A STUDY OF SOIL WATER MOVEMENT AS AFFECTED BY DRAINAGE

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Joseph Bornstein

1949

This is to certify that the

thesis entitled

"A Study of Soil Water Movement as
Affected by Drainage"

presented by

Joseph Bornstein

has been accepted towards fulfillment
of the requirements for

M.S. degree in Agr. Engr.

F. W. Peikert
Major professor

Date March 10, 1949

A STUDY OF SOIL WATER MOVEMENT AS AFFECTED BY DRAINAGE

By

Joseph Bornstein

A Thesis

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
In partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

1949

ACKNOWLEDGEMENTS

The author wishes to express his apprecia-tion to the following:

Professor Frank W. Peikert of the Agricul-tural Engineering Department for his continued assistance during the entire construction, oper-ation, and reporting of this project;

B. A. Meyers, District Conservationist, Soil Conservation Service, Saginaw, Michigan, Dennis Mcguire, Farm Service Adviser, Consumers Power Co., Owosso, Michigan, and Paul Albosta, farmer, Alicia, Michigan, for assistance and equipment;

Professor J. N. Winburne of the Written and Spoken English Department for his constructive criticism of this thesis.

TABLE OF CONTENTS

LIST OF FIGURES, TABLES, AND GRAPHS

Page

A Study of Soil Water Movement as Affected by Drainage

Introduction

Proper spacing and depth of tile and moles for land drainage was the primary objective of this project. If wider spacing would give adequate drainage considerable time and money might be saved in future tiling of farm land. More effective drainage would result if it was found that closer spacing was needed. Also of great importance was the determination of the practicability for further research of the sump and observation well method which was used. This is its first trial in Michigan and one of the few in the United States.

The soil of Saginaw County, Michigan, includes areas of Clyde clay loam which are considered to be poorly drained soils. Without artificial drainage this soil has definitely limited farming use. Properly drained, however, the Clyde loams are very productive. When the water table is lowered sufficiently it produces abundant yields of sugar beets, navy beans, onions, and forage crops. Therefore, it is to the advantage of owners of Clyde soils to be sure that their subsurface drainage systems are properly designed.

During the last two years there has been considerable interest in tiling and in plowing of mole drains on the 7500 acres of land known as the Prairie Farms in Saginaw County. Much of this area is classed as Clyde soil. In 1948 alone several miles of tile plus a limited number of mole drains were placed.

Before this investigation no attempt had been made to find the optimum spacing and depth for tile and moles for these Prairie Farms' soils. This sump and observation, or test well method was tried during May and June, 1948. The project, set up cooperatively by the Soil Conservation Service and the Agricultural Engineering Department of Michigan State College, consisted of a central sump or well from which water was pumped and observation wells. The latter were placed in two lines at right angles to each other, and the sump was located at the intersection of the lines.

REVIEW OF LITERATURE

Permeability and Drainage

Most drainage researchers have approached the problem of depth and spacing of tile and mole drains through a study of soil permeability. If there is a relatively pervious layer of soil resting on an impervious substratum, the incidence of rain causes a body of ground water to build up, bounded above by the water table. The height of the water table can be controlled by artificial drainage for given conditions of rainfall, soil permeability, and drainage layout.[3] The investigation of the shape and location of this free water surface and the nature of ground water flow to the drains is primarily a study of hydraulic head. Design of drainage structures also involves the quantity of water to be handled and the dimensions of the aquifer. The aquifer is defined as "those strata that provide a medium through which water may flow at a satisfactory rate toward a drainage facility."[1]

Although there is no generally applicable procedure for mathematical analysis of the problem, Darcy's Law of flow through porous media has been called the fundamental equation of ground water movement. This law, which follows in equation form, states that flow porous media to drains is directly proportional to the hydraulic gradient and the cross sectional area and inversely proportional to the length of flow.

$$Q = \frac{KA\ (h_2 - h_1)}{L}$$

"Q" is equal to the quantity of flow (cfs)

"K" is equal to the constant of proportionality and depends upon permeability of the medium, viscosity and density of the fluid, and the gravitational constant.

$h_2 - h_1$ is equal to the hydraulic gradient (equal to the vertical distance from the crest of the water table to the water in tile).

A is equal to the cross sectional area of flow

L is equal to the length of flow

There are other equations for permeability calculations. Some of these attempts to simplify the procedure have given inaccurate results. These have assumed that flow takes place below the level of the drain, that above the drain all streamlines are horizontal, and that the water table must intersect the drain lines.[4]

Good drainage, according to J. H. Neal, is primarily the removal of excess or injurious water. Insurance against drouth is an added characteristic. By lowering the water table early in the growing season roots can get down to a permanently moist soil. The water table for grain crops can be one foot below the surface all the time or two feet below three-fourths of the time without injury.[16] Drainage results in improvement of the physical properties of the topsoil, but the effect decreases with depth. With proper drainage bacterial action can take place which causes the decomposition of organic matter, and increases the available plant food. Also the improved ventilation aids the stabilization of colloidal material in the top layers of the soil. Porosity increases when drain spacing is decreased. Cracks, root cavities, and worm bores all develop with time. During early years of a tile system four feet deep in heavy clay, water will not drain as fast as is required; however, soils will become more open in time and much valuable plant food will become available as the subsoil is loosened.[20] It has been shown, too, that deeper tile in fairly permeable soil start to drain first when rain has saturated the subsoil and raised the water table. Deeper tile will also carry more water longer after a storm than shallow tile. There

is, however, the danger of tile or moles being too deep in a tight subsoil. In which case until the system begins to take effect crops may be drowned before the injurious water is removed.[20] To allow for this improvement with time, J. R. Haswell of Pennsylvania State College recommends that an adequate system of mains be planned first.[11] H. B. Roe's studies of drainage improvement in Minnesota are shown in Table (1).[19] Some average depth and spacings of tile drains which have been suggested are shown in Table (2).

Table 1. Changes in Permeability

Date Installed	1915	1915	1925
Topsoil	very fine sandy loam traprock fragments	clay loam	12 - 18" of peat over
Subsoil			muck
Depth	3 - 3½'	3½'	2½ - 4'
Spacing	220'	66 - 110'	125'
When wet	sticky, impervious	ditto, lacustrine clay	
Effect of time	little drainage (1921 but increasing influence to present time, 1938)	little till after 1919, increasing	Slowly increasing influence, 1925 to 1938

Coefficient of Permeability

Most attempts to solve the depth and spacing problem by mathematical formulae have made use of a coefficient of permeability while other equations have been based on moisture equivalent,[2,23] which is a function of permeability. The former drainability factor varies with

---

23 Moisture equivalent is the amount of moisture remaining in capillary pores of soil after centrifuging a saturated sample in perforated cups at a speed equivalent to a force 1000 times that of gravity.

Soil
Clay
Clay
Clay
Clay
Clay
Hardpan
Clay loam
Clay loam
Clay loam
Peat topsoil Medium sand subs
Clay loam

*Note: Germany
of Minne
season w
heaviest

22Hygroscopicity
temperature by

the moisture content of the soil, but is not a simple relationship, although it does diminish rapidly with moisture content.[4] Don Kircham refers to this constant as governing the rate of flow through the soil.[13] Its determination for application to drainage design requires measurement of permeability of disturbed soil samples and measurement and correlation of permeability of undisturbed samples taken parallel and normal to bedding planes. Comparisons must be made between laboratory and field measurements. Also an indirect method of rapidly evaluating the coefficient so it can be applied directly to drainage planning must be developed.[1] In drainage work permeability includes rate of infiltration as well as percolation below ground surface.

