State of South Dakota

Harlan J. Bushfield, Governor

STATE GEOLOGICAL SURVEY

E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 41

A HYDROLOGIC STUDY of the WHITE RIVER VALLEY

by

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University of South Dakota
Vermillion, S. Dak.
February, 1942

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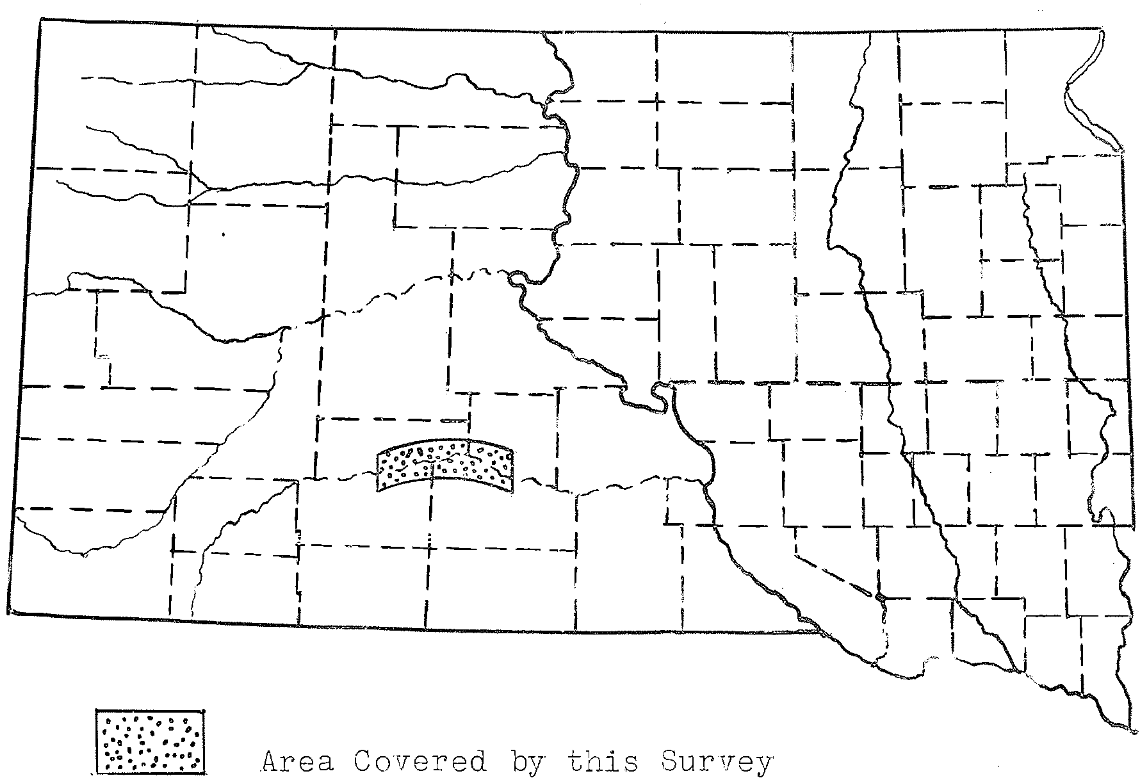
INDEX MAP



Area Covered by this Survey

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INTRODUCTION

Purpose of the Report

The investigation here reported was undertaken to determine the feasibility of pump irrigation in the White River valley. Irrigation of small plots in this valley had met with considerable success, indicating that the conditions were right for agriculture except for the shortage of water. Most of these projects had used surface water pumped from the White River. This stream, however, is subject to a great fluctuation, going dry during the summer when water is needed the most, and flooding with every heavy thunder shower. It was thought that if a dependable supply could be obtained from shallow wells, sufficient irrigation could be carried on to supply gardens and small fields, to carry crops over the dry part of the summer, and considerably increase the amount of crop farming possible in the valley.

The project, therefore, was undertaken to determine the amounts of water available for such irrigation.

Methods of Work

The only source of shallow water in this region is the fill of the White River valley. To ascertain the amount of water available, therefore, an examination of the underflow in the valley was undertaken. The method of attacking this problem, therefore, was to measure the depth of the fill, and the amount of water which it contained, getting as much information on the possible recharge as could be obtained.

A portion of the valley near the main highway and the Milwaukee Railroad, extending from Kadoka nearly to Murdo, was chosen as the most likely place for developing this type of farming.

Profiles were made across the valley as nearly at right angles to its length as topographic conditions would permit, and spaced about two miles apart. Electrical soundings were made along the profiles and checked here and there by drilled wells from which samples were carefully taken at depths of from two to five feet. The samples were prepared and tested for porocity and permeability. The course of the river and area of available irrigation land was obtained by mapping the entire length of this section of the valley with plane table.

The work was started in 1937 by a party under the direction of Professor H. E. Brookman of the State University, assisted by Mr. Hugo Aldrich and Mr. Dan Schenk. The plane table work was done by Mr. Leonard Stevens.

The survey was completed during the summer of 1941 by a party headed by the State Geologist. The electrical soundings on this survey were made by Professor Wayne Marshall of the State University; drilling was under the direction of Mr. Dorian Lavier, Assistant Geologist for the Survey; and plane table mapping was done by Richard Aroner, assisted by Edward Ries. This report, therefore, is the result of two summer's field work by two different parties. Data which requires long periods of observation would be very desirable, but could not be obtained, and before extensive development is undertaken considerable more detailed information would be advisable. This work, however, was designed to show the volume of water obtainable, the sorts of sediments that could supply it, the possibility of obtaining wells of large production, the depth from which water could be obtained, and some information on the quality of the water.

Since electrical sounding is rather new in the state, a brief description of this method will be in order. An electric current carried into the earth between two electrodes will penetrate to any depth desired provided the current is strong enough and the electrodes properly placed. During the course of its travel, the current must penetrate rocks of different resistance. By measuring the current at various places in the field produced between the two electrodes, it is possible to determine approximately the depth at which rocks of different resistances lie. Thus a portion of a curve showing high resistances is interpreted as passing through sand or gravel, while one showing low resistances is traveling through a clay or similar material.

The 1937 party employed a Gish-Rooney type of resistivity machine. These readings were checked and new measurements made by the 1941 party with a potential gradiometer made by the Heiland Geophysical Corporation of Denver. Soundings were taken every three feet to a depth of forty feet and every six feet thereafter to a depth of one hundred feet. Since the main object was to determine the depth of the White River fill and this depth had been shown to lie between twenty-five and forty feet in test holes, this part of the curve was given the most careful attention. The change from the high resistivities of the sand and gravel of the fill to the low resistivity of the underlying blue shales of the Pierre formation could easily be detected.

The test wells were drilled with a small spudding machine using cable tools and drilling a four-inch hole. The tools were followed closely by a string of four-inch casing which kept out unwanted water and prevented mixing of the materials obtained in the samples. Various attempts to obtain samples without this type of equipment had been frustrated by quicksand which inevitably halted the drilling.

Most of the information on the character of the water was obtained from reports of residents of the valley. Two samples, however, were analyzed in the State Chemical Laboratory under the direction of Mr. Guy G. Frary, State Chemist. These samples were carefully collected by the State Geologist and are representative of the types of water found in the valley.

Location and Area

The area covered by this report included a twenty-seven mile stretch of the White River between the bridge for State Highway 73, about seven miles directly south of Kadoka, and a point about four miles up river from the bridge for U. S. Highway 183, twelve miles directly south of Murdo. The valley averages about three-quarters mile in width, and the total area contains 18,000 acres which might be put under cultivation if water were available.

As the White River makes the boundary between the counties north and south of it, the area lies in Jackson, Jones, Washabaugh, and Mellette counties. Most of it lies in Township 3 South, of the 44th parallel base line, and extends from the western side of Range 22 East, Black Hills meridian, to the middle of Range 20 East. The valley reaches its northernmost position about three miles south of Stamford in Ranges 25 and 26 of Township 2 North.

GEOLOGY

The geology which concerns the water resources in this valley is relatively simple. It includes a valley trough cut in shales of marine origin and filled with wash from much younger terrestial formations. It might be likened to a spongy fill in a rubber trough, for the shales in which the trough is cut are impervious to water, and the sands and gravels and clays that make up the valley fill are relatively porous.

The Pierre Shale

The country rock in which this valley is cut is a dense, gumbo-forming shale belonging to the Pierre formation. It is gray to black and outcrops on the bluffs of the valley from high on the divides to the valley floor. All test holes drilled in the valley showed this same rock lying beneath the fill. Thus a thickness of 550 feet of the Pierre formation is exposed in the valley walls.

