ONE YEAR'S EXPERIENCE
with
ELECTRICAL SOIL MOISTURE UNITS

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There is not much question that most of the runoff of western streams, each season, comes originally from the preceding seasons snow pack. From this premise we should assume that, if we had some index of the amount of snow in the mountains, we could tell in advance what the runoff will be. This is the basic principle of water supply forecasting from snow surveys.

Unfortunately, the water that falls as snow must satisfy other requirements before it is available for runoff. Among these other requirements are evaporation, transpiration, groundwater and particularly the relative soil moisture under the snow. The dominance of these factors vary from season to season. In my opinion, recent research on water in mountain watersheds indicate that this soil moisture factor is far the most variable between seasons than any of the factors mentioned. In other words, I am inclined to believe that this variation in soil moisture is one of the principle reasons for our errors in water supply forecasts. The other reason for error is departure from normal of precipitation, and temperature from the forecast date until after the snow has melted. In some watersheds or areas the departure is quite a factor. In other areas it is not so significant.

From snow surveys alone, we have some evidence that we lose a lot of water making up the deficiency in soil moisture. In areas of the west where snowfall is realtively high (50"-60" in a season) we find a fairly direct relationship between the snowfall index and runoff. In other areas, such as the South Platte watershed in Colorado, it would be difficult to determine statistically if there is any relation between April 1 snow cover and subsequent stream flow. In some parts of this watershed the average seasonal accumulation of snow water is only 10" at 11,000 feet elevation. Average seasonal accumulations over 20" of water measured on existing snow courses is rare. The climate is also against the forecasters. About one-half of the annual rainfall occurs in April, May and June. Without some knowledge of soil moisture conditions in this watershed we had better look at the "Crystal Ball" rather than snow survey alone if we expect to make accurate forecasts.

At the Forest Experiment Station near Frazer, Colorado the range of soil moisture deficiency has been from about 2" to 10" in late September over a five year period. The elevation was near 9,000 feet which is representative of the major part of the water producing area of the watershed. At this elevation the seasonal snow water accumulation is about 11 inches on the average. With a little imagination, we

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could visualize a season where there would be no runoff from snow at this elevation. All that is needed is slightly below average snow accumulation and a high deficiency in soil moisture. At the other extreme, we might have well above normal runoff from this less than normal snow cover if the soil moisture deficiency is relatively low. Soil moisture deficiencies at high elevations are not so variable but elevations above 11,000 feet represent only a small part of the watersheds.

We need data on soil moisture. The problem is how to obtain and evaluate the information so we can improve accuracy of forecasts.

This soil moisture factor has been recognized for some time. The pioneers in snow surveys, have tried to evaluate this factor. Mr. Work in Oregon and Mr. Clyde in Utah have used soil samples but apparently found that it was not too satisfactory. To me the idea of digging away snow that is ten feet deep and trying to force a soil tube through soil diluted with boulders and other assorted debris is a little revolting. More recently it has been our practice to consider fall precipitation as an index to soil moisture. While this has been of value in some watersheds, our experience in Colorado has indicated that precipitation records leave much to be desired as an index to soil moisture condition in the fall. The principal problems are what period to use for the fall precipitation factor, how to adapt precipitation data from lower elevation stations and to determine just how effective total precipitation is on soil moisture conditions. These relationships are confusing.

The trials in the field of electrical resistance soil moisture units is just another attempt to obtain an index of soil moisture for use in forecasts. Experience with this type of equipment has been generally limited to research projects. We do not know how they will work for us and it will take some years to find out for sure. The first years experience indicates they might be good. The urgency to evaluate soil moisture conditions in an attempt to improve forecasts is apparent as the value of water increases. On the basis of the first years experience, I would personally be willing to risk a substantial part of the time and resources available to snow surveys next season to expand and maintain this network of soil moisture stations. We may lose, but if we wait till we are sure, we may also lose several years of record.

<u>The Colman Unit</u>

The Colman type unit was selected principally because of the probability that it will perform for several years in the soil and that the reading obtained from the units bears a consistent relation with soil moisture at its particular location. This unit was developed by the Forest Service. It has been used at a number of their research stations. I understand it was used first at the San Dimas Station in Southern California. You can see it consists essentially of two electrodes made of monel metal with a fiber glass layer between. The resistance between the two electrodes depends on the moisture content of the fiber glass. This is related to soil moisture content, The assembly of the units as shown in the illustrations is what we designed for use in Colorado. With this arrangement we can make the readings above the snow cover. The units also contain a thermistor which indicates approximate temperature. Temperature is necessary to correct resistances to standard temperature. The ohm-meter scale is in microamperes which is converted to resistances and then to approximate soil moisture content in percent. Detailed instructions on operation can be obtained from the manufacturer, The Berkeley Scientific Co., Sixth and Nevin St. Richmond, California. The cost of the units is about \$4.50 each and the cost of the ohm-meter is \$175.00. Material cost for each installation is about \$35.00. On the basis of one ohm-meter for three stations I would say that the total cost of each station when finished is about \$250.00.

