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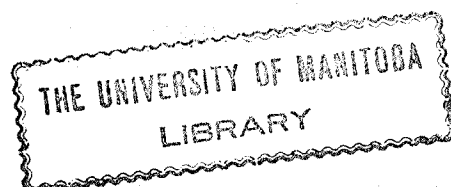
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SEASONAL VARIATIONS IN THE COMPOSITION
OF THE RED RIVER.

BY G. WARD, B.Sc.

Presented in partial fulfillment of the
requirements for the Master of Science
Degree in the University of Manitoba.

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VALLEY OF THE RED RIVER OF THE NORTH.

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OF THE RED RIVER.

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THE GEOGRAPHIC LOCATION OF THE RED RIVER SYSTEM.

(1)
The Red River formerly known as the Red River of the North, is formed by the union of two branches, the Ottertail River which flows from a small lake in Minnesota, and the Bois des Sioux River, the outlet of Lake Traverse, on the boundary line between Minnesota and North Dakota. The two streams unite at Breckenridge, Minn., and from that point the Red River flows northward and enters Lake Winnipeg

(2)
The various tributaries as one descends the river have, for the most part, a drainage basin of from 40 to 75 miles in length, excepting the Red Lake, the Sheyenne, the Pembina, and the Assiniboine. The drainage basins of these four rivers are of considerable extent and the character of the water carried exerts a decided influence upon the Red River. In summer droughts, several of these tributaries excepting the four mentioned, are dried up along the greater part of their course. (3)
The stage of rivers whether in partial flood or at the level of seasons of drought decides to a large extent whether the dissolved ingredients are little or much. The amount of fine sand or clayey mud borne along mechanically suspended in the water of the rivers is vastly increased by their rise and stronger currents in time of flood, but dissolved matter is much less at

1. Clarke, F.W., Prof. Paper, U.S. Geol. Surv., No. 135, 1924
2. Upham, Warren The Glacial Lake Agassiz, U.S. Geol. Surv., 1895.
3. Upham, Warren, The Glacial Lake Aggasiz, U.S. Geol. Surv., 1895.

(2)

flood time!" Such is to be expected and must be borne in mind when considering the influence of the various tributaries.

In connexion with this work the geology of the Red River Valley should first be described.

(4)

"The lowest portions of this valley consist of stony clay with much gravel at the base and boulders and stones scattered thru-out. The stones are from various formations, but about 75% seems to belong to the Winnipeg limestone; the rest are granitic. This vast clayey deposit of unmodified drift rises to the surface around the margin of the valley and spreads out in extensive flats on both sides of the river. It is essentially and typically a glacier deposit, its various aspects being due to the agency of water, present at the time of deposition, and either running with considerable current so as to wash out the clay and make stratified gravels and sands within the mass; or in the form of standing water, by which the clayey parts were retained and the whole spread out with a smooth upper surface, without much modification of structure."

In brief, the drift contains much carbonate and sulphate of calcium and magnesium derived from Cretaceous strata, which covered this area and was ploughed up by the ice-sheet, mixed with much drift from the region of granite, gneiss and crystalline schist on the northeast and deposited as till.

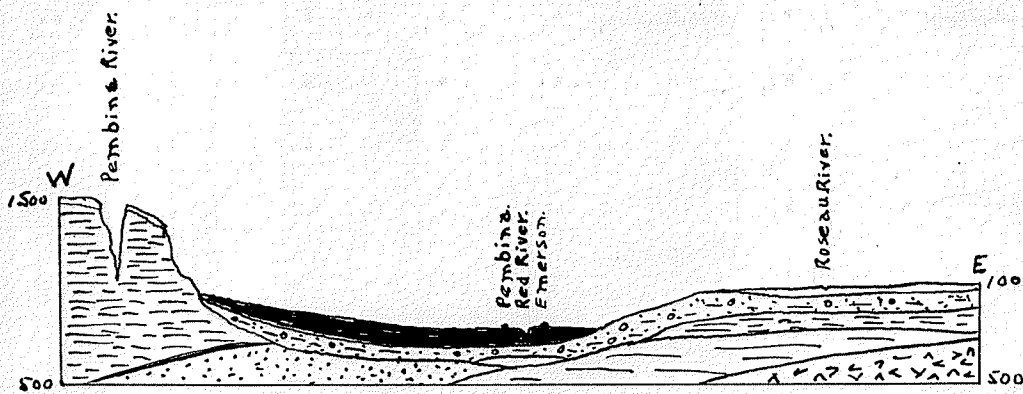
"After this drift clay was deposited there was for a long period of time, a large body of fresh water, (Lake Agassiz), standing over the whole valley, which had an outlet toward the south by way of

(4) Winchell, N.H., The Water Supply of the Red River Valley.

Annual Report, University of Minnesota, for the year 1878.

the Minnesota Valley and the Mississippi River. The fine deposits which it spread widely during the time of its higher stages were withdrawn by the receding beach-line during times of its shrinkage and partial discharge northward.

It was the water of this lake, during the period of agitation and instability that produced the next noteworthy member of the drift deposits in the Red River Valley. This is a layer of sand and gravel sometimes containing fresh water shells in abundance, which nearly everywhere underlies the lacustrine clay and affords water. This is sometimes several feet thick. It lies directly on the upper surface of the boulder clay, but it does not extend generally over that surface where the lacustrine clay is wanting.



Section across the Red River at the International Boundary (7).

- | | |
|---|----------------------------------|
|  | Modified drift, sand and gravel. |
|  | Lacustrine clay. |
|  | Till. |
|  | Gravel. |
|  | Cretaceous shale. |
|  | Dakota sandstone. |
|  | Upper and lower Silurian. |
|  | Archean. |

(7) Upham, Warren, Glacial Lake Agassiz, U.S. Geol. Surv. 1895.

The lacustrine clay is horizontally stratified and contains no stones (at least none have been seen), nor gravel. It is fine and close, of yellowish color and at considerable depths is bluish. It contains less "alkali" than the drift clay. Its special location is along the river covering a belt on either side and widening east and west up the tributary valleys".

Pleistocene clays in Minnesota and North Dakota overlie the Paleozoic limestone to an extent of from 125 feet to 300 feet ⁽⁵⁾; whereas in Manitoba in the vicinity of Winnipeg the thickness is approximately 60 feet ⁽⁶⁾. The drift clays increase in thickness as one goes south and the lacustrine clays decrease.

From a study of the water derived from the various strata it is learned that the drift clay affords a water that is strongly alkaline, while the lacustrine clay produces a water that is slightly alkaline or non-alkaline.

THE CLIMATE OF THE RED RIVER VALLEY.

The climate of the basin is that of the northern half of the temperate zone, with cold winters and warm summers; and the alternation of freezing and thawing helps to disintegrate the rock and soil rendering them more easily decomposed by percolating waters. The snowfall over the area is medium, that is, an average of two feet over the entire valley, and the freshets due to the spring thaws carry away much of the water as mere surface run-off, which has taken up a little saline matter.

(5) Upham, Warren, The Glacial Lake Agassiz, U.S. Geol. Surv., 1895.

(6) Wallace, R.C., The Geological Formations of Manitoba, The Natural History Society of Manitoba.

THE COLLECTION OF SAMPLES.

One winchester was sent to each of the various points of collection, with a request that they be filled at the end of each month. The following points complied with this request.

- (1) Wahpeton, N.D., collected through the courtesy of L.H. Dominick, Superintendent of Schools.
- (2) Grand Forks, N.D., Professors A.G. Leonard and E.F. Chandler assisted at this point.
- (3) Red Lake River at Grand Forks, N.D., also collected through the courtesy of Professors A.G. Leonard and E.F. Chandler.
- (4) Pembina River at Pembina, N.D., C.D. Curtis, Superintendent of Schools, collected and forwarded the samples.
- (5) Emerson, Man., obtained through the kindness of G. White Superintendent of Schools.
- (6) River Park, Man., collected by G. Ward.
- (7) Kildonan Park, " " " "
- (8) Mouth of the Assiniboine River, Winnipeg, collected by G. Ward.
- (9) La Salle River, St. Norbert, Man., " " " "
- (10) Selkirk, Man., Collect through the courtesy
- (11) Mouth of the Red River, Man., of Mr. J.W. Simpson, of the
- (12) Four Miles out in Lake Winnipeg, Man., Northern Fish Co.,
- (13) Black Island, Lake Winnipeg, Man., Selkirk, Man.,
- (14) Assiniboine River at Portage la Prairie, Man., Samples from here were collected and forwarded by H.M. Dunham, of the Board of Trade, Portage la Prairie.
- (15) Roseau River at Dominion City, Man., Mr. Woodside, Principal of the High School and Mr. Lawson of the Bank of Montreal gave their services here.

Unless otherwise stated the samples obtained were of the Red River.

The Wahpeton sample represents ^{the Red River at} the junction of the Ottertail and the Bois des Sioux rivers. At Grand Forks the sample was taken, of the Red River, well above the confluence of the Red Lake River, and most sewage. Professor Chandler of the University of North Dakota writes, "The points of collection were approximately the same as used by Professor Leonard. Namely, The Red River, at the Minnesota Avenue bridge, about 200 yards above the confluence of the Red Lake River. A sewer, the Elm Avenue sewer, enters the stream on the left hand side, about one-tenth mile farther upstream; But this is not a large sewer, and I took the sample from the eastern portion of the channel, flow being nearly straight here, so that I think none of the sewer outflow could have reached the point of collection. The Eighth Avenue sewer, which serves a population of 2000, enters about three-quarters of a mile farther up; there was no convenient method of getting a good sample above that point, but in the three-fourths mile it will be well distributed, so that the sample is presumably normal".

The Red Lake River sample was obtained about 200 yards above its mouth, as was the case with all the tributaries. The sample of the Red River, at River Park, Winnipeg, was taken above all sewage; whereas the sample at Kildonan Park was taken below all sewage outlets of the City of Winnipeg. The samples of Assiniboine water from Portage la Prairie were uncontaminated by sewage, but the samples from near the mouth contain considerable sewage from Winnipeg.

CORRECTNESS OF ANALYSIS.

All the analys^{es} above mentioned have been subjected to H. Stablers, "reaction coefficients"⁽⁸⁾, and the basic radicles balanced satisfactorily against the acid radicles, thus signifying accuracy of analysis.

THE MONTHLY VARIATION IN COMPOSITION.

In the month of June, sodium chloride and sodium sulphate, for the river as a whole, accumulate rapidly as far as Emerson. This is the result of the confluence of such streams as the Forest, the Park and the Pembina, in particular. Calcium carbonate shows a gradual increase and the carbonate radicle appears to have come in with eastern waters, such as the Red Lake River. Then due to the influx of water bearing less saline matter a rapid decrease is apparent from Emerson to the city. The influence of the Assiniboine River and the pollution by sewage is evident in the sample from Kildonan Park. The slight increase to Selkirk may be due to the close proximity of sewage to the point of sample taking. The dispersal of the river in the lake can readily be observed from a study of the graphs.

For the mid-summer months, of July and August, the various ingredients in the river, once again show a general increase to Emerson, with the sodium and chlorine peaking at this point. The behaviour between Emerson and Winnipeg (River Park), is the result of the Roseau, the Rat and the La Salle rivers. The discharge in cubic feet per second of these three rivers (see table of analys^{es}) has decreased, but a somewhat rapid increase in total solids, particularly in the La Salle tends to offset the loss of water.

8. Dole, R.B., Water Supply Paper 236, U.S. Geol. Survey.

The variations in the remainder of the curves are but relative. The sample taken at the mouth shows undoubted lake contamination.

The fall months of September and October, produce an expected regularity; the effect of the spring floods has passed; the summer months have done their work and gone. Apparently September is the month when greatest regularity is found. The peaks at Grand Forks, for October are explainable from a consideration of the analyses of the Red Lake River and the Pembina, for the two rivers although entering below Grand Forks are typical of the east and west tributaries. The resemblance between the sodium and the chlorine curves for the period studied leads to the conclusion that sodium chloride is entering above Emerson. In fact it was feared that the samples had been taken before the two rivers had properly mixed and that the peaks at Emerson were caused by too much Pembina River water, this in the light of recent inquiries does not seem feasible. The behaviour of the curves between Emerson and River Park, for these two months is the result of the advanced seasonal changes in the tributaries between these points. It is somewhat difficult to separate the results of the confluence of the Assiniboine River, whose salinity has greatly increased, from the effects produced by human contamination. However the combined influence is seen when the curves from River Park to Kildonan Park have been considered.

The composition of the river between Winnipeg and Selkirk, for September is similar to its composition for July. That is all the ingredients decrease but calcium and sulphate, and these show a slight increase. In August the sodium and the sulphate increased to a slight extent and the balance has swung in favor of an increase in calcium for September. Apparently the low rainfall for September and

and October is the cause of a decrease in underground seepage or else the river level has dropped below the formations it has been leaching in the earlier part of the year. The regularity of decrease in all constituents, between these points in January, aids either theory but seems to favor the underground seepage more than the leaching hypothesis.

It was not found feasible to obtain winter samples for all months, so the decision was arrived at, that samples for January would have to be taken as in a measure representative of the period during which the river is covered by ice.

For January, all the elements increase to Grand Forks, N.D., and the carbonate curve exhibits a distinct peak. If the rivers from the east possess as much carbonate as the Red Lake River which enters at Grand Forks, then a reason for the peak at this point is apparent. The chlorine increases at the expense of the carbonate radicle in the Emerson sample; and the sodium shows a rise that is in keeping with that of the chlorine. The decrease of the other elements must be relative to this increase in sodium chloride. A noticeable feature of this graph is the rapid rise of the sulphate curve. Can it be possible that since the sodium curve increases, that sodium sulphate is being fed to the river by saline springs between Emerson and Winnipeg? If such is the case the added constituents must be magnesium sulphate and sodium sulphate as only these two bases show an increase. The behaviour of the other curves is dependent upon the amounts of sodium, magnesium and sulphate present. Passing the city nothing need be said as at this point the confluence of the Assiniboine (highly saline) and the entrance of sewage are self-evident. The general tendency of the curves to remain horizontal is as would be expected. The

amount of sodium sulphate present indicates a reduction of this salt after passing Winnipeg. This can possibly be put down to the increase in carbonate radicle. Referring back to the horizontal character of the curves between Winnipeg and Selkirk, it is obvious that the freezing of the ground prevents any addition to the river between these points and puts an end to leaching. All the curves fall away to give the apparent composition of Lake Winnipeg at Black Island. As indicated in the analyses and on the graphs the samples at the mouth of the Red River and four miles out in the Lake could not be obtained.

SUMMARY.

(9)

Calcium. For the period of time involved the calcium shows a constant increase to Grand Forks, N.D. This is followed by a slight increase to Emerson and an increase to River Park, on the outskirts of Winnipeg; in fact so small is the variation between Grand Forks and Winnipeg that the curves could almost be said to be constant. The behaviour upon passing the city to Kildonan Park, is a result of the incoming Assiniboine River and the city sewage. At Selkirk the calcium curves show by their increase for the early summer months evidence of leaching due to high water or else a strong influx of underground water between Winnipeg and this point. The decrease in the late summer months and the fall and winter, favors either of these assumptions. It appears that the amount of this element in the river increases gradually from spring to winter, at each point. Magnesium: This graph indicates for the constituent under consideration, explanations that are similar to those given for calcium. The increase and decrease of the two elements appears to be subject to the same primary influence. That is although the magnesium is

much less in amount, than the calcium, its curves are practically the exact counterpart of those of the calcium.

Sodium: For the period from late spring to late fall the curves as far as Emerson behave in a similar manner. It is interpreted from these graphs that the amount of sodium in the river rises as the water approaches Emerson, with the greatest concentration in September or early fall and the lowest concentration in October or late fall. An even lower concentration at Emerson, is shown in the winter months as depicted by the January line. The flattening out of the January curve above Grand Forks is due to the freezing of certain small fresh water streams that drain swamps existing in the upper reaches of the valley. The percentage of saline material in the LaSalle increases very rapidly as the summer wanes and as a result it is found that the late fall and winter curves flatten out, on their approach to Winnipeg, to give a gradual increase in sodium, at River Park, as the year progresses. No comment is necessary in regard to the curves as they pass the city. At Selkirk the decrease in July or the increase in the month of June is unexplainable from the curves alone. At all points, with the exception of Grand Forks for January, a progressive increase in sodium is worthy of note.

