STATE OF SOUTH DAKOTA
JOE FOSS, GOVERNOR

STATE GEOLOGICAL SURVEY
E. P. ROTHROCK, STATE GEOLOGIST

REPORT OF INVESTIGATIONS

No. 83

GEOLOGY AND SHALLOW WATER RESOURCES BETWEEN HOVEN AND BOWDLE, SOUTH DAKOTA

BY

K. Y. LEE

UNIVERSITY OF SOUTH DAKOTA
VERMILLION, SOUTH DAKOTA
MAY 1957

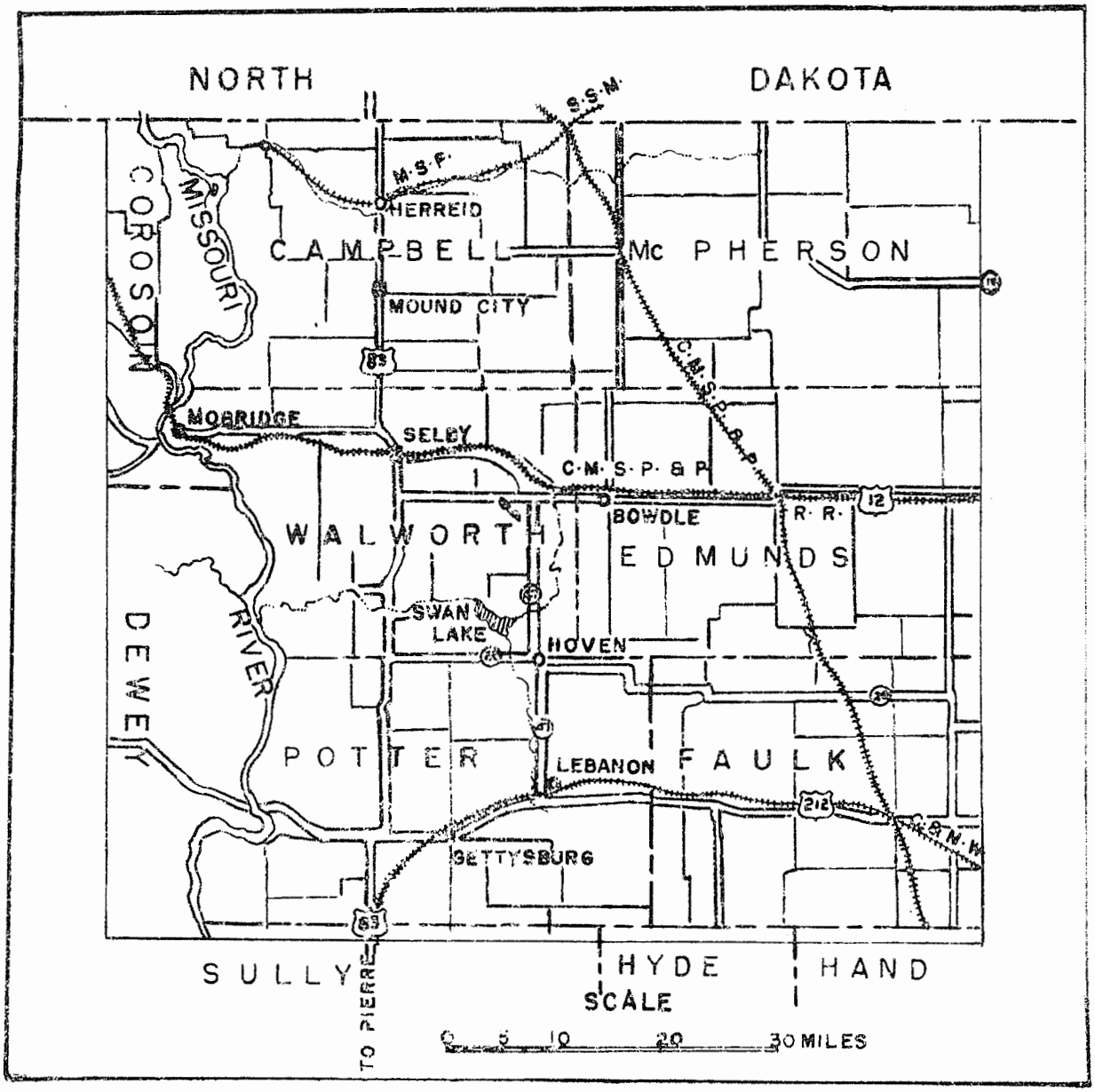


FIG. 1 INDEX MAP

CONTENTS

ILLUSTRATIONS

PLATE — PAGE

FIGURE

TABLE

GEOLOGY AND SHALLOW WATER RESOURCES BETWEEN HOVEN AND BOWDLE SOUTH DAKOTA

BY

K. Y. LEE

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

THE PRESENT INVESTIGATION IS THE CONTINUATION OF A PROJECT WHICH WAS UNDERTAKEN BY THE STATE GEOLOGICAL SURVEY SINCE THE SUMMER OF 1955. BECAUSE FREQUENT DROUGHTS HAVE CAUSED REPEATED CROP FAILURES IN THE REGION BETWEEN HOVEN AND BOWDLE DURING THE PAST DECADES, INTEREST HAS BEEN AROUSED IN THE POSSIBILITY OF IRRIGATION FROM SHALLOW WATER WELLS IN THIS AREA.

A SYSTEMATIC FIELD INVESTIGATION WAS THEREFORE CONDUCTED IN THE SUMMER OF 1956. THE INVESTIGATION WAS MAINLY AIMED AT DECIPHERING THE SHALLOW WATER CONDITION, THE QUANTITY, MOVEMENT AND AVAILABILITY OF WATER FOR THE FUTURE DEVELOPMENT OF IRRIGATION WITHIN THIS AREA. IN ADDITION TO THIS, PHYSICAL CHARACTERS, PROCESSES OF DEPOSITION, AND SAND AND GRAVEL RESOURCES HAD BEEN STUDIED IN DETAIL IN ORDER TO ESTIMATE THE WATER STORAGE CAPACITY IN THE RESERVOIR AS WELL AS THE SUITABILITY OF THESE MATERIALS FOR CONSTRUCTION.

LOCATION AND EXTENT OF THE AREA

THE AREA (INDEX MAP AND PLATE I) COVERS ABOUT EIGHTY-FIVE SQUARE MILES, AND OCCUPIES THE TOWNSHIPS 121, 122 AND 123 NORTH, IN THE RANGES 74 AND 73 WEST. IT LIES TWENTY MILES EAST OF SELBY AND ABOUT TWENTY-TWO MILES NORTHEAST OF GETTYSBURG.

HOVEN, LOCATED AT THE NORTHEASTERN CORNER OF POTTER COUNTY, LIES NEARLY AT THE CENTER OF THE SOUTHERN LIMIT OF THIS AREA. STATE HIGHWAYS 20 AND 47 PASS THROUGH THE MAIN STREET AND TURN WEST. STATE HIGHWAY 20 JOINS U. S. HIGHWAY 83 ABOUT THIRTEEN MILES WEST OF HOVEN. THE JUNCTION OF STATE HIGHWAY 47 AND U. S. HIGHWAY 12 LIES ABOUT FOURTEEN MILES NORTH OF THE CITY OF HOVEN.

BOWDLE IS SITUATED NEARLY DUE WEST OF IPSWICH, THE COUNTY SEAT OF EDMUNDS COUNTY, AND AT THE NORTHEASTERN CORNER OF THIS AREA. IT LIES ABOUT TWENTY-SIX MILES EAST OF SELBY AND THIRTY MILES WEST OF IPSWICH. U. S. HIGHWAY 12 PASSES THROUGH ITS SOUTHERN PORTION.

METHOD OF INVESTIGATION

THE FIELD WORK WAS DONE BY THE COOPERATION OF A GEOLOGIST, A GEOPHYSICIST AND THREE FIELD ASSISTANTS. THE GEOLOGIST WAS IN CHARGE OF SETTING THE LOCATION OF ELECTRIC SOUNDINGS. SUBSEQUENTLY MEASUREMENTS WERE CARRIED OUT BY THE GEOPHYSICIST. IN THE FIELD TWO HUNDRED AND THIRTY-EIGHT STATIONS WERE MEASURED. OF THESE, ONE HUNDRED AND SEVENTY-ONE WERE SELECTED TO PLOT ON THE MAP FOR INTERPRETATION.

A CARL A. BAYS AND ASSOCIATES' EARTH RESISTIVITY INSTRUMENT ER-7 (1953 MODEL) WAS USED FOR THE MEASUREMENT. THE INTERPRETATION ON APPARENT RESISTIVITY DATA WAS MADE BY THE GEOPHYSICIST AND GEOLOGIST ACCORDING TO THE MOONEY AND WETZEL'S MASTER CURVES. THE THICKNESS OF SAND AND GRAVEL WAS SUBSEQUENTLY DETERMINED BY THE GEOLOGIST.

A TOPOGRAPHIC AND GEOLOGIC MAP WAS MADE BY PLANE TABLE SURVEYING, ON A SCALE 1:2500 WITH A CONTOUR INTERVAL OF 5 FEET. TWO HAND AUGERS WERE USED TO DETERMINE THE THICKNESS OF OVERBURDEN AS WELL AS THE ACCURATE BOUNDARY OF THE OUTWASH. NINETY-FIVE DOMESTIC SHALLOW WATER WELLS WERE INSPECTED. ON MORE THAN NINETY PERCENT OF THESE WELLS IT WAS POSSIBLE TO CARRY OUT MEASUREMENTS ON THE DEPTH OF WATER.

TEXTURAL STUDIES ON THE SAND AND GRAVEL WERE MADE IN THE LABORATORY OF THE STATE GEOLOGICAL SURVEY.

PREVIOUS INVESTIGATION

DURING THE PAST DECADES SEVERAL RECONNAISSANCE TRIPS WERE CARRIED OUT THROUGH THIS AREA. IN 1896, JAMES E. TODD, MADE A GENERAL STUDY OF THE GLACIAL FEATURES. IN THE SUMMER OF 1926, E. P. ROTHROCK, STATE GEOLOGIST OF SOUTH DAKOTA, IN COOPERATION WITH THE STATE HIGHWAY COMMISSION CONDUCTED A MAPPING PROJECT. HE GAVE THE ACCURATE ACCOUNT ON THE GLACIAL FEATURES AND LOCATIONS, RESOURCES AND PHYSICAL CHARACTERS OF SAND AND GRAVEL IN

THIS AREA. RICHARD E. FLINT TOOK A RECONNAISSANCE TRIP THROUGH THIS AREA IN THE SUCCESSIVE SUMMER SEASONS FROM 1946 TO 1949. HIS STUDY HAS GENERALLY CLARIFIED SOME CONFUSION ON THE CHRONOLOGY OF GLACIAL DRIFTS IN EASTERN SOUTH DAKOTA.

ACKNOWLEDGEMENT

THE WRITER IS INDEBTED TO DR. E. P. ROTHROCK FOR HIS HELP IN CARRYING OUT THIS WORK; TO PROFESSOR T. H. BEDWELL, SOUTHERN STATE TEACHER'S COLLEGE, SPRINGFIELD, SOUTH DAKOTA FOR HIS TEDIOUS WORK IN THE FIELD. MESSRS. D. DONOVAN, D. VALANDRY AND F. KROGMAN AS FIELD ASSISTANTS, DID MUCH TO MAKE THE SUCCESSFUL COMPLETION OF THIS WORK.

SPECIAL THANKS ARE DUE TO THE RESIDENTS OF THIS AREA FOR THEIR CORDIAL COOPERATION AND HELP.

GEOGRAPHY

TOPOGRAPHY

TOPOGRAPHICAL FEATURES ARE SHOWN ON THE TOPOGRAPHIC MAP (PLATE 1), AND GENERALLY RANGE FROM A GENTLY SLOPING SURFACE OF FINE SILT AND SAND TO AN EXTREMELY UNDULATING SURFACE WITH KETTLES AND SLOUGHS OF ROLLING HILL SURFACE. THE MAXIMUM RELIEF IS TWO HUNDRED AND THIRTY-EIGHT FEET. THE HIGHEST ELEVATION IS 2110 FEET AND LOCATED AT A PEAK IN SECTION 8, TOWNSHIP 123 NORTH, AND RANGE 74 WEST, WHILE THE LOWEST ELEVATION IS 1872 FEET, COMPUTED NEAR THE WATER SURFACE OF SWAN LAKE. ON THE BASIS OF CONFIGURATION, THE TOPOGRAPHY OF THIS AREA IS CLASSIFIED INTO GROUND MORAINE, END MORAINE, OUTWASH PLAIN, AND VALLEY TRAIN.

GROUND MORAINE: THE GROUND MORAINE IS POPULARLY CALLED "SWELL AND SWALE" TOPOGRAPHY. IT IS CHARACTERIZED BY UNDULATING PLAINS WITH GENTLY SLOPING SAGS, SWELLS, AND MANY CLOSED DEPRESSIONS. IN THIS AREA THE GROUND MORAINE BORDERS THE WESTERN SIDE OF THE OUTWASH AND EXTENDS SOUTHWESTERLY TO THE PRESENT SITE OF SWAN LAKE, AND EXTENDS FROM THE OUTWASH TO THE MISSOURI RIVER. IT INCLUDES A PART OF TODD'S "ALTAMOUNT MORAINE".

THE CHIEF MATERIAL OF GROUND MORAINE IS TILL. IT HAS BEEN THOUGHT TO HAVE ACCUMULATED LARGELY BY LODGEMENT BENEATH THE ICE BUT PARTLY ALSO BY BEING LET DOWN FROM THE UPPER SURFACE OF THE

ICE THROUGH THE ABLATION PROCESS. THE DEPRESSIONS ON THE SURFACE ARE MUCH SHALLOWER THAN ON THE TERMINAL MORAINE. THE DEGREE OF ITS ROUGHNESS IS TENTATIVELY ESTIMATED ABOUT TWO SWELLS PER ONE SECTION AND ONE HOLLOW PER TWO SECTIONS. THE LOCAL RELIEF VARIES FROM 10 FEET TO 15 FEET, AND THE DEPTH OF THE HOLLOWS LOCALLY VARIES FROM 15 FEET TO 25 FEET.

END MORAINE: THE END MORAINE OCCURS IN THE EASTERN PORTION OF THIS AREA, EXTENDING NORTHERLY AND NORTHWESTERLY UNTIL IT ENTERS THE STATE OF NORTH DAKOTA IN THE NORTHEASTERN PART OF CAMPBELL COUNTY. IT INCLUDES TODD'S "ALTAMOUNT MORAINE" TO THE EAST AND ROTHROCK'S LEBANON END MORAINE TO THE SOUTH.

AN END MORAINE GENERALLY IS A RIDGELIKE ACCUMULATION OF DRIFT, BUILT ALONG THE MARGIN OF AN ICE SHEET. DUE TO THE ROUGH SURFACE AND STONY SOIL, MOST OF THE RIDGES FORM GOOD PASTURE BUT ARE GOOD LANDS FOR CULTIVATION. THEY ARE CHARACTERIZED BY "KNOBS AND KETTLE" TOPOGRAPHY WITH DEEPER UNDRAINED DEPRESSIONS. THE LOCAL RELIEF RANGES FROM 25 FEET TO 75 FEET, AND AREAL ROUGHNESS IS ABOUT THREE TO FOUR KETTLE HOLES PER SQUARE MILE.

OUTWASH PLAIN AND VALLEY TRAIN: THE OUTWASH PLAIN AND VALLEY TRAIN WERE FORMED THROUGH THE PROCESSES OF GLACIAL OUTWASH. ACCORDING TO THE AREAL DISTRIBUTION THE OUTWASH IS SUBDIVIDED INTO THE BOWDLE OUTWASH AND THE HOVEN OUTWASH, RESPECTIVELY. HOWEVER BOTH OUTWASHES ARE GENERALLY CONFINED BETWEEN THE CARY END MORAINE TO THE EAST AND THE IOWAN GROUND MORAINE TO THE WEST (PLATE I).

THE OUTWASH PLAIN IS A SHEET-SHAPED OUTWASH BODY ON THE SURFACE, WITH A VERY GENTLE SLOPE. THE VALLEY TRAIN IS A NARROW BODY OF OUTWASH CONFINED WITHIN A VALLEY. AS A WHOLE, THE LOCAL RELIEF OF OUTWASH PLAIN RANGES FROM 10 FEET TO 25 FEET AND ITS SLOPING GRADIENT IS ABOUT 15 FEET PER MILE. THE HIGHEST ELEVATION OF THE OUTWASH SURFACE IS 2050 FEET, AND WAS RECORDED IN SECTION 10, TOWNSHIP 123 NORTH AND RANGE 74 WEST, WHILE THE LOWEST ELEVATION IS RECORDED AS 1885 FEET ABOVE SEA LEVEL NEAR THE BASE OF THE VALLEY TRAIN IN THE WESTERN PART OF THE HOVEN OUTWASH.

THE BOWDLE OUTWASH COVERS ABOUT TWENTY-FOUR SQUARE MILES. THE OUTWASH PLAIN HAS A SLOPE GRADIENT OF ABOUT 25 FEET PER MILE TOWARD THE NORTHWEST AND IS ROUGHLY CONFINED IN A NORTH-SOUTH DRAINAGE BASIN. THIS OUTWASH IS GRADUALLY TERMINATED BY THE IOWAN DRIFT IN SECTIONS 25, 26 AND 27, TOWNSHIP 122 NORTH, AND RANGE 74 WEST. THE VALLEY TRAIN OCCURS ALONG BOTH SIDES OF THE MAIN INTERMITTENT STREAM AND ITS TRIBUTARIES, AND IS LOCATED IN

SECTIONS 1, 2, 11 AND 14, TOWNSHIP 122 NORTH, AND RANGE 74 WEST; SECTIONS 26, 35 AND 36, TOWNSHIP 123 NORTH, AND RANGE 74 WEST, AND SECTIONS 31 AND 30, TOWNSHIP 123 NORTH, AND RANGE 73 WEST.

THE HOVEN OUTWASH COVERS ABOUT TWENTY-TWO SQUARE MILES AND IS SITUATED IN AN ELONGATED NORTHEAST-SOUTHWEST DRAINAGE BASIN. THE SLOPE GRADIENT OF OUTWASH PLAIN AVERAGES ABOUT 10 FEET PER MILE. THE VALLEY TRAIN IS MAINLY CONFINED WITHIN THE VALLEY OF SWAN CREEK AND IS ALSO WELL-DISPLAYED IN SECTIONS 30 AND 31, TOWNSHIP 121 NORTH AND RANGE 74 WEST (PLATE 1).

IN ASSOCIATION WITH THE OUTWASH, ICE-CONTACT LAND FORMS, KAMES AND ESKERS WERE COMMONLY FORMED. THESE FEATURES WERE DEVELOPED ALONG THE FRONT OF THE END MORAINE. THE KAMES WERE LEFT AS ROUNDED HILLS OF SAND AND GRAVEL, WHILE THE ESKERS REMAINED AS SAND AND GRAVEL RIDGES WITH UNDULATING CREST LINES, WHERE PROGLACIAL CHANNELS AND CREVICES HAD EXISTED DURING THE DISSIPATION OF ICE. ALTHOUGH BOTH FEATURES ARE NOT WELL-DEVELOPED IN THIS AREA, NEVERTHELESS THEY ARE STILL RECOGNIZABLE IN THE SOUTHEASTERN CORNER OF THE HOVEN OUTWASH AND ALSO IN SECTIONS 5 AND 33, TOWNSHIP 122 NORTH AND 123 NORTH AND RANGE 73 WEST.

DRAINAGE

THE GLACIATION PLAYS A MAJOR ROLE IN CONTROLLING THE DRAINAGE SYSTEM. IN THIS AREA THE PRESENT COURSES OF THE MAIN INTERMITTENT STREAMS AND THEIR TRIBUTARIES ARE MORE OR LESS CONFINED TO THE MARGIN OF OUTWASH. EVENTUALLY THEY EMPTY INTO SWAN LAKE.

IN THIS AREA SWAN CREEK IS THE MAIN INTERMITTENT STREAM AND ORIGINATED IN SECTIONS 7 AND 8, TOWNSHIP 123 NORTH AND RANGE 74 WEST. IT FLOWS FROM THE NORTHWEST TO SOUTH IN THE BOWDLE OUTWASH AND PASSES THROUGH A STEEP GORGE IN SECTIONS 26 AND 35, TOWNSHIP 122 NORTH AND RANGE 74 WEST; IT THEN TURNS WEST AT THE SOUTHERN MARGIN OF SECTION 35, TOWNSHIP 122 NORTH, AND RANGE 74 WEST AND ENTERS SWAN LAKE IN SECTION 18, TOWNSHIP 121 NORTH AND RANGE 74 WEST. ITS GRADIENT IS ABOUT 5 FEET PER MILE AND BECAUSE OF ITS CUTTING THROUGH THE IOWAN DRIFT, IT WAS PROBABLY FORMED POST-IOWAN AND PRE-LATE CARY. FOUR DISTINCT TRIBUTARIES ENTER IT AND FACILITATE THE WATER FLOWS TO THE MAIN INTERMITTENT STREAM. THREE OF THEM ARE LOCATED IN THE BOWDLE OUTWASH, THE OTHER IS SITUATED IN THE NORTHEASTERN CORNER OF THE HOVEN OUTWASH.

IN THE BOWDLE OUTWASH THE FIRST TRIBUTARY RISES IN SECTION 29, TOWNSHIP 123 NORTH AND RANGE 73 WEST ABOUT A MILE AND A HALF

WEST OF THE CITY OF BOWDLE. THIS STREAM FLOWS SOUTHWESTERLY WITH A GRADIENT OF ABOUT 5 FEET PER MILE AND ENTERS THE MAIN INTERMITTENT STREAM IN SECTION 2, TOWNSHIP 122 NORTH AND RANGE 74 WEST. THE SECOND TRIBUTARY FLOWS THROUGH THE IOWAN GROUND MORAINE FROM WEST TO SOUTHEAST WITH A GRADIENT OF ABOUT 3 FEET PER MILE, AND ENTERS THE MAIN INTERMITTENT STREAM AT THE SOUTHEASTERN CORNER OF SECTION 22, TOWNSHIP 122 NORTH, AND RANGE 74 WEST. THE THIRD TRIBUTARY ORIGINATED FROM AN OUTWASH SWAMP IN SECTION 13, 14, 23 AND 24, TOWNSHIP 122 NORTH AND RANGE 74 WEST; IT FLOWS SOUTHWARD THROUGH SECTION 23, TOWNSHIP 122 NORTH AND RANGE 74 WEST, AND ENTERS THE MAIN INTERMITTENT STREAM IN SECTION 26, TOWNSHIP 122 NORTH AND RANGE 74 WEST.

IN THE HOVEN OUTWASH, SWAN CREEK FLOWS ALONG THE NORTHERN MARGIN OF THE OUTWASH. THE FOURTH TRIBUTARY FLOWS NEARLY DUE WEST WITH GRADIENT OF 10 FEET PER MILE AND IS IN ACCORDANT JUNCTION WITH SWAN CREEK IN THE NORTHERN PART OF SECTION 2, TOWNSHIP 121 NORTH AND RANGE 74 WEST. IN ADDITION TO THIS, THERE IS ANOTHER INTERMITTENT STREAM WITH ONE TRIBUTARY. IT FLOWS IN FROM THE SOUTH AND JOINS ITS TRIBUTARY AT THE NORTHERN BOUNDARY OF SECTION 31, TOWNSHIP 121 NORTH AND RANGE 74 WEST. THIS STREAM ENTERS SWAN LAKE WITH A GRADIENT OF ABOUT 8 FEET PER MILE IN SECTION 30, TOWNSHIP 121 NORTH AND RANGE 74 WEST.