Location of Units

We installed six of these stations in the fall of 1952 and five more in July 1953. The soil was at the lower limit of soil moisture or wilting point in the fall of 1952 and very nearly as dry in 1953. An exception was apparently part of the Rio Grande basin in 1953. During the snow melt season we noted that there was no material increase in stream flow until a few days after the 4th foot unit was wet. The rise in streams was about three weeks later than normal, which could be partially credited to filling the soil mantle to capacity. Three of these stations were read at about two week intervals from April 1 to November 1. The elevations ranged from 9,000 to 10,400 feet. Rain gages were located near each station. One interesting observation was that the vegetation (lodgepole pine) used up all of the moisture in the top four feet (estimated at 7" to 8") plus rainfall (7") from July 1, 1953 to November 1, 1953 at the lowest elevation station. After July 15 rainfall (Maximum 1 3/4" in two weeks) did not appear to have much affect on soil moisture readings.

In locating soil moisture units we selected locations which, in our judgment, would provide the most adequate index of soil moisture. The following are some of the principles used.

1. Locate units in a typical soil mass for the watershed with usual vegetative cover. Avoid locations on alluvial fills, near exposed rock formations on near surface drainage channels. On the South Platte watershed a glacial till, soil on a side hill, is about as good as available. On the Rio Grande watershed a reasonably well developed soil was available in some locations to a depth of four feet. Soil at very high elevations is likely to be extremely shallow.

2. Select elevations that represent a large area of the watershed above the normal winter snow-melt line. Elevations should be low enough that a substantial soil moisture deficit might be expected in the fall and still have enough snow available in most years to replenish the deficit and provide for some runoff. I would consider this elevation to be

in the range of the medium toward low elevations snow courses. In most of Colorado this would include elevations from 8,500 to 10,000 feet. This will vary with the climate and elevation distribution in each watershed. It is believed that extremely high elevations are not representative of the watershed or of soil moisture deficiency and the lower elevations are of no consequence as far as runoff is concerned.

Installation

To install the units in the mountains, it is usually necessary to dig a pit although an auger may be used in some locations. Without special equipment the depth of a auger hole is limited to the arms length. In our installations we have placed four units at 8", 20", 32" and 44" depth respectively. We believe this may be a little more than adequate for the area but we consider it standard. The depth of this unit depends on the soil and root zone, the prevalence of solid rock and the energy of the pit digger. The units should be placed in a vertical position 3" to 6" in the side of the pit in relatively undisturbed soil. A small hole can be made with a knife, pick or screw driver. Soil should be packed around the unit. The lead wires should move down a few inches before turning up toward the pipe (Fig. 1). In order to have fairly reliable readings in a few days, we believe that it is well to wet the unit in water before placing it in position. Otherwise, if the soil is dry, it may take a season for the moisture in the fiberglass to correspond to the moisture in the soil.

The bottom unit should be placed first with the other units being placed in the side of the pit as it is refilled. It is necessary to replace and pack the soil in similar layers to the original position. In our installations the wires are lead into the bottom of a two inch pipe which extends five to seven feet above ground. The pipe may have to be longer so it will be above the snow.

The units come with six foot lead wires. Additional lead wires are needed. The extra lead wire we used is Belden #8913, a No. 20, .025" plastic insulated hook-up wire. Joints in the wire as well as connections to the switch (Fig. 2) should be soldered and taped with plastic tape. The switch itself should be enclosed with tape. The trade name of the switches we used is "Centralab" switches of the 1420 series. A switch of three banks with at least six switch positions is needed.

The switch fits rather tight in the top of the pipe. A plywood ring inserted at the joint in the pipe prevents the switch from falling down. Electrical jacks are attached to leads from the switch to provide a connection for corresponding ohmmeter leads. Integrity of wire color should be maintained to avoid confusion of wires (Fig. 3).

In the 5 1/2" section of pipe shown in Fig. 4 a few 1/4" holes should be drilled in the side to prevent moisture condensation inside the pipes.

The electrical system is not tight as there may be leaks to the soil as well as the pipe. However, the resistances will far exceed that of the fiberglass. Anything approaching a short will be immediately apparent on the ohm-meter. The needle will go over the scale. If the circuit is broken the needle will go to zero.