Carbonates: The river behaves as a carbonate river as far as Emerson, with the exception of the October and January months, when there is a tendency for the water to become high in sulphates. The drop in these two months is probably the result of the low discharge values for the eastern rivers. A fair rainfall in the western part of the valley would increase the sulphate and chlorine radicals thus producing a decrease in carbonates. The spring

floods are well pictured in the months of June and July at River Park.

Chlorides: Little need be written about this element in the Red River, except to draw attention to the extreme regularity of its behaviour. The peaks at Emerson owe their origin undoubtedly to the Pembina River and its potent tributary, the Tongue River. Also, at this point, the early summer months show a much lower concentration of chlorine than do the late summer and winter months. The behaviour of the remaining curves do not warrant further explanation.

Sulphates: The general trend of the curves as far as Winnipeg is much the same and can be best explained by premising high spring floods and low fall water. The January sample expresses well the lack of leaching in the frozen ground. The startling increase from Emerson to Winnipeg, for January, can only be accounted for by the Pembina River. But why did not this increase show in the analysis of the sample taken at Emerson, below the confluence? Is it possible that an underground spring or flowage of water between these two points is responsible for this rapid rise? The remainder of the curve is as one would expect for a winter month, where the ground freezes to a depth of six feet.

Total Salinity: All the foregoing can be summed up by a consideration of the salinity of the river. For the months of June, July, August and September, the graphs show a progressive increase in dissolved solid matter with a high point at Emerson for June and September. The June peak could be accounted for rather readily by leaching. In the previous summer months, considerable

efflorescent material(MgSO_4 and Na_2SO_4) would be carried to the surface by ascending water. Here deposition would take place and as a result a white efflorescence appears in places upon the valley. This material would be greatest where the glacial drift is thickest, that is, on the southern side of the International Boundary. Late summer and occasional fall rains would remove but little. The melting of the winter's snow, however, would convey this material to the various drainage basins and thus to the Red River. This material has attracted attention in Minnesota and an analysis ⁽¹⁰⁾ has been made by Professor J.A.Dodge. He took an alkali efflorescence from a till surface in Minnesota and showed it to be a hydrous sulphate of magnesium with slight traces of sodium, potassium and calcium. The proportion of SO_3 to MgO were as in epsomite, but it had less water of crystallization. Again, the river passes over limestone ridges and certainly must roll along its bed, boulders from the till, 75% of which are limestone, (see above). This coupled with the undoubted greater velocity in the upper reaches would tend to give at some point, in its early course, a peak in the salinity curve. Later dilution by tributaries, where the speed of the river has lessened, because of a smaller decrease in level, would decrease this salinity. Then, again, underground seepage, of which there is certainly a large volume, when one considers the low, flat valley, must convey water of a much higher salinity to the river below the International Boundary, where the drift abounds, than is brought to the stream in its lower reaches. Considering now decrease in volume of water with the change in season, and the effect of such upon the above, a series of curves as determined for the various months is obtained.

(10) Geol. and Nat. Hist. Survey of Minn., 10th annual Report 1881.

One would expect more or less, that one month would show a peak, such as is indicated by September at Emerson, (see salinity graph). This would represent a time, or a month, when all the tributaries of any length, were carrying their maximum load to the main stream. Following such a curve a gradual flattening out or rather a constantly increasing salinity should be expected. This is, in fact, well-shown by the month of October. Here the tributaries have decreased in size and number and the amount of water of low salinity added is at a minimum. For the winter months one can account for the greater salinity by the removal of water through freezing.

ST. LAWRENCE AND RED RIVERS CONTRASTED.

"Much⁽¹¹⁾ of the territory drained by the St. Lawrence River is either forested or fertile and the soil is therefore rich in organic matter. The decay of such substances generates abundant carbonic acid, which tends to convert the dissolved inorganic matter into carbonates, mainly of lime and magnesia, and therefore the water for the system is to be classed as a carbonate water".

	St. Lawrence River at Ogdensburg, N. Y.	Red River at Winnipeg, Man.
Ca.	31.0	62.4
Mg.	7.2	29.9
Na.	6.3	55.8
K.		6.7
SiO ₂ .	6.6	19.6
(Al, Fe) ₂ O ₃ .	0.05	6.8
CO ₃ .	118.9	144.1
Cl.	7.7	40.3
SO ₄ .	12.0	92.4

⁽¹¹⁾ Clarke, F.W., Prof. Paper, U.S. Geol. Surv., No. 135, 1924.

The total salinity of the St. Lawrence River and ^{of} the Red River is respectively 134 and 458. The analysis of the St. Lawrence River was obtained from F.W. Clarke's paper "The Composition of the River and Lake Waters of the United States" and represents the mean of 11 analyses. The Red River analysis is the mean of 6 made by G. Ward. The analyses are reported in the customary parts per million.

A consideration of the above two analyses shows the wide differences in the composition of the two rivers. A review of the geology of the Red River Valley (see above), clearly indicates that differences such as appear would result.

The material carried in solution by the St. Lawrence River as it passes Ogdensburg, N.Y., amounts to 3,276,736 tons for an annual discharge of 248,518 cubic feet per second ⁽¹²⁾. The Red River on the other hand, carries 2,774,117 tons per annum, with a discharge passing Winnipeg of approximately 64,000 cubic feet per second. The added solubility of the old glacial lake sediments over the material in the St. Lawrence Valley is well shown by the erosive action of the respective rivers.

CORRELATION WITH F.W. CLARKE'S, "RIVERS AND LAKE WATERS OF THE UNITED STATES"

"The general character ⁽¹³⁾ of most of the larger tributaries can be described thus. The tributaries from the western side flow for some distance in their upper courses, with not very high fall, thru the rolling prairies; those from the eastern side thru a wooded glacial moraine lake region or swamp region, which also has small slope. On approaching the outermost boundaries of the former glacial lake Agassiz, each stream has a section of comparatively rapid descent, down channels thru the glacial drift, until it reaches the smooth

(12) Clarke, F.W., Prof. Paper, U.S.G.S. No. 135, 1924.

(13) Chandler, E.F., Quarterly Jour. Univ. of North Dakota.

surface of the old lake bottom; in these sections water-powers are available, on such of the tributaries as have great enough continuous flow to warrant development".

Considering now, the general character of the Red River, it can be seen that the tendency of the stream in its early stages, say up to Grand Forks, is that of a carbonate water. However the effect of passage over limestone in its upper reaches are out-balanced by the influx of sulphate tributaries; tributaries which have passed thru the western drift area, and which abounds in gypsum, as can be seen by references to well-water analyses⁽¹⁴⁾.

The increase of sulphates observed in the lower reaches of the Red River are due to city contamination, added to the sulphate carried in, by the lengthy Assiniboine River, from the west. In spite of this the river remains of carbonate character thruout its extent.

One of the main additions to the river at Emerson, Man., is shown by the large increase in the chlorine and the sodium content. The country in the drainage basin of this vicinity contains many salt springs. These springs contain large quantities of sodium chloride.

SPRING WATER ANALYSES.

	River Lot #65, LaSalle River (parts per million)	Rosenfeld, Man.
Ca.	4885.6	1419.8
Mg.	2000.0	516.7
Na.	523.1	14598.8
K.	140.0	208.9
SiO ₂	---	12.6
(Al, Fe) ₂ O ₃	TRACE	TRACE
CO ₃	2120.0	46.6
Cl.	444.1	23567.8
SO ₄	321.7	2905.8
	10433.9	43277.0

(14) Upham, Warren, The Glacial Lake Agassiz, U.S. Geol. Surv. 1895.

The well at Rosenfeld is typical of the water derived from the strata between Morris, Man. and the Boundary, whereas that of Lot #65 is representative of the water obtained between Morris and the LaSalle River.

The area of drainage is one of sedimentation that is, the material traversed by the river system is the detrital matter laid down in Lake Agassiz, hence the bases are to some extent derived from igneous rocks particularly feldspars. On the whole, however, the immediate source of this material is the gypsum, limestone and various salt formations, abounding in this area. Undoubtedly considerable silica was laid down over the region and the Red River is at present carrying northward, a fair share of this ingredient.

"To a certain extent the salinity⁽¹⁴⁾ of a water is determined by its geological environment, that is, it depends upon the solubility of the rocks from which its dissolved solids were derived. In a stream issuing from an area of crystalline rocks the salinity is generally low, usually less than 100 parts per million, and the same is true of waters flowing from areas of shale or sandstone. A limestone water, on the other hand, is much higher in salinity, carrying as much as 200 parts per million and often more. The waters of arid regions are highest in salinity, for they are loaded with desert salts."

A consideration of the analyses of the Red River and its tributaries will show that the area drained is of complex geological character. That is, the various waters come in contact with many formations, Palaeozoic limestone, Cretaceous shale, detrital matter from an igneous area and glacial clays. The region drained by the river places the system in the sedimentary class of Clarke.

14. Clarke, F.W., Prof. Paper, U.S. Geol. Surv., No. 135, 1924.

The following analyses show the comparison of the Red River with rivers that are placed in this class by Clarke.

ANALYSES FOR OCTOBER.

	Illinois River near LaSalle, Ill.	Red River at River Park, Winnipeg.	Iowa River at Iowa City, Iowa
Ca.	51.0	76.7	64.0
Mg.	22.0	27.9	26.0
Na.	21.0	30.1	13.0
K.	-	10.7	-
SiO ₂	9.8	11.1	36.0
(Al, Fe) ₂ O ₃ .	0.04	6.1	trace
CO ₃	213.0	168.3	274.0
SO ₄	45.0	131.2	44.0
Cl.	219.0	64.6	3.9
Salinity	268.0	570.6	312.0

The tributaries of the Red River can be divided into eastern or carbonate waters and into western or sulphate waters. The Red Lake, the Roseau and the Rat are typical of the eastern group; the Sheyenne and the Assiniboine represent the western tributaries. The Assiniboine is of considerable interest, and shows the effect of meandering thru the glacial clays. The analysis of this water at Portage la Prairie clearly indicates the leaching of gypsum. As would be expected from the composition of the Red River and its tributaries the bulk of the water addition is from the west.

In brief, the Red River thruout its entire course represents a carbonate river. It shows well the influence of the various tributaries and illustrates to a marked degree, in its lower reaches, the effect of the continually increased addition of sulphate waters. These sulphate waters tend to change the carbonate character of the stream to that of a sulphate river. The chlorides to a large extent come from the western tributaries but they also show the effects of human contamination, particularly so below Winnipeg.

SEDIMENTATION:

In the month of June there was carried to Lake Winnipeg 629.8 parts per million of suspended matter. By the time this water reached Black Island, some fifty miles up the lake, its suspended matter had diminished to 6.3 parts per million. The following table gives the variation in these figures.

	Red River at Selkirk.	Black Island Lake Winnipeg.	Deposited
June	225.4	6.3	219.1
July	102.4	8.4	94.0
August	118.4	18.0	104.0
September	111.2	31.0	80.2
October	172.6	33.2	139.4
January	17.5	30.7	-13.2

In addition there is a difference in soluble matter as can be seen by a comparison of the total salinity at various points.

	Red River at Selkirk.	Black Island Lake Winnipeg.	Difference
June	425.7	160.6	265.1
July	415.0	158.9	256.1
August	504.8	169.8	335.0
September	559.6	166.4	393.2
October	546.2	160.8	385.4
January	640.4	246.0	294.4

When the above differences are multiplied by the monthly discharges of the Red River, the amount of material remaining in the lower end of the lake is found to be enormous.

Analyses of the material carried in suspension, deposited on the river bottom and deposited in the lake are interesting, as the table on the next page will show.

SEDIMENT ANALYSES.

	River Suspended Matter at River Park.	River Bottom at River Park.	Lake Bottom 4 Miles from Mouth.
SiO ₂	45.45%	49.49%	41.68%
(Al, Fe) ₂ O ₃	19.48	18.10	21.86
CaO	7.15	6.47	7.69
MgO	8.66	8.66	10.79
Na ₂ O	3.05	3.26	3.74
K ₂ O	1.92	1.81	2.53
Ignition Loss	113.97	12.20	11.69
	99.68	99.99	99.98

SIZE OF PARTICLE.

Fine Clay	16.12%	12.36%	37.26%
Coarse Clay	26.83	22.76	19.87
Silt	42.12	57.82	36.00
Fine Sand	8.39	4.93	4.01
Coarse Sand	6.05	1.86	2.81
	99.51	99.72	99.95

The size of particle was determined by screening, centrifuging
(15)
and elutriating .

The sample of river suspended matter was obtained during the months of June and July by allowing bi-weekly samples to settle, until clear. The water was obtained above all sewage, and the sample of the river bottom was also taken above the sewer outlets and about three-quarters way across the river toward the fill side. The sample from Lake Winnipeg is probably ^{from near} the edge of the Red River delta, or may even be farther out than the limits of the delta proper.

A reference back to the first table under sedimentation, discloses an interesting fact, in the light of the recent investigations
(16)
of sedimentation bands or "varves" . It can be seen that thruout the "open" season, i.e. absence of ice on the system, that the suspended matter is carried to the lake and settles rather rapidly or else is cleared by quicker flowage during this season. But for the month of January, there is more suspended matter in the lake

(15) Holmes, Arthur, Petrographic methods and Calculations.
(16) Antevs, E., Memior 146 Canadian Geological Survey

than there is in the other months, relative to the amount carried down by the river, that is to say, that the value in the right hand column of the table is negative. Is this material of finer grade than the summer sediment, settling slowly and thus conforming with the winter band of Antevs "varves", or is it just due to the difference in sample taking? This increase may be due to the presence of ice. The average depth of the lower end of the lake is 15 feet and the formation of two feet of ice would remove sufficient water to make the increase in suspended matter relative. Then again, water has its greatest density at 4°C. and the temperature of the shallow lake would be closer to this figure in the winter than in the warm "open" season. Add to this the increased specific gravity caused by the increase in dissolved solids and a reason for the greater suspension in winter can perhaps be made clear.

CHEMICAL DENUDATION.

	Mean Flow of Red River Below Winnipeg.	Total Solids Below Winnipeg.	Total Suspended Matter Below Wpg.
June	18090 sec-ft.	337.4 PPM.	170.8 PPM.
July	8462	438.9	170.4
August	1920	509.8	72.4
September	1534	530.0	49.8
October	1685 (1)	586.7	29.8
January	535 (1)	618.0	31.9

(1) Estimated for the past ten years as the 1926 figures were not available. All discharge values were obtained from the Dominion Water Power branch at Winnipeg.

By means of the above table the amount of suspended matter plus material in solution, being carried to the lake by the river can be calculated. The flow of the water will decrease from October to

April and the November flow can be considered as about two-thirds of the October. The months of December, February and March may be considered as similar in flow and material in solution and suspension ^{to} as January. March will resemble November and May is approximately double the October flow. These proposed figures are well in agreement with the runoff for the past ten or twelve years ⁽¹⁷⁾. Hence it is found that the material carried monthly to the lake is as follows.

Month.	Soluble Material.	Insoluble Material.	Total.
June	996,944,000	498,470,000	1,495,414,000
July	595,787,720	210,112,000	805,899,720
August	163,933,380	20,134,000	184,067,380
September	131,705,000	13,108,000	144,813,000
October	165,387,250	8,538,700	173,925,950
November	110,260,000	5,699,000	115,959,000
December	42,990,000	2,200,000	45,190,000
January	42,990,000	2,200,000	45,190,000
February	40,090,000	2,004,000	42,094,000
March	42,990,000	2,200,000	45,190,000
April	110,260,000	5,699,000	115,959,000
May	336,780,000	6,600,000	337,380,000
Total	2,774,117,350lbs.	776,964,700lbs.	3,551,082,050lbs

(18)
It has been estimated that 107 pounds of load represents one cubic foot of rock and soil. Therefore there has been eroded from the Valley of the Red River 33,187,683 cubic feet of material in one year. The united drainage area of the valley is represented by 116,000 square miles ⁽¹⁹⁾ and this would be lowered one inch in 812 years or one foot in 9,744 years. It has been calculated by geologists that 8,000 years have passed since the recession of the glaciers have permitted the streams to reoccupy their blockaded

(17) Dominion Water Power Board Winnipeg.

