Fifteenth Biennial Report

OF THE

STATE ENGINEER

TO THE

GOVERNOR OF NORTH DAKOTA

1931-1932

ROBT. E. KENNEDY
State Engineer

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LETTER OF TRANSMITTAL

The Honorable
William Langer,
Governor of North Dakota.

Sir:

This report usually has been delayed to include the office copies of stream gaging records prepared by the U. S. Geological Survey because their publication schedule in the past has been three or four years behind.

This is the excuse again but when it was found they would be able to publish these records in a few months the duplication of expense was obviously unwarranted.

Respectfully submitted,

ROBT. E. KENNEDY,
State Engineer.

Bismarck, North Dakota,
February 1, 1933.
(Due September 30, 1932.)

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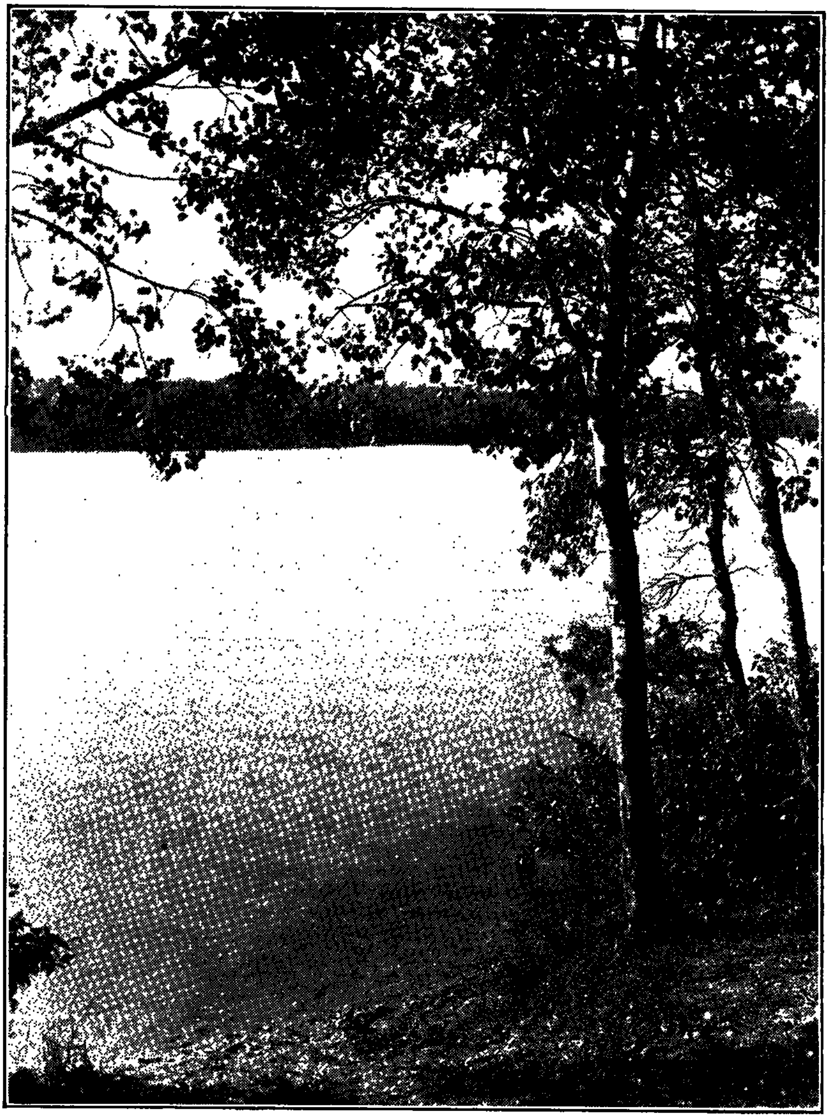
of the

TURTLE MOUNTAIN LAKES

STATE ENGINEER DEPARTMENT

Bismarck, N. Dak.

December, 1932



LAKE UPSILON

CONSERVATION OF THE TURTLE MOUNTAIN LAKES

By Robt. E. Kennedy, State Engineer

After one has visited the Turtle Mountains a most persistent question arises: Why are they so little known? Why are they not one of North Dakota's most popular playgrounds? The lakes are there, in profusion, about a lake on a general average to a section of land. The larger lakes are permanent, they have never been known to go dry. The woods are deep and thick; —primeval over many of the rolling hills. They seem like a bit of Minnesota that strayed away from the main land somehow when the world was being made. One thing they have over their Minnesota competitors is the elevation above the surrounding country. From the mountain side one can see over an immense vista of level plain, a grand panorama of villages, fields, railroads, and highways.

Perhaps lack of proper advertising is one reason. But another large reason is the difficulty of maintaining continually thru the years an adequate supply of fish. For after all what are lakes without fish? True, there are still swimming and boating to be enjoyed. And the beauty is not impaired. But fishing is a great attraction. Lake Metigoshe has demonstrated that. It is just now coming back into its prime fishing condition again. In 1930 there were 166 fishing licenses sold in Bottineau County. In 1931 there were 2070 licenses sold. Most of them were used at Lake Metigoshe. Fishing and the new graveled road account largely for its present popularity.

These lakes develop cycles in fish life. During periods of small inflow and little change of water the fish suffocate during the ice covered season. When that occurs large quantities of dead fish are sometimes washed upon the shore in the spring. Then conditions will change. Perhaps a series of wet years will freshen the lake. The restocking will be successful and in a few years fishing will be excellent and remain so until another cycle sets in.

Scientific Data Being Gathered

Scientific data in the Turtle Mountains upon which to base run-off and evaporation estimates are almost entirely lacking. For this purpose this Department has installed a water stage staff and a weather bureau rain gage at both Lake Upsilon and Lake Metigoshe, the two lakes having the greatest present commercial development. At Lake Metigoshe we also installed for a limited period an anemometer or wind velocity instrument loaned us by the Weather Bureau and thermometers and hygrometer. We are making frequent analysis of the water from the lake for dissolved oxygen content in the hope that this will yield us a sign of approaching retrogression. Before proceeding to a detailed description of the projects proposed, a general description of the region is in order.

General Description

The region is a turtle-back shaped elevation cut approximately on the long axis by the international boundary a bit east of the midway of the state. It is about 24 miles wide by 44 miles long and covers about 700 sections of land, 450 square miles of which lie in North Dakota. The top is from 400 to 600 feet above the surrounding plain and has an elevation of about 2200 feet sea level. The highest peak recorded is marked by Boundary Post 699 and has an elevation of 2541 feet.

Topographically the area is a rolling hilly plateau. It is timbered with varieties of oak and quaking aspen. A striking feature is the enormous number of beautiful timber-fringed lakes. There are 704 lakes shown on the available maps, 570 of which lie wholly within the United States. Ten of these, including the largest one, Lake Metigoshe, are crossed by the International Boundary. Many of these smaller lakes do not now contain water. On the other hand the maps of the public land survey show only those crossed by the section lines. Many fine lakes are not shown. It is probably safe to say that there is still on a general average a lake to a section of land on the North Dakota side. Most of them are shallow, only three or four feet in depth and cover from five to 100 acres in area. Only four are twenty feet or a little more in depth.

The permanency of the larger lakes is another notable feature. They have never been known to go dry. Lake Metigoshe attained a high stage of about 2137.7 feet sea level in 1927. That is about 2½ feet above the 1931 stage and equals approximately the stage occurring about 1905 according to several old timers. A small dam two feet high had some effect in 1927 but an eight foot section was blown out with dynamite about October of that year. Between these two peak stages the lake went down about seven feet according to local recollection but dates are uncertain.

Conservation Program

The development of the Turtle Mountains has been heretofore mostly a hit or miss array of unorganized effort. Some of it has been useless, such as for instance, the dam at the outlet of Lake Metigoshe. A small dam like that merely raises the entire range of water surface fluctuations. It does not dampen them down to any appreciable amount. But what is most desirable for a summer resort lake is a plan which will tend to maintain the stage at a fairly consistent elevation. An orderly program covering a period of years is offered at the end of this report.

The Lake Metigoshe Projects

Lake Metigoshe, derives its name from the Indian phrase "Metigoshe washegum" meaning "clear-water-lake-surrounded-by-oaks". It is located about ten miles from the western end of the mountains and about 15 miles by graveled road from Bottineau, North Dakota. It has an area from the General Land Office maps of 1520 acres, about 60 acres of which lie in Canada. Its shore line as measured on the map is 26 miles long, including its five islands. The estimated boat travel required to explore all its bays and inlets is about ten miles. The maximum depth found on July 11, 1931, was 21 feet and the average depth of the 35 soundings taken is 14.4 feet with a water surface elevation of 2135.7 feet sea level. Upon its shores are platted and recorded 408 cottage sites. There were 71 cottages and community buildings counted in May, 1932.

In preparing a conservation program for Lake Metigoshe the first difficulty encountered is the fact that it is now practically on the "roof of the world" and no additional watershed is available. Here it is a matter of making immediately available to the lake run-off which heretofore filled tributary lakes up to their outlet and remained there as dead storage.

Rost Lake Drainage Canal

Our surveys revealed the fact that about 1/3 of the Metigoshe's watershed of 43 square miles is tributary to two adjacent lakes, Rost and School Section Lakes. Rost Lake, according to the 1931 stage, must rise 3 feet before it will flow into School Section Lake and School Section Lake must rise 2½ feet before it overflows into Lake Metigoshe. This means that 1228 acre-feet of water must first collect in these lakes before any water will flow into Lake Metigoshe. This, if it could be released at one time, would raise the lake nine inches. But whether released at once or over a period of years it means nine inches more water than the lake now gets. It is now lost in evaporation.

The first step in our conservation plan would be to open up these two lakes with a drainage canal to Lake Metigoshe. The outlet from Rost Lake would be at the elevation of the 1931 stage so the lake would not be entirely drained and destroyed.

This project as scaled from the contour map is about 6500 feet long. The canal with a six foot bottom width and 1½ to 1 side slopes involves about 17,700 cubic yards of earth. The maximum cut is seven feet, the average about five. The bottom width is more or less arbitrary and governed by practical as well as theoretical conditions. A six foot bottom width is the narrowest practical width for teams. The narrower the ditch the longer it takes to drain out the upper pond and the longer that water is exposed to evaporation. As it is now designed it would take 75 days running a foot deep in the ditch to raise Lake Metigoshe nine inches.

The estimated cost exclusive of right of way, and if done by local teams, is

17,700 cubic yards at 25c	$4,425.00
Three small farm bridges at $150.00	450.00
	$4875.00

Cost for 1228 acre-feet = $3.97 per acre foot.

Right of way costs thru the small amount of private land should be nominal because the canal will protect these hay meadows from becoming inundated during the wet season. One half of the canal is located on a school section.

This cost per acre foot may appear at first glance as excessive compared to the pumping costs at Lake Upsilon. Here it is for storage capacity which will be filled and emptied many times before the ditch is finally filled up, even if nothing is done to keep it cleaned out. But with an occasional cleaning the cost per acre foot capacity becomes practically the interest on a perpetual investment. At 3% that is about 12c an acre foot a year. It would not run every year but if it flowed one year out of five it still would not exceed pumping costs.

Rost Lake Reservoir

The second step in the conservation plan is a dam over the outlet of this drainage canal. Gates in the dam would be so arranged that the last 1228 feet in the reservoir could still be drained out thru the canal and the lake raised the last nine inches.

The purpose of the dam is to store water during the wet cycle of years to maintain the desired water stage and freshness in Lake Metigoshe during the dry years when evaporation takes its toll. However evaporation will also deplete the reservoir. The only difference is that none will be lost at the outlet from the reservoir while outflow occurs from Lake Metigoshe, or did in 1927.

It may also be countered that the reservoir water will get just as stale as Lake Metigoshe during the dry years, which is true. But the outlet thru the dam can be easily and cheaply designed to aerate the discharge and fill it with dissolved oxygen.

A dam twenty feet high and 76 feet long was tentatively designed for cost estimate but it may be that when more run-off information has been collected a lower and cheaper dam would be more suitable. The estimate does not include land damages. The reservoir will cover about 800 acres, one fourth of which is on a school section.

The estimate is:

280 cubic yards concrete at $18.50	$5180.00
14,000 lbs. steel at 4c	560.00
1,200 cubic yards structural excavation at $1.00	1200.00
2,500 cubic yards dry embankment at 25c	625.00
	$7565.00
Cost of canal	4875.00
	$12,440.00

Total cost for storage of 7390 acre-feet = $1.68 per acre foot.

Assuming that the right of way costs brought the total acre-foot cost to the round figure of $2.50. At 3% interest on a perpetual investment that would be 7½c an acre-foot a year. If it were needed only half the time, that would be only 15c an acre-foot a year.

Rost Lake is an international lake so no action can be taken without the approval of the International Waterway Commission. A conference was obtained June 18-19, 1932, with Mr. S. E. McColl, Director, Surveys Branch, Department of Mines and Natural Resources, Province of Manitoba. His tentative conclusions were that Canadian interests were in no way jeopardized, but were really benefited since Rost Lake was in a Forest Reserve on their side of the line and had no commercial development. So they would no doubt be willing to have it used to maintain Lake Metigoshe which was also an international lake with promising commercial development on their side of the line also.

Oak Creek Reservoir

The third phase of the project is more or less fantastic at the present stage of our knowledge. If we do find enough water to store in Rost Lake and if it accumulates sufficiently not only to maintain the desired stage in Metigoshe but also to flush it out, then the "flushings", so to speak, can be caught in another reservoir lower down on Oak Creek. A dam, 10 feet high below the two Jacobson Lakes would raise them and two other lakes, Duck Lake and Harmon Lake and create another large reservoir in the channel of the creek. Then the water would be made to serve three purposes before we finally had to let it go. First in Rost Lake it would be a supplemental supply and incidently be a breeding ground for wild fowl. In Metigoshe it would maintain the stage and condition of the water and in the Oak Creek Reservoir it would again harbor wild fowl.

The Lake Upsilon Project

Lake Upsilon shaped like a Greek letter Y, is located about seven miles from the eastern end of the mountains and from St. John, North Dakota, to which it is connected by a good county road.

The lake enjoyed immense popularity some 15 or 20 years ago with large hotels and pavilions to accommodate its patronage. There are 807 cottage sites platted around its shores and recorded by various community names. There are now 44 cottages, (May, 1932) a State Fish Hatchery, a State Game Park stocked with buffalo and deer, and much summer activity in spite of the fact that the lake is very low in dissolved oxygen content and almost barren of fish at the present time.

It is a beautiful lake with steep wooded banks and sandy beach. Together with the two small Walker Lakes joined to it by this Department in 1931 by a canal of ten foot bottom width and three foot water depth, the area is about 400 acres. The combined shore line from the General Land Office maps is 13 miles long and the boat route necessary to explore its many coves and bays is about six miles. The maximum depth found in 1931 was 23½ feet and the average of 57 soundings on

Lake Upsilon itself was 12½ feet. The water surface elevation was 2003.6 feet sea level September 21, 1931.

The lake sets off on the eastern side of the main channel of the Wakopa Creek and has a total watershed, including the Walker Lakes drainage recently added, of four sections of land.

At present there is only about 1½ sections of land actually contributing direct run-off to Lake Upsilon itself. The original outlet has been filled with a low barrier of rock and earth, the top of which has an elevation of 2006.5 feet sea level and is about 3 feet above the 1931 water surface. A small amount of seepage passes thru this dam. Otherwise the lake has no outlet and no opportunity for any extensive change of water.

Former Improvements

With such a small watershed it is difficult to understand how the lake has managed to stay up as well as it has. Two improvements may explain it in part. One was the drainage into Upsilon of part of four lakes namely; Big and Little Kuhl, Gravel and Crow Lake. This is in accordance with a State Engineer Department survey in 1919.

This made available run-off which formerly was dead storage below the outlet of these lakes. The lakes were not entirely drained and are still attractive looking lakes. But further drainage to effect Lake Upsilon beneficially would have to destroy them entirely.

The other experiment was initiated by E. J. Wright, a civil engineer of St. John, North Dakota in 1922. He suggested a dam in the Wakopa Creek four and one half feet high at a point having 14 square miles of tributary watershed. From this pond he proposed to pump water into the "lower" of the two Walker Lakes. From there it would flow through a short gravity ditch into Lake Upsilon. The installation was completed in a rather hasty and temporary manner and water was actually pumped into Lake Upsilon, for three or four seasons. The lake was raised several inches each time. It was abandoned however, partly because of local irritation over hay meadows inundated and partly because the ditch from the pond to the pump was of such temporary construction that it soon caved in and filled up.

1931 Improvement

In looking about for a means of restoring and improving Lake Upsilon it was evident that a method of obtaining the run-off now caught by adjacent lakes had been largely utilized. Our survey confirmed the essential merit in the Wright scheme of diversion. A large additional watershed was made available. The engine, a Diesel type, Fairbanks Morse, of 25 horsepower was found to be in excellent condition practically ready to run. The investment already made varies according to different sources but it probably was about $1,000.00 for the engine, second hand, and $240.00 for the pump. Repairs and cost of installation totaled the investment to about $1,650.00.

The pump will lift 3,000 gallons per minute thru the maximum lift of 16 feet. This is about thirteen acre-feet a day and would raise a 400 acre lake six inches in 16 days if the final area was 440 acres. The cost of operating this pump at that head would be about 25c an hour for fuel and oil based upon fuel at 10c a gallon. An estimated operating cost for raising the lake 6 inches would be:

Fuel and oil 384 hours at 25c per hour	$ 96.00
Attendance 16 days at $2.50 a day	40.00
Total	$136.00

Unit cost for 210 acre-feet = 65c per acre foot.

The amount necessary to pump could be gaged by the increase in the amount of dissolved oxygen content in the water of the lake. Our survey also revealed the fact that 491 acre-feet can be stored safely behind the present dam. By a little ditching in the upper end of the reservoir this storage could be increased to 896 acre-feet or enough to put about 20 inches of fresh water over the lake.

The construction work done by this Department was (1) to clean out and enlarge the ditch from the dam to the pump (2) change the inlet into Lake Upsilon from a point only a few yards from the present outlet of the lake to a point near the middle of the lake (3) to connect Lake Upsilon and the two Walker Lakes by a canal large enough to accommodate boat travel. The total construction cost was $2,508.70.

Wakopa Reservoir

It is the opinion of this Department that drastic action is necessary to permanently restore and recondition Lake Upsilon. All the water from Wakopa Creek must be made available for the lake.

A survey was made to investigate the feasibility of a gravity flow thru the lake. The objection raised to this scheme by the State Engineer report of 1919 is the uncertainty of there being enough water running off from the watershed to fill the reservoir sufficiently to flow over into Upsilon. We have no run-off data for this area. Even our drainage areas are uncertain. For those lakes with drainage areas which seem to be very small according to available maps such as Carpenter Lake, for instance, have persisted in spite of the ravages of evaporation. Perhaps a large sub-soil inflow occurs. Nevertheless, if Lake Upsilon with four sections of watershed, Carpenter with five sections, and Belcourt Fish with eight sections can stay up thru the recent dry years, it would seem reasonable to assume that the Wakopa Reservoir with fourteen sections of watershed would be more or less filled most of the time.

A contour was surveyed at an elevation of 1½ feet above the 1931 Upsilon stage. The water would be eleven feet at the dam. The lands inundated would amount to 936 acres, about one half of which is now in lake areas. One improved farm of about 100 acres would have to be obtained. Under this scheme the old outlet dam would have to be repaired and made safe for overflow and the engine house would have to be raised above high water line.

Cost Estimate

In making a cost estimate no attempt was made to appraise the lands inundated. A general estimate of the other items is as follows:

Dam in Wakopa Creek, spillway 11 feet high, 30 feet long	$1,500.00
Improving present dam at outlet	200.00
Raising engine and building new pump house	800.00
Total	$2,500.00

It is not essential to the success of the scheme that all the water will actually flow by gravity into Lake Upsilon. It is only necessary that it be stored. When it will not flow it can be pumped. The cost of pumping at, say, only six foot difference in elevation would be greatly reduced. At that head the pump would throw 4500 gallons per minute or about 20 acre-feet a day. This would raise the present lake six inches in 10 days at a cost of 20c an hour for fuel and oil, based on 10c a gallon for fuel. The estimated cost of operation then is as follows:

Fuel and oil for 240 hours at 20c	$ 48.00
Attendance for 10 days at $2.50	25.00
Total	$ 73.00

Unit cost for 210 acre-feet = 35c per acre foot.

The Carpenter Lake Project

Carpenter Lake, in point of size is the third largest lake in the Mountains, covering an area of 820 acres according to the township plats. It is a beautiful lake with an abundance of fish at the present time. It is located at the head of a series of lakes which would be filled with any overflow from this lake. The lake has a fair depth at present, 7½ feet, but if retrogression occurs the fish will freeze out in a few years.

The lake has a small watershed about 5 square miles. Our survey revealed that four square miles could be added by a ditch 6800 feet long involving a maximum cut of 15 feet and 24,000 cubic yards of material.

The estimated cost of the project is $7,000.00.

Jarvis—Long Lake Project

These two lakes, located about 12 miles south of Lake Upsilon are separated by a marshy channel 1500 feet long. Jarvis is a deep lake having a maximum depth of 23.0 feet and an average of 14.6 feet. Its area is 264 acres.

Long Lake has an area of 94 acres, and an average depth of 10.7 feet. The maximum depth sounded was 15.0 feet.

A ditch between the two lakes to provide a waterway 17 feet top width, 5 feet bottom width, and three feet deep would involve the excavation 5000 cu. yds. of material, much of which would be wet, and the construction of one bridge.

