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Return flow study of the North Platte River

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Department:

RETURN FLOW STUDY OF THE NORTH PLATTE RIVER

BY

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A

THESIS

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PREFACE

The data used as the basis for this thesis was obtained from an original study of Return Flow from Irrigation of the North Platte River, made during the summer of 1930. The original study was made by the author in conjunction with Mr. J. J. Doland, Assistant Professor of Civil Engineering, University of Illinois, while in the employ of the War Department, U.S. Engineer Office, Kansas City, Missouri. The present writing is in no way a reproduction of the original report on the problem as turned over to the War Department, but the author's own discussion from the original data and work sheets.

Acknowledgment is rendered Lt. J. M. Young, in charge of the Office, and Professor Doland for permission to use the original data as a basis for a paper.

E.W.C.

CONTENTS

	Page
INTRODUCTORY	1
GENERAL CONSIDERATIONS	3
Topography	3
Geology	4
Surface Waters	5
Climate	5
Soils and Crops	6
Irrigable Area on Project	6
Irrigation Plan of the North Platte Project	7
FACTORS AFFECTING RETURN FLOW	9
Water Applied by Irrigation	9
Precipitation	12
Evaporation	12
Soil Evaporation	15
Interception	15
Transpiration	15
Canal Seepage and Evaporation	16
Reservoir Losses	17
Surface Waste	17
Deep Percolation	18
DISCHARGE RECORDS OF THE NORTH PLATTE RIVER	18

CONTENTS (CONTINUED)

	Page
MODIFIED FLOW HABITS OF STREAM	19
Development of Storage	19
Development of Irrigation	20
Development of Drainage	21
Construction of Flow-Habit Graphs	21
RETURN FLOW CALCULATIONS	25
General	25
Summary of Diversions	27
Return Flow Calculation from Canal Diversions	32
Visible Return Flow	34
Summary of Flow Accounting	37
Method of Determining Gain in River Flow	37
SUMMARY OF STATISTICAL DATA	39
CONCLUSIONS	40
Bibliography	42

TABLES AND CHARTS

		Page
Table 1:	Area Irrigated Under Government Project .	6
Table 2:	Summary of Total Irrigable Area, Path. Div.	7
Fig. 1 :	Coefficient of Variation From Mean Flow, Bridgeport	23
Fig. 2 :	Coefficient of Variation From Mean Flow, North Platte	24
Table 3:	Irrigable Acreage and Water Delivery - Ft. Laramie Div.	27
Table 4:	Irrigable Acreage and Water Delivery - Interstate Div.	28
Table 5:	Irrigable Acreage and Water Delivery - Tri-State Canal	29
Table 6:	Irrigable Acreage and Water Delivery - Northport Div.	29
Table 7:	Summary of Water Diverted from North Platte River	30
Fig. 3 :	Measured Visible Return - 1921-29- Monthly Average	35
Fig. 4 :	Measured Visible Return - 1921-29-Yearly.	36
Table 8:	Summary of Flow Accounting	38
Fig. 5 :	Map of North Platte Project	44

RETURN FLOW STUDY OF THE NORTH PLATTE RIVER

INTRODUCTORY

The investigation of return flow on the North Platte River, between Whalen, Wyoming and North Platte, Nebraska, was authorized by House Bill No. 308, "Flood Control Act," Mississippi River and Tributaries, February, 28, 1929. The purpose of this study was to determine, if possible, the amount of return flow from the United States Reclamation Service "North Platte Irrigation Project", and its effect on the future development of irrigation in the North Platte Valley, flood control of the North Platte River, and it's ultimate effect upon navigation possibilities of the Missouri River.

The particular phase of the above problem of which this paper has a bearing, is the effect of the return flow of the North Platte River on the future development of irrigation in the North Platte Valley and the resultant change in the flow habits of the stream.

Previous investigations have been carried on in a more or less complete manner by Mr. R. H. Willis, Water Superintendent for the State of Nebraska, and to a limited extent by the Reclamation Service. These past

investigations have all been of value, but in most cases have covered a comparatively short period of years and with insufficient data available for the proper solution of the problem.

This paper attempts to consider not only the amount of increase by which the normal flow of the North Platte River has been augmented, but also to consider the periods of the water year in which the increase may reach a maximum and the period in which it is a minimum. The economic value is not only the determination of the extent of the return flow and its practical importance in the management and distribution of water to irrigators, but it will afford, in a general way, a means of evaluating this return flow in future diversions.

In the present investigation it was found to be impracticable to make any well defined distinction between seepage, return flow, and surface runoff. Although in the solution of the problem it will become apparent that a number of the various factors, such as precipitation, evaporation, surface run off, visible and invisible return automatically take care of themselves, and that the ultimate result (the gain in river flow) can only be accounted for by the return flow directly or indirectly from diversions due to irrigation

of adjacent lands.

After careful consideration of all the available data regarding stream flow measurements, diversions, storage, irrigated areas, climatological data, etc., it was deemed advisable to attack the problem by sectionizing the river and treating the problem as two distinct parts or periods; namely, the period prior to 1909 or before the construction of Pathfinder Reservoir, and the period 1920 to 1930, or the period of great irrigation development.

GENERAL CONSIDERATIONS

Topography:- The region is a portion of the Great Plains, which in general present wide tabular surfaces sloping eastward, with isolated buttes and outlying ridges, and with shallow river valleys margined by irregular and often deeply incised slopes. The topographic features vary considerably, and it is difficult to make concise statements that will apply to the entire valley. In general, the larger topographic features are the wide valley of the North Platte River, the table-land surmounted by sand hills to the north, and the spurs of table-land on the south, which is a part of the high plain extending to the southern border of the State.

The valley of the North Platte River lies from 500 to 600 feet below the general level of the adjoining highlands, having an altitude of about 4600 feet on the east to 4800 feet on the west, with a fall of about six feet to the mile. Along the center of the valley is a level plain on either side of the river extending from one to three miles to slopes and low terraces which reach back several miles to a line of buttes rising abruptly to the highland level.

Geology:- The formations appearing at the surface are clays, sands, soft sandstones, conglomerates, calcareous grits, volcanic ash, and mixtures of sand and gravel. They are all of sedimentary origin. The greater part of these deposits are in sheets, lying one above another and having a general downward slope to the east and to the south. In the valleys these are thin sheets of material brought by the streams and spread over the eroded surfaces of the older formations, while on the uplands there are extensive areas of wind-blown sands, forming dunes. The entire area is underlain with Brule clay, a pale, buff-colored, sandy clay of compact texture, locally known as "harapan". About 350 feet of this clay is exposed on the slopes of the North Platte Valley, and it probably extends somewhat

deeper below the surface. It sometimes contains thin beds of sand and conglomerate, which may explain the probable loss of water from the North Platte Valley to the Republican River on the south as underflow.

Surface Waters:- The North Platte is a constantly flowing stream which occupies a bed averaging over a half-mile in width. In the spring months the flow of water is several feet deep, but in the summer it dwindles greatly and finally occupies only shallow channels among sand banks. As a large volume of water is taken out of the river by the various irrigation canals in Nebraska and Wyoming, the records of flow at various gaging stations do not indicate the total volume of water which flows down the valley. It should be borne in mind also that under the bed of the river there is considerable an underflow of greater volume than that flowing over the surface in the long period of dry weather.

Climate:- Western Nebraska and eastern Wyoming have a climate of typical Plains character. It is dry and hot in the summer, moderately moist in late spring, and cold with little snow in winter. The range of temperature on the irrigable area is from -38° to 104°F. The average elevation of the irrigable area is

about 4,100 feet above sea level. The length of irrigating season is 183 days, April 1 to September 30. Since the climate is classed as semi-arid, the yearly rainfall on the irrigable area is rather low, being 14.66 inches for a ten year average.

Soils and Crops:- The character of the soil of the irrigable area varies from the sandy soils on some portions of the Interstate unit to the heavier gumbo soils occurring in some portions of the Fort Laramie unit. A greater part of the soil is a sandy loam. The principal products are alfalfa, cereals, corn, sugar beets, and potatoes.