No attempt was made to correlate this part of the formation but the few fossils collected and the lithologic character of the rock indicates that most of it corresponds to the Virgin Creek member of the formation as described from the Missouri valley. The shale is very dense, and for all practical purposes impervious to water. Therefore, it cannot be relied upon as a source of ground water from which the fill can be recharged. Its imperviousness, however, prevents the escape by seepage of any water which enters the fill. Since the entire valley is cut in Pierre shale, only two avenues of escape are possible for water entering it. One is through the mouth of the valley, and the other is through evaporation in the stream channel.

So far as was ascertained, the formation is homogeneous. Small differences in coloration suggest differences in composition which might be of petrologic or stratigraphic interest, but not of practical significance to this investigation. The material is all shale; sands do not exist, and what limestone there is occurs as nodular concretions.

The White River Beds

These beds do not occur in this part of the White River valley, but they are of particular interest because they have furnished all the coarse material and most of the fine material in the fill. Indeed, the name "White River" is derived from the fact that the white clays of the White River beds give the river a light gray color.

White River beds outcrop over much of the valley in the Bad Lands above Kadoka, and are found outcropping on the divide south of the portion of the valley here discussed. They are in place, however, so far south of the bluffs of the valley that they have no direct effect on the water supply in the valley.

These beds are of Tertiary age, usually dated as Oligocene, and are composed of approximately the following rocks:

Brule formation:	White, grey, and sometimes pink clays. Sand bars of old river channels scattered irregularly through the formation. Volcanic ash beds in the upper part.
Chadron formation:	Grey gumbo clays. Much white arkosic sand, and bars of gravel. Coarse gravel containing conspicuous feldspar pebbles.

An interesting component of the valley fill is chalcedony. This mineral occurs in large quantities and in colors varying from the pale bluish white or gray to dark gray or black material. This chalcedony is not very abundant in the White River beds as a whole, though in some places it occurs in considerable quantities. It has been concentrated by river action in the valley fill, however, where it is an important component of the gravel bars from which water will have to be obtained.

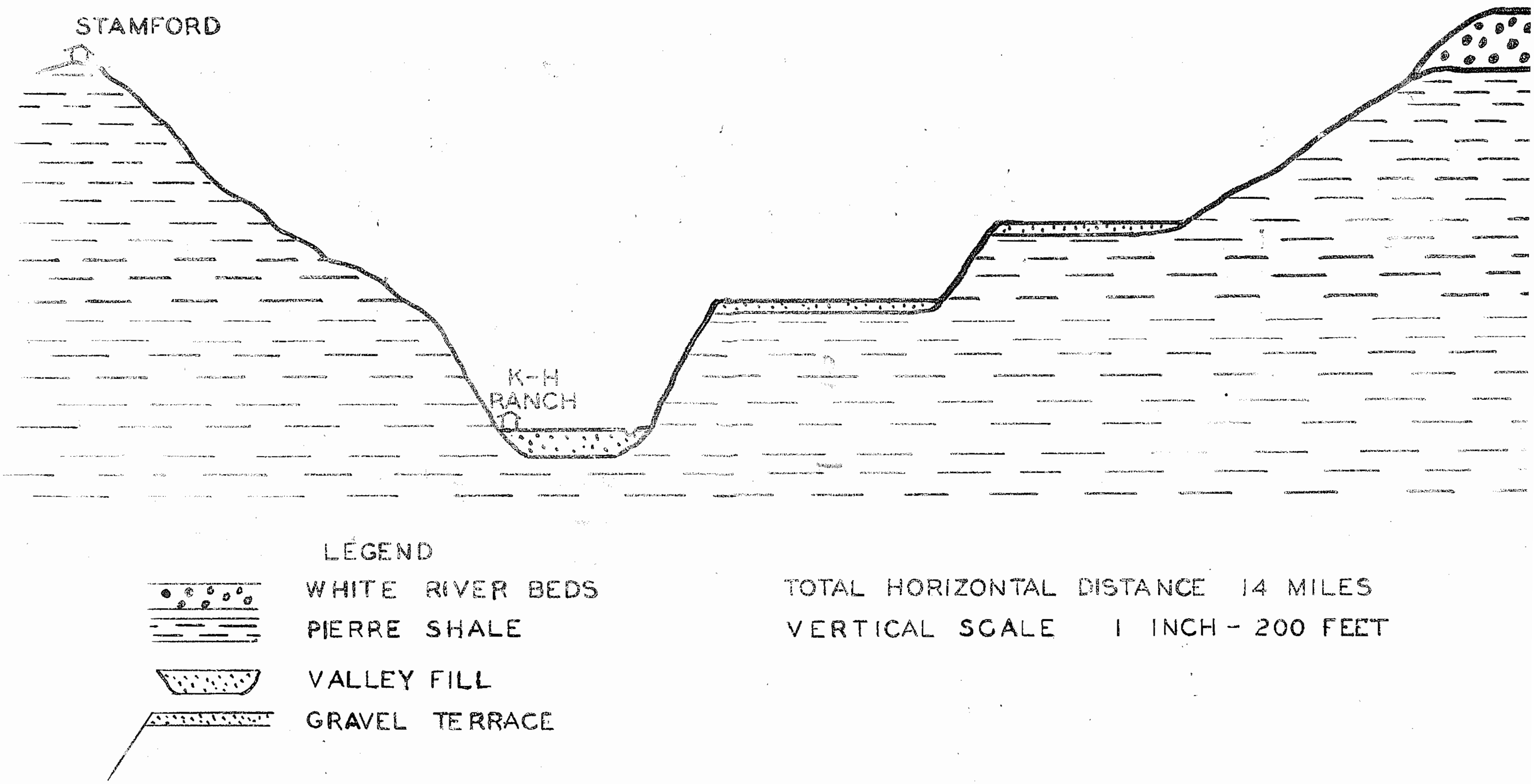
Origin of the White River Valley

Though the main course of the White River valley is eastward, the portion here described swings in a large arc eight to ten miles north of its main trend. The section from the Kadoka bridge to the Stamford bridge bears about twenty degrees north of east. At the Stamford bridge the valley turns toward the southeast and continues this direction to the bridge south of Murdo. No major loops or bends mar the smoothness of this arc, though the valley makes some minor local curves.

In cross section the valley presents a rough "V" shape. The bluffs are very steep, but the bottom is wide and flat. The north bluff descends very steeply to the valley and is cut here and there by short tributaries which reach back a mile or two into the uplands. The southern bluff, however, is much more gentle and is broken, over much of its length, by remnants of two large terraces averaging a mile or a mile and a quarter in width. The north terrace is 160 feet above the floor and the upper one 115 feet still higher. These terraces are not of particular importance to the water situation in the bottom of the valley, though they do support some very large springs. So far as is known, none of them furnish water in sufficient volume to make any appreciable charge of the valley fill.

A reconstruction of the geologic history of the valley may throw some light on the character of the fill. It must be remembered that before this valley was cut, the rock formations which have just been described covered the entire western half of South Dakota. Thus the new-born White River had to make room for itself by first cutting a valley through the Brule and Chadron formations. In the Badlands upstream, the River is still working in these formations. After the stream

CROSS SECTION
OF THE
WHITE RIVER VALLEY
THROUGH
STAMFORD BRIDGE



which has been sorted and re-sorted from the original rocks in the Badlands area upstream and from the old terraces on the valley bluffs.