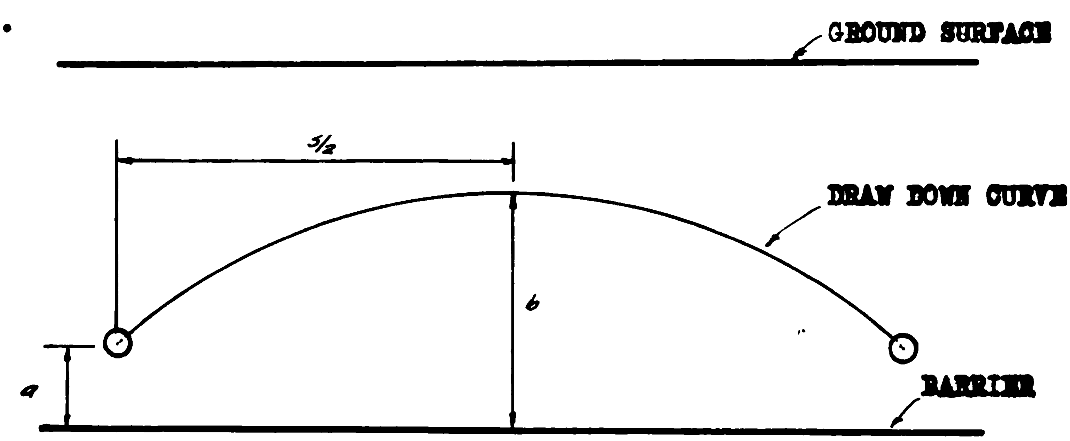
Application of Coefficient of Permeability

The use of a coefficient of permeability has been made by Aronovici and Donnan for design of a sump and observation well system and for tile spacing. Mole drain spacing may also be computed from the same formula. With the permeability of the aquifer known they have predicted draw down curves for wells and sumps. For sandy loam soil:

$$S \text{ equal to } 4P(b - a)Q$$

where S equals spacing, P the coefficient of permeability, a and b equal the limits of the draw down curve (Figure 1), and Q is the amount of water

Fig. (1).



drained from a soil profile per unit of time.[1]

When applying this formula a strata survey is first made to determine the extent of the aquifer through which percolation takes place. With piezometers the hydraulic gradient of flow is established, including pressure and direction of water movement. The piezometers will also be useful in determining the efficiency of various drainage methods tried in the future.[6] The experimental evaluation of P, the coefficient of permeability, completes the data necessary for percolation quantity computations.[1] Darcy's Law is assumed correct, the hydraulic potential in a vertical direction is considered constant, and horizontal is assumed not to occur in the capillary stratum of sandy soil. Aronovici and Donnan emphasize the danger of trying to simplify the solution of field problems with laboratory procedure.[9]

Piezometers and Soil Water Flow

Discussing the piezometers as applied to ground water studies in relation to drainage, Christiansen,[7] as quoted below, finds that the path of a drop of soil water and the "shape of the equipotential surfaces which are everywhere normal to the direction of flow will depend to a very large extent upon how permeability of a soil varies with depth.

> Ground water piezometers offer a means of studying the soil water flow conditions in the field. With piezometers one can determine ground water potential at any point in the soil mass. These ground water potentials are everywhere proportional to hydraulic head or height to which water will stand in an open manometer tube. By making simultaneous measurements of hydraulic head at a number of points in the soil mass in the same vertical plane one can determine the components of the hydraulic gradient and direction of flow. Plotting the equipotential lines on a vertical section the ground water flow pattern is obtained. It should be recognized that these equipotential lines are the intersections of the equipotential surfaces and an arbitrary vertical plane and

> that unless this vertical plane is selected to coincide with the direction of flow the hydraulic gradients as indicated on the flow pattern are not the true gradients but only the components along this plane.

Thus piezometers are satisfactory for determining general flow patterns and show promise of being aids to determining the actual soil permeability.

Other Draw Down Investigations

Sven Norling,[17] reporting on his depth and spacing experiments at Albert Lea, Minnesota in 1921-23 feels that the soil survey should go to a depth of seven or eight feet for all drainage work. His project was similar to this Saginaw County drainage study with observation wells spaced between tile lines. Wells were dug six to ten feet deep, lined with five inch tile, and covered with a wooden block. During the three seasons of investigation complete rainfall records were kept. Accurate soil profiles were taken between each tile line. On heavier soils deep drainage was needed to increase percolation, to limit the runoff, and to protect the lower lands from flooding.

Neal's field studies, similar to this investigation of soilwater movement as affected by drainage, and Aronovici and Donnan's work show that flow toward drains occurred only when the hydraulic head was greater than five feet per 100 feet, varying somewhat with soil and tile spacing. Fluctuations in test well level and tile flow were attributed to precipitation, transpiration, evaporation, runoff, and deep seepage. Neal used six foot observation wells of four and five inch tile spaced five and ten feet apart.[16]

Moisture Equivalent and Soil Water Movement

Based on the field work described above and the formulae of Rothe,[16] Neal developed equations for rate of water table decline and tile depth and spacing. Rothe's equation

$$E = \frac{117}{W} + \frac{638}{W_e}$$

based on soil hygroscopicity was not a readily adaptable index for engineers working with farmers. In Rothe's formula

E equals spacing; in meters,

W equals hygroscopicity, and

W_e equals percent of particles less than 0.002 mm. minimum diameter at 1.25 meters.

Instead Neal worked from moisture equivalent, which though not easily determined in the field, could be related to both soil plasticity and clay content. He found that the plasticity and clay content of soil have definite percentages of moisture equivalent when scaled together on the nomograph. The percent of clay was determined by the hydrometer. Also, Mr. R. L. Patty of South Dakota State College states that soil drainability depends largely on particle size and clay colloid content. A soil having 35% colloidal clay has average drainage qualities, while, at 45% it has poor drainability.[18] According to Neal the average rate of drop of ground water midway between tile is found from the equation

$$R_d = 0.165\ S$$

where R_d is the rate of drop of ground water midway between tile, in feet. S is hydraulic slope. Neal also reports that

$$R_d = K(T_s)^{0.7}$$

K is a drainage factor depending on soil and hydraulic slope. It is measured by moisture equivalent when a definite slope is considered.

T_s equals tile spacing in feet.

Graphs in Neal's report relate K to lower and upper plastic limit, moisture equivalent, and clay content. In equation

$$T_s = \frac{12000}{(M_e)^{1.6}} \quad \text{and}$$

$$T_d = \frac{17.5}{(M_e)^{0.5}} \quad ,$$

M_e is moisture equivalent, and

T_d equals tile depth in feet.

The reasoning behind the above formulae is that the larger the pores the faster the soil water movement will be; therefore the spacing and the depth of drain lines is a function of non-capillary porosity. Pore space is, of course, a function of moisture equivalent; therefore, Neal says, it is reasonable to expect drain spacing and depth to be directly influenced by the moisture equivalent, a factor more easily determined than pore space. Combining the known or desired values it is possible to vary drain placement to give different rates of drop of water table, within the range of 0.2 to 2.0 feet per day.[16] Results of the application of this method can be checked with results from other areas with accuracy and the method is readily applicable by field engineers.

Electrical Analysis in Drainage Studies

The difficulties of mathematical analysis of field drainage problems are at present unsolvable, according to Mr. E. C. Childs[5] of the Cambridge University Agricultural Experiment Station, Cambridge, England. Progress has been made with electrical analogy, since the equation of ground water flow to parallel drain lines is also the equation of two-dimensional flow of electricity in a sheet conductor cut to the shape of the soil cross section. Three sets of experiments are presented by Mr.

Childs. In one he shows how the water table is lowered by increasing drain diameter, and by decreasing tile spacing. A second investigation gives the relation of water table height to rate of rainfall. The water table midway between tile lines is at higher elevations for greater rainfall intensities. The third study determines the effect the impermeable soil layer below the drains has on tile efficiency. The influence of the hardpan on drain lines varies with its depth below the lines. It is shown that the well known formula giving an elliptical water table section is not in agreement with the requirements of the theory of flow through soil from higher to lower elevation. In later studies of ground water movement affected by drainage using electrical analogues, Mr. Childs found that observation wells may cause significant disturbance to the water table and to soil moisture seepage, particularly at the point of examination. He also found that lowering the water level in drains alters the shape of the water table and lowers its height at the midpoint by an approximately equal amount, that an open ditch is more efficient than the same ditch piped and filled in, and that neglecting the capillary fringe causes little error in estimating the position of the water table. The capillary fringe is the distance above the water table of a given soil that water will move upward by capillary action.[5]

Summary of Previous Investigations

Depth and spacing research and subsurface drain design require consideration of several factors. Some of those considered are outlined below.

1. The texture of the soil is one of the most important factors.[17]
2. Neither intense nor long-continued rainfall are themselves good indeces of needed capacity of a subsurface drainage system.

3. Heavy subsurface runoff, soon after rainfall, is not always required but its necessity depends on soil and subsoil texture, previous soil moisture content, and the season relative to plant growth.

4. Proper determination of the maximum required effectiveness of a tile system should generally be based on soil moisture and runoff conditions present during the early weeks of the growing season.

5. Effectiveness of a tile system as crop protection and growth stimulator is dependent on rate of drop of the watertable at the midpoint between lines. This rate depends upon texture and moisture condition of soil when drained and on depth and spacing of tile. Previous discussion has shown that the rate of drop of the water table and the depth and spacing of tile are definite functions of moisture equivalent, plasticity, and clay content of soil considered.

6. Methods of design require checking on different soils under various climates. Research is needed to determine rate of water table lowering for other areas.