The estimated cost is $2,500.00.

Long Lake was 3.55 feet higher in elevation than Jarvis Lake on August 11, 1931. This construction would raise Jarvis Lake one foot and lower Long Lake 2½ feet. The benefits would be one large lake of about 340 acres, 8 miles shore line and with four miles of boat travel. The average depth would be about 12 feet.

No additional drainage area was found available for these lakes.

Construction Program

On the basis of this report an orderly program of construction in progressive stages is suggested.

The two principal lakes in the Mountains are Lake Upsilon and Lake Metigoshe. They should receive first consideration because of the large investment about their shores.

Lake Upsilon is in much the greater need of fresh water. Twenty-five hundred dollars was spent there for improvements in 1931. Temporary arrangements are now available so that any flow in the Wakopa Creek may be pumped immediately into the lake.

The next improvement should be undertaken therefore at Lake Metigoshe. This should be the construction of the Rost Lake Drainage Canal. It should be constructed within the next two or three years or before the approaching wet cycle* reaches us and the present hay meadows on School Section Lake thru which it passes become swamps and shallow lakes again. Construction will be impractical then.

The next logical step after that is the construction of the two dams, one creating Rost Lake Reservoir for Lake Metigoshe and one creating Wakopa Reservoir for Lake Upsilon.

This is assuming, of course, that the hydrological studies indicate that such construction is warranted and will serve the purpose for which it is designed.

The construction of the Carpenter Lake project is in the same category. It should be postponed until more information is available. At the present time it is anybody's guess whether or not four sections of land added to the watershed of a lake which is about a section or more in area is worth $7000. It is the guess of this Department that it is doubtful.

This program involves an expenditure of say $25,000 in the next four or five years. It should put the Turtle Mountains in the first rank as one of North Dakota's summer resorts, drawing patronage from the entire northern half of the state.

See Bulletin on "Weather Cycles," page 48.

TURTLE MOUNTAINS DATA

General

Area

Length	44 miles
Breadth	24 miles
Area in North Dakota	450 square miles
Area in Canada	250 square miles
Total Area	700 square miles

Lakes

Number shown in Canada on topographic sheets	124
Number shown in North Dakota on General Land Office Maps	570
Number crossed by Boundary	10
Total	704
Number commercially developed in North Dakota	3

Elevations

	Authority	Elev. in feet sea level
General Elevation of top	Canadian Map	2200
Elevation of highest point recorded, Boundary Post No. 699	International Boundary Map	2541
Elevation of towns around foot of Mountains		
Bottineau, North Dakota	G. N. Railway	1645
Dunseith, North Dakota	G. N. Railway	1708
Rolla, North Dakota	G. N. Railway	1828
St. John, North Dakota	G. N. Railway	1944
Wakopa, Manitoba	Canadian Map	1853
Bossevain, Manitoba	Canadian Map	1681
Deloraine, Manitoba	Canadian Map	1642
Goodlands, Manitoba	Canadian Map	1651
Carbury, North Dakota	G. N. Railway	1652

Meteorology

		Mean Annual		Mean Summer Data					
				June		July		August	
	Yrs. Record in 1932	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
Bottineau, N. Dak.	40	36.2	15.85	61.3	3.31	66.6	2.30	64.1	2.19
Souris, Manitoba	22	36.0	18.68	61.0	2.75	66.0	2.18	62.0	1.94

COMPARATIVE MONTHLY WEATHER DATA
Bottineau, N. Dak., Lake Metigoshe and Lake Upsilon

Month / Station	Temp. Degree F. Mean	Highest	Date	Lowest	Date	Precipitation in inches Total	Greatest in 24 hrs.	Date
1931								
October								
Bottineau	45.6	82	2	17	18	0.52	0.20	27
Lake Metigoshe	44.0	76	1	25	31	0.64	0.20	26
Lake Upsilon						1.10	0.41	28
November								
Bottineau	29.2	67	2	-6	27	0.03	0.02	16
Lake Metigoshe	27.0	62	2	-9	26	0.06	0.03	21
Lake Upsilon						0.53	0.49	21
December								
Bottineau	19.6	42	2*	-13	7*	0.01	0.01	11
Lake Metigoshe	18.0	45	23	-14	6	......	......	....
Lake Upsilon						0.06	0.06	11
1932								
January								
Bottineau	8.0	42	25	-32	31	0.38	0.15	13
Lake Metigoshe	9.1	45	16	-38	30	0.75	0.41	23
Lake Upsilon						1.08	0.30	16
February								
Bottineau	9.2	60	28	-29	14	0.13	0.11	7
Lake Metigoshe	11.0	54	27	-30	13	0.06	0.04	5
Lake Upsilon						0.20	0.12	8
March								
Bottineau	15.9	54	25	-27	6	0.63	0.22	1
Lake Metigoshe	14.0	46	24	-24	5	0.42	0.25	30
Lake Upsilon						0.51	0.20	29
April								
Bottineau	40.2	70	19	9	3	0.38	0.24	23
Lake Metigoshe	39.7	68	19*	5	2*	0.81	0.71	22
Lake Upsilon						1.18	0.39	23
May								
Bottineau	54.6	94	13*	27	1	0.66	0.35	5
Lake Metigoshe						0.06	0.04	28
Lake Upsilon						2.69	0.90	22
June								
Bottineau	66.4	88	5	42	18	5.91	2.83	9
Lake Metigoshe						6.49	2.05	29
Lake Upsilon						4.84	1.12	30
July								
Bottineau	66.6	97	17*	40	1	3.15	1.06	20
Lake Metigoshe						2.03	1.25	20
Lake Upsilon						3.24	0.92	3
August								
Bottineau	66.7	90	15*	38	18	1.13	0.59	1
Lake Metigoshe						1.68	1.30	1
Lake Upsilon						2.08	1.49	1
September								
Bottineau	53.3	91	8	22	27	0.38	0.25	18
Lake Metigoshe						0.61	0.44	26
Lake Upsilon						1.36	0.70	26

*Other dates also

SUMMER STORM PRECIPITATION—TURTLE MOUNTAINS

Stations:

B—Bottineau, D—Dunseith, M—Metigoshe, R—Rolla, S—St. John.

Only storms of two inches or more are shown. Not more than one storm per month occurred during period of record 1892-1932.

Year	May			June			July			August			September			October		
	Days	Precip.	Station	Days	Precip.	Station	Days	Precip.	Station	Days	Precip.	Station	Days	Precip.	Station	Days	Precip.	Station
1894													1	1.95	B	3	2.00	B
1896				3	2.20	B												
1897							1	1.75	D									
							6	2.54	S									
1898				4	2.50	S										1	2.15	B
				10	4.32	S												
1899	1	1.25	B	1	4.00	D	1	3.08	D	1	2.00	D						
1900							2	2.40	D	2	2.96	D						
										3	3.78	S						
1901				3	2.79	B	3	2.95	D									
1902	2	2.00	B															
	5	3.00	B															
1904				4	2.60	R	1	2.10	R	4	2.68	D						
1905	2	3.23	B							1	1.97	B	1	6.40	R			
													1	1.17	D			
													1	0.95	B			
1906	5	2.49	R	1	2.85	B												
1908				2	3.52	B												
1909							3	2.09	D									
							5	2.73	B									
1915	2	2.11	B															
	4	2.08	D															
1916							2	2.10	D	1	2.28	B						
										7	4.05	D						
1918							2	2.10	D									
1919										1	4.08	D						
										1	2.00	B						
1920										1	3.07	B						
										1	0.07	D						
1921	1	2.54	D							3	2.99	D	3	2.07	B			
	5	2.40	B							3	2.40	B						
1922													2	1.93	D			
1923				2	3.90	B	1	2.90	D	1	2.90	B						
				2	1.77	D	1	1.57	B	4	4.46	B						
1924																2	1.71	D
																5	2.69	D
1926				3	3.77	D												
				3	3.38	M												
				2	2.53	B												
1927	2	2.50	D				2	2.61	B	3	2.81	D						
	2	2.63	B				4	2.23	D	3	2.18	B						
1928				1	2.02	M	1	1.95	B									
				5	6.04	M	3	2.30	D									
				2	4.07	B												
				4	5.76	B												
				4	2.90	D												
1932				1	2.05	M												

COMPARATIVE EVAPORATION DATA

Month and Year	Devils Lake Wind Vel.	Devils Lake Apparent Evaporation	Lake Metigoshe Wind Vel.	Lake Metigoshe Apparent Evaporation	Lake Upsilon Apparent Evaporation
	m.p.h.	Inches	m.p.h.	Inches	Inches
Oct. 1931	6.2	2.48	4.7	0.64	1.58
Nov.	6.2		4.6		
Dec.	5.3		4.3		
Jan. 1932	6.2		....		
Feb.	6.6		4.0		
Mar.	7.5	-1.97	5.8	-0.39	
Apr.	6.3	1.22	5.7	0.09	-2.08
May	6.4	3.02	4.9	3.18	4.73
June	5.3	5.38	4.3	5.53	5.32
July	4.5	5.36	4.6	3.47	3.72
Aug.	4.0	4.74	6.5	5.04	6.28
Sept.	5.4	4.36	6.6	4.33	5.56
Total	69.9	24.59	56.0	21.89	25.11
Ave.	5.8		5.1		

N. B. Wind velocities were taken two feet above ground on shore of lake. Apparent evaporation is change in water surface elevation after precipitation has been deducted.

A negative figure indicates rise in water surface due to inflow from watershed.

C. F. Gorder is observer at Lake Metigoshe.

B. W. Kuhl is observer at Lake Upsilon.

Maps Available

Canadian

Topographic sheets, "Turtle Mountains" and "Dufferin" Office of Surveyor General, Ottowa, Canada.

Turtle Mountain Forest Reserve (showing Peace Garden) Map No. 242, Surveys Branch, Department of Mines and Natural Resources, Winnipeg, Manitoba.

United States

International Boundary Maps Number 46, 47, 48, International Boundary Commission, Washington, D. C.

North Dakota

Available from State Engineer Department, Bismarck, North Dakota.

(1)	Township plats of General Land Office	V
(2)	General Map Turtle Mountains	3-A-13
(3)	Rost Lake Reservoir and Lake Metigoshe	3-A-9
(4)	Contour Map Rost Lake Reservoir	V-1
(5)	Profile Rost Lake Drainage Canal	1-A-4
(6)	Map of Upper Oak Creek	3-A-10
(7)	Oak Creek Profile	3-A-11
(8)	Profile Carpenter Lake Project	4-A-1
(9)	Proposed Wakopa Reservoir	V-2
(10)	Upsilon—Carpenter Area Map	2-A-7
(11)	Jarvis—Long Lake Project (sketch)	4-A-2

Lake Metigoshe

Definition: Metigoshe washegum "clear-water-lake-surrounded-by-oaks".

Area and Shape

Area from General Land Office Maps—surveyed 1888	1520 acres
Area in Canada	58 acres
Overall length	3½ miles
Overall width	1.4 miles
Length of shoreline, including five islands measured from map	26 miles
Boat travel available for exploration of lake	10 miles

Elevation

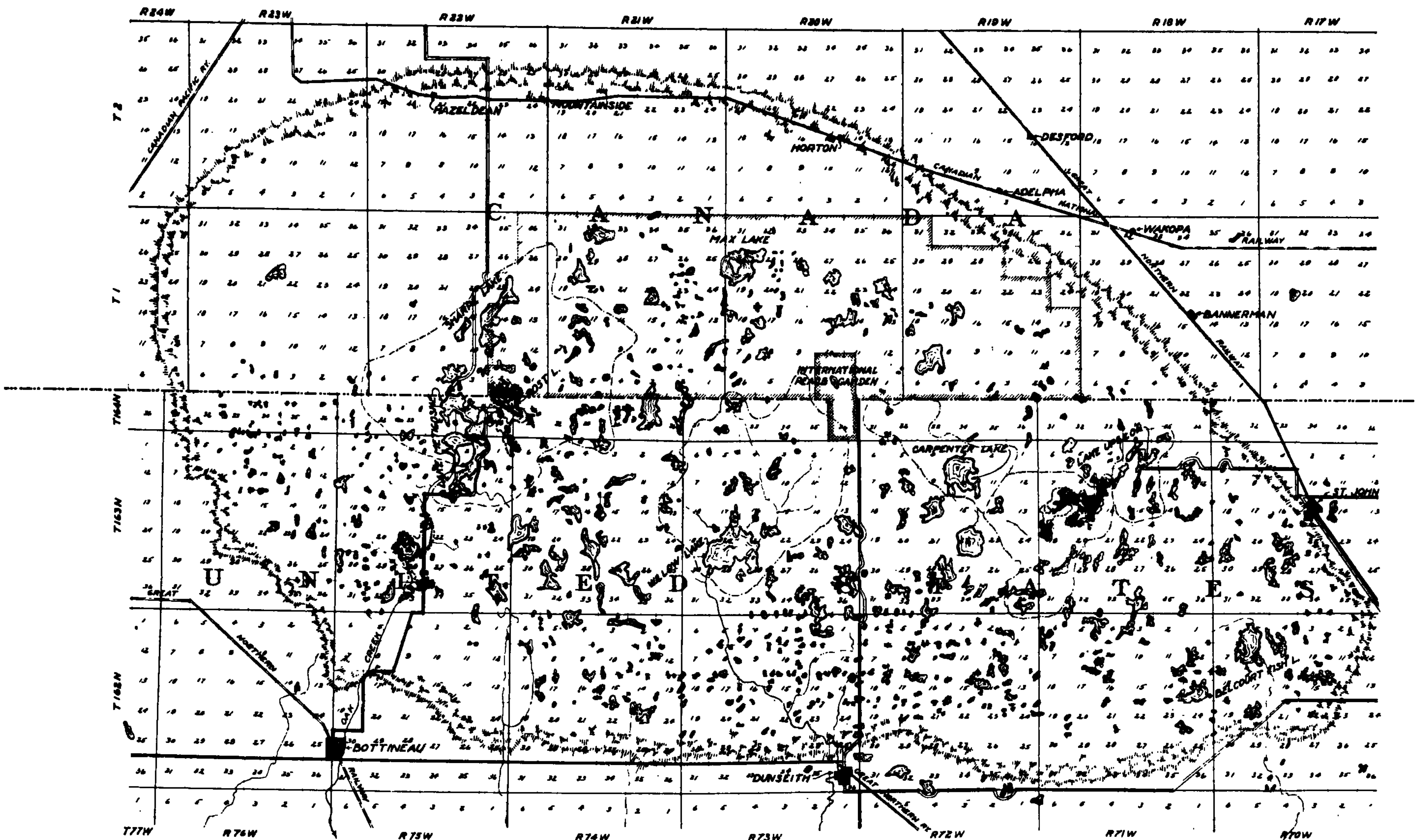
Elevation of water surface October 3, 1931 ....2135.0 ft. sea level
Gage height of water surface October 3, 1931 .... 11.3 ft.

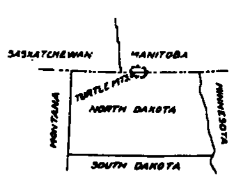
Elevation of zero of gage ....2123.68 ft. sea level

N. B. Sea level elevation obtained by check levels from Boundary Post No. 701, elevation 2153.16, to water surface on quiet day.

Elevation of high water line on "Maid of Moonshine" bridge 2137.7

Elevation approx. bottom of channel under "Maid of Moonshine" bridge 2128.0





LEGEND

- OUTLINE OF PROPOSED RESERVOIRS
- CANADIAN FOREST RESERVE
- OUTLINE OF APPROXIMATE DRAINAGE AREAS
- INTERNATIONAL PEACE GARDEN

NB NUMEROUS COUNTY ROADS NOT SHOWN

SCALE

SCALE OF ORIGINAL MAP 1" = 2 MILES

STATE OF NORTH DAKOTA
DEPARTMENT OF STATE ENGINEER

GENERAL MAP
TURTLE MOUNTAINS

DRAWN: B.P. JACOBSON
CHECKED: R.E.K
SUBMITTED:
APPROVED: [signature]

BISMARCK, N DAK JULY 5, 1932 | 3-A-13

Bench mark:

Concrete abutment of "Maid of Moonshine" bridge at inside corner of vertical angle iron on south end of eastside hand rail. Elevation is 2149.55. Staff is enameled U. S. G. S. type bolted to north abutment of bridge.

Depths—July 11, 1931

Area north of bridge	Maximum depth found	21.0 feet
	Average depth (18 soundings)	16.5 feet
Area south of bridge,	Maximum depth found	18.0 feet
	Average depth (17 soundings)	12.2 feet
General average depth (35 soundings)		14.4 feet

Watershed

Total theoretical .... 42 square miles

Commercial Development

Platted cottage sites		408
Buildings erected (to May, 1932)		71
Fishing licenses		
Bottineau county	1930	166
	1931	2070
	1932	1878

Rost Lake Drainage Canal

Length of canal scaled from map	6500 feet
Bottom width	6 feet
Side slopes	1½ to 1
Grade	0.8 ft. per 1000 feet

Carrying capacity (Kutter's "n"—0.030)

Water depth in feet	Cubic feet per second
1	7.8
2	29.0
3	64.5

Rost Lake Reservoir

Derivation of Name

This lake has had a variety of names;—Eramosh Lake on the International Boundary map and Lake Kippax on the General Land Office map. The local name most used was Ross Lake, but when inquiry was made as to its accuracy the local Chamber of Commerce of Bottineau requested that the term be changed to Rost Lake in honor of the original homesteader on the shores of the lake for whom the local name was probably intended.

Rost Lake

Area, 1931 survey	240 acres
Area in Canada .....110 acres	
Area in North Dakota .....130 acres	
Depth (3 soundings)	3 feet
Elevation July 3, 1931	2142.84 feet sea level
Elevation of outlet	2146.0 feet sea level

Bench Mark:

Top of only very large white boulder near outlet of lake—marked "B.M." .....2145.07 feet sea level

School Section Lake

Elevation, December 1, 1932	2137.4 feet sea level
Depth	2.0 feet
Elevation of outlet	2140.1 feet sea level

Reservoir

Watershed theoretical (including reservoir)	15 square miles
Total storage in proposed reservoir	7390 acre-feet
Dead storage in Rost Lake (from elev. 2142 to outlet)	1034 acre-feet
Dead storage in School Section Lake (from elev. 2135 to outlet, est'd)	182 acre-feet
Total dead storage	1228 acre-feet
Elevation of proposed maximum water surface	2155 feet sea level

Topography of Reservoir site

Area of proposed reservoir in lakes (1932)	283 acres
Area in proposed reservoir in meadow	325 acres approx.
Area of proposed reservoir in timber & grazing	200 acres approx.
Total area of proposed reservoir	808 acres
Area of private land inundated	200 acres

Area by contours (sea level)

elev. in ft.	area in acres	elev. in ft.	area in acres	elev. in ft.	area in acres
2155	808	2148	528	2141	70
2154	769	2147	475	2140	64
2153	719	2146	436	2139	51
2152	692	2145	392	2138	43
2151	646	2144	360	2137	35
2150	619	2143	333		
2149	574	2142	306		

Lake Upsilon

Definition: Shaped like the Greek letter Y.

Area and Shape

Averall length—Lake Upsilon	2 miles
Overall width—Lake Upsilon	1 mile
Area from maps General Land Office—1897 survey	381 acres
Area of Walker Lakes—General Land Office map	102 acres
From General Land Office Maps—1897 survey	
Combined area	483 acres
Estimated present area (combined)	400 acres

Shore line from General Land Office maps

Lake Upsilon	9.5 miles
Walker Lakes	3.6 miles
	13.1 miles

Boat Travel

Lake Upsilon	4.4 miles
Walker Lakes	1.5 miles
	5.9 miles

Depths, 1931 stage

Lake Upsilon,	Maximum	23.5 feet
	Average (57 soundings)	12.5 feet
Walker Lakes,	Maximum	4.5 feet
	Average (24 soundings)	3.0 feet

Watershed

Directly contributing to Lake Upsilon	1½ square miles
Total theoretical including Walker Lakes	4 square miles

Elevations

Elevation of water surface October 3, 1931	2103.6 ft. sea level
Elevation of zero of the gage	2100.67 ft. sea level

N. B. Sea level elevation obtained by check levels from Boundary Post No. 718 elev. 2065.45 to water surface of Lake Upsilon on quiet day.

Bench Mark:

Top of large rock 21′ south from S. W. corner of state boat house by Fish Hatchery, elev. 2109.41 feet.

Elevation 1919 State Engineer Survey .... 73.8 ft.
(Gravel Lake datum, elevation 100)

Present Dam

Original outlet; rock and earth; no spillway.

Top elevation	2006.4

Dam is about 3 feet in height, 100 feet long and 30 feet wide at bottom.

Commercial Development

Platted and recorded cottage sites	807
Buildings erected (to May, 1932)	44

Fishing licenses

Rolette County	1930	568
	1931	799
	1932	249

Wakopa Reservoir

Watershed theoretical including reservoir	14	square miles
Elevation of proposed maximum water surface	2105.0	ft. sea level
Total storage at proposed max. water surface elev.	6120	acre-feet
Total dead storage below elev. 2003.5 feet sea level	4780	acre-feet
Storage above 2103.5 to 2105.0	1340	acre-feet

Pump capacity

Discharge pipe diameter	12	inches
Intake pipe diameter	15	inches

Discharge under 16 ft. head, 3000 gallons per minute; 6 2/3 cubic feet per second; 13 acre-feet per day. Discharge under 6 ft. head, 4500 gallons per minute; 20 acre-feet per day.