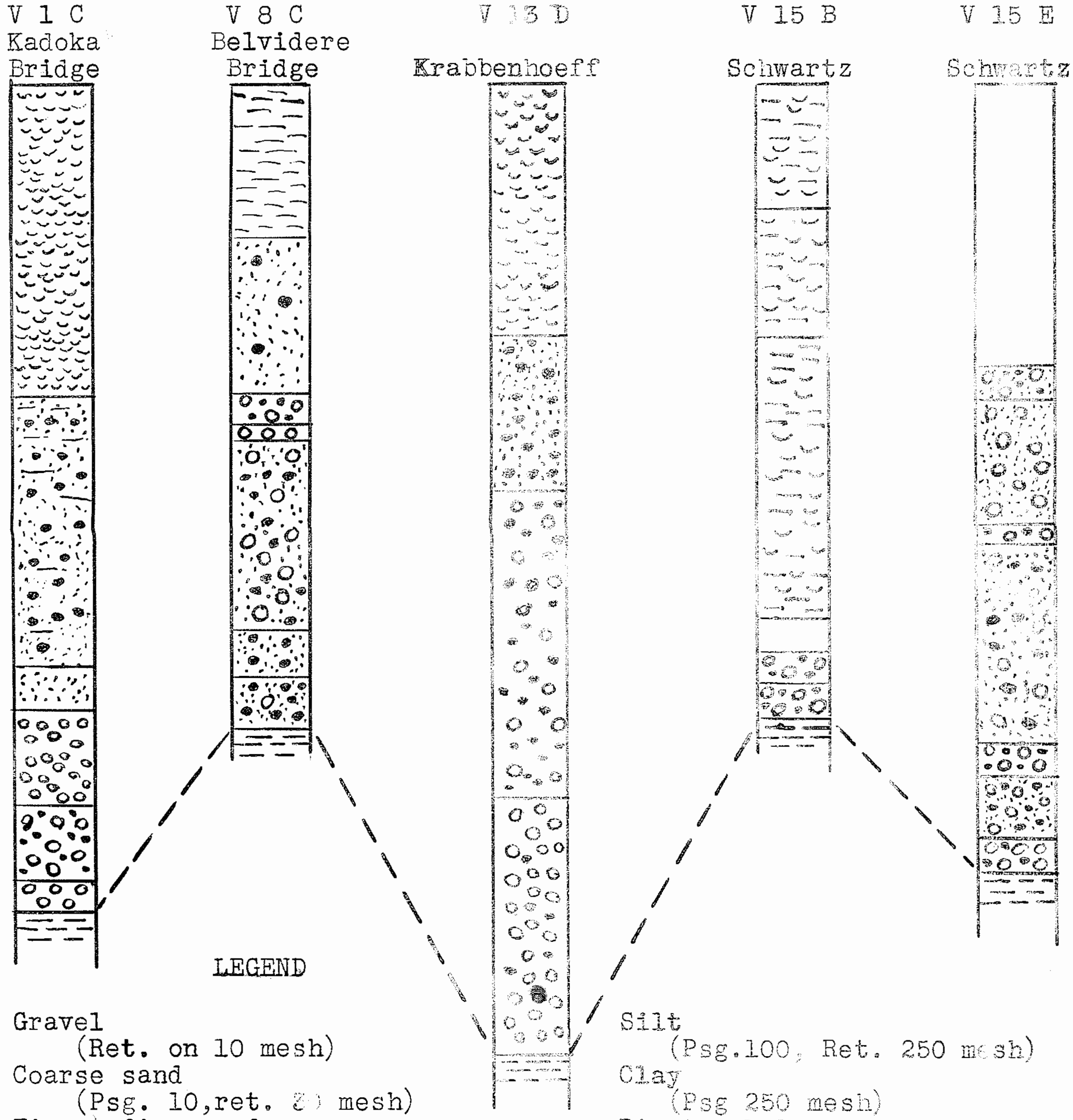
A perusal of the cross sections made from drill records shows that a large part of the fill is sandy though clays do occur here and there. Gravel bars are encountered in which the pebbles run up to the size of one's fist. In general the coarser materials are more abundant in the lower portions of the fill. Those in the upper part are finer, silts and sands comprising most of the materials near the surface. The latter frequently combine clays with the sand so that they become very impervious to the passage of water and are therefore not good aquifers.

As is usual in stream deposits, these materials are not distributed according to any definite plan. In most wells, the coarser lie near the bottom and the finer in the upper part. However, it was not uncommon to find sand near the top and clays at the bottom. These coarse materials are therefore in the form of river bars of greater or lesser extent. For a detailed description of these materials and their sizing, the reader is referred to the following analyses tables.

MATERIALS OF THE WHITE RIVER FILL

SHOWN BY THE

LOGS OF FIVE TEST WELLS



LEGEND

Gravel
(Ret. on 10 mesh)
Coarse sand
(Psg. 10, ret. 30 mesh)
Fine medium sand
(Psg. 30, ret. 100 mesh)

Silt
(Psg. 100, Ret. 250 mesh)
Clay
(Psg 250 mesh)
Pierre shal

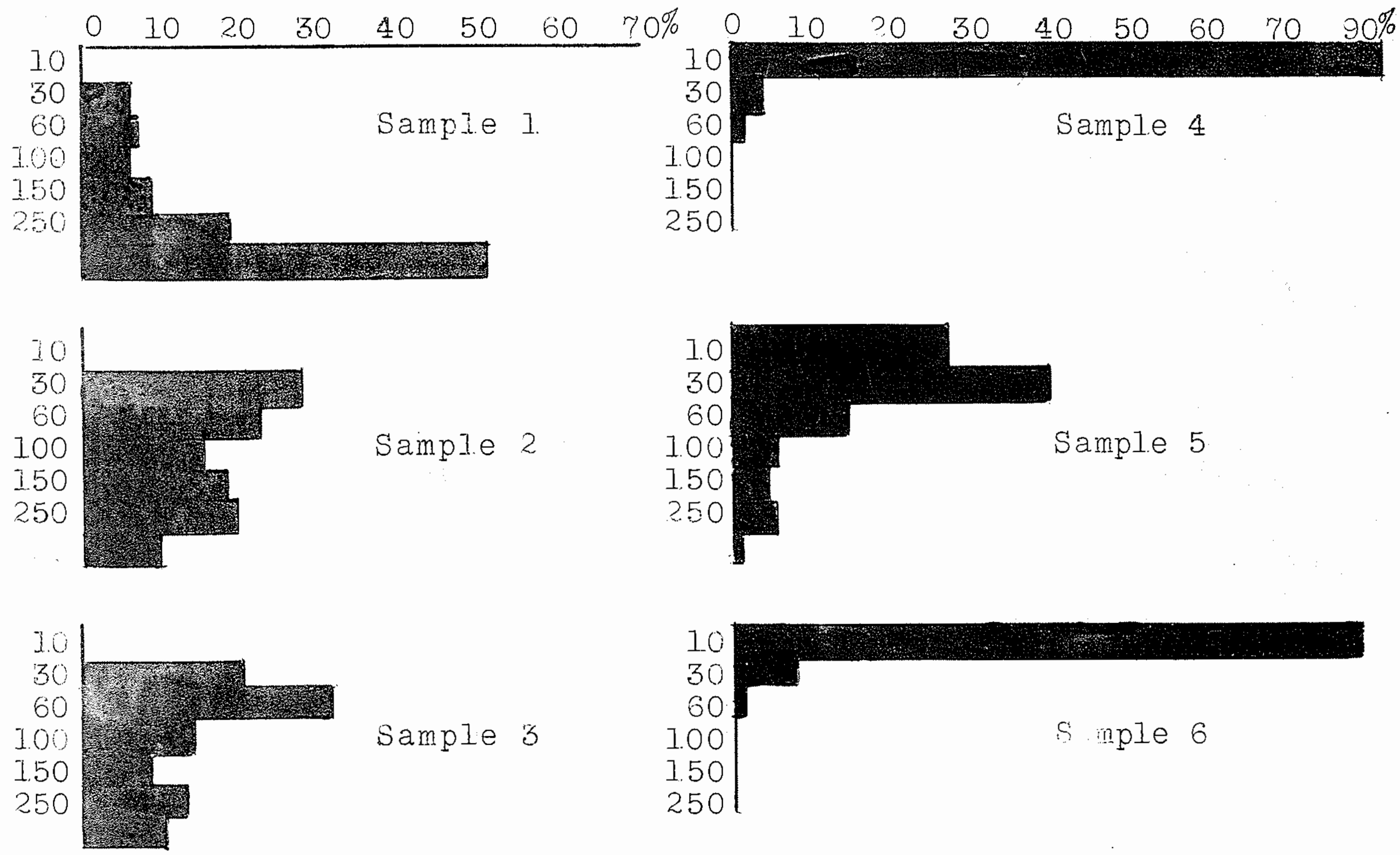
Scale: 1" = 5 feet

MECHANICAL ANALYSIS

Samples from test hole drilled on the Phil Carley ranch about 6 miles south of Kadoka. Drilled on profile V 1 C.

Sample Number	Depth Feet	R.10	P.10 R.30	P. 30 R. 60	P. 60 R.100	P.100 R.150	P.150 R.250	P.250	Total Per Cent
1	0-10	0000	5.50	6.50	6.00	8.50	19.50	53.50	99.50
2	10-18½	0000	29.50	24.00	16.00	19.50	20.00	9.50	98.50
3	18½-20	0000	21.00	33.00	14.00	8.00	13.00	10.50	99.50
4	20-23	94.50	4.00	1.00	0000	0000	0000	0000	99.50
5	23-26	28.00	41.00	15.00	6.00	4.00	4.50	1.00	99.50
6	26-27	91.50	7.50	1.00	0000	0000	0000	0000	100.00
7	27	PIERRE SHALE							