TABLE I

AREA IRRIGATED UNDER GOVERNMENT PROJECT
NORTH PLATTE VALLEY

Year	Pathfinder or Interstate	Goshen Hole and Ft. Laramie	Northport	N.P.C.C.	Total
1910	42362			6175	48537
1911	44736			4675	49411
1912	50252			5381	55633
1913	56829			6377	63206
1914	60532			7168	67700
1915	70007			8050	78057
1916	75620			8588	84208
1917	83203			9350	92553
1918	86464	4865		9137	100466
1919	88990	6258		10428	105676
1920	88005	8537	1220	9635	107397
1921	86955	12254	1737	11022	111968
1922	87300	20090	3645	12042	123077
1923	87404	32441	8950	10833	139628
1924	81888	39064	9169	7615	137736
1925	84116	69093	9489	8686	171384
1926	84248	76315	10268	9930	180761
1927	87873	77689	9419	9481	184462
1928	89894	84632	11241	10250	196017
1929	87995	89072	11385	8962	197414

This acreage could be materially increased should water be available, as is shown by the following data:

TABLE 2

SUMMARY OF TOTAL IRRIGABLE AREA
PATHFINDER DIVISION 1928

	Class 1	Class 2	Class 3	Class 4
Total Irrigable Area:	8,525	17,718	23,850	35,657
Less Wyoming Lands:	0	87	57	1,028
	8,525	17,631	23,793	34,629

	Class 5	Class 6	Totals
Total Irrigable Area:	28,255	445	114,450
Less Wyoming Lands:	1,634	84	2,890
	26,621	361	111,560

While this table represents only one of the four districts under the Government Project, there is considerable irrigable area in each division not now under water, which might be placed under irrigation possibilities obtained.

The Irrigation Plan of the North Platte Project: - The plan of the project provides for an average of two and one-half acre-feet of water per acre per annum at the farm. This figure was found

to be considerably below the actual duty of water as practiced on the project as will be noted from a further study of the problem.

The charges per acre of irrigable land for constructing the project ranges from $45.00 to $55.00; the annual operation and maintenance, $1.00 per acre-foot of water used before June 20 and after August 31; $1.50 per acre-foot for water used after June 20 and before September 1, with a minimum charge of $2.20 per acre.

The project provides for the storage of flood waters of the North Platte River in a reservoir controlled by the Pathfinder Dam, about three miles below the junction of the North Platte and Sweetwater Rivers and about 50 miles southwest of Casper, Wyoming, Reservoir, Guernsey, Wyoming. Additional storage and control of the river is obtained in smaller reservoirs along the canal lines; and the diversion of water from the North Platte River by a dam near Whalen, Wyoming into the Interstate Canal, supplying water for lands on the north side of the river, and into the Fort Laramie Canal, watering lands on the south side of the river.

The completed features are: Pathfinder Reservoir,

Guernsey Reservoir, Whalen Dam, the Interstate Canal system, the Fort Laramie Canal system, Reservoir No. 1, known as Lake Alice, and Reservoir No. 3 known as Lake Minatare. All area as represented on the appended map of the North Platte Project as coming under the Warren Act Contracts, is furnished water by the Government through the various canals as indicated on the map.

FACTORS AFFECTING RETURN FLOW

Water Applied by Irrigation:- In determining the amount of water applied in irrigation, the problem divides itself into two factors, irrigable area and local duty of water. The first is simply measured, except in some special cases, while the second factor is not so easily handled, as the local duty of water is as yet a matter of jugement. It varies with the soil types, present and future crops, drainage, character of supply and extent of cultivation.

The depth of water necessary for irrigation depends largely on the skill and care with which the land has been prepared for irrigation and on the skill of the irrigator in applying the water. The depth of the water applied too often has no relation to the amount needed, but usually is the maximum that can

be obtained even though harmful to the land. The U. S. Army Engineers and the U. S. Geological Survey have adopted 2½ acre feet per acre as the duty of water for irrigation measured at the point of diversion, allowing nothing for evaporation and seepage in canals and ditches.

Mr. Perry, Water Superintendent at Mitchell, Nebraska, states that canal losses run from one third to one half of the total water diverted, and that canals through burle clay show greater losses than through sand, as this clay has seams through which water percolates readily. Assuming Mr. Perry's observations to be reasonably correct, these losses would leave from 1.12 to 1.70 acre feet per acre as the duty of water delivered at the farm, which is hardly sufficient to satisfy the consumptive use requirements of the major crops grown on this project. Therefore the recommended duty of water by the Bureau of Reclamation as 2½ acre feet per acre at the point of diversion is found to be insufficient,and it was found from this study that the actual duty of water as practiced on this project was 3.25 acre feet per acre at the point of diversion.

The almost universal disposition of irrigators to

use too much water is well known. Few supplies are dependable, particularly during the latter part of the irrigating season when the streams are low. This results in the wasteful and harmful plan of using excessive quantities during times of plenty to store water in the soil. The water-logging and temporary ruining of large areas of valuable land is the general experience in almost all western irrigation projects. The North Platte Project, being comparatively young, has not as yet experienced a great deal of lost acreage due to water-logging, although some lands bordering the river have been lost to cultivation and this practice of excessive use of water has brought about a drainage problem even in so young a project.

This excessive use of irrigation water has materially affected the return flow as evidenced by the chart of Visible Return Flow on page 35. The excess water is wasted back to the stream through drainage canals. This excess consists of surface water from the irrigated fields, canal waste and seepage. The chart shows a material gain in visible return during the irrigating season of May to October, which is directly accountable to irrigation. The excess return during the months of October, November and December is seepage return, which

takes a longer time to reach the drains as visible flow.

Precipitation:- The precipitation records between Whalen and North Platte were studied in great detail, but for the exception of a few extremely wet years, such as 1915, 1918 and 1923, the precipitation records show little or no variance from the normal. Therefore, the gain in river flow during the period of 1920 to 1930 was not due to precipitation, as the runoff return from precipitation was on an average the same for both periods of study, i.e., previous to the irrigation development and afterwards. In other words, the gain by the river from precipitation return balanced in both periods therefore could be properly neglected in this problem.

Evaporation:- Considerable study was made on the probable loss of water over the whole irrigated area through the medium of evaporation. The water losses classified as follows:

Water area: Evaporation
Land area : Soil evaporation,
Interception
Transpiration.

Very little reliable data was obtainable on actual evaporation, as North Platte was the only station in

or near the Project where completed records were available. Here the average evaporation per year was 42.63". The results were obtained by the "pan" method from a free water surface. Partial records of evaporation from a free water surface were obtained at Mitchell and Fort Laramie. Since records of evaporation were not available at the majority of control points for their investigation, a number of stations outside the area from which reliable data were to be had, were found to check very closely with results obtained by calculating the evaporation by the Dalton-Meyer formula: Example, North Platte, Nebraska:

A 15 year record gives the evaporation from a free-water surface of 42.63" per year (pan method).

By the Dalton-Meyer formula:

Let E = evaporation

" Vw = maximum vapor pressure

" V = average vapor pressure in air

" W = wind velocity.

Then $E = 15 (Vw - V) (1 + \frac{W}{10})$

Substituting values for North Platte,

$12 \times E = 12 \times 15 (.342 - .342 \times .65) (1 + .92)$

$= 41.3"$ per year.

This value checks very closely with the actual

record of 42.63" per year.

Having found that the Dalton-Meyer formula could be used with some confidence, the evaporation from a free-water surface was calculated for the following stations:

Station	Evaporation in inches per year
Pathfinder Reservoir	49.7
Fort Laramie	39.1
Mitchell	38.2
Scottsbluff	40.5
Bridgeport	39.8
Oshkosh	40.5
North Platte	41.3

While this data was of little value in calculating "return flow", as the increased evaporation loss resultant from increased free-water surface due to irrigation canals, storage and controlled river flow, served only as a measure of the net loss in total river flow by irrigation development. This loss in river evaporation alone amounted to about two second feet per mile per day between Whalen and Mitchell, and three second feet per

day between Mitchell and North Platte or a total loss of 612 second feet per day between Whalen and North Platte in the flow of the North Platte River.

