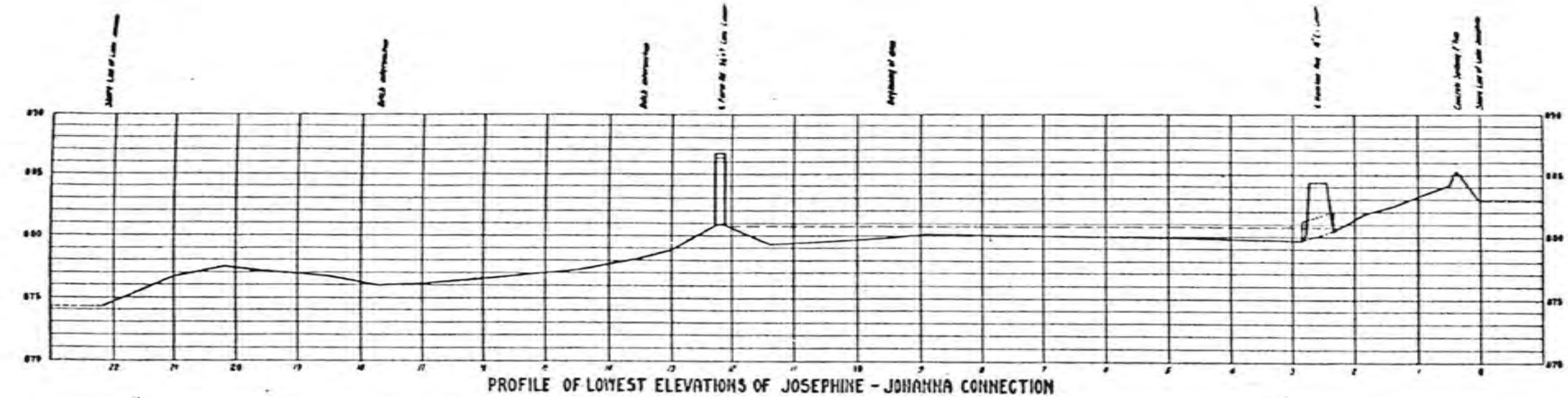

PROFILE
TYPICAL CROSS-SECTIONS
RICE CREEK
TURTLE LAKE
MARSDEN LAKE
LEXINGTON AVE.
CO. RD. T
DITCH
3
11
10
COUNTY ENGINEER'S OFFICE
RAMSEY COUNTY, MINN.
Paul H. Coulter County Eng'r.
Study of Divide
TURTLE LAKE - RICE CREEK
SECTION LINE
1/4 SECTION LINE
SEC. 3, 10 & 11, R. 23 W., T. 30 N.
FILED

Fig. 37

Fig. 37


PROFILE OF LOWEST ELEVATIONS OF JOSEPHINE - JOHANNA CONNECTION

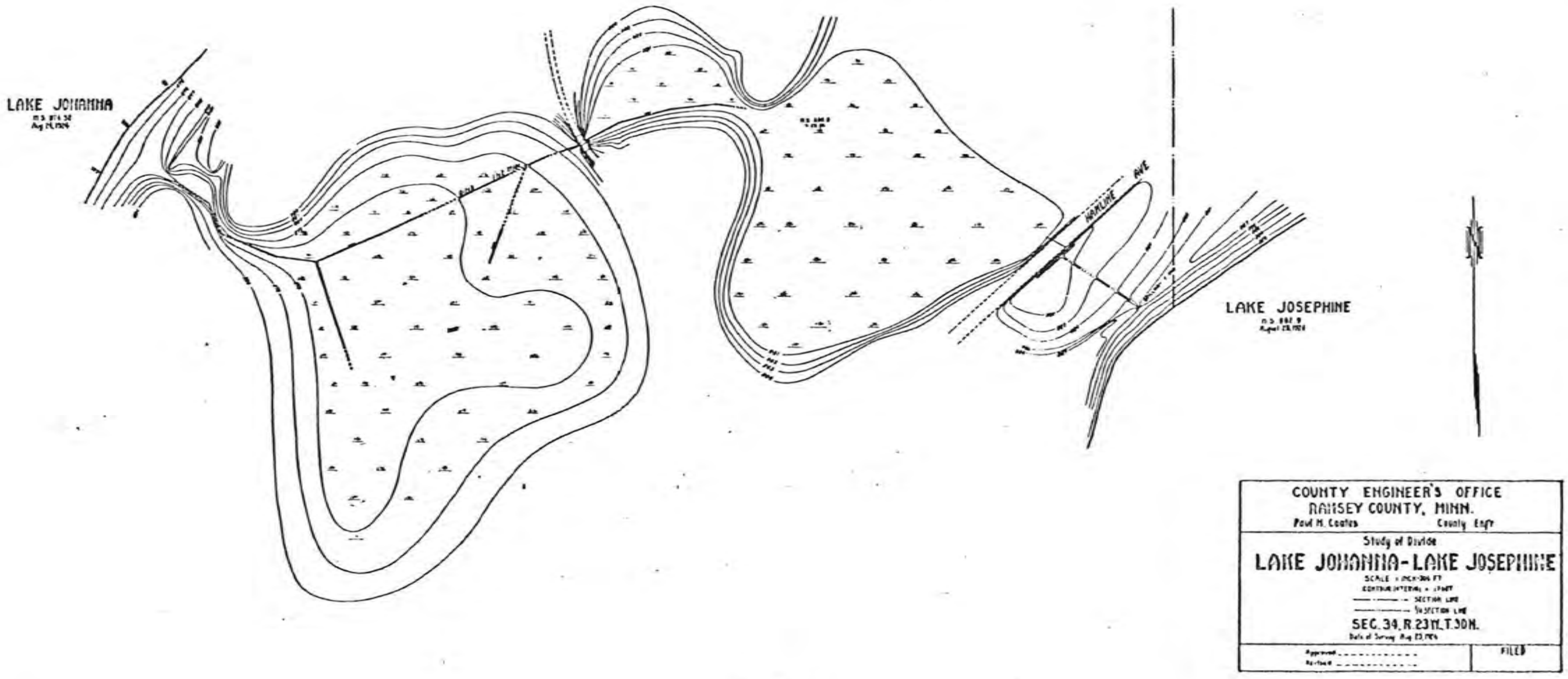

LAKE JOHANNA
HAMLINE AVE
LAKE JOSEPHINE
COUNTY ENGINEER'S OFFICE
RAMSEY COUNTY, MINN.
Paul H. Coates
County Engr
Study of Divide
LAKE JOHANNA-LAKE JOSEPHINE
SECTION LINE
SEC. 34, R.23W, T.30N.
FILED