CLIMATE

THIS AREA HAS A REMARKABLE CONTINENTAL CLIMATE WITH EXTREME SUMMER HEAT, EXTREME WINTER COLD, AND RAPID FLUCTUATION OF TEMPERATURE. ON THE BASIS OF CLIMATE RECORDS (TABLE 1), ISSUED BY THE U. S. WEATHER BUREAU STATIONS AT MOBRIDGE AND BOWDLE, THE COLDEST WINTER WAS RECORDED AS HAVING A MEAN ANNUAL TEMPERATURE OF 39^{0} IN 1950 IN THE PERIOD FROM 1930 TO 1955. HOWEVER IN 1917 THE ANNUAL MEAN TEMPERATURE WAS RECORDED AS 39.22^{0} F AT THE STATION IN IPSWICH. IT INDICATES THAT THE FLUCTUATION OF ANNUAL MEAN TEMPERATURE WAS NEVER OVER 10^{0} F IN THE SPAN OF 33 YEARS. THE ANNUAL MEAN TEMPERATURE WAS NEVER OVER 59.8^{0} F DURING THE PAST 48 YEARS.

THE ANNUAL PRECIPITATION HAD BEEN QUITE VARIABLE DURING THE PERIOD FROM 1930 TO 1955. THE ANNUAL AVERAGE PRECIPITATION WAS RECORDED AS 17.48 INCHES AT THE STATION IN BOWDLE DURING THE PAST 25 YEARS. THE DRYEST YEARS OCCURRED FROM 1931 TO 1937, AND THE LOWEST ANNUAL PRECIPITATION, 7.95 INCHES, WAS RECORDED IN 1936. NEVERTHELESS SINCE 1937 THE ANNUAL PRECIPITATION REACHED A RECORDED HIGH OF 26.54 INCHES IN 1953. AS A WHOLE,

TABLE I

ANNUAL AND MONTHLY AVERAGE PRECIPITATIONS AND MEAN TEMPERATURES
1930 - 1955
(DATA BASED ON THE RECORDS ISSUED BY THE U.S. WEATHER BUREAU)

YEAR	ANNUAL MEAN TEMPERATURE* (F^{o})	ANNUAL PRECIPITATION** (INCHES)	MONTHLY AVE. PRECIPITATIONS** 1930-1955	
			MONTH	PRECIPITATION (INCHES)
1930	45.1	18.92		
1931	49.4	15.94	JANUARY	0.59
1932	44.4	21.87		
1933	48.1	15.59	FEBRUARY	0.54
1934	49.8	8.75		
1935	46.0	17.19	MARCH	0.95
1936	44.9	7.95		
1937	44.6	15.53	APRIL	1.72
1938	48.0	13.63		
1939	48.4	16.58	MAY	2.49
1940	45.4	12.93		
1941	46.6	16.56	JUNE	4.00
1942	44.1	24.27		
1943	43.2	18.75	JULY	2.04
1944	43.7	25.21		
1945	42.7	15.55	AUGUST	2.00
1946	45.2	22.98		
1947	44.3	16.12	SEPTEMBER	1.23
1948	44.3	21.01		
1949	43.8	21.38	OCTOBER	1.05
1950	39.7	14.25		
1951	40.6	22.39	NOVEMBER	0.54
1952	44.4	10.43		
1953	46.0	26.54	DECEMBER	0.33
1954	45.8	17.31		
1955	44.2	14.81	TOTAL	17.48

* STATION AT MOBRIDGE, WALWORTH COUNTY, SOUTH DAKOTA.
** STATION AT BOWDLE, EDMUNDS COUNTY, SOUTH DAKOTA.

MAY, JUNE, JULY AND AUGUST ARE THE YEARLY WET MONTHS, WHILE NOVEMBER, DECEMBER, AND JANUARY ARE THE YEARLY DRY MONTHS.

POPULATION AND AGRICULTURE

THE HUMAN POPULATION IS SPARSE. IT IS ABOUT TWO FAMILIES PER SQUARE MILE. MOST OF THE RESIDENTS ARE CONCENTRATED IN BOWDLE AND HOVEN. BOWDLE HAS ABOUT 788 PEOPLE WHILE HOVEN HAS 552 RESIDENTS. FARMING IS THE CHIEF OCCUPATION WITH CORN AND WHEAT THE CHIEF CROPS. LIVESTOCK, ESPECIALLY CATTLE AND HOGS, ARE VERY COMMON.

THE SOIL IS GENERALLY LOAMY, AND DARKISH BROWN. THE TOPSOIL CONTAINS MUCH ORGANIC MATERIAL, ESPECIALLY IN THE TILL PLAIN REGION. ITS TEXTURE RANGES FROM LIGHT TO HEAVY WITH RATHER GOOD PERMEABILITY. THE SUBSOIL IS GRAY TO BROWNISH BLACK WITH COMPARATIVELY LOWER PERMEABILITY THAN THE TOPSOIL. HOWEVER IN THE OUTWASH REGION BOTH TOPSOIL AND SUBSOIL ARE SILT AND SANDY-RICH, AND CONTAIN LESS ORGANIC MATERIALS. THE PERMEABILITY IS COMPARATIVELY MORE RAPID THAN THAT IN THE TILL PLAIN REGION.

THE MAIN VEGETATION IS GRASS. HEAVY STANDS OF GRASS OCCUR COMMONLY ALONG THE BANKS OF STREAMS AND SWAMPS. DUE TO THE SCANTY MOISTURE, HOWEVER, GRASS STANDS ARE NOT SO HEAVY IN THE REST OF THIS AREA.

TABLE 2

GENERALIZED GEOLOGIC SECTION FOR THE REGION BETWEEN HOVEN AND BOWDLE

SYSTEM	SERIES	STAGE	SUBSTAGE	DESCRIPTION	THICKNESS (FEET)	REMARKS
	RECENT			ALLUVIUM: CLAY, SILT, AND SAND	3-9	AS TRANSMITTING AGENT IN RECHARGE TO GROUND WATER
QUATERNARY	PLEISTOCENE	WISCONSIN	LATE	OUTWASH: MARGIN LAKE DEPOSITS & ALLUVIUM; PARALLEL CLAY, SILT & SAND WITH FINE LAMINATION	2-6	
				OUTWASH: PLAIN & VALLEY TRAIN; SAND AND GRAVEL WITH SILTY CLAY AND SILT ON TOP	1-123	CHIEFLY YIELD WATER TO WELL WHEN SATURATED
			CARRY	TILL: BOULDER CLAY WITH SUBANGULAR ROCK FRAGMENTS & SAND-SILT-RICH MATRIX. LIGHT YELLOW TO MEDIUM GRAY WHEN DRY; YELLOW TO SOMEWHAT ORANGE WHEN MOIST.	10-20	YIELD ABUNDANT SUPPLIES OF WATER & ALSO AS TRANSMITTING MEDIUM IN UPLAND AREAS
			CARRY	OUTWASH: PLAIN & VALLEY TRAIN; SAND AND GRAVEL; LOCALLY WITH SILTY CLAY & SILT ON TOP	2-158	CHIEFLY YIELD WATER TO WELL WHEN SATURATED
				TILL: BOULDER CLAY CHIEFLY CONSISTING OF SUBANGULAR ROCK FRAGMENTS. GRAY TO LIGHT YELLOWISH GRAY WHEN DRY; OLIVINE-GREEN TO ORANGE & GRAY WHEN MOIST. SILT-RICH MATRIX	20-30	YIELD ABUNDANT SUPPLIES OF WATER & ALSO AS TRANSMITTING MEDIUM IN UPLAND AREAS
			IOWAN	TILL: BOULDER CLAY CONSISTING OF ROUNDED TO SUBANGULAR ROCK FRAGMENTS WITH CLAY & SILT-RICH MATRIX & CEMENT GRAY TO BLACKISH GRAY SOMEWHAT MEDIUM GRAY WHEN DRY; GRAY-BROWN TO OLIVINE GREEN WHEN MOIST	40-90±	YIELD ABUNDANT SUPPLIES OF WATER & ALSO AS TRANSMITTING MEDIUM IN UPLAND AREAS

GEOLOGY

STRATIGRAPHY

THE REGIONAL STRATIGRAPHY IS MADE UP OF THE WISCONSIN GLACIAL DEPOSITS IN WHICH THREE DRIFTS ARE TENTATIVELY RECOGNIZED AS IOWAN, CARY AND LATE CARY IN AGE (PLATES I AND 3, TABLE 2). GENERALLY THE WISCONSIN DRIFT CONSISTS OF TILLS, OUTWASHES, AND OUTWASH MARGIN-LAKE DEPOSITS AND ALLUVIUM. IN THIS AREA THE OUTWASHES ARE VERY PREDOMINANT, WHILE TILLS, AND OUTWASH MARGIN-LAKE DEPOSITS AND ALLUVIUM ARE SUBORDINATE. RECENT ALLUVIUM DEPOSITS OCCUR SPORADICALLY ALONG THE INTERMITTENT STREAMS AND THEIR TRIBUTARIES.

PLEISTOCENE

WISCONSIN

DURING THE PLEISTOCENE TIME THE WISCONSIN GLACIAL DRIFT SHEETS COMPLETELY COVERED THE EASTERN HALF OF SOUTH DAKOTA, AND WERE SPREAD OVER THE EROSION SURFACE OF PIERRE SHALE. IN THIS AREA THE GROUND MORAINE TO THE WEST OF THE OUTWASH BELONGS TO THE IOWAN DRIFT. THE CARY AND LATE CARY TILLS ARE THE CHIEF CONSTITUENTS OF END MORAINE TO THE EAST AND NORTH. THE OUTWASH MATERIALS WERE DERIVED FROM THE CARY AND LATE CARY TILLS DURING THE TIME OF ICE RETREAT.

IOWAN DRIFT: THE IOWAN DRIFT CONSISTS OF TILL WITH INCLUSIONS OF SAND AND GRAVEL, AND IS WELL EXPOSED IN THE WESTERN PORTION OF THIS AREA. THE DEMARCATION OF THIS DRIFT IS ROUGHLY CONFINED TO THE WESTERN SIDE OF SWAN CREEK. SOME ROUNDED ROLLING TILL RIDGES ARE, HOWEVER, RECOGNIZED AS IOWAN IN AGE, IN SECTIONS 25, 26 AND 27, TOWNSHIP 122 NORTH AND RANGE 74 WEST AND IN SECTIONS 23, 25, 26 AND 30, TOWNSHIP 123 NORTH AND RANGE 74 WEST OF THE BOWDLE OUTWASH; A SMALL TILL RIDGE, TRENDING DUE SOUTH AND NORTH IS ALSO LOCATED IN SECTIONS 29 AND 32, TOWNSHIP 121 NORTH AND RANGE 74 WEST OF THE HOVEN OUTWASH.

TOPOGRAPHICALLY THIS DRIFT IS CHARACTERIZED BY A WELL-INTERGRADED DRAINAGE PATTERN AND A LACK OF COMPLETELY CLOSED DEPRESSIONS. A SECTION PROFILE WAS EXAMINED IN DETAIL ALONG BOTH SIDES OF A STEEP GORGE IN SECTION 27, TOWNSHIP 122 NORTH AND RANGE 74 WEST. NUMEROUS HAND AUGER BORINGS WERE MADE TO DETERMINE THE DEPTH OF SOIL PROFILES AS WELL AS THE DISTRIBUTION OF THIS DRIFT.

THE EXPOSED THICKNESS OF THIS DRIFT IS ESTIMATED AS BEING FROM 40 FEET TO 90 FEET.

TILL: THE IOWAN TILL CONSISTS CHIEFLY OF CLAY WITH SCATTERED BOULDERS AND COBBLES IN THE LOWER PART, AND OCCASIONALLY IS INTERCALATED WITH SOME INCLUSIONS OF SAND AND GRAVEL. ACCORDING TO THE FIELD INVESTIGATION THE ROCK FRAGMENTS OF PEBBLE-COBBLE SIZE ARE GENERALLY COMPOSED OF 37 PERCENT OF LIMESTONES AND DOLOMITES, 32 PERCENT IGNEOUS AND METAMORPHIC ROCK TYPES, PLUS 29 PERCENT OF PIERRE SHALE, CLAY IRONSTONES AND SOME SANDSTONES, AND 5 PERCENT OF AMORPHOUS QUARTZ (LEE 1956, 1957). A GENERALIZED DESCRIPTION OF THE LITHOLOGY OF THIS TILL IS GIVEN IN DESCENDING ORDER AS BELOW:

UPPER
- SOIL, DARKISH BROWN, SILTY AND SANDY, WITH LEACHED ZONE RANGING FROM 1-2 FT.
- SUBSOIL, CLAY, GRAY TO MEDIUM GRAY, CONSISTING OF NUMEROUS PATCHES OF NONTRONITIC MATERIALS, 3-4 FT.
- LOESS OR SILT, LOCALLY EXPOSED, BUFF, YELLOWISH GRAY TO GRAY, WITH SOME MEDIUM-GRAINED SAND NEAR THE BASE, 0-1.5 FT.

LOWER
- TILL, GRAY TO GREENISH GRAY AND OLIVINE GREEN, WHEN MOIST; DUST YELLOW AND LIGHT GRAY WHEN DRY. ROCK FRAGMENTS ARE SCATTERED THROUGH WITH CLAY-RICH CEMENT AND SANDY MATRIX, 20-30 FT.
- TILL, BLACK, SOMEWHAT BLUISH GRAY AND OLIVINE GREEN, CONSISTING OF RATHER ABUNDANT COBBLES AND PEBBLES WITH CLAY-RICH CEMENT AND SILT AND SAND MATRIX, 16-52 FT.

CARY DRIFT: THE CARY DRIFT CONSISTS CHIEFLY OF "BOULDER CLAY" TILL AND OUTWASH. THE TILL OCCURS ALONG THE EASTERN PORTION OF THIS AREA, AND WAS TRUNCATED BY THE LATE CARY READVANCE END MORAINE IN SECTION 30, TOWNSHIP 122 NORTH AND RANGE 73 WEST. THE OUTWASH IS A MERGING OF THE CARY END MORAINE, AND COVERS THE SOUTHERN HALF OF THIS AREA.

TILL: THE CARY TILL REPRESENTS THE NORTHERN EXTENSION OF THE LEBANON END MORAINE AND PART OF THE WESTERN PORTION OF THE ALTAMOUNT MORAINE. THIS TILL IS MADE UP CHIEFLY OF GRAY, YELLOWISH GRAY TO OLIVINE GREENISH GRAY CLAY AND SILT, THROUGH

WHICH ABUNDANT PEBBLES AND COBBLES ARE PRESENT WITH COARSE- TO MEDIUM-GRAINED SAND MATRIX.

ON THE BASIS OF NUMEROUS HAND AUGER BORINGS, THE SOIL IS COMPARATIVELY MORE SANDY THAN THAT DEVELOPED ON THE IOWAN TILL. IT CARRIES A LEACHED ZONE UP TO ONE FOOT THICK. AT THE BASE OF THE TOPSOIL, GRAY TO MEDIUM GRAY CLAY COMMONLY OCCURS WITH PATCHES OF NONTRONITIC AND CALCAREOUS MATERIALS, AND ITS THICKNESS AVERAGES TWO FEET. SILTY AND LOESSIC MATERIALS ARE LOCALLY PRESENT AT THE BASE OF THE SOIL ZONE, BUT IN THIS AREA THE SOIL ZONE IS GENERALLY OVERLYING THE GRAY TO YELLOWISH GRAY PEBBLE-CLAY TILL, THROUGH WHICH SMALL COBBLES ARE SCATTERED. ACCORDING TO THE FIELD INVESTIGATION, THE COMPOSITION OF PEBBLE-COBBLE SIZE ROCK FRAGMENTS CONSISTS OF ABOUT 37 PERCENT OF LIMESTONES AND DOLOMITES, 31 PERCENT OF SHALE, CLAY IRONSTONES AND SOME SANDSTONES, AND 29 PERCENT OF IGNEOUS AND METAMORPHIC ROCK TYPES. THE EXPOSED THICKNESS RANGES FROM 20 FEET TO 30 FEET.

OUTWASH: THE CARY OUTWASH IS CALLED THE "HOVEN OUTWASH". THE MAIN OUTWASH BODY LIES IMMEDIATELY NORTH OF THE CITY OF HOVEN, WHEREAS THE VALLEY TRAIN OCCURS IN THE VALLEYS OF THE INTERMITTENT STREAMS. THE OUTWASH COMPRISES CHIEFLY PEBBLE-SIZE ROCK FRAGMENTS WITH SAND-RICH MATRIX, AND NUMEROUS SILT AND SAND LENSES ARE FREQUENTLY INTERCALATED WITH THE SAND AND GRAVEL; SCATTERED FERRIC OXIDE MATERIALS APPEAR SPORADICALLY IN THE MASS OF SAND AND GRAVEL.

SAMPLES COLLECTED BOTH FROM THE OUTWASH PLAIN AND THE VALLEY TRAIN WERE SEPARATED BY SCREENING INTO CERTAIN SIZE GROUPS (TABLE 4) ACCORDING TO THE WENTWORTH SCALE (TABLE 3). THE RESULTS WERE COMPUTED INTO WEIGHT PERCENTAGE OF EACH GRADE LIMIT. THE RESULTS SHOW THAT THE OUTWASH CONSISTS OF THE FOLLOWING PERCENT AVERAGES BY WEIGHT:- 5 PERCENT OF COBBLES, 50 PERCENT OF PEBBLES, 10 PERCENT OF GRANULES, 34 PERCENT OF SANDS AND 1 PERCENT OF SILT AND CLAY. THE LITHOLOGIC COMPOSITION OF PEBBLE-COBBLE SIZE ROCK FRAGMENTS OF OUTWASH IS MADE UP OF 38 PERCENT OF LIMESTONES AND DOLOMITES AND THEIR ASSOCIATES, 30 PERCENT OF SHALE, CLAY IRONSTONES AND SOME SANDSTONES, AND 29 PERCENT OF IGNEOUS AND METAMORPHIC ROCK TYPES (TABLE 5). THE FINE FRACTION, INCLUDING GRANULES AND SANDS, COMPRISES ABOUT 90 PERCENT OF QUARTZ GRAINS, AND 10 PERCENT OF ROCK FRAGMENTS AND OTHER ACCESSORY MINERALS.

ACCORDING TO THE INTERPRETATION ON ELECTRIC SOUNDING CURVES (TABLE 6, APPENDIX) THE THICKNESS OF OUTWASH IN THIS REGION RANGES FROM 2 FEET TO 158 FEET.

TABLE 3

WENTWORTH'S PARTICLE SIZE CLASSIFICATION

Grade Limits		Name
Diameter in mm.	Diameter in inches	
Above 256	10	Boulder
256-128	10-5	Larger cobble
128-64	5-2.5	Small cobble
64-32	2.5-1.25	Very large pebble
32-16	1.25-0.62	Large pebble
16-8	0.62-0.31	Medium pebble
8-4	0.31-0.15	Small pebble
4-2	0.15-0.078	Granule
2-1	0.078-0.039	Very coarse sand
1-1/2	0.039-0.019	Coarse sand
1/2-1/4	0.019-0.009	Medium sand
1/4-1/8	0.009-0.004	Fine sand
1/8-1/16	0.004-0.0024	Very fine sand
Below 1/16	0.0024	Coarse silt & fine clay

TABLE 4

TEXTURAL STUDY OF GLACIAL OUTWASH SEDIMENTS BETWEEN HOVEN AND BOWDLE, SOUTH DAKOTA

Locality	Sample No.	Mechanical Analysis* (Diameter in mm)												Total Wt. %	Textural Parameters			
		128-64	64-32	32-16	16-8	8-4	4-2	2-1	1-1/2	1/2-1/4	1/4-1/8	1/8-1/16	1/16-		Q1	M	Q3	SO
Sec. 21, T121N, R74W.	1	33.40	3.64	14.16	9.77	8.12	8.06	8.15	7.66	4.36	1.61	0.51	0.51	99.95	17.70	17.00	2.50	5.567
Sec. 31, T121N, R74W.	2		8.16	2.48	9.90	10.61	10.11	12.09	14.40	21.35	4.74	0.71	1.11	95.66	5.70	1.23	0.41	3.741
Sec. 17, T121N, R74W.	3		20.69	7.92	11.21	9.36	6.25	9.43	16.31	10.21	4.06	2.04	2.47	99.95	21.50	3.50	0.68	5.656
Sec. 24, T123N, R74W.	4		36.63	11.08	8.65	6.23	4.21	4.19	5.86	10.72	8.97	2.24	1.22	100.00	42.00	13.50	0.63	8.185
Sec. 24, T123N, R74W.	5		24.60	4.24	8.63	9.81	12.90	13.36	13.30	9.64	2.93	0.31	0.22	99.94	30.50	3.45	0.94	5.656
Sec. 24, T123N, R74W.	6		17.87	17.12	16.92	14.83	9.77	7.11	6.21	6.09	2.80	0.53	0.60	99.85	23.50	8.60	2.25	3.162
Sec. 17, T121N, R74W.	7		5.73	11.09	19.43	15.32	14.35	13.33	11.47	6.76	1.77	0.32	0.37	99.94	12.20	4.20	1.25	3.162
Sec. 17, T121N, R74W.	8						0.51	0.50	3.83	15.63	63.19	12.94	3.37	99.97	0.245	0.20	0.145	1.414
Sec. 9, T121N, R74W.	9		23.04	5.10	15.41	10.35	8.42	9.25	14.51	7.41	2.08	1.76	2.62	99.95	25.00	5.00	0.86	5.385
Sec. 9, T121N, R74W.	10		25.03	10.15	17.79	13.69	12.27	9.62	5.84	3.59	0.99	0.44	0.55	99.96	32.50	9.00	2.60	3.605
Sec. 36, T122N, R74W.	13		34.58	12.71	12.35	6.83	5.50	6.92	9.48	5.85	2.57	1.21	1.94	99.94	40.00	13.50	1.50	5.196
Sec. 21, T123N, R73W.	15	31.19	4.06	7.80	9.44	10.53	9.65	8.01	8.21	6.17	2.46	0.76	1.66	99.94	76.00	10.00	1.65	6.782

*Wentworth's Grade Limits Q1, 1st Quartile Q3, 3rd Quartile M, Median SO, Sorting Coefficient ($\sqrt{Q1/Q3}$)

TABLE 5

LITHOLOGIC COMPOSITION OF THE GRAVEL (PERCENT IN NUMBER)