Schedule of Measurements

For an operational schedule of measurement we have in mind the dates of about November 1 at the start of the snow season and the forecast dates of April 1 and May 1. The November date is after the date of any probable snow melt in the fall. The later dates would indicate any increase in soil moisture due to snow melting before the forecast dates. These dates are probably satisfactory for Colorado but would have to be adjusted for other climatic conditions.

Use of Ohm-Meter

The ohm-meter specifically designed for the Colman soil moisture units has two standard resistances indicated on a high and low scale. The scale is graduated from 0 to 200 microamperes. If the soil is so dry that the low scale shows below 30, the high scale should be used. In a typical soil, field capacity is when the needle reads from 130 to 160 on the low scale and at wilting point when the needle reads 20 to 40 on the high scale. Conversion to resistance in ohms may be obtained from the chart titled Fig. 5.

Temperature corrections must be applied for accurate determinations of moisture. After finding the resistance corresponding to the meter reading, approximate temperature may be obtained from Fig. 6. Temperatures are read on the low scale. A reading of 100 is about freezing and room temperature is about 170. Soil temperature during the summer months show a meter reading from 130 to 145. After temperature is determined the corrected soil moisture resistance may be obtained from Fig. 7. Enter indicated resistance on the left and follow to intersection of the 60°degree line. The corrected resistance is read below the point of intersection at the actual temperature line. Soil temperatures in mountain areas will all be below the 60 degrees standard.

In order to determine soil moisture content a chart similar to the one shown in Fig. 8 is used. In addition to the three field types and one lysimeter loam soil, we have added a curve for typical mountain soil at one of the soil moisture stations. This curve was based on very limited sampling of soil. It is interesting to note that the meter reading reasonably corresponds to wilting point and field capacity on all types of soil regardless of the indicated soil moisture in percent.

Application to Water Supply Forecasting

After soil moisture percentage is determined we still have to convert this percentage into some type of an index that can be applied to water supply forecasting. This procedure is yet to be determined. However, I should like to present some ideas that would eliminate most of the above procedure, and convert meter readings almost directly into soil moisture deficiency in inches.

Refer to Fig. 9. This chart was developed from very limited data at our Longs Peak soil moisture station. The soil here is glacial till, containing occasional boulders and numerous small rocks up to 2" in diameter, but the soil itself would rate between a sandy and silt loam. From measurements we know that the soil reaches a minimum about 3 percent moisture at about 25-30 indicated reading on the high scale. After the last snow melt, (June 1953) we took samples containing 14 to 16 percent moisture with meter readings of 130-145 on the low scale. We had some points in between. Thus we have a reasonable figure for the limits of wilting point and field capacity.

The chart shows meter readings plotted, against soil moisture deficiency in inches. In this case we have assumed from study of our data that when we have a meter reading of about 135 on the low scale the soil is at field capacity and the deficiency in soil moisture is zero. We have noted also that when the average meter reading is about 25 on the higher scale the first four feet of soil is at wilting point. The soil moisture deficiency at wilting point is estimated at 7 1/2 inches. We have no data to support this estimate except that it is in a reasonable range for this type of soil. It is conceivable that if a laboratory or lysimeter test could be run on these soils the deficiency might range from 4 inches to 10 inches. In mountain soils the e tests might be impractical to do. The effect of this assumption on forecasting data will be discussed in subsequent paragraphs.

On the chart, (Fig. 9.) there is listed some standard resistances corresponding to meter readings for information only. Corrections for each 10 degrees temperature change from standard are also listed for resistances in the range used. For instance, a reading on the low meter scale of 54 would show a measured resistance of 10,000 ohms at 60 degrees. However, if the temperature was 40° the actual resistance would be about 7,200 ohms. This would change the indicated soil moisture deficiency about 1/2 inch. The charts could be constructed to show 35 to 40 degrees as standard thus eliminating this correction for all practical purposes. Corrections for individual units could also be eliminated in chart construction since they are relatively small.

The line on the chart is not based on sufficient data to be reasonably accurate in shape between wilting point and field capacity. The curve extends beyond zero deficiency to indicate the range between field capacity and saturation.

This method is based on estimates, assumptions and possibly some significant inaccuracies. However, it can be improved somewhat as more data is available. In any event, it will tend to give us a relative index of soil moisture which is statistically adaptable for use with a snow water content index. Whatever figure is determined from such a chart will have to be multiplied by a constant derived from a statistical procedure when applied to a forecast formula. While we wait for data to be accumulated, no doubt a better system will be devised.