Fig. 38

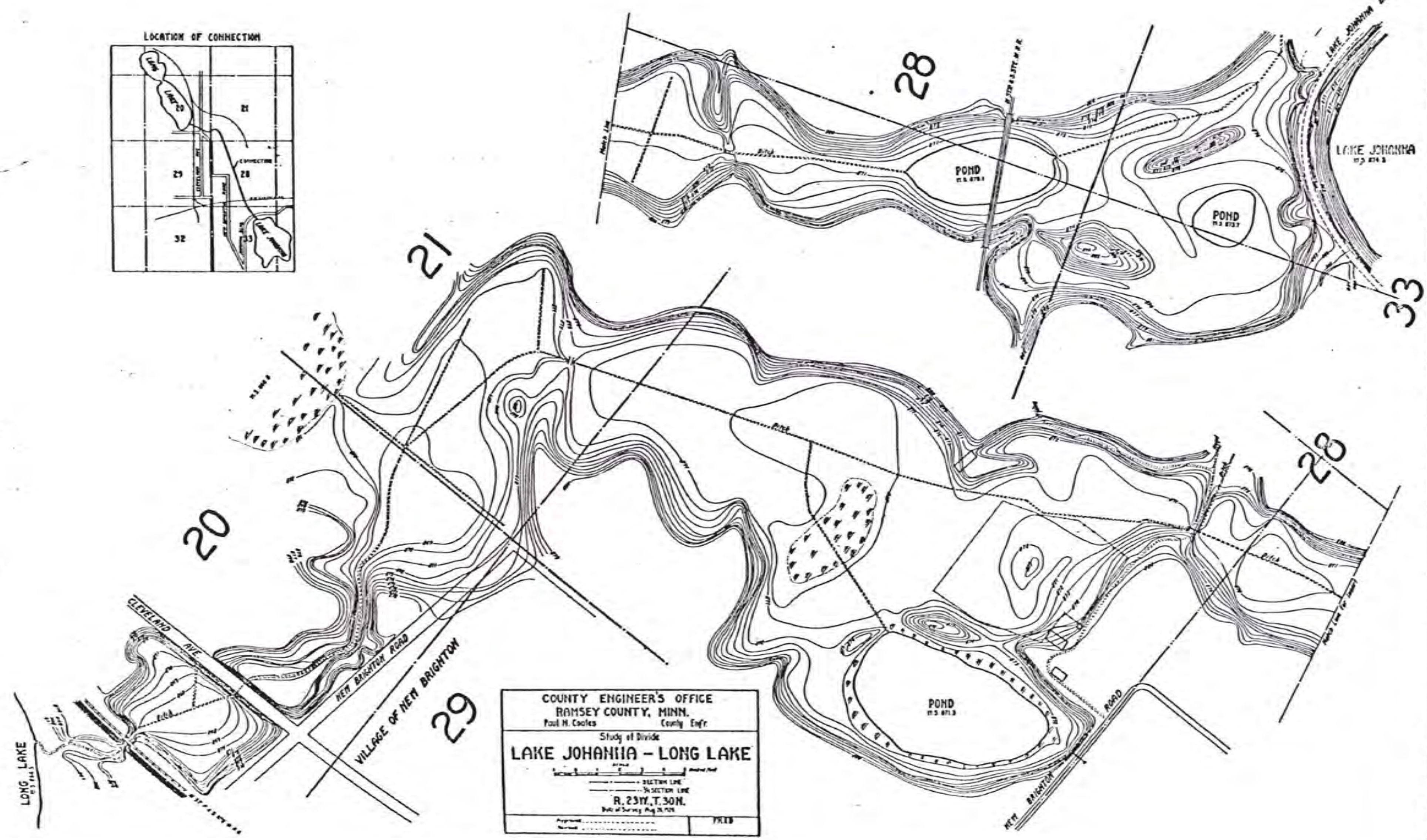

LOCATION OF CONNECTION
LAKE JOHANNA
LAKE JOHANNA BLVD.
POND
POND
POND
28
21
20
29
33
28
CLEVELAND AVE.
NEW BRIGHTON ROAD
VILLAGE OF NEW BRIGHTON
NEW BRIGHTON ROAD
LONG LAKE
COUNTY ENGINEER'S OFFICE
RAMSEY COUNTY, MINN.
Paul N. Coates County Eng'r.
Study of Divide
LAKE JOHANNA – LONG LAKE
SECTION LINE
¼ SECTION LINE
R. 23W., T. 30N.

Fig. 39

Fig. 39

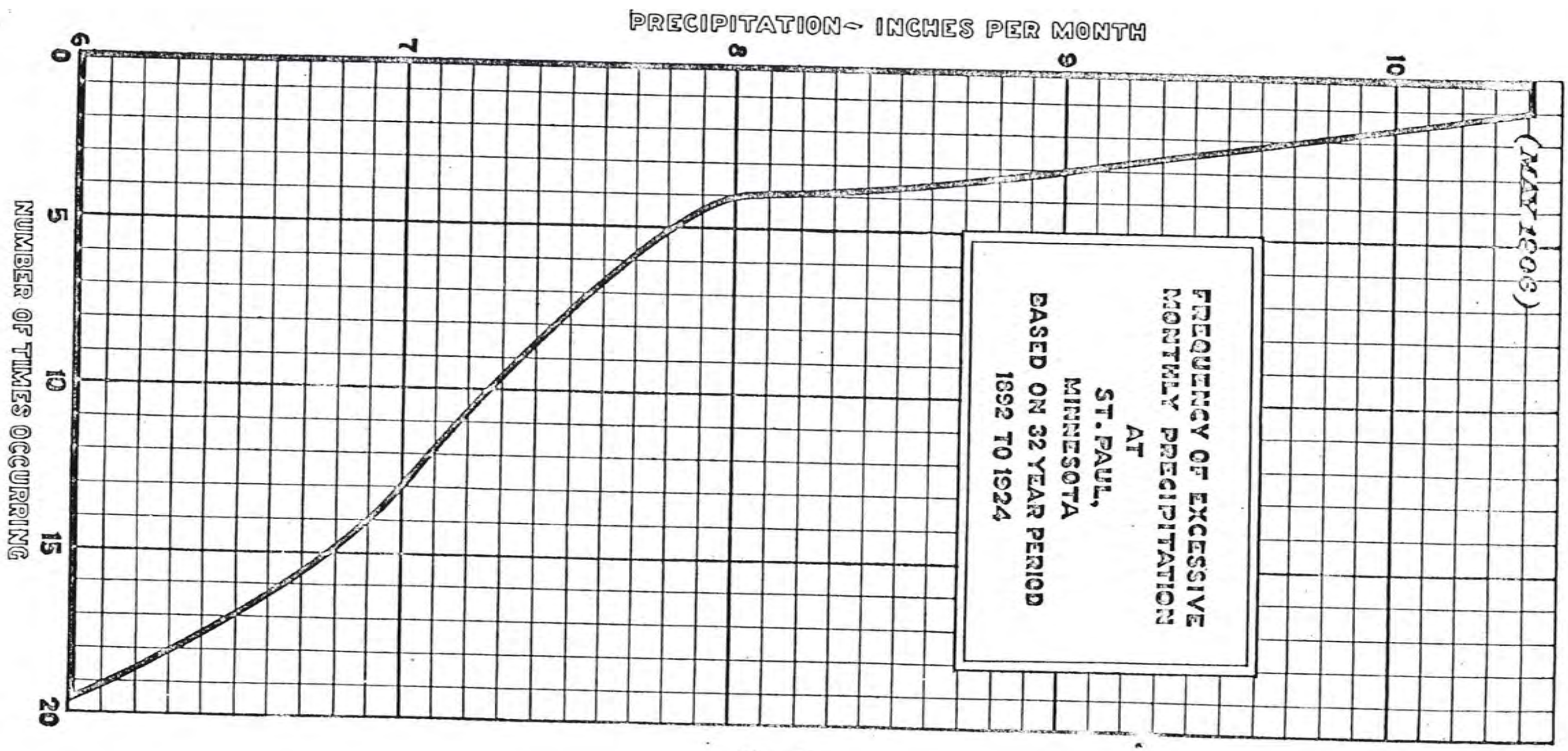

PRECIPITATION~ INCHES PER MONTH
6
7
8
9
10
NUMBER OF TIMES OCCURRING
0
5
10
15
20
(MAY 1906)
FREQUENCY OF EXCESSIVE
MONTHLY PRECIPITATION
AT
ST. PAUL,
MINNESOTA
BASED ON 32 YEAR PERIOD
1892 TO 1924

Fig. 40

As previously acknowledged, the proper design of the spillways is an engineering problem in itself, that would require considerable investigation; a rough estimate is offered for a temporary basis.

The cost involved in constructing the average spillway would be approximately $2,000.00, whereas in special cases where road construction has obstructed the natural outlet, the cost would probably be doubled.

PUMPING COSTS

The recent installation of new pumping machinery in the county wells at White Bear has been of great value as a basis for estimating costs of the suggested pumping units and their operation. These pumps are motor driven deep well turbines which have proven very satisfactory. This type of pump is thought to be the most economical for bringing water to the surface from great depths.

The cost of delivering water from deep wells is directly proportioned to the lift with a constant power rate and pump efficiency. As shown by curves for various lakes, (Fig. 41, Page 96.) The power rate in this case is an average rate and typical of this part of the country. The pump efficiency used for these curves is very conservative and would vary but a little regardless of the pump capacity.