Sample No. / Location / Rock Type	1 Sec. 21, T12N, R74W	2 Sec. 31, T12N, R74W	3 Sec. 17, T12N, R74W	4 Sec. 24, T23N, R74W	5 Sec. 24, T23N, R74W	6 Sec. 24, T23N, R74W	7 Sec. 17, T12N, R74W	9 Sec. 9, T12N, R74W	10 Sec. 9, T12N, R74W	13 Sec. 36, T22N, R74W	15 Sec. 21, T23N, R73W	Dia. Rge. (Inches)
Dolomite												
Gray	5.65	2.64	9.79	2.91	3.41	9.30	5.23	6.77	4.23	1.87	1.32	0.15-0.82
Brown	2.60	1.88	7.75	0.97	3.41	6.97	6.19	4.68	5.50	3.28	1.76	0.15-1.25
Other(Calcic)	0.43	0.75	7.34	0.97	0.85	7.75	1.42	5.20	7.20	1.87	0.88	0.15-0.82
Limestone												
Light gray	4.78	9.81	6.53	10.67	8.11	6.97	7.14	6.25	6.35	7.98	4.84	0.15-2.50
Gray	6.95	8.67	4.08	31.16	12.82	7.75	5.23	7.81	6.35	9.85	6.60	0.15-2.50
Dark (Black)	2.17	3.01	2.44	5.82	3.41	0.77	0.95	1.56	2.11	2.81	8.81	0.15-1.25
Other(Dolo.)	5.65	3.77	7.34	1.94	1.28	10.07	12.85	6.77	6.35	1.87	2.20	0.15-5.00
Chert	0.43	2.26	1.22		0.85	1.55	1.42	1.04	1.27	1.40	2.20	0.15-1.25
Calcareous Rocks and Associates	28.66	32.79	46.49	54.44	34.14	51.13	40.43	40.08	39.36	30.93	28.61	
Sandstone												
Gray	C 0.43	C 0.37		C 0.97	C 0.42	C 0.77	C 0.47		C 0.42	C 0.46		0.15-2.50
Brown			C 0.40				Nc 0.95			C 0.46		0.15-0.82
Shale												
Black(Gray)	Nc36.52	Nc29.43	Nc 2.04	Nc 5.82	Nc23.93	Nc13.95	Nc12.38	Nc15.10	Nc16.94	Nc23.94	Nc16.74	0.15-1.25
Clay Ironstone	10.86	11.69	19.18	6.79	9.82	8.52	8.09	6.77	6.77	10.79	18.49	0.15-2.15
Clastic Rocks & Associates	47.81	41.49	21.62	13.58	34.17	23.24	21.89	21.87	24.13	35.65	35.23	
Igneous												
Granitic	12.17	15.47	10.61	21.35	21.36	13.17	22.38	20.31	17.37	14.08	24.22	0.15-2.50
Dioritic	3.45	1.50	5.30	0.97	1.28	0.77	4.76	3.12	6.77	4.69	1.32	0.15-1.25
Basaltic	1.30	0.75	6.93	0.97	0.42	3.87	6.19	5.20	3.38	1.87	2.20	0.15-1.25
Metamorphic												
Quartzite	2.60	2.26	1.63		2.99	1.55	1.90	1.56	2.96	5.63	2.20	0.15-2.50
Slate	3.45	4.15	5.71	6.79	4.27	3.87	1.90	5.20	4.23	5.16	4.84	0.15-1.25
Schist	0.43	1.50	1.22	1.94	1.28	2.32	0.47	2.08	1.69	1.40	1.32	0.15-1.25
Gneiss			0.40					0.52		0.46		0.15-2.15
Crystalline Rocks	23.40	25.63	31.80	32.02	31.60	25.55	37.60	37.99	36.40	33.29	36.10	
Total %	99.87	99.91	99.91	100.04	99.91	99.92	99.92	99.94	99.89	99.87	99.94	

C, Calcareous Nc, Non-calcareous

LATE CARY DRIFT: THE LATE CARY DRIFT COMPRISES "BOULDER CLAY" TILL AND OUTWASH. IT FRINGES THE MARGIN OF THE BOWDLE OUTWASH TO THE EAST AND NORTH. A THIN LAYER OF LOESSIC SILT IS OCCASIONALLY PRESENT AT THE BASE OF THIS DRIFT IN SECTION 30, TOWNSHIP 122 NORTH AND RANGE 73 WEST.

TOPOGRAPHICALLY AND LITHOLOGICALLY THIS DRIFT IS LITTLE DIFFERENT FROM THE CARY DRIFT, HOWEVER THE COLOR OF THE TILL, THE LEACHED ZONE OF THE SOIL PROFILE, AND THE LITHOLOGICAL COMPOSITION OF THE TILL INDICATE THIS DRIFT WAS FORMED LATER THAN THE TYPICAL CARY DRIFT.

TILL: THE LATE CARY TILL PROBABLY INCLUDES PART OF THE WESTERN PORTION OF ALTAMOUNT MORAINE, AND CONSISTS OF LIGHT YELLOWISH GRAY TO GRAY, BUFF TO LIGHT OLIVINE GREEN CLAY AND SILT WITH WHICH ABUNDANT COBBLES AND PEBBLES ARE INTERCALATED.

ON THE BASIS OF NUMEROUS HAND AUGER BORINGS, THE LEACHED ZONE ON THE UPLAND SURFACE IS UP TO 8 INCHES. THE SOIL IS MADE UP OF THE DARKISH BROWN CLAY, SANDY CLAY AND SILT, AND PATCHES OF NONTRONITIC CALCAREOUS MATERIALS ARE SCATTERED THROUGH THE MASS OF SUBSOIL. THE SOIL ZONE COMMONLY GRADES DOWNWARD TO LIGHT GRAY TO YELLOWISH GRAY, SOMEWHAT BUFF, TO OLIVINE GREEN CLAY WITH PEBBLES. ROCK FRAGMENTS OF COBBLE SIZE ARE USUALLY FOUND IN THE LOWER PART OF THIS TILL. THEIR CHIEF CONSTITUENTS ARE LIMESTONES AND DOLOMITES, WITH ABOUT 30 PERCENT IGNEOUS AND METAMORPHIC ROCK TYPES AND 26 PERCENT SHALES, IRONSTONES, AND SANDSTONES. THE EXPOSED THICKNESS RANGES FROM 10 FEET TO 20 FEET.

OUTWASH: THE LATE CARY OUTWASH IS NAMED "BOWDLE OUTWASH". IT COVERS THE MAIN PORTION OF THE NORTHERN PART OF THIS AREA. THE CITY OF BOWDLE IS SITUATED AT THE NORTHEASTERN CORNER OF THIS OUTWASH. A SHEET-SHAPED SURFACE GENTLY SLOPES WESTERLY FROM THE LATE CARY END MORAINE AND IS DISSECTED BY SWAN CREEK NEAR THE WESTERN MARGIN, AND ITS TRIBUTARIES IN THE CENTRAL PART ALONG WHICH THE VALLEY TRAIN DEPOSITS ARE FOUND.

THE OUTWASH COMPRISES MAINLY PEBBLE SIZE ROCK FRAGMENTS AND SANDS. ACCORDING TO THE MECHANICAL ANALYSES, THE AVERAGE WEIGHT PERCENTAGE OF OUTWASH CONSISTS OF 10 PERCENT COBBLES, 47 PERCENT PEBBLES, 9 PERCENT GRANULES, 32 PERCENT SANDS, AND 2 PERCENT SILT AND CLAY. THE ROCK FRAGMENTS OF PEBBLE-COBBLE SIZE AVERAGE 42 PERCENT LIMESTONES AND DOLOMITES AND THEIR ASSOCIATES, 26 PERCENT SHALES, CLAY IRONSTONES AND SANDSTONES, AND 31 PERCENT IGNEOUS AND METAMORPHIC ROCK TYPES; THE FINE DETRITUS OF SAND-GRANULE SIZE CONSISTS MAINLY OF QUARTZ AND OTHER ACCESSORY

MINERALS. THE THICKNESS OF OUTWASH RANGES FROM 1 FOOT TO 123 FEET ON THE BASIS OF ELECTRIC SOUNDINGS.

OUTWASH MARGIN-LAKE DEPOSITS AND ALLUVIUM: THE OUTWASH MARGIN-LAKE DEPOSITS ARE CLOSELY ASSOCIATED WITH THE FLUVIO-SEDIMENTS, AND ARE GENERALLY ALONG THE MARGIN OF THE MAIN OUTWASH PLAIN. SWAN LAKE IS LOCATED IN THE WESTERN PORTION OF THE HOVEN OUTWASH. A LARGE SWAMP IS SITUATED IN THE SOUTHERN PORTION OF BOWDLE OUTWASH AND COVERS SOME SMALL PORTIONS OF SECTION 13, 14, 23 AND 24, TOWNSHIP 122 NORTH AND RANGE 74 WEST.

SWAN LAKE WAS PROBABLY FORMED DURING THE POST-IOWAN AND PRE-CARY TIME, WHILE THE OTHER ONE WAS FORMED AS A SWAMP-SHAPED DEPRESSION AT THE TIME OF LATE CARY ICE RETREAT. THEY HAVE SINCE BEEN RECEIVING SEDIMENTS THROUGH THE MEDIUM OF RUNNING WATER. THE LITHOLOGY OF THESE DEPOSITS THEREFORE IS DESCRIBED UNDER THE SAME STRATIGRAPHICAL SEQUENCE.

THE LAKE SEDIMENTS CONSIST OF GRAY TO BLUISH GRAY AND SOMEWHAT BLACK CLAY, AND LIGHT GRAY PARALLEL BEDDED SILT, AND SOME FINE- TO MEDIUM-GRAINED SANDS WITH FINE LAMINATIONS; THEY ARE WELL-DEVELOPED ALONG THE SHORE OF SWAN LAKE, WHERE CLAY REACHES THE THICKNESS UP TO 5 FEET, AND GRADES DOWNWARDS INTO FINE SILT AND SAND SATURATED WITH WATER.

RECENT

ALLUVIUM: THE ALLUVIUM IS CONFINED TO BOTH SIDES OF THE INTERMITTENT STREAMS AND THEIR TRIBUTARIES. IT CONSISTS OF CLAY, SILT AND SOME LENTICULAR SANDS WITH FINE LAMINATIONS AND FAINT CROSS-BEDDING.

CHRONOLOGICAL DISCUSSION ON THE LATE CARY DRIFT

IN THIS AREA THE LATE CARY TILL WAS FORMERLY MAPPED AS "MANKATO" IN AGE BY R. F. FLINT (1955). HIS MAPPING WAS BASED ON THE STRATIGRAPHICAL SEQUENCE, TOPOGRAPHICAL FEATURES, AND THE POORER DEVELOPMENT OF SOIL PROFILE PRESENT IN THE MANKATO DRIFT. LATER ZUMBERGE AND WRIGHT JR'S WORK IN SOUTHERN MINNESOTA, WARRANT THAT THE NAME "MANKATO" SHOULD BE USED IN A VERY CAREFUL WAY.

ZUMBERGE AND WRIGHT JR. STATE (1956, P. 65 AND P. 80):-

"....THE DRIFT AT MANKATO IN SOUTHERN MINNESOTA, PERHAPS SHOULD BE CORRELATED WITH THE CARY (PRE-TWO CREEKS) RATHER THAN WITH THE VALDERS (POST-TWO CREEKS).....ANALYSES OF 19 SAMPLES OF SURFACE TILL SHOW THAT THE TEXTURE AND STONE COUNT ARE UNIFORM FROM THE AREA OF MANKATO TO THE EASTERN MARGIN OF THE DES MOINES LOBE (BEMIS MORAINE), WHERE TILL IS INTERBEDDED WITH CARY DRIFT OF THE SUPERIOR LOBE.....THE IMPLICATIONS OF A LATE CARY CORRELATION OF THE WHOLE DES MOINES LOBE AND ITS OFFSHOOT THE GRANTSBURG SUBLOBE HAVE NOT BEEN FULLY EXPLORED IN THE FIELD. THE CASE IS STRENGTHENED, HOWEVER, BY TWO RADIOCARBON DATES FROM THE ANOKA SAND PLAIN (A WASTAGE FEATURE OF THE GRANTSBURG SUBLOBE) AND FIVE DATES FROM LAKE AGASSIZ (WHOSE EXPANSION FOLLOWED THE RETREAT OF THE DES MOINES LOBE). ALL BUT ONE OF THESE DATES EXCEED 11,000 YEARS. IN VIEW OF THE SUSPICION CAST ON THE VALIDITY OF THE TERM MANKATO BY RADIOCARBON DATING, THE WRITERS FAVOR THE USE OF THE VALDERS FOR THE MAXIMUM ICE ADVANCE THAT IMMEDIATELY AFTER THE TWO CREEKS INTERVAL.",

THE LATE WISCONSIN GLACIAL SEQUENCE THUS BECOMES TAZEWELL-CARY-TWO CREEKS-VALDERS. THE MANKATO DRIFT AT TYPE LOCALITY IN THIS INTERPRETATION MAY BE CORRELATED WITH VALDERS (POST-TWO CREEKS) IN A GENERAL WAY. NEVERTHELESS THEIR STUDY HAS NOT YET REACHED A CONCLUSIVE STAGE.

ON THE BASIS OF FIELD INVESTIGATION, THE WRITER BELIEVES THE NAME MANKATO IN THIS AREA SHOULD BE REPLACED BY LATE CARY READVANCE. TOPOGRAPHICALLY BOTH OF CARY AND LATE CARY TILLS SHOW THE SAME TYPE OF CONSTRUCTIONAL LAND FORMS. THE LATE CARY DRIFT INCLUDES MORE STRATIFIED DRIFT THAN DOES THE TYPICAL CARY, AND THE LATE CARY TILL CONSISTS CHIEFLY OF LIGHT YELLOWISH GRAY TO BUFF AND SOMEWHAT OLIVINE GREEN BOULDER CLAY. THE ROCK FRAGMENTS OF LATE CARY CONTAIN ONLY ABOUT 4 PERCENT MORE LIMESTONES AND DOLOMITES THAN THAT OF THE CARY TILL. THE AMOUNT OF SOIL LEACHING IN THE LATE CARY TILL ON THE UPLAND IS COMPARATIVELY LESS THAN THAT PRESENT IN THE CARY TILL. THE AVERAGE LEACHED ZONE OF THE LATE CARY DRIFT IS ABOUT 7 INCHES, WHILE THE CARY DRIFT CARRIES AN AVERAGE LEACHED ZONE OF ABOUT 9 INCHES. ACCORDINGLY THE FACT TENTATIVELY INDICATES THAT THE LATE CARY READVANCE WAS FORMED IN A SHORT PERIOD OF TIME AFTER THE CARY ICE RETREAT, AND DURING THAT TIME THE SCATTERED LOESSIC SILT MATERIALS WERE DEPOSITED ON THE TOP OF CARY TILL..

IN SHORT, IN THIS AREA THE REPLACEMENT OF MANKATO BY LATE CARY AS A STRATIGRAPHIC SEQUENCE IS TENTATIVELY SUGGESTED. THE FINAL CONFIRMATION OF THIS POSSIBILITY WILL, NEVERTHELESS, TAKE SOME TIME. A MORE DETAILED FIELD STUDY ON A LARGE SCALE, AND THE RADIOCARBON DATES OF THIS DRIFT SHOULD BE MADE TO DETERMINE

A LATE CARY SEQUENCE FOR MANKATO IN THIS AREA AS WELL AS IN EASTERN SOUTH DAKOTA.

PETROGRAPHY AND SEDIMENTATION OF OUTWASH

THE PETROGRAPHICAL FEATURES OF A SEDIMENT ARE DIRECTLY CONTROLLED BY THE SEDIMENTATION, IN WHICH THE SEDIMENTARY ENVIRONMENTS AND PROCESSES ARE GENERALLY INCLUDED. AS A RULE, THE SEDIMENTARY ENVIRONMENTS AND PROCESSES OPERATE HAND IN HAND IN FORMING A DEPOSITION OF CLASSIC SEDIMENTS.

PETROGRAPHY

THE PETROGRAPHICAL STUDY ON OUTWASH INCLUDES TEXTURE, STRUCTURE, AND COMPOSITION, FROM THESE THE SEDIMENTARY ENVIRONMENTS AND PROCESSES ARE TENTATIVELY REFLECTED. IN THIS AREA THE OUTWASH REPRESENTS A TYPICAL MECHANICAL MIXTURE OF THE COARSE PEBBLE AND COBBLE FRACTION IN ASSOCIATION WITH FINE- TO COARSE-GRAINED SANDS, AND SOME SILT AND CLAY DETRITUS.

ACCORDING TO WENTWORTH'S GRADE LIMITS (TABLE 3), THE TEXTURAL PROPERTIES OF OUTWASH ARE DETERMINED BY MECHANICAL ANALYSIS. THE SIZE DISTRIBUTION DATA ARE ARRANGED AS PERCENTAGES BY WEIGHT IN THE SEVERAL GRADES (TABLE 4). GRAPHIC REPRESENTATION OF SIZE DISTRIBUTION DATA IS SHOWN BY THE COMPOSITE HISTOGRAMS AND CUMULATIVE CURVES (FIGS. 1-3 AND 4). THE HISTOGRAM IS A BLOCK DIAGRAM, WHICH GIVES THE PERCENTAGE OF GRAIN WEIGHT IN THE GRADE SIZE PRESENT IN THE SEDIMENT. FROM THE HISTOGRAM DATA A CUMULATIVE CURVE IS MADE BY ADDING THE WEIGHT PERCENTAGE IN SUCCEEDING GRADES, AND THEN DRAWING A SMOOTH CURVE THROUGH THE POINTS OF INTERSECTION.

BY MEANS OF CUMULATIVE CURVES, THE STATISTICAL TREATMENT OF THE DATA ARE CARRIED OUT, AND THREE CHIEF PARAMETERS ON THE TEXTURAL STUDY ARE QUANTITIVELY EXPRESSED. THEY ARE NAMELY MEAN, QUARTILES, AND COEFFICIENT OF SORTING. MEAN IS THE MEDIAN DIAMETER OR AN AVERAGE GRAIN SIZE OF A CLASTIC SEDIMENT, AND IT IS CONTROLLED BY THE STRENGTH OF THE CURRENT THAT MOVED THE MATERIAL TO THE SITE OF DEPOSITION. THE QUARTILES ARE DETERMINED BY FOLLOWING THE ONE-FOURTH (Q1), 25 WEIGHT PERCENTAGE, AND THREE-FOURTH (Q3), 75 WEIGHT PERCENTAGE LINES ON THE GRAPH TO THE RIGHT UNTIL THEY INTERSECT THE CUMULATIVE CURVE AND READING THE VALUES ON THE SIZE SCALE, WHICH LIES DIRECTLY BELOW THE INTER-

SECTIONS. THE COEFFICIENT OF SORTING IS DEFINED AS THE SQUARE ROOT OF THE RATIO OF THE ONE-FOURTH QUARTILE TO THE THREE-FOURTH QUARTILE (TRASK 1932). GENERALLY THE SORTING COEFFICIENT IS AN INDEX OF THE RANGE OF CONDITIONS PRESENT IN THE TRANSPORTING FLUID, WHICH IS REGARDED AS THE RANGE OF VELOCITIES, AND DEGREES OF TURBULENCE, AND TO SOME EXTENT REFLECTS THE DISTANCE OF TRANSPORTATION.

THE SIGNIFICANCE OF THE DEGREE OF SORTING IS THAT IT INDICATES THE SPREAD OF THE DISTRIBUTION OF UNIFORM SIZE PRESENT IN SEDIMENT, WHICH IS SHOWN BY THE CUMULATIVE CURVE, AND ALSO DIRECTLY INFLUENCES THE PERCENTAGE OF PORE SPACE IN A SEDIMENT. GENERALLY THE WIDER THE SPREAD, THE POORER THE SORTING; POORLY SORTED SEDIMENTS ARE LESS POROUS THAN WELL-SORTED SEDIMENTS. ACCORDING TO TRASK (1932) THE WELL-SORTED SEDIMENTS HAVE VALUES OF SORTING COEFFICIENT (SO) LESS THAN 2.5, MODERATELY SORTED SEDIMENTS RANGE FROM 2.5 TO 4.0 AND POORLY SORTED SEDIMENTS HAVE VALUES LARGER THAN 4.0. SAMPLES UNDER STUDY IN THIS AREA SHOW THE AVERAGE VALUE OF SORTING COEFFICIENT (SO) AS 4.8, IN OTHER WORDS, THE OUTWASH SEDIMENTS WERE POORLY SORTED DURING THE PROCESSES OF TRANSPORTATION. THE MEDIAN DIAMETER OF THE OUTWASH SEDIMENTS RANGES FROM 0.2 TO 7 MM., AND HAS THE AVERAGE VALUE LARGER THAN 7 MM., THEREFORE IT INDICATES THESE SEDIMENTS HAD REQUIRED A RATHER STRONG TRANSPORTING MEDIAN TO MOVE THEM TO THE SITE OF DEPOSITION.

AS TO THE STRUCTURAL FEATURES, THE OUTWASH SEDIMENTS SHOW SOME REMARKABLE TABULAR AND LENTICULAR CROSS-BEDDING IN THE SAND FRACTION. THE MAJORITY OF TABULAR CROSS LAMINATED UNITS CONSIST ONLY OF THE FORSET LAMINAE SHARPLY TRUNCATED AT THE TOP AND TANGENTIAL AT THE BASE UNDER THE CONDITIONS OF FREQUENTLY SHIFTING CURRENT DIRECTIONS. THE COARSE GRAVELS ARE COMMONLY INTERCALATED WITH SILT AND SAND LENSES IN WHICH CUT AND FILL STRUCTURE IS WELL-DEVELOPED. IMBRICATION OF FLATTER PEBBLES AND COBBLES IS GENERALLY PRESENT, AND SHOWS THE CLEAR DIRECTION OF CURRENT MOVEMENT.

ACCORDING TO THE MECHANICAL ANALYSIS, THE AVERAGE WEIGHT PERCENTAGE OF THE GRAIN SIZE PORTION OF THE OUTWASH SEDIMENTS CONSISTS OF 7.5 PERCENT COBBLE, 48 PERCENT PEBBLE, 9.5 PERCENT GRANULE, 33 PERCENT SAND, AND 1.5 PERCENT SILT AND CLAY. THE CONSTITUENTS OF THE COARSE DETRITUS, RANGING FROM COBBLE TO PEBBLE IN SIZE AVERAGE 39 PERCENT LIMESTONES AND DOLOMITES, AMORPHOUS QUARTZ FRAGMENTS 1.3 PERCENT, 29 PERCENT SHALES AND IRONSTONES, SOME SANDSTONE, AND 32 PERCENT IGNEOUS AND METAMORPHIC ROCK TYPES. THE GRANULE FRACTION CONSISTS CHIEFLY OF ROCK FRAGMENTS OF LIMESTONE, DOLOMITE, IGNEOUS AND METAMORPHIC TYPES.