7. Results of depth and spacing formulae should be comparable to recommendations of American drainage engineers and investigators.[16]

EXPERIMENTAL WORK

The project outlined called for determination of the "gradient of the water table in a given soil."[25] The central sump, sump pump, and radiating observation wells were installed in a typical soil at a suitable location in the area known as the Big Prairie in Saginaw County, Michigan. Measurements of the water level in the wells were made periodically while the pump was in operation. From the above measurements it was proposed that proper depth and spacing of tile or moles could be determined for the particular soil. The bases for the sump and test well system for water table measurements were the recommendations of Mr. L. A. Jones, Chief, Division of Drainage and Water Control, Soil Conservation Service, Research Division, as outlined by him in late 1945.

Soil Description

On May 13, 1948, the topsoil was found to have 93-112% moisture by dry weight. The tight yellow clay subsoil also appeared saturated although the moisture content was only 39-38% of dry weight. Results of the size particle analysis by the Department of Soils, Michigan State College showed the clay subsoil was 12.7% sand, 21.6% clay, and 65.6% clay. In the soil profile the clay was located at 15 inches, overlain by a black, mucklike topsoil, and the change from muck to clay was quite marked.

The description of Clyde clay loam as given by J. A. Bonsteel[3] in the United States Department of Agriculture Department Bulletin #141 and by the soil survey report of Saginaw County is verified by the experimental conditions.[15] According to these publications Clyde clay loam and Clyde clay loam, mucky phase, were formed through redeposition of fine

25 Appendix, P. 42.

grained glacial materials in the beds of extinct glacial lakes and particularly in depressed areas where natural drainage conditions were very poor and where partially decomposed organic matter accumulated abundantly.[3] The mucky phase differs from the typical soil in having a surface covering that is as much as 12" in thickness. Where the experiment was located had 15" of muck. This is close enough to specifications to be included in the Clyde series. As mapped in Saginaw County the Clydes are restricted to the natural flood plain of the rivers, where adverse natural drainage and water conditions necessitate large expenditures to reclaim the land for crops. Nearly 90 percent of the total area of this soil supported a cover of marsh grass and sedge after it was uncovered by glacial lake waters.[15] Where substantial amounts of organic matter have accumulated the clay loam is classed as mucky phase. Such a condition is closely related to the typical soil. The topsoil is friable and easily worked when not too wet, for such fine textured soil. Lime Carbonate content is generally between one and two percent. The subsoil, a depth of 36 inches, is clay of light gray to yellow mottled color with some gravel. It is no exaggeration to add that it is a dense sticky material when wet.

Project Construction

Previous to setting up the project in the field, numbered marker stakes and observation well covers were made. A pump shelter was constructed and a battery operated depth measuring device was designed and assembled. Tools used at the Prairie Farms are shown in Figure 2. A tile puller, the second item from the right, was simply a threaded bent piece of pipe about 4" long that could be attached to the handle of the post hole auger, with the blade removed. When disassembling the project

Figure 2. Tools Used For Project Construction

Figure 3. Observation Well Electrical Depth Measurer

it was lowered into an observation well, hooked under the bottom tile, and withdrawn with all the tile.

The depth measuring device shown in Figure 3 depended on the electrolytic action of the soil water to complete the circuit. A $2\frac{1}{2}$ volt dry cell supplied the current to a Model T Ford Spark coil and an electric fence light. When the measuring rod was lowered into a well the wires at the lower end of the rod, making contact with the water, completed the circuit. The light would then be illuminated. A six foot scale attached to the rod was read directly against the side of the tile nearest the marker stake. (An ordinary six foot steel tape was also tried and found practical for this purpose. As the water level receded, however, it became more and more difficult to see just when the lower end of the tape reached the water surface.)

Preliminary work at the Prairie Farms was done during the second half of April, 1948, just after the flood waters had receded enough to leave the land of the project area visible. The poles were erected and powerlines were strung to the pumpsite (Figure 4). A wooden box open at both ends was constructed in the $2\frac{1}{2}$ x $2\frac{1}{2}$ x $5\frac{1}{2}$ foot sump to prevent caving of the sides (Figure 5). The pump shelter (Figure 6) was placed over this central well and the $\frac{1}{4}$ H.P. Flint and Walling sump (Figure 7), equipped with an automatic float switch, was hung from its roof. Three sections of hose totaling 150 feet were attached to carry the water away from the immediate drainage zone. By having the pump suspended from the roof of the shelter there was no possibility of it digging itself into the ground (Figure 5). The pump was lowered into the sump enough to reduce sump water level to approximately five feet below the ground level. At the same time the twenty-eight test wells were sunk and tile placed in them up to the ground surface (Figures 7 through 11). Ends

Figure 4. Electric Poles Wired to the Sump Location

Figure 5. Sump, Showing Pump Outlet, Supporting Rope, and Sump Box

Figure 6. Pump Shelter Showing Power Line Lead-in and Water Discharge Hose.

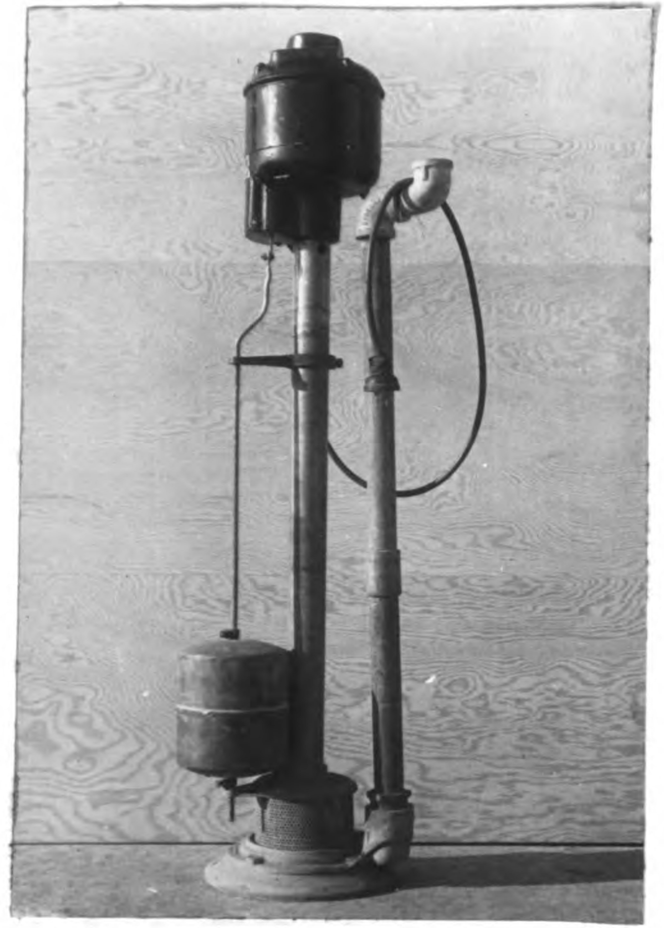


Figure 7. Flint & Walling $\frac{1}{4}$ HP Sump Pump with Automatic Float Switch.

of each tile were chipped slightly to insure easy flow of water into the wells. The topsoil was packed just tightly enough around the tile to hold them in place.

The depth of the test wells varied from three to five feet. Going outward from the sump the first three wells were five feet deep, the next three were four feet, and the last one was three feet in depth. The lines of wells were run arbitrarily northeast, southeast, northwest, and southwest from the sump, and were, starting from the sump, spaced at 5, 5, 10, 15, 25, 40, and 32 feet apart (Figures 12 and 13). As the wells were dug and tiled the numbered stakes were placed next to them and cover was placed over each one. Covers later proved to be of no particular value. Two additional wells were dug and tiled, one at 330' north and one at 330' east of the sump to serve as control wells. It was hoped that these would show a different rate of drainage from that recorded in the observation wells. In both of these outer wells, however, the water level receded at a rate equal to the drainage in the sump area. A rain guage set into the ground within the radius of the observation wells (Figure 4) showed no precipitation during operations.

The levels of the tops of all the wells, except the two at 330 feet, were taken in relation to a bench mark. Readings of water level in the observation wells were made at least three times a day from May 14 through June 3rd, except May 30, when only one measurement was recorded. The depth readings, in inches below the top of the tile, were converted to feet and tenths and substracted from the elevation of each tile in order to plot the draw down curves.