The lift, or distance between the pump discharge and the elevation at which the water stands in the well when pumping, has been estimated from data collected from various deep wells in Ramsey County, as illustrated by Fig. 42, Page 97, and shown by contours, (Fig. 32, Page, 68.) This, however, is a rough estimate, being as near as can be determined with the data available.

The table shown on page 95, is a summary of pumping costs and suggested pump capacities for various Ramsey County Lakes. The costs as tabulated can be referred to as the best estimates procurable with available data.

TABLE SHOWING PROBABLE PUMPING CONDITIONS AND ESTIMATED COST

TABLE SHOWING PROBABLE PUMPING CONDITIONS AND ESTIMATED COST FOR PUMPING WATER INTO VARIOUS RAMSEY COUNTY LAKES

Location of Pumping Station	Estimated Well Diameter.	Estimated Pump Capacity.	Elevation of Pump Discharge.	Probable Normal Water level in Well. (Not Pumping).	Probable Normal Head. Lift.	Probable Pumping Head. Lift.	Number of Days Derived from Curves to Pump the Equivalent of one foot on Lake	Power Cost Derived from Curves to Pump Equivalent of one foot on Lake	Estimated Cost of Wells drilled to Water Bearing Strata.	Estimated cost of Pumping Machinery (Deep Well Turbine Type) Including #600 Pump House
	Inches	G.P.M.	Elev.	Elev.	Feet	Feet	Days	Dollars	Dollars	Dollars
Turtle	18	250	893.0	863.0	30.0	40.0	410	960.00	6100.00	2750.00
Snail	18	750	884.0	860.0	24.0	38.0	50	335.00	6700.00	3100.00
Josephine	18	750	885.0	815.0	70.0	85.0	64	950.00	6700.00	3500.00
Johanna							40	580.00		
Owasso	18	500	888.0	850.0	38.0	50.0		1085.00	6700.00	2800.00
Kohlman Gervais Keller Phalen	18	1000	860.0	835.0	25.0	43.0	141	1410.00	6800.00	3250.00
Bald Eagle	18	750	911.0	900.0	11.0	27.0	324	1520.00	6700.00	2800.00
Island	16	200	945.0	845.0	100.0	113.0	67	375.00	6200.00	3850.00
Round	12	200	891.0	825.0	66.0	75.0	154	540.00	5800.00	3100.00
Valentine	12	200	878.0	823.0	55.0	63.0	75	240.00	5800.00	3000.00
Long			865.0	820.0	45.0					
McCarrons			840.0	800.0	40.0					
Birch	12	200	919.0	900.0	19.0	25.0	142	165.00	5700.00	2500.00

Note: The pumping condition as tabulated for Lake Josephine and Lake Johanna is assumed with one well at Lake Josephine supplying both lakes.
The location of the assumed well for the Lake Phalen series is at the north end of Lake Gervais

CURVES SHOWING THE COST OF PUMPING, WITH VARIOUS HEADS, THE EQUIVALENT OF ONE FOOT RISE IN ELEVATION ON RAMSEY COUNTY LAKES WHEN PUMPING 500 GAL. PER MIN. WITH 65 PER CENT PUMP EFFICIENCY AND CURRENT AT 2.5 CENTS PER K.W. HOUR