Engine Type: Diesel Make: Fairbanks Morse.

Horsepower	25 h. p.
Speed	325 r. p. m.

Cost:

Engine, second hand	$1000.00
Pump	240.00

Operating cost based on 10c per gallon for fuel

16 foot lift—25c per hour
6 foot lift—20c per hour

Topography of reservoir site

Area now in lakes ....425 acres
Area now in meadow ....450 acres approximately
Area now in timber and grazing .... 61 acres approximately

Total area of proposed reservoir ....936 acres
Area by contours (sea level)

elev. in ft.	area in acres	elev. in ft.	area in acres	elev. in ft.	area in acres
2105	936	2100	544	2095	325
2104	871	2099	501	2094	151
2103	822	2098	453	2093	11
2102	760	2097	382	2092	8
2101	664	2096	351		

Present Dam

Top elevation ....2098.0 ft.
Bottom elevation ....2094.0 ft.
Length of top .... 130 ft.
Width of top .... 9 ft.
Width of bottom .... 25 ft.

Culvert through dam, wooden box, 24x24 inches with wooden gate.
Elevation present safe maximum water surface..........2097 ft.
Total storage which can be made available by ditching (elev. 2097 ft.) .... 896 acre-feet
This would raise Lake Upsilon about 20 inches above 1931 stage of 2003.6 ft. sea level.
Total storage now available (elev. 2097 ft.) .... 491 acre-feet

Carpenter Lake Project

Area of Carpenter Lake, from lots shown on township plats of General Land Office—1897 survey.. 820 acres

Shoreline from maps of General Land Office.............. 8 miles

Depths, 1931 survey

Maximum .... 8½ feet
Average (19 soundings) .... 7½ feet

Watershed present .... 5.2 sections
added by proposed construction .... 3.9 sections

Elevation water surface August 5, 1931 ....2182.8 ft. sea level

N. B. Elevation carried in to bench mark on shores by check levels from Boundary Post No. 713, elev. 2271.74.

Proposed Construction for additional watershed

Length of ditch	6800 feet
Dimensions of ditch:	
Bottom width	5 feet
Side slopes	1:1
Maximum cut	15 feet
Total yardage	24,000 cu. yds.

Cost estimate

24,000 cu. yds. at 25c	$6,000.00
Two bridges at $500.00 each	1,000.00
	$7,000.00

Jarvis - Long Lake Project
(Upsilon vicinity)

Project:

These two lakes are separated by a marshy channel 1500 feet long. Jarvis Lake was 3.55 feet lower than Long Lake August 11, 1931.

Jarvis Lake:

Area from General Land Office Maps—1897 survey	246 acres
Shore line	5½ miles
Depth, Maximum found	23.0 feet
Average (33 soundings)	14.6 feet

Long Lake

Area from General Land Office maps—1897 survey	94 acres
Shore line	2¾ miles
Depth, Maximum found	15.0 feet
Average (29 soundings)	10.7 feet

Combined Lakes

Area on basis General Land Office Maps	340 acres
Shore line	8¼ miles
Boat Travel	4 miles
Depths, Maximum in Jarvis Lake	24.0 feet
Maximum in Long Lake	12.5 feet
Average of combined	12.1 feet

N. B. The canal will raise Jarvis Lake one foot and lower Long Lake 2½ feet from the 1931 stage and provide a waterway 17 feet wide, 3 feet deep and 5 feet bottom width.

Cost Estimate

Canal (5′ bottom width, 2:1 side slopes) (Max. cut 7 feet)

5000 cu. yds. at 40c	$2,000.00
One bridge	500.00
	$2,500.00

Miscellaneous Lake Data

Willow Lake

Area from General Land Office Map—1897 survey	1058 acres
Shore line	10½ miles
Depth, Maximum found	5.0 feet
Average (20 soundings)	3.5 feet
Watershed	30 square miles
Difference in elev. between Dec. 1931 water surface and invert of six-foot corrugated metal culvert at outlet	1.4 feet

Lake Upsilon Watershed

Gravel Lake (Tributary to Lake Upsilon)

Area from General Land Office Map—1897 survey	105 acres
Area from 1931 survey	74 acres
Depth, Maximum found	14.0 feet
Average (23 soundings)	10.8 feet
Elevation of water surface, August 1931	2127.0 feet sea level
Elevation of water surface, 1919 State Engr. survey	100.0 feet

Crow Lake (Tributary to Lake Upsilon)

Area from General Land Office map—1897 survey	55 acres
Area from 1931 survey	36 acres
Depth, Maximum found	16.5 feet
Average (13 soundings)	13.2 feet
Elevation of water surface, November, 1931	2018.8 feet sea level
Elevation of water surface, 1919 (Gravel Lake Datum)	89.3 feet

Little Kuhl Lake (Tributary to Gravel Lake)

Sometimes called Garber Lake.

Area from General Land Office map—1897 survey	36 acres
Area from 1931 survey	22 acres
Depth, Maximum found	8.0 feet
Average (14 soundings)	6.3 feet
Elevation of water surface, August, 1931	2142.2 feet sea level
Elevation of water surface, 1919 (Gravel Lake Datum)	112.6 feet

Big Kuhl Lake (Tributary to Gravel Lake)

Sometimes called Big Garber Lake.

Area from General Land Office map—1897 survey	50 acres
Area from 1931 survey	35 acres
Depth, Maximum found	17.0 feet
Average (17 soundings)	11.8 feet
Elevation of water surface, August, 1931	2159.5 feet sea level
Elevation of water surface, 1919 (Gravel Lake Datum)	128.9 feet

Boyd Lake (Tributary to Lake Upsilon)

Sometimes called "35" Lake

Area from General Land Office map—1897 survey	85 acres
Area from 1931 survey	53 acres
Depth, Average (17 soundings)	5.5 feet
Elevation of water surface, August, 1931	2113.0 feet sea level
Elevation of water surface, 1919 (Gravel Lake Datum)	85.5 feet

Loon Lake (Metigoshe vicinity)

Area from General Land Office maps—1897 survey	343 acres
Depth, Maximum found	10 feet
Three soundings taken, viz.	7.5; 10.0; 10.0

Belcourt Fish Lake (on Indian Reservation)

Area from General Land Office map—1897 survey	490 acres
Shore line General Land Office map—1897 survey	8.5 miles
Watershed General Land Office map—1897 survey	8 square miles
Depth, Maximum found June 21, 1932	18.0 feet
Average (15 soundings)	12.3 feet

Commercial Development

25 lots on "Done Workin" beach
18 cottages (to July, 1932)

Comparative Lake Data

Lake	Area-Acres	Authority	Ave. Depth ft.	Watershed sq. miles
Lake Metigoshe	1520	Gen. Land Office Map	14.4	42
Willow Lake	1058	Gen. Land Office Map	3.5	30
Carpenter Lake	820	Gen. Land Office Map	7.5	5
Sharp (Canada)	660	Canadian Map	4.0	9
Belcourt Lake	490	Gen. Land Office Map	12.3	8
Upsilon Lake	483	Gen. Land Office Map	12.5	4

Authority for Investigation

Chapter 72, page 80, 1931 Session Laws
(H. B. No. 278—Acheson & Halvorson)

CONSERVATION LAKES AND STREAMS

An act providing for the conservation of lakes and streams of North Dakota under the supervision of the state engineer, and making appropriation therefor.

Be It Enacted by the Legislative Assembly of the State of North Dakota:

1. The state engineer of the State of North Dakota is hereby authorized and empowered to take such action as may be necessary to conserve the water levels and rehabilitating the streams and brooks in the Turtle Mountain region of North Dakota lying in Bottineau County and Rolette Counties, and to do any and all acts necessary in bringing about such rehabilitation of streams, lakes and brooks.

2. There is hereby appropriated from funds in the state treasury not otherwise appropriated, to be used for the above purpose, the sum of $7,000.00.

Approved March 11, 1931.

Distribution of Expenditures

October 1, 1932

Previous Biennium, June, 1931	
Oak Creek Channel	$ 885.61
Present Biennium	
Oak Creek Channel and Reservoir	2531.33
Lake Upsilon Pumping Project Surveys	609.56
Lake Upsilon Pumping Project Construction	2508.70
Wakopa Reservoir Survey and Associated Projects Surveys	669.53
Rost Lake Reservoir—including Evaporation Studies	1868.19
Willow Lake	44.62
Carpenter Lake	193.16
	$9310.70

WEATHER CYCLES

By

ROBT. E. KENNEDY

State Engineer

State Engineer Department

Bismarck, N. Dak.

January, 1933

ACKNOWLEDGEMENT

Mention was made in the last Biennial Report of a study of weather cycles destroyed in the Capitol fire of December 28, 1930. I was about to abandon the effort until I began corresponding with Mr. J. W. Shuman, Power Engineering Company, Minneapolis, Minnesota.

His ideas were very interesting and I am indebted to him for the impetus of this paper. He has published several articles in the Monthly Weather Review, the last one in the March 1931 issue. I feel inclined to criticize his work, however, on at least three counts. First, he has a bewildering number of cycles and he lays them one over the other on his graphs four or five deep. Second, many of his curves are sketched in free hand which permits the unconscious intrusion of that procrustean tendency to conform them to the answer desired. Third, none of them actually and precisely fit the data. They are more or less approximations. The longer the cycle the more the approximation. Many of them have, to my notion, very doubtful merit. These in turn made me reluctant to assail his apparently long and tedious mathematical procedure.

But when it occurred to me to try out his ideas with that simple and old reliable process, the five year average, I was surprised and delighted to find revealed many of the curves which he had been using.

ROBT. E. KENNEDY.

WEATHER CYCLES

By Robt. E. Kennedy, State Engineer

There are a multiplicity of cycles proposed, too many to be considered here. Figure I is a list prepared by Mr. Shuman. To make the bewilderment complete one should add Clough's cycle of twenty-eight months and Gillette's "lunatino" cycle of 7.38 days for four consecutive times. Yet in fairness to the "cyclists" it should be said that no one single thread of data is expected to go thru all these contortions at the same time. Curve No. 5, for instance, known by various names according to the locality, follows closely the annual fluctuations in many data. According to Dinsmore Alter in the October, 1928, Monthly Weather Review, the annual sunspot data tend to approach a certain harmonic series of oscillations similar to that curve. After "treating" these data so that the annual oscillations are "processed" out as shown at the top of Plate I another series of oscillations is revealed which are not apparent in the annual figures, and so on.

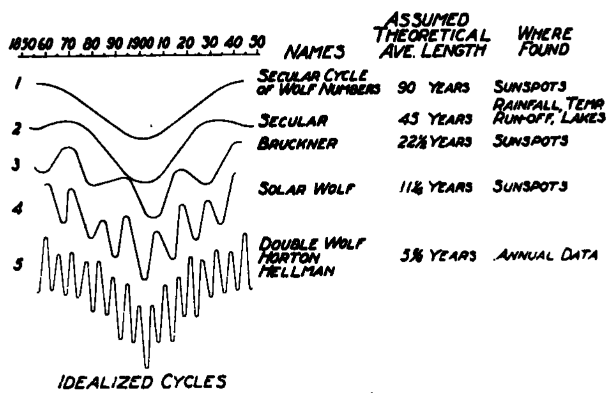


FIGURE I

This paper does not purport to make any contribution to the technical discussion. It desires only to explain in non-technical language the eleven year and the Bruckner cycle. If their effect on terrestrial phenomena can be established it will be very valuable to the citizens of the state in predicting long range trends in the future. It affords only a nominal aid however, in year to year forecasting.

I am well aware that predicting the weather is an ancient and timeworn delusion. Modern science is only beginning to make inroads upon our colossal ignorance. Any effort made here will obviously be hedged about with all available precautions.

Conclusions

On the basis of this study, however, I am encouraged to suggest that we may anticipate a downward change in the mean annual temperatures which reached their record high in 1931 thruout this and neighboring states. They should reach the lower culmination of the cycle in the neighborhood of 1937. This is based upon an interesting coincidence with eleven year sunspot cycles thruout eastern United States since about 1916 and for local stations since 1905.

These seem to be the only meteorological data which have any degree of cyclic precision. Whatever cycles we may find in other weather phenomena must be traced to annual temperatures thru a gamut of extraneous influences.

Annual precipitation, in which we are more interested, does not seem to rigidly coincide with annual temperatures. It frequently will agree for several cycles. Then it will fade and emerge again in another phase.

But we can expect from the temperature cycle cooler summers, colder winters and accompanying snows, late springs and the increased possibility of spring floods and ice jams.

Spring floods are related to annual temperature thru the chain of cold winters and late springs which is only one of the three predominating causes, altho it seems to be largely in control. Mouse River floods have so far followed a fairly apparent cycle which when extended indicates a recurrence sometime around 1937. But that is not offered as a scientific prediction for it is beset with too many uncertainties. It is little better than a guess.

Comment is made on the striking decline of Devils Lake and the wide-spread assumption that the advent of the plow to the watershed is a contributing factor.

This is attacked and denied for three reasons. First, it does not account for the recession of the lake prior to settlement. Second, the amount of water in crops exported is absurdly negligible and finally recent experiments tend to indicate that there may be less water consumed by cultivated crops than by the prairie sod; and that there might be theoretically even a little more run-off, if anything, rather than less with the coming of the white man.

The primary causes for the recession of Devils Lake are beyond man's control. They are the pothole character of gravelly terrain which greatly reduces run-off and the climatic conditions of temperature and rainfall.

If the lake is to avoid final extinction the anticipated 1937 temperature trough must be deep and the 1933 or 1934 rainfall peak must be high, both of which are quite reasonable possibilities.

The Turtle Mountain lakes offer a striking contrast to Devils Lake in that they seem to be much more permanent. This is probably due to a steeper, more rolling topography of clay soil. But recession has occurred in these lakes and will recur with unprofitable effect on the larger lakes now commercially developed unless steps are taken to conserve all available run-off.

Precise long range weather forecasting is still in the offing. Certain tendencies and trends and possibilities may be revealed but we must be prepared to be surprised frequently by many of the inexplicable eccentricities of Nature.

Processing the Weather Data

The process here used is the simple and long established five year average. With an adding machine with a subtracting device the method is fast and accurate. The first five years are added, a subtotal taken, the first year subtracted, the sixth year added, another subtotal taken, and so on. The subtotal divided by five represents the middle year of its respective group. This is repeated until the plotted points produce as smooth a curve as is desired. For the mean annual temperature the second addition appears to be sufficient. This is illustrated on Plate I by the graphs for Williston, North Dakota. The annual precipitation records require three averagings to take out all the kinks.

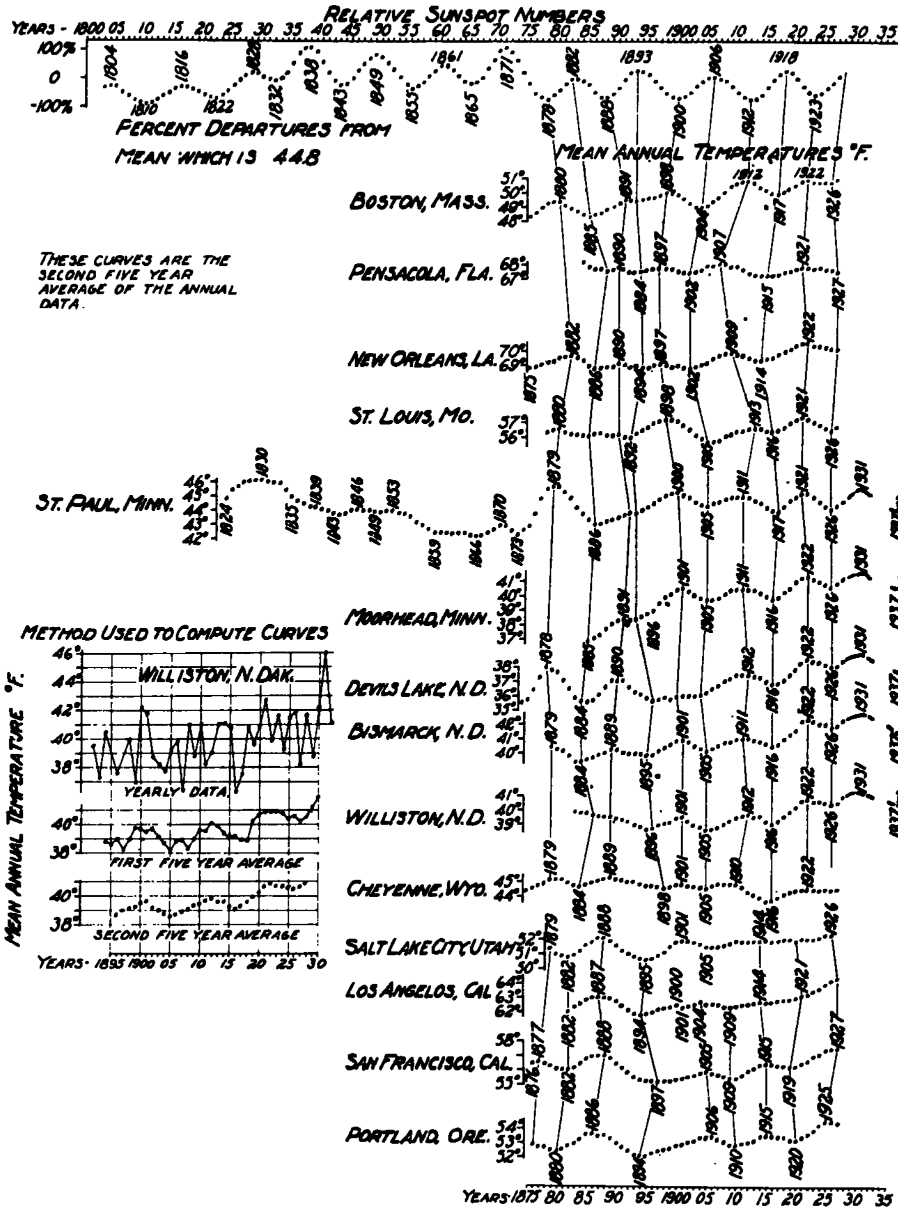
This method dampens the yearly oscillations and pyramids the larger items. The second five year average covers a period of nine years. The first and ninth year enter the computations only once. The fifth year represents the period. It is used five times. The third five year averaging covers a span of thirteen years. The fifth to the ninth year inclusive are used five times. It is plotted for the seventh year of the series. It may sound complicated but the adding machine takes care of it automatically.

Relative Sunspot Numbers

The relative sunspot numbers reveal a most striking uniformity of fluctuation. A graph of the second addition of the five-year average is shown at the top of Plate I, which was taken from the curve published by Dinsmore Alter, University of Kansas, in the October, 1928, Monthly Weather Review, previously referred to. A longer record than here shown is available. But this much shows ten of the eleven year cycles.

It would be interesting if we knew more about those sunspots. They seem to come from the sun's poles and increase as they move towards its equator. Dr. W. S. Adams, Director of the Mount Wilson Observatory said* there was a fairly close relationship between them and the magnetic storms in the earth's atmosphere, also the amount of ultraviolet radiation received on earth. He also admitted there was evidence

*A symposium on Climatic Cycles, National Academy of Science, Washington, D. C. April 26, 1932, as reported in June-July 1932 Bulletin, American Meteorological Society.



COMPARISON OF RELATIVE SUNSPOT NUMBERS WITH MEAN ANNUAL TEMPERATURES

PLATE I

of a correlation between them and atmospheric temperature but further than that he was reluctant to go.

I am including this graph on the suggestion offered by Streiff† that these cycles act as a pattern behind our own weather periodicy. At least they excuse our search for cycles of eleven years rather than some other length.

On the sunspot graph Plate I, reading backward on the upper side it shows:

	Cycle in Years	
Percent Departure from Mean	Solar or Wolf	Bruckner
42.8% in 1918		
	12	
21.2% in 1906		25
	13	
43.4% in 1893		24
	11	
12.8% in 1882		22
	11	
120.2% in 1871		21
	10	
57.0% in 1861		22
	12	
98.0% in 1849		23
	11	
116.6% in 1838		21
	10	
27.0% in 1828		22
	12	
-23.6% in 1816		24
	12	
-19.7% in 1804		
	114 yrs.	
Average	11.4 "	22.7 yrs.

†Monthly Weather Review, July, 1926.

On the lower side reading backward it shows:

Present Departure from Mean		Cycle in Years Solar or Wolf	Bruckner
-39.0% in 1923			
		11	
-58.4% in 1912			23
		12	
-53.6% in 1900			24
		12	
-49.2% in 1888			22
		10	
-58.2% in 1878			23
		13	
- 8.2% in 1865			23
		10	
-20.0% in 1855			22
		12	
-16.0% in 1843			23
		11	
1.8% in 1832			21
		10	
-62.6% in 1822			22
		12	
-85.9% in 1810			
		113 yrs.	
	Average	11.3 "	22.6 yrs.

The Bruckner cycle is not apparent on the graph without further treatment.

Mean Annual Temperature

The eleven year cycle is well established in the sunspot data. But when the effort is made to co-ordinate it to terrestrial phenomena it will not coincide in any precise manner for any length of time over any extensive area. Disturbances and interferences, local and world wide, known and unknown, distort and eliminate it. There are such purely local conditions as the encroachment of city growth and development around the observing station and the personal equation of the observers. Then there are the world-wide disturbances such as magnetic storms and other electric disturbances, also volcanic eruptions with their rough regularity which throw minute particles of ash into the stratosphere to float around the world for two or three years before they get back to earth.