(18) Water Supply Paper 274, pl64, U.S. Geol. Surv.

(19) Baker, F.W.? A Study.... Natural Waters, M.Sc. Thesis 1925.

outlets on the north. In this time approximately 0.82 of a foot has been eroded from the entire lake bottom by the Red River system.

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(7)

Red River at Wahpeton, N.D.
(parts per million)

Red River at Wahpeton, N.D. (parts per million)												
Date	SiO ₂	R ₂ O ₃	Ca	Mg	Na	K	CO ₃	SO ₄	Cl	Total Solids	suspended matter.	Discharge in sec.-ft.
1925												
June (1925)	12.0	0.2	48.4	30.0	16.6	7.3	137.3	39.4	9.5	290.8	51.0	-
July	12.9	1.1	42.4	28.8	15.4	5.1	123.0	37.6	9.4	275.6	35.4	-
Aug.	Sample not returned											
Sept.	14.4	0.4	47.9	24.6	13.1	3.9	128.2	32.9	4.8	271.3	11.6	-
Oct.	15.4	1.9	52.4	33.5	19.1	1.2	147.1	60.8	3.9	327.8	17.3	-
Jan. (1926)	14.4	20.4	54.9	35.3	30.5	5.7	158.2	24.1	9.5	345.6	11.2	-

Red River at Grand Forks, N.D.

June 14.4 (1925)	22.0	52.6	22.9	46.3	8.0	147.8	87.0	23.8	419.4	582.2	3080
July 19.4	0.4	66.1	29.6	56.2	2.2	158.2	122.4	21.4	450.1	211.8	1590
Aug. 17.4	2.1	60.9	31.4	57.9	2.8	161.7	120.3	20.6	478.0	100.7	253
Sept. 11.2	0.2	62.8	24.8	53.1	4.0	142.4	121.1	22.4	445.2	35.4	187
Oct. 10.6	0.2	69.9	35.5	52.4	4.7	169.5	124.6	23.8	489.3	60.8	214*
Jan. 22.8 (1926)	19.0	80.0	38.6	36.0	6.9	214.7	56.6	21.0	487.0	19.2	-

Red River at Emerson, Man.

June 15.4 1926	0.8	53.3	25.3	87.8	9.3	151.7	96.1	47.6	484.6	401.8	10500
July 20.1	0.9	54.9	24.5	87.6	2.9	147.1	100.5	44.9	479.3	426.5	3400
Aug. 22.8	0.2	60.7	25.7	88.4	4.2	158.2	108.8	48.5	520.0	534.4	519
Sept. 11.0	2.6	63.6	31.2	105.6	19.2	146.9	118.8	96.0	584.0	132.4	559
Oct. 15.8	2.8	66.9	28.8	76.1	16.0	135.6	112.9	102.2	550.8	161.2	650
Jan. 9.0 1926	9.8	74.0	31.8	72.2	7.1	180.8	59.4	91.4	549.2	27.8	500*

Discharge Data - Dominion Water Power Branch, Winnipeg.

* Calculated from Discharge Data for Past Ten Years.

(8)

Red River at River Park, Man.
(Parts per million)

Date	SiO ₂	R ₂ O ₃	Ca	Mg	Na	K	CO ₃	SO ₄	Cl	Total solids.	Suspended matter.	Discharge in sec.-ft.
June (1915)	18.4	2.6	47.9	30.3	12.2	0.5	110.4	44.7	19.0	297.6	990.2	-
July	22.0	3.6	54.5	25.3	40.1	8.9	115.6	52.9	23.7	328.8	142.6	-
Aug.	23.6	2.2	68.3	30.6	60.8	4.5	156.9	96.0	49.9	458.8	99.4	-
Sept.	20.8	3.8	65.2	26.4	65.5	11.9	149.3	99.3	61.2	487.0	26.2	-
Oct.	11.1	6.1	76.7	27.9	80.1	10.7	165.3	131.2	64.6	570.0	35.9	-
Jan. (1916)	21.6	22.8	62.0	38.8	76.2	4.8	166.9	130.1	33.2	561.0	12.8	-

Red River at Kildonan Park, Man.

June (1915)	19.8	1.2	44.7	25.1	37.8	5.0	123.0	63.2	28.5	337.4	170.8	-
July	21.2	4.2	59.4	26.1	58.3	7.9	132.7	69.6	60.2	438.9	170.4	-
Aug.	9.2	0.2	72.9	32.3	58.3	10.2	146.9	108.2	71.3	509.8	72.4	-
Sept.	19.6	2.2	65.6	35.6	67.3	4.6	146.9	120.0	69.2	530.0	49.8	-
Oct.	20.2	5.4	74.6	36.7	78.9	7.2	160.1	128.6	80.3	586.7	29.8	-
Jan. (1916)	13.0	19.4	81.1	43.8	81.9	5.5	172.3	153.5	66.6	618.0	31.9	-

Red River at Selkirk, Man..

June (1915)	14.8	1.4	63.1	32.7	46.5	6.5	135.6	97.6	32.8	425.7	225.4	-
July	23.0	9.2	65.0	22.7	41.0	7.8	119.1	85.8	38.5	415.0	102.4	-
Aug.	28.8	9.6	69.1	29.4	60.6	6.1	126.9	121.6	52.3	504.8	118.4	-
Sept.	36.0	18.0	70.2	29.5	65.6	4.5	139.5	125.8	62.0	559.6	111.2	-
Oct.	16.6	trace	67.5	31.6	75.1	7.8	135.6	135.2	85.6	546.2	172.6	-
Jan. (1916)	12.6	16.6	80.0	40.3	71.2	8.2	182.4	144.0	58.0	640.4	17.5	-

(9)

Red River at its Mouth, Man.
(Parts per million)

Date	SiO ₂	R ₂ O ₃	Ca	Mg	Na	K	CO ₃	SO ₄	Cl	Total solids	Suspended matter	Discharge in Sec.-ft.
June (1925)	7.0	6.8	47.5	27.0	63.8	7.0	113.0	109.9	38.0	409.9	629.8	-
July	43.5	7.4	37.0	35.5	59.1	8.4	113.0	115.2	23.8	447.2	78.8	-
Aug.	18.8	1.2	48.8	23.5	26.3	4.2	95.6	109.5	23.8	343.2	64.0	-
Sept.	9.8	0.2	55.5	20.8	27.6	6.2	101.7	102.5	23.8	357.6	37.0	-
Oct.	10.0	trace	56.9	34.7	44.5	6.7	124.3	97.0	69.9	437.0	12.4	-
Jan. (1926)	Sample not obtained.											

Lake Winnipeg, Man. Four miles out from Red River.

June (1925)	16.4	12.0	27.5	13.8	54.4	2.9	50.4	47.0	14.3	224.0	296.0	-
July	27.8	8.2	36.4	14.4	13.0	2.8	43.9	49.4	29.0	223.8	81.8	-
Aug.	5.4	1.4	25.4	16.6	18.3	3.6	59.1	34.7	20.9	189.6	117.2	-
Sept.	9.4	0.2	26.1	10.8	11.6	3.8	56.5	21.2	14.3	156.4	36.4	-
Oct.	8.0	0.8	26.8	14.3	17.7	4.2	63.0	45.8	19.0	200.2	26.2	-
Jan. (1926)	Sample not obtained.											

Lake Winnipeg at Black Island.

June (1925)	16.3	11.3	15.1	13.4	11.6	1.2	48.3	36.8	7.3	160.6	6.3	-
July	15.2	9.6	17.2	9.1	12.4	0.4	45.2	44.7	9.5	158.9	8.4	-
Aug.	15.0	3.6	20.3	13.3	17.2	4.0	45.2	31.8	11.9	169.8	18.0	-
Sept.	1.8	0.2	31.6	11.3	9.5	5.4	67.8	18.8	16.6	166.4	31.0	-
Oct.	6.8	0.8	32.1	12.6	6.1	1.6	65.2	17.6	17.9	160.8	33.2	-
Jan. (1926)	29.2	17.2	32.6	18.3	6.4	1.1	90.4	16.4	29.7	246.0	30.7	-

Nelson River (Outlet of Lake Winnipeg)
(Parts per million)

Date	SiO ₂	R ₂ O ₃	Ca	Mg	Na	K	CO ₃	SO ₄	Cl	Total solids	Suspended matter	Discharge in Sec.-ft.
June (1917)	6.8	0.2	31.6	4.6	15.5	2.4	36.5	49.4	14.3	160.1	4.5	-

TRIBUTARIES TO THE RED RIVER.

Red Lake River at Grand Forks, N.D.

June (1918)	16.0	41.6	45.7	15.9	11.2	4.4	87.8	44.7	9.8	270.8	632.4	2690
July	12.4	1.6	65.8	29.6	15.8	5.6	131.2	49.4	16.6	319.2	95.0	580
Aug.	10.5	7.2	60.7	29.9	15.1	2.3	145.7	51.3	15.2	335.0	39.4	180
Sept.	6.8	0.2	40.3	20.5	2.4	1.8	101.7	51.8	4.8	231.4	26.0	300
Oct.	12.2	1.2	64.0	24.4	8.1	2.4	146.9	67.6	4.8	328.2	21.0	-
Jan. (1916)	11.4	16.8	58.8	18.9	8.4	1.9	146.9	36.4	9.5	301.0	21.6	-

Pembina River at Pembina, N.D.

June (1915)	23.8	13.6	61.8	25.7	61.9	1.8	138.2	112.9	44.3	484.0	496.0	253
July	Sample not returned											112
Aug.	Sample not returned											19
Sept.	14.8	0.4	65.8	30.5	62.8	7.0	135.6	129.3	49.0	495.0	492.0	64
Oct.	9.6	0.4	74.4	29.2	47.8	5.6	128.2	138.2	53.2	486.5	493.8	-
Jan. (1916)	37.2	27.2	106.2	57.3	122.5	38.6	300.3	211.9	42.8	947.6	33.4	-

Roseau River at Dominion City, Man.
(Parts per million)

Date	SiO ₂	R ₂ O ₃	Ca	Mg	Na	K	CO ₃	SO ₄	Cl	Total solids	Suspended matter	Discharge in Sec.-ft.
June (1915)	14.0	1.4	57.5	21.4	21.3	2.6	141.7	23.5	9.5	290.8	325.2	1710
July	23.0	19.0	48.2	26.4	25.6	0.5	150.1	trace	9.5	299.4	109.0	1580
Aug.	20.6	3.2	65.0	25.3	32.5	3.4	122.5	35.6	9.4	326.0	47.0	155
Sept.	10.3	1.6	53.6	24.8	33.7	2.4	166.9	12.9	9.4	316.0	27.6	184
Oct.	15.2	2.2	49.3	20.3	19.8	0.6	134.5	20.0	11.9	271.8	30.8	200
Jan. (1916)	18.2	20.6	63.4	38.4	11.8	3.8	226.0	29.4	9.5	429.5	9.7	10

LaSalle at St. Norbert, Man.

June (1915)	12.6	7.4	36.3	2.4	25.4	0.2	67.8	8.2	28.5	197.3	110.2	90
July	3.9	1.9	40.1	24.7	119.4	11.5	120.6	137.2	110.8	569.0	90.7	42
Aug.	4.1	2.0	92.5	48.8	220.4	24.5	180.8	197.6	330.6	1079.1	79.2	4
Sept.	10.7	2.5	120.1	51.9	276.1	29.0	224.3	312.7	326.1	1344.7	66.3	2
Oct.	2.2	0.2	138.2	140.3	530.5	43.5	67.8	484.5	1122.4	2483.1	166.0	-
Jan. (1916)	River frozen too solid although not completely.											

Assiniboine at Portage La Prairie, Man.

June (1915)	18.2	2.8	61.9	21.3	41.5	1.9	135.6	36.4	9.5	324.6	312.6	-
July	21.3	4.1	44.6	27.9	31.3	2.7	141.9	41.9	11.2	328.7	69.1	-
Aug.	19.2	5.6	76.2	37.1	104.2	5.9	158.2	120.0	23.7	541.4	84.4	-
Sept.	14.4	27.2	83.2	36.6	50.1	2.0	180.8	146.4	19.0	556.8	40.6	-
Oct.	14.2	4.0	87.9	29.7	41.6	5.6	160.8	157.5	26.2	537.5	30.2	-
Jan. (1916)	14.3	16.2	92.0	40.6	37.8	4.3	188.6	192.9	28.0	602.0	20.1	-

12

Assiniboine River at its Mouth, Winnipeg, Man.
(Parts per million)

Date	SiO ₂	R ₂ O ₃	Ca	Mg	Na	K	CO ₃	SO ₄	Cl	Total solids	Sus- pended matter	Discharge in sec.-ft.
June	11.7	4.9	52.1	22.7	42.3	3.1	141.5	55.3	9.9	340.4	495.4	4430
July	11.5	5.4	66.5	25.5	39.6	3.6	156.7	66.5	15.3	393.6	97.2	2970
Aug.	9.4	7.1	80.4	24.4	81.2	4.1	161.2	155.6	34.6	558.0	103.8	1160
Sept.	7.2	20.5	87.2	39.6	61.2	2.5	178.4	168.8	27.6	590.4	70.3	705
Oct.	15.2	3.1	90.1	40.1	47.2	10.1	171.6	167.6	34.2	579.2	20.1	800
Jan.	1.2	12.6	125.5	46.2	38.5	11.6	206.0	248.1	32.8	831.6	27.3	308

In addition to the above analysés the following have been collected.

1. Sheyenne River at Lisbon, N. Dakota⁽¹⁾
2. Forest River at Forest River, N. Dakota⁽¹⁾
3. Rat River, C.P.R. analysis

	1.	2.	3.
Ca.	103.0	116.0	68.0
Mg.	56.0	35.0	20.4
Na.	124.0	25.0	17.0
K.	-	-	-
SiO ₂	14.0	11.0	23.0
(Al, Fe) ₂ O ₃	3.4	16.0	6.0
CO ₃	237.0	208.0	193.0
SO ₄	295.0	118.0	12.6
Cl.	36.0	12.0	17.0
Salinity	868.4	541.0	357.0

(1) Clarke, F.W., Prof. Paper No. 135, U.S. Geol. Surv. 1924.