P -- PASSING R -- RETAINED FIGURES REFER TO SCREEN MESH

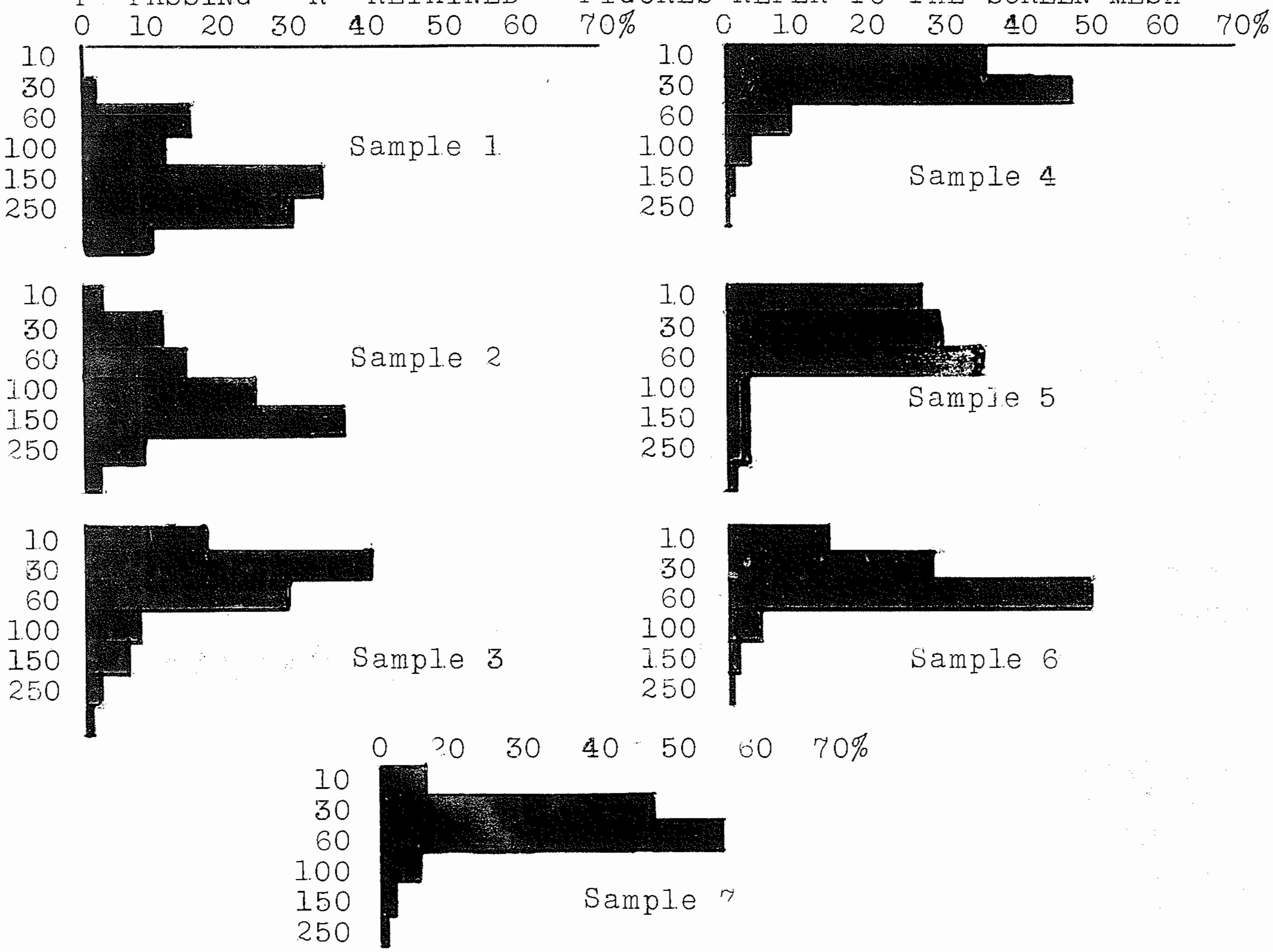


MECHANICAL ANALYSIS

Samples from test hole drilled on the White Turtle Estate about 6 miles south of Belvidere. Drilled on Profile V 8 C.

Sample Number	Depth Feet	R. 10	P. 10 R. 30	P. 30 R. 60	P. 60 R.100	P.100 R.150	P.150 R.250	P.250	Total Per Cent
1	0- 5	000	1.50	15.50	11.00	33.00	29.00	9.50	99.50
2	5-10	2.00	10.50	13.00	24.00	36.50	8.00	1.50	99.50
3	10-11	16.00	39.50	28.00	7.00	6.00	1.00	0.50	100.00
4	11-11½	37.00	49.00	9.50	3.00	1.00	0.50	0000	100.00
5	11½-17	28.00	29.50	35.00	2.00	2.00	2.00	1.00	99.50
6	17-19	14.00	29.00	51.00	4.00	1.50	0.50	0000	100.00
7	19-21	6.00	38.50	48.00	4.00	2.00	1.50	0000	100.00
8					PIERRE SHALE				

P--PASSING R--RETAINED FIGURES REFER TO THE SCREEN MESH

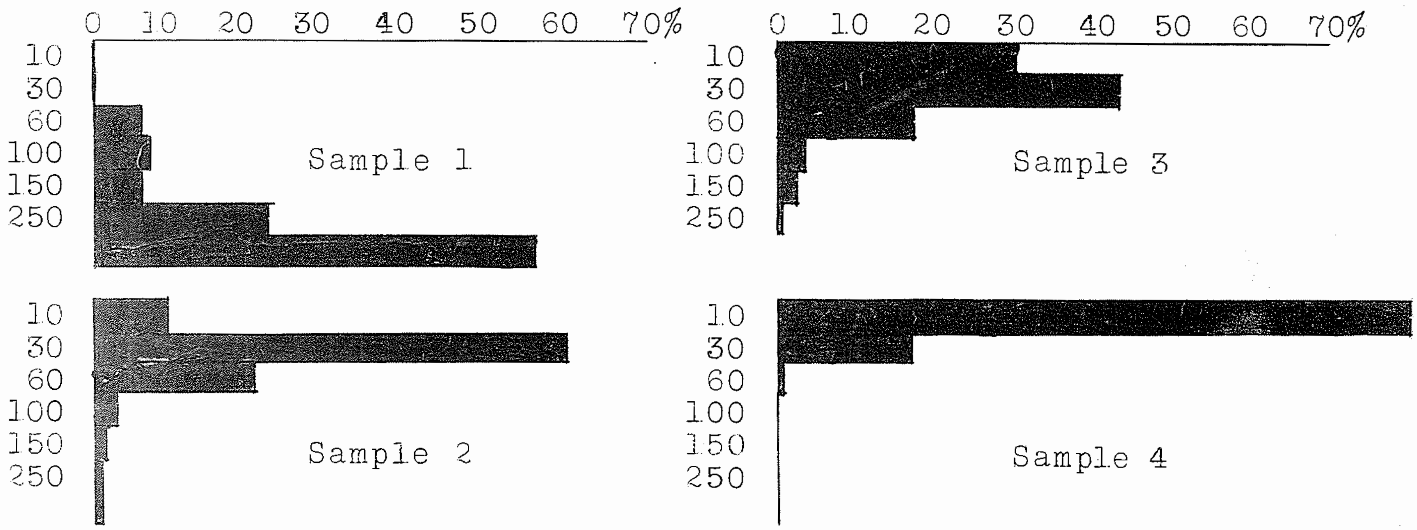


MECHANICAL ANALYSIS

Samples from test hole drilled on the Krabbenhoef Ranch about 3/4 of a mile below the Stamford Bridge. Drilled on profile V 13 D.

Sample Number	Depth Feet	R. 10	P. 10 R. 30	P. 30 R. 60	P. 60 R.100	P.100 R.150	P.150 R.250	P.250	Total Per Cent
1	0 - 8	0000	0000	6.00	7.00	6.00	23.00	57.50	100.00
2	8-13	10.00	62.00	21.00	3.00	1.50	1.00	1.00	99.50
3	13-23	31.00	45.00	18.00	3.50	2.00	0.50	0000	100.00
4	23-31	82.00	17.00	0.50	0000	0000	0000	0000	99.50
5	31				PIERRE SHALE				

P--PASSING R--RETAINED FIGURES REFER TO THE SCREEN MESH

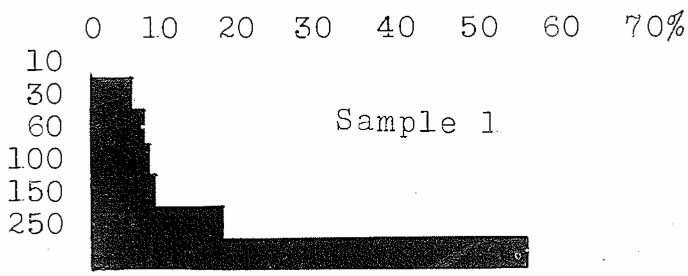


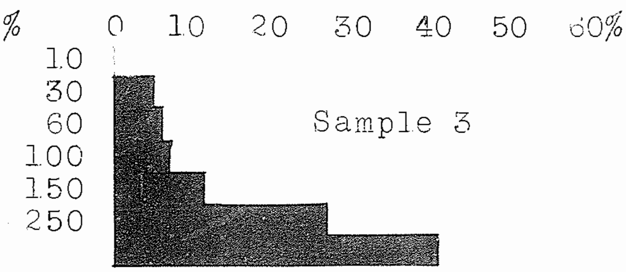
MECHANICAL ANALYSIS

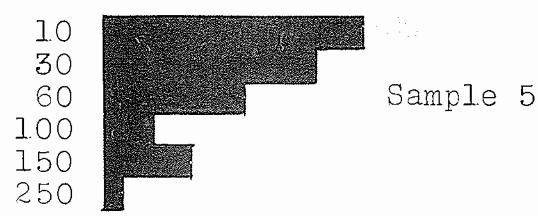
Samples from test hole drilled on the Schwartz Ranch
about 3½ miles below the Stamford Bridge.
Drilled on profile V 15 B.