Soil Evaporation, Interception, and Transpiration:- Soil evaporation refers to water losses due to evaporation of rainfall (or snow) as it lies on or just below the surface of the ground, and the same general laws apply as with a free-water surface. On the other hand, the condition of the land surface, whether cultivated in grass or vegetal cover, the character of soil and subsoil is of great importance in affecting the amount of such evaporation, in addition to the meterorological conditions. Vegetation by shading the ground tends toward a lower temperature, as well as slightly increasing the relative humidity. Hence the greater crop areas due to irrigation tend toward a lessened amount of soil evaporation.

The other water losses of transpiration and interception must be also taken into account in studying the net effect of vegetation on water losses. Meyer, in his experiments on transpiration and interception losses for the north central United States, found that for grains, grass and crops, the seasonal loss ranged from 9 to 10 inches of water. Since the North Platte Valley

is practically timberless, the transpiration and interception losses have not been materially changed by the irrigation development and its resulting crop cultivation. Therefore, this feature of the study automatically cancelled itself in the two periods of study, and any effect these losses may have on the amount of "return flow" back to the river was beyond accurate calculation. However, the final net gain to the river in"return flow" would reflect all such losses even though it was impossible to segregate them.

OTHER LOSSES

Canal Seepage and Evaporation:- Canal seepage and evaporation, while they cannot be segregated, constitute a very important item. The evaporation, of course, is a total loss as regards "return flow", but the greater portion of the seepage losses are either regained by intercepting drains,or finds its way back to the river through percolation. There is, however, a loss through deep percolation that in all probability passes out of the valley entirely and will be recovered in the Republican River drainage basin to the south. These amounts cannot be accurately determined, but such amounts as are finally intercepted by the river will be reflected in

the gain in flow after the diversions and shown as "return flow".

The average canal and lateral losses as a percentage of the total diversions for the season, over a fourteen year period, equals 43%. The above percentage figure does not include losses in Reservoirs 1, 2 and 3, losses above Northport diversion in Tri-State Canal, nor lateral losses in North Platte Canal and Colonization System (about 10% of total area), but this does include losses on Lingle power diversions. The above figure is, however, representative of the losses due to canal and lateral seepage and evaporation over the whole project.

Reservoir Losses:- From the nature of the soil (sandy loam) evaporation and seepage losses in the Reservoirs are often more than offset by return in bank storage and surface runoff from the small surrounding drainage area. In the cases of Lake Alice and Lake Minitaire, it is often found that more water can be drawn from these lakes than was diverted to them. This gain is probably augmented by seepage from the High Line Canal.

Surface Waste:- The average surface waste as a percentage of the total diversions for the season over a fourteen year period, equals 5.29%. This waste water is

returned directly to the river through drains and waste-ways, and is accounted for in the visible return.

Deep Percolation:- Deep percolation represents a factor of uncertain quantity. But a close study of the geologic structure of the North Platte Valley indicates that this loss may be a considerable one and that it is probably recovered by the Republican River to the south. It has been previously stated, that under the bed of the river there is a considerable thickness of coarse sand which contains an underflow of great volume, and that the basement of the valley consists of seamed brule clay dipping to the east and slightly to the south. Therefore it can be easily possible for a large quantity of water to be lost into the Republican River drainage. Such loss as is obtained in this manner is a total loss to the North Platte River in every respect.

DISCHARGE RECORDS OF NORTH PLATTE RIVER

A study of the discharge records of the North Platte River revealed that while several gaging stations were maintained along the project, only three (Whalen, Bridgeport and North Platte), had records over a sufficient period of time to be of value as control stations for this problem. The stations at Fort Laramie, Guernsey,

Michell, Scottsbluff, Melbeta, Northport and Overton, were found to be of considerable value in coordinating the records of the three control stations and in determining the disposition of flow along the river. The discharge records at Pathfinder Reservoir were extremely valuable in determining the effect of storage on the control and flow habits of the stream subsequent to the development of the North Platte Irrigation Project. The detailed records of these stations may be found in the Water Supply Papers, published by the U. S. Geological Survey.

MODIFIED FLOW HABITS OF THE STREAM

Development of Storage:- Since 1909, or the completion of the Pathfinder Reservoir, there have been two main factors affecting the flow habits of the river, the storage of flood water in the Pathfinder Reservoir, and secondly, the increased diversions from the stream. Pathfinder Reservoir serves as a direct retard of the flow of the stream from the non-irrigation season to the irrigation season. The effects which flood storage and "return flow" have had on the lower section of the North Platte River are shown graphically in Figures 1 and 2, pages 23 and 24. The average percentage variation from

the mean monthly flow before and after the completion of the Pathfinder Reservoir is shown for each month of the year. It will be noted that since the construction of the reservoir the mean flow at North Platte for May and June has been approximately 40 and 50% less than the mean prior to that time. For July the mean flow has been 43% more; for August, 100% more; for September, 118% more; and for October, 9% more, than the mean flow prior to the beginning of storage in the Pathfinder Reservoir. This increased flow during the months cited is the result of the application of water to the irrigated area between Whalen and North Platte. The effect of the storage in Lake Alice, Lake Minatare, Lake Winters Creek, and Guernsey Dam is all reflected in the above figures.

Development of Irrigation:- The increased diversion of irrigation water has also been a prime factor in the changing flow habits of the stream. Approximately 1,200,000 acre-feet of water has been diverted from the North Platte River during each season, since the period of heavy irrigation development between Whalen and Bridgeport. This water is conducted to the farming lands in the project over which it is spread for the purpose of irrigating crops. About 75% of this

water comes back to the stream as "return flow" or"unused water". This quantity of "return flow" to the river, after being diverted for irrigation, is amazing to those who have not observed the flow habits of this stream and is the chief source of the increased flow during the summer and fall months, as shown in Figures 1 and 2.

Development of Drainage:- Hand in hand with irrigation comes drainage. There are at present many miles of drainage canals in use in the North Platte Valley, but many more must be constructed in the near future to assist in efficiently bringing the return water back to the river and preventing the future water-logging of large areas of irrigable lands. A large percentage of the return flow is rapidly conducted to the river in this manner, but probably the major portion is returned through deep percolation, and, being slower, accounts for the increased flow of the river during the late fall and winter months.

Construction of Flow Habit Graphs:- It was found that a graphical representation of the changed flow habits of the North Platte River could best be shown by graphing the coefficient of Variation as a percentage of the mean flow of the stream for both periods, i.e.,

previous to 1909 and after 1920. The discharge records for Bridgeport were available from 1900 to 1909, and from 1920 to 1929 inclusive, and for North Platte from 1895 to 1909 and from 1920 to 1929 inclusive. The flow for each month of each year was tabulated and the mean value obtained for each month for both periods. The variation of flow from the mean for each month of each year was then calculated and tabulated. Then from the Hazen formula, the value of the coefficient of variation was obtained for each month of the year for both periods. This information was plotted in Figures 1 and 2 as a percentage of variation from the mean flow at Bridgeport and North Platte.

Example of calculation of data for plotting graphs:

Bridgeport, Nebraska - September - 1920-1929
(As modified by irrigation).