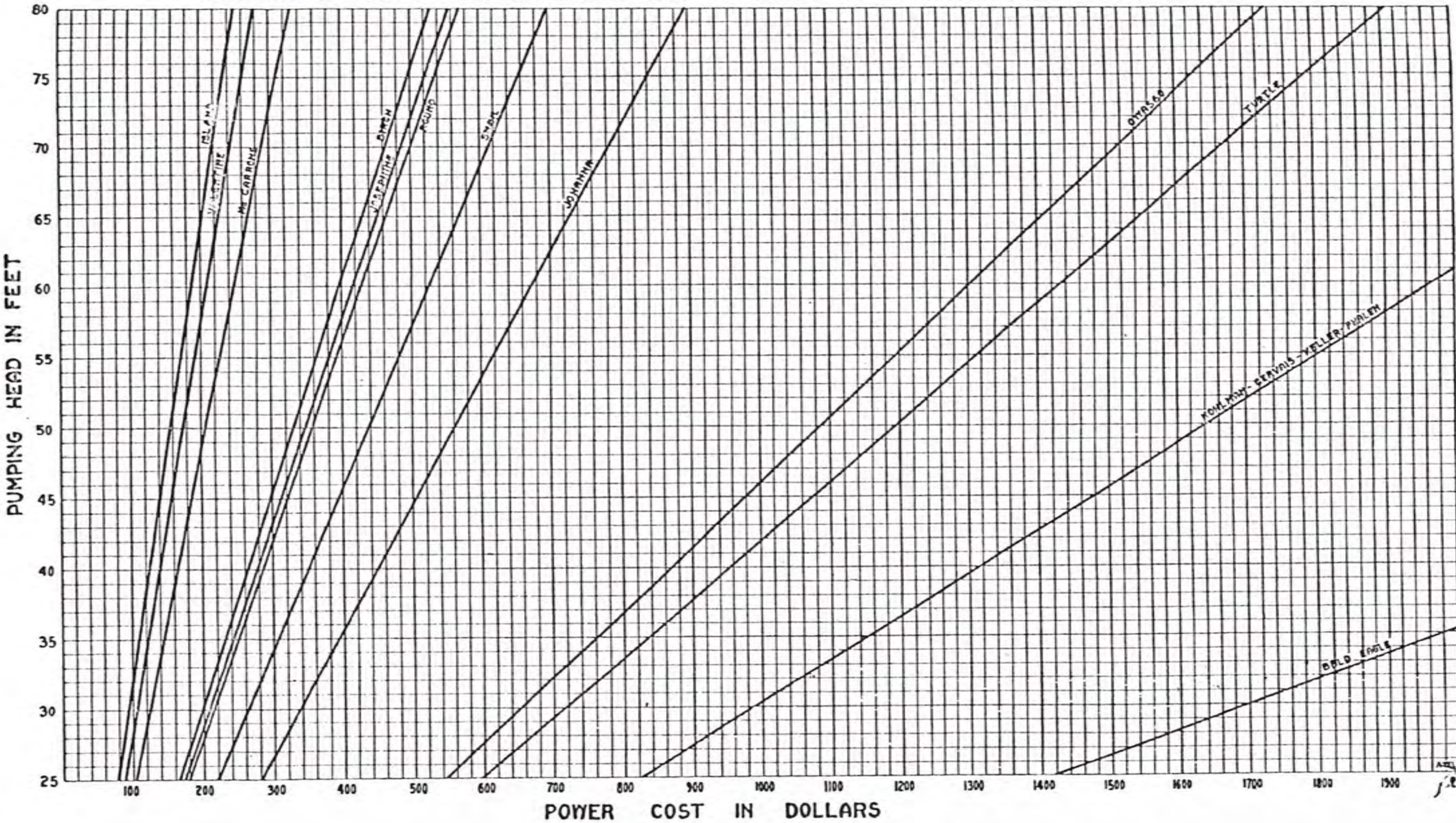


Fig. 41

CHART SHOWING LOGS OF VARIOUS RAMSEY COUNTY WELLS

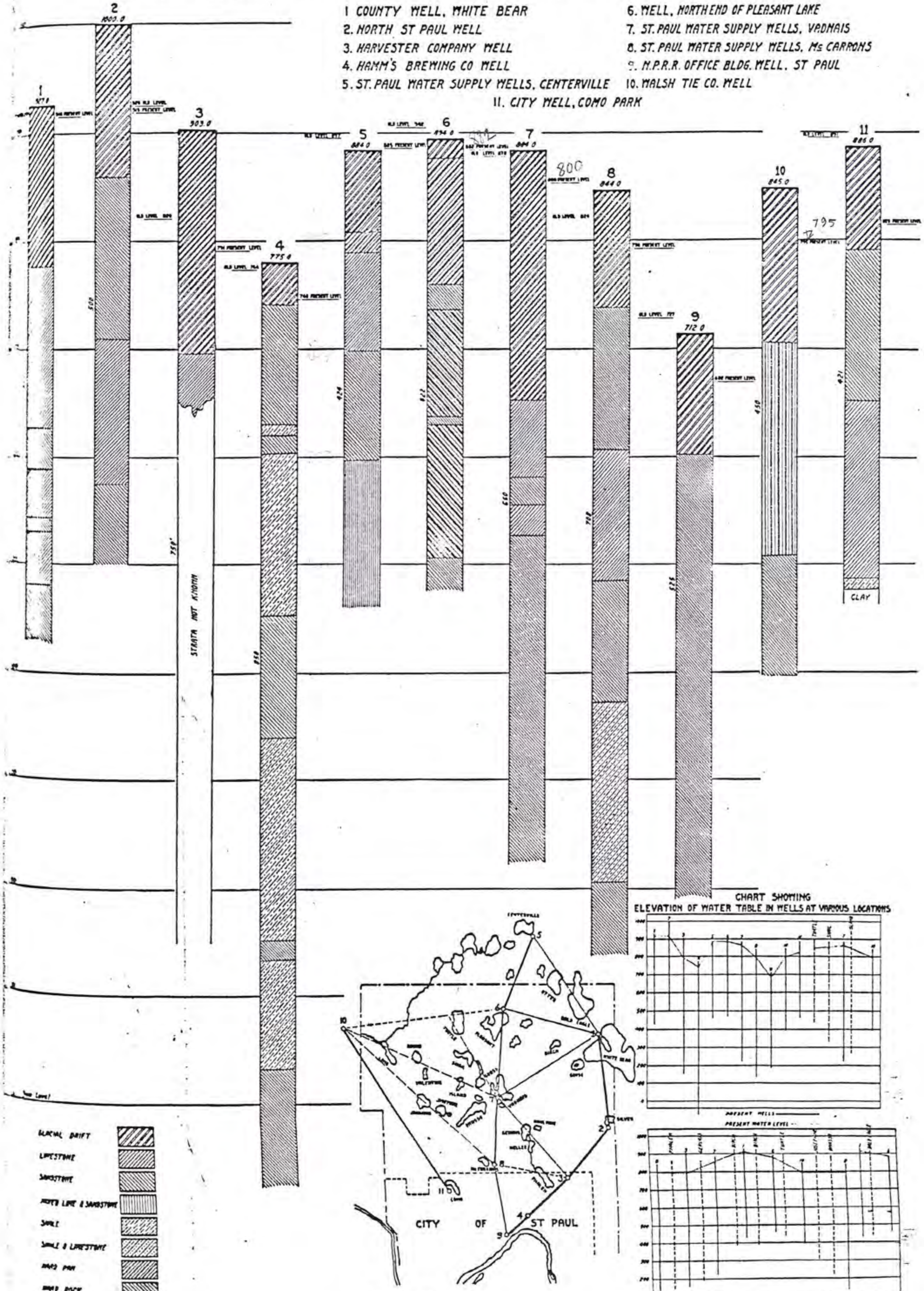


Fig. 42

EXPERIMENTAL ACTIVITIES

Weed Cutting

Experiments made by this department during the past two seasons, in hopes of procuring successful methods for the extermination of weed growth, have proven very valuable.

In view of ascertaining what could be accomplished by cutting the weed growth in our lakes, a power driven weed cutting device was designed and mounted on a boat. This weed cutter was designed to cut a ten-foot swath and the cutter bar so arranged that it could be regulated for cutting at various depths down to five feet below the surface.

The weed cutter was completed and put into operation early in August, 1923, on Keller Lake where the weed growth was exceptionally heavy. About 50 acres was cut in Keller Lake in 1923, and the initial experiment and the design of the machine proved very successful although several alterations were made.

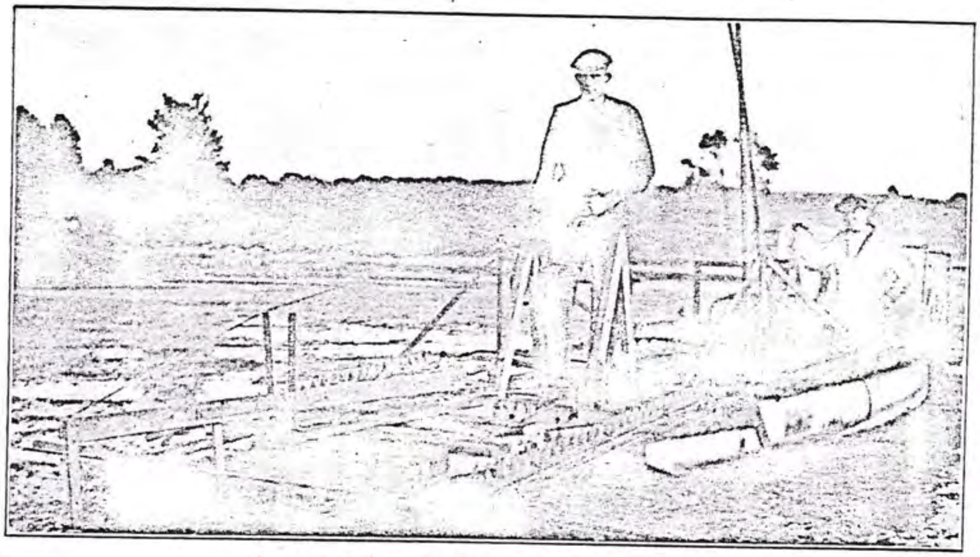
Soon after the weeds are cut they come to the surface and are carried by wind and wave action to the shore or to where a barrier of uncut weeds stops the movement. As a result of a strong wind, large mats of cut weeds collect and pack on or near the shore.

The removal of the cut weeds from the lakes is as essential as the cutting, for if the weeds were allowed to remain in huge mats and later in the year settle to the bottom and decompose, there would be additional mud deposits built up along the shores. This should be prevented.

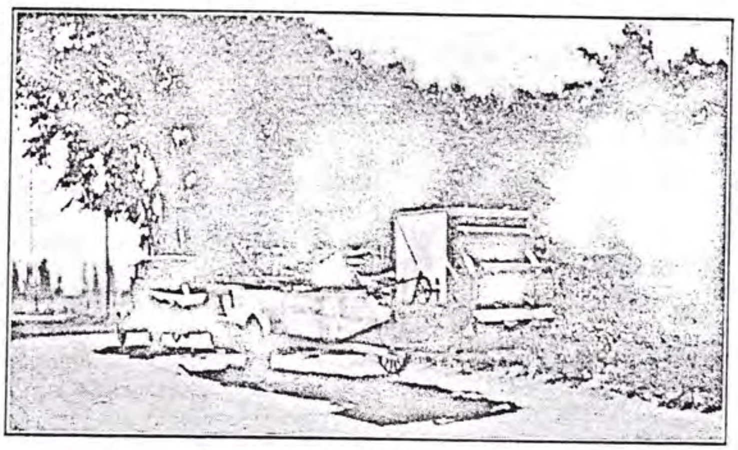
When cut weeds, driven by high winds, collect and pack on the shore, it is relatively easy to remove them by using garden rakes and forks but it must be done before the direction of the wind changes or they will be taken to other parts of the lakes.

Where a barrier or a line of uncut weeds keeps the mat from approaching the shore, it is necessary to go out and bring them in. The most successful method used in this case is a specially designed apparatus consisting of a long iron chain, wood floats or buoys and a power driven spool. The chain with attached floats, which have 18-inch leads, is distributed from a boat around a large area of cut weeds and forms a boom around the weeds. One end of the chain is made secure on shore and the loose end is wound on the power driven spool, also on shore. The floats or buoys with 18-inch leads suspend the boom chain 18 inches below the surface and when the chain is drawn in it, collects the weeds and brings them to the shore where they are removed by hooks and forks.