—JUNE—

SCALE: 1" = 20 PPM.
1" = 20 MILES

100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400

Grand Forks

MILES FROM WAHPETON

Emerson

River Park

Kildonan Park

Selkirk

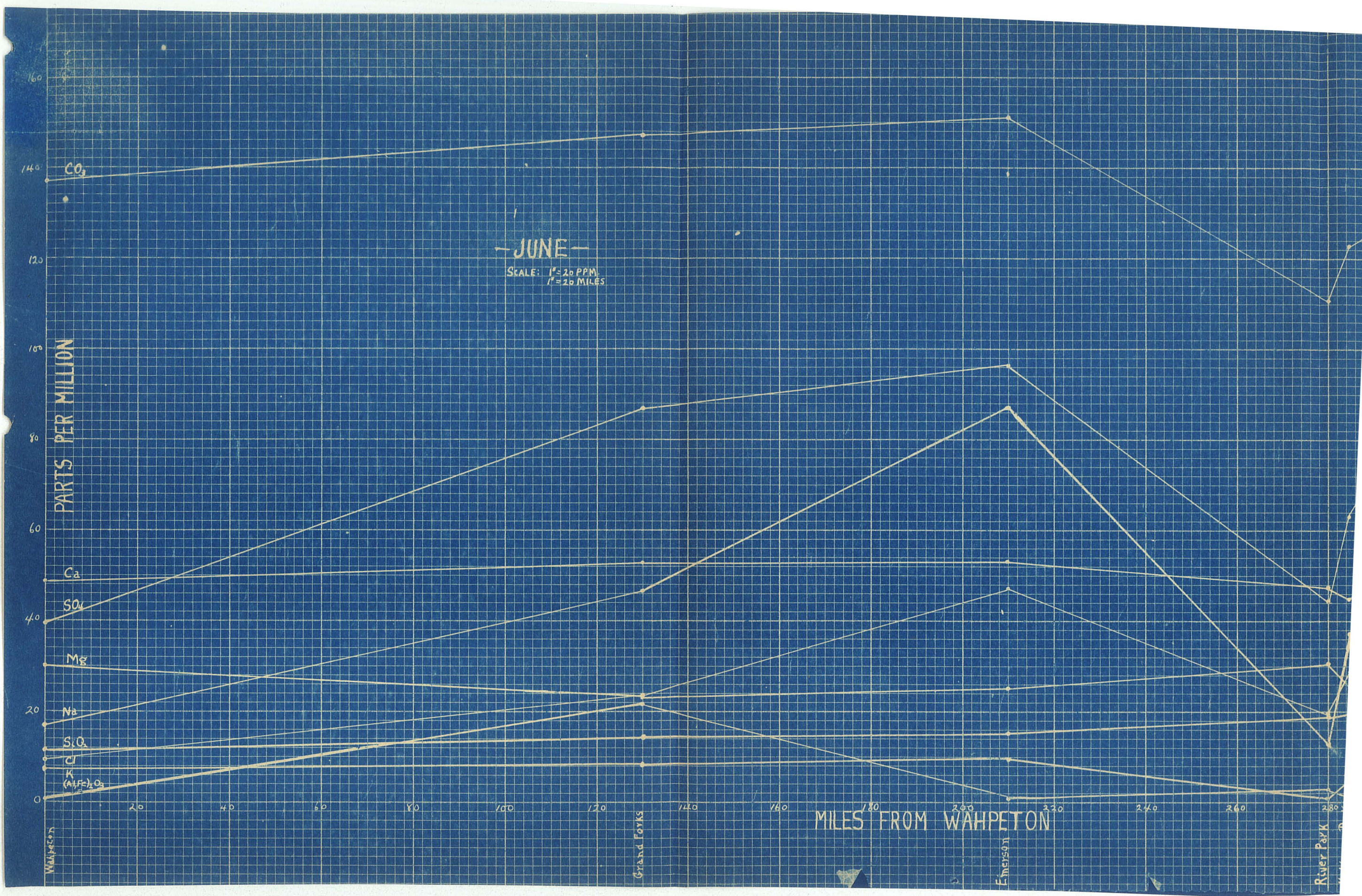
Mouth of River

Four Miles in Lake Winnipeg

Black Island

CO₂
SO₄
SiO₂
Ca
Mg
Na
(Al, Fe)₂O₃
Cl
K

160
140
120
100
80
60
40
20
0



160

140

120

100

80

60

40

20

0

PARTS PER MILLION

CO₂

C₂

SO₄

Mg

Na

SiO₂

Cl

K

(Al, Fe)₂O₃

JULY

SCALE: 1" = 20 PPM
1" = 20 MILES

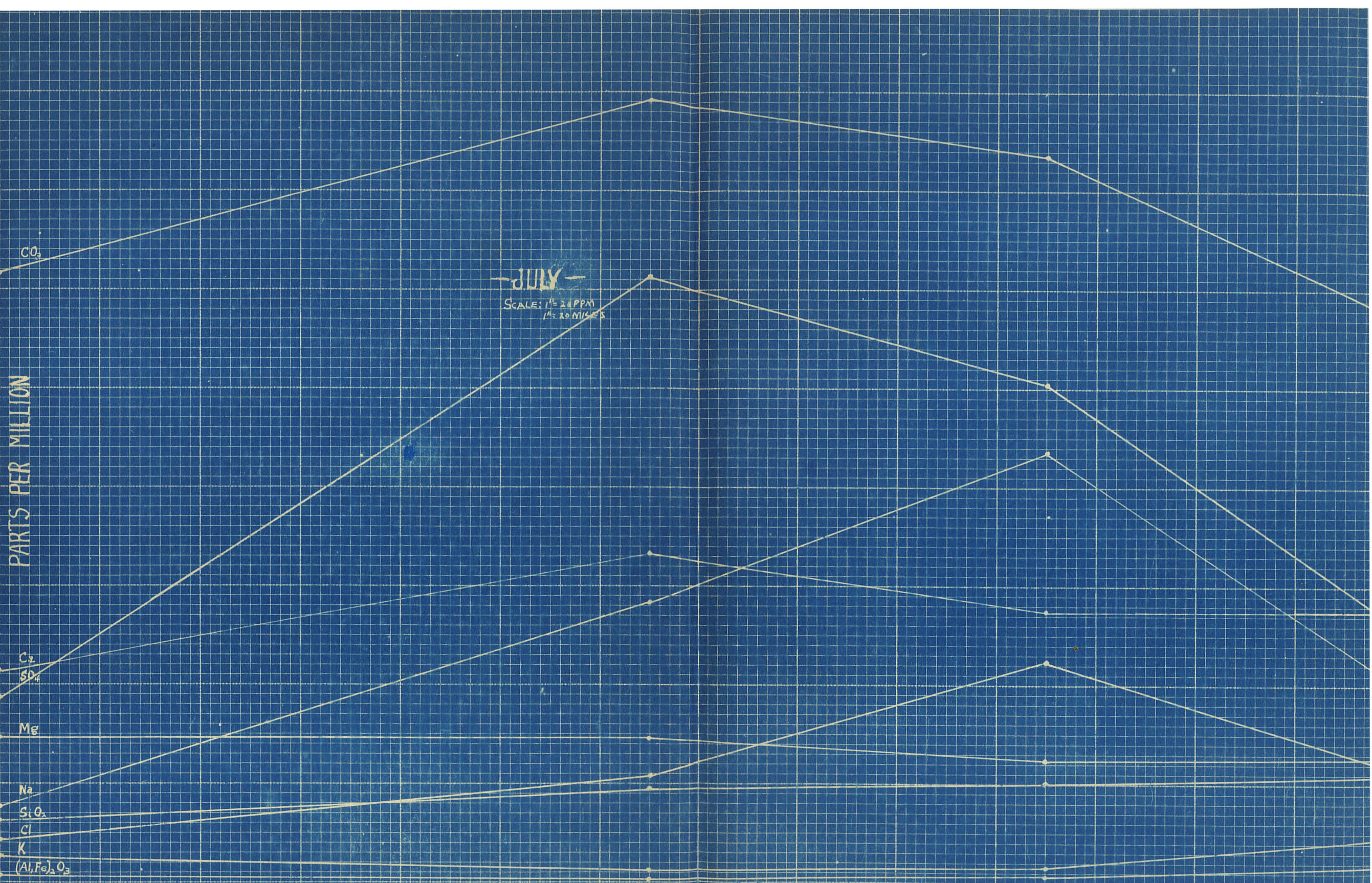
Wahpeton

Grand Forks

Emerson

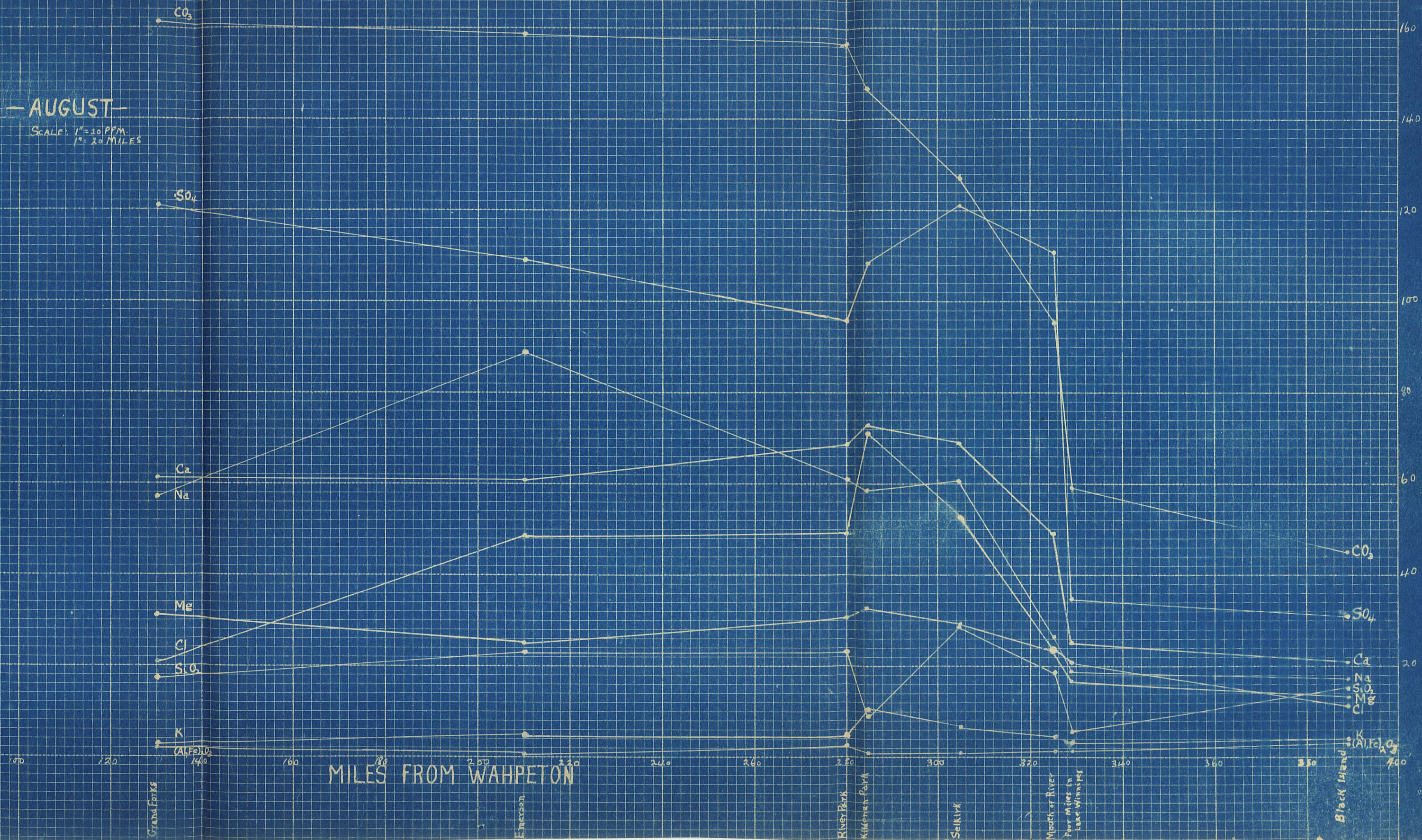
MILES FROM WAHPETON

20 40 60 80 100 120 140 160 180 200 220 240 260



- AUGUST -

SCALE: 1" = 20 PPM.
1" = 20 MILES



180

160

140

120

100

80

60

40

20

0

PARTS PER MILLION

- AUGUST -

SCALE: 1" = 20 PPM.
1" = 20 MILES

Wahpeton Sample not Returned

Wahpeton

Grand Forks

Emerson

CO₃

SO₄

Ca

Na

Mg

Cl

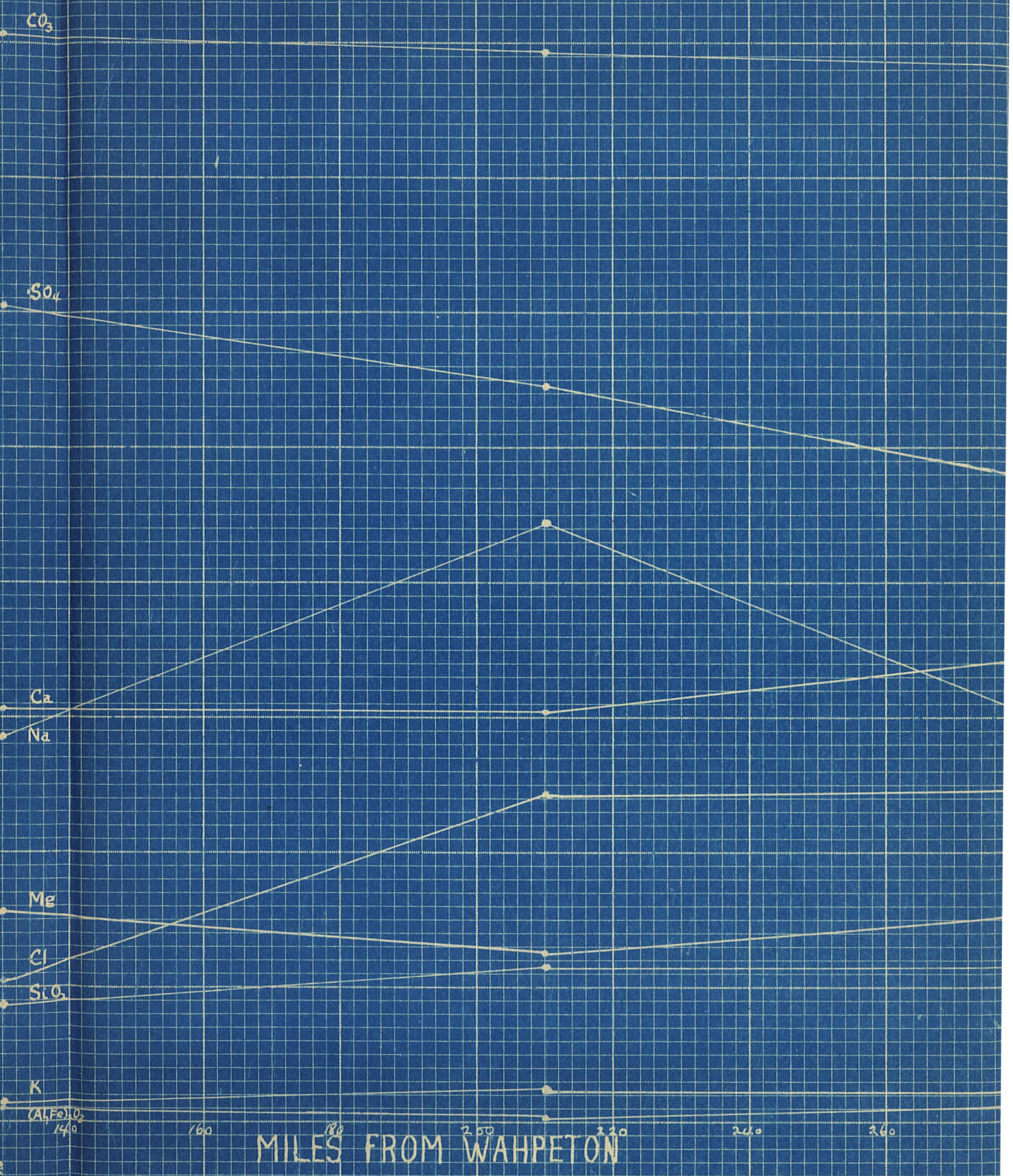
SiO₂

K

(Al, Fe) PO₄
1400

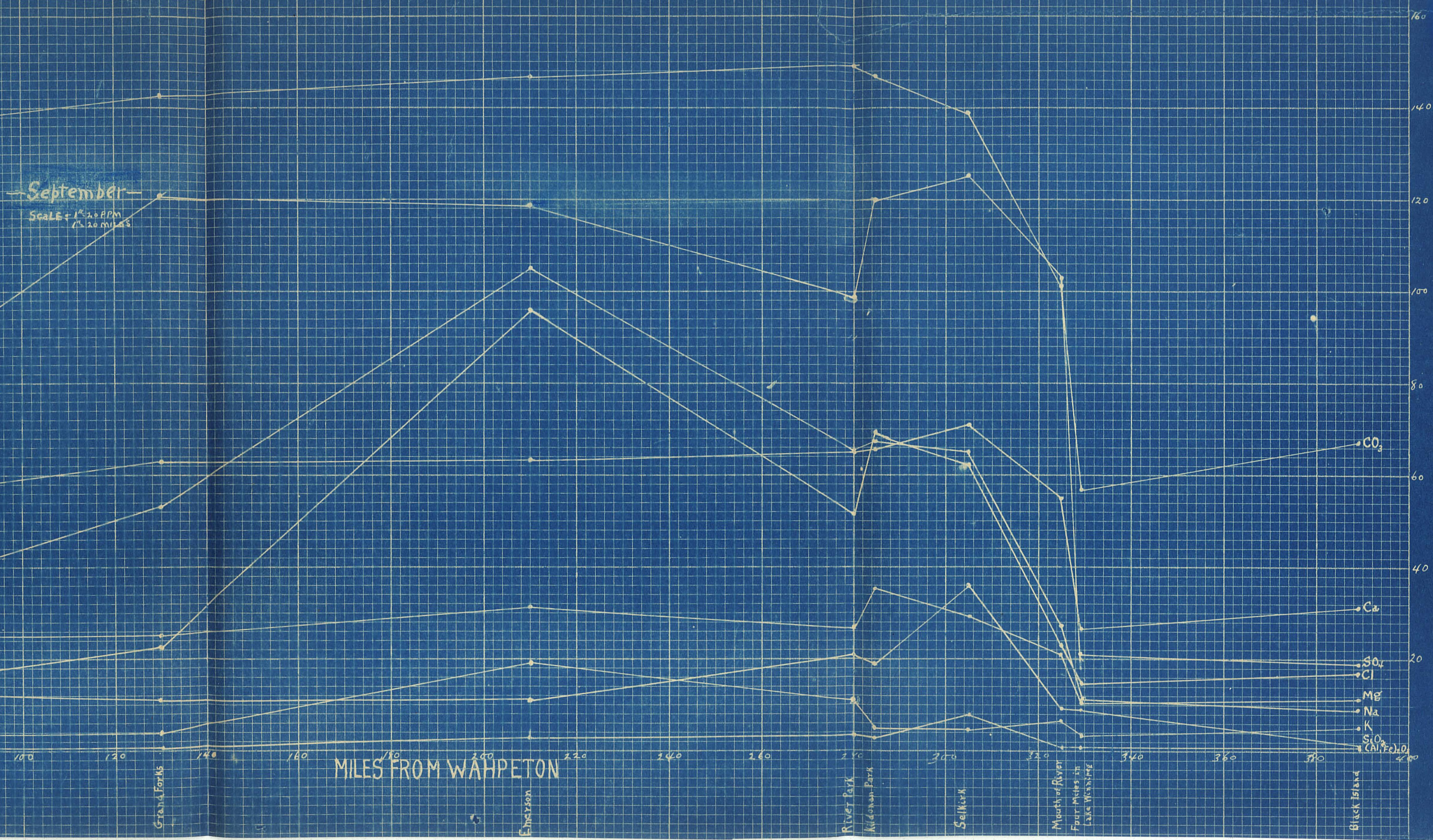
MILES FROM WAHPETON

20 40 60 80 100 120 140 160 180 200 220 240 260 280 300



September

Scale - 1" = 20 PPM
1" = 20 miles



MILES FROM WAPETON

Grand Forks

Emerson

River Park

Kildonan Park

Selkirk

Mouth of River
Four Miles in
Lake Winnipeg

Black Island

160

140

120

100

80

60

40

20

0

PARTS PER MILLION

Wahpeton

(Al₂Fe₂O₃)