DATA

Year	Flow	Mean	v	v^2	Std.V.	Coef.of.V.
1920	105.0	122.7	-17.7	312.0		
1921	102.0	"	-20.7	428.0		
1922	49.0	"	-73.7	5420.0		
1923	95.9	"	-26.8	718.0		
1924	103.0	"	∔40.3	1630.0		
1925	111.0	"	-11.7	137.0		
1926	144.0	"	∔21.3	454.0		
1927	128.0	"	∔ 5.3	28.1		
1928	104.0	"	-18.7	350.0		
1929	225.0	"	∔ 2.3	5.3	32.4	26.4
TOTAL				9482.4		

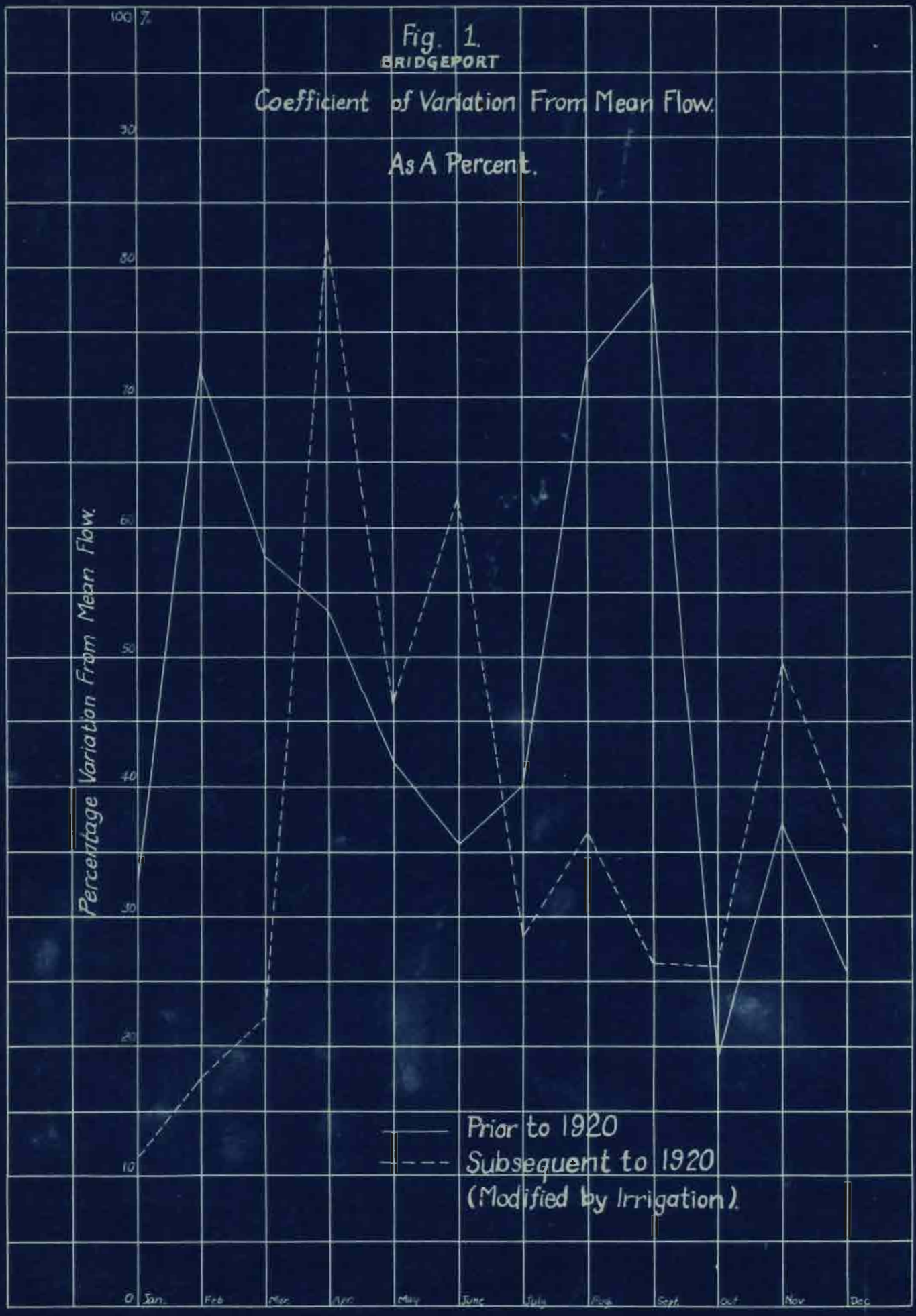


Fig. 1.
BRIDGEPORT
Coefficient of Variation From Mean Flow.
As A Percent.
Percentage Variation From Mean Flow.
100 %
90
80
70
60
50
40
30
20
10
0
Jan.
Feb
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct
Nov
Dec.
Prior to 1920
Subsequent to 1920
(Modified by Irrigation).

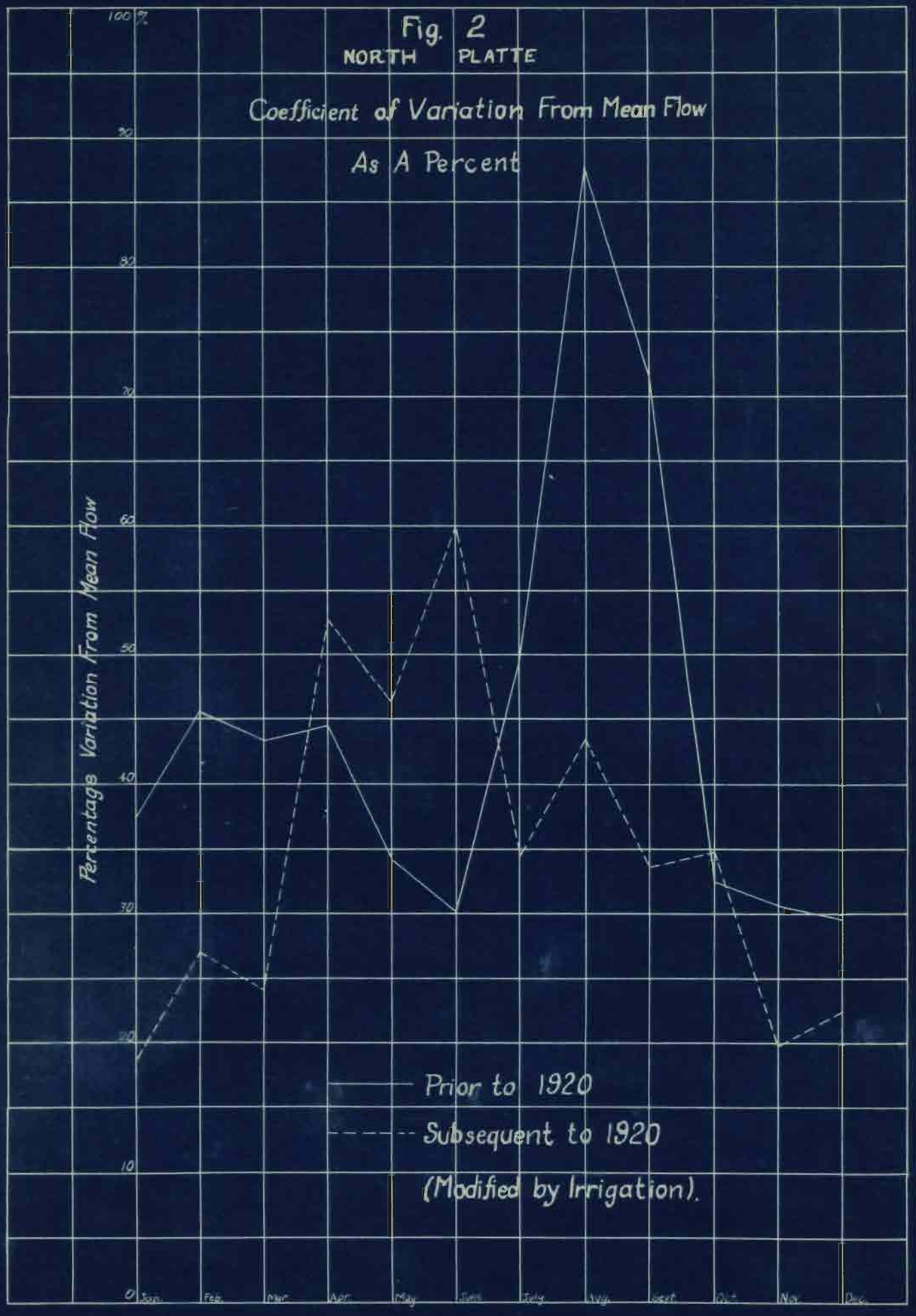


Fig. 2
NORTH PLATTE
Coefficient of Variation From Mean Flow
As A Percent
Percentage Variation From Mean Flow
100 %
90
80
70
60
50
40
30
20
10
0
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Prior to 1920
Subsequent to 1920
(Modified by Irrigation).