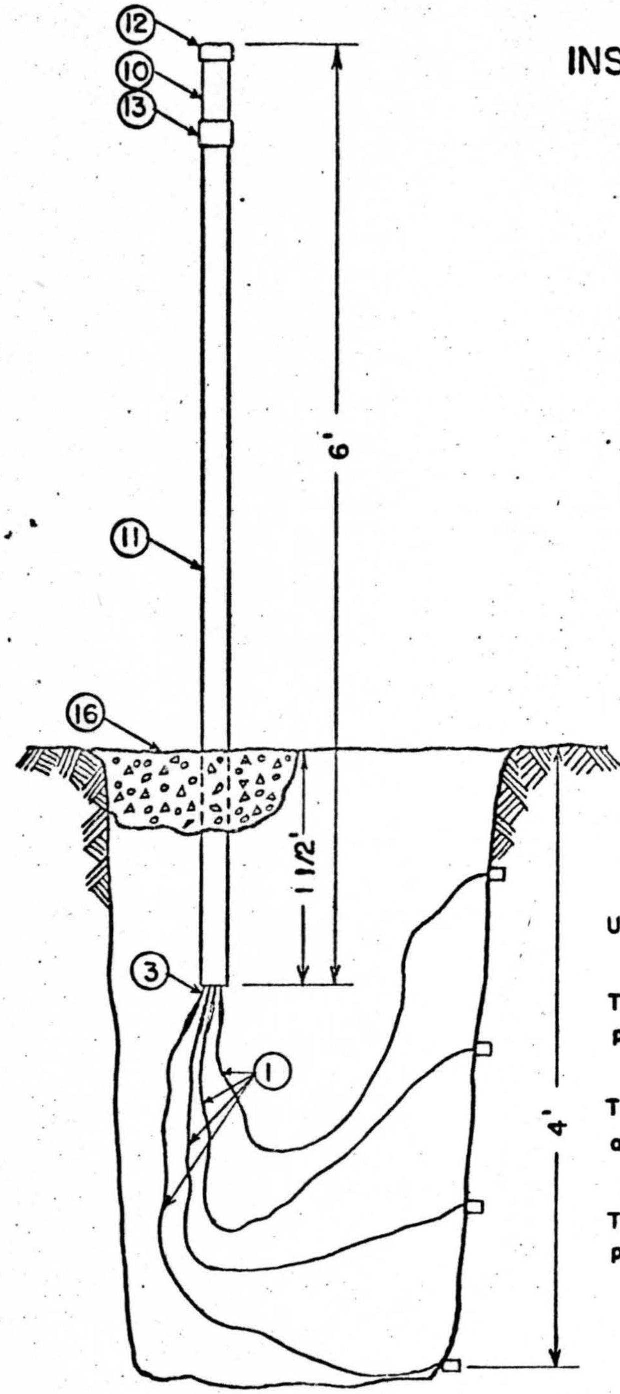
Conclusion

The use of electrical resistance soil moisture units appears to have reasonable expectations of being a partial solution to an index of soil moisture. This index could be applied to forecasting procedure. Although there is nothing in our experience to date that indicates they will fail, it is possible they will not prove practicable. Some hydrologists, who have had experience with earlier types of these electrical resistance units such as gypsum blocks, have advised me that the results will be poor. Others with limited experience with the Colman units feel their results to date are inconclusive. A few believe these units have possibilities in our work. The apparent necessity of having data on soil moisture for water supply forecasting has inspired their trial. I would like to have other stations established, particularly east of the Continental Divide, and in areas of Utah and Arizona. I do not have adequate knowledge of watersheds in coastal and other intermountain regions to advise if these units would be valuable.

Note: Figures 5, 6, 7 and 8 of this paper are copies from a publication concerning the Model 300 Ohm-meter by Berkeley Scientific Co., Richmond, California.

INSTALLATION DIAGRAM

SCALE 1" = 1'



- (1) Moisture Unit Wires
- (3) Belden Hook-up Wire
- (10) Switch Section
- (11) Main Pipe
- (12) Pipe Cap
- (13) Coupling
- (16) Cement Support

NOTES

Units are placed at the desired depths.

The length of the pipe will depend on the prevailing snow depth on the site.

The moisture unit wires must slope down and away from the units for at least 10".

The soil stratum must be replaced and packed to resemble its original condition.