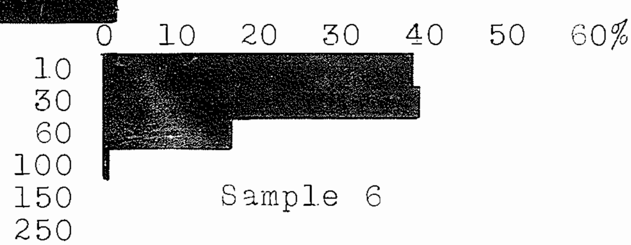
Sample Number	Depth Feet	R. 10	P. 10 R. 30	P. 30 R. 60	P. 60 R.100	P.100 R.150	P.150 R.250	P.250	Total Per Cent
1	0-4	0000	5.00	6.50	7.00	8.00	17.00	56.50	100.00
2	4-8	0000	6.00	6.50	8.00	7.50	32.00	40.00	100.00
3	8-17	0000	4.50	6.00	7.00	11.50	28.00	42.50	99.50
4	17-18				(No Sample)				
5	18-19	34.00	28.00	18.50	6.00	11.00	2.00	0000	99.50
6	19-20	41.00	42.00	16.50	0.50	0000	0000	0000	100.00
7	20				PIERRE SHALE				

P---PASSING R---RETAINED FIGURES REFER TO THE SCREEN MESH







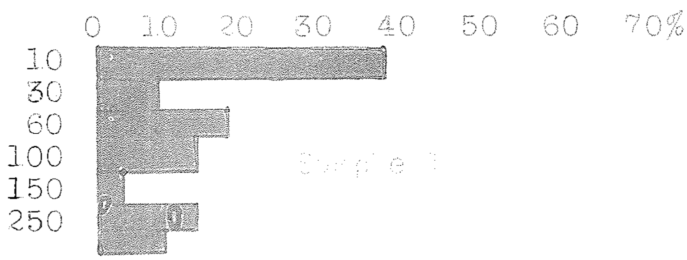


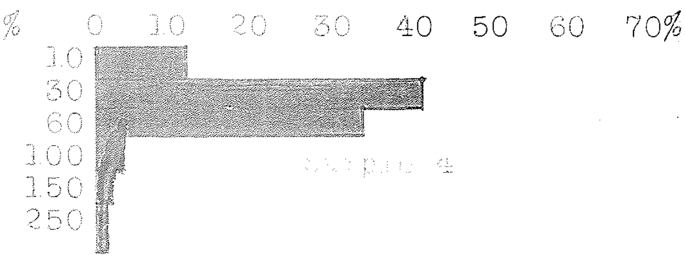
MECHANICAL ANALYSIS

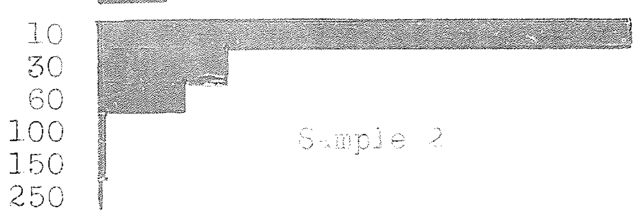
Samples from test hole drilled on the Schwartz Ranch
about 3½ miles below the Stamford bridge.
Drilled on profile V 15 E. 1500 S. of V 15 B

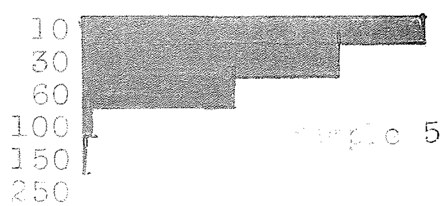
Sample Number	Depth Feet	R. 10	P. 10 R. 30	P. 30 R. 60	P. 60 R. 100	P. 100 R. 150	P. 150 R. 250	P. 250	Total Per Cent
1	0-9			NO SAMPLE					
2	9-10	28.00	8.00	17.50	12.50	3.00	12.50	8.50	100.00
3	10-14	69.50	16.50	10.50	1.00	1.00	0.50	0.00	99.00
4	14-14½	12.50	28.00	26.00	18.00	5.00	6.00	3.50	99.00
5	14½-21	12.00	43.00	35.00	3.00	2.00	1.50	1.50	98.00
6	21-22	45.00	33.00	20.00	1.00	0.50	0000	0000	99.50
7	22-24	45.00	26.00	19.00	5.00	1.00	2.00	1.00	99.00
8	24-25	83.00	10.00	3.00	2.00	1.00	0000	0000	99.00

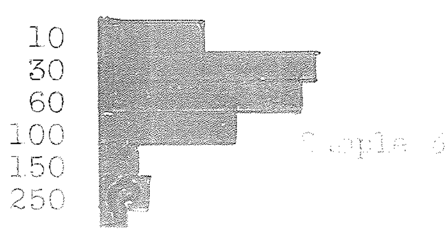
P---PASSING R--RETAINED FIGURES REFER TO THE SCREEN MESH

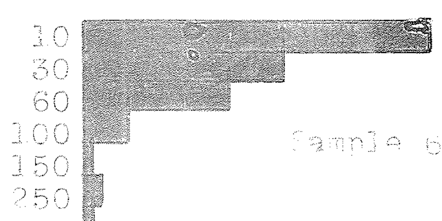


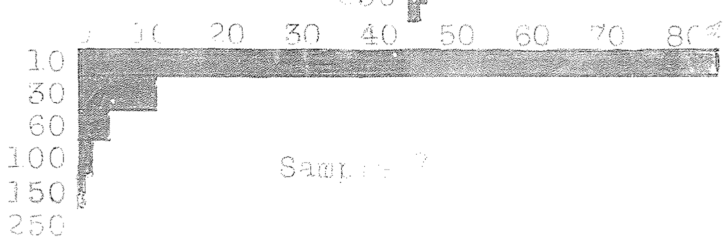












The clays are white or light gray gumbos, in appearance and texture much like those of the Tertiary formations. Some bars, however, contain dark gray to black clays which have been derived from the Pierre shale. Such bars are most abundant just below large cut banks in the valley bluffs, and make a relatively small part of the fill. This dark clay must be scattered through all of the clays in this part of the White River fill. It does not occur in sufficient abundance, however, to materially change the color since they still retain the light color of the clays from the Tertiary rocks.

The sands are made largely of quartz grains. Much of it is clear, vein quartz, which may have been derived from the erosion of the Rocky Mountains and the Black Hills, and the rest is chalcedony. Some grains are well rounded and show the effects of considerable travel. Others are quite angular.

A grain count of the sand portion of a sample from the lower part of the fill contained the following materials:

<u>Sample #3 V15E</u>

From Test Well on Schwartz Ranch
About 3½ Miles S. of Stamford Bridge
on Resistivity Profile V15
Depth 10-14 Feet

Vein and chalcedonic quartz	95%
Milky quartz	1%
Feldspar (probably orthoclase)	1%
Garnets	1%
Limonite and pyrite	1%

The coarser material ¼ to ½ inch pieces from the same sample gave:

Flints & Cherts	32%
Chalcedony	29%
Vein quartz	9%
Quartzite	9%
Concretionary limestone	16%
Caliche limestone	3%
Iron (limonite)	2%

The gravels are perhaps most interesting because of the predominance of chalcedony. This mineral makes as high as fifty per cent of the pebbles and cobbles in some bars. Associated with it are pebbles of light gray limestone which have come from the concretions in neighboring bluffs of the Pierre shale, flint and cherts from the Black Hills, and a few miscellaneous, igneous, and metamorphic rocks. Chunks of feldspar, ½ to 1 inch across, are abundant. These came directly from the Chadron gravels, and give the gravels and coarse sands of some bars an appearance much like that of the Chadron gravels found in place. Many of the feldspars are perthitic like those of the Black Hills pegmatites, from which they were obviously eroded to form a constituent of the Tertiary gravels, which were subsequently reworked to form the present valley fill.