K

Cl

Na₂SO₄

Mg

SO₄

Ca

CO₂

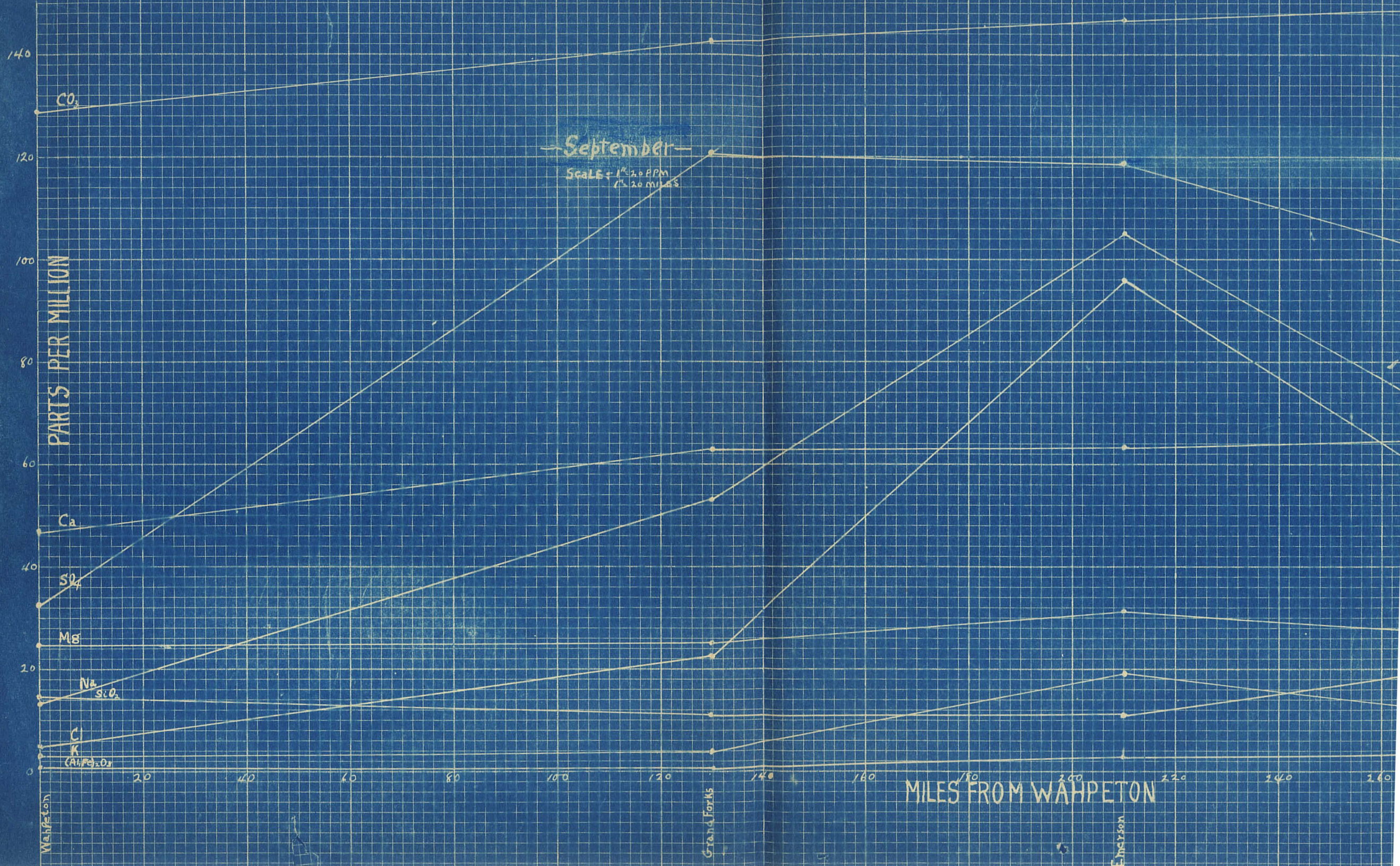
September

Scale - 1" = 20 PPM
1" = 20 miles

Grand Forks

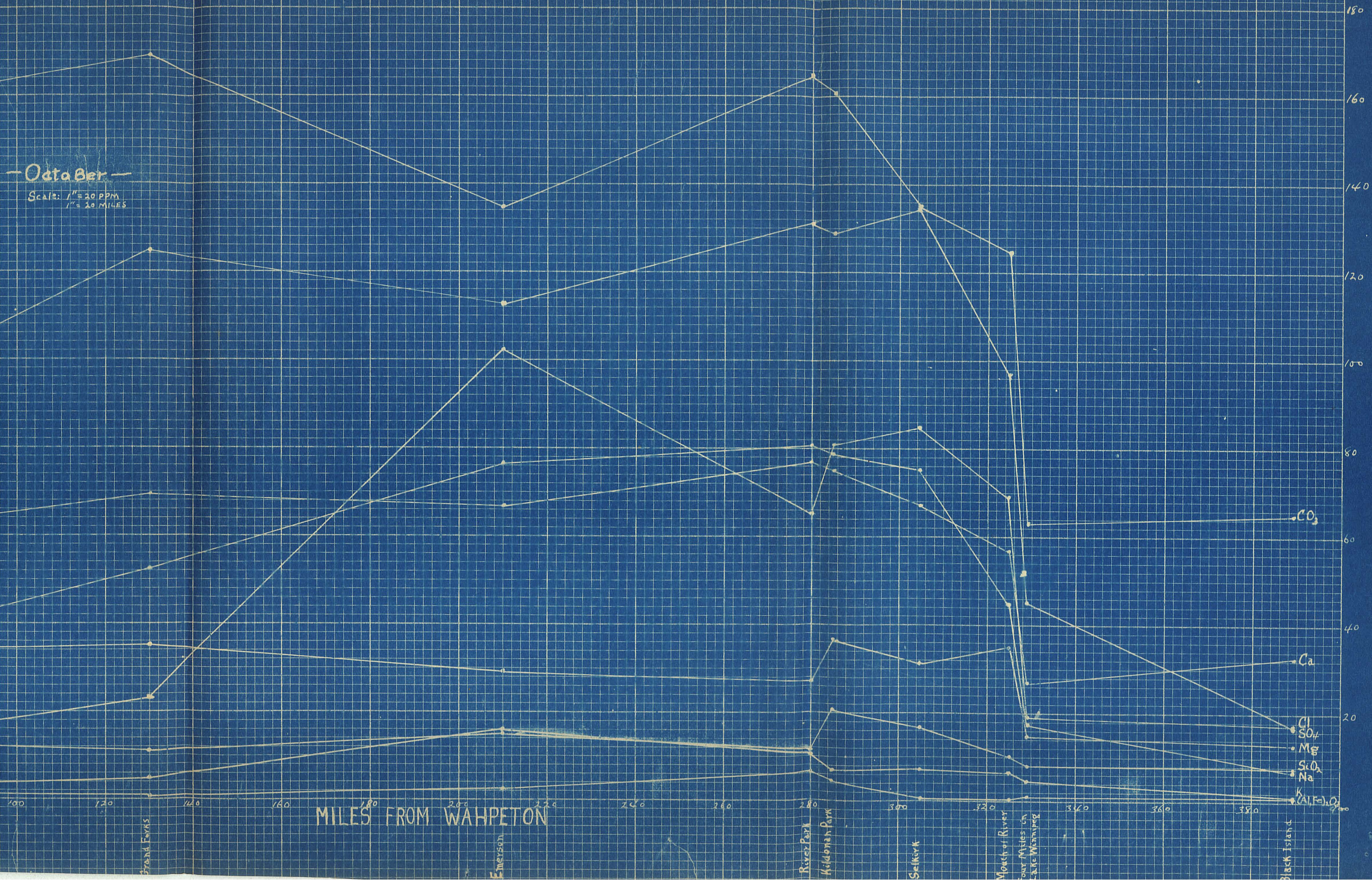
MILES FROM WAHPETON

Emerson



— October —

Scale: 1" = 20 PPM
1" = 20 MILES



180

160

140

120

100

80

60

40

20

0

PARTS PER MILLION

CO₂

SO₂

Ca

Mg

Na

SiO₂

Cl

(Al, Fe)₂O₃

K

— October —

Scale: 1" = 20 PPM
1" = 20 MILES

MILES FROM WAHPETON

Wahpeton

Grand Forks

Emerson

20

40

60

80

100

120

140

160

180

200

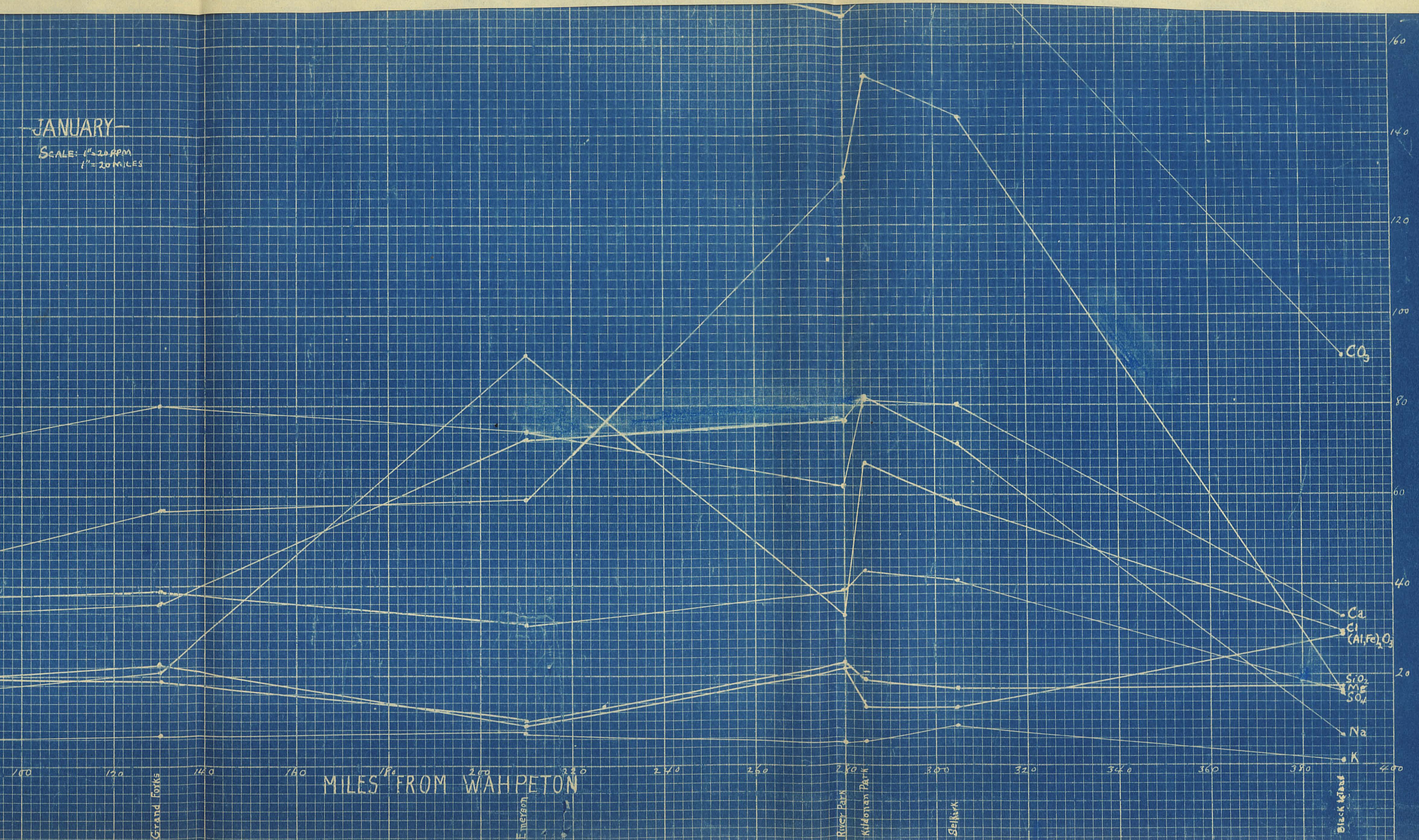
220

240

260

JANUARY-

SCALE: 1" = 20 RPM
1" = 20 MILES



150

160

140

120

100

80

60

40

20

0

PARTS PER MILLION

CO₂

Ca

Mg

Na

SO₄

SiO₂

(Al, Fe)₂O₃

Cl

K

JANUARY