The "Hazen" formula for Coefficient of Variation:

$$\text{Standard variation} = \sqrt{\frac{v^2}{n-1}} = \sqrt{\frac{9482.4}{10-1}} = 32.4$$

$$\text{Coefficient of variation} = \frac{\text{Std. v}}{\text{Mean}} = \frac{32.4}{122.7} = .264$$

$$= 26.4\%$$

"v" is the variation from the mean flow and "n" the whole number of years. The flow is tabulated in hundreds of thousands of acre-feet.

RETURN FLOW CALCULATIONS

General:- Flow records were available at Whalen, Bridgeport and North Platte for a period as far back as 1895. It was found by careful comparison with earlier records of North Platte, that the period prior to 1909 was fairly well represented by the means of the records from 1895 to 1909. Therefore the means of the records from 1895 to 1909 were used in order to make the three control stations comparable.

The mean monthly flow below Whalen Dam was found by adding the mean monthly flow of the Platte River at that point and the mean monthly flow of the Laramie River obtained from the records of the Fort Laramie Station. The Mean monthly flow of the river at other points was obtained from records of the station at the point considered.

The records of diversions were obtained subsequent to 1920 on the Government Projects from the Reclamation Service representatives at Guernsey, Torrington, Mitchell, and Gering. These records were complete and had been obtained regularly with a high degree of accuracy, therefore they were used with confidence. The Nebraska diversions were obtained through records furnished by Mr. R. H. Willis, Water Superintendent, Bridgeport, Nebraska. There were no diversions on Government Projects prior to 1909, as these projects were then non-existant. The records of diversions for existing (Nebraska) irrigation, during this period were of such an incomplete nature as to require an estimation to be made of the diversions. This estimation was based on the average diversions for the Nebraska canals subsequent to 1920. Considering the extent and rate of increase in irrigation prior to 1909,in comparison with the present extent of the Nebraska irrigation development, exclusive of the Government Projects. It was found that the average diversions in the Nebraska canals prior to 1909 was approximately 50% of the average subsequent to 1920. Rather complete records for the diversions into the Nebraska canals were available for the period 1920 to 1929.

Summary of Diversions:- The following tables give a summary of the water diverted from the North Platte River in acre-feet. Tables 3, 4, 5 and 6 are the diversions for the Government Projects and Table 7 is a summary of the total water diverted, including Nebraska diversions above Overton.

TABLE 3
NORTH PLATTE PROJECT - NEBRASKA - WYOMING
Ft. Laramie Division
Irrigable Acreage and Water Delivery

Year	Acreage Irrigable	Area in Cultivation	No. of Farms Irrigated	Acre-Feet Delivered To Land	Acre-Feet per acre Irrigated
1918	6540	4865	40	4870	1.0
1919	11000	6258	62	17522	2.8
1920	16200	8494	126	16755	2.0
1921	16200	12254	190	22665	1.7
1922	44091	20302	320	43689	2.15
1923	58320	32441	717	45808	1.41
1924	75755	39064	770	98757	2.53
1925	94619	69093	979	141878	2.06
1926	106780	76315	1219	146706	1.92
1927	106733	77689	1055	113863	1.47
1928	106565	84632	1240	169849	2.01
1929	106672	89072	1291	154561	1.74

TABLE 4
NORTH PLATTE PROJECT - NEBRASKA - WYOMING
Interstate Division
Irrigable Acreage and Water Delivery

Year	Acreage Irrigable	Area in Cultivation	No. of Farms Irrigated	Acre-Feet Delivered To Land	Acre-Feet per acre Irrigated
1908	3417	16191	225	19400	1.20
1909	66810	34416	628	109166	3.17
1910	70120	42362	688	166238	3.93
1911	79024	44736	759	190427	4.26
1912	85821	50250	777	113251	2.25
1913	91475	56829	908	141489	2.49
1914	91504	60532	944	176915	2.92
1915	111877	70007	1095	96467	1.38
1916	112019	76620	1189	164240	2.17
1917	111941	83203	1274	177472	2.13
1918	111941	88771	1310	204819	2.31
1919	111823	88990	1300	201505	2.27
1920	111823	88005	1325	175153	1.99
1921	111387	86995	1340	186328	2.14
1922	112305	87300	1340	222509	2.55
1923	112266	87404	1307	155600	1.78
1924	112266	81888	1325	262245	2.72
1925	112263	84116	1363	221458	2.63
1926	113490	84248	1338	194980	2.31
1927	114027	87873	1418	159900	1.82
1928	114450	89894	1417	207983	2.31
1929	113097	87995	1376	207919	2.36

TABLE 5
MONTHLY WATER DIVERSIONS FROM TRI-STATE CANAL
QUANTITIES IN A.F.

Month	1922	1923	1924	1925	1926	1927	1928
April	00	00	00	00	00	00	65
May	830	1839	3309	3126	3576	1966	7611
June	3863	6172	7748	10146	6399	7382	8070
July	8104	8352	13470	13575	11421	12765	5898
Aug.	5126	8503	13816	8855	13575	10058	10266
Sept.	4437	7724	11258	7156	9526	8817	13143
Oct.	1020	00	133	00	786	422	3847
TOTAL	23380	32590	49734	42858	45283	41410	48900
Acreage Irrigated	2703	8950	8189	9489	10399	10394	11241
Per Acre Irrigated	8.65	3.64	5.42	4.52	4.35	3.98	4.35

TABLE 6
NORTH PLATTE PROJECT - NEBRASKA - WYOMING
Northport Division
Irrigable Acreage and Water Delivery

Year	Acreage Irrigable	Area in Cultivation	No. of Farms Irrigated	Acre-Feet Delivered To Land	Acre-Feet per acre Irrigated
1922	4712	2703	61	11723	2.5
1923	16350	8950	148	16821	1.9
1924	16350	9169	179	30535	3.3
1925	15982	9489	167	24645	2.6
1926	16214	10268	175	20933	2.0
1927	16174	10393½	144	20143	1.94
1928	16174	11241	194	22463	2.00
1929	16174	11385	194	25225	2.18

TABLE 7

SUMMARY OF WATER DIVERTED FROM THE PLATTE RIVERS IN ACRE FEET BETWEEN PATHFINDER RESERVOIR AND OVERTON, NEBRASKA.

SEASON 1925

	May	June	July	Aug.	Sept.	Total
Pathfinder-Whalen	108763	142098	185222	174138	135768	745989
Whalen-Mitchell	40440	83797	102954	94303	52290	373784
Mitchell-Melbeta	5940	8943	12455	8707	6736	42781
Melbeta-Bridgeport	4324	13752	21670	12960	12242	66048
Bridgeport-Belmar	5023	4497	11877	5663	4287	31347
Lemoyne-North Platte	6249	22332	28842	29033	14793	101249
North Platte-Overton	7677	23824	24225	31433	22178	109337
Totals	179516	299243	387245	356237	248294	1470535

SEASON 1926

	May	June	July	Aug.	Sept.	Total
Pathfinder-Whalen	102249	145937	174879	186905	136593	746563
Whalen-Mitchell	55372	46347	93527	109204	73211	377661
Mitchell-Melbeta	5693	7355	10583	13844	7783	44658
Melbeta-Bridgeport	6600	11421	18274	19308	10242	65935
Bridgeport-Lemoyne	4042	9664	6458	10566	6214	36944
Lemoyne-North Platte	21894	19992	22755	29827	18445	112913
North Platte-Overton	19831	27708	24868	41264	24894	138565
Totals	215681	268424	251344	410318	277382	1523239