Figure 1

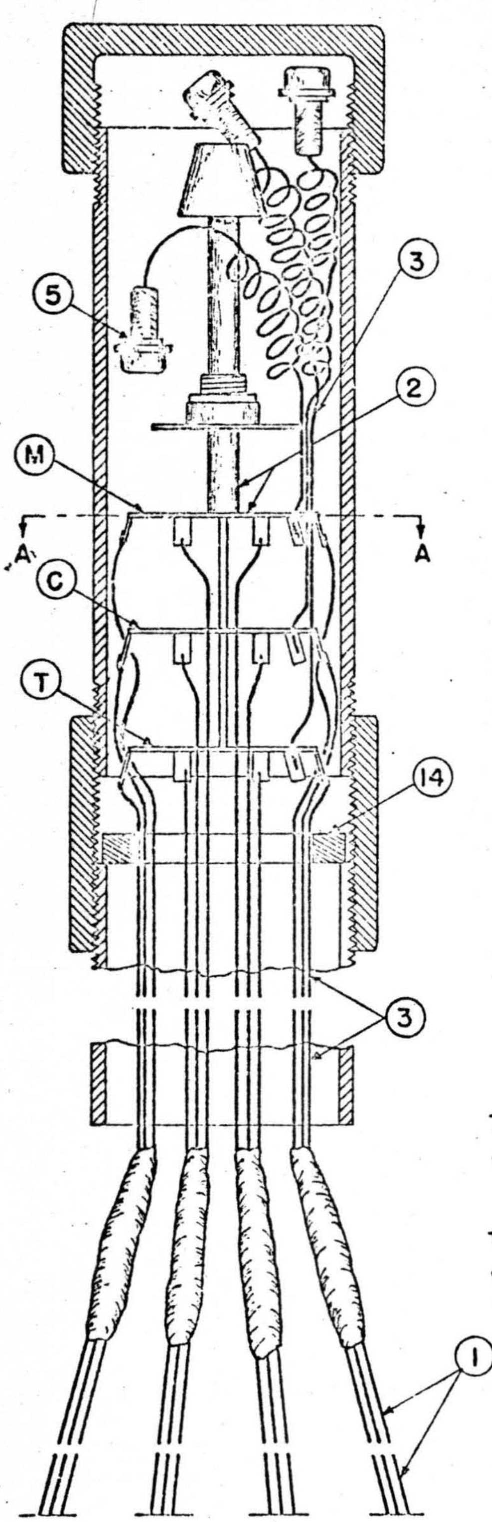
Cooperative Snow Surveys and Streamflow Forecasts

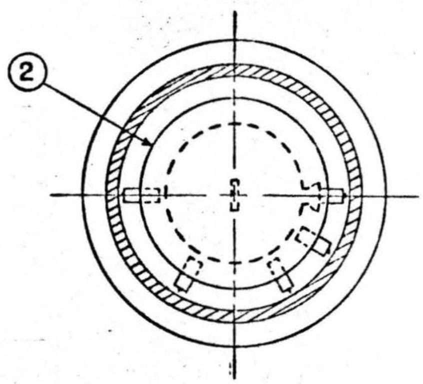
Soil Moisture Unit Installations

Drawn by B. Binford 8/22/52

ASSEMBLY DIAGRAM

SCALE 3/4" = 1"





SECTION AA

(C) Common-lead Section
(M) Moisture "
(T) Temperature "
(1) Moisture Unit Wires
(2) Selector Switch
(3) Belden Hook-up wire
(5) Plug
(14) Plywood Ring

NOTES

The wires are taped together at regular intervals to prevent them from tangling.

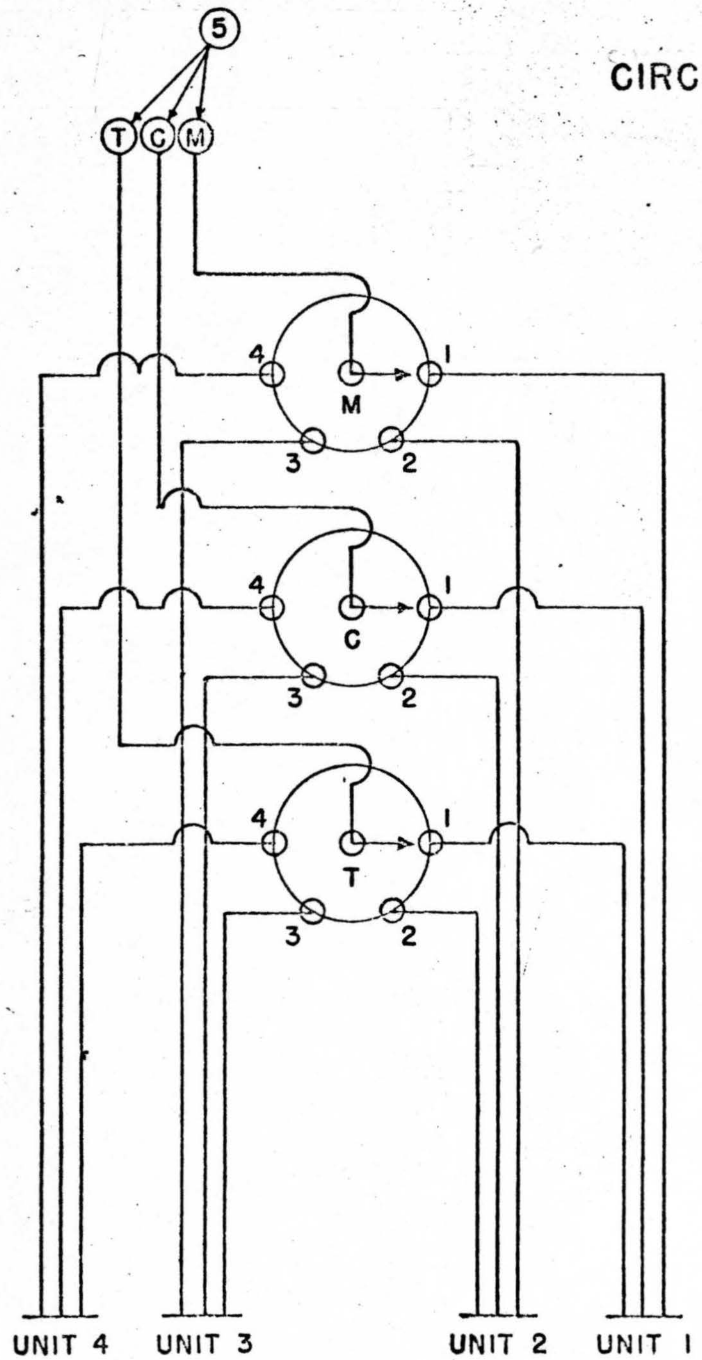
The three switch sections and plugs should be wrapped with tape for protection.