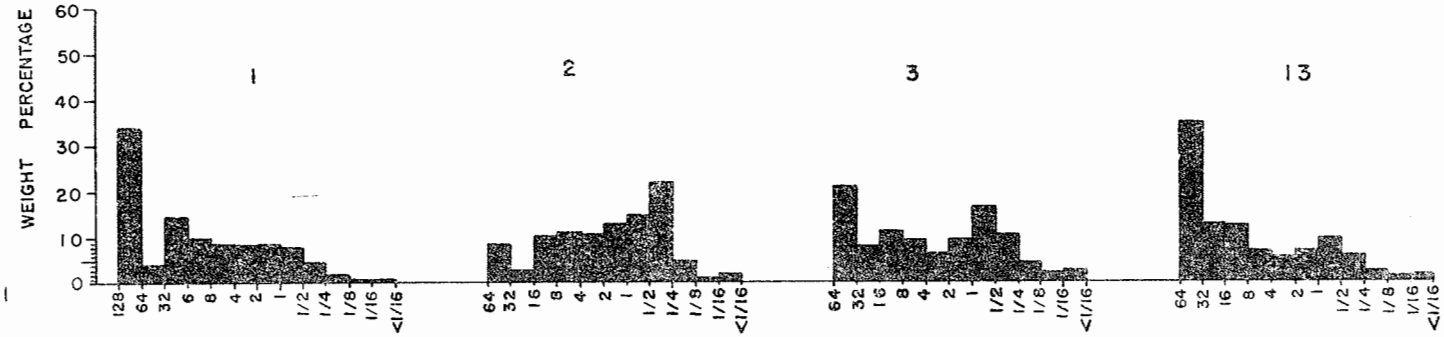


FIG. 1

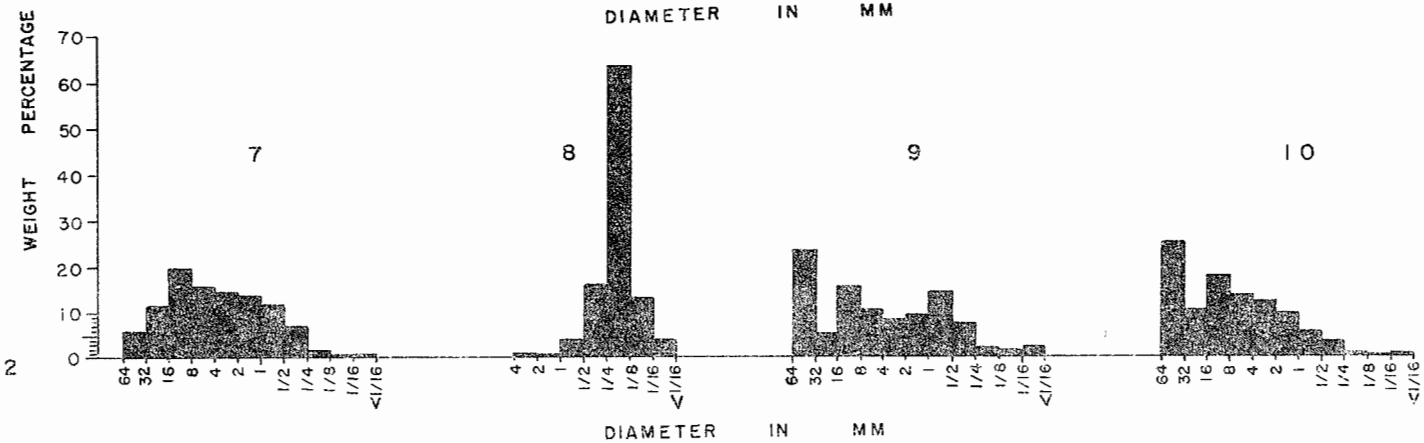


FIG. 2

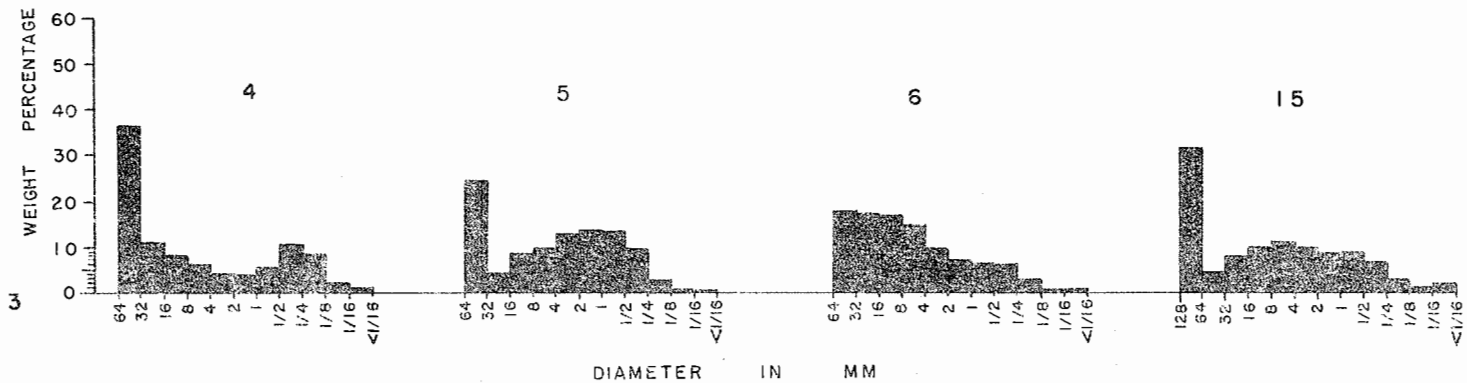


FIG. 3

FIGURES 1-3, HISTOGRAMS SHOWING GRAIN-SIZE DISTRIBUTIONS OF THE OUTWASH SEDIMENTS BETWEEN HOVEN AND BOWDLE, S. D.

(SAMPLES: 1, SEC. 21, T121N, R74W, WALWORTH CO. 2, SEC. 31, T121N, R74W, WAL. CO. 3, SEC. 17, T121N, R74W, WAL. CO. 13, SEC. 36, T122N, R74W, WAL. CO. 7, SEC. 17, T121N, R74W, WAL. CO. 8, SEC. 17, T121N, R74W, WAL. CO. 9, SEC. 9, T121N, R74W, WAL. CO. 10, SEC. 9, T121N, R74W, WAL. CO. 4, SEC. 24, T123N R74W, WAL. CO. 5, SEC. 24, T123N, R74W, WAL. CO. 6, SEC. 24, T123N, R74W, WAL. CO. & 15, SEC. 21, T123N, R73W, EDMUNDS CO. DATA BASED ON TABLE 4.)

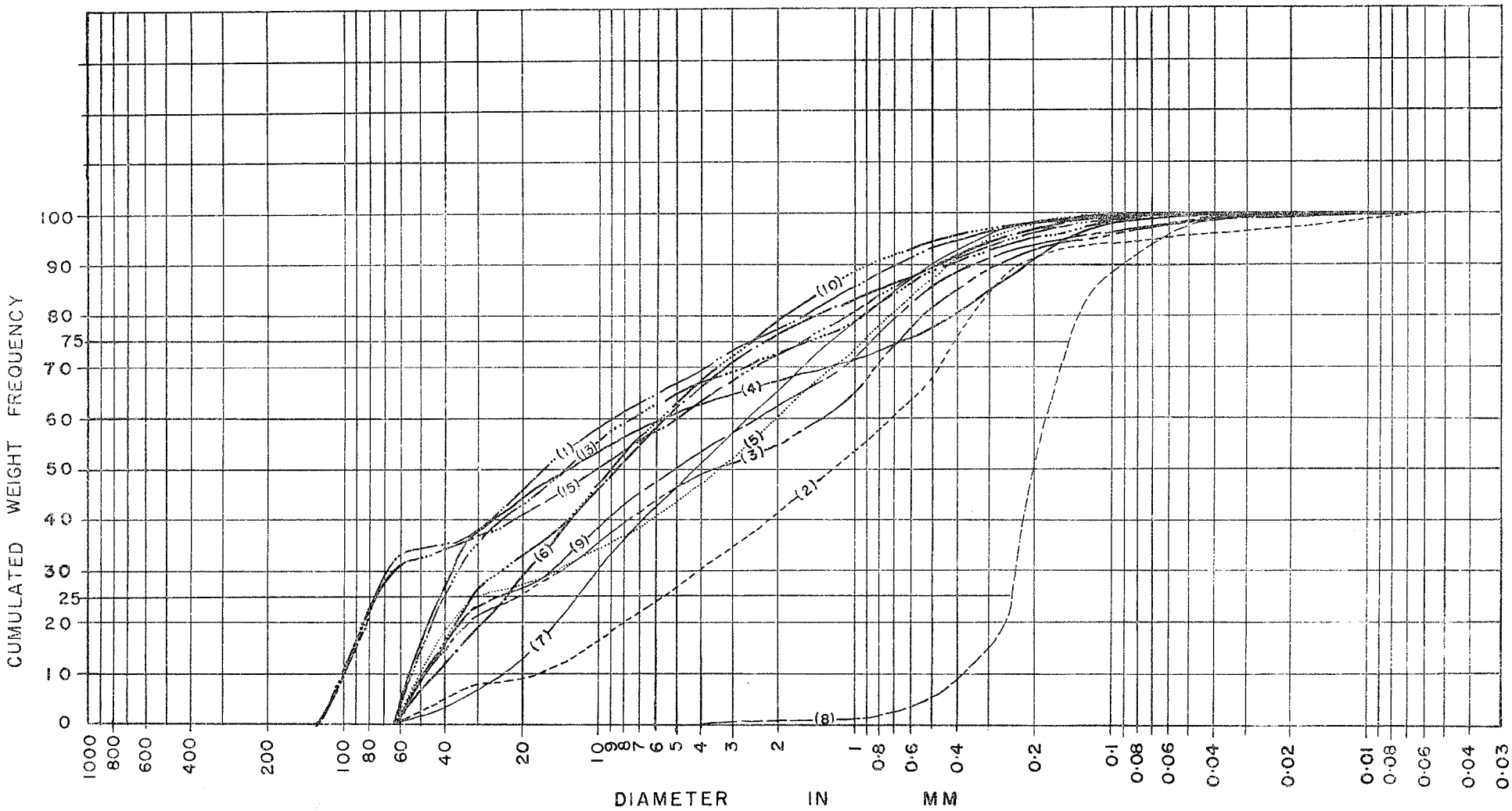


FIG. 4, CUMULATIVE CURVES SHOWING GRAIN-SIZE FREQUENCIES OF THE SAME SEDIMENTS PRENETED AS HISTOGRAMS IN FIGURES 1-3.

THE SAND AND SILT FRACTIONS COMPRISE MAINLY ROUNDED TO SUBANGULAR QUARTZ GRAINS WITH SOME PINK POTASH FELDSPARS, AND OTHER ACCESSORY MINERAL GRAINS. PATCHES AND LENTICULAR MASSES OF FERRIC IRON-OXIDE MATERIALS ARE SCATTERED THROUGH THE OUTWASH SEDIMENTS.

SEDIMENTATION

ON THE BASIS OF PETROGRAPHICAL FEATURES, THE OUTWASH SEDIMENTS WERE CHIEFLY FORMED IN THE GLACIAL AND ALLUVIAL ENVIRONMENT; FROM WHICH A TENTATIVE INTERPRETATION ON THE SEDIMENTARY PROCESSES IS DEDUCED. GENERALLY THE CHARACTERISTICS OF A SEDIMENT DEPEND MAINLY ON THE NATURE OF THE SOURCE ROCK, THE TOPOGRAPHIC EXPRESSION AND RELIEF OF SOURCE AREA, AND THE PATTERN OF ENVIRONMENT IN THE DEPOSITIONAL AREA; AMONG THESE THE PATTERN OF ENVIRONMENT IN THE DEPOSITIONAL AREA IS ONE OF THE MOST IMPORTANT FACTORS IN CONTROLLING THE DEPOSITION OF A SEDIMENT.

SEDIMENTARY ENVIRONMENT: ACCORDING TO THE GEOPHYSICAL INVESTIGATION, THE DEPOSITIONAL AREA OF OUTWASH WAS ENTRENCHED BY SEVEN PRE-MORAINE VALLEYS. FOUR OF THEM OCCUR IN THE BOWDLE OUTWASH, WHILE THE OTHER THREE ARE LOCATED IN THE HOVEN OUTWASH.

THE FIRST PRE-MORAINE VALLEY LEADS AWAY FROM THE NORTHERN PART OF SEC. 21, T123N., R73W.; IT PASSES THROUGH THE WESTERN PORTION OF THE CITY OF BOWDLE AND TURNS DUE WEST IN SEC. 29, T123N., R73W. THE DEPTH OF THE SAND AND GRAVEL FILLING RANGES FROM 11 FEET TO 58 FEET AND AVERAGES 33 FEET. THE SECOND IS LOCATED IN SEC. 33, T123N., R73W., AND PASSES THROUGH SEC. 32, T123N., R73W., TO THE SITE OF THE PRESENT INTERMITTENT STREAM. THE AVERAGE SAND AND GRAVEL FILLING IS 56 FEET AND THE DEPTH RANGES FROM 11 FEET TO 196 FEET. THE THIRD LEADS AWAY FROM THE WESTERN PART OF SEC. 7, T122N., R73W., AND RUNS WESTERLY THROUGH SEC. 6, T122N., R73W., SECS. 1 & 12, T122N., R74W. THE DEPTH OF SAND AND GRAVEL FILLING RANGES FROM 89 FEET TO 102 FEET AND AVERAGES 73 FEET. THE FOURTH ORIGINATES IN SEC. 13, T122N., R74W., PASSES THROUGH THE NORTHEASTERN PORTION OF SEC. 14, T122N., R74W., AND JOINS THE PRESENT COURSE OF SWAN CREEK. THE DEPTH RANGES FROM 10 FEET TO 123 FEET AND THE AVERAGE SAND AND GRAVEL FILLING IS 34 FEET.

IN THE HOVEN OUTWASH THE FIFTH ORIGINATES IN SEC. 31, T122N., R73W., AND SEC. 6, T121N., R73W. IT OCCUPIES THE EASTERN PART OF SEC. 35, T122N., R74W., AND SEC. 36, T122N., R74W., AND SECS. 1, 2, 11, 14 AND THE NORTHERN PART OF SEC. 23, T121N., R74W. THENCE IT TURNS WESTERLY THROUGH THE PRESENT SITES OF SECS. 15,

16, 17, 21 & 22, T12IN., R74W. IT IS THE DEEPEST PRE-MORAINE VALLEY IN THIS AREA, AND CARRIES THE SAND AND GRAVEL FILLING UP TO 158 FEET; THE AVERAGE VALUE IS 72 FEET. THE SIXTH IS LOCATED IN THE WESTERN PORTION OF SEC. 27, T12IN., R74W; IT PASSES THROUGH SECS. 28 & 29, T12IN., R74W., AND ENTERS INTO SWAN LAKE IN SEC. 29, T12IN., R74W. THE DEPTH OF SAND AND GRAVEL FILLING RANGES FROM 14 TO 68 FEET AND AVERAGES 26 FEET. THE SEVENTH HAS ITS UPSTREAM PORTION IN SEC. 34, T12IN., R74W; IT COVERS THE PRESENT SITES OF SECS. 33 & 32, T12IN., R74W., AND MEETS THE SIXTH IN THE SOUTHEASTERN PORTION OF SEC. 29, T12IN., R74W. THE DEPTH OF SAND AND GRAVEL FILLING RANGES FROM 6 FEET TO 87 FEET AND AVERAGES 32 FEET.

THESE PRE-MORAINE VALLEYS ACTED AS THE CHIEF PATTERN OF ENVIRONMENT TO RECEIVE THE OUTWASH SEDIMENTS FROM THE UNSORTED MECHANICAL MIXTURES OF BOULDER CLAY TO THE EAST. THE LOCAL RELIEF OF THIS SOURCE AREA RANGES APPROXIMATELY FROM 15 FEET TO 45 FEET, HOWEVER THE COMPARATIVE RELIEF BETWEEN THE SOURCE AREA AND DEPOSITIONAL AREA AVERAGE 97 FEET IN THE BOWDLE DISTRICT AND 123 FEET IN THE REGION NORTH OF THE CITY OF HOVEN. THESE RELIEFS ARE THE CHIEF FACTOR TO FACILITATE THE TRANSPORTATION AND DEPOSITION OF THE OUTWASHES.

DURING THE ICE RETREAT, THE HETEROGENEOUS TILL SEDIMENTS WERE CARRIED DOWN ALONG THE SITES OF THESE PRE-MORAINE VALLEYS BY THE MEDIUM OF MELT WATER. SUBSEQUENTLY COALESCENT FANS WERE FORMED IN SEVEN OF THESE PRE-MORAINE VALLEYS. DUE TO INCREASE OF THE OUTWASH SEDIMENTS FROM UPSTREAM, THE COALESCENT FANS GRADUALLY GREW THICKER, AND A SHEET-SHAPED PLAIN SURFACE WAS ACCORDINGLY BUILT LEVEL WITH THEIR INDIVIDUAL APICES.

AS A CONSEQUENCE, THE OUTWASH WAS BUILT NEAR THE MOUTHS OF THOSE PRE-MORAINE VALLEYS IN DELTA-LIKE FORMS, AND WAS CARRIED FURTHER AWAY ALONG THE OLD CHANNELS OF THE PRESENT MAIN INTERMITTENT STREAMS AS VALLEY TRAIN.

SEDIMENTARY PROCESSES: A BRIEF DISCUSSION ON SEDIMENTARY PROCESSES IS BASED ON THE TEXTURAL DATA OF OUTWASHES (TABLE 4), AND DECIPHERS THE GENERAL SEQUENCE OF SETTLING VELOCITY BY WHICH THE OUTWASH WAS DEPOSITED. ACCORDING TO THE TEXTURAL DATA, THE MEDIAN DIAMETER OF OUTWASH MATERIAL RANGES FROM 0.2 MM. TO 17 MM., AND HAS AN AVERAGE VALUE OF ABOUT 7 MM. THESE FIGURES INDICATE THAT THE OUTWASH SEDIMENTS WERE CHIEFLY FORMED UNDER THE TRANSITIONAL GLACIAL AND ALLUVIAL CONDITIONS, IN WHICH THE ALLUVIAL CONDITION HAD PLAYED A MAJOR ROLE IN THE PROCESSES OF TRANSPORTATION AND DEPOSITION. THE GLACIAL CONDITION WAS SUBORDINATE. ALTHOUGH THE MELTWATER DEPOSITION OF OUTWASH HAS MOST OF THE

CHARACTERISTICS OF ALLUVIAL DEPOSITS; ITS MEDIAN DIAMETER IS NEVERTHELESS SMALLER THAN THAT OF THE ALLUVIAL DEPOSITS. THEREFORE A STRONGER CURRENT WAS REQUIRED TO MOVE THE ALLUVIAL SEDIMENT TO THE SITE OF DEPOSITION.

AS A RULE, SAND AND GRAVEL REQUIRE MORE TURBULENT CONDITION OF CURRENT FOR TRANSPORTATION, BECAUSE MOVEMENT OF PARTICLES ON A STREAM BED IS DUE TO THE DRAG OF THE MOVING FLUID OVERCOMING GRAVITATIONAL AND COHESIVE FORCES ON THE PARTICLE. IF THE MOMENTARY VERTICAL VELOCITY IS GREATER THAN THE SETTLING VELOCITY, THE PARTICLE IS SWEPT UPWARD INTO SUSPENSION, AND DIRECTLY PROPORTIONAL TO THE SQUARE ROOT OF THE PARTICLE DIAMETER (RUBEY 1937). IN OTHER WORDS, THE COBBLE AND PEBBLE ROCK FRAGMENTS ARE MORE EASILY SETTLED THAN THE SAND AND IN A MUCH SHORTER TIME. NEVERTHELESS FINE SAND ONCE PICKED UP IS MORE LIKELY TO BE CARRIED ON FURTHER THAN COARSER PARTICLES. FINE SAND, ONCE DEPOSITED, WILL NOT BE PICKED UP AGAIN EXCEPT IN A CURRENT WITH A VELOCITY ABLE TO MOVE GRAVEL. DURING THE PROCESSES OF TRANSPORTATION, SEDIMENTARY TEXTURE AND STRUCTURE IS FORMED MAINLY BY VELOCITY FLUCTUATIONS OF THE CURRENT.

ON THE BASIS OF THE FOREGOING STATEMENT, THE SELECTIVE TRANSPORTATION IS ONE OF THE MOST IMPORTANT FACTORS IN CONTROLLING THE DEPOSITION OF OUTWASH. IN THIS AREA THE MOST TYPICAL CONTRAST WITHIN THE OUTWASH IS BETWEEN CHANNEL-TYPE COARSE DEPOSITS NEAR THE SOURCE, CHARACTERIZED BY THE DEPOSITION OF COBBLE AND PEBBLE DETRITUS, AND THE BYPASSING FINE DETRITUS, CHARACTERIZED BY THE DEPOSITION OF FINE-GRAINED DETRITUS AND NON-ARRIVAL OF THE COBBLE DETRITUS ALONG DOWNSTREAM.

RESERVES OF SAND AND GRAVEL

ESTIMATES OF THE AMOUNT OF SAND AND GRAVEL IN THE OUTWASH WERE COMPUTED BY PLACING A GRID OVER THE MAP AND COMPUTING THE NUMBER OF CUBIC YARDS IN EACH SQUARE. THE AVERAGE THICKNESS OF SAND AND GRAVEL WAS OBTAINED FROM TABLE 6 (APPENDIX), AND THE TOPOGRAPHIC FACTORS HAS BEEN TAKEN INTO CONSIDERATION.

THE TOTAL ESTIMATED AMOUNT IS 1,372,600,584 CUBIC YARDS, OF WHICH THE HOVEN OUTWASH CONTAINS 726,572,464 CUBIC YARDS, WHILE THE BOWDLE OUTWASH HAS 646,028,120 CUBIC YARDS.

THE COMPOSITION OF GRAVEL IS MADE UP CHIEFLY OF LIMESTONES, DOLOMITES, AND GRANITES; SHALES, IRONSTONES, AND SOME METAMORPHIC ROCK TYPES ARE SUBORDINATE IN AMOUNT. THE SAND FRACTION CONSISTS

MAINLY OF CRYSTALLINE QUARTZ GRAINS IN ASSOCIATION WITH A FAIR AMOUNT OF PINK POTASH-FELDSPAR AND SOME OTHER ACCESSORY MINERALS.

AS TO THE RESULT OF TEXTURAL STUDY;- THE SILT AND CLAY FRACTION HAS THE AVERAGE VALUE OF WEIGHT PERCENTAGE OF ABOUT 1.5 PERCENT, THEREFORE THE PLASTICITY INDEX OF SAND AND GRAVEL IS TENTATIVELY INDICATED AS LOW IN VALUE. ON THE BASIS OF THE PHYSICAL PROPERTIES OF SAND AND GRAVEL, THESE MATERIALS ARE GOOD, NOT EXCELLENT, FOR USE IN HIGHWAY SURFACING AND CONCRETE AGGREGATE.

SHALLOW WATER

GENERAL SETTING

THE SHALLOW WATER RESOURCES ARE GENERALLY CONTROLLED BY THE MEAN VALUES OF ANNUAL PRECIPITATION, THE CHARACTERS OF COUNTRY ROCKS, AND REGIONAL TOPOGRAPHY. THE DISCUSSION ON SHALLOW WATER RESOURCES IN THIS AREA HEREBY INCLUDES HYDROLOGY, AND SUGGESTIONS FOR THE FUTURE DEVELOPMENT OF IRRIGATION.

IN THIS AREA THE WISCONSIN DRIFT SHEETS, ESPECIALLY THE OUTWASHES, PLAY A LEADING ROLE IN THE SHALLOW WATER SUPPLY. THE OUTWASHES ACT AS GOOD WATER RESERVOIRS; AND FACILITATE THE MOVEMENT OF WATER SEEPAGES IN THE RESERVOIR; THE AMOUNT OF WATER IN THE RESERVOIR NEVERTHELESS DEPENDS ON THE MEAN VALUE OF THE ANNUAL PRECIPITATION, AS WELL AS THE INFLOWS PERCOLATING FROM SURROUNDING TILL SEDIMENTS. REGIONAL TOPOGRAPHY OF BOTH THE DRIFT SURFACE AND THE SURFACE OF THE RESERVOIR HAS A DIRECT INFLUENCE ON THE RATE OF RECHARGE AND DISCHARGE OF THE WATER SUPPLY.