The Weather Bureau data which reveal cycles of most similarity are the mean annual temperatures as Dr. Adams said. Plate I shows the Mean Annual Temperatures for several readily available stations worked out to the second addition of the five-year averages. Vertical lines have been drawn from the sunspot curves to emphasize whatever correlation may exist.

One thing noticed at first glance is the absence of a definite and precise coincidence. There are both lag and distortion. Then one is impressed with the fact that after the Weather Bureau took over the work in 1891 the curves all improved in regularity,—no doubt a mere coincident. But prior to that and for some years afterward also a great many substitutions and combinations were necessary to make a continuous record. The early temperature records may be subject to some discredit. It is a tempting alibi at least.

Another interesting feature revealed is a further confirmation of the fact that the area of the United States east of the Rocky Mountain barrier has a weather distinct from that on the Pacific Coast.

It should also be noted that this eleven year cycle has more elasticity in terrestrial matters than in the sunspot data. There it is from ten to thirteen years in length, but on the earth it runs from seven to fifteen years in the records selected.

Disturbances Within the "Solar or Wolf" Cycle

The feature which makes these temperature cycles useful for prediction is the fact that they all show a remarkable coincidence after about 1916. Prior to that all the stations but Bismarck show distortions and eliminations due either to a poor record or preferably to the presence of some local disturbance which seriously interfered with their marching time. Whatever the cause all the stations east of the Rocky Mountains show the effect of an unusually cold winter which occurred within a year or two of 1916. The warm years of 1921 or 1922 show a complete synchronizing with the 1923 sunspot "low" thru all these stations. From then to 1926 or 1927 the lines are downward faintly on the seaboard stations, decidedly downward at St. Louis and St. Paul, then their declivity progressively fades as they go westward thru Moorhead, Devils Lake, Bismarck, Williston, to Cheyenne. There it is zero or flat. At Salt Sake, Utah, and on the Pacific Coast it is reversed and rises.

Most of the curves stop in 1927 because the arithematical process did not include the 1932 record, but we know that 1931 was a warm year, a record maximum for many stations. So we are safe in "predicting" another high point for 1931 or 1932 which is ten years after 1921 and 1922.

It is with some trepidation that I venture to predict another low on or about 1937 for the local stations shown on the plat. They have been marching along together in pretty good step since about 1905. I am guessing they will continue for at least ancther beat before a magnetic cyclone or something hits them.

Relation of Annual Precipitation and Temperature

Temperature and precipitation curves have been worked out for four localities and are shown on Plate II. These graphs are more difficult to present than those on Plate I and will require more patience on the part of the reader.

Limits must be set as to what shall constitute agreement. If there is a difference of more than two years between corresponding points on the curves no coincidence is assumed to exist. Coincidence is also assumed for convenience of discussion to be in reverse order. That is, a high point on the temperature curve must correspond to a low point on the precipitation curve and vice versa.

It will be seen, however, that for only one station, Bismarck, do the annual curves thus coincide and then only since 1901. The annual curves for the Turtle Mountains are mainly inconsistent in that respect. They move more nearly parallel to each other rather than reverse each other in phase.

The Mouse River curves also parallel each other. The Devils Lake curves parallel each other after 1912. The annual precipitation for Williston, North Dakota, not shown, parallels the mean annual temperature after 1908. But the annual precipitation for St. Paul, Minnesota, not shown, does coincide properly in reverse phase, with the mean annual temperature after about 1900. But prior to that they parallel each other back to 1880. From then back to 1840 it is pretty much hit or miss.

Cycles of precipitation seem to appear with noticeable consistency with the annual temperature for a number of beats, then they fade and reappear in another phase of coincidence. That makes it difficult to project them into the future.

Winter Precipitation and Temperature

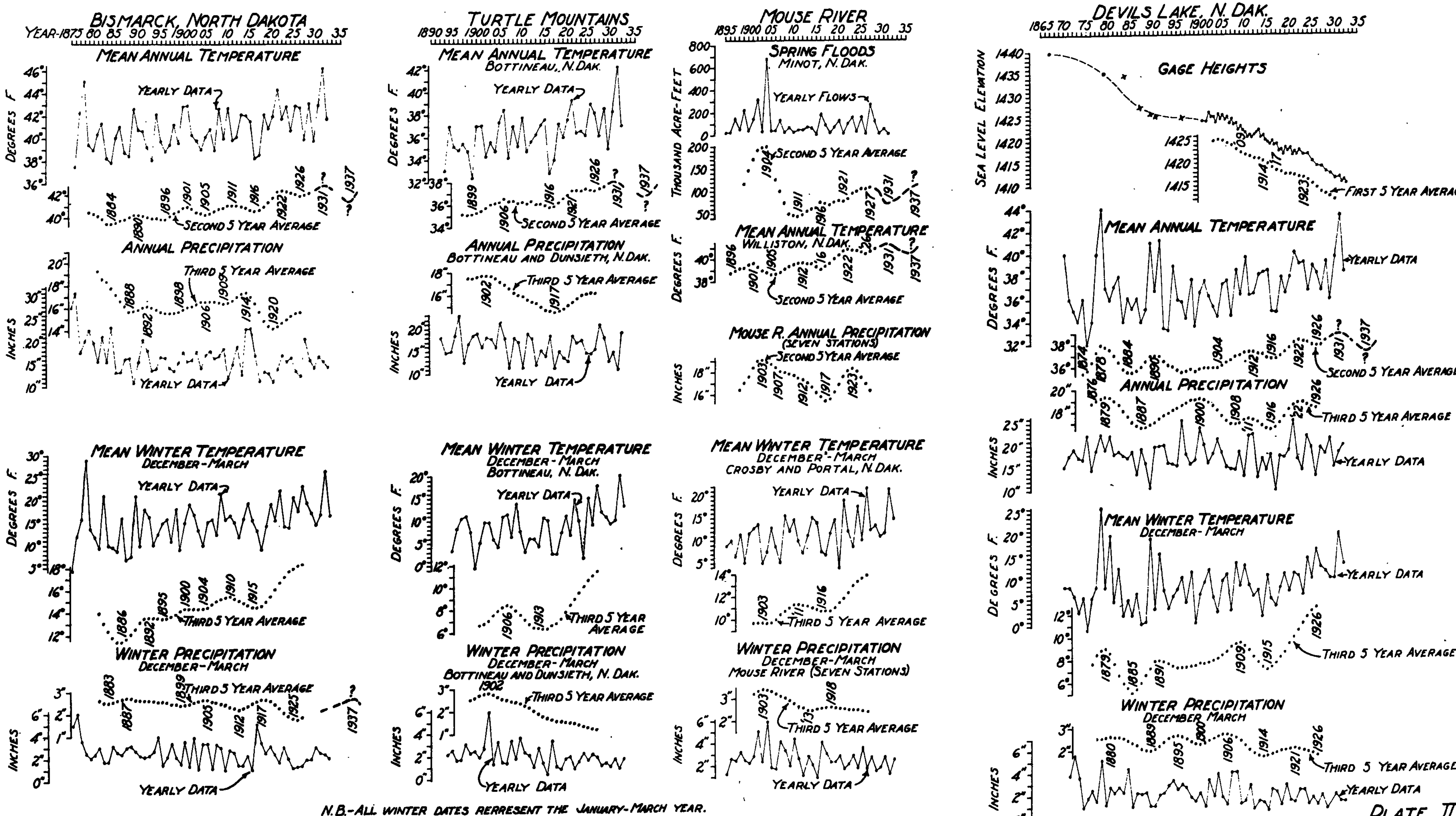
Winter relations between precipitation and temperature should be somewhat more consistent. Winter snows lie on the ground longer than summer showers and are subject to very little evaporation and to no plant consumption.

The winter curves for Bismarck and the Mouse River are consistent thruout within the limits prescribed.

The winter precipitation curve for the Turtle Mountains is nearly a straight line. The curve for Devils Lake is mainly inconsistent.

Some allowance must be made for the arbitrary limits chosen for the winter period. Much precipitation and cold weather in the fore part of a December-March period may be followed by a February thaw which would raise the mean temperature but would not of course change the amount of precipitation.

These curves are interesting in other ways. Winter temperatures at Bismarck have been gradually rising since 1886 and in a pronounced



N.B.-ALL WINTER DATES REPRESENT THE JANUARY-MARCH YEAR.

PLATE II

manner since 1915. An increasing amplitude is noticeable in the "solar or Wolf" cycle in both curves but it fades out after 1915 and 1917 and comes up with a flourish in the temperature curve in 1925 and 1926. Now will it oscillate back to a lower culmination in 1937? This is twenty-two years after 1915.

In any event coal dealers and gas companies should have more prosperous winters ahead.

Spring Floods

Spring floods are related to annual temperatures thru the part played by cold winters and late springs. A flood as here used is any pronounced increase in discharge.

The winter temperature curves should and do parallel quite closely the annual because they make up a large part of it.

There are three dominating conditions which I believe affect the occurrence of spring floods in this region. These were outlined in my Thirteenth Biennial Report. It is pertinent here to state my position, revise it in part, and answer some criticisms which have been offered.

These three factors are (1) available moisture (2) a late spring with no intermittent thaws and (3) a soil previously filled with moisture from fall rains, which is the point in question.

Available Moisture is quite obvious. During a cold winter, losses from evaporation are negligible. Our largest winter monthly precipitation usually comes in March. It is not necessary that the winter snowfall be excessive. There appears to be enough water in a normal accumulation to make a flood if other factors are favorable. The last floods at Minot, North Dakota, occurred with the average, less than normal, in fact, at its lowest point on the curve, about 2.4 inches.

Temperature conditions are more important. The situation most conducive to high spring run-off, other conditions being favorable, is a cold winter with no early thaws and a late spring which turns warm quickly and permanently. Then the snow is melted rapidly into water and thrown down in a manner similar to a hard rain storm.

On the other hand a succession of early thaws and cold snaps almost always forestalls a flood because during the thaw a part of the winter precipitation is let down to get away into the soil while melting is temporarily suspended by the following cold snap. The ground under a heavy blanket is never frozen to any extent because of the latent heat from the earth beneath.

The type of spring is roughly indicated by the number and length of early thaws and freezes.

Soil conditions are more difficult to analyze. It is obvious that they must play a part, for the soil has first chance at the water.

Watersheds in this state are all sod covered, with no extensive timbered areas. Water applied to a root zone of fine texture is subject to two opposing forces. Gravity pulls it downward, capillarity pulls it upward. Additional water applied at the top unbalances the equilibrium and releases water to travel on down to the ground water table located on the first impervious stratum beneath. Summer heat also unbalances the equilibrium by removing moisture from the upper side, which must be replaced before the ground water table is replenished.

This capillary moisture is very effective in controlling the downward movement of additional moisture because it fills and blocks the minute channels. It renders the surface temporarily impervious when large quantities are suddenly applied.

The real question is how to measure it. I have suggested that the fall rains are a rough yardstick.

September seems to be the turn of the year. Early frosts come then which stop most plant transpiration. Excess precipitation then will fill the capillary pores and should survive even a dry October because October's air temperature is cool. October's precipitation is important but it frequently comes in temporary snows which largely evaporate.

August is still summer. Its precipitation is subject to large evaporation and vegetation losses.

When fall precipitation is tucked away in the soil, winter conditions are not of the nature to disturb it. It should remain very much the same until the spring thaws occur. If it is an inch short of normal in the fall, that should afford room for an inch more of snow water in the spring. For that reason I offer it as a rough measure of the soil's capacity for additional water. But compared to the other two factors it usually plays a relatively minor roll.

Getting back to the question of cycles, while the temperature factor is the only one actually related to annual temperature, yet it is in the position of control. The available snowfall factor is ruled out because it will be present during some of the cold winters within the annual temperature trough in at least a normal amount. The only uncertain factor is the soil condition. If the other two are favorable for a flood, it is easily overbalanced. So for watersheds not subject to summer floods, the annual temperature has a definite tho tenuous connection with the flood occurrence.

The Mouse River Cycles

This is exemplified by the Mouse River data. This river at Minot, North Dakota, drains some 10,000 square miles of very flat prairie topography, chiefly Canadian, thru the Souris and its tributaries in Saskatchewan.

Referring to the curves on Plate II, some note-worthy conditions are there revealed graphically. For instance, the curve for Spring

Floods* has no particularly precise agreement with the curve of annual precipitation. Most of the summer storms produce no appreciable run-off.

This is further confirmed by the fact that the spring flood curve almost exactly coincides with the curve for total annual run-off which is not shown for that reason. The major run-off for the year occurs in the spring.

The general shape of the spring flood curve, its slope and the amplitude of its oscillations are a result of factors extraneous to this discussion and so are immaterial. What does matter is the fact that each oscillation, aside from its size, so closely agrees in proper reverse phase with the oscillations of the annual temperature curve for Williston, North Dakota, a First Class Weather Bureau station, located about forty miles south of the watershed. There is no more than a year's discrepancy at any point.

The Next Mouse River Flood

The eleven year cycle seems to be hitting along without undue elasticity. Points on the upper side of the curve indicate increased flow years. They came first in 1904, then 12 years later in 1916, and eleven years later in the biennial series culminating in 1927. Minimum flows shown on the lower side are just ten years apart, 1911, 1921 and 1931, the latter of course being outside the mathematical procedure.

Now will the next flood occur in 1937 or thereabouts? If so, that is about all that is revealed. Nothing is indicated as to size or duration.

But the set-up is not infallible. Nature may not perform as instructed. The record is short. Only one 23 year Bruckner cycle is available. Since 1911 the amplitude of the "Solar or Wolf" cycle has been feeble. Would we have picked 1916 for a flood year if we had not already known it? The "hump" is not very prominent. The 1927 peak is less so. We might even have missed it but for the yearly curve above. It is easy for the hand to slip toward the answer in the back of the head. The 1923 and 1925 floods do not appear.

But most uncertain of all is our basic annual temperature cycle. If it should get derailed before 1937, our story would fall to pieces. At best it is little better than a clever guess.

The Red River of the North

The record of the Red River of the North at Grand Forks, North Dakota, since 1882 offers an interesting comparison. Its watershed receives a much larger annual precipitation than that of the Mouse River. It has had floods from purely summer storms. Total annual flows are used rather than spring floods. In that sense they are not strictly comparable. Yet peak flows correspond closely to annual tem-

*Floods prior to 1904 were taken from Table 6, 13th Biennial Report.

perature troughs at Devils Lake, North Dakota, and Moorhead, Minnesota, the nearest First Class Weather Bureau stations.

Peak Flows	Temperature Troughs
1882	1884
1897	1896
1904, '06	1905
1916	1916
1927 (?)	1926

The curve, not shown, is irregular in amplitude and length of phase. It does not show the large annual flows in 1892 and 1893 because they are overshadowed by the much larger flow in 1897.

But the most debatable coincidence is the 1927 flow. While it was much larger than any for four years on either side of it yet it was very nominal in quantity.

It was large enough probably to prove a slender control of the annual temperature cycle, but, if so, the other factors combined together to very definitely challenge that authority.

Devils Lake

Devils Lake was once, and is yet, North Dakota's most beautiful lake. In 1867 it had an area of 142 square miles and was nearly 40 feet deep. Now, January, 1933, its area has shrunk to perhaps 15 square miles and it is about nine feet deep. Much investment, both public and private, has been made upon its wooded shores. Most of it will be abandoned if the lake finally dries up.

The lake is located on the extreme southern edge of a relatively flat watershed whose theoretical area is 3,500 square miles. It has been described as the knob and kettle type of Pleistocene glacial drift lying on Pierre shale[1]—with numerous small lake beds and pot holes thruout. The "region is almost unmarked by drainage lines save a few shallow winding coulees thru which little or no water flows today——."[2]

Of these Mauvais Coulee is the largest and connects an extensive chain of lakes. In the early history of the region it carried a large enough volume to require a wagon ferry at the present town of Churchs Ferry.

The gaging record is very sketchy from 1867 to 1901. Since then the annual elevations have been recorded with fair consistency thanks to the persistent effort of Dean E. F. Chandler, University of North Dakota. It shows on Plate II a general and persistent decline with fluctuations only in its rate of decline. Those marked with an x are reported by others and not checked by the Dean. From 1901 to 1930 it fell about five inches a year. From October, 1930, to October, 1932, it fell about eight inches a year. At the present rate it will be dry in 1945.

[1]U. S. G. S. Bulletin 598, p. 73, by Prof. Howard Simpson, State Water Geologist, University of North Dakota, Grand Forks, North Dakota.

[2]Loc. cit., p. 189.

The weather record is carried back to 1870 by combining three stations and substituting for many missing months. The precipitation record from 1870 to 1890 inclusive is taken from Fort Totten on the south shore of the lake. From 1891 to 1896 the only record available is at Churchs Ferry, about ten miles north of the lake at one time. From 1897 to date the record is for the city of Devils Lake located in 1883 on the shore of the lake which has since receded about five miles. The temperature record is a much greater patchwork of neighborhood records.

Negligible Effect of Cultivation on Lake Stages

Assertion is frequently made that the rapid decline in the lake has been influenced at least, if not largely caused, by the coming of agriculture to the watershed which changed the soil cover from tight prairie sod to porous wheat stubble. The reduced run-off is said to be caused by the loss of water due to an increase in deep percolation, in plant consumption, and to exportation of farm products, mainly wheat from the watershed.

The idea has wide-spread acceptance. Prof. Simpson* says "owing to the rather rapid lowering of the lake level since cultivation of this region began, the area has been greatly reduced." On the following page he says the lake level is subject to "some significant modifications that are the result of human agencies, such as drainage and the cultivation of the soil." But he states clearly that the large primary causes are climatic control.

The most recent reference is in the December, 1932, issue of the Proceedings of the American Society of Civil Engineers by Prof. Daniel W. Mead, head of the Department of Hydraulics and Sanitary Engineering, University of Wisconsin, and honorary member of the Society. In a discussion on the effects of deforestation he offers as apropos man's settlement of the Devils Lake watershed with a map of the lake and graphs of the gage heights and rainfall. He says on page 1820,

> "Since the land around the lake has been settled and cultivated, there has been a considerable decrease in run-off and a marked shrinkage in the height and area of the lake, evidently due to the opening of the land by cultivation."

But the usual effect of deforestation is to provide more run-off rather than less. So whatever other factors may prevail, conditions similar to those resulting from deforestation have not occurred here. Moreover, it is going to be difficult to prove that the mere changing of the soil cover from one type of sod to another has any appreciable effect one way or the other.

The gage heights do not show it. An inspection of the gage height curve on Plate II show that the sharpest decline in the entire record

*Loc. cit., p. 190.

occurred in the Eighties. Settlement was just beginning then. Now fifty years later only about half of the watershed has ben plowed up. The lake fell 11.3 feet in the twenty years from 1867 to 1887. That is 6¾ inches a year. From then to October, 1932, a period of 45 years it fell 16.4 feet, or at the rate of 4 1/3 inches a year. Only climatic conditions could affect it the first twenty years. If human agencies modified it since we must look elsewhere for the evidence.

A readily computable factor frequently quoted is the amount of water shipped out in farm products. But that is negligible. Eighteen inches of rain a year is the equivalent to 2,000 tons to the acre. Fifteen bushels of wheat to an acre contains only about 130 pounds of water. But according to the report of the State Commissioner of Agriculture only about a half of the land was plowed up in 1928 and 1929. So that would mean that not to exceed 75 pounds of water per acre existed in grain products and not all of that was exported.

It might even be asserted with some display of statistics that somewhat more run-off rather than less could result from the introduction of cultivated crops. Professor Mead quotes from experiments made in Wisconsin in 1929 on run-off from areas covered with certain types of vegetation in which he says, page 1819,

> "The highest average percentage of run-off found was less than 2% for forest covering, 20.1% for pastures, 24.1% for oat lands, 25.6% for corn land, and 21.5% for hay lands, the last three being probably somewhat reduced by the less average slope."

Hay and pasture land are sod covered areas. They showed less run-off than oat and corn land, altho he goes on to say, "Here, again, the actual soil conditions are somewhat indefinite and the nature of the soil involved is not clearly discernible."

As to the water consumed it appears from Table 13, page 1822, that lucerne and meadow grass use 20% more water than oats and 100% more than wheat. According to Table 14 sod returns 33% more water to the atmosphere by transpiration than mixed crops do.

The inference is this. Sod yields less run-off, consumes more water, and returns more to the atmosphere than certain cultivated crops.

Theoretical reasons are available. There could be less run-off from a sodded area because there are more plant obstructions per square foot. There could be more evaporation because more water is held by capillarity in the matted blades of grass. They stay wet longer after a rain. Certain grain crops are an exception for a short time. Cultivated areas usually have more bare ground. The root zone is not so compact and dense. Less water is caught there and devoured. More gets by to the ground water table beneath. So cultivated crops might cause more run-off, less plant consumption, more deep percolation, and less surface evaporation than sodded areas. More run-off and more deep percolation would raise the lake rather than lower it.

However, be that as it may, there probably always has been a relatively small surface run-off because of the gravelly terrain. Subsoil seepage into the lake is large. It frequently is enough to be noticeable during the winter by the difference in fall and spring gage heights. But there is no evidence that it has increased. There is no report of any extensive rise in the ground water table. No large land drainage projects have been suggested.

Climatic Factors Responsible

There are two factors which are primarily responsible for this situation. They are temperature which induces evaporation losses from the lake and precipitation which directly replaces this loss as far as possible, reinforced by whatever contributions are available from the watershed in run-off and subsoil seepage inflow.