Pebble counts of gravel samples taken from the bars encountered below the surface in drilling test wells gave the following results:

Sample V 1C #4
From test well on Carley Ranch at Kadoka Bridge
Depth 20-23 Feet

Flint and chert	30%
Chalcedony	22%
Vein quartz	44%
Light grey concretionary limestone	33%
Dark grey concretionary limestone	4%
Porous lime caliche	11%
Sandstone, quartzitic	1%
Feldspar	1%
Metamorph	1%

Sample V 1C #6
From test well on Carley Ranch at Kadoka Bridge
Depth 26-27 Feet

Flint and chert	9%
Chalcedony	33%
Vein quartz	23%
Light grey concretionary limestone	10%
Dark grey concretionary limestone	2%
Porous lime caliche	2%
Pyrite	2%
Iron (limonite)	21%

HYDROLOGY

Porosity and Water Content of the Fill

The porosity of the materials of the fill is of particular interest because it will determine the amount of water that can be stored in the fill. This is especially important in this region because irrigation is needed most in the dry summer months when there will be little recharge except from the underground movement of water. Thus the amount of water that is available for any irrigation project will depend on, 1) the amount of water that the gravel holds at any particular time and 2) the rate at which it can be recharged by underflow.

Laboratory examinations of the porosity of the fill were not possible since apparatus for taking undisturbed cores of the material was not available. Considerable information concerning porosity, however, can be obtained by a study of the size of grains and the proportion of various sizes in the samples. If the grains were perfect spheres and all of them the same size it would be possible to calculate very accurately the amount of pore space in the rocks. As has been pointed out, however, there is a wide variation in size and the assortment is far from perfect. Grains of small size, such as clays, may lodge in the pores between larger sand grains and pebbles, cutting down the porosity of the deposit. It is possible, therefore, to make only rough estimates as to the total volume of water present, but it is hoped that these estimates can serve as a guide for further investigation if extensive irrigation is to be undertaken, and as sufficiently accurate for small irrigation projects.

A study of the sieve analyses (p. 9-13) shows that the particles of the fill vary in size from cobbles a couple of inches across, to the finest of clays. Though the tests show only the amount of fine material that passed a 250 mesh sieve, some clays carried in the streams and lodged in the deposits are colloidal. Even when the current is low the water is milky with suspended clays. All grades of porosity are therefore available. If these particles were perfectly spherical and sorted into beds of uniform size and packed as tightly as possible, the porosity would be 25.95 per cent.[1]

The lack of sphericity of the particles could run the porosity up to ninety per cent in some cases,[2] and the mixing of various sized particles could run it down to less than five per cent or even theoretically to zero. The average percentage of pore space in unconsolidated sediments, however, may run as high as fifty per cent. In quicksand, it may be forty per cent; in gravel, twenty-five per cent, according to Tolman.[3]

Rough porosity tests were run on four samples taken from the test well near the Kadoka bridge by pouring water into a given volume of the sample till the voids were filled. The water thus added to the sample was weighed in grams. The gram weight of the water added to the sample gave its volume in cubic centimeters. From this figure and the volume of the sample, it was possible to compute the per cent of pore space. In all cases the figures thus obtained were lower than the average given above. A fine sand showed 28% porosity, a medium gravel 28.8%, a coarse gravel 20%, and a medium gravel 35%. Thus it appears that the average porosity of the White River fill is in the neighborhood of 30%. At least, this is a conservative figure and sufficiently accurate to give a usable idea of the amount of water in the fill. Since a thorough survey of porosities was not feasible these figures will have to be used as representative, and for the purpose in hand will have sufficient accuracy.

During the summer in which the field work was carried on, the water table lay about ten feet below the surface of the fill leaving on the average about fifteen feet of the fill saturated with water. A vertical column of the fill a foot square would contain approximately 4.5 cubic feet of water at an average of 30 per cent porosity, at the low water stage. This would amount

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1. Graton, L. C. and Fraser, H. J., "Systematic Packing of Spheres--With Particular Relation to Porosity and Permeability," <u>Journal of Geology</u>, Volume 43, No. 8, November-December, 1935 p.805.
2. Tolman, C. F., <u>Ground Water</u>, McGraw-Hill Co., 1937, p. 112.
3. <u>Loc. cit.</u>

would amount to 33.6 gallons of water per square foot of surface area of 1,463,616 gallons per acre. In engineering practice it is customary to think of irrigation water in terms of acre feet; that is, the amount of water necessary to cover one acre to a depth of one foot. In these terms, the water stored beneath each acre of the fill would amount to 4.5 acre feet, and that beneath each square mile of valley floor would amount to something like 2,880 acre feet. If more than that amount is to be used at any point, it must be supplied by recharging from neighboring parts of the fill, from rainfall, or by seepage from farther up the river.

It must be borne in mind that not all this water can be used for irrigation. There is a certain amount which cannot be pumped out because of the tendency of water to stick to the grains of sand. In fine grained sediments this property is so pronounced that it is difficult to cause any movement of the water at all. In the White River sediments this retained water probably will not be more than 10 or 15 per cent of the total. These figures, however, will give some idea of the amount of water that is lodged in the fill during the dry part of summer and the amount that might be abailable for irrigation. Since there is little recharge except by underground seepage during the dry months, the stored water will form a limiting factor for irrigation in this valley.

Permeability and Capacity of the Fill

Permeability is the ability of a rock to transmit water. In other words, it is the ease with which water can move through its pores. This flow is governed largely by the size of the openings, or voids, between the grains of the sediments. When these openings are large, water passes through easily because there is little friction between the grains among which it must percolate. If the openings are small, the friction is high, and the water moves very slowly. Thus, clay may actually have more pore space than gravel, but because of the small size of the individual openings, it is the poorest water transmitter of all the rocks, while gravel with lower porosity but larger pores is the best

The openings in shale are so small that friction overcomes nearly all movement of water through them. Clay beds, therefore, are said to be impermeable, while gravel beds and sand beds are very permeable. The permeability of the rocks of the White River valley fill will determine first, whether it will be possible to pump large volumes of water from them rapidly, and secondly, whether water from other parts of the valley can recharge the parts from which water is pumped. In short, the permeability of the rocks of the White River fill will determine the feasibility of pump irrigation to a large extent.

Tests for permeability were made on all samples collected from the test wells, using a method developed by Dr. O. A. Meinzer and used in the laboratories of the U. S. Geological Survey. This method involves measuring the amounts of water that can pass through one square centimeter of the sample in a minute of time under a 100% hydraulic gradient. The instrument used was a constant-head permeameter described in the U. S. Geological Survey Water Supply Paper Number 596-F.

In making these determinations water under a uniform head is run through the sample in a chamber of given diameter. The time taken by a given amount of water in flowing through the sample is observed, and the permeability computed from the formula

$$P = \frac{q\ l\ t}{T\ a\ h}$$

q being the quantity of water discharged, in cubic centimeters (grams); l, the length of the column of sand in the sample chamber, in centimeters; t, the temperature; T, the time, in minutes; a, the area of the cross section of the sample chamber, in square centimeters; and h, the value of the water head. These results were then converted into gallons per square foot per day to correspond with the coefficient as ordinarily defined. The results can be used as coefficients of permeability since they represent the permeability of a given volume of sediment in a given time under a 100% hydraulic gradient.

PERMEABILITY COEFFICIENTS

Measured on Samples of the White River Fill. Taken from test wells drilled entirely through the fill.

Coefficients expressed as the number of gallons that would pass through a square foot of the sample in a day under a hydraulic gradient of 100% at a temperature of 60° F.

V 1 C

Well Drilled on Phil Carley Ranch East of the south end of the Kadoka Bridge

Sample No.	Depth in Feet	Coefficient
1	0 - 10	impervious
2	10 - 18½	impervious
3	18½ - 20	10.6
4	20 - 23	28,660.7
5	23 - 26	1,802.3
6	26 - 27	26,080.9
7	27 - 29	Pierre shale, impervious

V 8 C

Well on White Turtle Estate
1000 feet southeast of the Belvidere Bridge

Sample No.	Depth in Feet	Coefficient
1	0 - 5	106
2	5 - 10	123.7
3	10 - 11	13,852.3
4	11 - 11½	2,313.7
5	11½ - 17½	15,266.8
6	17 - 17½	13,217.2
7	17½ - 19	9,789.2
8	19 - 21	Pierre shale impervious

V 13 D

Well on the Krabbenhoef Ranch
3/4 miles below the Stamford Bridge

Sample No.	Depth in Feet	Coefficient
1	0 - 8	impervious
2	8 - 13	5,170.2
3	13 - 23	10,637.3
4	23 - 31	12,371.5
5	21 - 33	Pierre shale impervious

V 15 E

Well drilled on Schwartz Ranch
3 3/4 miles below the Stamford Bridge

Sample No.	Depth in Feet	Coefficient
1	0 - 9	impervious
2	9 - 10	3.5
3	10 - 14	725.5
4	14 - 14½	360.5
5	14½ - 21	6,021.9
6	21 - 22	5,131.4
7	22 - 24	812.8
8	24 - 25	19,401.6
9	25 - 26	Pierre shale impervious

V 15 B

Well drilled on Schwartz Ranch
3 3/4 miles below the Stamford Bridge

Sample No.	Depth in Feet	Coefficient
1	0 - 4	impervious
2	4 - 8	impervious
3	8 - 17	impervious
4	17 - 18	no sample
5	18 - 19	8,244.8
6	19 - 20	10,071.9
7	20 - 22	Pierre shale impervious

In 83 measurements made in this manner permeability coefficients varied from zero to 28,660. The average permeability of the fill is probably represented with considerable accuracy by the average of the coefficients of the samples from the five test wells which penetrated the fill to the underlying shale. This average is 5,492 and includes the surface as well as subsurface beds. Using the samples which were not impermeable an average coefficient of 8300 was obtained. Since the impervious samples were all from the upper part of the fill this average probably represents approximately that which percolating water of the underflow will encounter.