Draw Down Curve Analysis

Pumping began on May 14, 1948. The draw down curves that resulted

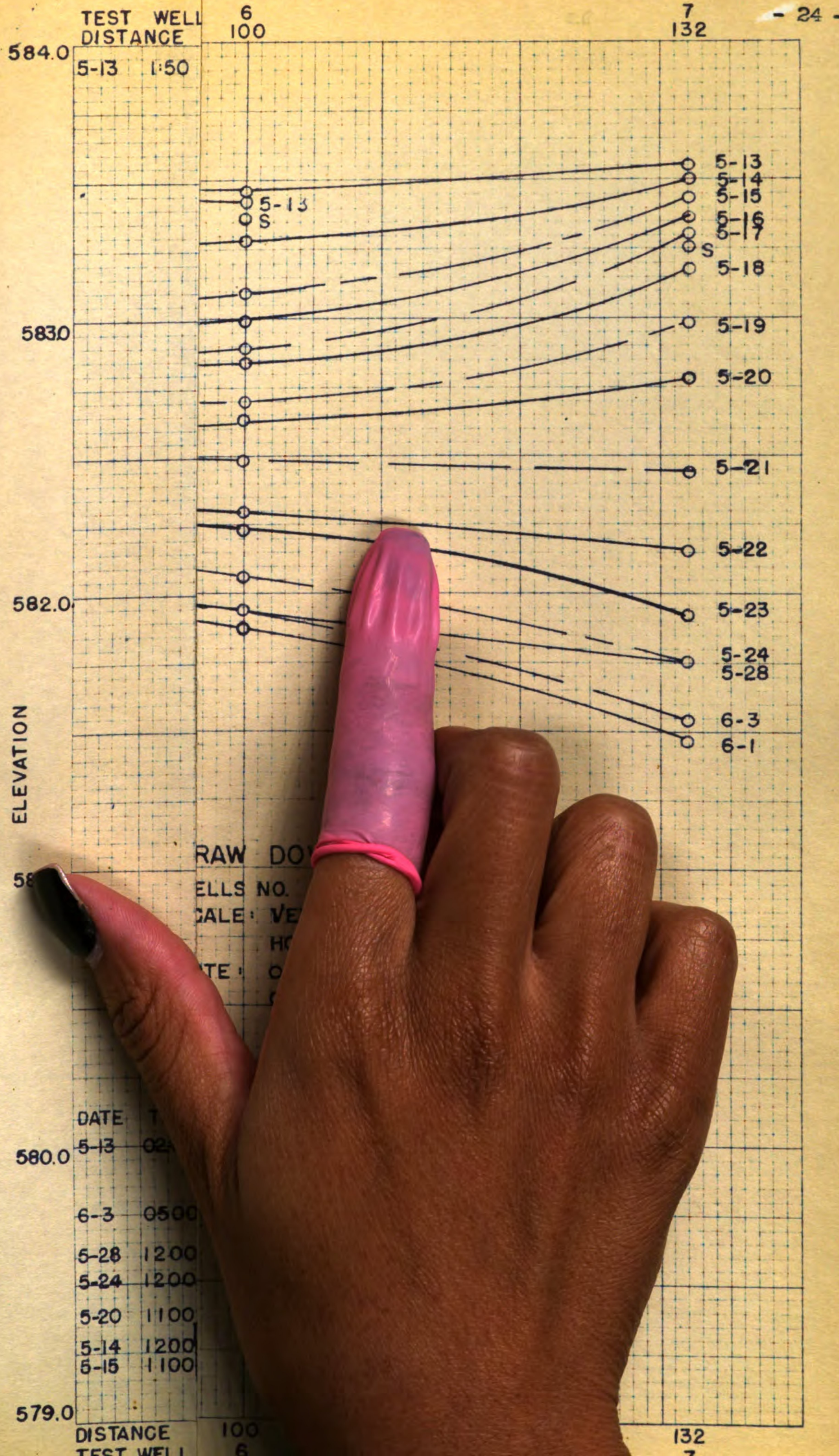
Figure 8.   Uncompleted Observation Well

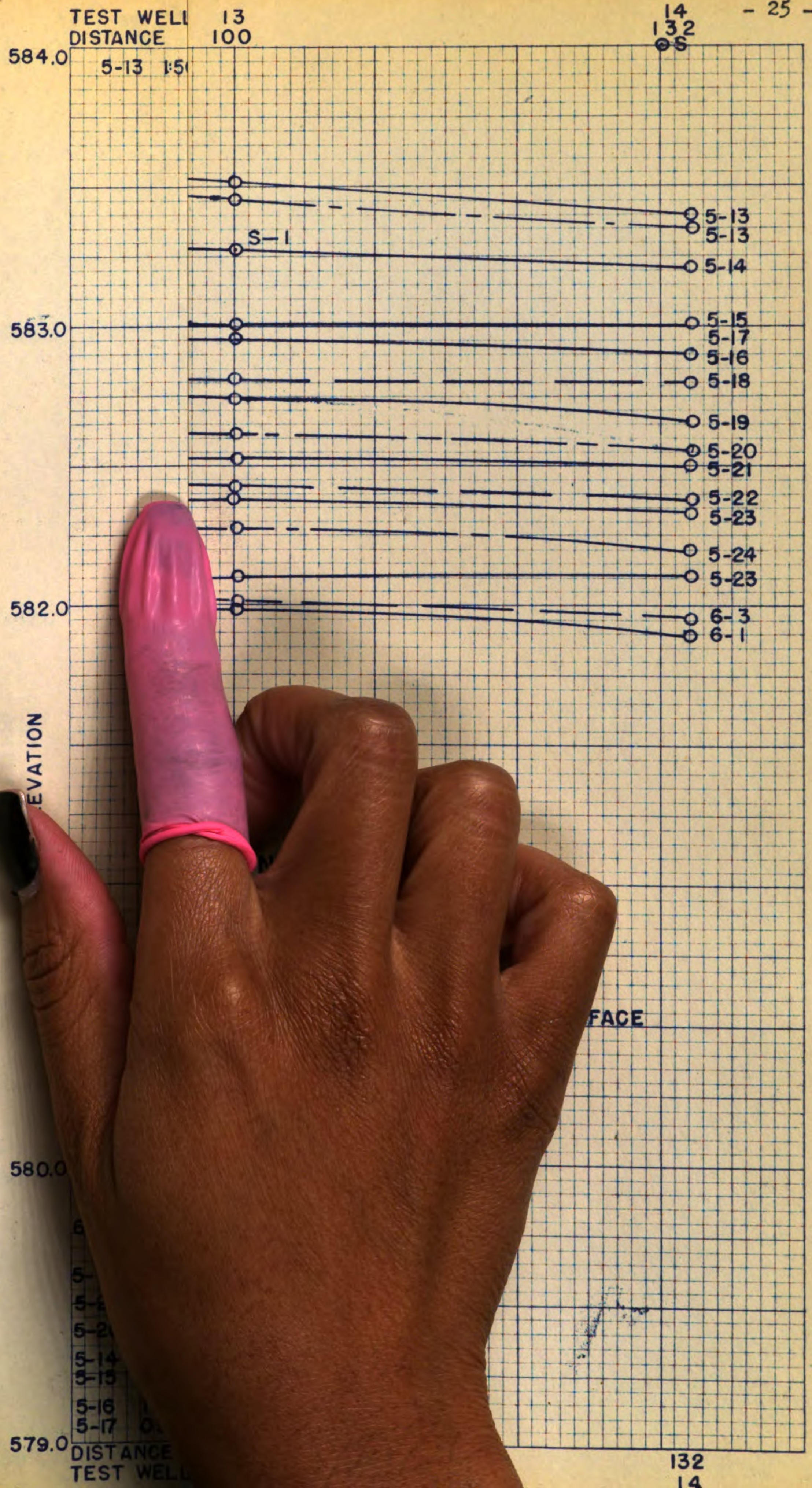
Figure 9.   Completed Observation Well

Figure 10. Project Area Looking Southwest.