The annual temperature curve represents the losses due to evaporation. The annual precipitation curve shows the major contribution which raises it. Then the combined slope of these two curves should be reflected in the slope of the gage heights. Let us inspect the curves in detail. See Plate II.

Thru the Eighties the gage heights show a precipitous decline, the largest in the record. Looking at the weather curves we see also the steepest rainfall decline in the record. Temperature goes down, so evaporation is less but the loss of the replacing contributions of rainfall and inflow entirely overshadows any gain in reduced evaporation. It may be during this period that the flow from the Mauvais Coulee began to fall off.

From 1887 to 1900 precipitation increases. It climbs out of the hole to about its former elevation and this flattens out the gage height curve. The lake shows very little change for a decade or so.

From 1900 to about 1912, temperature begins a climb, so evaporation increases. At the same time precipitation falls off. Both contribute to a falling lake stage. The special little slump in the rainfall curve in 1908 is reflected in the little additional dip in the gage height curve in 1909.

From 1912 to 1916 both curves fall but again rainfall has the stage and the 1917 sag in the gage heights is the result. From 1916 to 1922 both curves rise. Rainfall has the leading role again but evaporation directs the play. The gage height curve flattens out noticeably but still it is nosed slightly downward.

From 1922 to date, evaporation has run away with the play. Temperatures have stayed up but precipitation has not. The lake has lost rapidly.

The Future of the Lake

The only immediate hope for the lake is for the anticipated 1937 trough in mean annual temperature to be deep and for the rainfall cycles to remain in the higher averages. Precipitation cycles are uncertain but in the Devils Lake data the eleven-year peaks begin with 1900 and hit 1911 and 1922 precisely. Chances are good for another one in 1933 or 1934.

The principle change, however, must come in the general range of the temperature curve. It has been generally rising since about 1896. It must come down. Whether it will do so abruptly or gently is impossible to predict.

Stump Lake

Judging from the behavior of Stump Lake, relatively abrupt changes are possible. This is a small lake about 25 miles east of Devils Lake so named because uprooted, fire-marked, waterlogged, oak trees are slowly emerging in certain places around the shore as the water recedes.

They are not petrified and are used by the local inhabitants for fuel. I counted 116 rings on one of them about 12 inches in diameter.

There is no way to account for these except that they grew there from the seed when the lake was below that particular place and it was dry ground for at least 116 years. Then a reversal of conditions must have set in and a rapid rise occurred. These trees were undermined and felled by wind and wave and fired by lightning. The rise must have been relatively rapid, for most of those that did not burn rotted away. Only in those particular places where they were especially protected by some local condition did the water rise fast enough to cover and preserve them. Now they are being uncovered as the water recedes. This has been going on for at least seventy-five years, for the lake was named for these stumps in the very early history of the state.

There is every reason to believe that Devils Lake has been dry or nearly so a number of times before. The same forces which filled it then are still operating without hindrance. It is very possible that sometime in the far distant future great engineering works will be necessary to keep the lake water out of the city of Devils Lake itself, now some fifty feet or more above the present water surface.

The Turtle Mountains

The Turtle Mountains are a turtle-back shaped elevation of wooded undulating topography comprising about 700 square miles and rising about 500 feet above the surrounding flat and treeless prairie. The maps of the General Land Office made from surveys between 1888 and 1897 show practically a 100% forest cover. Now perhaps a third of the timber has been taken off and partially replaced by cultivated areas.

The area is filled with lakes, 704 are shown on available maps. Many are now dry but the notable feature is the apparent permanency of the larger ones. Lake Metigoshe is a typical example. It is reported about as high in 1927 as it was during the period around 1905. Between these two peaks the lake went down about seven feet.

In the absence of records to the contrary we may assume that Metigoshe elevations paralleled the average precipitation curve in a general way with oscillations caused by temperature changes. See Plate II. From 1902 to 1917 precipitation went down. The lake probably did too for temperature conditions remained comparatively steady. From 1916 to 1921 there was an unusual rise in temperature. The annual rose from 32.8° in 1916 to 39.3° in 1921. Increased evaporation must have very seriously challenged the effort on the part of precipitation to raise the lake. Since then conditions have been more or less favorable for the lake.

In comparison with Devils Lake the Turtle Mountain temperatures average over the total record about a degree cooler. Precipitation is about two inches less. There is the same knob and kettle type of topography but the hills are steeper. But the principle difference is the typ of soil. It is generally clayey rather than gravelly. The unimproved roads, when wet, are black, slippery and sticky. Run-off must be much greater.

Concerning deforestation, Mr. J. C. Stevens, Member of the American Society of Civil Engineers and a Consulting Engineer in Portland, Oregon, makes perhaps the most concise statement in the December, 1932, Proceedings previously mentioned. He says on page 1811,

> "After many years of guessing and useless argument some authentic information has been produced at last as to the effect of forests on stream flow. The final conclusions are exceedingly simple. They might have been—in fact, actually were—anticipated many years ago. The forest, like every other vegetable crop, consumes large quantities of water for its growth. Unlike small plants, however, it also dissipates large quantities of water by mechanical means. It prevents a substantial portion of rain and snow from reaching the soil, permitting rapid evaporation from branches and leaves. When the forest is removed, the water thus consumed by it appears as run-off. As new growths appear the run-off gradually diminishes again in proportion to this crop and mechanical consumption."

From the appearance of the precipitation curve the Turtle Mountain lakes are over the hump and headed for another decline. This will be interrupted by temporary wet periods, one of which may result from the snow run-off anticipated in the forthcoming 1937 trough of annual temperature. But unless steps are taken to prevent it by storing all available run-off, these lakes will continue in the general recession which is already slightly apparent in the gage heights of Lake Metigoshe.

The following is a table of monthly elevations at the two lakes most largely commercialized.

Lake Metigoshe		Lake Upsilon	
Date	Elevation	Date	Elevation
June 13, 1931	2135.9		
July 27, 1931	2135.5		
Aug. 24, 1931	2135.4		
Sept. 25, 1931	2135.2	Sept. 26, 1931	2103.6
Oct. 25, 1931	2135.0	Oct. 30, 1931	2103.6
Nov. 23, 1931	2135.0	Nov. 14, 1931	2103.5
Dec. 29, 1931	2134.9		
Jan. 31, 1932	2134.8		
Feb. 28, 1932	2135.1		
April 4, 1932	2135.1		
May 3, 1932	2135.2	May 16, 1932	2104.0
June 2, 1932	2134.9		
July 2, 1932	2135.0		
Aug. 2, 1932	2134.9	July 1, 1932	2103.8
Sept. 5, 1932	2134.4	Sept. 1, 1932	2103.8
Sept. 30, 1932	2134.3	Sept. 30, 1932	2103.1

Just when the trough of the next recession will occur is impossible to predict. But if the precipitation curve continues in its long sweeping cycle the next trough should be twenty-two or three years after 1917 or about 1940.

Long Range Weather Predicting

There is no precise scientific method yet found for long range predictions. These solar cycles reveal only a very rough and general trend in the temperature record. When it comes to a year by year prediction the best way for the layman to do is to prepare a set of graphs for the seasons he is interested in, keep them up to date, and make his own predictions. His guess is as good as any. Take for instance, the annual precipitation at Bismarck, North Dakota. The last two years have shown a downward trend making three in a row all less than normal. Looking back over the graph several times when there were three in a row like that the next year was "up." So 1933 bids fair to be "up" in precipitation at Bismarck.

The precipitation at Devils Lake is due for more comeback than has yet occurred. Precipitation in 1933 may be down somewhat but if it is then 1934 should be decidedly up.

The Turtle Mountain precipitation staged its comeback in 1932. What it will do in 1933 is problematical.

Note: Mr. Shuman read this chapter in manuscript and defended his free hand curves on the ground of emphasis. I am more inclined to think it is because no amount of mathematics would actually obtain them as shown. That is where he takes leave of mathematics and steps off into the realm of fantasy. In defense of his ninety year cycle he points to the fact that all our local temperatures have risen since the Eighties. This is especially noticable in the winter temperature curves Plate II for Devils Lake and Bismarck. From 1886, say, to 1931 is forty-five years. The inference is that forty-five years hence we will be having the same kind of weather that occurred forty-five years ago. But that is not borne out, for instance, in the St. Paul record, Plate I. From 1830 to 1873 is forty-three years and apparently it is the downward side of his ninety year cycle. Then a smoothly flowing curve with a general upward trend could be drawn from 1873 to 1931. But does it actually represent the facts? Why ignore the big comeback in 1879, and the fact that the "waves" from 1900 to date show no upward trend? They are level at least if not a bit downward. He has no assurance but that North Dakota temperatures may do the same thing and come down abruptly rather than gently.

EVAPORATION FROM

DEVILS LAKE

IN

NORTH DAKOTA

By

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Bismarck, North Dakota

January, 1933

ADMISSIONS, CONFESSIONS AND ACKNOWLEDGEMENTS

I have been struggling intermittently with the subject of evaporation since 1924. Again and again I have thought I had arrived at a defendable conclusion only to see it dissolve under a new set of conditions.

One Saturday night with a sigh of hope I stacked together on my desk a thick package of computations together with a copy of the manuscript of Mr. Rohwer's treaties "Evaporation from Free Water Surfaces," later published as Technical Bulletin No. 271, of the U. S. Department of Agriculture.

The next morning, December 28, 1930, it was destroyed in the Capitol fire. Two years of daily open water gaging record on Devils Lake were lost but it also cleaned out many dead ideas. With a clean slate I gathered together the abundant material from outside sources, mainly the Bureau of Plant Industry, and prepared a thesis which I submitted to Purdue University for a professional degree of Civil Engineer. This was granted June 9, 1931.

I gratefully acknowledge valuable aid and suggestions from correspondence with Robert E. Horton, a hydrologist of national reputation; with Leonard B. Loeb, Department of Physics, University of California, author of a helpful book "Nature of a Gas;" with several members of the U. S. Geological Survey; and with Carl Rohwer, with whom I had also a personal conference. His work is one of the best efforts I have seen to demonstrate and defend the Daltonian hypothesis by laboratory methods. Frequent reference is made to it in this paper.

ROBT. E. KENNEDY.

FIGURES, PLATES AND TABLES

EVAPORATION FROM DEVILS LAKE IN NORTH DAKOTA

By Robt. E. Kennedy, State Engineer

Invisible to the eye, illusive of direct measurement, the process of evaporation is a fundamental function in the economy of Nature upon which depends all precipitation and all life. The persistent effort to isolate the laws governing its operation testify to their importance in the engineering world.

Devils Lake in the northeastern part of the state offers a gaging record since 1867 and a parallel Weather Bureau record since the U. S. G. S. gaging record began in 1901. See Figure I. The lake is now about five miles in diameter and nine feet deep. It is also getting salty, specific gravity is now 1.021. It contained abundant fish in the Eighties. It has no outflow, a small surface inflow, no diversions and a simple geological structure of watershed.

Conclusions and Recommendations

This study leads to the conclusion that there is much ambiguity and uncertainty about the fundamental operation of the process of evapor-

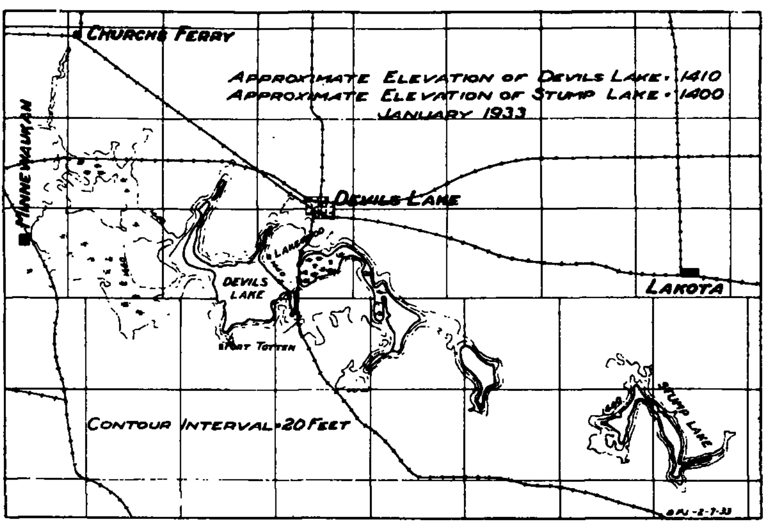


Figure I. Contour Map of Devils Lake's Former Lakebed.

ation. Several hundred papers have been written on various phases, yet with results largely discordant. It is doubtful if any formula yet proposed has universal application. Much of the difficulty lies with the appraisal and use of the component data such as wind velocities and relative humidities. A large part lies with the Daltonian hypothesis itself.

A formula for monthly evaporation from Devils Lake was developed from monthly rather than daily data, since daily observations from a large body of water are complicated by wind velocities which not only cause waves but raise the entire water surface at times.

It is recommended that a standard weather bureau evaporation pan be added to the installation now in use, and that several observation wells of post hole size be installed around the lake to observe the seepage inflow. This will involve only a small additional expense and should yield valuable information not now available.

Molecular Nature of Evaporation

Evaporation of water is the escape of the faster molecules from their "captured" condition in a solid or liquid state. These molecules are submicroscopic particles composed of protons and electrons combined in atomic nuclei in some sort of a solar system arrangement whose orbits probably have various fantastic shapes, some of which may look like tripods, indian clubs and dumbbells.

They have an average speed comparable to that of a rifle bullet, but the variation from the average is great. The straight line path between collisions is minute but it has been computed. They actually never collide but are repelled from each other before they quite touch.

This vapor pressure in a gaseous state is the basis of the Dalton theories. It is the pressure caused by this bombardment against each other and against the molecules in the walls of the container. As the temperature of the gas is reduced, the molecular velocity is reduced. At a certain critical point it becomes slow enough to allow them to become entangled and interlocked with each other which is a liquid state. Further reduction of velocity creates a sort of meshed lattice-work structure which is the solid state.

The Daltonian Hypothesis

The present theories of evaporation have been extensively but erroneously ascribed to the great chemist Dalton who made certain observations on evaporation of water and the diffusion of gases in 1801.

But according to Humphreys[1] more accurate credit for the present difference in vapor pressure theory should be given to Weilenmann and Stelling who worked it out separately and independently.

The theory briefly stated is to the effect that evaporation is largely a function of two conditions, first, the difference in vapor pressure and secondly, as Dalton suggested, the velocity of the wind which is assumed to remove the vapor blanket.

According to the **difference in vapor pressure** theory, the rate of evaporation, other factors remaining constant, is proportional to the difference between the saturated vapor pressure at the water surface temperature and the partially saturated vapor pressure in the atmos-

[1] "Physics of the Air" page 247, McGraw Hill Book Company, New York.

phere above. Since water vapor in the air must become saturated before it is precipitated into a liquid form it is fair to assume that when the process is reversed and vapor is escaping from the water surface to the air a thin layer of vapor lies on the water surface at least a "few molecules deep," as Horton says, which is just this side of saturation. Then there is a pressure gradient from the water to the outer air in which this difference in vapor pressure is a large component factor. But the theory omits among other things the atmospheric pressure and more especially the length and temperature gradient of the diffusion zone.

The length may be anything from zero as when the air is saturated to "all outdoors." But judging from Mr. Rohwer's experiments[1] the greater part of the diffusion occurs within the first inch for he took all his readings for atmospheric vapor pressure at that distance from the water surface.

The theory is especially applicable to most conditions where there is a wide difference between the air and the water temperatures.

It fails, however, in certain particular situations. One is when the water is warmer than the air and the air is saturated. Then there must be a difference in vapor pressure in the computations because the water is warmer. That indicates evaporation. But when the air is saturated there can be no evaporation.

Mr. Rohwer[2] in commenting upon his experiments with a heated water surface as published in his Table 6 says, "The table shows that except for periods of heavy snowfall there is a fairly close agreement between the observed and computed——." He thought the difficulty was due to the wind blowing some of the snow out of the rain gage. That may account for part of the discrepancy but a larger part must be charged to the failure of the theory to meet that particular situation.

These experiments were conducted by Mr. Rohwer to check the interesting suggestion offered by Freeman[3] that evaporation from the Great Lakes may be actually greater in the winter than in summer because the water is kept from freezing by wave action. So its surface temperature is 32° F.

The experiment tends to prove Mr. Freeman's idea correct. The theory is quite applicable except for the small per cent of the time the lakes are covered with fog or storm.

It fails again apparently or at least it reveals an unexpected condition when the reverse condition prevails and the water is cooler than the air. Freeman[4] reports the average air temperature over Lake Michigan as 63.3° F. and the water temperature as 56° F. during June.

[1]Technical Bulletin No. 271, p. 6, 46, U. S. Department of Agriculture, Washington, D. C.
[2]Loc. cit., p. 28.
[3]Regulation of Great Lakes and Effect of Diversions by Chicago Sanitary District, page 146. Chicago Sanitary District.
[4]Loc. cit., p. 110, 116.

Then a negative difference in vapor pressure occurs for all relative humidities above 77%. A negative evaporation would be precipitation which can occur only when the relative humidity is about 100%. But even so it may not be so entirely erroneous as will be seen in a moment under "Temperature Gradient."

If the air and water temperatures are practically identical, the difference in vapor pressure becomes the air dryness, or its **saturation deficit.** Concerning this, Humphreys[1] says, "Many observations have shown that to at least a first approximation the rate of evaporation is directly proportional other things being equal to the difference in temperature indicated by the wet and dry bulb thermometer of a whirled psychrometer." The saturated vapor pressure at the air temperature indicates what the space we call air can hold. The partial vapor pressure is what it actually is holding. The difference is what it can take.

In many places, as for instance Devils Lake, either the air and water are found to be practically the same or only a few months of water temperatures are known. Then the saturation deficit is the only function available for computation. It fails, as would be expected, when there is any material difference between air and water temperatures.

Temperature Gradients

The relation between air and water temperature seems to be a very important factor. When the water is colder than the air it may actually collect some vapor out of the immediately adjacent atmosphere on the same principle that beads of moisture collect on a cold water pitcher on a hot summer day. The actual contribution would probably be negligible, but there certainly would be no evaporation for there would be no chance for the liberated molecules to get away. It would be a sub-adiabatic condition in meteorological parlance.

When the reverse condition prevails, the water is warm and the air is cold, the temperature gradient is reversed. Masses of moist air warmer than the surrounding atmosphere rise as long as their loss of heat per unit of altitude is more than that of the surrounding air. Thus molecular escape is encouraged.

The rate of evaporation seems to be affected in a large measure by the removal of the vapor blanket by adiabatic processes.

Wind Velocities

Wind movement has been assumed to remove the vapor blanket and bring in a supply of drier air, somewhat after the fashion of continuously moving layers of blotting paper, with the layer next the water moving the slowest. But it has been a troublesome term. Measurement exactly at the water surface is impossible. Weather Bureau records have been obtained under varying elevations and conditions of encroachment which render them practically useless.

[1] Loc. sit., p. 245.

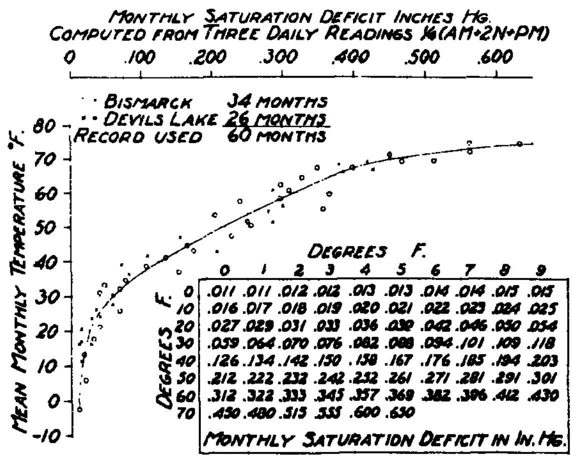
Under the controlled laboratory conditions as devised by Mr. Rohwer they are a definitely contributing function. But under outdoor conditions using monthly data they are not so important as may be seen from the graphs in which they are omitted. The reason may lie in the predominating activity of the adiabatic movements.

Relative Humidities

Relative humidities which accurately represent the diurnal change in vapor pressure have been difficult to agree upon. After trying several approximations, that proposed by Mr. Theis[1] seems to give the most consistent results. He combines the three daily readings by averaging the morning and noon with the noon and evening reading thus; $\frac{AM + 2N + PM}{4}$. Night evaporation is ignored. The curve of monthly Saturation Deficits shown on Figure II was obtained by thus computing the deficit for each of the three daily readings for each day of the month and plotting the monthly average against the mean air temperature for the month.

Evaporation Formula

The Daltonian analysis contains three variables (1) evaporation (E): (2) vapor pressure difference (Vp) or its less reliable substitute saturation deficit (Sd); and (3) the wind velocity (W).



DEGREES F.

DEGREES F.	0	1	2	3	4	5	6	7	8	9
0	.011	.011	.012	.012	.013	.013	.014	.014	.015	.015
10	.016	.017	.018	.019	.020	.021	.022	.023	.024	.025
20	.027	.029	.031	.033	.036	.039	.042	.046	.050	.054
30	.059	.064	.070	.076	.082	.088	.094	.101	.109	.118
40	.126	.134	.142	.150	.158	.167	.176	.185	.194	.203
50	.212	.222	.232	.242	.252	.261	.271	.281	.291	.301
60	.312	.322	.333	.345	.357	.369	.382	.396	.412	.430
70	.450	.480	.515	.555	.600	.630				

MONTHLY SATURATION DEFICIT IN IN. HG.

Figure II. Monthly Saturation Deficits.