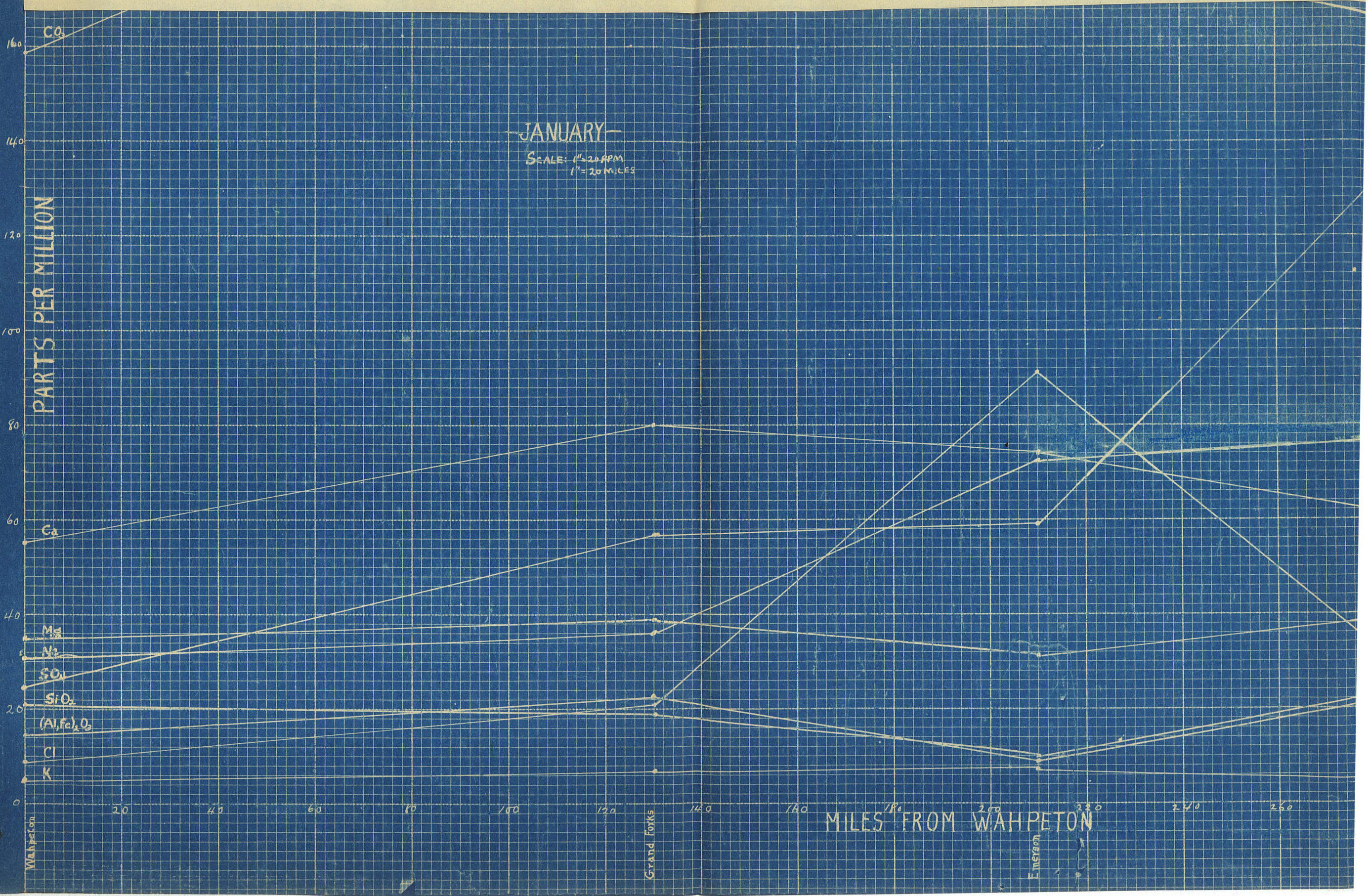
SCALE: 1" = 20 ppm
1" = 20 MILES

Wahpeton

Grand Forks

Emerson

MILES FROM WAHPETON



nate:

1" = 20 PPM

1" = 20 Miles

Grand Forks

Legend:

June

July

Aug.

Sept.

Oct.

Jan.

Emerson

River Park

Kildonan Park

Selkirk

Mouth of River

Black Island

Miles from Wahpeton

220

200

180

160

140

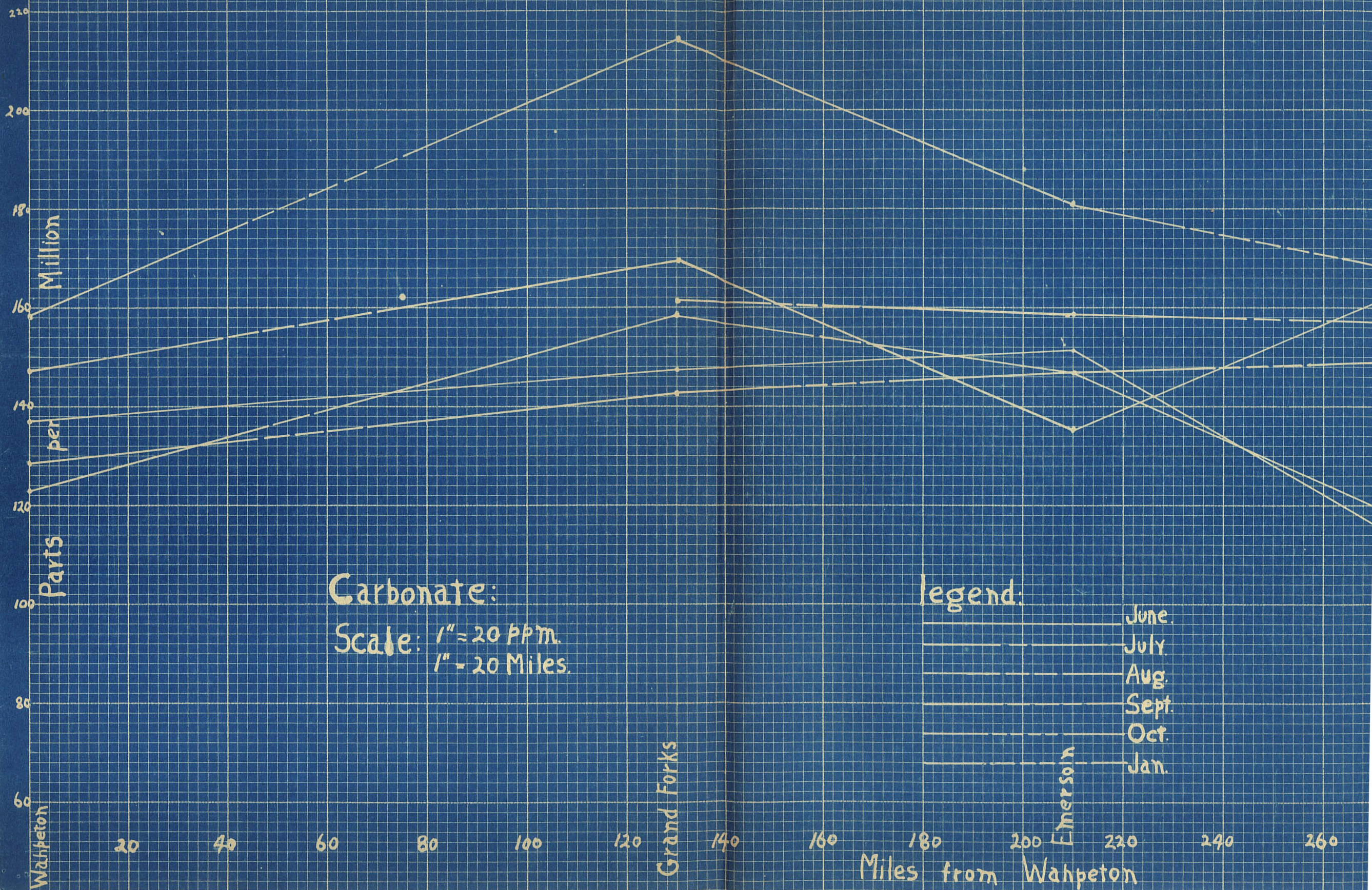
120

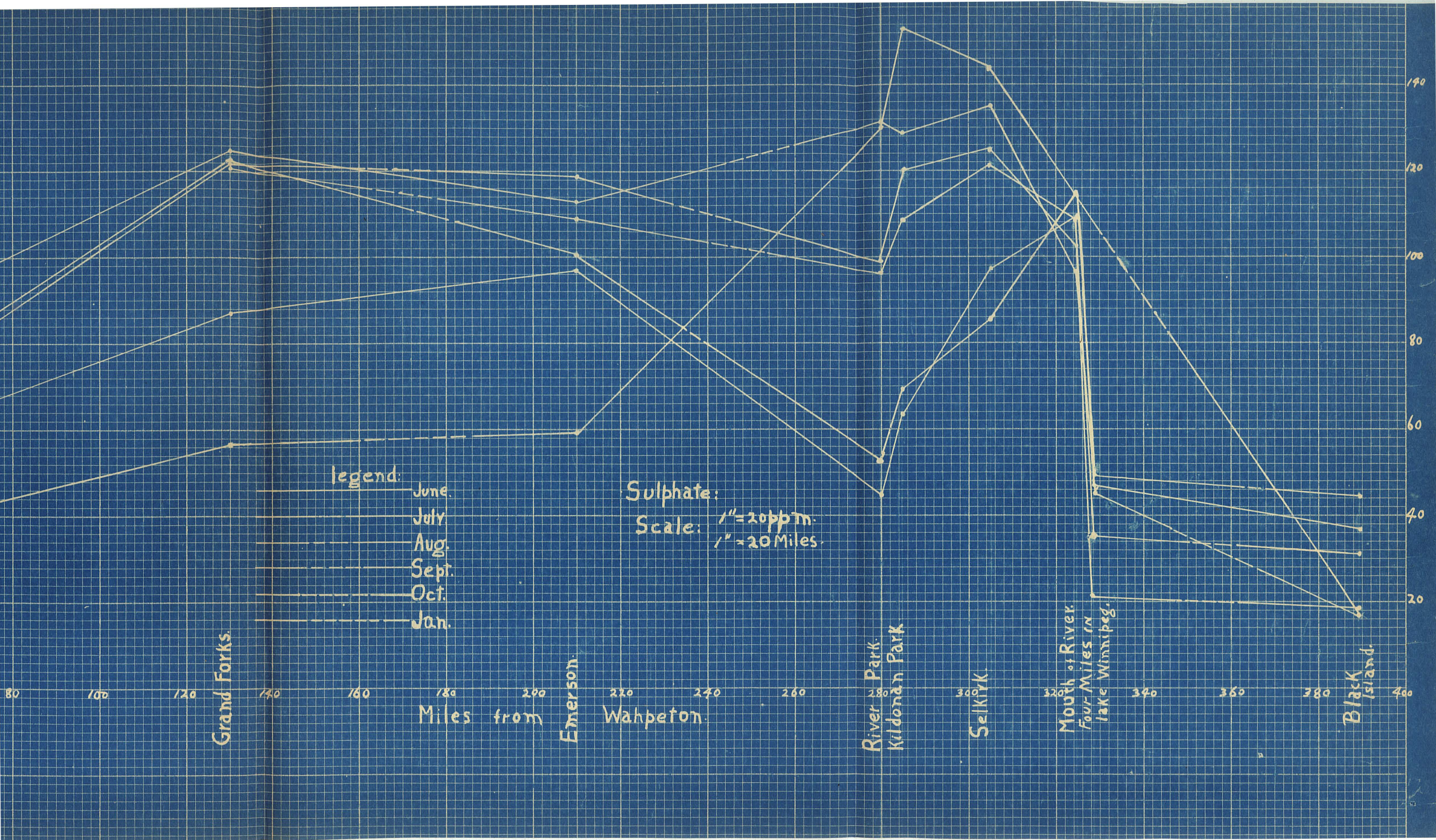
100

80

60

40





legend:

- June
- July
- Aug.
- Sept.
- Oct.
- Jan.

Sulphate:
Scale: 1" = 20 ppm.
1" = 20 Miles.

Grand Forks.

Miles from Emerson Wahpeton.

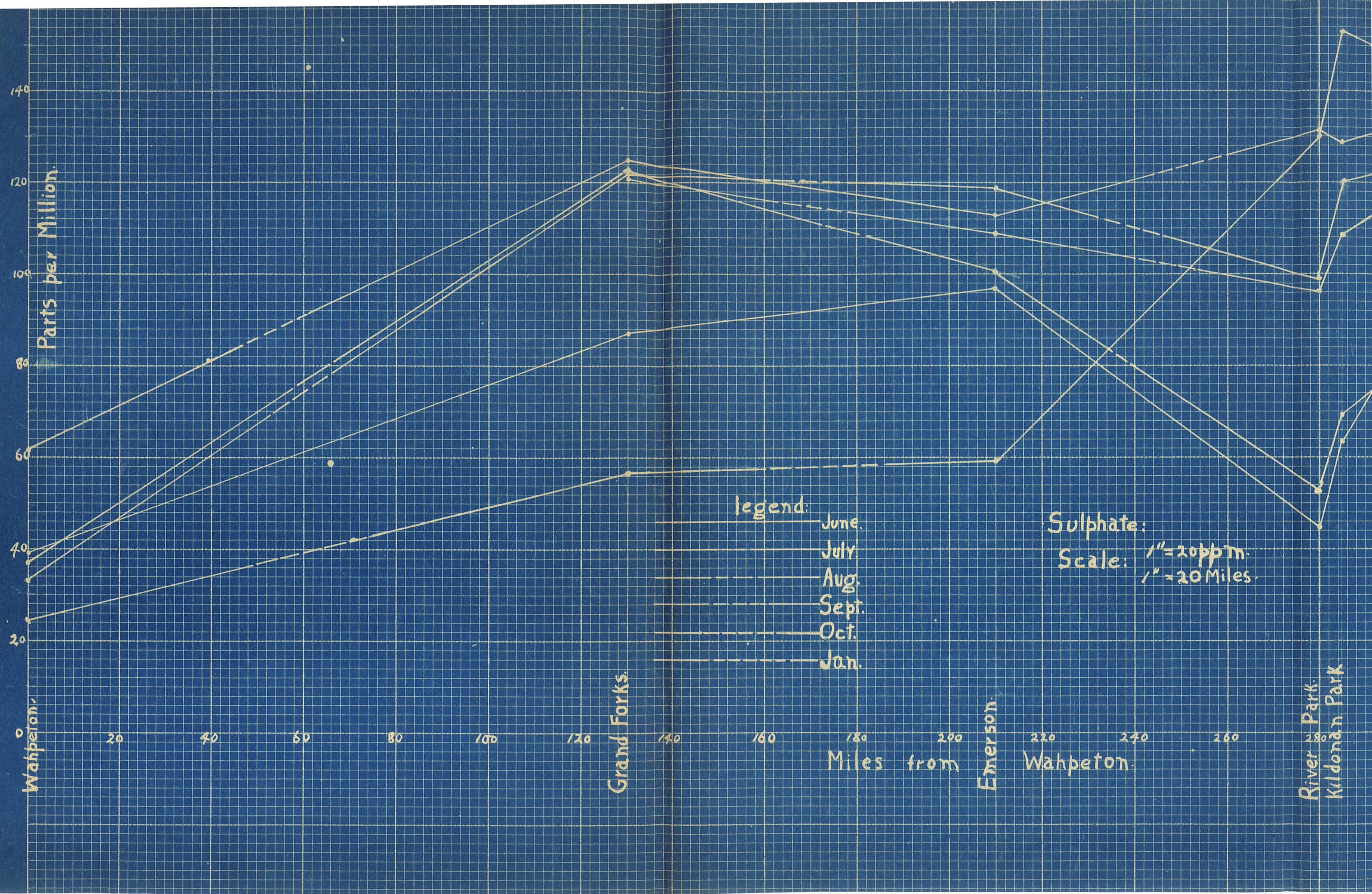
Emerson.

River Park.
Kildonan Park

Selkirk.

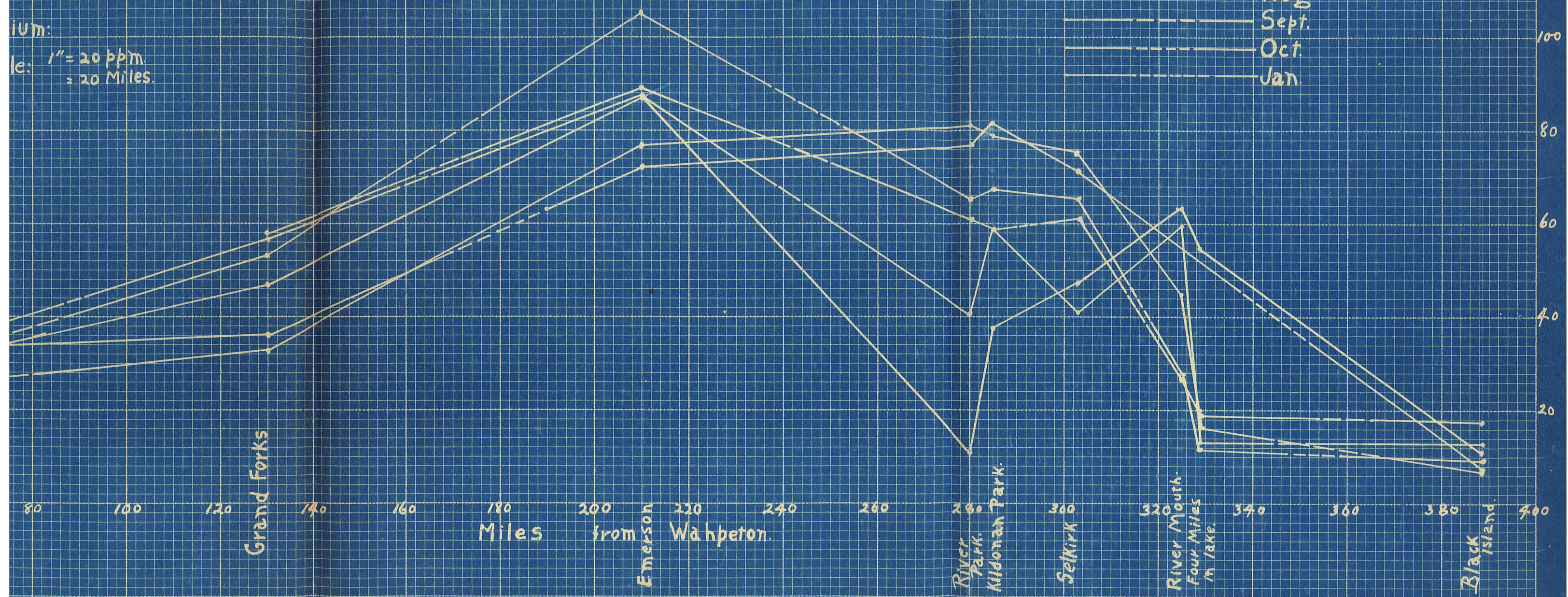
Mouth of River.
Four Miles in
Lake Winnipeg.