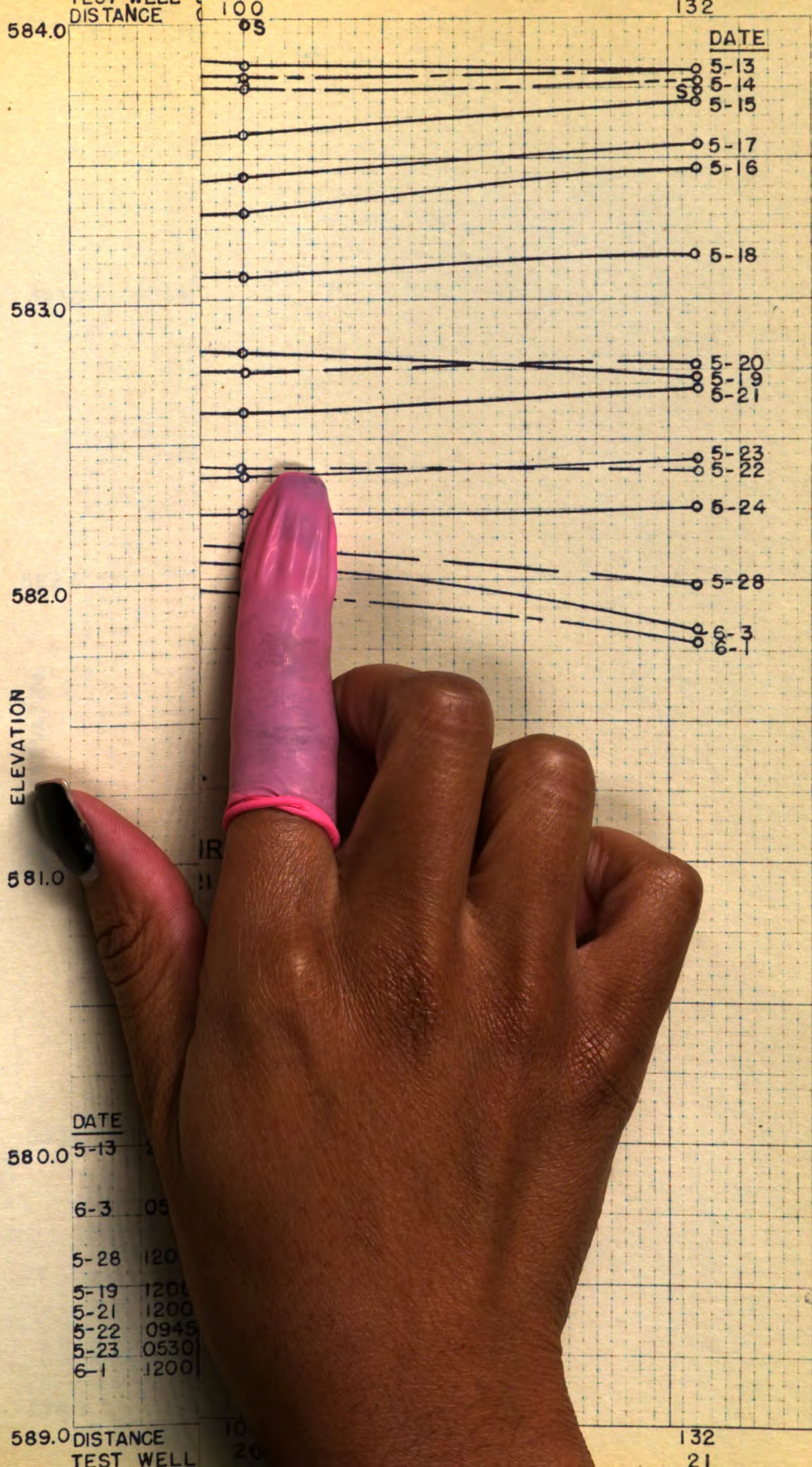
Figure 11. Project Area Looking Northeast.

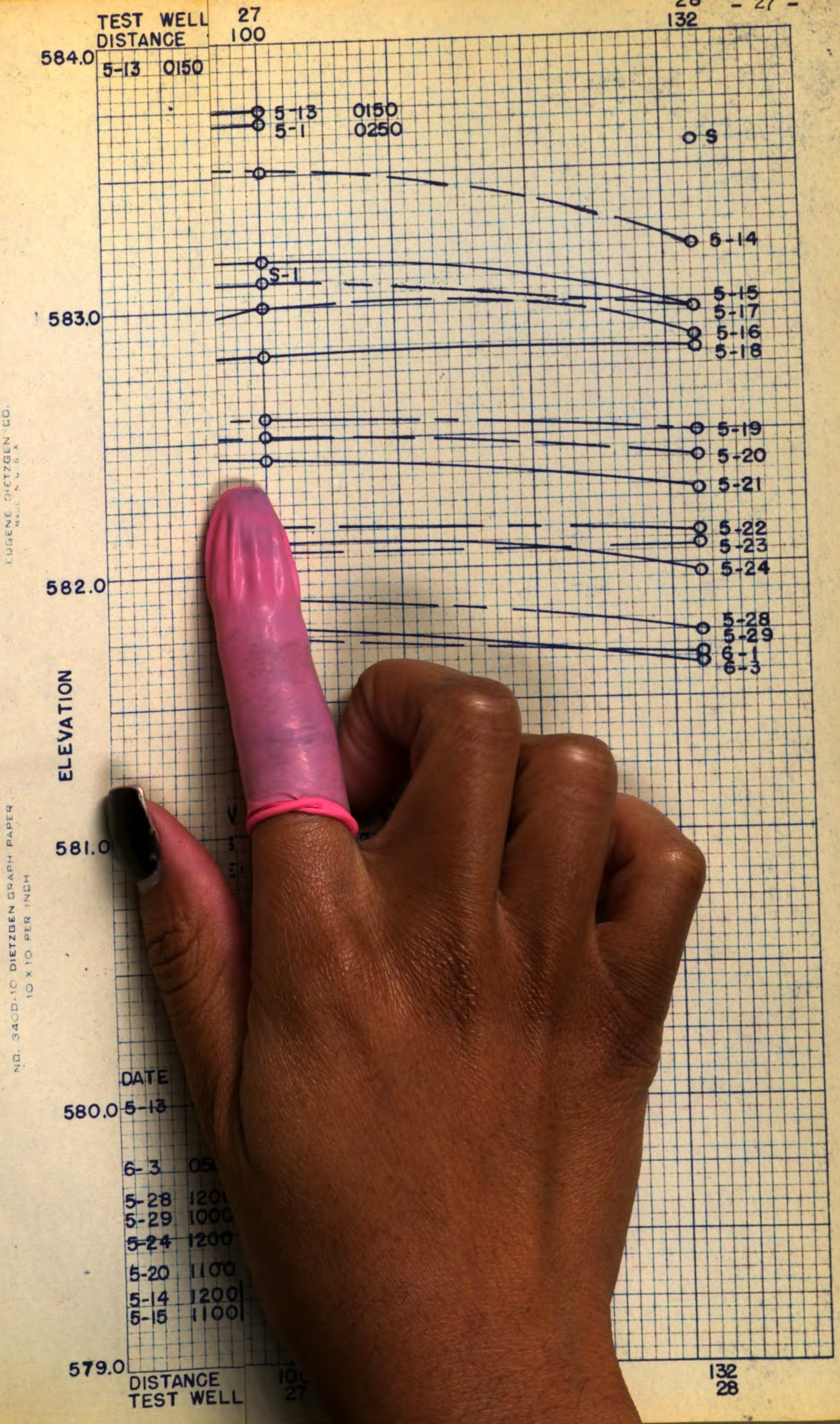
Figure 12. Rain Guage in Observation Well Area.