According to these figures a four inch well producing from a depth of 10 feet below the water table in fill material having the average permeability could yield at a rate of 288,000 gallons a day if pumped hard enough to give a 10 foot drawdown, according to a yield formula given by Tolman.[1] If wells were pumped from the coarser gravels in the bottom of the fill, higher rates of pumpage should be possible. This is an extreme figure which would not be reached in ordinary pumping, but will serve as a limiting figure for the yield.

This is of particular interest since the best places from which to obtain a sufficient quantity of water for irrigation will be in gravel bars in which the permeabilities are high. A glance at the permeability tables above will show that there are a great many places in the valley in which there are no materials of high permeability. They may be sufficient to supply farm wells, but not sufficient for pump irrigation. It is important to note that the depth at which highly permeable material is encountered varies considerably, and any irrigation project that is undertaken must first determine the location and depth of such material. It is important to note that before an irrigation project is undertaken a careful survey of the sub-surface should be made to determine where the coarse gravel bars lie, and wells should be drilled into these bars.

It will be noted that the permeability of the surface material in most tests is low. This is because considerable clayey material has been incorporated into

1. Tolman, C. F., Ground Water, McGraw-Hill Company 1937, Formula 4, p. 386.

the sands. Such a combination makes an impervious bed by filling up the normal voids of the sands with small bits of clay. Such a rock may have a high porosity, but the pores are small. It is rather fortunate that so much of the surface material is tight since the small openings allow water to be drawn into the soil by capillary action but will not allow it to seep rapidly out of the irrigation ditches. Thus water can be transported a long distance without great loss.

The average permeability is also of importance since it will determine the amount of recharge that is possible. If large amounts are withdrawn from the underground reservoir in any one place, sufficient water must be moved in from farther upstream or from other parts of the valley to take its place. Otherwise the reservoir will be depleted before sufficient water has been obtained to do the necessary irrigating. Thus the average permeability will have a great deal to do with the amount of water that can be withdrawn from the reservoir in any one season. It also shows the ability of the fill to recharge from rain and river water from the channel.

As has been stated above, the surface soil in most of the area is fairly impervious. There are large sand patches, however, which will take up rain almost as fast as it falls. In these there is no runoff, but a complete use of all rainfall for recharging the fill. The sandy character of most of the fill below the soil allows the water in the channel to seep readily into it. This recharge from the river takes a large amount of the stream flow. It is not uncommon for a condition to arise in which a considerable stream may be flowing in the upper part of the valley which disappears into the fill within twenty miles.

A study of the permeability of the White River fill shows that, though the theoretical yield of 4 inch wells can be about 200 gallons per minute, the same sized wells can be made to yield at five times that rate in certain locations and from certain bars in the fill. It also indicates that in most parts of the valley the surface material will carry water with a minimum of seepage. It further shows that recharge is readily accomplished by seepage from the stream when it is flowing and from underground water moving through the fill as underflow.

The Underflow

The foregoing description has been intended to give an idea of the physical character of the valley and its fill. A consideration of the ground water will be next in order.

From the description of porosity it was shown that there is a large volume of water stored in the sediments of the valley, which could amount to some 81,022 acre feet, in the length of the valley which has been mapped. This, however, is not a static body of water but is constantly moving downstream by percolation through the fill at a rate between one and five feet per day. The amount of water in the fill, therefore, changes with the seasonal rainfall. During wet times rainfall in the valley adds a foot or two during the year, and the run off from the surrounding impervious hills adds many times that much to the White River from which it seeps into the fill until it brings the water level of the entire valley up to the level of the river. After this seepage ceases, the excess flows out of the valley into the Missouri River. In dry times recharge comes only by percolation through the fill with some water added by percolation through the soils of the shallow fills of the tributary valleys.

Thus most of the recharge in the White River valley is carried on during the spring and fall when melting snow and fall rains add a maximum of water to the valley. During the summer the only surface recharge comes from occasional thunder storms which send torrents of water down the channel to seep into the fill. During dry times the river ceases to flow and the only water in the channel lies in scattered pools formed in depressions scoured below its usual depth. These pools are fed by percolation from the underflow and it is worthy of note that they have supplied sufficient water for pump irrigation on a number of farms in the valley. It is also noteworthy that pools are in existence even after the longest dry spells, indicating that the recharge has been sufficient to keep a body of water approximately twenty feet deep in the gravels of the fill.

The rate of recharge by percolation during the dry months can be roughly estimated from the average permeability and the hydraulic gradient under which the underflow moves. Between the Kadoka bridge and the profile four miles above the Murdo bridge, a distance of 27.1 miles, the water table falls a distance of about 263 feet. This is a gradient of 9.7 feet per mile or approximately 0.2 per cent. Since water moves through coarse sand, which is about the average size of the White River sediments, at a rate of 6.33 feet per day under a 1% hydraulic gradient,[1] it should move about 1.3 feet per day under the gradient existing in the White River valley. In some gravels it probably speeds up to five feet per day since the velocity through the average gravel under a one per cent head is 25 feet per day.

Though the recharge expressed in these terms seems small, it represents the movement of a large amount of water. The area of the saturated part of the average cross section of the fill is about 40,000 feet. Water moving through this cross section at the average rate would move 390,000 gallons a day, or 271 gallons a minute. If it moves nearer the faster rate, it would recharge the valley at a rate of 1,500,000 gallons a day or 1,040 gallons per minute.

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1. Tolman, C. F., Ground Water, p. 219.

CHARACTER OF WATER

The residents of the valley recognize two types of water, usually designating them as "hard and soft water." The hard water is not used where any other is obtainable, as it contains higher percentages of salt which make it hard, alkaline, and often unpleasant to taste. The so-called soft water is the type of water known on the southern great plains as sweet water. It is soft, non-alkaline, and much like rain water in taste. It is hauled long distances by the residents of the uplands for use as drinking and household water. An analysis of the hard water was made in the State Chemical Laboratory with the following results:

Water Sample
from
Well Drilled in Center of Valley
near Stamford Bridge

Alkalinity		
Phenophthalein	None	
Methyl Orange	684	p.p.m. in terms $CaCO_3$
Total Solids	2872	p.p.m.
Sulphate	1380	p.p.m.
Calcium	236	p.p.m.
Magnesium	47	p.p.m.
Sodium (calculated)	665	p.p.m.

This water is too highly charged with solids to be satisfactory for extensive irrigation use. The large amount of sulphates is particularly objectionable in such waters. The large amount of sodium sulphate would doubtless give the water laxative properties.[1]

1. Analysis made by the State Chemical Laboratory, September 20, 1941. Guy G. Frary, State Chemist.

A second sample of the soft water taken from a well near the river bank gave the following results:

Water Sample
from
Well on Schwartz Ranch
3 3/4 Miles Below Stamford Bridge

Alkalinity as $CaCO_3$	
Phenolphthalein	14 p.p.m.
Methyl Orange	359 p.p.m.
Total Solids	744 p.p.m.
Sulphate	216 p.p.m.
Calcium	45 p.p.m.
Magnesium	6 p.p.m.
Sodium (calculated)	218 p.p.m.