HYDROLOGY

GENERALLY SPEAKING, HYDROLOGY IS A SCIENCE TO STUDY THE PHENOMENA, PROPERTIES, AND DISTRIBUTION OF WATER, WITH SPECIAL REFERENCE TO THE GROUNDWATER RESOURCES. ACCORDINGLY IT TENTATIVELY INCLUDES THE SOURCE, OCCURRENCE, NATURE OF MOVEMENT, QUALITY OF WATER, UTILIZATION OF WATER, AND STORAGE CAPACITY OF SHALLOW WATER IN THE RESERVOIR. IN CONNECTION WITH THESE, OTHER FACTORS IN CONTROLLING WATER SUPPLY ARE ALSO TAKEN INTO CONSIDERATION.

SOURCE: IN THIS AREA THE WISCONSIN DRIFT HAS BEEN A GOOD TRANSMITTING MEDIUM ON WATER SUPPLY. AS A WHOLE THE SHALLOW WATER IS ENTIRELY FURNISHED BY PRECIPITATION IN THE FORM OF RAIN OR SNOW. PART OF THE WATER FROM PRECIPITATION IS CARRIED AWAY BY SURFACE RUNOFF, AND EVENTUALLY IS LOST TO STREAMS; HOWEVER THE MAJORITY OF WATER PERCOLATES DOWNWARD THROUGH THE SANDY SOIL AND UNDERLYING HETEROGENEOUS TILLS UNTIL IT REACHES THE SO-CALLED "WATER TABLE", WHERE IT JOINS THE BODY OF SHALLOW WATER IN THE ZONE OF SATURATION. THE PROCESSES OF EVAPORATION AND TRANSPIRATION ARE CONSIDERED TO BE THE SUBORDINATE ROLES IN CONCERNING THE LOSS OF PRECIPITATION.

OCCURRENCE: IN THIS AREA, THE OCCURRENCE OF SHALLOW WATER IS CONTROLLED BY THE PHYSICAL PROPERTIES, AND DISTRIBUTION OF THE WISCONSIN DRIFT. TEXTURAL STUDY ON THE WISCONSIN DRIFT SHOWS THAT THE TILLS CONTAIN PARTICLES OF GREAT VARIETY IN SIZE, AND THE OUTWASHES HAVE THE VALUE OF AN AVERAGE SORTING COEFFICIENT OF 4.8. THESE FACTS INDICATE THE WISCONSIN DRIFT, AS A WHOLE, IS POORLY SORTED. THE POROSITY AND PERMEABILITY ARE DEDUCED RESPECTIVELY FROM THE TEXTURAL FEATURES.

GENERALLY SPEAKING, THE POROSITY IS THE PERCENTAGE OF THE VOIDS OR INTERSTICES IN A SEDIMENT. IT IS A FUNCTION OF THE UNIFORMITY OF PARTICLE SIZE AND SHAPE AND OF THE STATE OF PACKING OF THE PARTICLES. AS A RULE, THE HIGHER DEGREE OF THE UNIFORMITY OF THE PARTICLE SIZE IS PRESENT IN THE WELL-SORTED SEDIMENTS. POORLY SORTED SEDIMENTS ARE GENERALLY LESS POROUS THAN WELL-SORTED SEDIMENTS. PERMEABILITY HAS NO DIRECT RELATIONSHIP WITH POROSITY, BUT NEVERTHELESS IT IS DETERMINED BY SIZE, SHAPE, AND ARRANGEMENT OF THE OPENINGS IN A SEDIMENT. THE AMOUNT OF SHALLOW WATER, WHICH CAN MOVE THROUGH THE OUTWASHES TOWARD A PUMPING WELL IS DIRECTLY INFLUENCED BY THE PERMEABILITY OF THE OUTWASH SEDIMENTS.

ON THE BASIS OF THE FOREGOING STATEMENTS, THE OUTWASHES HAVE A RATHER LOW VALUE OF POROSITY. IN OTHER WORDS, THE PASSAGE FOR FLUIDS IS COMPARATIVELY EASY THROUGH THESE SEDIMENTS, BECAUSE COARSE GRAVEL HAS LARGE OPENINGS BETWEEN THE PEBBLES. AS THE PARTICLES BECOME SMALLER, THE PORES ALSO BECOME SMALLER. THUS A GREATER FORCE OR A GREATER LENGTH OF TIME IS REQUIRED TO DRIVE A UNIT VOLUME OF FLUID THROUGH THE SEDIMENTS. GENERALLY WATER MOVES MOST FREELY THROUGH A ROCK THAT HAS RELATIVELY LARGE AND WELL CONNECTED OPENINGS.

NATURE OF MOVEMENT OF SHALLOW WATER: THE NATURE OF MOVEMENT OF SHALLOW WATER DEPENDS ON THE REGIONAL TOPOGRAPHY OF THE DRIFT SURFACE AND THE SURFACE OF THE RESERVOIR, AND THE PERMEABILITY OF THE DRIFT. IN GENERAL, THIS TENTATIVELY COMPRISES THE TOPOGRAPHIC FACTOR IN CONTROLLING THE IRREGULARITIES OF THE WATER TABLE, RECHARGE, DISCHARGE, AND RECOVERY OF SHALLOW WATER IN THE RESERVOIR.

TOPOGRAPHIC FACTOR IN CONTROLLING THE IRREGULARITIES OF THE WATER TABLE: THE WATER TABLE IS DEFINED AS THE UPPER SURFACE OF THE ZONE OF SATURATION, EXCEPT WHERE THAT SURFACE IS FORMED BY AN IMPERMEABLE BODY (MEINZER 1923). GENERALLY SPEAKING, THE IRREGULARITIES OF THE WATER TABLE ARE CONTROLLED BY THE DIFFERENCES IN PERMEABILITY OR THICKNESS OF THE WATER-BEARING MATERIALS, UNEQUAL ADDITION TO OR WITHDRAWALS FROM THE RESERVOIR AT DIFFERENT PLACES, TOPOGRAPHY, AND THE STRUCTURE OF COUNTRY ROCKS. OF

THESE THE TOPOGRAPHIC FACTOR PLAYS A MAJOR ROLE IN CONTROLLING THE SHAPE AND SLOPE OF THE WATER TABLE.

THE SHAPE OF THE WATER TABLE COMMONLY CONFORMS TO THE REGIONAL TOPOGRAPHY, THEREFORE A WELL DRILLED IN A VALLEY WILL GENERALLY ENCOUNTER WATER AT A SHALLOWER DEPTH THAN A WELL DRILLED ON A NEARBY DIVIDE. IN THIS AREA, THE MAIN BODIES OF SHALLOW WATER IN THE RESERVOIR GENERALLY FLOW ALONG THE CHANNELS OF THOSE PRE-MORAINE VALLEYS, AND PART OF THE COURSES OF PRESENT INTERMITTENT STREAMS AND THEIR TRIBUTARIES. THE RELIEF BETWEEN THE SURFACE OF THE TILL AND THE SURFACE OF THE RESERVOIR AVERAGES 97 FEET IN THE BOWDLE DISTRICT, AND 123 FEET IN THE REGION IMMEDIATELY NORTH OF THE CITY OF HOVEN. THESE RELIEFS HAVE BEEN FURNISHING RUNOFF WATER TO THE RESERVOIR EVER SINCE THE DEPOSITION OF THE OUTWASH.

IN THE RESERVOIR THE VELOCITY OF WATER FLOW DEPENDS ON THE COEFFICIENT OF PERMEABILITY OF THE OUTWASH AND THE HYDRAULIC GRADIENT.

ALTHOUGH THE FIELD DATA ARE NOT SUFFICIENT TO ESTABLISH A HYDRAULIC MAP FOR THIS AREA, NEVERTHELESS THE GENERAL PICTURE OF THE HYDRAULIC GRADIENT, WHICH TENTATIVELY SHOWS THE DIRECTIONS OF THE SHALLOW WATER MOVEMENT IN THE RESERVOIR, IS DEDUCED ACCORDING TO THE FIELD INVESTIGATION ON DOMESTIC WATER WELLS (TABLE 7, APPENDIX). IN THE BOWDLE OUTWASH THE HYDRAULIC GRADIENT AVERAGES 10 FEET PER MILE, AND SLOPES SOUTHERLY AND SOUTHWESTERLY. THE HIGHEST READING IS 2046 FEET IN SEC. 11, T123N., R74W., WHILE THE LOWEST READING IS COMPUTED AS 1911 FEET IN SEC. 18, T122N., R73W. IN THE HOVEN OUTWASH THE HIGHEST READING OF HYDRAULIC GRADIENT IS RECORDED AS 1909 FEET IN SEC. 12, T121N., R74W., AND THE LOWEST READING VALUE, 1873 FEET, IS LOCATED IN SEC. 7, T121N., R74W; THESE FIGURES SHOW THE HYDRAULIC GRADIENT IN THIS REGION GRADUALLY DECREASES WESTERLY TOWARD THE SHORE OF SWAN LAKE. THE AVERAGE VALUE OF THE HYDRAULIC GRADIENT IN THIS DISTRICT IS ABOUT 3 FEET PER MILE.

ACCORDING TO THE FOREGOING STATEMENT, THE DIRECTION OF MOVEMENT OF THE MAIN SHALLOW WATER BODIES IS GENERALLY FROM THE NORTH AND NORTHEAST TOWARD THE SOUTHWEST AND WEST. THE SURFACE ELEVATION OF SWAN LAKE WAS RECORDED AS 1882 FEET LAST SUMMER, AND IT IS ABOUT 10 FEET LOWER THAN THE LOWEST READING OF THE WATER TABLE IN THIS HOVEN DISTRICT. IN OTHER WORDS, THE SWAN LAKE WATER HAS BEEN PLAYING THE MAJOR ROLE IN STABLIZING THE WATER LEVEL OF DOMESTIC WELLS IN THIS REGION.

IN ADDITION TO THE IRREGULARITIES OF THE WATER TABLE DUE TO TOPOGRAPHIC FACTOR, THE FLUCTUATION OF THE WATER TABLE IS MAINLY

CAUSED BY THE AMOUNT OF PRECIPITATION, AND THE AMOUNT OF WATER PUMPED FROM WELLS. BECAUSE OF THE RAPID ANNUAL CHANGES OF CLIMATE IN THIS AREA, THE FLUCTUATION OF THE WATER TABLE IS GREAT. DURING THE WET MONTHS THE WATER TABLE MAY RISE CONSIDERABLY, AND DURING THE DRY SEASON IT WILL GRADUALLY DECLINE. IF THE AMOUNT OF WATER PUMPED FROM WELLS EXCEEDS THE INFLOW, THE WATER TABLE WILL DECLINE; CONVERSELY, IF THE INFLOW EXCEEDS THAT DRAFT, THE WATER TABLE WILL RISE.

RECHARGE: RECHARGE IS A PROCESS OF THE ADDITION OF WATER TO THE UNDERGROUND SHALLOW WATER RESERVOIR. IN THIS AREA, RECHARGE IS ACCOMPLISHED MAINLY FROM LOCAL PRECIPITATION, SUBSURFACE INFLOWS, AND A SMALL AMOUNT OF WATER FROM LOCAL PONDS AND SWAMPS; THE AMOUNT AND FREQUENCY OF RECHARGE HOWEVER DEPENDS ON THE DEPTH TO THE WATER TABLE AND THE TYPE OF MATERIAL OCCURRING ABOVE THE WATER TABLE.

DURING THE PERIOD FROM 1930 TO 1955, THE ANNUAL PRECIPITATION WAS 17.48 INCHES, AS RECORDED BY THE U.S. WEATHER BUREAU STATION AT BOWDLE (TABLE 1). IN THIS AREA THE MANTLE ROCKS, WHICH ACT AS THE CHIEF TRANSMITTING AGENT IN RECHARGE, ARE THE TYPICAL HETEROGENEOUS MECHANICAL MIXTURE SEDIMENTS; IN OTHER WORDS, THE AMOUNT OF RECHARGE TO THE UNDERGROUND SHALLOW WATER PROBABLY REACHES NEARLY ONE HUNDRED PERCENT OF THE TOTAL PRECIPITATION THROUGH THESE CLASTIC SEDIMENTS.

THE DEPTH TO THE WATER TABLE RANGES FROM 4 FEET TO 65 FEET, AND CARRIES THE AVERAGE VALUE, 23 FEET, IN THE BOWDLE DISTRICT. IT RANGES FROM 4 FEET TO 42 FEET AND AVERAGES 21 FEET IN THE DISTRICT NORTH OF THE CITY OF HOVEN (TABLE 7, APPENDIX). THESE DEPTH FIGURES INDICATE THAT THE PROCESS OF RECHARGE REQUIRES A RATHER SHORT TIME. IN OTHER WORDS, THE FREQUENCY OF RECHARGE IS RATHER HIGH REGARDLESS OF THE LOCAL TOPOGRAPHIC RELIEF. ONCE THE WATER BECOMES A PART OF THE SHALLOW WATER BODY, IT MOVES DOWN THE SLOPE OF THE WATER TABLE, LATER TO BE DISCHARGED FOR THE MOST PART INTO THE CHANNELS OF THE SUBSURFACE STREAMS, WHICH EVENTUALLY EMPTY INTO THE SWAN LAKE.

THE SUBSURFACE INFLOWS, WHICH FURNISH A VERY LARGE AMOUNT OF WATER TO THE SHALLOW WATER IN THE RESERVOIR, AS WELL AS TO THE SHALLOW WATER WELLS IN THE TILL REGION, ARE DERIVED FROM THE WISCONSIN TILLS. THE IOWAN, CARY AND LATE CARY TILLS YIELD CONSIDERABLE WATER SUPPLIES, AND ALSO ACT AS A TYPICAL TRANSMITTING MEDIUM IN UPLAND AREAS. SEVERAL DOMESTIC WELLS (TABLE 7, APPENDIX) ARE LOCATED IN THE TILL REGION, AND NEAR THE MARGIN OF OUTWASHES; THEY ARE REPRESENTED BY THE FOLLOWING WELLS:-

NICKISCH'S WELL IN SEC. 20, T123N., R73W.
SCHICK'S WELL IN SEC. 21, T123N., R74W.
HAUPT'S WELL IN SEC. 7, T123N., R73W.
SIMON'S WELL IN SEC. 24, T121N., R74W.
MERTZ'S WELL IN SEC. 10, T123N., R74W.
HINTZ'S WELL IN SEC. 22, T123N., R74W.
WEISZHARR'S WELL IN SEC. 11, T123N., R74W.

MOST OF THESE DOMESTIC WELLS PENETRATE THE TILL. THE DEPTH OF WATER RANGES FROM 15 FEET TO 178 FEET AND AVERAGES 78 FEET. IN ADDITION TO THESE WELLS, SEVERAL SPRINGS OCCUR IN SEC. 15, T123N., R74W., AND ALONG THE NORTHERN SIDE OF THE CREEK IN SEC. 36, T122N., R73W. SUCH DEPTHS HAVE NOT YET BEEN FOUND IN THE DOMESTIC WELLS, WHICH ARE LOCATED IN THE OUTWASH PLAIN, AND APPARENTLY THIS WATER FURNISHES THE MAIN RECHARGE TO THE SHALLOW WATER BODY IN THE RESERVOIR.

PONDS AND SWAMPS ARE SCATTERED ALONG THE MARGIN OF THE END MORAINE TO THE EAST, AND THE MARGIN OF THE OUTWASHES. AT THE TIME OF INVESTIGATION, MOST OF THEM WERE DRY EXCEPT THE SWAN LAKE, WHICH HAS BEEN FURNISHING A CONSIDERABLE AMOUNT OF WATER FOR THE RECHARGE OF THE SHALLOW WATER IN THE HOVEN RESERVOIR. ONE OF THE SWAMPS, WHICH IS LOCATED AT THE SOUTHERN END OF THE BOWDLE OUTWASH HAS BEEN DRY FOR THE FIRST TIME, AND MOST OF ITS WATER PERCOLATED DOWNWARD TO THE SHALLOW WATER BODY.

DISCHARGE: DISCHARGE IS A PROCESS OF WATER LOSS FROM THE SHALLOW WATER RESERVOIR. IN THIS AREA, THE DISCHARGE IS ACCOMPLISHED BY THE SHALLOW WATER MOVEMENT FROM THE RESERVOIRS INTO THE MAIN STREAM CHANNELS, PUMPING FROM WELLS, AND THE NATURAL DISCHARGE AT THE SURFACE. OF THESE THE WATER MOVEMENT INTO THE MAIN STREAM CHANNELS AND PUMPING FROM WELLS ACCOUNT FOR MOST OF THE DISCHARGE. SOME OF THE WATER MAY EVAPORATE OR BE ABSORBED BY VEGETATION AND TRANSPIRED INTO THE ATMOSPHERE.

IN THIS AREA, DOMESTIC WATER WELLS CONSTITUTE ONE OF THE PRINCIPAL MEANS OF DISCHARGE OF SHALLOW WATER IN THE RESERVOIR; THE TOTAL QUANTITY OF WATER PUMPED ANNUALLY FROM THOSE WELLS IS NOT KNOWN HOWEVER. AT BOWDLE THERE ARE NO PUMPING RECORDS FROM THE THREE CITY WELLS, BUT THE APPROXIMATE DAILY PUMPING RECORD AVERAGES 35,000 GALLONS. A STATISTICAL ACCOUNT FROM THE CITY WELLS AT HOVEN IN THE SUMMER OF 1955 SHOWED THE AVERAGE MONTHLY DISCHARGE WAS 2,075,713 GALLONS (LEE 1956). MOST OF THE RESIDENTS IN THIS AREA OBTAIN THEIR DOMESTIC SUPPLIES FROM THE SHALLOW WELLS, BUT THE TOTAL VOLUME OF WATER PUMPED FOR SUCH USES IS PROBABLY LESS THAN THAT USED BY THE CITIES OF HOVEN AND BOWDLE.

RECOVERY: RECOVERY IS THE PROCESS OF RECHARGE AFTER THE WELL IS PUMPED. GENERALLY SPEAKING, IF THE RESERVOIR IS SATURATED WITH WATER, THE RATE OF RECOVERY IS DIRECTLY PROPORTIONAL TO THE PERMEABILITY OF THE WATER-BEARING MATERIALS. WHEN WATER IS WITHDRAWN FROM A WELL, THERE IS A DIFFERENCE IN HEAD BETWEEN THE WATER INSIDE THE WELL AND THE WATER IN THE SURROUNDING MATERIAL FOR SOME DISTANCE FROM THE WELL. WHEN THE PUMPING IS IN PROGRESS, THE WATER IN THE VICINITY OF THE WELL DEVELOPS A CONE OF DEPRESSION. AS A RULE, A HIGHER PUMPING RATE PRODUCES A GREATER DRAWDOWN OF THIS CONE, AND THE DIAMETER OF THE CONE AND OF THE AREA OF INFLUENCE WILL BE GREATER. IN CONNECTION WITH THIS PROCESS, THE "SPECIFIC CAPACITY" OF A WELL IS DEFINED AS THE RATE OF YIELD PER UNIT OF DRAWDOWN, AND IT IS COMMONLY STATED IN GALLONS A MINUTE PER FOOT OF DRAWDOWN AFTER A SPECIFIED PERIOD OF PUMPING. WHEN A WELL IS PUMPED, THE WATER LEVEL DROPS RAPIDLY AT FIRST AND THEN MORE SLOWLY; IT MAY CONTINUE TO DECLINE UNTIL A BALANCE IS REACHED BETWEEN RECHARGE AND DRAWDOWN. THEREFORE IT IS IMPORTANT TO CONTINUE PUMPING UNTIL THE WATER LEVEL REMAINS APPROXIMATELY STATIONARY.

GENERALLY IF THE WATER-BEARING MATERIAL IS COARSE AND OF FAIRLY UNIFORM SIZE IT WILL READILY YIELD LARGE QUANTITIES OF WATER TO A WELL WITH A MINIMUM DRAWDOWN; IF THE WATER-BEARING MATERIAL IS FINE OR POORLY SORTED IT WILL OFFER MORE RESISTANCE TO THE FLOW OF WATER, THEREBY DECREASING THE YIELD AND INCREASING DRAWDOWN. THUS THE DRAWDOWN OF A WELL VARIES INVERSELY WITH THE PERMEABILITY OF THE WATER-BEARING MATERIAL. THIS PRINCIPLE IS WELL-APPLIED IN THIS AREA. WELLS, WHICH ARE LOCATED IN THE OUTWASHES, OR PENETRATED STRATIFIED DRIFT, SAND AND GRAVEL, IN THE TILL REGION WERE REPORTED TO HAVE A COMPARATIVELY RAPID YIELD AND SLOW DRAWDOWN. ON THE BASIS OF TEXTURAL STUDY, THE OUTWASHES CONSIST OF A RATHER HIGH PERCENTAGE OF GRANULE AND PEBBLE SIZE ROCK FRAGMENTS, AND HAVE A GOOD PERMEABILITY, THEREFORE THESE MATERIALS AFFORD THE EASY PASSAGE FOR FLUIDS REGARDLESS OF THE IRREGULARITIES OF SURFACE RELIEF IN THE RESERVOIR WHICH GENERALLY INFLUENCE THE HYDRAULIC PRESSURE. FOR INSTANCE, THE NICKISCH'S WELL IN SEC. 20, T123N., R73W., WEISZHARR'S WELL IN SEC. 11, T123N., R74W., AND MERTZ'S WELL IN SEC. 10, T123N., R74W., WERE EXAMINED, AFTER BEING PUMPED A SHORT TIME, THE RECOVERY PRECEDED RAPIDLY.

IN THIS AREA, MOST OF THE DOMESTIC WATER WELLS WERE DUG BY DRILLING AUGER, AND A FEW 3 INCH TO 4 INCH HOLES (TABLE 7, APPENDIX) WERE DRILLED BY PROFESSIONAL WATER WELL DRILLERS. THE DEPTH OF WELLS RANGES FROM 5 FEET TO 185 FEET AND AVERAGES 42 FEET. THESE WELLS ARE OPERATED MOSTLY BY WIND-MILL. PITCHER PUMPS ARE USED ON SOME DUG WELLS, AND JET PUMPS ARE USED BY SOME

OF THE FARMERS. TURBINE PUMPS ARE USED BY THE CITY OF BOWDLE. SOME OF THE DOMESTIC WATER WELLS ARE POWERED BY ELECTRIC MOTORS.

QUALITY OF WATER: GENERALLY, THE QUALITY OF WATER IS VERY IMPORTANT IN DETERMINING ITS SUITABILITY FOR SANITARY PURPOSES, DRINKING, DOMESTIC USES, AND THE SAFE USE IN BOILERS FOR MAKING STEAM. THE CHANGES IN QUALITY OF WATER ARE NEVERTHELESS DIRECTLY INFLUENCED BY THE NATURE OF THE COUNTRY ROCKS, IN WHICH IT OCCURS, OR THROUGH WHICH IT PASSES. IN THIS AREA THE WISCONSIN DRIFT CONTRIBUTES A GREAT AMOUNT OF "SOLIDS" TO THE COMPOSITION OF SHALLOW WATER, BECAUSE IT IS A HETEROGENEOUS MECHANICAL MIXTURE OF CLAY AND SAND DETRITUS INTERCALATED CHIEFLY WITH CARBONATE ROCKS, AND ALSO SOME IGNEOUS AND METAMORPHIC ROCK TYPES.