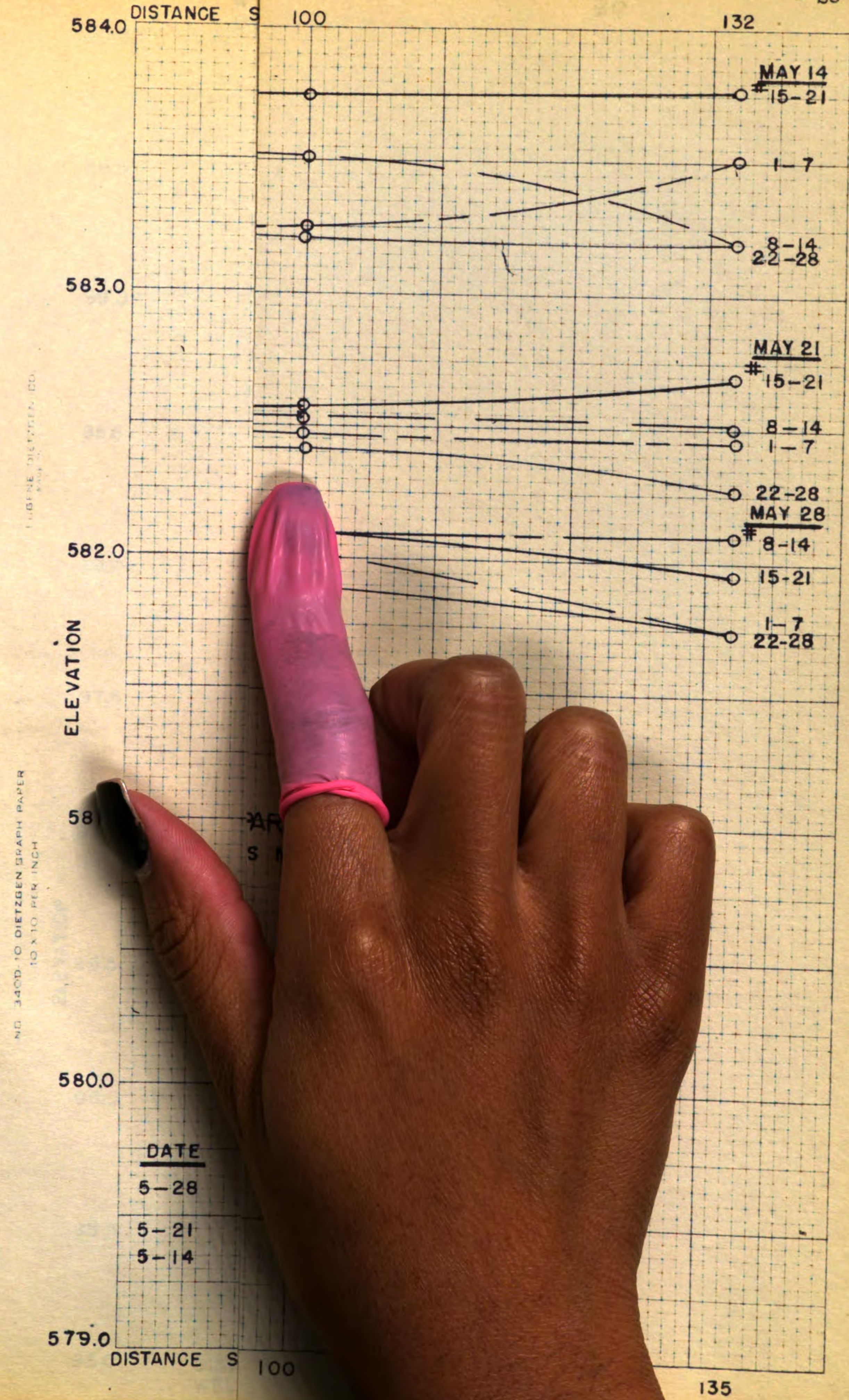

TEST WELL 6 7
DISTANCE 100 132
584.0
583.0
582.0
580.0
579.0
ELEVATION
5-13 1:50
5-13
S
5-13
5-14
5-15
5-16
5-17
S
5-18
5-19
5-20
5-21
5-22
5-23
5-24
5-28
6-3
6-1
RAW DO
ELLS NO.
ALE: VE
HO
TE:
DATE
5-13
6-3 0500
5-28 1200
5-24 1200
5-20 1100
5-14 1200
5-15 1100
DISTANCE 100 132
TEST WELL 6
NO. 340D-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
EUGENE DIETZGEN CO.

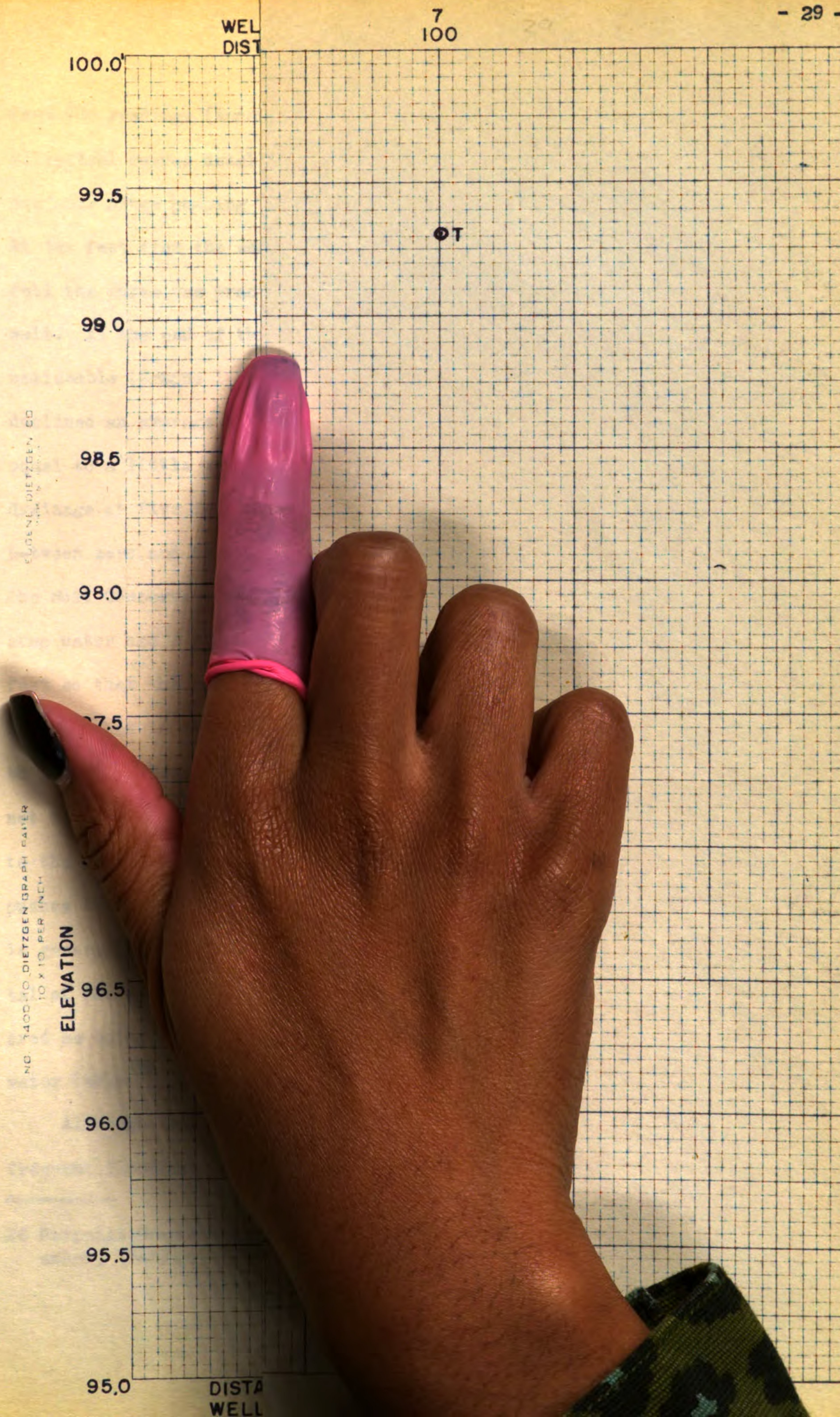


TEST WELL
DISTANCE
13
100
14
132
584.0
583.0
582.0
580.0
579.0
S-1
5-13
5-13
5-14
5-15
5-17
5-16
5-18
5-19
5-20
5-21
5-22
5-23
5-24
5-23
6-3
6-1
132
14


TEST WELL
DISTANCE
20
100
21
132
DATE
5-13
5-14
5-15
5-17
5-16
5-18
5-20
5-19
5-21
5-23
5-22
5-24
5-28
6-3
6-1
584.0
583.0
582.0
581.0
580.0
589.0
ELEVATION
DATE
5-13
6-3
5-28
5-19
5-21 1200
5-22 0945
5-23 0530
6-1 1200
DISTANCE
TEST WELL
132
21


TEST WELL 27 28
DISTANCE 100 132
584.0
583.0
582.0
581.0
580.0
579.0
ELEVATION
5-13 0150
5-1 0250
S
S-1
5-14
5-15
5-17
5-16
5-18
5-19
5-20
5-21
5-22
5-23
5-24
5-28
5-29
6-1
6-3
DATE
5-13
6-3
5-28 120
5-29 100
5-24 1200
5-20 1100
5-14 1200
5-15 1100
DISTANCE 132
TEST WELL 28
EUGENE DIETZGEN CO.
NO. 340D-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH


DISTANCE S 100
132
584.0
MAY 14
#15-21
1-7
8-14
22-28
583.0
MAY 21
#15-21
8-14
1-7
22-28
MAY 28
#8-14
15-21
1-7
22-28
582.0
ELEVATION
NO. 340D-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
580.0
DATE
5-28
5-21
5-14
579.0
DISTANCE S 100
135


WEL
DIST
7
100
100.0'
99.5
T
99.0
98.5
98.0
96.5
96.0
95.5
95.0
ELEVATION
DISTA
WELL
EUGENE DIETZGEN CO
NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

from the readings (Appendix) show the usual trend, though not the smooth elliptical curves usually shown in texts (Graphs 1 through 5). Within one hour after pumping began there was rapid drainage close to the sump. At ten feet from the sump the curve had leveled off. Beyond the ten foot well the curve was practically level even out to the last observation well. At the end of three weeks of operation similar leveling off was noticeable (Graphs 1 through 5) although the entire water table had declined an average of about one and one half feet. This decline was equal to a little more than "A" horizon thickness. There was good drainage at five feet from the sump, a condition which changed rapidly between zero and ten feet out, giving curves similar to those plotted by the Soil Conservation Service at Blacksburg, Virginia.[26] The removal of sump water had a great effect on the water movement at 5, 10, and 20 feet so that the curve to the last point is steep. More exactly it might be said that in three weeks the water in the surrounding area had a chance to percolate downward to replace that removed by the pump. It should not be inferred that water necessarily flowed along the draw down curves to the sump. Instead the effect seemed to be that the hydraulic head pushes the water down by the shortest, most easily accessible route. It is generally stated by experienced investigators that flow is horizontal at the water table to the tile or sump. Percolation flow is considered as being as vertical as the soil structure will allow, down to the water table.[21]

Although the original or natural condition of this soil was one of frequent flooding, high water table, and very poor drainage, about three-

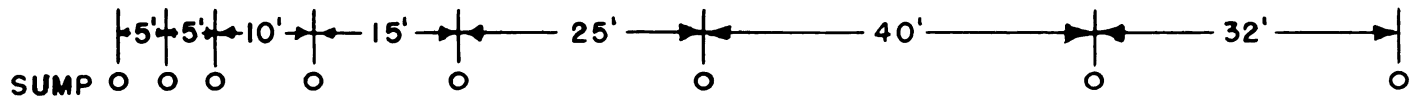
---

26 Personal Communication from T. W. Edminster, Project Supervisor (November, 1948).

⊙ 7.