SEASON 1927

	May	June	July	Aug.	Sept.	
Pathfinder-Whalen	71035	139787	199491	156529	144317	711159
Whalen-Mitchell	12214	73934	109280	81324	83382	358134
Mitchell-Melbeta	188	7418	13853	12914	11094	45467
Melbeta-Bridgeport	992	8632	19170	15135	12087	36016
Bridgeport-Lemoyne	191	8310	13312	9199	4882	35894
Lemoyne-North Platte	6480	21011	35824	16595	17597	97507
North Platte-Overton	8856	15417	38863	30157	31356	124649
Totals	99956	274509	428793	321853	303715	1428826

SEASON 1928

TABLE 7 (CONTINUED)

SEASON 1928

	May	June	July	Aug.	Sept.	Total
Guernsey-Whalen	134355	114894	181702	200518	172847	804316
Whalen-Torrington	9223	11245	12052	12052	11662	56234
Torrington-Mitchell	66839	67830	72558	103364	101923	412514
Mitchell-Melbeta	3504	8032	8731	13097	11900	45264
Melbeta-Bridgeport	7932	9044	11806	18447	12435	59664
Bridgeport-Oshkosh	1721	5295	2090	7440	9877	26423
Oshkosh-North Platte	24702	24573	27240	33327	25347	137189
North Platte-Overton	27609	23681	48577	53373	48373	201613
Totals	276885	265594	364756	441618	394364	1743217

SEASON 1929

	May	June	July	Aug.	Sept.	Total
Guernsey-Whalen	83089	147135	220003	223155	124237	797617
Whalen-Torrington	2271	9663	11548	12502	3848	39832
Torrington-Mitchell	28102	83032	118188	119586	68090	416998
Mitchell-Melbeta	1059	12173	13844	15995	8577	51648
Melbeta-Bridgeport	1741	14335	26313	18540	5870	66799
Bridgeport-Oshkosh	1632	6693	7133	6043	3099	24600
Oshkosh-North Platte	9962	26938	38209	37735	19960	132804
North Platte-Overton	0	12147	46439	57553	32422	148561
Totals	127856	312114	481677	491109	266103	1678859

STATE OF NEBRASKA
DEPARTMENT OF PUBLIC WORKS

Compiled by R. H. Willis, Chief
Bureau of Irrigation, Water Power and Drainage

Revised March 9, 1929

Average monthly divisions were calculated for each of the two periods of study prior to 1909 and subsequent to 1920, and these figures are shown on the Flow Accounting Summary Sheet, page 38.

Return Flow Calculation from Canal Diversions, Example:-

Interstate Canal from 1927 Record:

Total Water Diverted	443,003 A.F.
Main Canal Waste	-40,360 A.F.
	402,643 A.F.
Lateral Waste	- 422 A.F.
	402,221 A.F.
H.L., L.L. & R.S.Waste	-4,375 A.F.
Net Diversion	397,846 A.F.

Delivered to:

N.P.C.C. Canal	30,749 A.F.
H. Line Canal	45,009 A.F.
	75,753 A.F.
Waste	-4,375 A.F.
Total	71,378 A.F.

Delivered to Land:

Interstate ⁄ N.P.C.C.	106,070 A.F.
High Line Canal	⁄16,555 A.F.
Low Line Canal	⁄20,386 A.F.
Reservoir Storage	⁄16,889 A.F.
Total Delivered =	159,900 A.F.

Then:

Net Diversion	397,846 A.F.
Total Delivery	-159,900 A.F.
Credited to Return Flow	237,946 A.F.

The above calculations were made for each Canal for each year of available records, and the data obtained was used as a check against the final Return Flow calculations as obtained for the River as a whole.

Visible Return Flow:- Visible return includes some waste water. All of the projects use drainage canals to conduct the excess water back to the stream, and it was found impracticable to separate the waste water from the seepage. Besides the surface run-off from precipitation, there is also surface water from irrigated fields bordering along the drainage canals that must be taken as visible return flow. Figure No. 3, page 35, shows the average of the Measured Visible Return by Months for the period 1921-1929, Figure No. 4, page 36, the amount of Visible Return between Whalen and North Platte for the years 1921-1929 inclusive. An examination of these charts reveals that the return flow has steadily increased up to 1927 with an apparent falling off, which indicates that the quantity may become fairly constant, unless further irrigation development occurs. Chart 3 shows that the quantity of water returning in a comparatively short time is remarkable, and that the quantity of visible return available for re-use during the irrigating season of five months is approximately 50% of the annual visible return. It will also be noted that this return flow is of such an amount as to materially increase the dry season flow of the North Platte River.

The data which forms the basis of these charts was obtained through the courtesy of Mr. Willis.

Fig. 3.