IN ORDER TO JUSTIFY THE WATER FOR HUMAN USE, THE QUALITY OF WATER IS DISCUSSED ON THE BASIS OF ANALYSES. IN THIS AREA THE CITY WELLS OF BOWDLE (TABLE 8) AND THE CITY WELLS OF HOVEN (LEE 1956) ARE SELECTED FOR THIS DISCUSSION. IN THE ANALYSIS OF WATER THE MOST IMPORTANT THINGS INCLUDE ACIDITY, ALKALINITY, AND PURITY. ALKALINITY IS DUE TO THE PRESENCE OF DISSOLVED CARBONATES OF THE ALKALINE EARTH METALS. ACIDITY IS DUE TO THE PRESENCE OF ORGANIC ACIDS. THE PURITY IS A DETERMINATION OF BACTERIA AND OTHER ORGANIC COMPOUNDS, WHICH OCCUR SUBORDINATE IN AMOUNT WITHIN THE WATER.

THE ALKALINE WATERS CARRY THE CHIEF COMPOUNDS FOR THE DETERMINATION OF "HARDNESS"; IN CONNECTION WITH THIS THERE ARE TWO KINDS OF HARDNESS: TEMPORARY HARDNESS AND PERMANENT HARDNESS, RESPECTIVELY. TEMPORARY HARDNESS IS GENERALLY DUE TO THE PRESENCE OF THE BICARBONATE OF CALCIUM AND MAGNESIUM; IT IS ALSO KNOWN AS "CARBONATE HARDNESS". THIS HARDNESS CAN BE PARTIALLY REMOVED BY BOILING, AND COMPLETELY DESTROYED BY A JUDICIOUS ADDITION OF LIME. PERMANENT HARDNESS, ALSO CALLED "NONCARBONATE HARDNESS", IS DUE TO THE PRESENCE OF SULPHATES OF CALCIUM AND MAGNESIUM. THIS HARDNESS IS BEST COUNTERACTED BY THE USE OF QUICKLIME OR OF BARIUM CARBONATE AND BARIUM OXIDE.

WATER ANALYSES OF BOTH THE CITY WELLS OF BOWDLE AND HOVEN, SHOW THE PRINCIPAL CONTENTS OF THESE CITY WATERS ARE BICARBONATE, SULFATE, AND CALCIUM. ALKALI, MAGNESIUM, CHLORIDE, NITRATE, FLUORIDE AND MANGANESE ARE SUBORDINATE IN AMOUNT. THE COMPOUNDS OF CALCIUM, SULFATE, AND MAGNESIUM CAUSE THE HARDNESS OF THE CITY WATER. ACCORDING TO FOX (1949) IF A WATER CONTAINS 50 TO 100 PARTS OF $CaCo_3$ (CALCIUM CARBONATE) IN SOLUTION IT IS A "SOFT WATER"; WITH 100 TO 200 PARTS OF $CaCo_3$ IT IS A "MEDIUM HARD WATER"; AND WITH 200 TO 300 PARTS OF $CaCo_3$ IT IS A "HARD WATER". ON THE BASIS OF THIS CLASSIFICATION, THE CITY WATER OF HOVEN

TABLE 8

WATER ANALYSES OF THE CITY WELLS, BOWDLE*

Contents	Wells		
	1	2	3
	Parts per Million		
Total Solids	533.00	650.00	513.00
Na (Alkali)	37.40	61.00	35.70
Ca (Calcium)	84.60	100.00	81.70
Mg (Magnesium)	28.20	33.60	27.00
Mn (Manganese)	0.20	0.10	———
N (Nitrate)	0.60	0.40	3.00
F (Fluoride)	0.50	0.27	0.25
Cl (Chloride)	47.30	38.80	26.70
SO_4 (Sulfate)	88.90	180.00	94.40
HCO_3 (Bicarbonate)	332.00	324.00	334.00
R_2O_3 (Oxides of iron and aluminum)	3.60	2.80	4.00
Hardness ($CaCO_3$)	327.00	388.00	315.00

* By O. D. Dunbar, Division of Sanitary Engineering, Pierre, South Dakota.

HAS THE VALUE OF HARDNESS ($CaCo_3$) RANGING FROM 382.30 PARTS PER MILLION TO 451 PARTS PER MILLION, WHILE THE CITY WATER AT BOWDLE HAS THE VALUE OF CARBONATE HARDNESS RANGING FROM 315 PARTS PER MILLION TO 388 PARTS PER MILLION; THEREFORE, THE WATER OF BOTH CITIES IS "HARD TO VERY HARD". NEVERTHELESS WATER CONTAINING LESS THAN 500 PARTS PER MILLION OF DISSOLVED SOLIDS IS ENTIRELY SATISFACTORY FOR DOMESTIC USES.

THE HYDROGEN ION CONCENTRATION (PH) OF BOTH CITY WATER IS 7.3, WHICH INDICATES THE ACIDITY OF WATER IS IN NORMAL CONDITION. THE IRON (FE) CONTENT IS 0.2 PARTS PER MILLION IN THE WATER OF BOTH CITIES. THE CHLORINE CONTENT RANGES FROM 14 PARTS PER MILLION TO 38 PARTS PER MILLION IN THE CITY WATER OF HOVEN, AND 26.70 PARTS PER MILLION TO 47.30 PARTS PER MILLION IN THE CITY WATER OF BOWDLE. THE PRESENCE OF THIS ELEMENT IS USUALLY AN INDICATION OF SEWAGE CONTAMINATION OR OTHER ORGANIC DECAY. THE PRESENCE OF NITRATE LEADS TO A SUSPICION OF ORGANIC POLLUTION. THE PRESENCE OF A SMALL AMOUNT OF MANGANESE IN BOTH CITY WATER MIGHT CAUSE THE "BLACK WATER" PROBLEM NOTED IN CLOTHING WASHED IN THE WATER, AND IN THE STAINING OF PLUMBING FIXTURES.

ACCORDING TO THE FOREGOING STATEMENT, THE CARBONATES OF LIME AND MAGNESIA ARE CHIEFLY FURNISHED BY THE LIMESTONES AND CALCIC DOLOMITES. SULFATE, MANGANESE, AND FLUORIDE MAY BE MOSTLY CONTRIBUTED BY IGNEOUS AND METAMORPHIC ROCKS. THE PIERRE SHALE ROCK FRAGMENTS AND IRONSTONE CONCRETIONS PRESENT IN THE DRIFT MAY FURNISH SOME MAGNESIUM, CHLORIDE, AND IRON HYDROXIDES.

UTILIZATION OF WATER: IN THIS AREA NINETY-FIVE DOMESTIC WATER WELLS WERE INVESTIGATED (TABLE 7, APPENDIX). THEIR UTILIZATION IS DIVIDED INTO DOMESTIC AND STOCK SUPPLIES AND PUBLIC SUPPLIES.

THE DOMESTIC AND STOCK SUPPLIES INCLUDED DRINKING, COOKING, WASHING, DISPOSAL OF SEWAGE, AND WATERING STOCK. DOMESTIC WELLS ARE LOCATED BY THE HOUSE OR IN THE BASEMENT, WHEREAS WELLS FOR STOCK ARE GENERALLY SITUATED NEAR THE BARN OR IN THE PASTURE. THE PUBLIC SUPPLIES ARE MAINLY CONFINED TO THE CITIES OF HOVEN AND BOWDLE. IN THE CITY OF HOVEN, THE NUMBER TWO WELL IS THE ONLY WELL TO FURNISH THE WATER SUPPLY FOR THE RESIDENTS OF HOVEN. EACH MONTH THE APPROXIMATE WATER PUMPAGE IS ABOUT 2,075,713 GALLONS (LEE 1956). THREE GOOD WELLS SERVE THE CITY OF BOWDLE, THE ESTIMATED DAILY PUMPAGE AVERAGES 35,000 GALLONS. PART OF THE WATER IN BOTH CITIES IS USED FOR THE DISPOSAL OF PUBLIC SEWAGES.

ESTIMATE OF WATER STORAGE CAPACITY: THE STORAGE CAPACITY

OF SHALLOW WATER IN THE RESERVOIR IS ESTIMATED ON THE BASIS OF THE SORTING COEFFICIENTS OF THE OUTWASHES, WHICH GENERALLY DIRECTLY INFLUENCE THE POROSITY, BECAUSE THE DEGREE OF SORTING IS A FUNDAMENTAL FUNCTION OF THE POROSITY OF A SEDIMENT. GENERALLY POROSITY DIFFERS GREATLY WITH CHANGES IN SIZE, SHAPE, AND DEGREE OF INTERCONNECTION OF THE INTERSTICES BETWEEN MINERAL PARTICLES OR ROCK FRAGMENTS; THEREFORE THE POROSITY OF THE OUTWASHES IN THIS AREA IS TENTATIVELY ASSUMED ON THE REGIONAL BASIS.

IN THE HOVEN DISTRICT, THE POROSITY OF THE OUTWASH SEDIMENTS IS ASSUMED AS 35 PERCENT IN SECS. 7, 8, 9, 10, 16, 17, 18, 19, 20, 21, 28, 29, 30, 31, 32 & 33, T12IN., R74W; THE RESERVE OF SAND AND GRAVEL IN THOSE SECTIONS IS 225,544,000 CUBIC YARDS OR 6,099,688,000 CUBIC FEET, AND WATER STORAGE CAPACITY WOULD BE 2,134,890,800 CUBIC FEET. THE ASSUMED POROSITY IS 30 PERCENT IN SECS. 15 & 22, T12IN., R74W.; THE ESTIMATED VOLUME OF SAND AND GRAVEL IS 142,489,600 CUBIC YARDS OR 3,847,219,200 CUBIC FEET, AND THE STORAGE CAPACITY IS COMPUTED TO BE 1,154,165,760 CUBIC FEET. THE VALUE OF THE POROSITY IS ASSUMED AS 25 PERCENT IN SECS. 36 & 35, T122N., R74W., SEC. 31, T122N., R73W., AND SECS. 1, 2, 11, 14, 23, 26, 27 & 34, T12IN., R74W.; THE ESTIMATED RESERVE OF SAND AND GRAVEL IS 358,538,864 CUBIC YARDS OR 9,680,549,328 CUBIC FEET, AND THE STORAGE SPACE FOR WATER WOULD BE 2,420,137,332 CUBIC FEET. THE TOTAL STORAGE CAPACITY OF THIS DISTRICT IS 5,709,193,892 CUBIC FEET OR 131,065 ACRE-FEET.

IN THE REGION OF THE BOWDLE OUTWASH, THE VALUE OF THE POROSITY IS ASSUMED AS 30 PERCENT IN SECS. 1, 2, 14 AND THE WESTERN PORTION OF SEC. 12, T122N., R74W., SECS. 22, 23, 24, 25, 26, 35, & 36, T123N., R74W., AND SECS. 30, 31 AND WESTERN PORTIONS OF SECS. 29 & 32, T123N., R73W.; THE RESERVE OF SAND AND GRAVEL IS CALCULATED AS 308,984,880 CUBIC YARDS OR 8,342,591,760 CUBIC FEET, AND THE STORAGE SPACE FOR WATER WOULD BE 2,502,777,528 CUBIC FEET. NEAR THE OUTWASH MARGIN, THE POROSITY IS ASSUMED TO BE 25 PERCENT IN SECS. 24, 13, 12 AND THE EASTERN PORTION OF SEC. 12, T122N., R74W., SECS. 7, 6 & 5, T122N., R73W., SECS. 18, 19, 20, 21, 28, 33, AND THE EASTERN PORTIONS OF SECS. 29 & 32, T123N., R73W., AND SECS. 10, 11, 12, 13, 14 & 15, T123N., R74W. THE ESTIMATED RESERVE OF SAND AND GRAVEL IS COMPUTED AS 433,017,520 CUBIC YARDS OR 11,691,473,040 CUBIC FEET, AND THE STORAGE SPACE FOR WATER WOULD BE 2,922,868,260 CUBIC FEET. THE TOTAL STORAGE SPACE FOR WATER IN THIS REGION IS 5,425,645,788 CUBIC FEET OR 124,556 ACRE-FEET.

THE TOTAL WATER STORAGE CAPACITY IN THE RESERVOIRS BETWEEN HOVEN AND BOWDLE IS 255,621 ACRE-FEET. DURING THE SUMMER SEASON OF 1956, THE AVERAGE DEPTH OF WATER IN THE HOVEN DISTRICT WAS 8

FEET; IF POROSITY AVERAGES 30 PERCENT, A VERTICAL COLUMN ON A SQUARE FOOT IN AREA WOULD CONTAIN 2.4 CUBIC FEET OF WATER. THE MASS OF THE HOVEN OUTWASH COVERS ABOUT 641,203,200 SQUARE FEET. IF THIS AREA IS FILLED WITH 8 FEET OF WATER, THE VOLUME OF WATER STORED WOULD BE 1,538,887,680 CUBIC FEET OR 35,328 ACRE-FEET. THIS FIGURE IS ABOUT ONE THIRD OF THE TOTAL WATER STORAGE CAPACITY OF THE RESERVOIR IN THE HOVEN DISTRICT. THE DEPTH OF WATER IN THE BOWDLE OUTWASH IN THE SUMMER SEASON OF 1956 AVERAGED 12 FEET. THE OUTWASH IN THIS REGION COVERS ABOUT 669,081,600 SQUARE FEET. IF THE POROSITY OF THE OUTWASH SEDIMENTS AVERAGES 27 PERCENT AND AN AREA OF 669,081,600 SQUARE FEET IS FILLED WITH 12 FEET OF WATER, THE VOLUME OF WATER STORED WOULD BE 2,167,824,384 CUBIC FEET OR 49,766 ACRE-FEET. THIS FIGURE IS ABOUT HALF OF THE TOTAL WATER STORAGE CAPACITY OF THE BOWDLE RESERVOIR. AS A WHOLE, DURING THE SUMMER SEASON OF 1956, THE VOLUME OF WATER STORED IN BOTH THE HOVEN AND BOWDLE RESERVOIRS IS, HOWEVER, ABOUT ONE THIRD OF THE TOTAL STORAGE CAPACITY OF THE RESERVOIRS.

SUGGESTIONS FOR THE FUTURE DEVELOPMENT OF IRRIGATION

THE FUTURE FOR DEVELOPMENT OF IRRIGATION IN THE RESERVOIRS BETWEEN HOVEN AND BOWDLE LOOKS VERY FAVORABLE; HOWEVER SEVERAL ITEMS CONCERNING SUCH IRRIGATION ARE GIVEN A BRIEF DISCUSSION BELOW.

CHARACTER OF SOIL: THE TOPSOIL DEVELOPED ON THE SURFACE OF OUTWASHES IS GENERALLY LIGHT IN TEXTURE, AND MORE SILTY AND SANDY THAN THE SOIL DEVELOPED ON THE SURFACE OF TILLS; THUS THIS SOIL HAS A RAPID TO MODERATE PERMEABILITY, IN OTHER WORDS, WATER CAN PERCOLATE DOWNWARD INTO THE RESERVOIR WITHOUT MUCH DIFFICULTY. ON THIS BASIS OF THIS FACT, THE FUTURE IRRIGATION IN THIS AREA SHOULD BE CARRIED OUT BY MEANS OF SPRINKLING SYSTEM RATHER THAN FURROW IRRIGATION SYSTEM.

THE MOISTURE CONTAINED IN THIS SILTY AND SANDY SOIL IS COMMONLY EASY TO LOSE THROUGH THE PROCESS OF EVAPO-TRANSPIRATION. CROPS GROWING ON THE SURFACE OF OUTWASHES OFTEN MEET DIFFICULTY DURING THE GROWING SEASON, ESPECIALLY CORN, WHICH NEEDS ABOUT 11 INCHES OF MOISTURE TO GIVE A FAIR PRODUCTION; THEREFORE AN ADEQUATE WATER SUPPLY FROM SHALLOW WATER WELLS BY SPRINKLING IRRIGATION IS VERY NECESSARY TO FULLY FILL THAT REQUIREMENT.

DEPTH AND LOCATION OF WELLS: IN THIS AREA, THE DEPTH OF THE FUTURE IRRIGATION WELLS WILL RANGE APPROXIMATELY FROM 6 FEET TO 156 FEET IN THE RESERVOIRS. IN THE BOWDLE OUTWASH, THE DEEPEST WELL WILL BE LOCATED NEAR THE RESISTIVITY STATION 126, IN SEC. 13, T122N., R74W., WHERE IT WILL ENCOUNTER THE THICKNESS OF SAND AND GRAVEL UP TO 126 FEET. ONLY 6 FEET OF SAND AND GRAVEL ARE FOUND IN SEC. 26, T123N., R74W., ALONG THE BANK OF THE INTERMITTENT STREAM. THE DEPTH OF THE SHALLOWEST WATER WELL IN THIS REGION THEREFORE WILL NOT EXCEED 7 FEET.

IN THE HOVEN DISTRICT, THE DEEPEST WELLS WILL BE LOCATED IN SECS. 2, 11, & 14, T121N., R74W., NEAR RESISTIVITY STATIONS NOS. 128, 229, 230, 232, 235, & 236, WHERE THE THICKNESSES OF SAND AND GRAVEL WILL BE ENCOUNTERED UP TO 156 FEET; WHEREAS THE SHALLOWEST WELLS WILL BE SITUATED IN THE VICINITY OF SWAN LAKE, AND THE DEPTH OF THESE WELLS WILL REACH THE LOWEST VALUE OF ABOUT 6 FEET.

IN THIS AREA SEVERAL ROLLING TILL RIDGES OCCUR SPORADICALLY, AND THEY ARE NOT GOOD PLACES FOR THE WATER STORAGE. THEREFORE THE DRILLER SHOULD CONFIRM THEIR LOCATIONS ACCORDING TO THE GEOLOGICAL MAP (PLATE 1). NEVERTHELESS IT IS NOT ADVISABLE TO

LOCATE THE IRRIGATION WATER WELLS NEAR THE SOURCE AREA OF OUTWASHES. AS MENTIONED BEFORE, A GREAT AMOUNT OF WATER CAN BE STORAGED IN THE LOWER PORTION OF THE OUTWASH MASS DUE TO RATHER HIGHER POROSITY OF SAND AND GRAVEL. WATER OCCURRING IN THE VICINITY OF SOURCE AREA IS COMMONLY EASY TO LOSE DUE TO HIGH PERMEABILITY OF COARSE SAND AND GRAVEL; SOME FINE- TO MEDIUM-GRAINED SAND LENSES ARE USUALLY INTERCALATED WITH THE COARSE DETRITUS, IN WHICH HOWEVER A CONSIDERABLE AMOUNT OF WATER CAN BE STORED FOR THE RECHARGE TO THE WELLS LOCATED IN THAT VICINITY.

DURING THE PUMPING SEASON, WELLS IN THE RESERVOIRS ARE USUALLY EFFECTED BY THE CONTINUOUS PUMPAGE ACCORDING TO THE PRINCIPLES OF RECOVERY. THIS PUMPAGE DEFINITELY EFFECTS THE DRAWDOWN OF WATER LEVEL IN THE VICINITY OF PUMPING WELLS, NEVERTHELESS IT WILL NOT HAVE APPRECIABLE INFLUENCE ON THE WATER LEVEL IN WELLS WHICH ARE LOCATED SEVERAL MILES AWAY FROM THE RESERVOIRS IN THE TILL REGION.

QUALITY OF WATER: THE QUALITY OF WATER AS DISCUSSED BEFORE IS SUITABLE FOR THE PURPOSE OF IRRIGATION. IN ORDER TO CHECK THE CHANGES OF WATER COMPOSITION CHEMICAL ANALYSIS OF WATER SHOULD BE CARRIED OUT REGULARLY DURING THE PERIOD OF IRRIGATION. ACCORDING TO MAGISTAD AND CHRISTIANSEN (1944) IF WATER CONTAINS ANY BORON COMPOUND IN CONCENTRATION LESS THAN 0.33 PPM, IT IS EXCELLENT TO GOOD FOR IRRIGATION. THIS COMPOUND HOWEVER HAS NOT YET BEEN FOUND IN THE WATER OF THIS AREA. GENERALLY AS A RESULT OF EVAPO-TRANSPIRATION AND RECIRCULATION ESPECIALLY DURING THE DRY SEASONS, AN INCREASE IN MINERALIZATION OF THE SHALLOW WATER WILL PROBABLY ACCOMPANY IRRIGATION, THEREFORE A NECESSARY MEASURE SHOULD BE TAKEN TO COUNTERACT IT, IN ORDER TO PREVENT THE EXCESSIVE CONCENTRATION OF SALTS IN THE SOIL.

SUMMARY

THE REGIONAL STRATIGRAPHY IS CHIEFLY MADE UP OF WISCONSIN GLACIAL DEPOSITS IN WHICH THREE DRIFT SHEETS ARE TENTATIVELY RECOGNIZED AS IOWAN, CARY, AND LATE CARY IN AGE. THE LATE CARY SEQUENCE IN THIS AREA WAS MAPPED AS "MANKATO" BY FLINT IN 1955, ON THE BASIS OF TEXTURAL AND LITHOLOGICAL STUDY. THE WRITER FOUND NO REMARKABLE DIFFERENCE BETWEEN THESE TWO DRIFTS, EXCEPT THE DEPTH OF THE LEACHED SOIL ZONE DEVELOPED ON THE SURFACE OF THE LATE CARY DRIFT WHICH AVERAGED TWO INCHES LESS THAN THAT DEVELOPED ON THE SURFACE OF THE CARY DRIFT. NEVERTHELESS THE FINAL CONFIRMATION OF THE REPLACEMENT OF "MANKATO" BY LATE CARY WILL TAKE MORE STUDY. THEREFORE A MORE DETAILED INVESTIGATION OF THE DRIFT SHEETS ON A LARGE SCALE AND THE RADIOCARBON DATING OF THESE DRIFTS ARE SUGGESTED.

THE CARY AND LATE CARY END MORAINES ACTED AS THE CHIEF SOURCES OF OUTWASH SEDIMENTS IN THIS AREA. TEXTURAL STUDY INDICATES THAT THOSE SEDIMENTS WERE FORMED FIRST UNDER THE GLACIAL CONDITIONS. THE TRANSITIONAL GLACIAL AND ALLUVIAL CONDITIONS APPEARED LATER.

THE OUTWASHES PLAY A MAJOR ROLE IN WATER SUPPLY. ESTIMATES OF THE RESOURCES OF SAND AND GRAVEL WERE MADE BY GRID SYSTEM ON EACH SECTION GIVING VOLUME IN CUBIC YARDS. THE TOTAL ESTIMATED AMOUNT IN BOTH THE HOVEN AND BOWDLE OUTWASHES IS 1,372,600,584 CUBIC YARDS.