2

28. ⊙



GRAPH 8. PROFILE OF OBSERVATION WELLS

WELLS 1—7 SCALE 1"— 20' 0"

fourths of its total area has been protected from overflow by the Prairie Farms' dikes and drainage pumps. Most of the area has also been ditched and about one half of it has been tiled. In spite of such drainage facilities three to five feet of water covered the project site for several weeks in March and April, 1948, previous to setting up the sump and observation well system.

The Farms' drainage ditches were pumped down before the drainage investigation was set up and again on Sunday, May 23rd. After the second draining, water movement from the land was too slow to fill the drainage channels more than half full before the project was terminated on June 3.

The first impression gained from a survey of the draw down curves (Graphs 1 through 5) is that the muck topsoil is drained much more rapidly than the tight clay underneath. There is a noticeable decrease in the rate of soil water movement after the water table is down to one and a half feet below the surface. The curves are more closely spaced, vertically, after May 23rd than up to that time. Drainage at the same time tends to be toward the sump only from a distance of 60 feet. Earlier the curve gradient extended downward from 132 and then 100 feet from the pump. The total drop in water table from May 14 to 31 showed some variance as seen from the Graphs 1 through 4, both from well to well in the same line, as expected, in addition to the variation between comparable wells in each of the four lines (Graph 5). A greater total decline in water level was found in wells #15 to #21 (except #16 and #21) than any of the others. This row was in the direction of the main drainage channel and was on land 0.75 feet above #7, 0.15' above #28, and 0.25 feet below #14. Moisture along the #15 to #21 row of wells had further to go to reach a level with the surrounding area. Then, too the ditch south of

the project could have some draw down effect at least on the outer two or three wells. What still seems unexplainable is that well #7 drained to a lower depth than any of the other outer observation wells. It was out in the field toward some buildings northwest of the sump, but much further from the ditches than either #28 or #14. A part of the drainage was, of course, due to the natural percolation downward through the soil. Possibly the area around #7 had the most pervious subsoil of the area under investigation. This well #7 was in a temporary 40 x 75 foot ellipse-shaped puddle of water until seven days after pumping began. The percolation of water in the 330' wells progressed at a faster rate than the observation wells during the last week and a half of pumping. The two 330' ones were not put in until that time. Neal commenting on similar action on other soils finds that the drop of ground water table due to deep percolation and transpiration is sometimes greater than movement in tile lines. It is difficult to separate water movements as they all work simultaneously.[16]

Observation Wells between Tile Lines

In an effort to see how this Clyde soil reacts under long time drainage a line of test wells was also placed at right angles to a five inch tile line which was at least ten years old (Figure 15). The sump was dug at the tile line and wells similar to those at the main project were spaced 3, 5, 10, 20, 35, 64, and 100 feet from the tile line. Water level readings were taken once every other day from May 22 through May 31, 1948. In graph #6 the draw down curves plotted from the data show the improvement in drainage with time. The curves have fairly uniform slopes unlike those of graphs 1 through 5. This shows that drainage in the tiled land has been more rapid than in the sump and observation well area.

The soil profile at these tile line observation wells was somewhat different from that in the untiled land. The topsoil blended into the substrata. Here the top material was more completely decomposed, although the top one foot closely resembled the muck of the uncultivated land. No crops had recently been taken from the area in the vicinity of the sump and test wells. Between the "A" horizon and the clay was 0.8 feet of loamy clay and then the tight pale yellow clay. The water table at the tile line was four feet below the surface.

Figure 13. Sump and Observation Wells Between Tile Lines

CONCLUSIONS

It is probable that draw down curves of soil water movement can be plotted from the sump and observation well method of investigation. From this study it seems clear that a properly plotted draw down curve will indicate the proper depth and spacing of tile to give the desired lowering of the water table midway between the drain lines. The results of this experiment do not, of course, give a final answer even for Clyde clay loam. A number of variables have not been considered. This is rather a trial of one method which shows possibilities for more complete study. If such a project were run for a period of years as is being done at Blacksburg, Virginia and at Clemson, South Carolina accurate depth and spacing data for tile and moles should result. Allowances should be made for a margin of improvement when using the data from this project, since drainage on tiled land and, on land drained by the sump method should improve with time. It is known that when tile are still working, drainage and therefore tilth will continue to develop even after ten or more years.[19]

RECOMMENDATIONS

To give more reliable results several improvements also might be applied to the method used here, in addition to increasing the time of operation. The project could be set up at several points in an area needing tile. More complete soil tests should be made, particularly as to permeability and to soil profile at each observation well. The Soil Conservation Service has outlined a standard soil permeability procedure that could be used.[22] More detailed size particle analyses should be made. By plotting a detailed soil profile along with the draw down curves the effect of the profile on drainage characteristics could be studied. Additional equipment that would prove useful includes a water meter to record total flow from the sump and automatic water level recording guages. The cost of the latter item makes it impractical for a short time, graduate subject.

Thus results from this or similar investigations could be applied only to the project area or to land having comparable soil conditions. Comparisons should, however, be made with studies from other soil types in an effort to reach the final objective -- the equation that can be used for determining depth and spacing of tile and mole drains on any agricultural land.

In conclusion it should be emphasized that this has been a study of method as well as an attempt to get closer to solving the problem of proper depth and spacing of tile and mole drains.

BIBLIOGRAPHY

1. Aronovici, V. S. and Donnan, W. W., "Soil Permeability as Criterion for Drainage Design," American Geophysical Union Transactions, vol. 27, (1946).

2. Baver, L. D., Soil Physics, John Wiley & Sons, New York, (1940).

3. Bonsteel, J. A., The Clyde Series of Soil, U. S. Department of Agriculture, Departmental Bulletin #141, (1914).

4. Childs, E. C., "The Water Table, Equipotentials, and Streamlines in Drained Land," Soil Science, vol. 56, (1943).

5. Childs, E. C., "Water Table in Drained Land," Soil Science, vol. 59, (1945).

6. Christiansen, J. E. and Pillsubry, A. F., "Installing Ground Water Piezometers by Jetting for Drainage Investigations," Agricultural Engineering, vol. 28, (September, 1947).

7. Christiansen, J. E., "Ground Water Studies in Relation to Drainage," Agricultural Engineering, vol. 24, (October, 1943).

8. Diserens, E., "Means for Determining of Mode of Action of Drainage Systems," International Congress of Soil Scientists, Transactions, Oxford England, vol. 3, pp. 45-65 (1935).

9. Donnan, W. W., "Model Tests for a Tile Spacing Formula," Soil Science Society of America, Proceedings, vol. 11 (1946).

10. Gardner, W., "Influence of Soil Characteristics on Drainage and Irrigation Practices," Soil Science Society of America, Proceedings, vol. 1,(1936).

11. Haswell, J. R., "Principles of Tile Drainage," Agricultural Engineering, vol. 21, (August, 1940).

12. Israelsen, O. W., "Application of Hydrodynamics to Irrigation and Drainage Problems," (abstract), Agricultural Engineering, vol. 8, (November, 1927).

13. Kirkham, Don, "Proposed Method for Field Measurement of Permeability Below the Water Table," Soil Science Society of America, Proceedings, vol. 10, pp. 58-68 (1940).

14. Lyon, T. L. and Buckman, H. O., The Nature and Properties of Soil, The Macmillan Co., p. 153 (1943).

15. Moon, J. W. and others, Soil Survey of Saginaw County, Michigan, Bureau of Chemistry on Soils, U.S.D.A., (1938).

16. Neal, J. H., Proper Spacing and Depth of Tile Determined by Physical Properties, Minnesota Station Technical Bulletin #101, (1934).

17. Norling, Sven A., "Subsoil as a Factor in Drainage Design," Agricultural Engineering, vol. 8, pp. 311-319 (November, 1927).

18. Patty, R. L., "How to Determine the Drainability of Soils," Agricultural Engineering, vol. 25, p. 221 (June, 1944).

19. Roe, H. B., "Some Soil Changes Resulting from Drainage," Soil Science Society of America, Proceedings, vol. 4, p. 402 (1939).

20. Schlick, W. J., Spacing and Depth of Laterals in Iowa, Engineering Experiment Station Bulletin #52, (October 16, 1918).