Mr. Rohwer quotes[2] several formulas involving various combinations of these factors. Nearly all authors assume that evaporation is more closely related to vapor pressure than to wind velocity. Mr. Rohwer

[1] "Some Recent Studies in Evaporation" page 222. C. V. Theis, U. S. G. S., Report Twelfth Annual Meeting (1931) Hydrological Section, Am. Geophysical Union, Washington, D. C.

[2] Loc. cit., p. 3, 4.

follows this precedure and divides (E) by (Vp) and plots the result against (W). This is shown graphically on Fig. 1, Plate I. Concerning it he says[1] "Only the 1923 observations are shown because too many points,—particularly where there is considerable dispersion—tend to obscure rather than classify the relation sought." The 1923 observations are shown with round dots. The balance of the data in his Table 4 taken in 1924 is shown with a small circle. They show as lighter weight points when reduced to the size shown in the cut.

Another procedure is to divide (E) by (W) and plot against (Vp). No defense in theory is offered except that it works. It shows less scattering of his 1923 points as may be seen in Fig. 2, Plate I.

Each of these two processes is an algebraic expression of the fundamental formula mathematically identical. But the marked difference in operation reveals further evidence that the Daltonian theory is more or less of an imperical approximation.

The third method here shown is based upon the air dryness theory with the wind factor ignored entirely. Fig. 3 of Plate I indicates that this cannot be done to advantage with the Rohwer daily evaporation figures. But in many of Weather Bureau and Bureau of Plant Industry monthly pan data it makes a very good showing.

Plate II shows the evaporation data from the six foot pan of the experiment stations of the Bureau of Plant Industry at Mandan and Dickinson, North Dakota, treated in the three methods described. The saturation deficits were obtained from Figure II because there is no wide difference reported in water and air temperatures. It will be noticed that the Rohwer procedure as shown in Fig. 1 produced such a scattering of points that the graph is useless. The other two methods produce workable graphs with little difference between them.

[1]Loc. cit., p. 21.

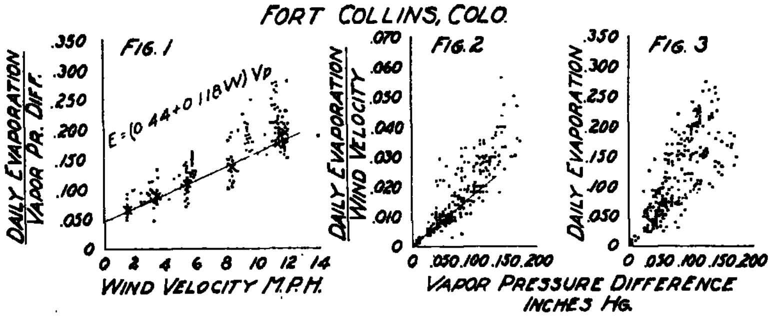


Plate I. Daily Evaporation in Inches at Fort Collins, Colorado.

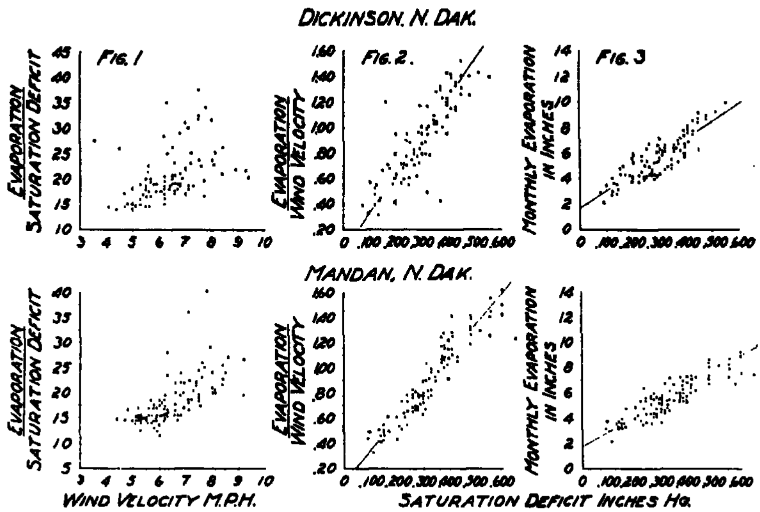


Plate II. Monthly Evaporation in Inches at U. S. Bureau of Plant Industry Experiment Stations at Dickinson and Mandan, N. Dak.

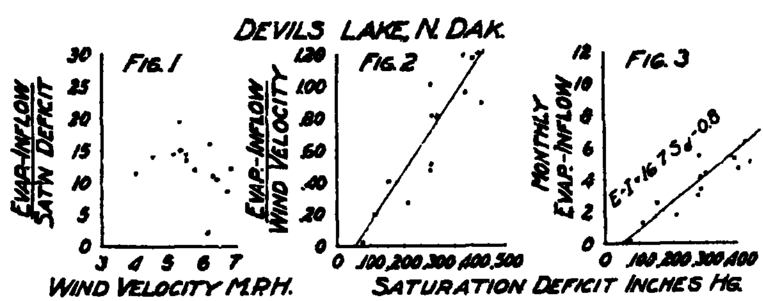


Plate III. Monthly Evaporation in Inches at Devils Lake, North Dakota.

Plate III shows the brief data obtained for Devils Lake, fourteen months of open water. Since the third method above described made the best showing, its formula in Fig. 3, was applied to the record since 1901 as shown in Table I.

Devils Lake

Devils Lake is a large sump hole in the shape of a pan dug out of the top of the Pierre shale.

The watershed is the pot hole, knob and kettle type of Pleistocene glaciated gravels.[1]

Surface inflow is now negligible. For the two year period of twice daily open water record shown in Table I no surface inflow was detected. It always has been relatively small because of the lack of well defined drainage channels and the gravelly character of the terrain. There was sufficient inflow thru the one main drainage inlet known as Mauvis Coulee in the early part of the record to require a wagon ferry at the town now called Churchs Ferry. But the effect upon lake stages was offset by the fact that the area was much larger in 1879, say, than it is now.

Sea Level Elevation	Area Square Miles	Approximate Years
1440	142	
1439		1867
1430	91	1879
1425		1890, 1904, 1906
1420	54	1914
1415	42	1925
1411	16	1932
1401 bottom	5	

Subsoil seepage inflow is large. It frequently affects the lake stages a noticeable amount during the winter when the evaporation is negligible. Its effect has not been increased by the recession of the size of the lake because the present areas of dry lake bed do not drain into the present lake. The original lake was a series of smaller lakes connected by shallow channels and bars.

The saline content of the lake was small enough at about the 1425 contour so that fish were able to exist. In the Eighties wagon loads at a time are reported to have been taken out.

[1]U. S. G. S. Bulletin 598, p. 73, by Professor Howard Simpson, University of North Dakota, Grand Forks, North Dakota.

An analysis is given in the First Annual Report of the Biological Station[1] in 1910.

Tonic Composition

	Parts per Million
Calcium	4.0
Magnesium	603.9
Sodium	2908.8
Bicarbonate Ion	708.0
Carbonic Acid Ion	126.0
Sulphuric Acid Ion	6098.4
Chlorine	1177.0
	11626.1

An analysis in 1932 is as follows:

	Parts per Million
Total Solids	24,409
Fixed Residue	23,097
Carbonates CO_3	657
Chlorides Cl	2,298
Sulphates SO_4	12,926
Sodium Na	5,334
Potassium K	822
Aluminum Al	517
Calcium Ca	80
Magnesium Mg	11

The amount of silicious matter was negligible.

Alkalinity:

Phenolphthalein	252 P.P.M. as Ca CO_3
Total	1095 P.P.M. as Ca CO_3

The present specific gravity is about 1.021.

Water surface temperatures were taken at the shore. To get a relation between shore temperatures and those out in the lake a series of surface temperatures were taken across the lake and at various depths on August 24, 1932.

[1]Submitted by Professor Simpson, University of North Dakota.

Relation of Shore to Lake Surface Temperatures

Devils Lake, N. Dak.

August 24, 1932.

Distance from gage	Water Depth Feet	Time	Air Temp. °F	Water Temp. °F	Wind
10	1	11:30 A. M.	74°	80°	
100	3			77°	
Middle of bay, boat drifting slowly	about 8 ft.			78°-77°-76°-75° 76°-77°-78°-79° 78°-77°-78°-79° 80°-79°-82°-83° Ave. 79°	None
West side of bay	1	12:00 N.	75°	79°	
Main Lake	7-9		76°	75° (many readings)	Light breeze
Shore at gage	1	2:30 P. M.	78°	87° Max. for day	

Relation of Temperature to Depth

Time, 1:30 P. M.

August 24, 1932

Depth	Temperature
Surface	76°
0.5 ft.	75°
2.0 ft.	72°
5.0 ft.	72°
7.0 ft.	71.5°
7.5 ft.	bottom

On the basis of this it is assumed that shore temperatures are higher than those over deep water and that monthly average temperatures of air and water over the general surface of such a shallow lake are not greatly different.

The U. S. G. S. gaging record was started in 1901 and several observations a season were usually obtained. They are published in the U. S. G. S. Water Supply Papers.

Prior to 1901 lake stages were gathered by Dean E. F. Chandler[1] from local records.

A twice daily gage record during the open water season has been obtained since September 28, 1930. Two readings are taken if waves are running. Dial reading on an anemometer located on the shore and two feet above the ground is recorded when the gage is read and twice a week during the winter.

There was no appreciable surface inflow during the two-year period. The largest precipitation was an average of 2.56 inches for a day which occurred October 18 at one side and October 19, 1932, at the other side of the lake. The gage heights were raised correspondingly but no subsequent rise was observed which could be charged to surface inflow. On the basis of this the assumption is made that no inflow occurred from storms less than 2½ inches a day at two stations on the watershed.

Formula for Devils Lake

In the absence of appreciable surface inflow and any outflow during the twenty-four months record, Monthly evaporation, (E) equals change in the water surface elevation during the month (W.S.), downward being plus in sign, plus monthly precipitation (P) plus inflow (I) from the watershed, being in this case all seepage. All computations are in inches.

In symbols only, $E = (W.S.) + P + I$

Then $E - I = (W.S.) + P$

Table I is the twenty-four months record ending October, 1932, with pertinent meteorological data.

Table II shows computations from Table I necessary for formula (1) and the graphs on Plate III. The formula from Plate III is

$$E - I = 16.7\ Sd - 0.8$$

Table III shows this formula applied to 53 periods of gage height record covering 31 years. The details of computation are simple. The sum of the Monthly Saturation Deficits are multiplied by $\frac{100}{6}$ and eight-tenths of the time in months subtracted therefrom.

In view of the roughness of the method the coincidences which occur between the computed and the observed E — I are interesting. Some of the wide discrepancies are assumed to be due in part to the difference in seepage inflow as compared with that in 1930-32. It is apparent that its effect shows no greater variation in the early part of the record than in the latter part.

[1]University of North Dakota, Grand Forks.

The accumulated winter precipitation makes no large effect upon the gage heights except in the spring of 1904.

To make this study complete, a relation between precipitation and seepage inflow should be obtained from observation wells at various accessible places around the lake.

As it stands the method is applicable to the study of the Turtle Mountain projects where seepage and evaporation need not be separated. Gage height and precipitation records are now being obtained from Lake Upsilon and Lake Metigoshe. Reservoirs are proposed near these lakes which should be subject to the same conditions of seepage inflow and evaporation.

TABLE I

MONTHLY EVAPORATION DATA FOR DEVILS LAKE, N. DAK., 1930-1932

1	2	3	4	5 Precipitation[2]					6 Temperature[3]				7	8 Ave. Monthly Wind Velocity			
Month and year	Water Surface Elevation at First of Month, Feet Sea Level	No. of Readings[1]	Change in Water Surface Elevation, Feet	Weather Bureau, Inches		Lakewood, Inches		Ft. Totten, Inches	Air, Weather Bureau, Degrees F.		Air at Lakewood Degrees F.	Water at Lakewood Degrees F.	Saturation Deficit[4] from Weather Bureau Data, Ins. Hg.	Weather Bureau at 41 Feet Elevation, M. p. h.	Lakewood: At 5¾ Feet Elevation, M. p. h.	Lakewood: At 3¾ Feet Elevation, M. p. h.	Lakewood: At 2 Feet Elevation, M. p. h.
1930 Oct.	1411.58	11	−0.16	2.26		1.85			39.6				.070	10.0	8.4		
Nov.	1411.74	8		0.81		0.94			27.8				.058	10.9	9.5		
Dec.				0.23		0.06			17.0				.015	8.9	7.4		
1931 Jan.			−0.17	0.19	2.46	0.19	2.29		16.7	22.2			.012	9.0	7.9		
Feb.				0.13		0.02			25.6				.035	9.0	7.4		
Mar.				1.10		1.08			23.9				.040	10.6	8.6		
Apr.	1411.91	1	0.10	0.65		0.45			42.4				.209	11.0	9.1		
May	1411.81	Estm'd	0.18	1.42		1.13			51.4				.287	11.1		8.9	
June	1411.63	14	0.24	2.54		1.84			66.8			69.0	.428	9.3		7.1	
July	1411.39	16	0.29	3.01		2.73			69.3			73.0	.418	8.6			5.3
Aug.	1411.10	11	0.14	3.89		3.34[7]			66.2			69.0	.386	9.0			
Sep.	1410.96	14	0.12	2.72		2.63			60.4			62.0	.286	8.7			5.1[6]
Oct.	1410.84	16	0.03	2.29		1.95			47.0			48.0	.156	10.0			6.2
Nov.	1410.81	2		0.48		0.25			29.9				.064	9.2			6.2
Dec.				0.09		0.05			20.0				.014	8.9			5.3
1932 Jan.			−0.33	0.35	2.04	0.55	1.94		7.4	16.8			.013	9.6			6.2
Feb.				0.40		0.65		0.29	10.5				.017	10.8			6.6
Mar.				0.72		0.44		0.76	16.0				.028	11.4			7.5
Apr.	1411.14	2	−0.10	2.58		2.51		2.32	41.8				.109	11.5			6.3

May	1411.24	13	0.05	2.24	2.55	2.30	54.6		55.0[5]	.280	10.7	6.4
June	1411.19	11	0.10	4.16	3.97	4.40	67.6	68.0	74.0	.279	8.5	5.3
July	1411.09	12	0.20	3.87	3.29	2.64	68.5	68.7	73.3	.377	8.2	4.5
Aug.	1410.89	12	0.33	1.22	0.20	1.35	67.6	68.4	72.3	.404	7.6	4.0
Sep.	1410.56	14	0.32	0.68	0.50	0.53	56.3	56.5	59.3	.302	8.6	5.4
Oct.	1410.24	11										
Biennium			1.34	38.03	33.17							

NOTES

1. Number of gage readings within four days or less to compute elev. Col. 2.
2. Weather Bureau Sta. is five miles northeast of lake. Lakewood is on north shore. Ft. Totten is on south shore of lake.
3. Water Temperature taken at lake shore twice daily in 1931, air and water by duo- thermograph in 1932. Air thermometer 6 ft. above water.
4. Computed on three daily rel. hum. readings ¼ (AM + 2N + PM).
5. Estimated from 19 days record during which average air temperature was 57.8°.
6. For Sept. 14-30, 1931.
7. Original amount 1.34″ abitrarily increased.

TABLE II

COMPUTATION OF MONTHLY EVAPORATION FROM DEVILS LAKE, NORTH DAKOTA, 1930-1932

1		2	3	4	5	6	7	8	9
Month		Change in W.S. Elev. Inches	Precip. Ave. of Two Sta. Inches	Apparent Evap. in E — I Inches	Saturation Deficit[1] (Sd) Ins. Hg.	Wind Vel.[2] 2′ Elev. M.p.h.	$\frac{E - I}{W}$	$\frac{E - I}{Sd}$	$E - I = \frac{Sd - 0.8}{.06}$
1930	Oct.	-1.92	2.06	0.14	.070	(6.1)	(0.02)	2.0	0.37
	Nov.				.058	(6.6)			0.17
	Dec.				.015	(5.4)			-0.55
1931	Jan.				.012	(5.5)			-0.60
	Feb.				.035	(5.5)			-0.22
	Mar.	-2.04	2.38	0.34	.040	(6.5)			-0.13
	Apr.	1.20	0.55	1.75	.209	(6.7)	(0.26)	8.4	2.68
	May	2.16	1.28	3.44	.287	(6.8)	(0.51)	12.0	3.98
	June	2.88	2.19	5.07	.428	(5.7)	(0.89)	11.8	6.33
	July	3.48	2.87	6.35	.418	5.3	1.20	15.2	6.17
	Aug.	1.68	3.62	5.30	.386	(5.5)	(0.96)	13.7	5.63
	Sep.	1.44	2.68	4.12	.286	5.1	0.81	14.4	3.97
	Oct.	0.36	2.12	2.48	.156	6.2	0.40	15.9	1.80
	Nov.				.064	6.2			0.27
	Dec.				.014	5.3			-0.57
1932	Jan.				.013	6.2			-0.58
	Feb.				.017	6.6			-0.52
	Mar.	-3.96	1.99	-1.97	.028	7.5			-0.33
	Apr.	-1.20	2.42	1.22	.109	6.3	0.19	11.2	1.03
	May	0.60	2.42	3.02	.280	6.4	0.47	10.8	3.87
	June	1.20	4.18	5.38	.279	5.3	1.01	19.3	3.85
	July	2.40	2.96	5.36	.377	4.5	1.19	14.2	5.48
	Aug.	3.96	0.78	4.74	.404	4.0	1.18	11.7	5.93
	Sep.	3.84	0.52	4.36	.302	5.4	0.81	14.4	4.23
Biennium		16.08	35.02	51.10	4.287				52.26

NOTE: [1]Saturation deficit is obtained on three daily relative humidity readings ¼ (AM + 2N + PM). at Weather Bureau.
[2]Parenthesis around computed wind velocities.

TABLE III

PERIODS OF EVAPORATION FROM DEVILS LAKE, NORTH DAKOTA, 1901 TO 1932

1	2	3	4	5		6	7	8	9	10
Date	Months	Precip. in Inches	Sum of Monthly Sat'n Deficits (Sd) Ins. Hg.	Water Surface Change Inches Up-	Down+	Obsd. E — I Inches	Computed E — I = 16.7 Sd −0.8 (in 1930-32) Inches	Seepage Compared to 1930-32	Excessive Rainfall[1] Inches	Accumulated Winter Precipitation[2] Inches
Jun. 7-Oct. 21, 1901	4.4	16.35	1.461		1.2	17.6	20.8			
Oct. 22-Apr. 30, 1902	6.3	4.39	.313	−6.6		−2.2	0.2			
May 1-Nov. 15, 1902	6.5	11.83	1.750		7.2	19.0	24.0	more		
Nov. 16-May 29, 1903	6.5	8.45	.478	−1.2		7.2	2.8	less		
May 30-Nov. 15, 1903	5.6	10.47	1.519		16.2	26.7	20.8	less		
Nov. 16-Apr. 24, 1904	5.3	5.85	.156	−10.8		−5.0	−1.6			3.6
Apr. 25-Nov. 29, 1904	7.2	16.38	1.495		0.6	17.0	19.1			
Nov. 30-Jul. 15, 1905	7.5	13.13	.886	−7.8		5.3	8.8	more		
Jul. 16-Nov. 29, 1905	4.5	5.61	1.039		10.2	15.8	13.7			
Nov. 30-Apr. 8, 1906	4.3	1.34	.118	−1.8		−0.5	−1.4			
Apr. 9-Nov. 16, 1906	7.3	11.61	1.916		14.4	26.0	26.1			
Nov. 17-May 7, 1907	5.7	6.08	.157	−9.0		−2.9	−2.0			4.2
May 8-Nov. 15, 1907	6.3	11.05	1.554		12.6	23.6	20.9			
Nov. 16-Apr. 21, 1908	5.2	4.32	.197	−4.8		−0.5	−0.9			3.3
Apr. 22-Aug. 29, 1908	4.3	7.49	1.297		12.0	19.5	18.2			
Aug. 30-Oct. 31, 1908	2.0	2.20	.476		6.0	8.2	6.3			
Nov. 1-Apr. 30, 1909	6.0	2.75	.195	−1.8		1.0	−1.6			
May 1-Oct. 31, 1909	6.0	15.74	1.802		4.1	19.8	25.2	more	2.6	
Nov. 1-Jun. 25, 1910	7.8	5.46	.925		4.1	9.6	9.2			
Jun. 26-Sep. 13, 1910	2.6	6.87	.941		10.4	17.3	13.6	less		
Sep. 14-Jul. 13, 1911	10.0	12.85	1.352		3.6	16.5	14.5			
Jul. 14-Sep. 30, 1911	2.6	9.50	.771		0.5	10.0	10.8			
Oct. 1-May 8, 1912	7.2	5.97	.439	−4.3		1.7	1.5			
May 9-Aug. 24, 1912	3.6	15.40	1.140	−10.6		4.8	16.1	more		
Aug. 25-Apr. 8, 1913	7.5	5.32	.605	−2.0		3.3	4.1			
Apr. 9-Oct. 31, 1913	6.8	11.32	1.859		14.4	25.7	25.6			
Nov. 1-Apr. 10, 1914	5.3	1.78	.198		0.6	2.4	−0.9			
Apr. 11-Nov. 2, 1914	6.7	14.86	2.038		9.8	24.7	28.6	more		

TABLE III—(Continued)

1	2	3	4	5		6	7	8	9	10
Date	Months	Precip. in Inches	Sum of Monthly Sat'n Deficits (Sd) Ins. Hg.	Water Surface Change Inches Up-	Down+	Obsd. E — I Inches	Computed E — I = 16.7 Sd −0.8 (in 1930-32) Inches	Seepage Compared to 1930-32	Excessive Rainfall[1] Inches	Accumulated Winter Precipitation[2] Inches
Nov. 3-Apr. 19, 1915	5.6	1.47	.255		1.2	2.7	−0.3			
Apr. 20-Oct. 2, 1915	5.4	12.68	1.528		10.8	23.5	21.2			
Oct. 3-Apr. 30, 1916	6.9	4.89	.370	−11.0		−6.1	0.7	more		
May 1-Nov. 5, 1916	6.2	14.03	1.818		9.6	23.6	25.3			
Nov. 6-Apr. 15, 1917	5.3	2.55	.147	−2.4		0.2	−1.8			
Apr. 16-Nov. 10, 1917	6.8	7.96	1.749		18.6	26.6	23.8			
Nov. 11-May 18, 1918	6.2	5.22	.432		1.2	6.4	2.2			
May 19-Oct. 7, 1918	4.6	10.61	1.369		8.4	19.0	19.1			
Oct. 8-Jun. 24, 1919	8.6	13.46	.945	−18.6		−5.1	8.9	more	4.1[3]	3.3
Jun. 25-Nov. 23, 1919	5.0	6.44	1.287		9.6	16.0	17.4			
Nov. 24-Jun. 22, 1920	7.0	7.98	.629	−4.8		3.2	4.9			
Jun. 23-Oct. 31, 1920	4.3	10.62	1.401		15.6	26.2	20.0	less		
Nov. 1-Jun. 30, 1921	8.0	10.26	.896	−6.0		4.3	8.5			
Jul. 1-Nov. 30, 1921	5.0	15.44	1.314		1.2	16.6	17.9		2.7	
Dec. 1-Jun. 25, 1922	6.8	8.30	.807	−7.2		1.1	8.0	more		
Jun. 26-Aug. 27, 1923	14.0	20.83	3.052		11.0	31.8	39.7	more		3.5
Aug. 28-Jun. 26, 1924	10.0	14.42	1.202		0.5	14.9	12.0			
June 27-Sep. 3, 1925	14.2	24.43	2.919		17.3	41.7	37.2			
Sep. 4-Sep. 7, 1926	12.1	16.73	1.982		14.4	31.1	23.3	less		
Sep. 8-Aug. 31, 1927	11.8	19.98	1.770			20.0	20.1			
Sep. 1-Jun. 19, 1928	9.6	10.53	1.102		10.6	21.1	10.7	less		
Jun. 20-May 30, 1929	11.4	16.01	1.692		6.8	22.8	19.1			
May 31-Aug. 10, 1929	2.3	8.85	.862		3.0	11.8	12.6			
Aug. 11-Oct. 1, 1930	13.7	19.94	2.692		11.2	31.1	33.9			
Oct. 1-Oct. 1, 1930-32	24.0	35.02	4.287		16.1	51.1	52.2			
	375.8	563.02	63.584	−110.7	295.0	747.2	759.1			

[1]At least 2½ inches a day average for two stations on watershed.
[2]From each winter monthly precipitation was subtracted a small assumed evaporation of 10 (Sd).
[3]Two day storm.