Keep the pipe threads well greased to prevent moisture leakage and rust.

Cooperative Snow Surveys and Streamflow Forecasts
Soil Moisture Unit Installations
Drawn by B. Binford 8/26/52

Figure 2

CIRCUIT DIAGRAM



Ⓒ Common-lead Section
Ⓜ Moisture "
Ⓣ Temperature "
⑤ Plugs

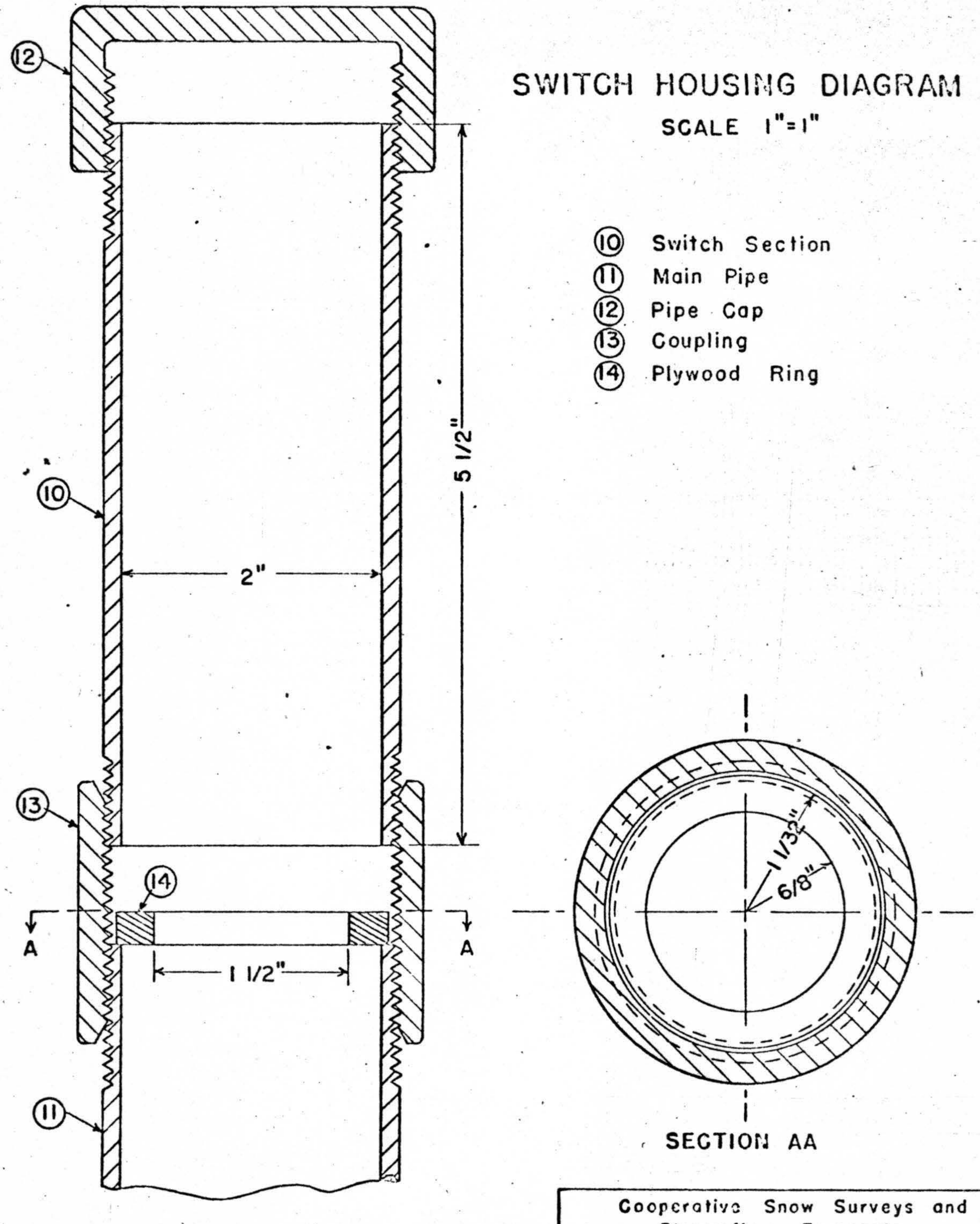
NOTES

Wire splices should be plastic coated, taped, and then coated several more times.

Figure 3

Cooperative Snow Surveys and Streamflow Forecasts
Soil Moisture Unit Installations

Drawn by B. Binford 8/26/52



VERTICAL SECTION

Cooperative Snow Surveys and Streamflow Forecasts
Soil Moisture Unit Installations