Black Island.



10m:
le: 1" = 20 ppm.
= 20 Miles.

legend:
June.
July.
Aug.
Sept.
Oct.
Jan.



140

120

100

80

60

40

20

0

Parts per Million

Wahpeton

20

40

60

80

100

120

140

160

180

200

220

240

260

Sodium:

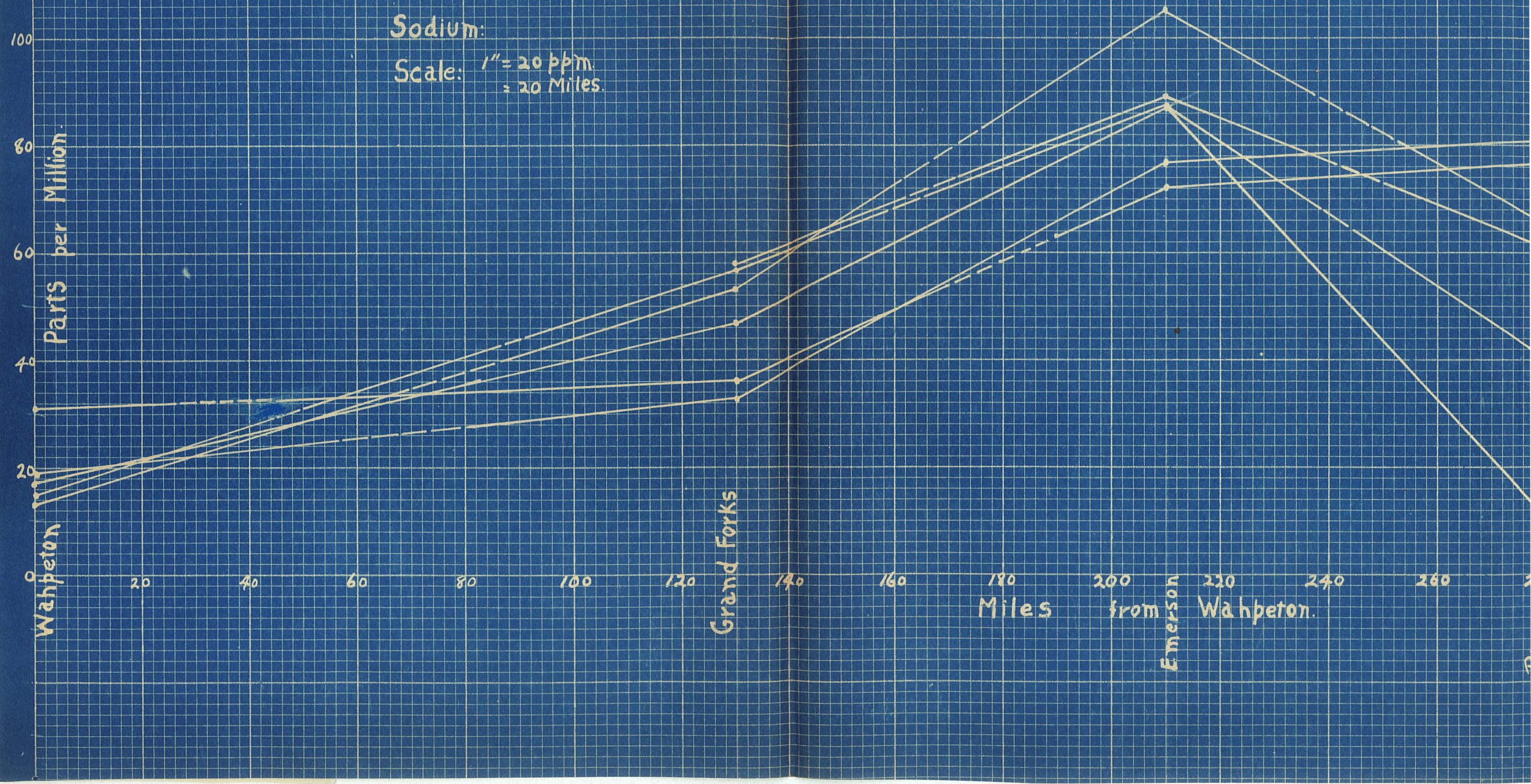
Scale: 1" = 20 ppm
= 20 Miles

Grand Forks

Miles

from Emerson

Wahpeton.



legend:

June.
July.
Aug.
Sept.
Oct.
Jan.

ca:

1" = 20 ppm.
1" = 20 Miles.

80

100

120

140

160

180

200

220

240

260

280

300

320

340

360

380

400

Grand Forks.

Miles from Wahpeton.

Emerson.

River Park.
Kildonan Park.

Selkirk.

Mouth of River.
Four Miles
in lake.

Black Island.

ppm.
Miles.

80

100

120

140

160

180

200

220

240

260

280

300

320

340

360

380

400

Grand Forks.

Miles from Wahpeton.

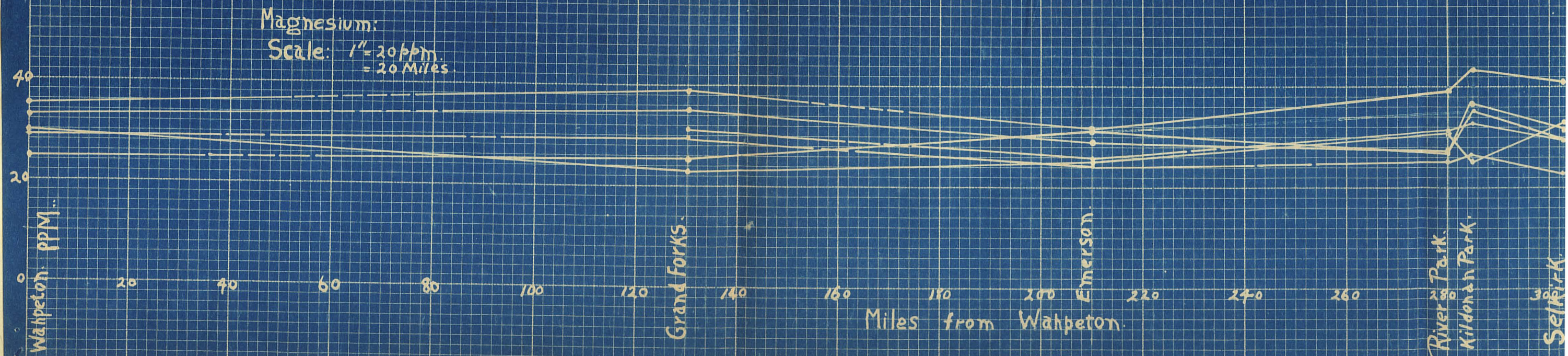
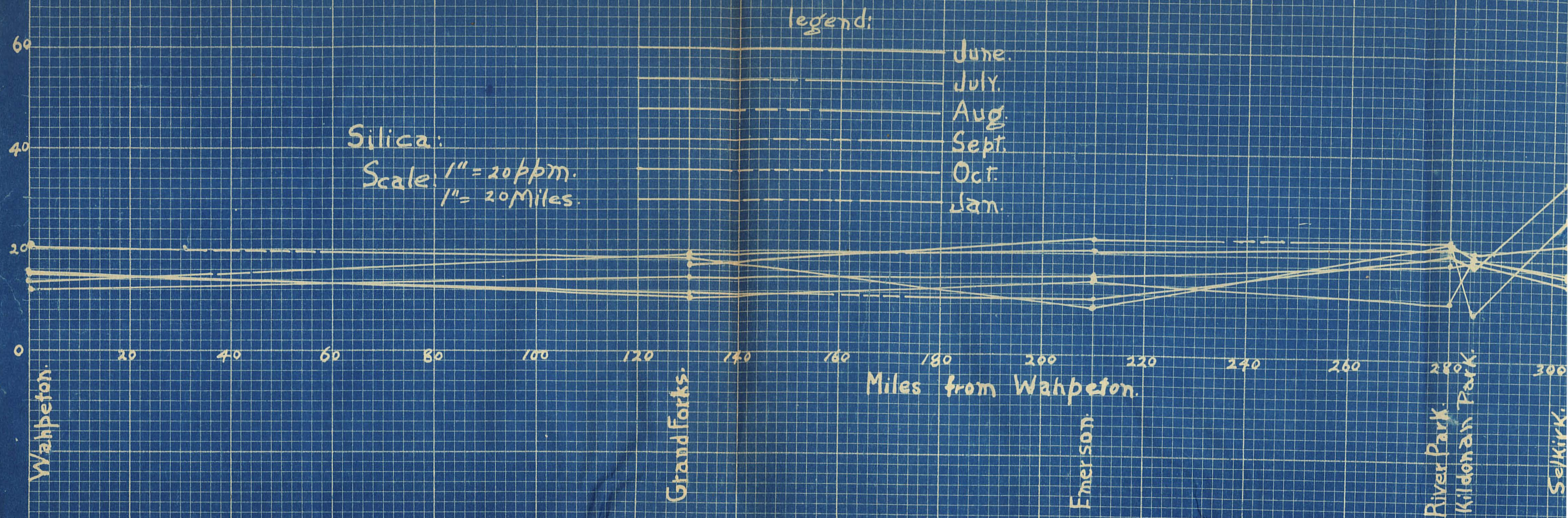
Emerson.

River Park.
Kildonan Park.

Selkirk.

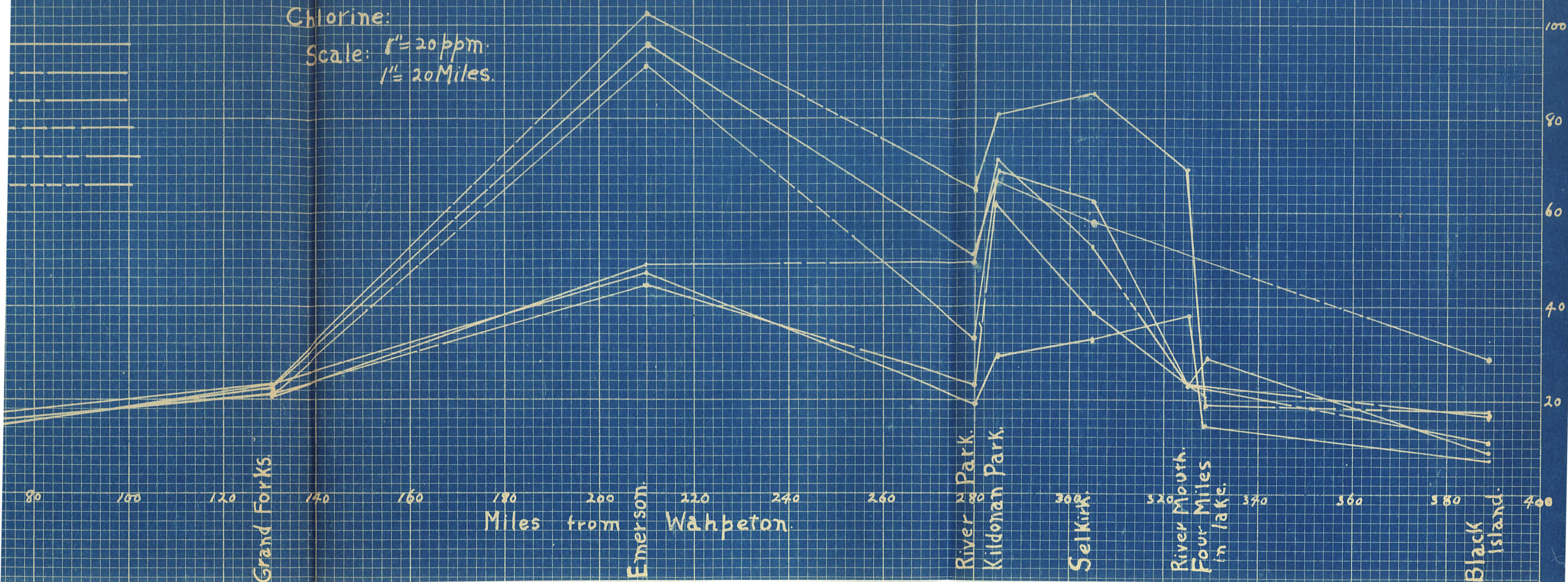
Mouth of River.
Four Miles
in lake.

Black Island.



Chlorine:

Scale: 1" = 20 ppm.
1" = 20 Miles.

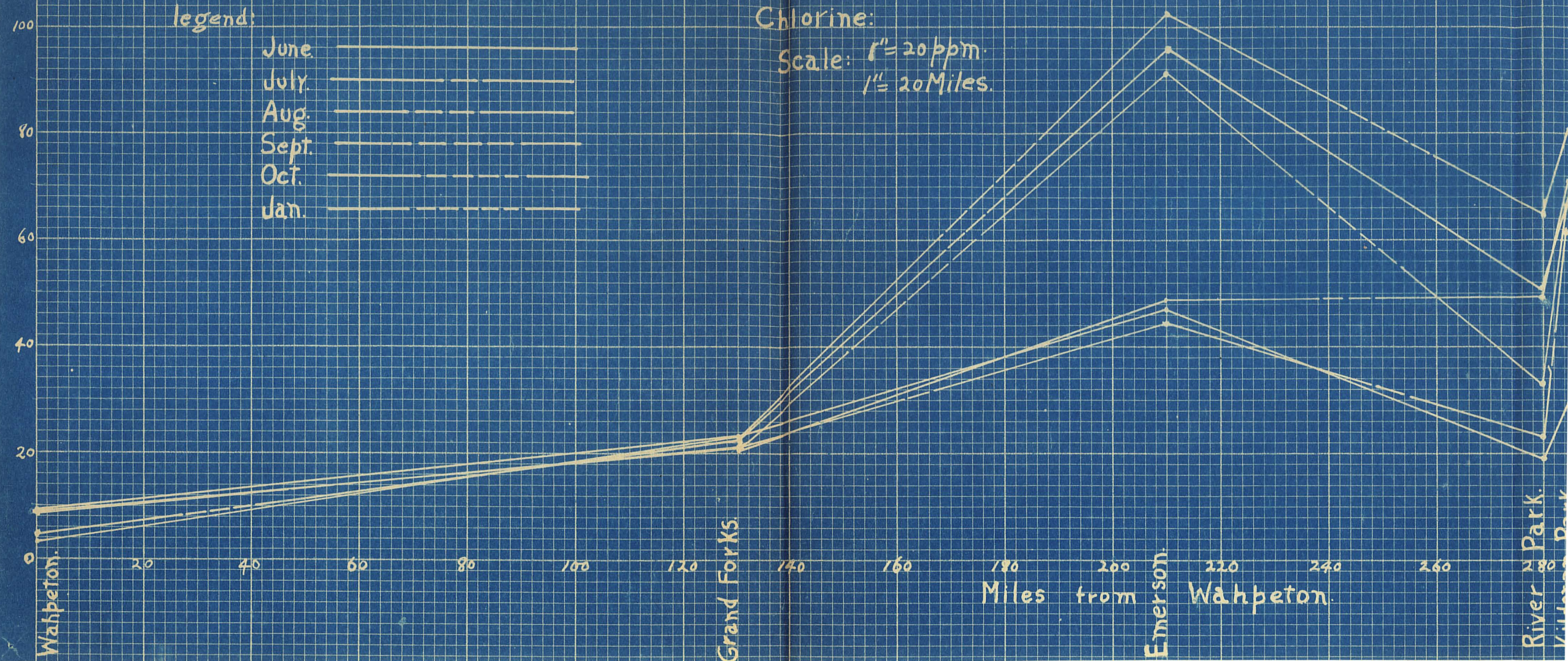


legend:

June	—————
July	—————
Aug.	—————
Sept.	—————
Oct.	—————
Jan.	—————

Chlorine:

Scale: 1" = 20 ppm.
1" = 20 Miles.