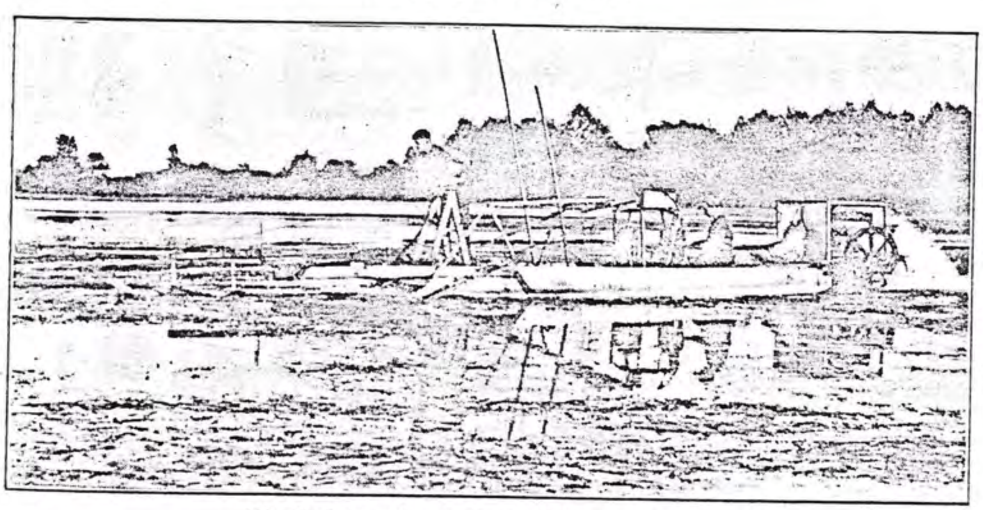
Hundreds of tons of cut weeds were removed in this manner from Keller Lake during the cutting season in 1923, and piled on the shores. The physical effect of weed cutting was at once noticeable, and Keller Lake was transformed from a mass of growing weeds so dense that a boat could not be operated on its waters, to an open lake free of all encumbrances.



Ramsey County's First Weed Cutter, 1923.



Portaging Weed Cutter.



Weed Cutter in Action—Keller Lake, 1923.

The value of the water weeds as a fertilizer has been known for many years and used extensively in the eastern states where they are collected along the sea shore. The weeds removed from Keller Lake in 1923, were analyzed at the State Agricultural School and found to contain a high percentage of nitrogen which, is an excellent fertilizer for heavy soils. An experiment was made on a plot of ground directly east of Keller Lake where twenty-five loads of weeds were hauled and spread over approximately one acre, through the center of the plot. The weeds were spread and plowed under during the fall of 1923, and corn was planted the following spring. There was not a noticeable effect in growth, due to this fertilizer, but the color of the corn stalks was a much darker green during the growing period, and by mounting a hill near by to look down on the field the outline of the fertilized area could be clearly seen. The real test for quality of ear corn was destroyed by the early frosts in the fall of 1924, but some difference in the kernal development was discernable.

Although our experiment fell short of local evidence, I do not hesitate to recommend the use of weeds from our lakes as fertilizer for it has been proven valuable and Mr. Freeman, our County Agent, has volunteered his services in making it a popular fertilizer.

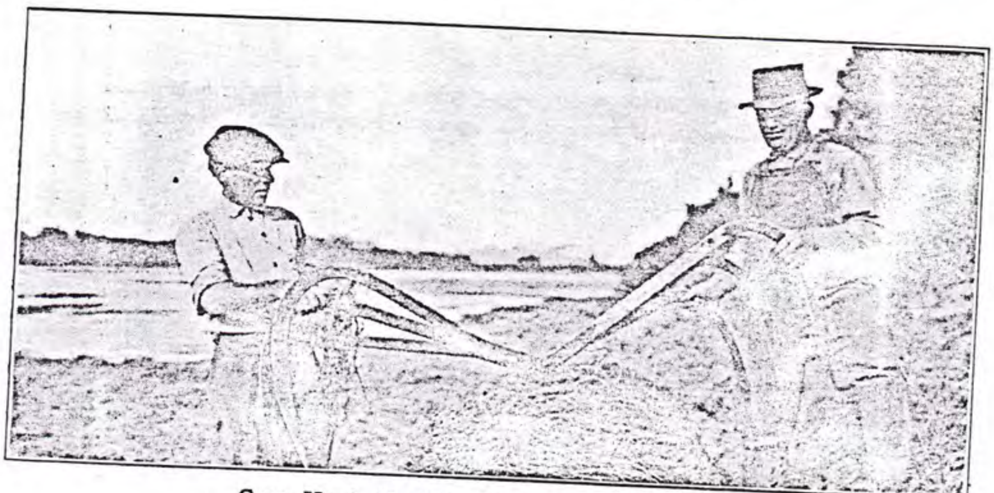
The results of the 1923 weed cutting experiment in Keller Lake in view of exterminating the growth was very noticeable when the weeds again started to grow in June, 1924. An estimate was made of the density of growth in 1924 compared to 1923 which showed a reduction of at least thirty per cent. This proved the experiment very valuable and the 1924 cutting operations were at once started.

The 1924 weed cutting program included the cutting and removing of weeds from several lakes in the County. The weed cutter was launched in Gervais about June 15th and operated along the north shore until July first. By this time the growth in Keller Lake, although not as heavy as in 1923, was well under way and the second year's cutting was made to advance the experiment.

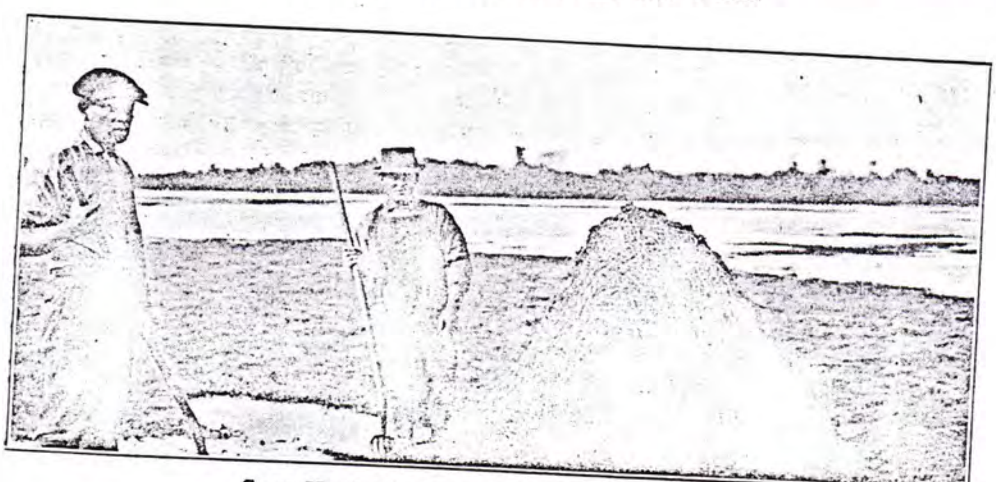
The early accomplishments of this experiment were soon broadcast to all parts of the county and the weed cutter was in demand at many lakes. It was then a matter of placing the weed cutter and distributing the time so that several lakes could benefit to some degree at least. The cutter was moved, by using a special designed trailer, to Owasso, Silver, White Bear and Turtle Lakes, respectively. Although it was impossible to cut all the weeds in each lake, with the one cutter in a limited time, some good was accomplished in the localities where the boat operated. Perhaps the most noticeable effects of weed cutting was in the southwest bay at White Bear Lake adjacent to the St. Paul Auto Club. Here the weed growth caused the waters of the bay to be more or less stagnant and not adaptable to boating. Two weeks' operation cut practically all of the weeds in this bay and hundreds of tons of wet weeds were removed from the lake. Wave action on the west shore, that had been counteracted by the weed growth, was restored and cut weeds were washed far upon the beach.

To successfully combat weed growth, it would be necessary to cut practically all of the weeds in a lake so that seeding would be checked.

Pulling in Boom Chain—Keller Lake, 1923.



Grap Hook Used for Removing Cut Weeds.



Grap Hook Coming Out With a Full Load.

It must be conceded, however, that it is quite impossible to cut all of the weeds because of the shallow water in some bays and along the shores which prohibit the operation of the weed cutter which draws 12 inches of water, but let us cut all that we possibly can and let wave action do what it will in cleaning the bays and shores. Each year that weeds are cut, there are less seeds that will grow and if this process is continued from year to year, it is obvious that the growth could be thinned out and trimmed down so that the cutting would be reduced and easily taken care of.