Drawn by D. Binford 8/22/52

Figure 4

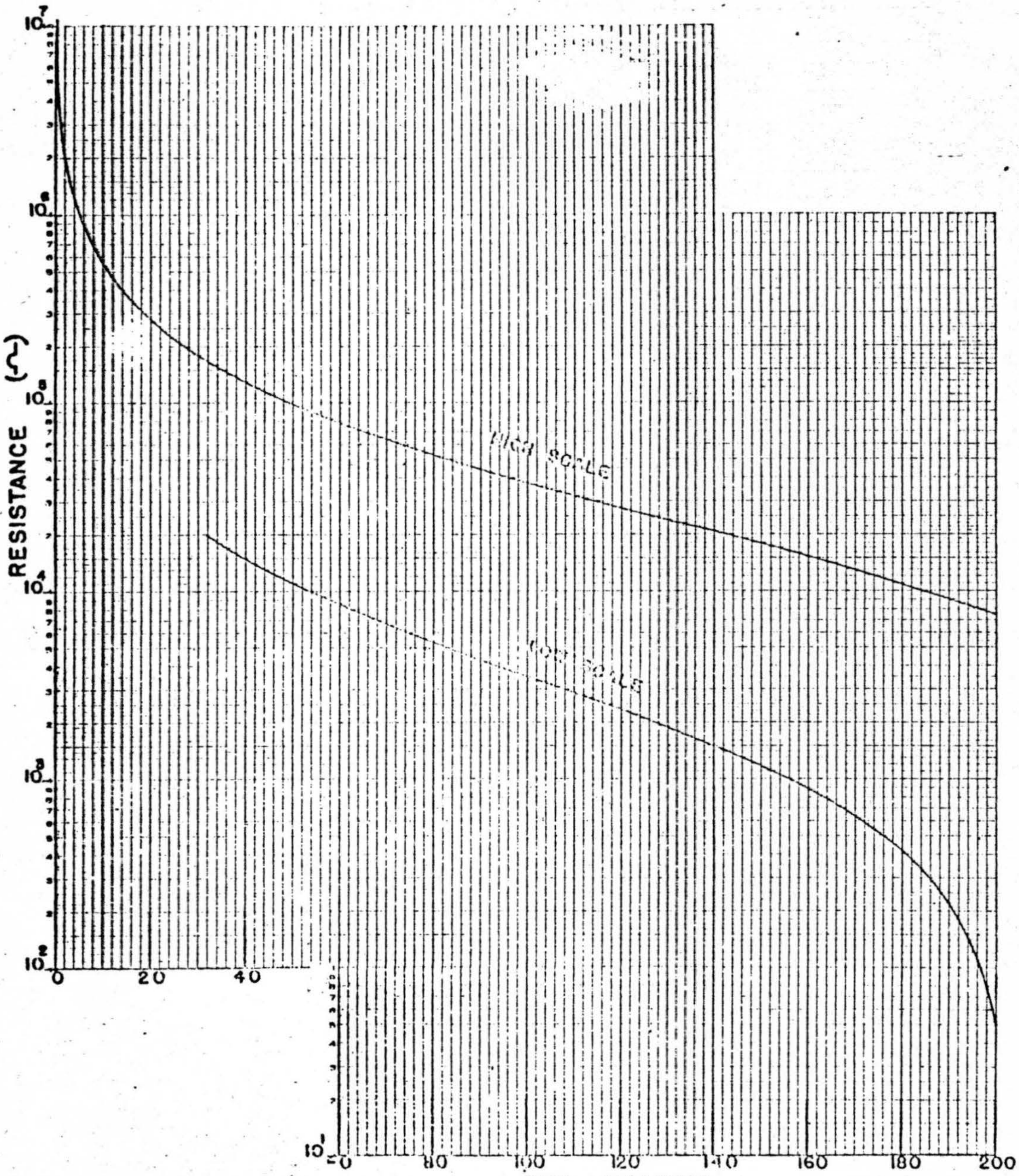


Figure 5.- - Calibration chart for A.C. ohmmeter