21. Schlick, W. J., Theory of Underdrainage, Iowa State College Engineering Experiment Station Bulletin #50, (September 25, 1918).

22. Uhland, R. E., Soil Permeability, United States Department of Agriculture, Soil Conservation Service, Washington, D.C., mimeographed (October 13, 1948).

APPENDIX

Proposed Drainage Investigations in Saginaw County

Soil Conservation Service

and

Agricultural Engineering Department

Michigan State College

Cooperating

The subjects to be investigated on a cooperative basis are the following:

I. MOLE DRAINAGE

II. DETERMINE GRADIENT OF WATER TABLE IN A GIVEN SOIL AS IT AFFECTS TILE AND MOLE SPACING.

At some suitable location in the Big Prairie or Little Prairie, install sump with electric pump and observation wells radiating out in all directions. Obtain a site having typical soil and near source of electric power.

Measure the water level in the observation wells at different distances from sump when the pump is in operation.

From above measurements, determine proper spacing for tile or moles in that particular soil.

DATA SHEET

	Date Time	5-13 1:50pm	5-13 2:50pm	5-14 12:00n	5-15 11:00am	5-16 11:00a	5-17 9:30am	5-18 9:00am
Observation Well No.	Distance Sump to Well (ft.)	Elevation of Water in Wells						
1	5	-	-	582.94	582.75	582.65	582.60	582.21
2	10	583.74	583.47	583.12	582.88	582.77	582.83	582.65
3	20	583.67	583.57	583.21	582.96	582.83	582.90	582.73
4	35	583.62	583.54	583.25	583.02	582.88	582.44	582.79
5	60	583.56	583.50	583.23	583.00	582.88	582.92	582.88
6	100	583.47	583.43	583.29	583.08	582.90	583.00	582.83
7	132	583.53	-	583.50	583.44	583.37	583.31	583.17
8	5	-	-	582.90	582.58	582.42	582.59	582.10
9	10	583.84	583.48	583.08	582.75	582.75	582.79	582.54
10	20	583.82	583.69	583.25	582.96	582.85	582.92	582.65
11	35	583.72	583.66	583.33	583.02	582.88	582.98	582.61
12	60	583.63	583.59	583.31	583.04	582.92	583.00	582.85
13	100	583.52	583.46	583.27	583.02	582.96	583.02	582.81
14	132	583.39	583.36	583.21	583.00	582.90	583.00	582.79
15	5	583.86	583.15	582.90	582.52	582.44	582.44	581.94
16	10	583.90	583.52	583.15	582.85	582.73	582.77	582.52
17	20	583.93	583.93	583.42	583.04	582.88	582.92	582.75
18	35	583.93	583.93	583.73	583.23	583.00	583.10	582.83
19	60	583.91	583.85	583.75	583.40	583.21	583.25	582.98
20	100	583.83	583.79	583.75	583.58	583.31	583.44	583.08
21	132	583.81	583.81	583.77	583.69	583.46	583.54	583.15
22	5	-	-	582.94	582.69	582.40	582.58	582.15
23	10	583.86	583.39	583.08	582.77	582.69	582.73	582.48
24	20	583.83	583.71	583.31	582.98	582.81	582.90	582.71
25	35	583.76	583.63	583.33	582.98	582.77	582.88	582.65
26	60	583.73	583.64	583.46	583.10	582.81	582.98	582.73
27	100	583.73	583.70	583.50	583.17	583.00	583.10	582.83
28	132	-	-	583.21	582.98	582.85	582.98	582.77
Sump	0	583.94	580	579.36	579.36	579.35	579.35	579.14

DATA SHEET

	Date	5-19	5-20	5-21	5-23	5-23	5-24	5-28
	Time	12:00N	11:10A	12:00 N	9:45 A	5:30 A	12:00N	12:00N
Observation Well No.	Distance Sump to Well (Ft.)	Elevation of Water in Wells						
1	5	581.99	581.75	581.65	581.52	581.42	581.31	581.25
2	10	582.46	582.31	582.21	582.08	582.00	581.88	581.65
3	20	582.58	582.54	582.33	582.31	582.27	582.21	582.06
4	35	582.65	582.60	582.48	582.40	582.37	582.31	582.17
5	60	582.67	582.60	582.50	582.42	582.35	582.23	582.25
6	100	582.69	582.63	582.48	582.29	582.23	581.94	582.06
7	132	582.98	582.79	582.44	582.15	581.92	581.75	581.75
8	5	581.77	581.58	581.58	581.40	581.19	581.15	581.10
9	10	582.23	582.15	582.04	581.94	581.77	581.75	581.58
10	20	582.60	582.54	582.42	582.29	582.15	582.10	582.00
11	35	582.67	582.60	582.48	582.35	582.40	582.23	582.08
12	60	582.67	582.60	582.50	582.42	582.40	582.25	582.06
13	100	582.73	582.60	582.52	582.44	582.40	582.27	582.10
14	132	582.65	582.56	582.50	582.38	582.33	582.21	582.12
15	5	581.56	581.44	581.37	581.29	581.25	581.08	581.04
16	10	582.27	582.15	582.02	581.94	581.77	581.62	581.60
17	20	582.54	582.50	582.37	582.31	582.23	582.17	581.98
18	35	582.67	582.58	582.50	582.33	582.33	582.21	582.04
19	60	582.79	582.69	582.60	582.42	582.35	582.31	582.17
20	100	582.81	582.73	582.58	582.40	582.37	582.23	582.10
21	132	582.73	582.75	582.69	582.40	582.42	582.25	581.98
22	5	581.75	581.56	581.48	581.40	581.27	581.17	581.00
23	10	582.25	582.12	582.02	581.94	581.31	581.65	581.52
24	20	582.54	582.46	582.35	582.27	582.17	582.08	581.98
25	35	582.46	582.40	582.29	582.17	582.10	582.07	581.92
26	60	582.54	582.46	582.31	582.17	582.10	582.02	581.98
27	100	582.58	582.52	582.44	582.19	582.08	582.10	581.90
28	132	582.50	582.47	582.29	582.13	582.08	581.92	581.75
Sump	0	579.44	579.38	579.44	579.44	579.44	579.52	579.60

DATA SHEET

Observation Well No.	Distance Sump to Well (ft.)	5-29 10:10A	5-31 12:30P	6-1 12:00N	6-3 5:00 A			
		Elevation of Water in Wells						
1	5	581.19	581.15	581.08	581.12			
2	10	581.69	581.62	581.63	581.54			
3	20	582.04	581.98	581.92	581.92			
4	35	582.17	582.12	582.12	582.06			
5	60	582.19	582.17	582.10	582.17			
6	100	582.04	581.98	581.86	581.94			
7	132	581.73	581.67	581.46	581.54			
8	5	581.10	581.08	580.96	581.02			
9	10	581.56	581.50	581.40	581.46			
10	20	581.98	581.92	581.85	581.85			
11	35	582.10	582.06	581.92	582.00			
12	60	582.08	582.04	581.92	582.08			
13	100	582.10	582.04	581.98	582.02			
14	132	582.15	582.00	581.92	581.96			
15	5	581.04	581.02	580.94	580.96			
16	10	581.60	581.54	581.48	581.46			
17	20	582.00	581.94	581.85	581.83			
18	35	582.10	582.08	582.00	582.00			
19	60	582.15	582.10	582.04	582.08			
20	100	582.12	582.06	581.94	582.06			
21	132	581.92	581.85	581.79	581.81			
22	5	581.06	581.02	581.00	581.00			
23	10	581.50	581.44	581.42	581.42			
24	20	582.00	581.94	581.87	581.88			
25	35	581.98	581.94	581.79	581.90			
26	60	581.96	581.94	581.90	581.85			
27	100	581.92	581.85	581.77	581.79			
28	132	581.75	581.71	581.63	581.67			
Sump	0	579.60	579.73	579.44	579.77			

DATA SHEET

OBSERVATION WELLS BETWEEN TILE LINES

	Date	5-22	5-25	5-25	5-27	5-29	5-31
	Time	-	1130a.m	200pm	1200n	910am	1000am
Well Number	Distance Well to Sump(')	Elevation of Water in Observation Wells					
1	3	95.77	95.73	95.73	95.71	95.71	95.69
2	5	95.83	95.79	95.79	95.77	95.68	95.72
3	10	95.99	95.91	95.91	95.87	95.85	95.80
4	20	96.19	96.07	96.07	96.00	95.96	95.92
5	35	96.69	96.48	96.48	96.40	96.34	96.25
6	64	97.05	96.88	96.88	96.82	96.78	96.71
7	100	96.90	96.74	96.74	96.67	96.63	96.59
Sump	0	95.50	95.50	95.50	95.50	95.50	95.50