We must bear in mind, however, that with the lakes at a normal elevation, the present shallow water areas now lending themselves to weed growth will be reduced materially. Where weeds now thrive in three feet of water, which is two feet below normal there would be under normal conditions, five feet of water that would kill the growth and move the weed line nearer shore.

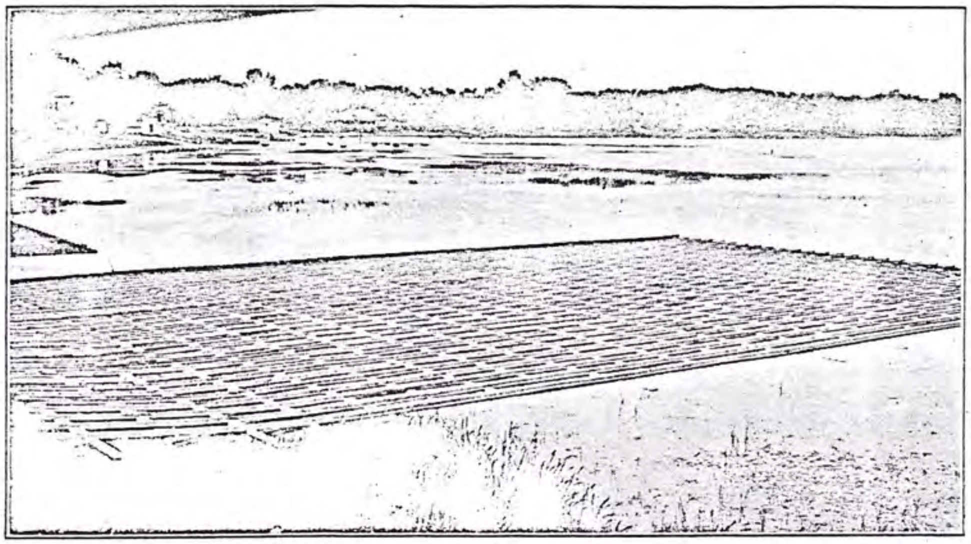
The rushes and cat tails existing along the shores of our lakes where the water does not exceed three feet in depth can be exterminated in a similar manner by continuous cutting. From experiments conducted along these lines, it has been found that the growth can be thinned out at about the same rate as the water weeds. The menace of these weeds is not considered as serious as the water weeds inasmuch as they grow in shallow water where they can be cut with a scythe by those whom they effect. With the lakes at a normal elevation, most of these weeds will disappear due to submergence.

It is believed that more can be accomplished for every dollar spent on lake improvement by cutting weeds than in any other way conceivable. Weeds are not only a physical menace, but they cause other irregularities such as breaking wave action and causing sedimentary deposits as previously outlined in this report. What has been accomplished with one weed cutting machine during the last season is a direct proportion to what can be done with three machines operating on all of our public lakes. The initial and operating cost of such machines is insignificant compared to the value received. The cost of a weed cutter complete is estimated at $900.00. The operating cost has averaged $10.00 per day or approximately $1.00 per acre under normal operating conditions.

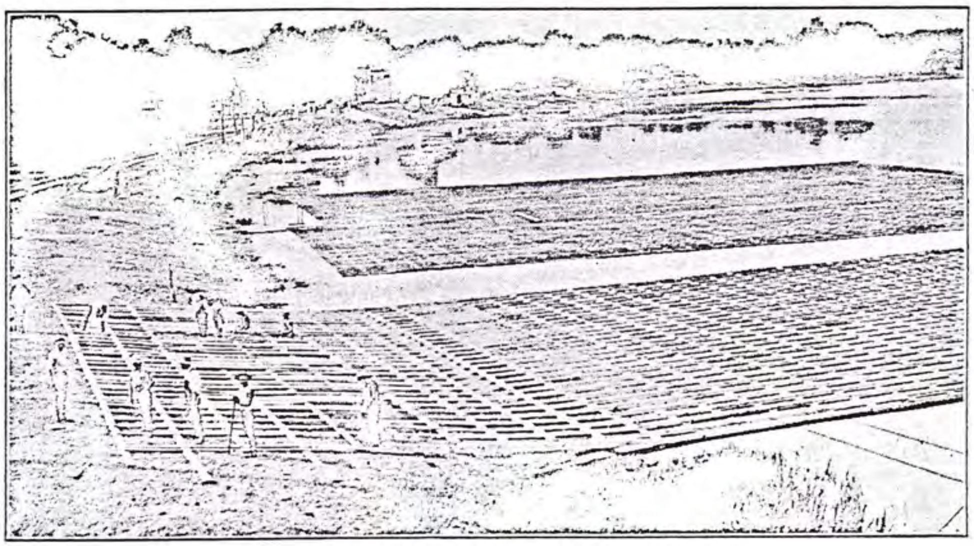
Artificial Bathing Beaches

A large percentage of the shore lines of the County Lakes are a soft mud which makes bathing a difficulty. Many summer homes on the County Lakes have no private bathing facilities due to the soft mud shores. These people, to indulge in the popular summer recreation, bathing, often go to public beaches or impose upon a friendly neighbor, who is more fortunate in having a hard bottom beach.

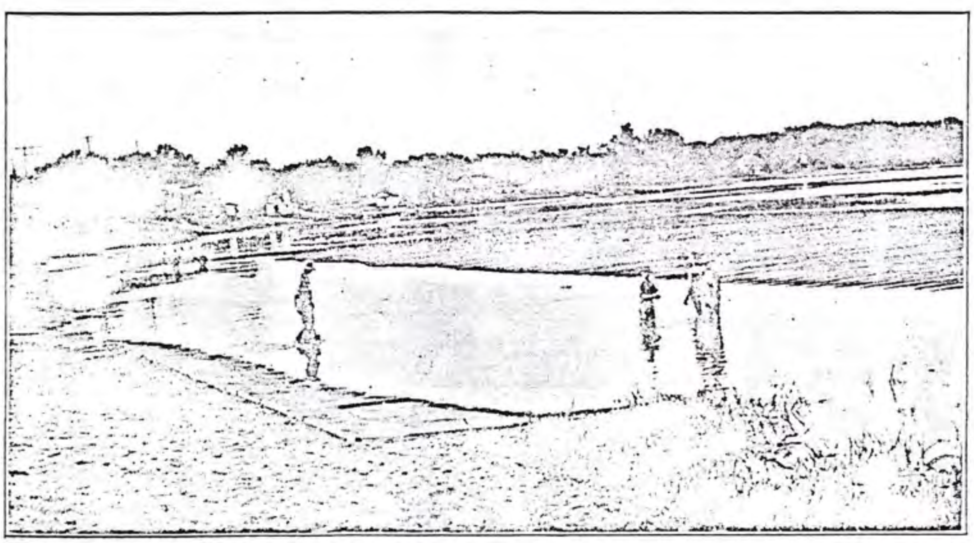
In view of solving the mud beach difficulties, experiments were made in 1923 to test the stability of an artificial hard bottom beach. This new type of beach was to be of standard concrete sidewalk tile, two feet square and two inches thick, placed on a wood rack constructed so as to hold all tile blocks in place. This concrete mat to be laid on the soft mud bottom and receive its support as a large flat unit which would not have as great a tendency for settling into the mud as a small flat unit such as a single tile block, i. e. the larger the area, the greater support the mud bottom will offer.



First Section of Wood Rack for White Bear Artificial Bathing Beach—July, 1924.



Completing Third Section of Wood Rack.



Sinking the Wood Rack with Concrete Tile.