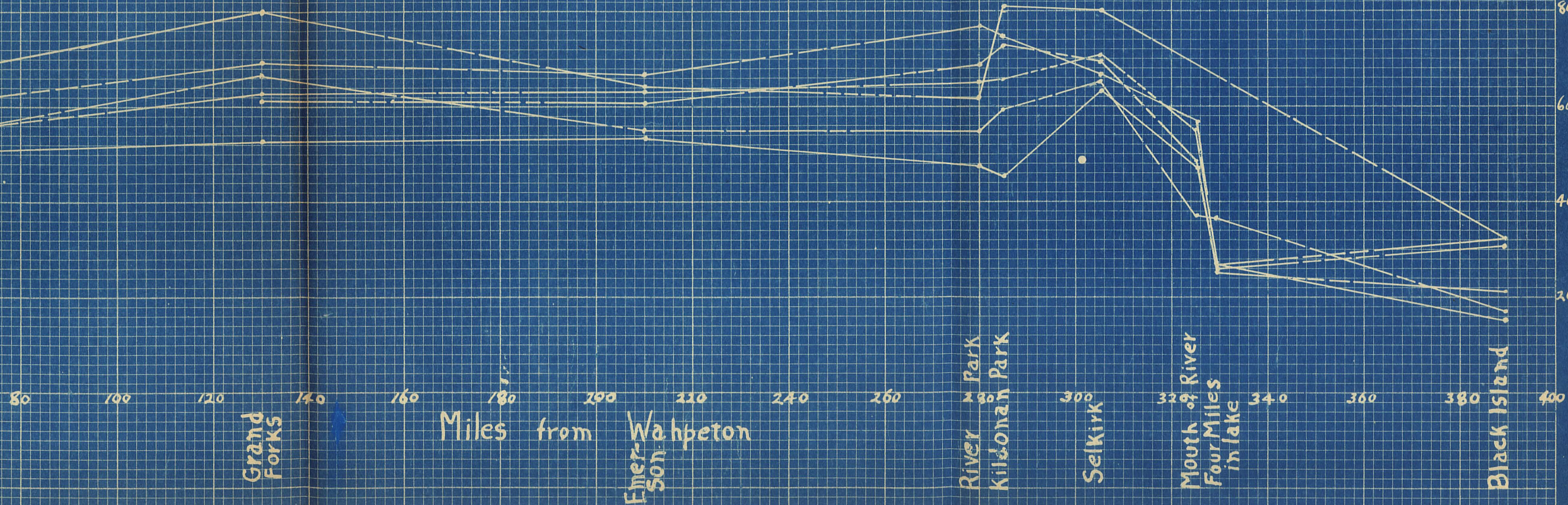


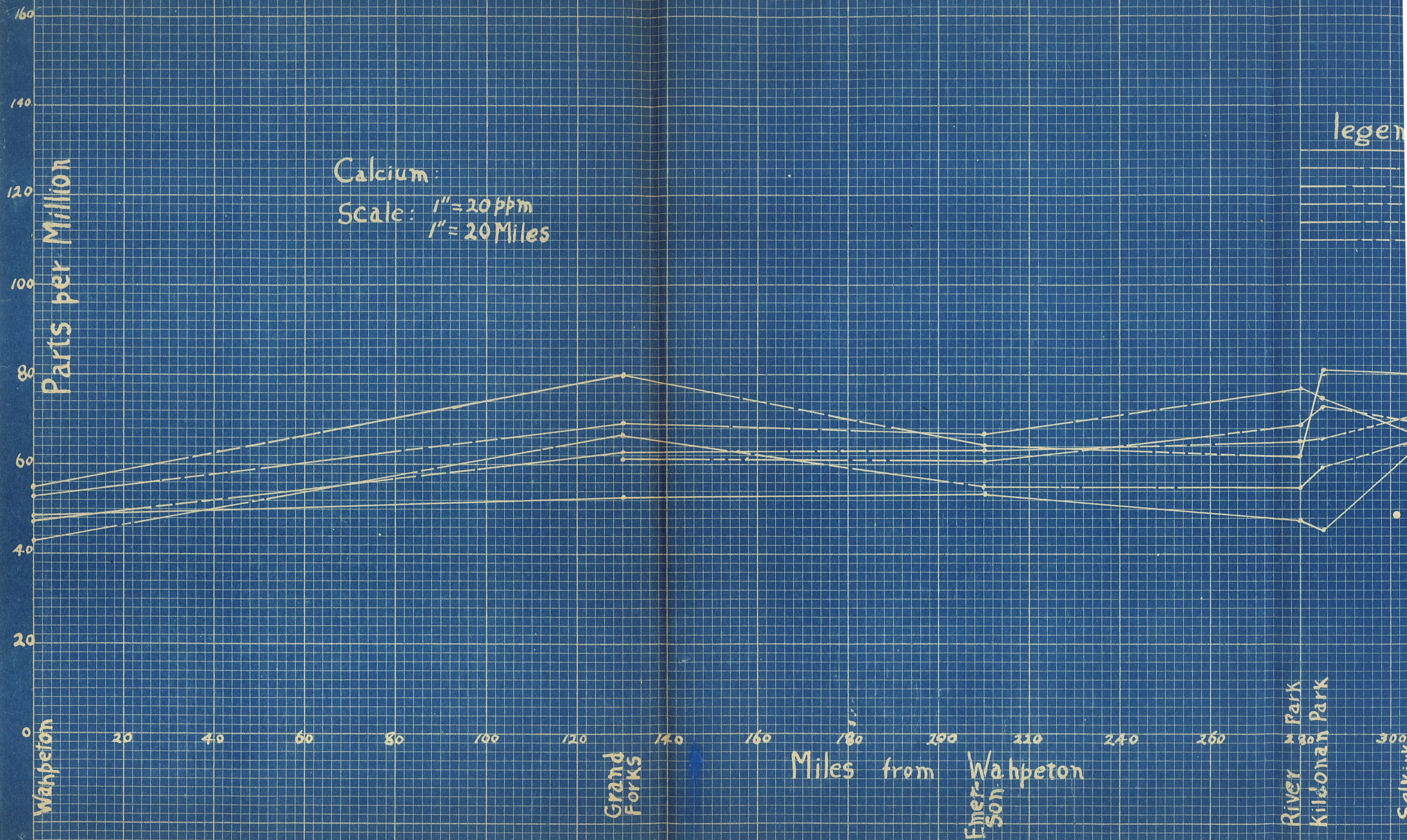
Calcium:

Scale: 1" = 20 ppm
1" = 20 Miles

Legend:

June.
July.
Aug.
Sept.
Oct.
Jan.

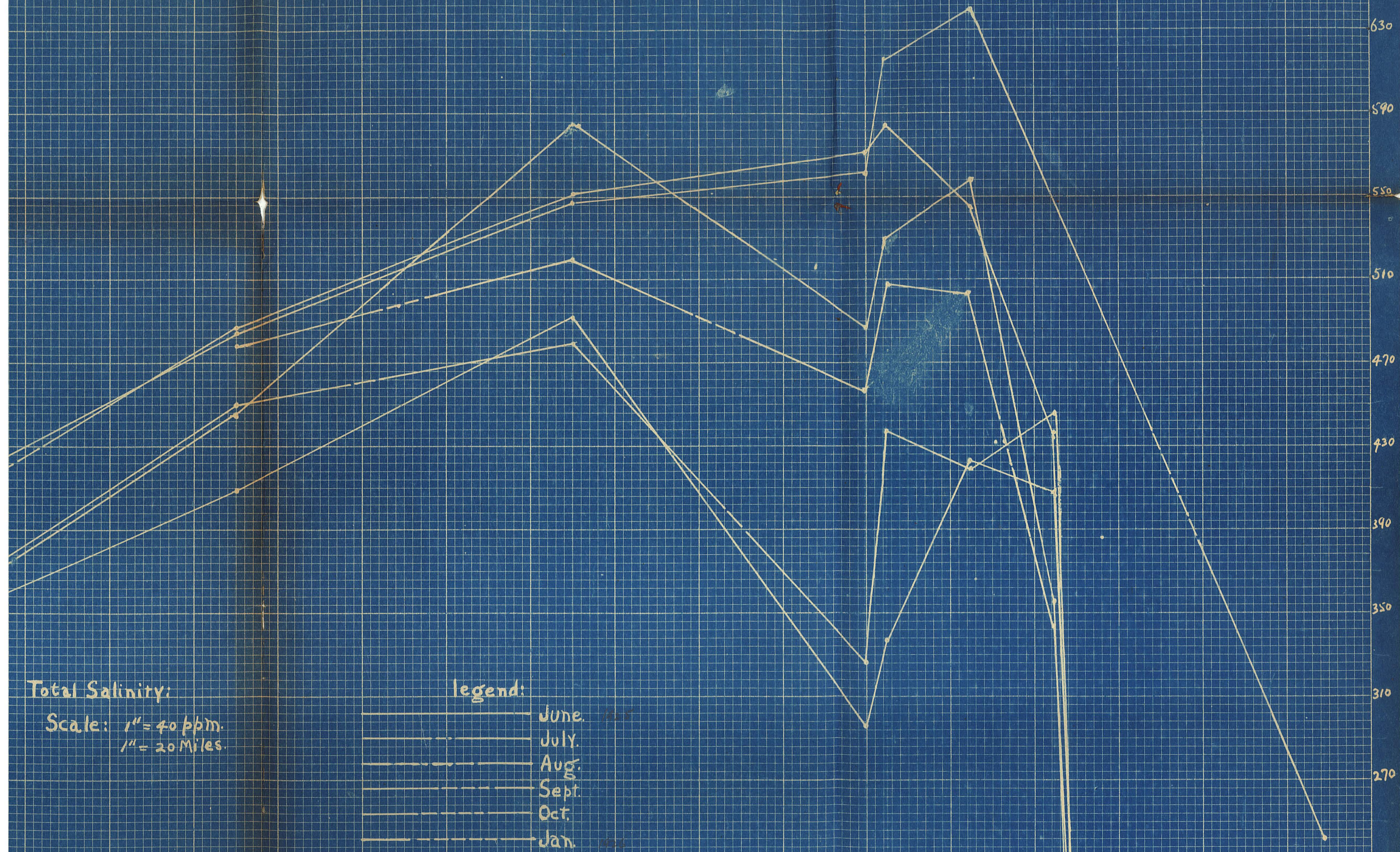




Total Salinity:

Scale: 1" = 40 ppm.
1" = 20 Miles.

Legend:



630
590
550
510
470
430
390
350
310
270

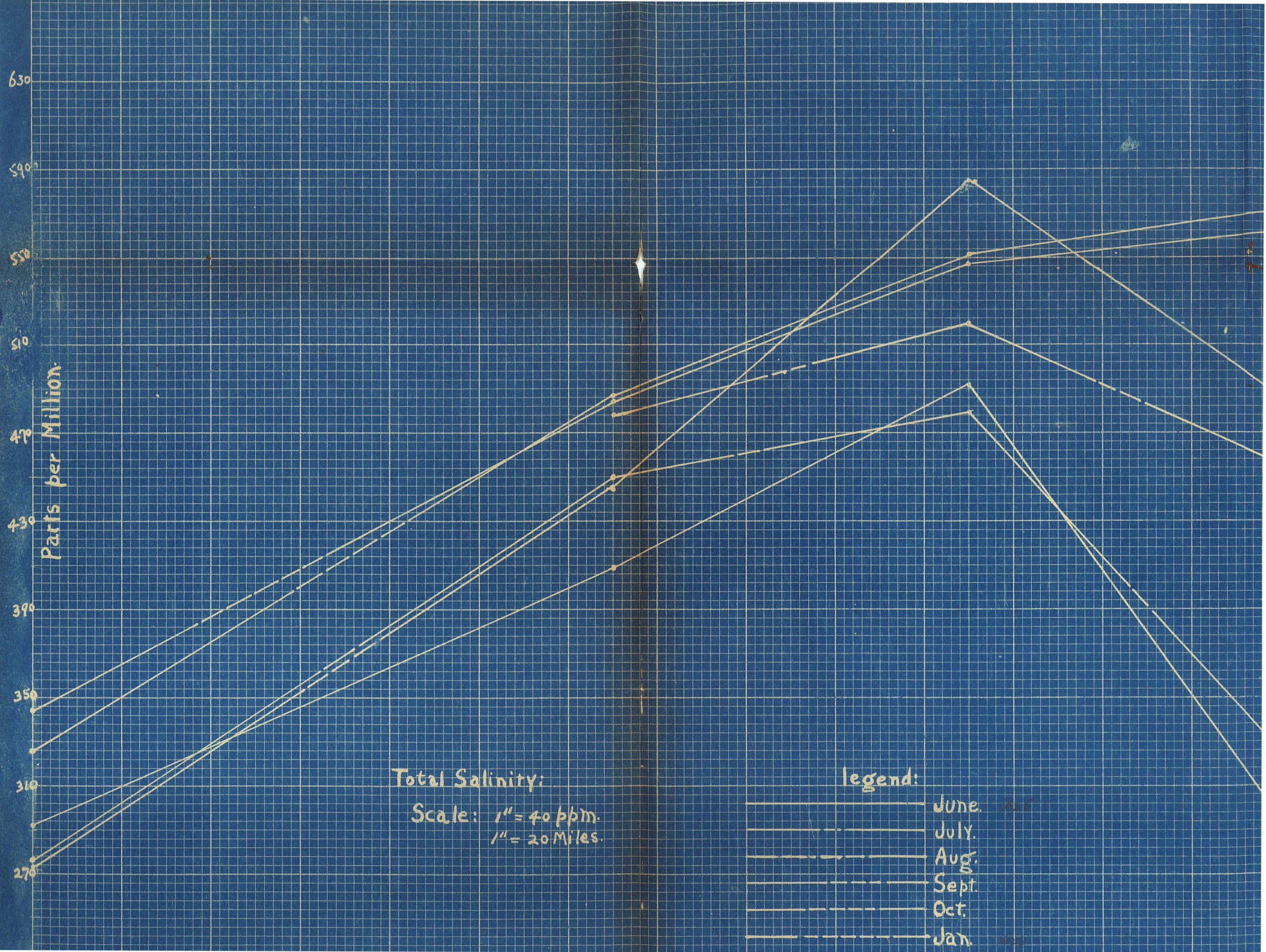
Parts per Million.

Total Salinity:

Scale: 1" = 40 ppm.
1" = 20 Miles.

Legend:

- June. 1915
- July.
- Aug.
- Sept.
- Oct.
- Jan. 1916



Total Salinity:

Scale: 1" = 40 ppm.
1" = 20 Miles.

Legend:

—————	June. 1915
- - - - -	July.
—————	Aug.
—————	Sept.
—————	Oct.
—————	Jan. 1916

Grand Forks.

Miles

from

Emerson.

Wahpeton.

River Park.
Kildonan Park.

Selkirk.

River Mouth.

Black

Parts per Million

510
470
430
390
350
310
270
230
190
150
110

Total Salinity:

Scale: 1" = 40 ppm.
1" = 20 Miles.

Legend:

- June. 1905
- July.
- Aug.
- Sept.
- Oct.
- Jan. 1906

Wahpeton.

Grand Forks.

Emerson.

Miles from Wahpeton.

20 40 60 80 100 120 140 160 180 200 220 240 260