ACCORDING TO THE MECHANICAL ANALYSES, THE AVERAGE WEIGHT PERCENTAGE OF EACH GRAIN SIZE LIMIT OF THE OUTWASH SEDIMENTS IS 7.5 PERCENT OF COBBLE, 48 PERCENT OF PEBBLE, 9.5 PERCENT OF GRANULE, 33 PERCENT OF SAND, AND 1.5 PERCENT OF SILT AND CLAY. THE CONSTITUENTS OF THE COARSE DETRITUS, RANGING FROM COBBLE TO PEBBLE IN SIZE, ARE MADE UP OF AN AVERAGE OF 39 PERCENT OF LIMESTONES AND DOLOMITES, 29 PERCENT OF SHALES AND IRONSTONES, WITH SOME SANDSTONES, AND 32 PERCENT OF IGNEOUS AND METAMORPHIC ROCK TYPES. THE GRANULE CONSISTS CHIEFLY OF ROCK FRAGMENTS OF LIMESTONES AND DOLOMITES, IGNEOUS AND METAMORPHIC TYPES. THE SAND AND SILT FRACTIONS COMPRISE MAINLY ROUNDED TO SUBANGULAR QUARTZ GRAINS WITH SOME PINK POTASH FELDSPARS, AND OTHER ACCESSORY MINERALS. ON THE BASIS OF THOSE PHYSICAL PROPERTIES OF SAND AND GRAVEL, THEY ARE CONSIDERED AS "GOOD" MATERIALS FOR USE IN HIGHWAY PAVING AND CONCRETE AGGREGATE.

IN THE RESERVOIRS THE TOTAL STORAGE CAPACITY IS COMPUTED AS 255,621 ACRE-FEET. IN THE SUMMER SEASON OF 1956, THE VOLUME OF

WATER STORED IN THE RESERVOIRS IS ABOUT ONE THIRD OF THE TOTAL STORAGE CAPACITY OF THOSE RESERVOIRS.

DUE TO THE GOOD PERMEABILITY OF THE OUTWASHES, THE RECHARGE, DISCHARGE AND RECOVERY ARE CONSIDERED TO BE RAPID. THE MAIN WATER BODIES FLOW MAINLY ALONG THE CHANNELS OF THE SEVEN PRE-MORAINE VALLEYS FROM THE NORTH, EAST AND NORTHEAST TO THE SOUTH-WEST AND WEST. ALTHOUGH THE FIELD DATA ARE NOT ENOUGH TO ESTAB-LISH A HYDRAULIC GRADIENT MAP FOR THIS AREA, NEVERTHELESS THE GENERAL PICTURE OF HYDRAULIC GRADIENT IS DEDUCED FROM THE RESULTS OF FIELD INVESTIGATION ON DOMESTIC WELLS. IN THE BOWDLE OUTWASH THE HYDRAULIC GRADIENT AVERAGES 10 FEET PER MILE, AND SLOPES DOWN SOUTHERLY AND SOUTHWESTERLY; WHILE IN THE HOVEN OUTWASH, THE AVERAGE VALUE OF HYDRAULIC GRADIENT IS ABOUT 3 FEET PER MILE, AND SLOPES GENTLY WESTERLY.

THE DEVELOPMENT OF IRRIGATION IN THE RESERVOIRS BETWEEN HOVEN AND BOWDLE WOULD SEEM TO BE VERY FAVORABLE, AND A SPRINK-LING SYSTEM IS SUGGESTED. ALTHOUGH THE QUALITY OF WATER IS SATISFACTORY FOR DOMESTIC, STOCK, PUBLIC AND IRRIGATION USES, CHEMICAL ANALYSIS OF THE WATER SHOULD BE CARRIED OUT FROM TIME TO TIME IN ORDER TO DETERMINE THE CHANGES THAT USUALLY COME WITH PUMPING. BEFORE ATTEMPTING IRRIGATION THE CHARACTER OF SOIL, DEPTH AND LOCATION OF WELLS, AND QUALITY OF WATER ON THE ACREAGE TO BE IRRIGATED SHOULD BE DETERMINED. THE SIGNIFICANCE OF THOSE ITEMS SHOULD BE TAKEN INTO A CAREFUL CONSIDERATION DURING THE PROCESS OF IRRIGATION.

BIBLIOGRAPHY

FLINT, R. F., (1955), PLEISTOCENE GEOLOGY OF EASTERN SOUTH DAKOTA: U. S. GEOL. SUR., PROF. PAPER 262.

FOX, C. S., (1949), THE GEOLOGY OF WATER SUPPLY: THE TECHNICAL PRESS, LTD. LONDON.

LEE, K. Y., (1956), GEOLOGY AND SHALLOW WATER RESOURCES OF THE BLUE BLANKET VALLEY AND HOVEN OUTWASH, POTTER COUNTY SOUTH DAKOTA: STATE GEOL. SUR., SOUTH DAKOTA, R. I. NO. 80.

_____, (1957), THE WATER SUPPLY NEAR SELBY, WALWORTH COUNTY, SOUTH DAKOTA: STATE GEOL. SUR., SOUTH DAKOTA.

MAGISTAD, O. C., AND CHRISTIANSEN, J. E., (1944), TENTATIVE STANDARDS FOR IRRIGATION WATERS: U. S. DEPT. AGRICULTURE, CIRC. 707, TABLE 2.

MEINZER, O. E., (1923), THE OCCURRENCE OF GROUND WATER IN THE UNITED STATES: U. S. GEOL. SUR. WATER SUPPLY PAPER 489.

ROTHROCK, E. P., AND NEWCOMB, R. V., (1932), SAND AND GRAVEL DEPOSITS IN POTTER AND FAULK COUNTIES: STATE GEOL. SUR. SOUTH DAKOTA, R. I. NO. 11.

RUBEY, W. W., (1937), THE FORCE REQUIRED TO MOVE PARTICLES ON A STREAM BED: U. S. GEOL. SUR. PROF. PAPER 189-E.

TODD, J. E., (1896), MORAINES OF THE MISSOURI COTEAU AND THEIR ATTENDANT DEPOSITS: U. S. GEOL. SUR. BULL. 144.

TRASK, P. D., (1932), ORIGIN AND ENVIRONMENT OF SOURCE SEDIMENTS OF PETROLEUM: GULF PUB. CO., HOUSTON, TEXAS.

ZUMBERGE, J. H., AND WRIGHT, H. E. JR., (1956), THE CARY-MANKATO-VALDERS PROBLEM: GEOL. SOCI. AM., GUIDEBOOK SERIES, NO. 3, GLACI. GEOL., EASTERN MINNESOTA, PP 65-78.

APPENDIX

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL
BETWEEN HOVEN AND BOWDLE, S. D.

Station No. on Map	Location (Plate 2)	Elevation Datum: Sea Level (feet)			Thickness (feet)	
		Surface	Sand & Gravel		Sand & Gravel	Mantle
			Top	Bottom		
1	Sec. 21, T123N, R73W	1988.09	1985.09	1960.09	25.00	3.00
2	Sec. 21, T123N, R73W	1986.09	1984.09	1966.09	18.00	2.00
5	Sec. 20, T123N, R73W	1981.09	1980.09	1963.09	17.00	1.00
6	Sec. 19, T123N, R73W	1969.91	1967.91	1963.91	4.00	2.00
8	Sec. 19, T123N, R73W	1976.91	1975.91	1974.91	1.00	1.00
9	Sec. 24, T123N, R74W	1986.19	1984.19	1949.19	35.00	2.00
14	Sec. 23, T123N, R74W	2004.91	2002.91	1987.91	15.00	2.00
15	Sec. 23, T123N, R74W	1997.20	1996.20	1990.20	6.00	1.00
18	Sec. 19, T123N, R73W	1980.91	1979.91	1973.91	6.00	1.00
19	Sec. 24, T123N, R74W	2001.83	1997.83	1953.83	44.00	4.00
21	Sec. 24, T123N, R74W	2004.21	2002.21	1939.21	63.00	2.00
22	Sec. 20, T123N, R73W	1984.24	1980.24	1949.24	31.00	4.00
23	Sec. 20, T123N, R73W	1996.80	1995.80	1991.80	4.00	1.00
24	Sec. 19, T123N, R73W	1999.34	1998.34	1995.34	3.00	1.00
25	Sec. 19, T123N, R73W	2004.11	2002.11	1997.11	5.00	2.00
26	Sec. 19, T123N, R73W	2001.11	1998.11	1961.11	37.00	3.00
27	Sec. 24, T123N, R74W	1999.11	1996.11	1987.11	9.00	3.00
28	Sec. 24, T123N, R74W	2006.71	2001.71	1983.71	18.00	5.00

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL BETWEEN HOVEN AND BOWDLE, S. D. (CON'T.)

STATION NO. ON MAP	LOCATION (PLATE 2)	ELEVATION DATUM: SEA LEVEL (FEET)			THICKNESS (FEET)	
		SURFACE	SAND & GRAVEL		SAND & GRAVEL	MANTLE
			TOP	BOTTOM		
29	SEC. 23, T123N, R74W	2015.21	2008.21	1997.21	11.00	7.00
31	SEC. 23, T123N, R74W	2002.71	2001.71	1995.71	6.00	1.00
34	SEC. 22, T123N, R74W	2014.26	2010.26	2001.26	9.00	4.00
45	SEC. 21, T123N, R73W	2020.22	2018.22	2006.22	12.00	2.00
46	SEC. 21, T123N, R73W	1998.80	1994.80	1942.80	52.00	4.00
47	SEC. 21, T123N, R73W	2016.72	-------	-------	-----	----
52	SEC. 21, T123N, R73W	2003.22	2002.22	1944.22	58.00	1.00
53	SEC. 21, T123N, R73W	2005.22	2003.22	1962.22	41.00	2.00
54	SEC. 29, T123N, R73W	1975.09	1974.09	1935.09	39.00	1.00
56	SEC. 28, T123N, R73W	1976.59	1965.59	1931.59	34.00	11.00
57	SEC. 33, T123N, R73W	1998.79	1995.79	1991.79	4.00	3.00
58	SEC. 32, T123N, R73W	1970.09	1968.09	1946.09	22.00	2.00
59	SEC. 32, T123N, R73W	1970.59	1967.59	1910.59	57.00	3.00
60	SEC. 29, T123N, R73W	1977.09	1974.09	1963.09	11.00	3.00
61	SEC. 32, T123N, R73W	1979.39	1976.39	1894.39	82.00	3.00
62	SEC. 33, T123N, R73W	1989.29	1987.29	1939.29	48.00	2.00
64	SEC. 33, T123N, R73W	2028.39	2024.39	1828.39	196.00	4.00
67	SEC. 32, T123N, R73W	1977.39	1973.39	1887.39	86.00	4.00

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL BETWEEN HOVEN AND BOWDLE, S. D. (CON'T.)

STATION NO. ON MAP	LOCATION (PLATE 2)	ELEVATION DATUM: SEA LEVEL (FEET)			THICKNESS (FEET)	
		SURFACE	SAND & GRAVEL		SAND & GRAVEL	MANTLE
			TOP	BOTTOM		
68	SEC. 29, T123N, R73W	1967.59	1964.59	1917.59	47.00	3.00
69	SEC. 32, T123N, R73W	1967.59	1963.59	1940.59	23.00	4.00
70	SEC. 32, T123N, R73W	1958.59	1955.59	1936.59	29.00	3.00
71	SEC. 31, T123N, R73W	1950.59	1946.59	1929.59	17.00	4.00
72	SEC. 29, T123N, R73W	1960.59	1958.59	1926.59	32.00	2.00
73	SEC. 32, T123N, R73W	1955.59	1954.59	1943.59	11.00	1.00
74	SEC. 32, T123N, R73W	1956.49	1954.49	1936.49	18.00	2.00
75	SEC. 32, T123N, R73W	1953.19	1951.19	1937.19	14.00	2.00
77	SEC. 32, T123N, R73W	1944.89	1940.89	1928.89	12.00	4.00
79	SEC. 31, T123N, R73W	1958.59	1954.59	1903.59	51.00	4.00
80	SEC. 6, T122N, R73W	1955.09	1948.09	1910.09	38.00	7.00
81	SEC. 36, T123N, R74W	1942.09	1941.09	1937.09	4.00	1.00
82	SEC. 31, T123N, R73W	1962.09	1960.09	1912.09	48.00	2.00
83	SEC. 31, T123N, R73W	1955.09	1953.09	1935.09	18.00	2.00
84	SEC. 31, T123N, R73W	1948.59	1945.59	1940.59	5.00	3.00
90	SEC. 30, T123N, R73W	1969.09	1967.09	1961.09	6.00	2.00
91	SEC. 36, T123N, R74W	1969.59	1967.59	1919.59	48.00	2.00
92	SEC. 25, T123N, R74W	1972.09	1970.09	1900.09	70.00	2.00

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL BETWEEN HOVEN AND BOWDLE, S. D. (con't.)

Station No. on Map	Location (Plate 2)	Elevation Datum: Sea Level (feet)			Thickness (feet)	
		Surface	Sand & Gravel		Sand & Gravel	Mantle
			Top	Bottom		
93	Sec. 36, T123N, R74W	1953.59	1951.59	1933.59	18.00	2.00
94	Sec. 25, T123N, R74W	1962.09	1960.09	1900.09	60.00	2.00
95	Sec. 35, T123N, R74W	1953.69	1950.69	1932.69	18.00	3.00
96	Sec. 35, T123N, R74W	1956.09	1951.09	1931.09	20.00	5.00
97	Sec. 26, T123N, R74W	1964.59	1961.59	1957.59	4.00	3.00
102	Sec. 2, T122N, R74W	1955.79	1953.79	1939.79	14.00	2.00
103	Sec. 35, T123N, R74W	1948.29	1944.29	1913.29	31.00	4.00
104	Sec. 2, T122N, R74W	1954.29	1952.29	1928.29	24.00	2.00
105	Sec. 2, T122N, R74W	1946.29	1943.29	1846.29	97.00	3.00
106	Sec. 1, T122N, R74W	1953.29	1950.29	1900.29	50.00	3.00
107	Sec. 36, T123N, R74W	1959.79	1958.79	1889.79	69.00	1.00
109	Sec. 6, T122N, R73W	1955.34	1949.34	1890.34	59.00	6.00
110	Sec. 6, T122N, R73W	1959.59	1956.59	1889.59	67.00	3.00
111	Sec. 1, T122N, R74W	1957.09	1954.09	1875.09	79.00	3.00
113	Sec. 12, T122N, R74W	1961.34	1960.34	1871.34	89.00	1.00
114	Sec. 1, T122N, R74W	1953.09	1951.09	1849.09	102.00	2.00
115	Sec. 2, T122N, R74W	1941.29	1940.29	1933.29	7.00	1.00
116	Sec. 2, T122N, R74W	1959.09	1956.09	1954.09	2.00	3.00

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL BETWEEN HOVEN AND BOWDLE, S. D. (CON'T)

STATION NO. ON MAP	LOCATION (PLATE 2)	ELEVATION DATUM: SEA LEVEL (FEET)			THICKNESS (FEET)	
		SURFACE	SAND & GRAVEL		SAND & GRAVEL	MANTLE
			TOP	BOTTOM		
118	SEC. 14, T122N, R74W	1940.64	1939.64	1895.64	44.00	1.00
119	SEC. 13, T122N, R74W	1937.64	1935.64	1913.64	22.00	2.00
120	SEC. 13, T122N, R74W	1943.14	1941.14	1897.14	44.00	2.00
121	SEC. 12, T122N, R74W	1964.04	1960.04	1862.04	98.00	4.00
125	SEC. 13, T122N, R74W	1968.05	1966.65	1962.05	4.60	1.40
126	SEC. 13, T122N, R74W	1961.95	1959.95	1836.95	123.00	2.00
127	SEC. 24, T122N, R74W	1943.18	1941.18	1930.18	11.00	2.00
128	SEC. 24, T122N, R74W	1937.88	1935.88	1920.88	15.00	2.00
129	SEC. 25, T122N, R74W	1930.12	1927.12	1917.12	10.00	3.00
AVERAGE THICKNESS OF THE LATE CARY OUTWASH					34.77	2.69

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL BETWEEN HOVEN AND BOWDLE, S. D. (CON'T.)

STATION NO. ON MAP	LOCATION (PLATE 2)	ELEVATION DATUM: SEA LEVEL (FEET)			THICKNESS (FEET)	
		SURFACE	SAND & GRAVEL		SAND & GRAVEL	MANTLE
			TOP	BOTTOM		
140	SEC. 35, T122N, R74W	1914.20	1913.20	1887.20	26.00	1.00
141	SEC. 35, T122N, R74W	1923.80	1922.80	1888.80	34.00	1.00
142	SEC. 35, T122N, R74W	1921.60	1919.60	1904.60	15.00	2.00
146	SEC. 36, T122N, R74W	1949.64	1949.64	1854.64	95.00	0.00
147	SEC. 36, T122N, R74W	1931.26	1930.26	1911.26	19.00	1.00
148	SEC. 36, T122N, R74W	1938.64	1937.64	1888.64	49.00	1.00
149	SEC. 36, T122N, R74W	1960.64	1955.64	1810.64	145.00	5.00
150	SEC. 31, T122N, R73W	1954.64	1954.64	1854.64	100.00	0.00
151	SEC. 1, T121N, R74W	1945.14	1943.14	1872.14	71.00	2.00
153	SEC. 1, T121N, R74W	1945.84	1943.84	1820.84	123.00	2.00
154	SEC. 1, T121N, R74W	1948.34	1946.34	1831.34	115.00	2.00
155	SEC. 1, T121N, R74W	1942.34	1940.34	1821.34	119.00	2.00
157	SEC. 2, T121N, R74W	1933.84	1932.84	1911.84	21.00	1.00
158	SEC. 2, T121N, R74W	1940.84	1936.84	1893.84	43.00	4.00
159	SEC. 10, T121N, R74W	1910.34	1909.34	1900.34	9.00	1.00
160	SEC. 16, T121N, R74W	1927.84	1926.34	1902.84	23.50	1.50
161	SEC. 16, T121N, R74W	1918.84	1914.84	1853.84	61.00	4.00
162	SEC. 16, T121N, R74W	1918.34	1914.34	1848.34	66.00	4.00

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL BETWEEN HOVEN AND BOWDLE, S. D. (CON'T.)

STATION NO. ON MAP	LOCATION (PLATE 2)	ELEVATION DATUM: SEA LEVEL (FEET)			THICKNESS (FEET)	
		SURFACE	SAND & GRAVEL		SAND & GRAVEL	MANTLE
			TOP	BOTTOM		
163	SEC. 15, T12N, R74W	1918.84	1915.84	1853.84	62.00	3.00
164	SEC. 15, T12N, R74W	1922.34	1919.34	1844.34	75.00	3.00
165	SEC. 15, T12N, R74W	1925.84	1921.84	1862.84	59.00	4.00
166	SEC. 15, T12N, R74W	1924.34	1919.34	1824.34	95.00	5.00
167	SEC. 16, T12N, R74W	1918.34	1914.34	1860.34	54.00	4.00
168	SEC. 16, T12N, R74W	1911.84	1903.84	1861.84	42.00	8.00
169	SEC. 16, T12N, R74W	1917.34	1913.34	1857.34	56.00	4.00
170	SEC. 16, T12N, R74W	1908.44	1904.44	1873.44	31.00	4.00
171	SEC. 17, T12N, R74W	1896.34	1893.34	1870.34	23.00	3.00
172	SEC. 17, T12N, R74W	1909.38	1904.38	1864.38	40.00	5.00
173	SEC. 17, T12N, R74W	1899.34	1895.34	1859.34	36.00	4.00
174	SEC. 18, T12N, R74W	1901.34	1896.84	1849.84	47.00	4.50
175	SEC. 18, T12N, R74W	1894.84	1892.34	1857.84	34.53	2.50
176	SEC. 17, T12N, R74W	1903.84	1899.34	1865.84	33.50	4.50
177	SEC. 17, T12N, R74W	1895.84	1892.54	1857.84	34.70	3.30
178	SEC. 17, T12N, R74W	1896.34	1894.14	1854.34	39.80	2.20
179	SEC. 20, T12N, R74W	1899.14	1895.14	1867.14	28.00	4.00
180	SEC. 30, T12N, R74W	1887.14	1886.14	1872.14	14.00	1.00

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL BETWEEN HOVEN AND BOWDLE, S. D. (CON'T.)

STATION NO. ON MAP	LOCATION (PLATE 2)	ELEVATION DATUM: SEA LEVEL (FEET)			THICKNESS (FEET)	
		SURFACE	SAND & GRAVEL		SAND & GRAVEL	MANTLE
			TOP	BOTTOM		
181 A	SEC. 30, T12N, R74W	1892.64	1890.64	1870.64	20.00	2.00
181 B	SEC. 29, T12N, R74W	1899.64	1890.64	1875.64	15.00	9.00
182	SEC. 29, T12N, R74W	1898.14	1894.14	1873.14	21.00	4.00
183	SEC. 30, T12N, R74W	1897.14	1893.14	1867.14	26.00	4.00
184	SEC. 30, T12N, R74W	1902.64	1897.64	1878.64	19.00	5.00
185	SEC. 30, T12N, R74W	1898.14	1893.14	1878.14	15.00	5.00
186	SEC. 32, T12N, R74W	1903.94	1900.94	1894.94	6.00	3.00
187	SEC. 32, T12N, R74W	1905.44	1903.44	1888.44	15.00	2.00
188	SEC. 32, T12N, R74W	1902.44	1899.44	1889.44	10.00	3.00
189	SEC. 32, T12N, R74W	1901.44	1897.44	1888.44	9.00	4.00
190	SEC. 29, T12N, R74W	1907.34	1903.34	1878.34	25.00	4.00
191	SEC. 28, T12N, R74W	1907.84	1903.84	1889.84	14.00	4.00
192	SEC. 28, T12N, R74W	1908.34	1904.84	1878.34	26.50	3.50
193	SEC. 29, T12N, R74W	1903.34	1900.34	1873.34	27.00	3.00
194	SEC. 28, T12N, R74W	1906.34	1903.34	1892.34	11.00	3.00
195	SEC. 20, T12N, R74W	1891.54	1890.54	1886.54	4.00	1.00
196	SEC. 28, T12N, R74W	1892.84	1891.34	1875.84	15.50	1.50
197	SEC. 21, T12N, R74W	1890.34	1887.34	1882.34	5.00	3.00

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL BETWEEN HOVEN AND BOWDLE, S. D. (CON'T.)

STATION NO. ON MAP	LOCATION (PLATE 2)	ELEVATION DATUM: SEA LEVEL (FEET)			THICKNESS (FEET)	
		SURFACE	SAND & GRAVEL		SAND & GRAVEL	MANTLE
			TOP	BOTTOM		
198	SEC. 20, T12N, R74W	1890.84	1882.84	1865.84	17.00	8.00
199	SEC. 17, T12N, R74W	1896.84	1893.84	1861.84	32.00	3.00
200	SEC. 16, T12N, R74W	1908.84	1905.84	1868.84	37.00	3.00
201	SEC. 16, T12N, R74W	1914.34	1911.34	1854.34	57.00	3.00
202	SEC. 15, T12N, R74W	1920.34	1916.84	1820.34	96.50	3.50
203	SEC. 15, T12N, R74W	1928.34	1925.84	1856.34	69.50	2.50
204	SEC. 15, T12N, R74W	1925.34	1923.34	1855.34	68.00	2.00
205	SEC. 22, T12N, R74W	1915.34	1913.34	1870.34	43.00	2.00
206	SEC. 22, T12N, R74W	1926.84	1922.84	1848.84	74.00	4.00
207	SEC. 21, T12N, R74W	1907.34	1905.34	1889.34	16.00	2.00
208	SEC. 28, T12N, R74W	1902.34	1899.34	1886.34	13.00	3.00
209	SEC. 28, T12N, R74W	1913.34	1910.34	1858.34	52.00	3.00
211	SEC. 28, T12N, R74W	1907.14	1905.14	1859.14	46.00	2.00
213	SEC. 33, T12N, R74W	1905.94	1902.94	1843.94	59.00	3.00
214	SEC. 33, T12N, R74W	1906.94	1903.94	1860.94	43.00	3.00
215	SEC. 34, T12N, R74W	1917.94	1915.44	1827.94	87.50	2.50
216	SEC. 33, T12N, R74W	1920.44	1915.44	1885.44	30.00	5.00
217	SEC. 27, T12N, R74W	1928.78	1926.28	1857.78	68.50	2.50

TABLE 6

RESISTIVITY DATA ON THE THICKNESS OF SAND AND GRAVEL BETWEEN HOVEN AND BOWDLE, S. D. (con't.)