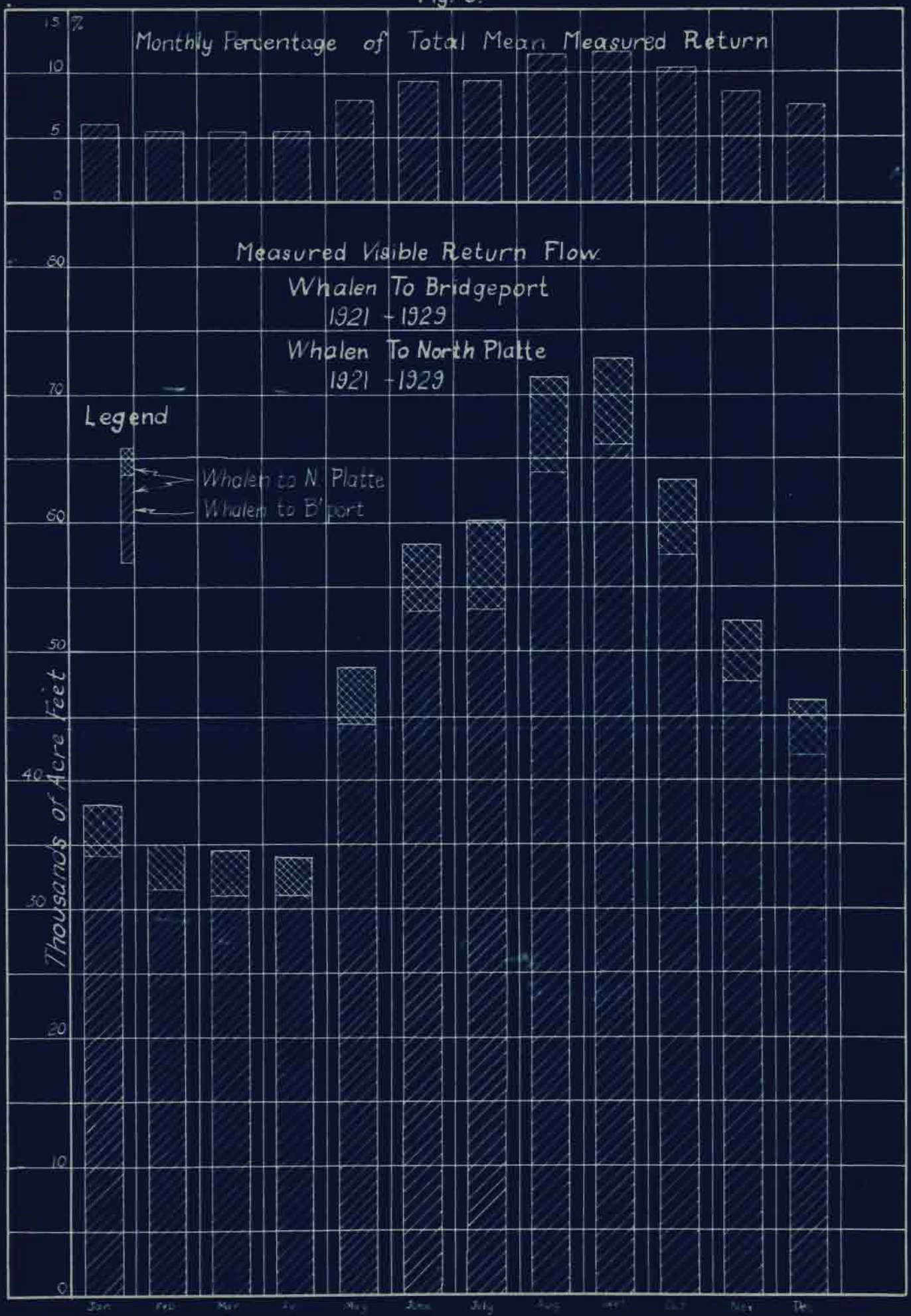
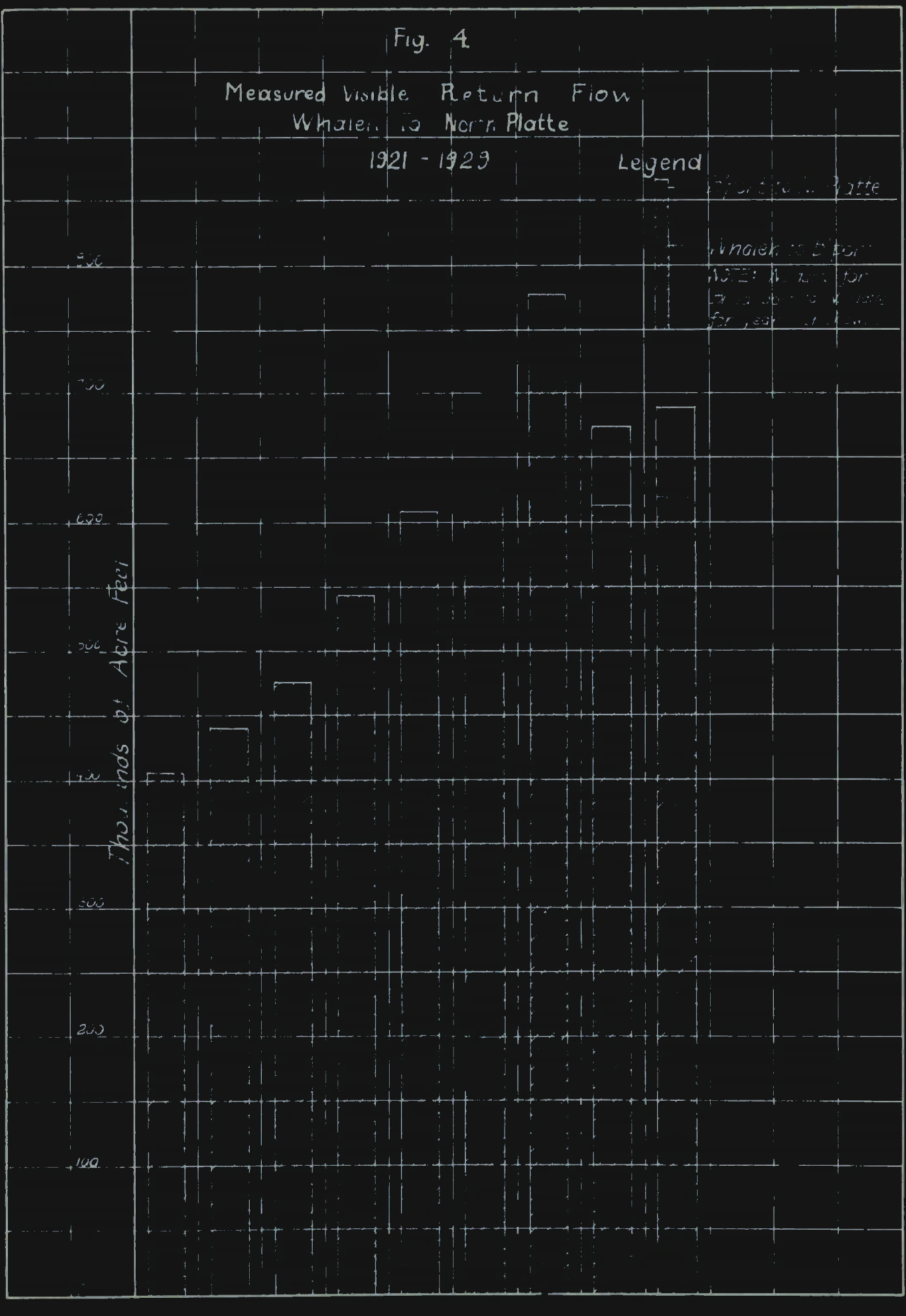

Monthly Percentage of Total Mean Measured Return
%
15
10
5
0
Measured Visible Return Flow
Whalen To Bridgeport
1921 - 1929
Whalen To North Platte
1921 - 1929
Legend
Whalen to N. Platte
Whalen to B'port
Thousands of Acre Feet
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

Fig. 4

Measured Visible Return Flow
Whalen to North Platte
1921 - 1929



Summary of Flow Accounting:- The summary of Flow Accounting is shown in Table 8, page 38. The flow is tabulated to show the gain by the River, due to return water, in thousands of acre-feet and in percentages, between Whalen and Bridgeport and between Bridgeport and North Platte. The data is tabulated for both periods of study.

Method of Gain in River Flow:- Having determined the mean monthly flow at the three control stations and the average monthly diversions, the next step is to determine the gain or loss in the river.

For example, taking one of the irrigating months such as August in the period 1920-1929, the gain in the river flow between Whalen and Bridgeport was found as follows:

Average Flow Bridgeport August	= 138.5
Total Average Diversions	= +279.7
Average Flow Bridgeport & Diversions	= 418.2
Average Flow at Whalen	= 296.2
Gain in thousands of A.F.flow, Whalen to Bridgeport	= +122.0

Or, in other words, subtracting the average flow at Whalen from the total of the average flow at Bridgeport plus diversions, will give the gain or loss in the river between these points. This gain is properly termed "return flow."

TABLE 8
SUMMARY OF FLOW ACCOUNTING
(In Thousands of A.F.)

	WHALEN TO BRIDGEPORT						BRIDGEPORT TO NORTH PLATTE					
	Av. Flow Whalen ≠ L.R.	Av. Flow Diversions	Av. Flow Bridgeport	Av. of Bport ≠ Div.	Gain	Gain Bport x 100	Av. Flow Bridgeport	Av. Flow Diversions	Av. Flow North Platte	North Platte ≠ Div.	Gain	Gain N.P. x 100
Jan.	67.9		53.0	53.0	- 14.9	- 28	53.0		117.5	117.5	≠64.5	≠55
Feb.	60.9		171.5	171.5	≠110.6	≠ 65	171.5		152.1	152.1	-19.4	-13
Mar.	92.2		230.6	230.6	≠138.4	≠ 60	230.6		234.3	234.3	≠ 3.7	≠02
Apr.	188.7		246.6	246.6	≠ 57.9	≠ 23	246.6		223.3	223.3	-23.3	-10
May	403.5	21.0	461.0	482.0	≠ 78.5	≠ 17	461.0	6.0	415.0	421.0	-40.0	-10
June	602.6	43.0	572.9	615.9	≠ 13.3	≠ 02	572.9	11.0	562.8	573.8	≠ 0.9	≠ 0
July	167.6	68.0	182.9	250.9	≠ 83.3	≠ 45	182.9	18.0	221.8	239.8	≠56.9	≠26
Aug.	54.8	65.0	40.0	105.0	≠ 50.2	≠125	40.0	17.0	48.9	65.9	≠25.9	≠53
Sept.	31.4	46.0	19.1	65.1	≠ 33.7	≠176	19.1	11.0	43.1	54.1	≠35.0	≠81
Oct.	45.3		35.9	35.9	- 9.4	- 25	35.9		67.6	67 .6	≠31.7	≠47
Nov.	57.0		39.6	39.6	- 17.4	- 44	39.6		82.2	82.2	≠42.6	≠52
Dec.	52.8		34.5	34.5	- 18.3	- 53	34.5		93.4	93.4	≠58.9	≠63
Prior to 1909	1824.7	243.0	2087.6	2330.6	505.9	≠30%	2087.6	63.0	2262.0	2325.0	237.4	≠29%
Jan.	29.0	1.1	108.8	109.9	≠ 80.9	74%	108.8		142.8	142.8	≠34.0	24%
Feb.	30.6	1.0	99.2	100.2	≠ 69.6	70%	99.2		166.1	166.1	≠66.9	40%
Mar.	45.4	2.1	107.6	109.7	≠ 64.3	60%	107.6		185.5	185.5	≠77.9	42%
Apr.	114.4	20.9	105.9	126.8	≠ 12.4	12%	105.9		223.2	223.2	≠117.3	53%
May	311.1	109.9	242.8	352.7	≠ 41.6	17%	242.8	12.0	291.3	303.3	≠60.5	21%
June	458.1	198.3	374.9	573.2	≠115.1	31%	374.9	22.4	426.4	448.8	≠73.9	17%
July	354.8	290.3	163.8	454.1	≠ 99.3	61%	163.8	35.0	170.0	205.0	≠41.2	24%
Aug.	296.2	279.7	138.5	418.2	≠122.0	88%	138.5	33.5	166.9	200.4	≠61.9	37%
Sept.	223.0	204.7	122.7	327.4	≠104.4	85%	122.7	22.4	140.4	162.8	≠40.1	29%
Oct.	73.9	28.5	138.7	167.2	≠ 93.3	67%	138.7	2.0	194.8	196.8	≠58.1	30%
Nov.	31.6	1.6	123.6	125.2	≠ 93.6	70%	123.6		161.6	161.6	≠38.0	24%
Dec.	25.1	1.6	106.5	108.1	≠ 83.0	78%	106.5		158.2	158.2	≠51.7	33%
1920-1929		1139.7	1833.0	2972.7	≠979.5	59%	1833.0	127.3	2427.2	2554.5	721.5	31%