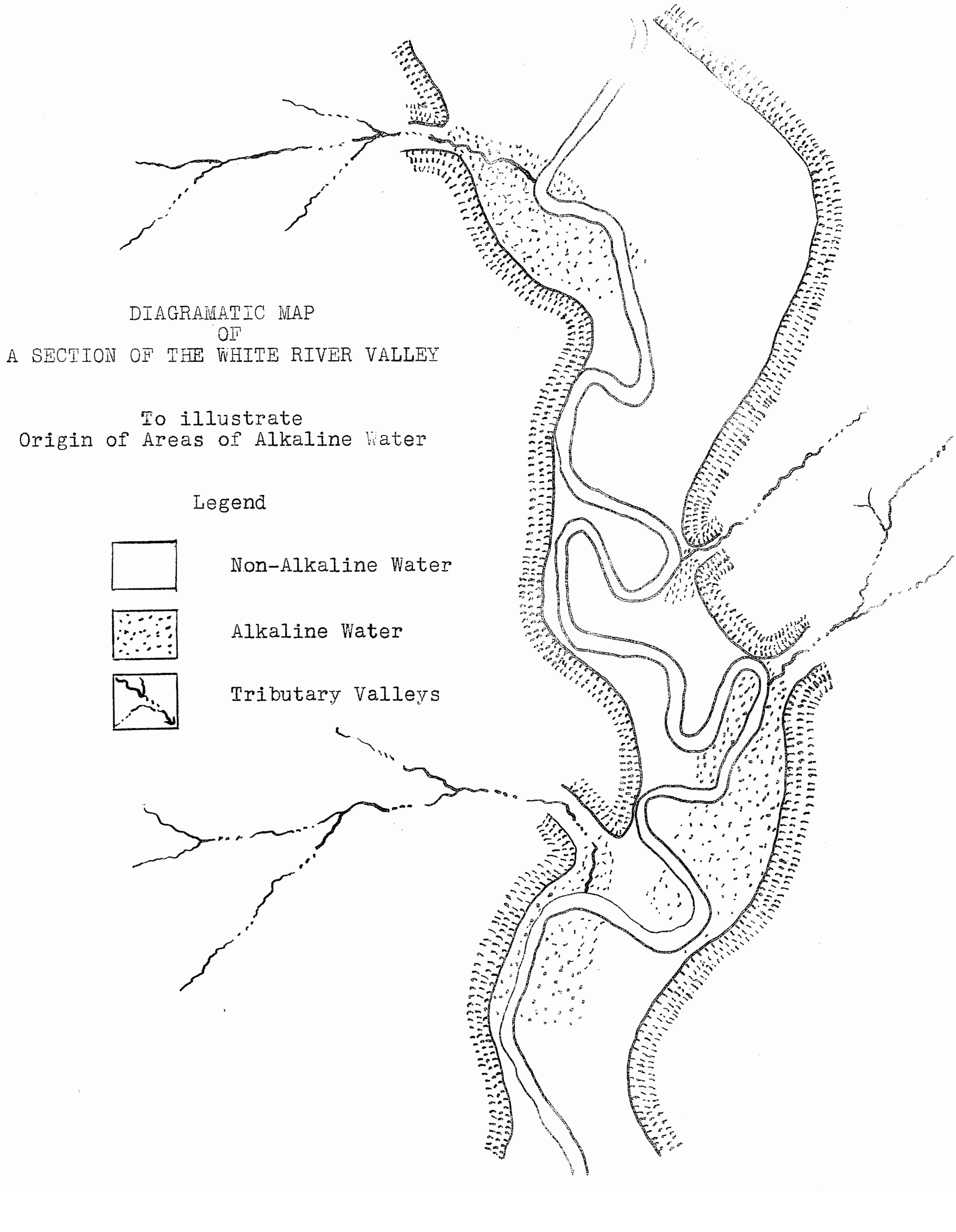
This water is only lightly charged with salts and should be satisfactory for extensive irrigation.[1]

While these two samples are not enough to furnish a comprehensive picture of the water in the fill, they can be used as indicators of the general character of the two types. Hard water in some localities may show a still higher content of total solids and it may be that the soft water will even run lower in solids than the water here analyzed. The point to be noted is that one type of water is poorly suited to irrigation, while the other type would be excellent. The location of these waters in the fill, therefore, is very important as is also their movement through the gravels and sands when the water levels are disturbed by pumping.

The boundaries between the two kinds of water are rather sharp; soft and hard wells sometimes being found within a few score feet of each other, and there is no order in the part of the valley fill occupied by either kind of water. One of the best and largest soft water wells was on a 50 foot bench between the river channel and shale bluffs, and a very hard well was drilled in a bend of the channel near the center of the valley.

Seepage water from the Pierre shale usually gives a water high in salts, especially sulphates. The loca-

1. Analysis made by the State Chemical Laboratory, Vermillion, S. Dak., September 20, 1941. Guy G. Frary, State Chemist.


DIAGRAMATIC MAP
OF
A SECTION OF THE WHITE RIVER VALLEY
To illustrate
Origin of Areas of Alkaline Water
Legend
Non-Alkaline Water
Alkaline Water
Tributary Valleys

tion of the hard and soft water wells observed shows that the hard water is evidently seepage water from the surrounding hills. Direct seepage from the bluffs, however, is not sufficient to give noticeable character to the water. But considerable amounts of water are delivered into the valley by the underflows of the larger tributary valleys.

The bottoms of these valleys are filled with wash from the Pierre shale of sufficient porosity to allow a movement of water through it by seepage. Though this is very slow, it apparently is a continuous process and the ground waters from the hills for large areas work their way through these fills into the White River fill. Thus below the mouth of each large tributary there is an area of alkaline water, which, in the case of some tributaries, seems to extend well across the valley. Above these tributaries the water is soft. It is possible to find soft water within a few rods of the mouth of the tributary upstream, while alkali wells may be encountered for a mile or more below the tributary.

The soft or non-alkali water, on the other hand, is apparently furnished directly from rainfall and by seepage from the White River. It is probable that the main underflow of the White River is water of this type. Surface water, whether from the White River, or from its tributaries, carries a low concentration of salts. The slow, downstream movement of the underflow, however, allows the highly concentrated seepage waters from the large tributaries to be diffused through a considerable volume of the White River underflow. Though these waters are very alkaline they are probably highly diluted from the concentrated condition in which they reach the White River valley.

The presence of these two kinds of water complicates irrigation problems considerably by limiting and more or less localizing the areas in which irrigation can be attempted. While the areas over the alkaline water can be irrigated with soft water run from upstream, it would be impossible to supplement these supplies with water from wells drilled in the immediate vicinity. Changes in the present boundaries will doubtless be affected if large quantities of non-alkaline water are spread over the alkaline water areas. The seepage from such water should dilute the alkaline water farther and in time might enlarge considerably the area from which irrigation water could be pumped.

Secondly, irrigation may cause more fresh water to come from farther up the valley where the underflow may be less alkaline. These are just possibilities, however, and for the immediate development it will be necessary to see that all wells which are to furnish irrigation water are drilled in areas of soft water. Locations should be selected upstream from the mouths of large tributaries or on the side of the valley opposite a large tributary valley. This will serve only as a rough guide, since the final location will have to be decided by drilling and sampling a number of test wells.

CONCLUSIONS

As a summary of the foregoing report the following conclusions are offered.

1. Approximately eighteen thousand acres of flat land, most of which is suitable for irrigation, lies in the bottom of the White River Valley. This area is cut into patches, varying from eighty to five or six hundred acres in extent, by the White River which meanders entirely across the valley undercutting both bluffs so as to completely isolate them from each other.

2. These valley flats are the surface of a fill of sands, gravels, and loams which has been washed into the valley largely from the Tertiary rocks which now occupy the southern divide and the bluffs in the upper reaches of the valley.

3. The total amount of water available in this fill during the dry months is approximately 81,000 acre feet, or enough water to cover the surface of the entire valley to a depth of four and one-half feet. All of this water is not available for irrigation because a portion of it sticks to the grains by capillary attraction. Eighty to ninety per cent of the water could be used, however.

4. Laboratory experiments on the permeability of these sediments indicates that on the average they are sufficiently permeable to permit pumpage of fairly large streams of water. Theoretically, four inch wells could pump two hundred gallons per minute as the upper limit. Practically, it should be considerably less.

5. The ground water surface slopes down the valley at the rate of 10.5 feet per mile, a hydraulic grade of about 0.2 per cent. This causes the water to move as an underflow through the fill at a rate between one and five feet per day. In other words the entire valley is discharging water towards its mouth at a rate of about 390,000 gallons per day, or about 271 gallons per minute. This is a slow movement, but since it is continually taking place through the entire valley, it will, in the course of a season, recharge a large volume of water which might be removed for irrigation.

6. The water of the fill which is furnished by seepage from the river is excellent water for irrigation and domestic uses. Below the mouths of the large tributaries, however, the water is contaminated by water which has seeped from the clay fills of these tributaries. Waters which have percolated through these clay fills are very high in sulphates and make an objectionable water for irrigation. It will be necessary, therefore, to select the well cites carefully.

7. The engineering features are fairly simple since the fill is not over 30 or 35 feet deep and averages only about 25 feet deep. Shallow wells of large diameter drilled into gravel bars, therefore, should furnish a good supply of water. The surface soils in most of the valley are tight loams which should make good water carriers and aid materially in the distribution of water without excessive seepage. The alkaline character of much of the water and the fact that it occurs in spots or patches would seem to preclude any chance of wholesale irrigation of the entire length of the valley. Careful location of wells and intelligent use of the available water, however, should make it possible to materially increase crop farming in this valley.