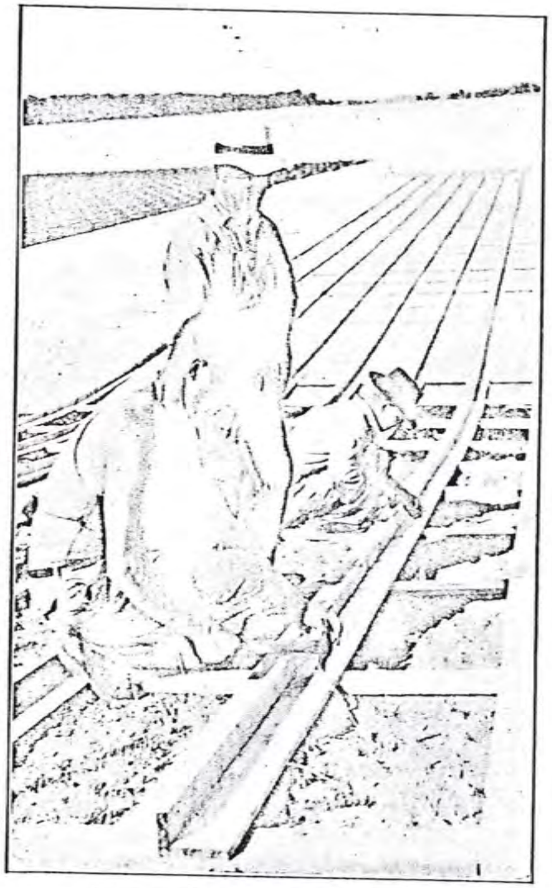
In August, 1923, the first artificial concrete bathing beach was laid in Lake Johanna. A wood rack, six feet wide and one hundred feet long was constructed on shore and floated out to where the beach was to be laid. After locating the raft or beach so that the shore end would be submerged in two feet of water, concrete sidewalk tile was placed in columns of three across the raft which was gradually submerged as more tile was laid until the last few columns of tile on the outer end caused the entire raft to rest on the mud bottom. The submergence of the outer end was in this case four and one-half feet. The depth of the mud on which the beach was laid varied from one foot on the shore end to ten or more feet on the outer end. The shore end of this beach, or submerged sidewalk out into the lake, was placed approximately fifty feet from shore in two feet of water so that it would be safely guarded against ice action in the spring. A temporary lead walk of the same material was placed from the shore out to the beach to determine the destructive action ice would have on the tile.

To determine the stability of this new type of beach, where the mud depth underlying the concrete was of greater depth than at Johanna, a similar beach was constructed later in August, 1923, at White Bear, on the west shore of the bay adjacent to the St. Paul Auto Club. This beach was sixteen feet by seventy-two feet with lead walk from the shore four feet wide and forty-eight feet long.

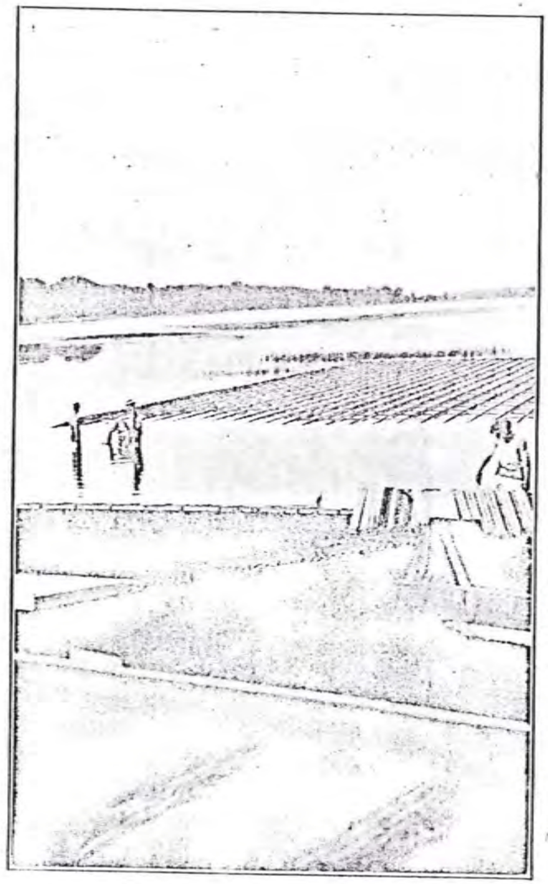
Elevations were taken at two-week intervals on these beaches so as to determine the settling action. It was found that in four months, the Johanna Beach settled five inches and the White Bear Beach, six, practically all of which occurred in the first two weeks after construction.

April 15th, 1924, when the ice broke up, careful observations were made concerning the effect it had on the tile in the lead walks which were frozen in during the winter months. The flexibility afforded by the wood racks on which the blocks were laid preserved the tile much better than was expected, and in each case, not over six blocks were cracked and displaced. The total settlement into the mud of the beaches to date only slightly exceeds that of the first two weeks after construction, which indicate the permanency is beyond doubt. There was a question as to whether additional settlement would take place when the weight of several people was added, but the beaches stood this test with no noticeable effect. When a person's body is partly or fully submerged in water, its bearing weight on the beach is reduced proportional to the amount of water displaced by the body, therefore, the beach supports but a small percentage of the total weight of those who use it.

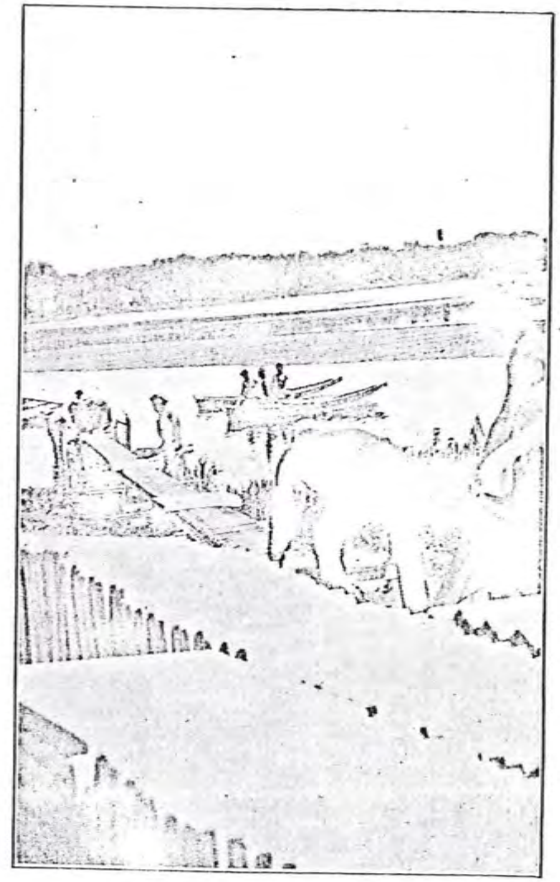
The success with the experimental beaches constructed in 1923, warranted procedure on a larger scale, so plans were formed last June to construct a public beach 200 feet by 160 feet at White Bear. The location selected was in the extreme southwest corner of the bay directly east of the St. Paul Auto Club where from ten to twenty feet of soft mud exists. It was necessary to select this location so that the beach would have proper submergence when the lake is restored to its normal elevation, (924.50). Construction started July 10th, 1924, and the beach was completed three weeks later. The wood raft was of No. 2 pine and held together with galvanized nails.



Showing Design of Wood Rack.



Distributing Concrete Tile.



Conveying Concrete Tile.

This raft was constructed on the shore in three sections which were floated and spliced, forming one large raft. Standard cement sidewalk tile two feet square and two inches thick was used. The shore edge of the beach was placed at an elevation of 921.50, flush with the shore line at the time the beach was laid. Ice action may break a few tile each year along the shore until the lake attains a normal elevation, but the damage thus caused will not be serious.

To protect those who use the beach from going beyond its limit and stepping off into the soft mud, buoys are anchored to the outer edge of the beach, at four foot intervals so the outline is clearly discernable. These buoys are removed during the winter months, so the ice action in the spring will not cause the anchor chains to be broken or pulled from the outer edge of the raft.

The beach from a point approximately fifty feet from the shore to the outer edge is relatively flat and had an average submergence of two feet when the lake was at an elevation of 921.50. With the lake at a normal elevation, the average submergence will be five feet which will enable those who use it to walk over the entire beach and swim without coming in contact with the cement bottom.