CONSERVE WATER, DAM IT!

An investigation was made during the summer of 1932 of the possibilities of water conservation by means of small dams. These projects were not solely for the benefits of swimming and boating and fishing which might be classified as luxuries. They contribute to the ground water table, tend to restore wells for drinking and stock water, provide refuges for wild fowl, and increase the humidity of immediately adjacent areas.

Professor Waldo E. Smith of the State College at Fargo was employed during the summer vacation to conduct these investigations.

It was immediately realized that the promotion of small dams by individual farmers was too large an undertaking, and in a sense unnecessary. Farmers did not need to be sold on the idea. Rather they wanted to be told how to do it. Western North Dakota is dotted with wrecks of ill-advised and unadvised attempts at dam building.

The circular included in this report was prepared and sent to applicants. Seven hundred copies have been distributed. Requests came from eighteen states and Alberta, Saskatchewan and Manitoba.

Concerning this work Gene Harrison, Editor of "American Game," Washington, D. C., said in a letter, September 30, 1932:

> "It may be of some use to you to know that we have played up you and your office in two or three newspaper stories going out to 2200 daily and weekly papers throughout the United States.

Mandan Dam

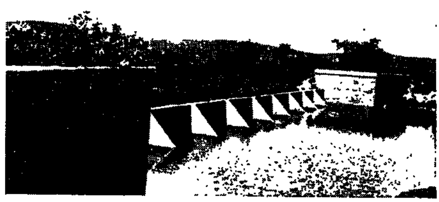
This is a dam made with a sandbag core covered with large boulders somewhat after the fashion of the design shown in Figure 2. It is not expected to be permanent. Its behavior will be watched with interest.

This cut is furnished by the courtesy of the NORTH DAKOTA STATE ENGINEER published by the students of the State Agricultural College at Fargo, North Dakota.

Walhalla Dam

A timber crib rock-filled structure across the Pembina River at Walhalla.

This cut is furnished by the courtesy of the NORTH DAKOTA STATE ENGINEER published by the students of the State Agricultural College at Fargo, North Dakota.



Reinforced Concrete Dam at Arrowwood Lake

This cut is furnished by the courtesy of the AMERICAN GAME, Washington, D. C.

We have also mentioned your work in our radio releases of fifteen minute talks to 220 stations that are using this material. Mr. Gordon has mentioned the work of your office in his magazine bulletin that is sent to twenty national and state outdoor magazines.

The work of your office has also been mentioned in releases to farm publications only, numbering forty. This latter is basic information which they are supposed to take and build their own stories upon. However, we find them frequently using it as received.

Undoubtedly the work of your office in connection with the 'Conserve Water—Dam It' campaign has received the greatest publicity of any wild life campaign in recent years. We find publications everywhere are using our releases regarding your work, and as you probably know, many newspapers are writing editorials commenting upon this splendid activity, and some going so far as to advocate that citizens of their states emulate this campaign and your work, which as I understand it, is the basis of the campaign."

Mr. Smith confined his attention to projects where a community organization was available. In organizing his work he first selected from the map 184 communities in the state which apparently could thus qualify and sent out letters to the Mayor or the Secretary of the Commercial Club inquiring if they were interested. He personally visited 171 of these communities. He also postered the state with 3000 placards.

CONSERVE WATER

DAM IT!

PUT A SMALL DAM ACROSS THAT NEARBY STREAM OR COULEE AND SAVE THE WATER THAT OTHERWISE RUNS AWAY.

BY DOING SO YOU MAY BE ABLE TO PROVIDE:

1. **WATER FOR SWIMMING, BOATING, FISHING AND SKATING.**
2. **WATER FOR FARM PURPOSES.**
3. **MORE GROUND WATER.**
4. **MORE WATER SURFACE FOR EVAPORATION.**
5. **WATER FOWL BREEDING AREAS.**

A SMALL EARTH DAM OR ROCK-FILL DAM PROPERLY LOCATED AND CONSTRUCTED COSTS LITTLE MORE THAN THE LABOR AND WILL FREQUENTLY GIVE SATISFACTORY SERVICE FOR YEARS.

SEND PROBLEMS ABOUT YOUR DAM TO STATE ENGINEER DEPARTMENT BISMARCK, N. DAK.

Two small survey parties, an instrument man with a plane table and a rodman in each party, began surveys of projects he approved.

Their progress was somewhat hampered by requests for aid from farmers, which were granted as far as possible.

The following list is a part of Mr. Smith's Report.

DAM SITES

Key:
Located.
*Located and Surveyed.
**Located, Surveyed, Report Submitted.
***Built according to Dept. Designs.

Town	County	Town	County
**Hannaford	Griggs	Cavalier	Pembina
***Strawberry Lake	McLean	Milton	Cavalier
*Golden Valley	Mercer	Edinburg	Walsh
*Stanton	Mercer	Maddock	Benson
*Hazen	Mercer	Harvey	Wells
*Zap	Mercer	Sheyenne	Eddy
Dodge	Dunn	New Rockford	Eddy
*Werner	Dunn	Fessenden	Wells
*Dunn Center	Dunn	Wing	Burleigh
*Manning	Dunn	Jamestown	Stutsman
*Gladstone	Stark	Hankinson	Richland
*Almont	Morton	Great Bend	Richland
New Salem	Morton	Mooreton	Richland
Shields	Grant	Milnor	Sargent
*Elgin	Grant	*Oakes (Ludden)	Dickey
*Regent (1st)	Hettinger	Berlin	La Moure
*Regent (2nd)	Hettinger	Dickey	La Moure
*Reeder	Adams	Montpelier	Stutsman
Haynes	Adams	Fullerton	Dickey
Ft. Yates	Sioux	Ellendale	Dickey
Lake Juanita		Forbes	Dickey
Blue Cloud Lake	Foster	Burnstad (Lake)	Logan
Grace City		Burnstad (Gulch)	Logan
(James River)		*Mandan	Morton
*Beach	Golden Valley	***New England	Hettinger
*Rhame	Bowman	(1929)	
**Watford City	McKenzie	***Silver Lake	Sargent
*Williston	Williams	(1931)	
Spring Brook	Williams	***Lisbon (concrete	Ransom
*Ray	Williams	facing 1929)	
*Tioga	Williams	***Crosby (1931)	Divide
*Noonan	Divide	***Arrowwood Lake	
*Mohall	Renville	(1931)	Stutsman
Mohall	Renville	***Jim Lake (1931)	Stutsman
Garrison	McLean	*Kenmare	Ward
Van Hook	Mountrail	***Walhalla (1931)	Pembina

DAM SITES—(Continued)

Town	County	Town	County
*Parshall	Mountrail	*Center	Oliver
*Washburn-Wilton	McLean	***Beulah (washed out)	Mercer
White Earth	Mountrail	Cooperstown	Griggs
Sherwood	Renville	Hope	Steele
Drake (recommendations made)	McHenry	Tolna	Nelson
Fordville	Walsh	Niagara	Grand Forks
Lankin	Walsh	Minto	Walsh
Hoople	Walsh	Aneta	Nelson
Pembina	Pembina	Warwick	Benson
Neche	Pembina	Larimore	Grand Forks

Please Pass This
on to a Friend

CONSTRUCTION OF SMALL DAMS

FOR

FARM

AND

Community Projects

STATE ENGINEER DEPARTMENT
Bismarck, N. Dak.
September, 1932

Page 77 is a blank page in the original report.

SMALL DAMS

Many small dams have been built in western North Dakota if one may judge from the wrecks and remains that dot the coulees and stream channels. Only a relatively few however have been so fortunately located and properly built as to stand for more than a few seasons. They were built largely without technical experience or special construction equipment. It is the purpose of this pamphlet to point out why they are apt to fail, where the present methods ordinarily used may be improved, and to encourage the construction of more dams.

Two types of dams are considered, the earth and the rock fill dam. The earth dam is described first (See Fig. 1). The following are five principle causes of failure together with their remedies.

Causes of Failure of Earth Dam

(1) Over Topping

By far the largest cause of failure of earth dams is an insufficient spillway to bypass the floods which therefore must go over the top of the dam.

The design of a spillway is decidedly an engineering problem but it can be side-stepped to a considerable extent by a proper selection of the site. (See Spillways.)

(2) Too Narrow a Bottom Width

Another cause of failure frequently observed is too narrow a bottom width thru the dam. Most people are more familiar with road embankments than with dams. But highways carry loads that press downward, whereas dams carry loads which push in a horizontal direction against a dam with the heaviest push at the bottom. The bottom width of a road embankment is about three times its height plus the top width. An earth dam should be at least five times its height plus the top width. Another criterion to observe is that the bottom width should be at least six times the depth of water to be stored behind the dam. This is to prevent excessive seepage.

All earth dams are porous. It is not to be expected that they stop absolutely all the water. They merely slow down the velocity of that small amount that does get thru to such an extent that it cannot dislodge and carry away the small particles of the soil of which the dam is made. The longer the base width the slower the velocity.

An indication of excess seepage is for it to show up on the downstream edge of the dam. If this occurs after the dam is built, erosion is apt to develop at this point which will eventually destroy the dam. To prevent this erosion to a large extent in event excessive seepage does develop it is desirable to place gravel and boulders in the toe of the slope as shown on the drawing, Fig. 1.

(3) Sod Under the Dam

Excessive seepage under an earth dam is frequently caused by failure to break up sod before building. This sod becomes a thin layer of fibrous material along which water will travel with comparative ease. The site should be plowed not as a field is plowed but rather by single plow furrows four or five feet apart along the long axis of the dam and at right angles to the direction of flow of the water. This will open up and allow fresh earth to come in contact with the new earth placed in the dam, and thereby in a sense key the dam to the foundation.

(4) Not Sufficient Packing and Tamping During Construction

Most small earth dams are built altogether too loosely. They are built too much like highway embankments, the earth merely hauled in and the top leveled off. Because earth dams are so porous at best anything done to make them more dense is a clear gain for permanence. They should be built up a layer at a time, only a foot or so thick, the earth spread and leveled out so that it can be packed and tamped by teams continually tramping over it. Much better if a heavy tractor with wide wheels could be driven back and forth across the dam as it is built up.

(5) Wave Action

Dams are sometimes destroyed by the action of the waves cutting away the top. This can be avoided by facing the dam with boulders carefully laid together. Willows are frequently used. They produce a fibrous root which discourages burrowing animals and offers some protection during brief overflow. They make it difficult to get to a break and make an emergency repair; which on the other hand, of course, is less likely to occur.

Spillways

Computation

The one thing most difficult to obtain for an "amateur dam" is a sufficiently large and safe spillway. A rough method for figuring the necessary size is here suggested. It will not be applicable in many places, but it will illustrate some of the conditions necessary for safety. It is based on the idea of making the cross sectional area in square feet, that is, the length times the depth, of the spillway equal to the cross sectional area of the largest known flood that went down the coulee in which the dam is to be built. From the observed high water marks on the banks or depths of water reported by observers figure the cross sectional area of the flood by measuring the distance across and multiplying that by the average depth. This is the amount the spillway will be called upon to carry away sometime at that critical period when the reservoir is full. The dam merely turns this flood thru the spillway.

Location

A most fortunate location for this spillway is a sag or saddle in the hill adjacent to the reservoir thru which the flood can flow out over prairie sod to another coulee. This assumes that the ground thru the saddle to the other coulee has about the same slope as that in the coulee to be dammed. Then the velocity of the water over either route would be about the same. The dam should be built up at least two feet above the elevation of the computed high water line thru the spillway.

An illustration will explain. The coulee to be dammed is, say, 300 feet wide and the largest known flood was on the average four feet deep. This may be obtained by stretching a line across from some observed high water mark such as a bunch of debris, small twigs, wisps of hay, or manure, and measuring down to the ground at frequent intervals and averaging the measurements. The cross sectional area of this flood then was 300x4 or 1200 square feet.

On one side of the coulee in the adjacent hill is a long sag or saddle, the bottom of which is practically flat for, say 500 feet, and is about 10 feet above the average bottom of the coulee in which the dam is to be built. Then to get a flood whose cross section is 1200 square feet thru this spillway whose bottom is 500 feet wide the depth of water must be about 2½ feet deep (1200 square feet divided by 500 feet). But in order to provide protection to the dam from waves while this flood is on, as well as from floods larger than figured, the top of the dam should be another two feet above this computed high water line, or 4½ feet above the bottom of the spillway and 14½ feet above the bottom of the coulee being dammed. Then the dam would be 14½ feet high.

There is one exception that might be noted. In case the pond created by the dam spreads out over the banks and is much wider than the channel being dammed, part of the incoming flood is first temporarily stored over the pond while the other part gets away thru the spillway. Then the stored part follows thru and it all eventually gets away. For this situation the spillway need not be made so large. But it is on the side of safety as well as easy computation to ignore this ponding effect and make the spillway large enough to take care of all the flood.

Excavated Spillways

It is usually necessary to excavate a spillway to meet these requirements. Then a hazard is introduced which frequently proves the undoing of the project. The spillway is usually given such a steep slope that once the water starts to flow thru it a cutting erosion develops and in a short time the entire stream is going thru the spillway and the dam is left high and dry. This is especially liable to occur if the spillway is cut around the end of the dam and back into the same coulee in which the dam is built.

This type of spillway requires expensive construction to be made safe. It is much better if possible to locate the dam farther upstream where the flood run-off is not likely to be so great at a point, say, only two miles or so from the head waters on the divide. Here the drawback, of course, is that the reservoir will be empty more of the time, but the dam will be safer. It may be built up two or three feet above the side of the channel. The flood water will then overflow the banks, run out into the adjacent field, and automatically irrigate it.

Culvert Spillways

Many small dams are protected by merely a pipe or box culvert thru the dam near the top. For a small dam near the divide it has proven successful. However another hazard is introduced. Water has a persistent tendency to seep along the under side of such a pipe or culvert because of the difficulty of tamping earth under it uniformly and firmly. To avoid this a concrete head wall and concrete collars have given the best results. The end must extend well beyond the downstream toe of the slope. Thoro and careful tamping along the entire length is very essential.

Outflow Pipes

If the pond is to be used as a reservoir, and water is to be withdrawn from time to time, a pipe may be placed *in the bottom of the dam.* This is a still more hazardous location because of the greater and more continuous water pressure. The valve is located preferably at the upper end. A trestle, similar to a small dock, must be built out to the valve stem to provide for the operation of the valve when the water is behind the dam.

Foundation

The principle foundation material to avoid is sand. Most any other material is suitable. Dig a hole and see what is underneath. If the sand is not deep it might be scraped off or a trench along the proposed center line may be dug down to expose better material and provide a contact with the dam.

Construction

Staking out the Site

A much better looking dam will be obtained if a little pains are taken to lay out on the ground just where the edges of the dam are to be. A small dam may be staked out without a surveying instrument. Stretch a line horizontally between the banks where the dam is to be built at about where the top edge of the dam on the water side will come.

Measure down to the ground at frequent points, say twenty feet apart, and drive a temporary stake. Figure the base width of the dam from the vertical distance down from the line to the ground. If it is 15 feet down, then measure three times this height or 45 feet upstream and drive a stake for the upstream edge of the dam. Then measure downstream a distance equal to the top width of 10 feet plus two times the height of 15 feet or 40 feet and drive a stake. That is the downstream toe of the dam. These stakes are easily lost in construction but if a furrow is plowed from stake to stake the outline of the dam will be more permanent.

Preparing the Site

Remove all brush, rocks, debris and rubbish. Plow the site as directed in (3) above. If ends of dam are to be placed against bare, cut bank where no sod exists scrape away outer soil till firm moist earth is exposed.

Construction

Material suitable for construction is most any type of soil but pure sand. Pure gumbo has a tendency to shrink and open up large cracks but once packed will not easily erode when temporarily overtopped. At all times tamp and roll and pack. Too much is not possible, too little is very often done. Make special effort to tamp well around ends of the dam against the bank. Construction procedure is described under (4) above.

Do not use manure, rock, and brush, straw and junk in one conglomerate mass. It is not successful. Do not plant trees on the downstream side. The roots will go thru to the water on the upstream side, thereby encouraging seepage.

ROCK FILL DAMS

Where an abundance of field stones and boulders is available a rock fill dam has the advantage over an earth dam in that it can be overtopped and in that sense be its own spillway. In many places they are much less likely to wash out than an earth dam. They are suitable where a small dam is desired in a creek or small river where some water is flowing. They can be constructed in the water and built up, while the water flows thru the spaces between the boulders. When the desired height is reached and the downstream slope completed, the dam may be made water tight by building up several layers of sand bags (burlap sacks half filled preferably with clay soil) on the upstream side against the dam. Then an earth fill must be placed against the sacks, not only to tighten up the small cracks between the sacks but more especially to lengthen the path of percolation and seepage under the dam. (See Fig. 2.)

Weak Points in a Rock Fill Dam

A rock filled dam needs careful attention in three places, where the water goes under the dam, over the dam, and to prevent it going around the ends.

Seepage Under Dam

There is usually more or less sand in a creek bed. It often happens that when the water begins to rise a few feet behind the dam little boils develop in the creek bottom below the dam and the water will be seen throwing up little turbulent cones of sand. That water is coming thru from above the dam and traveling along a sort of pipe which it has formed thru the sand under the dam. The sand is coming from under the dam itself. It will be only a question of a few hours before those "pipes" will develop into a large hole and the dam is destroyed. The remedy is to fill in upstream with dirt until those little cones cease boiling, or muddy water ceases coming from under the dam. This earth fill upstream lengthens the distance the water must travel. The farther it has to go the slower is the velocity because of the greater amount of friction en route.

Rolling Off Top Boulders

The effect of high water over a rock fill dam is to roll off the top layer of boulders and move them downstream. There is no infallible remedy for this so long as the boulders are loosely laid together. The best thing to do it to make the dam very wide and flat and not very high as shown in the sketch, Fig. 2. Four feet in height is about the maximum. With the additional expense of a little concrete a plaster coat around the boulders of the top layer will hold them together and make the dam more permanent.

Abutments

The water in passing a dam sets up turbulences at each end along the creek bank, which erode away the earth and unless special protection is provided the entire stream will soon be going around one end or the other.

A U-shaped abutment similar to that used for the approach to a bridge is the most satisfactory. The bottom of the abutments should be even with the bottom of the dam. The wings should extend into the bank a distance at least three times the height of the dam. They should be at least one-half again as high as the dam and should be as wide as the dam is up and downstream.