Station No. on Map	Location (Plate 2)	Elevation Datum: Sea Level (feet)			Thickness (feet)	
		Surface	Sand & Gravel		Sand & Gravel	Mantle
			Top	Bottom		
218	Sec. 27, T121N, R74W	1933.88	1931.38	1927.88	3.50	2.50
219	Sec. 27, T121N, R74W	1910.28	1908.28	1906.28	2.00	2.00
220	Sec. 27, T121N, R74W	1917.38	1913.38	1856.38	57.00	4.00
222	Sec. 22, T121N, R74W	1923.38	1922.38	1853.38	69.00	1.00
223	Sec. 22, T121N, R74W	1922.88	1920.88	1832.88	88.00	2.00
224	Sec. 23, T121N, R74W	1932.38	1929.38	1843.38	86.00	3.00
225	Sec. 23, T121N, R74W	1927.38	1925.38	1920.38	5.00	2.00
226	Sec. 15, T121N, R74W	1923.38	1921.38	1853.38	68.00	2.00
227	Sec. 22, T121N, R74W	1922.38	1920.38	1862.38	58.00	2.00
229	Sec. 14, T121N, R74W	1927.88	1923.88	1822.88	101.00	4.00
230	Sec. 11, T121N, R74W	1929.88	1926.88	1859.88	67.00	3.00
232	Sec. 11, T121N, R74W	1935.38	1931.38	1785.38	146.00	4.00
233	Sec. 11, T121N, R74W	1933.38	1929.38	1783.38	146.00	4.00
234	Sec. 14, T121N, R74W	1929.88	1926.88	1844.88	82.00	3.00
235	Sec. 2, T121N, R74W	1944.88	1940.88	1784.88	156.00	4.00
236	Sec. 2, T121N, R74W	1936.88	1933.88	1861.88	72.00	3.00
237	Sec. 1, T121N, R74W	1946.38	1944.38	1786.38	158.00	2.00
238	Sec. 14, T121N, R74W	1933.38	1930.38	1849.38	81.00	3.00
Average Thickness Of The Cary Outwash					50.86	3.05

TABLE 7

WELL RECORDS (JULY-AUGUST, 1956)

J: JET PUMP
P: PITCHER PUMP
T: TURBINE
E: ELECTRIC
H: HAND OPERATED
W: WINDMILL
D: DOMESTIC
S: STOCK
DR: DRILLED
D: DUG

No. on Map	Location (Plate 2)	Owner or Tenant	Type of Well	Depth of Well (ft)	Dia. of Well (in)	Type of Casing	Top Edge of Casing	Height Above Sea Level (feet)	Height of Casing Above Gr. Level (inches)	Principal Water Bearing Beds		Method of Lift	Use of Water	Depth of Water Summer 1956 (feet)
										Character of Material	Geologic Source			
1	Sec. 21, T123N, R73W	City of Bowdle	Dr	103	12	Steel	Cement	1992.97	24 (basement)	Sand & gr.	Outwash	TE	D	58.00
2	Sec. 21, T123N, R73W	City of Bowdle	Dr	96	15	Steel	Cement	1995.90	24	Sand & gr.	Outwash	TE	D	56.00
4	Sec. 21, T123N, R73W	City of Bowdle	D	19	24	Wood	Wood	1988.50	12	Sand & gr.	Outwash	PH	D	6.00
3	Sec. 28, T123N, R73W	City of Bowdle	Dr	85	12	Steel	Cement	1995.50	24	Sand & gr.	Outwash	TE	D	47.00
5	Sec. 19, T123N, R73W	E.M. Mertz	D	37	24	Wood & Steel	Cement	1978.84	10	Sand & gr.	Outwash	HEP	D	21.00
6	Sec. 23, T123N, R74W	L. Erbe	D	20	30	Tile	Tile	1995.71	24	Sand & gr.	Outwash	JEP	D	8.00
7	Sec. 10, T123N, R74W	E. Mertz	D	20	36	Wood	Cement	2044.41	18	Sand & gr.	Outwash	EWP	DS	12.50
8	Sec. 14, T123N, R74W	J. Greger	D	58	30	Wood Steel Cement	Wood	2048.21	24	Sand & gr. Clay	Stratified Drift & Till	HP	DS	---
9	Sec. 14, T123N, R74W	J. Greger	D	31	36	Wood	Wood	2023.31	10	Silt & clay	Till	EP	D	8.00
10	Sec. 11, T123N, R74W	A.J. Weiszhaar	D	70	24	Wood	Cement	2075.91	12	Sand & gr. Shale	Outwash Pierre Shale	WP	DS	40.00
11	Sec. 12, T123N, R74W	E. Lorenz	D	48	24	Wood	Wood	2053.20	5	Sand & gr. Clay	Outwash Till	WP	D	36.00
13	Sec. 12, T123N, R74W	E. Buechler	Dr	115	3	Steel	Steel	2015.31	--	Sand & gr. Clay	Stratified Drift, Till	WEP	DS	87.00
14	Sec. 12, T123N, R74W	A. Schick	D	28	24	Wood	Wood	2037.81	30	Sand & gr.	Outwash	WP	DS	10.00
16	Sec. 14, T122N, R74W	V. Hoven	D	65	24	Wood	Cement	1925.17	24	Clay Sand & gr.	Till, Stratified Drift	EP	DS	60.00

TABLE 7

WELL RECORDS (JULY-AUGUST, 1956) CON'T.

No. on Map	Location (Plate 2)	Owner or Tenant	Type of Well	Depth of Well (Ft)	Dia. of Well (In)	Type of Casing	Top Edge of Casing	Height Above Sea Level (Feet)	Height of Casing Above Gr. Level (Inches)	Principal Water Bearing Beds		Method of Lift	Use of Water	Depth of Water Summer 1956 (Feet)
										Character of Material	Geologic Source			
17	Sec. 23, T122N, R74W	V. Hoven	D	50	24	Wood	Cement	1916.67	24	Clay & Quicksand	Till, Stratified Drift	WP	S	50.00
18	Sec. 26, T122N, R74W	V. Hoven	D	35	24	Wood Steel	Tile	1899.10	24	Sand & gr. Shale	Outwash & Pierre Shale	WP	S	4.00
19	Sec. 11, T122N, R74W	V. Hoven	D	12	24	Wood	Wood	1939.69	6	Sand & gr.	Outwash	WP	S	4.00
20	Sec. 15, T122N, R74W	H. Mertz	D	40	24	Wood Steel	Steel	1924.88	24	Clay, sand gravel	Till, Stratified Drift	EP	DS	20.00
21	Sec. 24, T122N, R74W	D. Zimmer	D	40	24	Wood	Wood	1959.48	6	Sand & gr.	Outwash	EP	SD	12.00
22	Sec. 25, T122N, R74W	A. Ham	D	19	24	Wood	Wood	1938.52	6	Sand & gr. Clay	Outwash Till	WP	S	3.00
64	Sec. 21, T123N, R74W	J. Herman Jr	D	81	24	Wood	3½'x3½' Cement	2057.31	12	Clay Sand & gr.	Till, Stratified Drift	WEP	DS	16.00
65	Sec. 21, T123N, R74W	F. Schick	D	60	24	Wood	Wood	2033.31	10	Clay Sand & gr.	Till, Stratified Drift	WP	SD	20.00
66	Sec. 22, T123N, R74W	D. Helmer	D	42	18	Steel Wood	Steel	2006.71	24	Clay Sand & gr.	Till, Stratified Drift	EP	DS	6.00
70	Sec. 24, T123N, R74W	H. Schlecht	D	70	24	Steel Wood	Steel	2005.41	12	Clay Sand & gr.	Till, Stratified Drift	WP	DS	25.00
71	Sec. 24, T123N, R74W	C. Schumacher	D	18	36	Steel	3'x3' Cement	1989.21	12	Sand & gr.	Outwash	WP	S	7.00
72	Sec. 24, T123N, R74W	C. Schumacher	D	18	24	Concrete	Wood	1989.21	12	Sand & gr.	Outwash	WP	DS	6.00
73	Sec. 30, T123N, R74W	O. Bollinger	D	11	36	Steel	Steel	1960.59	6	Sand & gr.	Outwash	EP	DS	1.50
74	Sec. 22, T123N, R74W	A. Hintz	D	18	36	Wood	Wood	1999.51	30	Sand & gr.	Outwash	WP	S	11.00
75	Sec. 22, T123N, R74W	A. Hintz	Dr	128	4	Steel	Steel	2001.51	60	Clay Sand & gr.	Till, Stratified Drift	Flowing	DS	128.00

TABLE 7

WELL RECORDS (JULY-AUGUST, 1956) CON'T.

No. on Map	Location (Plate 2)	Owner or Tenant	Type of Well	Depth of Well (ft)	Dia. of Well (in)	Type of Casing	Top Edge of Casing	Height Above Sea Level (feet)	Height of Casing Above Gr. Level (inches)	Principal Water Bearing Beds		Method of Lift	Use of Water	Depth of Water Summer 1956 (feet)
										Character of Material	Geologic Source			
76	Sec. 7, T123N, R73W	C. Haupt	Dr	158	2	Steel	4'x4' Cmt, Wood	2035.31	18	Clay Sand & gr.	Till, Stratified Drift	EWP	DS	149.00
77	Sec. 18, T123N, R73W	O. Buechler	Dr	171	4	Steel	Cement	2022.81	18	Clay Sand & gr.	Till, Stratified Drift	EP	DS	167.00
78	Sec. 20, T123N, R73W	K. Nickisch	Dr	185	2.5	Steel	Wood	2008.80	18	Clay Sand & gr.	Till, Stratified Drift	WEP	DS	178.00
80	Sec. 8, T123N, R73W	R. Lemke	D	61	24	Wood Cement	Wood	2060.81	10	Clay Sand & gr.	Till, Stratified Drift	WEP	DS	11.00
81	Sec. 34, T123N, R73W	M.J.Gutjahr	D	70	24	Wood	Wood	2005.99	12	Sand & gr.	Outwash	WP	SD	50.00
82	Sec. 29, T123N, R73W	M.Hoffman	D	18	30	Wood	Wood	1978.09	6	Sand & gr.	Outwash	WP	SD	5.00
83	Sec. 22, T123N, R73W	J. Voller	D	25	24	Cement Wood	Cement	2009.72	12	Clay Sand & gr.	Till, Stratified Drift	EP	SD	10.00
84	Sec. 27, T123N, R73W	E. Merkel	D	28	36	Wood	Wood	2000.29	36	Clay Sand & gr.	Till, Stratified Drift	WP	S	6.00
85	Sec. 27, T123N, R73W	A.Albrecht	D	65	12	Steel	Steel	2001.79	12	Sand & gr. Clay	Outwash Till	WP	D	15.00
86	Sec. 33, T123N, R73W	J.P. Bieber	D	50	24	Wood	Wood	1988.89	8	Clay Sand & gr.	Till, Stratified Drift	WP	S	---
87	Sec. 31, T123N, R73W	T. Leidholt	D	12	24	Wood	Wood	1951.59	18	Sand & gr. Clay	Outwash Till	WEP	DS	3.00
63	Sec. 31, T123N, R73W	A. Schuh	D	10	72 x 72	Cement Wood	Cement	1949.09	6	Sand & gr. Clay	Outwash Till	WP	S	3.00
99	Sec. 15, T123N, R73W	J.Weisjhaar	D	30	24	Wood	Wood	2012.82	30	Clay, some Sand & gr.	Till, Stratified Drift	WP	DS	20.00
68	Sec. 26, T123N, R74W	A. Leidholt	D	8	48 x 48	Wood Steel	Wood	1968.59	12	Sand & gr. Clay	Outwash Till	WP	DS	3.00
69	Sec. 26, T123N, R74W	A. Leidholt	D	8	36	Steel	Steel	1965.50	12	Sand & gr.	Outwash	WP	S	3.00

TABLE 7

WELL RECORDS (JULY-AUGUST, 1956) CON'T.

No. on Map	Location (Plate 2)	Owner or Tenant	Type of Well	Depth of Well (ft)	Dia. of Well (in)	Type of Casing	Top Edge of Casing	Height Above Sea Level (feet)	Height of Casing Above Gr. Level (inches)	Principal Water Bearing Beds		Method of Lift	Use of Water	Depth of Water Summer 1956 (feet)
										Character of Material	Geologic Source			
97	Sec. 34, T123N,R74W	A. Fleck	D	45	24	Wood	Wood	1972.09	8	Clay Sand & gr.	Till, Stratified Drift	WEP	DS	10.00
98	Sec. 35, T123N,R74W	J. Lassle	D	40	30	Wood	Wood	1926.09	24	Clay "quicksand"	Till, Stratified Drift	WP	S	7.00
58	Sec. 36, T122N,R74W	H. Brehmer	D	7	36 x 48	Wood	Wood	1906.34	30	Sand	Outwash	WP	S	3.00
59	Sec. 18, T122N,R74W	A. Buechler	D	60	24	Wood	Steel	1965.04	12	Clay Sand & gr.	Till, Stratified Drift	WEP	DS	6.00
60	Sec. 14, T122N,R74W	A. Bieber	D	12	24	Cement	Cement Wood	1933.64	12	Sand & gr.	Outwash	WP	SD	2.00
61	Sec. 1, T122N,R74W	R. Bollinger	D	15	36	Steel	43x43 Cement	1955.09	6	Sand & gr.	Outwash	WEP	DS	3.00
62	Sec. 1, T122N,R74W	R. Bollinger	D	22	24	Wood Steel	Steel	1943.69	24	Sand & gr.	Outwash	WP	S	4.00
95	Sec. 22, T122N,R74W	Mrs. C. Walz	D	60	24	Wood	Wood	1940.02	24	Clay, sand, grav. & shale	Drift Pierre shale	EP	D	6.00
96	Sec. 2, T122N,R74W	J. Lassle	D	40	30	Wood	30x30 Wood	1975.59	6	Clay "quicksand"	Till, Stratified Drift	WP	DS	6.00
88	Sec. 5, T122N,R73W	W. Thurb	D	24	30	Wood	36x36 Wood	1963.59	12	Sand & gr.	Outwash	WP	DS	5.00
89	Sec. 8, T122N,R73W	E. Schnaible	D	72	24	Steel Wood, Cmt	Cement	1963.05	12	Sand & gr. Clay	Outwash Till	EP	D	26.00
90	Sec. 7, T122N,R73W	J.F. Doerr	D	40	36	Wood Cement	Wood	1971.04	6	Sand & gr. Clay	Outwash Till	WEP	DS	15.00
91	Sec. 31, T122N,R73W	E. Haberer	D	30	18	Wood	Wood	1936.06	12	Sand & gr.	Outwash	WEP	DS	15.00
92	Sec. 6, T121N,R73W	E. Haberer	D	19	18	Wood	Wood	1921.64	12	Sand & gr.	Outwash	WP	S	10.00
23	Sec. 8, T121N,R74W	W. Arbach	D	20	48	Cement Wood	48x48 Cement	1900.00	9	Sand & gr.	Outwash	EP	DS	7.00

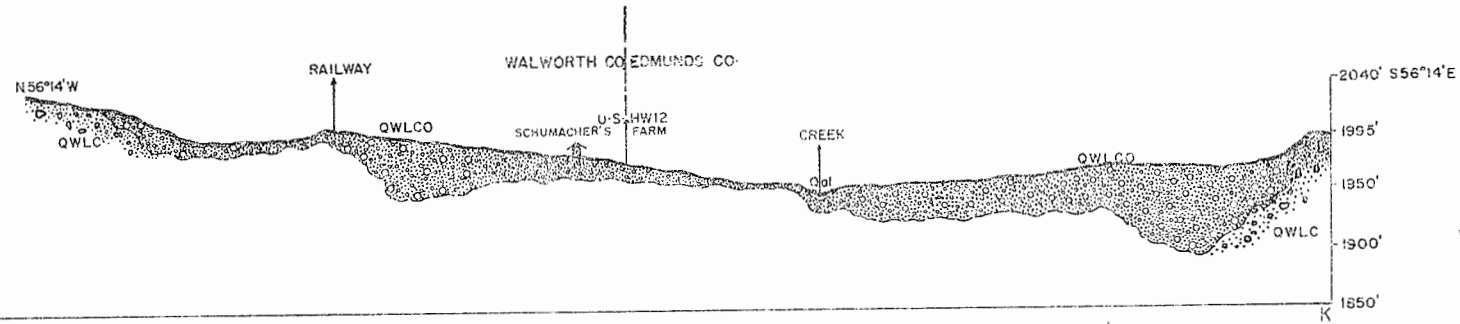
TABLE 7

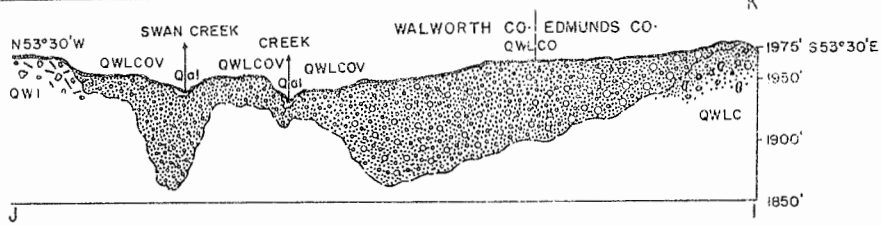
WELL RECORDS (JULY-AUGUST, 1956) CON'T.

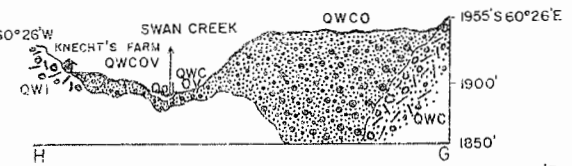
No. on Map	Location (Plate 2)	Owner or Tenant	Type of Well	Depth of Well (ft)	Dia. of Well (in)	Type of Casing	Top Edge of Casing	Height Above Sea Level (feet)	Height of Casing Above Gr. Level (inches)	Principal Water Bearing Beds		Method of Lift	Use of Water	Depth of Water Summer 1956 (feet)
										Character of Material	Geologic Source			
53	Sec. 34, T12N, R74W	J. J. Meyer	D	22	12	Steel Rock, Cmt.	Rock Cement	1911.14	16	Sand & gr.	Outwash	WP	DS	6.00
55	Sec. 11, T12N, R74W	J. Dereis	D	42	24	Wood	Wood	1936.38	6	Clay Sand	Till, Stratified Drift	WEP	DS	3.00
56	Sec. 12, T12N, R74W	R. Duenwald	D	42	24	Wood	Wood	1944.88	12	Clay Sand	Till, Stratified Drift	EP	D	6.00
57	Sec. 2, T12N, R74W	G. Knecht	D	17	36	Steel	Cement	1904.34	12	Sand & gr.	Outwash	EWP	DS	9.00
79	Sec. 18, T12N, R74W	F. Arbach	D	12	36	Cement	36x36 Cement	1885.00	24	Sand & gr.	Outwash	WP	SD	4.00
94	Sec. 31, T12N, R74W	H. Schaefer	D	90	24	Wood	Wood	1884.54	24	Clay, Sand Grav. Shale	Till, Drift Pierre sh.	WP	DS	10.00

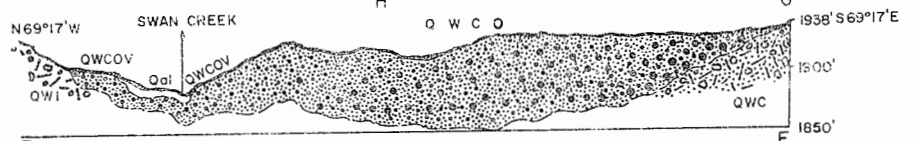
STRATIGRAPHIC CROSS SECTIONS OF THE WISCONSIN DRIFT BETWEEN HOVEN AND BOWDLE SOUTH DAKOTA

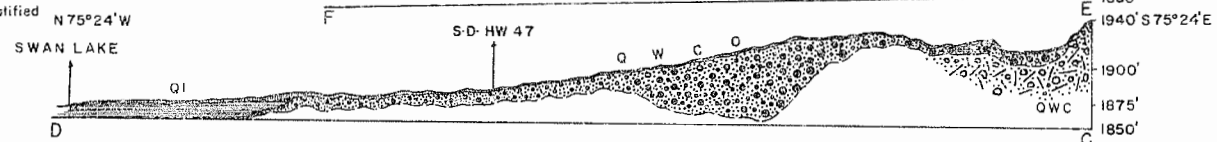
(Data Based On The Electric Soundings And Domestic Water Well Records. Sections K-L And I-J Located In The Bowdle Outwash. Sections G-H, E-F, C-D, And A-B Located In The Hoven Outwash)

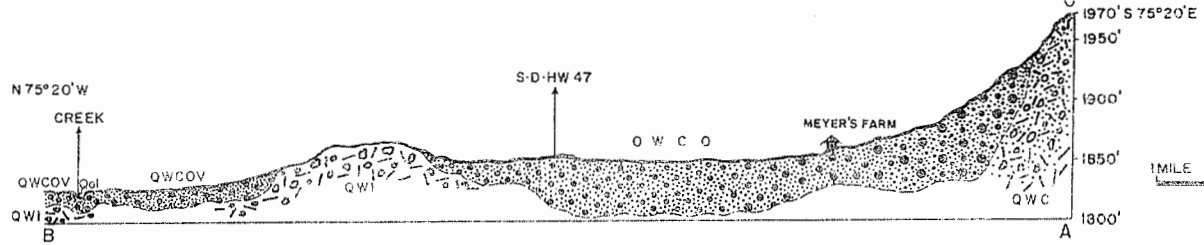












EXPLANATION

- Qal — ALLUVIUM (clay, silt and fine sand)
- QI — CUTWASH-MARGIN LAKE DEPOSITS AND ALLUVIUM (clay, silt and fine sand)
- QWLCOV — VALLEY TRAIN; QWLCO — PLAIN — LATE CARY OUTWASH (sand and gravel)
- QWLC — LATE CARY TILL (Boulder Clay with inclusions of stratified sand and gravel)
- QWCOV — VALLEY TRAIN; QWCO — PLAIN — CARY OUTWASH (sand and gravel)
- QWC — CARY TILL (Boulder Clay with inclusions of stratified sand and gravel)
- QWI — IOWAN TILL (chiefly of clay intercalated with inclusions of stratified sand and gravel)

SCALES

1 MILE 1/2 MILE 1/4 — 150 100 50 0 FEET

MARCH, 1957

PREPARED BY K. Y. LEE