The beach with an area of 32,000 square feet will comfortably accommodate 250 people at one time. Relatively few people used the beach last season because of the shallow water and the inaccessibility due to road construction in the vicinity. However, the popularity of the beach will reach its height when the normal lake elevation is attained and a bath house erected.

For those who have muddy shore lines adjoining their lake shore property, this type of beach will prove to be an inexpensive asset and simplify the irregularities of a muddy shore and beach. The permanency of small beaches adaptable to private use would be the same as of larger beaches and with proper attention, would serve for many years. The construction and placement is not a complicated matter and any property owner who is desirous of having a private hard bottom beach, can profit by investigating these beaches, and the methods used in their construction.

LEGISLATIVE REQUIREMENTS

During the preparation of this report, it became obvious that if the County desired to act on its recommendations, further legislative authority might be desirable if not absolutely necessary. While there are parts of our drainage laws that might apply it is felt that their short comings are too great for general use in connection with an effort to derive the greatest benefit from needed lake improvement.

A realization of the great public benefit accruing from artificial restoration, control of fluctuations, and weed cutting, thoroughly justifies the expenditure of public funds.

In connection with these general benefits, there will be found a great many private benefits, of such a special nature, that public criticism might follow any attempt to foster a much needed public improvement without due regard for a just assessment against them.

An example of this case might be foreseen in connection with the installation of pumping equipment, for the purpose of artificial restoration and reservoir control. Property owners having summer homes along the lake shore will, beyond question receive a special benefit, and it is suggested that they be assessed for this benefit to the extent of payment for the cost of operating the pumps once they are installed. This cost has been conservatively estimated at $0.15 per foot of shore line per year and would amount to but $15.00 per year for the owner of a 100-foot strip of shore line.

Many property owners have been consulted in regard to some such assessment and, have enthusiastically endorsed the suggestion. Further suggestion is made for a one-half mill state tax, to be used by Counties throughout the state facing similar problems. This fund would be furnished by the State as aid to counties for their improvements, and to be expended under the general supervision of the Commissioner of Drainage and Waters of the State of Minnesota. The establishment of this fund may require a constitutional amendment, and if laws applying to the particular problems of Ramsey County are enacted, and made use of, the experience will be of great value to the State.

Should all efforts for legislation fail at this time, the value of this report will not have been lost. The value of data is appreciated most by those who depend upon it for determinations. With records extending back over a period of years, as complete as those tabulated by this department during the past eighteen months, the correlation of this report would have been simplied with a resultant saving to the taxpayers. We have bridged a period of inadequate records and, with the equipment now in place for the collecton of important data, the continuation of this work can be carried on at a very small expense each year, and will be invaluable in the future.

STATEMENT OF AIMS, SCOPE AND RESULTS OF LAKE IMPROVEMENT INVESTIGATION

By

Adolph F. Meyer, Consulting Engineer

To have been connected with an investigation made possible by a Board of County Commissioners that recognized the need for engineering data as the basis for public expenditures on lake improvement projects; and to have worked with a County Engineer and staff that approached the problem before us with unbiased minds and attacked it with vigor and whole-hearted enthusiasm, has, indeed, been a gratifying professional engagement.

As usually happens, the questions to be answered were found to be more ramified than anticipated; various lines of investigation had to be extended several times, and even now the data collected have, in many cases, been found inadequate bases for ultimate conclusions. However, the positive value of what is presented in the body of this Report, cannot be questioned by anyone who reads it. In many respects information presented constitutes a real contribution to engineering literature.

As a background for more detailed studies and a basis for all lake improvement projects of whatsoever character, shore line surveys and soundings were first made on most of our lakes. These surveys included a determination of the size of the lakes themselves and the tributary drainage areas, together with measurements of outlet channels. About a dozen rain gauges were placed in strategic locations around the lakes in the fall of 1923. The record secured afforded an invaluable basis for estimating the seepage and evaporation losses from our lakes.

The present low level of all of our lakes is so evidently undesirable that the underlying causes were first investigated. It was found that the rainfall has been abnormally low for some years past, and the evaporation from the lake surfaces has been higher than normal. The general trend of rainfall during the next ten years will undoubtedly be upward, yet this investigation discloses that even should the most favorable past decade of rainfall be just ahead of us only a few of our lakes would rise sufficiently so that water would flow from their outlets. Such a period of high rainfall would necessarily be followed by a series of dry years, as in the past, during which many of our lakes would no doubt fall still lower than at present.

It appears that the lowering of the ground-water level as the result of pumping from deep wells in the City of St. Paul and the vicinity, has resulted in sufficiently increased seepage losses from our lakes to materially retard their natural recovery during periods of high rainfall, and even to make the probability of many of the lakes again reaching former highwater stages extremely remote.

Nature's balance having been disturbed, it is now proposed to assist her by pumping water back into our lakes. There need be no fear that pumping water from the underground reservoir into our lakes will still further lower the watertable. The proposed pumping constitutes merely the return of seepage water which is escaping from the lakes.

Overflow and escape of water from the basin is to be prevented so far as possible by conserving flood water for use in St. Paul's water supply. Flood reserves of from one to two feet depth within which the outflow is controlled are to be established in all the lakes, and the occasional necessary outflow, so far as practicable is to be led into the lakes constituting part of St. Paul's water supply. With a view to such conservation, these latter lakes should be kept at as low stages as possible.

Many of our lakes at present, have inadequate outlet spillways or none at all. The establishment of normal lake elevations and the provision of adequate spillways of proper type are essential, whether pumping projects are adopted or not. Several of our lakes will undoubtedly reach an overflow stage again. If no adequate spillways are provided some of them will rise to objectional elevations and on others the water will flow over the sandy ice-ridge at the lowest point of the rim and inevitably cut it down, with the subsequent lowering of lake levels and possible damage to property below the outlets from high rates of outflow.

While proposing to assist nature in restoring our lakes to desirable stages we do not propose to eliminate all fluctuations in stage, but merely to prevent the excessive lowering that occurs during a series of dry years. During extremely dry summers such as those of 1910, for example, our lakes would still fall about a foot in three months but over a period of five years continuous pumping at the rates proposed would add about five feet depth to our lakes. This is more than sufficient to maintain them at satisfactory stages.

The pumping rates at present recommended average about one inch depth on the lakes each month. For eleven lakes studied the aggregate amount of pump capacity recommended is less than 5,000 gal. per min. The pumps will probably not need to be operated half the time to maintain the lakes at reasonably satisfactory stages. Utilization of St. Paul's new source of water supply at Fridley should reduce the draft on the underground reservoir and assist in the gradual recovery of the water table or at least reduce its rate of lowering. The distances the water must be lifted out of the wells will not be great. The proposition appears economically feasible from every angle.

It is proposed to dig wells of ample capacity for the largest pumps that may later be found useful for still further improving the natural regime of lake levels whenever the value of our lakes warrants it, and also as a possible means for supplying water to homes around the lakes. The added cost is very small.

Considerable attention was given to the question of shore improvement such as the elimination of weeds and the improvement of beaches. The experimental work done during the past two seasons indicates that the systematic cutting and removal of weeds will do more for the improvement of our lakes than an equal expenditure of money for any other purpose. Weed growths largely prevent the beneficial wave action that forms good beaches by carrying the fine sediment out into the deep, quiet water. By stilling the water, near shore weeds encourage the deposition of fine silt, and they add to the objectionable mud by their decomposition.

A study was made of various means for improving bathing beaches on our lakes. At present the best portion of most of the beaches is out of water. Higher stages will greatly improve these beaches. On many of the lakes, however, muddy bottoms extend out to shallow water. For these beaches a pavement was designed that has thus far proven quite satisfactory. This pavement consists of standard sidewalk tile two feet square and two inches thick laid on a framework or raft of one inch by four-inch boards. This pavement has been successfully laid on more than ten feet of soft mud with a settlement of only about six inches.

These, all too inadequately told, constitute the principal aims and results of the lake imrpovement investigation. In the preceding pages the County Engineer and his staff have dealt fully with the several matters here briefly mentioned.

Grateful acknowledgment is made to the following firms and individuals for their aid and interest in furnishing information of assistance for this report.

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