$\frac{1824.7}{168.5}$ Net gain 473.6 $\frac{2262.0}{165.2}$ 484.1

Return in ac.ft./acre = $\frac{957.7}{388.9}$ = 2.46

Return flow in % of Diversion $\frac{2.46}{3.25}$ = 75%

SUMMARY OF STATISTICAL DATA

Acres reported Irrigated, 1920-1929:

Whalen to Bridgeport	3,123,100
Bridgeport to North Platte	765,500
Total	3,888,600
Average Acres Irrigated Yearly	3,888,860

Diversions, 1920-1929:

Whalen to Bridgeport	11,384,900
Bridgeport to North Platte	1,252,900
Total	12,637,800

Apparent Dury of Water $\frac{12,637,800}{3,888,600}$ = 3,25 A.F./A

Computed Return, (Yearly Average):

Whalen to Bridgeport	473,600 A.F.
Bridgeport to North Platte	484,100 A.F.
	957,700 A.F.

Return Flow in A.F./Acre = 957,700/388,860 = 2.46

Return Flow in percent of Diversions = 2.46/3.25 = 75%

Return Flow in A.F. per Year per Mile of River:

Whalen to Bridgeport	= 473.6/93 = 5,092
Bridgeport to North Platte	= 484.1/129 = 3,750
Av. Whalen to North Platte	= 957.7/222 = 4,313

CONCLUSIONS

In conclusion, several significant facts are apparent from the data gathered in this study:

(1) The return water is sufficient for all diversions east of Mitchell, Nebraska. Or it is sufficient to take care of all prior irrigation rights of the state of Nebraska, below the Government Project.

(2) Should the return water be used to satisfy the prior rights of the State of Nebraska, the prior right water now passing Whalen Dam could be diverted at that point for further development on the Government Project.

(3) Should the prior right water be allowed to pass Whalen Dam, further diversions can be made by the state of Nebraska for development of the lower valley.

(4) The return flow between Bridgeport and Overton comprises only a small part of the total flow of the stream for the reason that only a small acreage is irrigated along that section of the river.

(5) The value of the return water from the North Platte Project, at an average figure of $1.25 per acre-foot, is approximately $1,200,000 each year.

(6) Due to Pathfinder Dam and other control features of

the irrigation development, the flow habits of the North Platte River has been materially changed. Instead of the uncontrolled spring flow with its devastating floods and almost zero dry season flow, there is almost complete control of the spring flow and a material increase in the summer flow. This change is very beneficial to flood control and navigation possibilities on the Missouri River.

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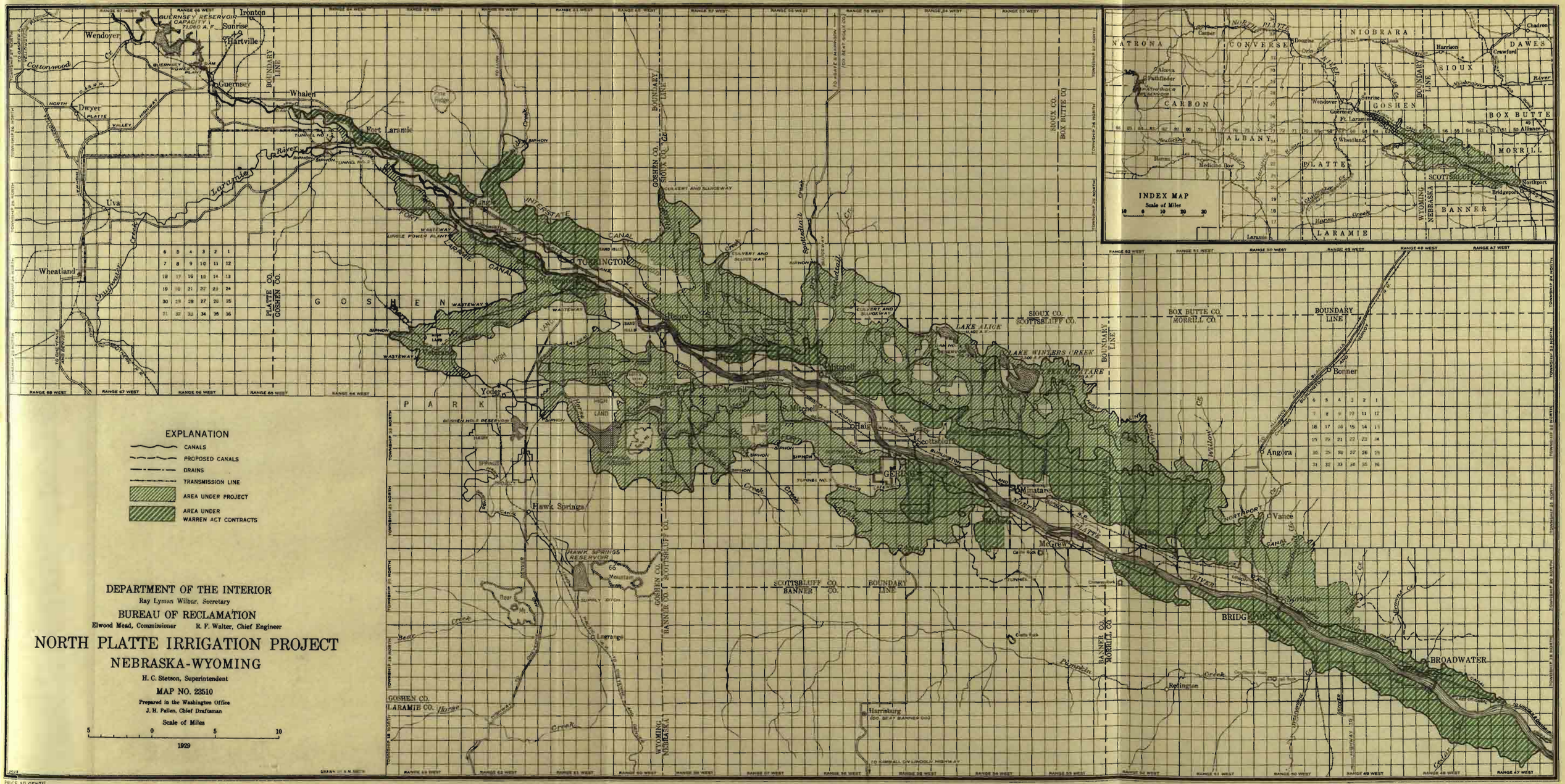

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