A good way is to excavate a wide trench into the bank for the two wings and fill it with boulders to the natural surface. The part facing the dam should then be laid up by hand on the same slope as that of the river bank.

Concrete Covered Rock Fill Dam

If concrete materials are available quite a permanent structure can be made of a rock fill dam by covering it over the outside with a plaster coat of concrete. (See Fig. 3.) The shape can also be modified to save the labor of hauling so many boulders.

The concrete should be mixed with only enough water to make it plaster well so it can be troweled in around the outer layer of boulders which are first stacked up carefully by hand to the shape and cross section shown.

If this type is to be placed in a stream channel the water must first be dammed off just upstream with a temporary earth dam, in order to give the concrete time to set. This earth dam may then be extended downstream and become a part of the permanent dam.

This type of dam was built at New England, North Dakota. It is seven feet high and 105 feet long. In dams of that height a reinforcing steel mesh and a good quality concrete at least six inches thick is necessary.

Cut-off Walls

For dams over four feet a cut-off wall should be constructed as an extra precaution against seepage which might work down between the fresh earth fill and the dam before the earth becomes settled.

In clay soils this cut-off wall need be only half the height of the dam. But in very sandy soil the wall should go down twice the height of the dam. For a seven foot dam this is possible only with a pile driver. The piling should be 3x12 plank, 20 feet long, driven carefully and tightly edge to edge. Tongue and groove is not necessary if the driving is done carefully between two pair of guides, one near the ground and the other about five feet off the ground. This is a technical job and rather beyond the ordinary layman. If this type of dam is contemplated, engineering advice is necessary.

However, if a low dam is to be built on a clay foundation, the construction of a cut-off wall is simple. The trench is dug wide enough to permit the building of a cut-off wall like a very tight board fence of one inch material and extending up to within a foot and a half or so of the top of the dam. The earth must be tamped back along the boards as firmly as one would tamp earth around a post or puddled in with water if available. This wall is located under the upstream edge of the dam and extended into the banks to the end of wing walls. This lumber will not rot if it becomes water soaked and remains that way.

Rock Filled Timber Crib Dam

A cheaper but also more temporary type of dam may be constructed by building wooden cribs of 2x6 boards laid flatwise in log cabin fashion with long rods through the corners. (See Fig. 4.) These 2x6 are usually spaced about six inches apart. The crib is about 16 feet long, 8 feet wide and four or five feet high tied thru the middle to make two compartments eight feet square. It is built upon a platform with ten feet of the platform extending downstream for an apron. The crib is placed next to the cut-off wall as shown on Fig. 4, and boarded up tightly on the upstream side. Abutments may be made in the same manner and sheeted up on the inside with two inch lumber. The abutments should also be sheeted to the top on the upstream face. These cribs should be covered to save fish from getting caught in the boulders in the crib in high water and dying. This is not a very permanent type of construction because the lumber is subject to alternate wetting and drying and hence rots quickly. Creosoted timber makes the cost approach that of the concrete covered type.

Theory of Small Dams

There are numerous variations of the above types of small dams. If something of the theory of a dam is understood changes can be made with more confidence. In theory these dams consist essentially of only two parts best illustrated in the rock fill dam. One part stops the water (that is, most of it) and the other part supplies the weight. The rock supplies the weight, the upstream wall of sacks or concrete or timber cuts off the water from going thru between the rocks and the wide upstream fill of earth or the wooden cut-off wall in the ground so lengthens the path under the dam that the percolating water cannot develop transporting velocities.

The earth dam works in the same way, only the dividing line in a small dam between the weight part and the water-stopping part is not so well marked.

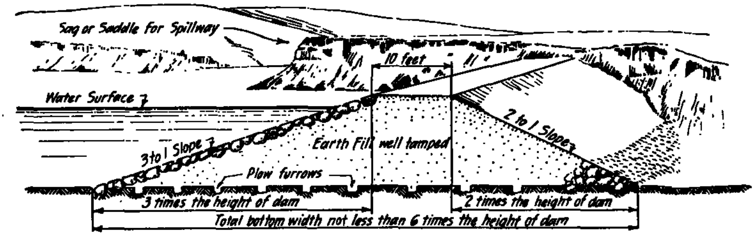


FIG. 1. CROSS SECTION OF EARTH DAM.

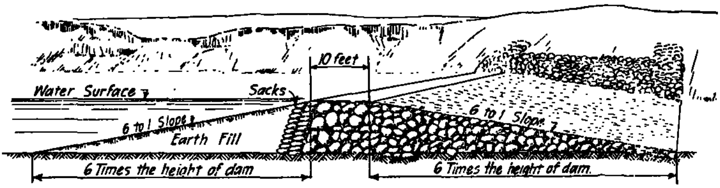


FIG. 2. CROSS SECTION OF ROCK FILLED DAM.

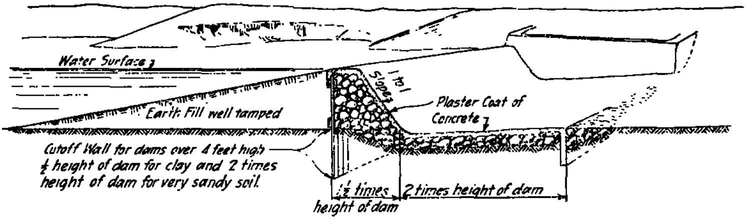


FIG. 3. CROSS SECTION OF CONCRETE COVERED ROCK FILL DAM.

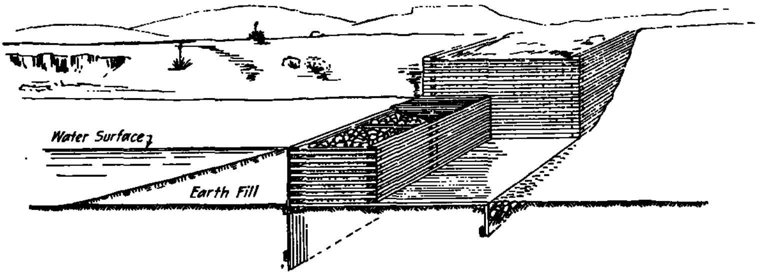


FIG. 4. CROSS SECTION OF ROCK FILLED TIMBER CRIB DAM.

LOWER YELLOWSTONE IRRIGATION PROJECT

The Lower Yellowstone Federal Reclamation Project comprises an irrigable area of about 59,000 acres. Approximately two-thirds of this area is in Montana and one-third in North Dakota. The project is served by a main canal, 71 miles long, having its intake from the Yellowstone River about 17 miles below Glendive. Other irrigation works comprise approximately 250 miles of laterals and about 100 miles of drainage ditches. Over 3000 structures are required to control and distribute the water. These consist of syphons, flumes, checks, drops, turnouts, bridges, etc.

The irrigated area in North Dakota is composed of approximately 15,000 acres of productive land and 5000 acres of temporarily unproductive land, so classified by reason of damage from seepage or from brush and timber covering. This land will pass into the productive list whenever changed conditions make it productive.

The Project was operated by the Federal Government until the end of 1931 when the management of the system was turned over to the water users. There are two irrigation districts on the project: Lower Yellowstone Irrigation District No. 1, covering the lands of Montana, and Lower Yellowstone Irrigation District No. 2, covering the lands in North Dakota. Mr. John A. Bird, Fairview, Montana, is secretary of the District No. 2.

No bonds have been sold by either District, the original cost being financed by the Federal Government and the operation and maintenance cost being financed by direct assessment of the lands under the project. So far the districts have been able to keep their payments on a cash basis.

The area irrigated and the per acre cost of water for the last three years is as follows:

Year	Area Irrigated	Ave. Const. Repayment	Operation & Maintenance	Total
1930	9,214	$1.45	$1.15	$2.60
1931	9,783	1.45*	1.15	2.60
1932	9,454	1.50*	1.15	2.65

*A relief Act of Congress deferred all of the 1931 and one-half of the 1932 charges to the end of the contract period.

Following is a comparison of the per acre returns from irrigated crops and dry-farmed crops within the State of North Dakota:

Year	Irrigated Crop	Dry-Farmed Crop
1930	$28.28	$ 4.94
1931	25.62	(Failure)
1932	20.56	2.73

Sugar beets are becoming the leading crop with alfalfa, barley and corn filling out the forage crops necessary to make proper use of the beet by-products. Feeding operations are increasing each year and in 1932 about 100,000 lambs were fed for market. With the large quantity of feed that is available, most of these lambs are placed on the market in top condition and provide a method of disposing of crops for much better prices than can be obtained under present market conditions.

A sugar factory at Sidney, handles all of the beets raised on the project. During 1932 over 9000 acres produced approximately 123,000 tons of beets. The down payment for this crop amounted to $550,000 and it is expected that there will be a substantial further payment after the sugar is sold. Sugar beets and resultant feeding operations are the only lines in which farmers are realizing more than the cost of production during the present economic conditions.

Respectfully submitted,
H. A. Parker,
Project Manager.

Sidney, Montana.
January 20, 1933.

THE MISSOURI RIVER DIVERSION IN NORTH DAKOTA

This project is probably the most stupendous and the most widely advertised engineering project ever proposed in North Dakota.

This Missouri River thru the Dakotas is a mighty river, far larger than any in neighboring states. It had a discharge of 201,600 cubic feet per second, March 24, 1928, a maximum which will no doubt be exceeded as the record is continued. Its ordinary low water flow during the ice-covered season is from five to ten thousand second-feet.

In the eastern part of the Dakotas are lakes and streams and cities which thirst with longing eyes for only a small and negligible proportion of this mighty volume.

But when the schemes so far proposed have been reduced to engineering terms they have been mainly a disappointment. The evolution of the ideas as conceived and abandoned is somewhat as follows:

Scheme	Why Abandoned
(1) A canal from the Missouri River.	Cannal would be over 200 miles long.
(2) A tunnel from the normal water level at Big Bend near Garrison.	Tunnel would be about 45 miles long to reach headwaters of Sheyenne River.
(3) High dam at Big Bend for storage of water for navigation and flood control on the lower Missouri River. Diversion tunnel shortened to about 20 miles.	(a) Diversion tunnel abandoned in favor of pumping by hydro-electric power produced. (b) Entire scheme found impossible because of unsufficient foundation for high dam.
(4) Pumping by local lignite-electric power.	

The following data will reveal the controlling features:

Topographical Data

Low water in Missouri River at Big Bend	1675 feet sea level
Water surface Devils Lake 1932	1410 feet sea level
Difference	265 feet sea level
Lowest elevation of saddle in Coteau immediately east of Missouri River	2000 feet sea level
Elevation above Missouri River	325 feet
Width of Coteau	40 miles
Distance air line between Missouri River and Devils Lake	100 miles
Distance by river channels approximately	150 miles
Elevation low water surface in Sheyenne River south of Flora	1424 feet sea level
Elevation of divide between Sheyenne River and Devils Lake	1550 feet sea level
Elevation of ground in West Bay three miles south of Minnewaukan	1430 feet sea level
Distance from Sheyenne River to West Bay thru Peterson Draw, Stony and Long Lakes	14 miles

A report on Scheme No. 3 above was made by this Department December 1, 1927. Some of the principle features are as follows:

Proposed Dam

The dam was to be of earth, 175 feet high and 11,000 feet long with a concrete spillway the width of the low water channel 1500 feet. Rough cost estimate 47½ million dollars.

Reservoir

The reservoir would be 140 miles long and contain 14,300,000 acre-feet. The high water elevation would submerge the roadway of the Elbowoods bridge 40 feet and that of the Sanish bridge 8 feet. It would submerge much of the little Muddy River valley at Williston and come within fifteen feet in elevation of the G. N. Railroad Depot.

Purpose

The primary purpose would be to regulate the river for benefit of navigation by increasing the low water flow and reducing floods. Secondary purpose would be production of power to pump water over the Coteau for replenishing lakes and streams in eastern North and South Dakota for municipal water supply and sewage dilution.

Foundation

The site of the proposed dam was investigated with deep test holes in the spring of 1932 by the Corps of Engineer U. S. Army. Local engineers who visited the operations, as bystanders only, and saw the cores obtained are of the unanimous opinion that the foundation material revealed is entirely inadequate for the size of dam proposed. Suitable stratum on the west side of the river was found too deep to be reached by present engineering methods of foundation construction. It was covered with several hundred feet of plastic clay which was very hydroscopic, had no structure, and came out of the hole as plain mud.

Washburn Bridge

A bridge about three miles above the proposed dam site was approved by the Acting Chief Engineer of the Corps of Engineers U. S. Army, June 2, 1932, and by the Assistant Secretary of War, June 4, 1932. The top of this bridge would be about 80 feet under water if the dam were built.

The inference is that the Corps of Engineers U. S. Army does not consider the dam feasible at least within the lifetime of the proposed bridge.

Alternative

It is not a function of a department of the State of North Dakota to search the Missouri River in North and South Dakota and Montana and elsewhere for reservoir sites with which to beneficially control the river between Kansas City and St. Louis.

The project as it now stands cannot be tied in with the national problems of navigation and flood control. It is purely a local undertaking.

Financial Statement

Status of budget at the end of the biennium, June 30, 1931:

	Present Budget	Total Expenditures	Balance
Salary, State Engineer	$ 6,000.00	$ 6,000.00	
Clerkhire, stenographic	2,700.00	2,970.00	
*From Mo. R. Com.	270.00		
Postage	100.00	10.25	89.75
Office Supplies	100.00	100.00	
Furniture & Fixtures	100.00	125.00	
**Furniture & Fix. (Cont'g)	25.00		
Printing	300.00	102.00	198.00
Miscellaneous	300.00	300.00	
Travel Expense	3,000.00	3,300.00	
*From Mo. R. Com.	300.00		
Field Assistants	3,000.00	3,375.00	
*From Mo. R. Com.	300.00		
**Field Ass't. (Cont'g)	75.00		
Hydrographic Survey	2,000.00	2,200.00	
*From Mo. R. Com.	200.00		
Missouri River Commission	3,600.00	1,621.50	908.50
To various funds	−1,070.00		
Flood Irrigation	2,954.41	2,403.32	551.09
General Prior	1,462.10	1,462.10	
Fire Contingent Fund	7,300.00	7,300.00	
Total	$34,086.51	$31,269.17	$ 1,747.34

*Transferred by consent of Emergency Commission, from Missouri River Commission.

**Fire Replacement Fund of Emergency Commission.

Distribution of expenditures for the last quarter of the biennium period ending June 30, 1931.

Principal Feature	This quarter	To date	Gen'l. Exp. & Deprec'n.	Final to date
Miscellaneous Examinations				
and Surveys	112.95	2,048.07	383.00	2,431.07
Irrigation		108.59		108.59
Hydrometry	640.71	3,546.72	665.00	4,211.72
Flood Control	72.00	298.56		298.56
River & Lake Improvement	1,803.98	8,033.41	1,532.00	9,565.41
Topographic Surveys		2,179.24	409.43	2,588.67
Meteorology	369.24	4,113.48	842.60	4,956.08
Subtotal	2,998.88	20,328.07	3,832.03	24,160.10

Undistributed Expenditures

Unconsumed General Expense	483.30	4,052.03	
New Equipment	214.70	1,391.32	1,391.32
Field Notes & Twp. Plats	5,717.75	5,717.75	5,717.75
Depreciation		-220.00	
Total	9,414.63	31,269.17	31,269.17

Total appropriation	$25,616.51
Fire Replacement Contingency Fund	7,400.00
Total appropriation	$33,016.51
Balance to date	1,747.34

Status of budget on June 30, 1932.

	Present Budget	Total Expenditures	Balance
Salary, State Engineer	$ 6,000.00	$ 3,000.00	$ 3,000.00
Clerkhire, stenographic	2,700.00	920.00	1,780.00
Postage	100.00	45.52	54.48
Office Supplies	400.00	238.19	161.81
Furniture & Fixtures	100.00	22.75	77.25
Printing	300.00	73.50	226.50
Miscellaneous	500.00	270.63	229.37
Travel Expense	3,000.00	2,353.34	646.66
Field Assistants	3,000.00	2,192.03	807.97
Hydrographic Survey	6,000.00	1,613.13	4,386.87
Missouri River Commission	5,000.00	1,209.06	3,790.94
Lake Conservation	7,000.00	6,783.67	216.33
Flood Irrigation	551.09		551.09
General Prior	1,196.25	963.57	232.68
Fire Contingent Fund	1,636.60	1,361.53	275.07
Total	$37,483.94	$21,046.92	$16,437.02

Distribution of expenditures for the quarter ending June 30, 1932.

Principal Feature	This quarter	To date
Miscellaneous Examinations and Surveys	148.57	1,063.99
Irrigation	58.29	341.28
Hydrometry	652.88	3,261.35
Flood Control	40.29	246.11
River & Lake Improvement	2,174.16	12,846.28
Topographic Survey		
Meteorology		
Subtotal	3,074.19	17,759.01

Undistributed Expenditures

Office Operation	56.61	360.55
14th Biennial Report		407.02
15th Biennial Report	12.23	12.23
Equipment	62.48	9,123.47
1931-32 Vacations	47.10	149.06
St. Engr. Convention		378.03
Sick Leave	23.78	23.78
Total withdrawn from appropriation	3,276.39	28,213.15
*Old Equipment		7,166.23
Total Payments		21,046.92

Total appropriation	$37,483.94
Expenditures to date	21,046.92
Balance to date	$16,437.02

*Equipment and Field Notes and Township Plats from previous Biennium.

BUDGET REDUCTIONS

	Present 1931-33 Budget	BUDGET FOR 1933 - 1935 Requested by Department	Suggested by Budget Board	Passed by Legislature	Signed by Governor
Salary, State Engineer:					
Biennium	$6,000.00	$5,400.00	$4,800.00	$3,840.00	$3,840.00
(Monthly rate)	(250.00)	(225.00)	(200.00)	(160.00)	(160.00)
Clerkhire:					
Biennium	2,700.00	2,400.00	2,160.00	500.00	500.00
(Monthly rate, chief stenographer)	(80.00)				
(Part time stenographers)	(75.00)				
Postage	100.00	100.00	100.00	100.00	100.00
Office Supplies	400.00	400.00	400.00	200.00	200.00
Furniture & Fixtures	100.00	100.00	100.00	100.00	100.00
Printing	300.00	300.00	300.00	200.00	200.00
Miscellaneous	500.00	500.00	500.00	400.00	400.00
Travel Expense	3,000.00	2,500.00	2,000.00	1,500.00	1,500.00
Items not included above:					
Field Assistants	3,000.00	3,000.00	2,400.00	1,200.00	
Hydrographic Survey	6,000.00	6,000.00	5,000.00	4,000.00	
Missouri River Comm.	5,000.00				
Lake Conservation	7,000.00				
Flood Irrigation	551.09				
General Prior	1,196.25				
Fire Contingent Fund	1,636.60				
Total	$37,483.94	$20,700.00	$17,760.00	$12,040.00	$6,840.00

Similarly drastic reduction was made by the Governor in nearly every department of the state government and institutions in an endeavor to bring the state's expenses within its probable income as reduced by the anticipated referendum of certain revenue measures.

This department will endeavor to maintain stream measuring stations where the observers can be induced to serve without pay or where a local organization interested in a continuous record will finance the daily observations, a matter of from $40.00 to $120.00 a year.

STREAM FLOW RECORDS

The following is a list of the North Dakota rivers and lake gaging stations being operated by the Helena, Montana, office of the U. S. Geological Survey maintained in cooperation with State of North Dakota:

Missouri River at Williston
Missouri River at Bismarck
Little Missouri River at Medora
Little Muddy River near Williston
Knife River at Hazen
Heart River at Sunny
Cannonball River near Timmer
James River at Jamestown

The following is a list of the North Dakota rivers and lake gaging stations being operated by the St. Paul, Minnesota, office of the U. S. Geological Survey:

Stations maintained in cooperation with State of North Dakota:
Bois des Sioux near Fairmount
Wild Rice River near Abercrombie
Sheyenne River at Sheyenne
Sheyenne River at West Fargo
Goose River at Hillsboro
Forest River near Minto
Park River at Grafton
Souris River at Minot
Devils Lake
Lake Upsilon
Lake Metigoshe

Stations maintained by funds transferred from U. S. Department of State:

Red River at Fargo
Red River at Grand Forks
Pembina River at Neche
Souris (Mouse) River near Sherwood
Souris (Mouse) River near Westhope

Gages installed in November, 1932, in cooperation with U. S. Army Engineers, St. Paul, office in connection with their study on Mouse River:

Souris (Mouse) River at Burlington
Souris (Mouse) River near Carpio
Souris (Mouse) River near Denbigh
Souris (Mouse) River at Logan near Minot
Souris (Mouse) River at McKinney
Souris (Mouse) River at Saugstad's Bridge near Minot
Souris (Mouse) River at Sawyer

Souris (Mouse) River at Towner
Souris (Mouse) River near Upham
Souris (Mouse) River at Velva
Souris (Mouse) River at Vastetlen Bridge near Verendrye

It is proposed to secure gage readings only at these gages except possibly at the Towner gage at which station an attempt may be made to obtain the discharge rating.

Additional information concerning any of these stations may be obtained from:

Mr. N. C. Grover, Chief Hydraulic Engineer, Washington, D. C., who is in charge of the Water Resources Branch of the U. S. Geological Survey, or to either of the following:

Mr. W. A. Lamb, District Engineer, U. S. Geological Survey, Helena, Montana.

Mr. Chas. L. Batchelder, District Engineer, U. S. Geological Survey, 632 State Office Building, St. Paul, Minnesota.