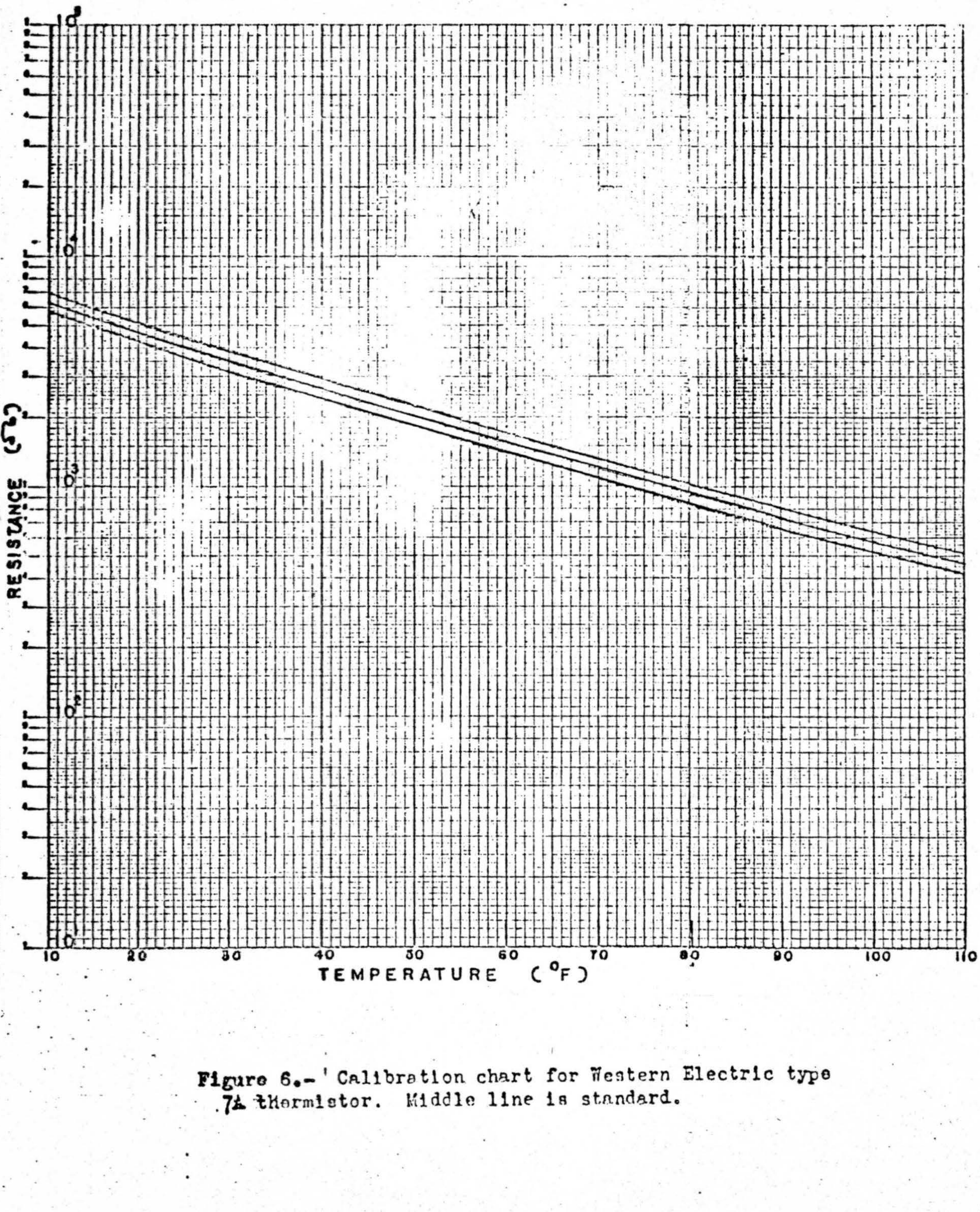


Figure 6.- Calibration chart for Western Electric type 7A thermistor. Middle line is standard.

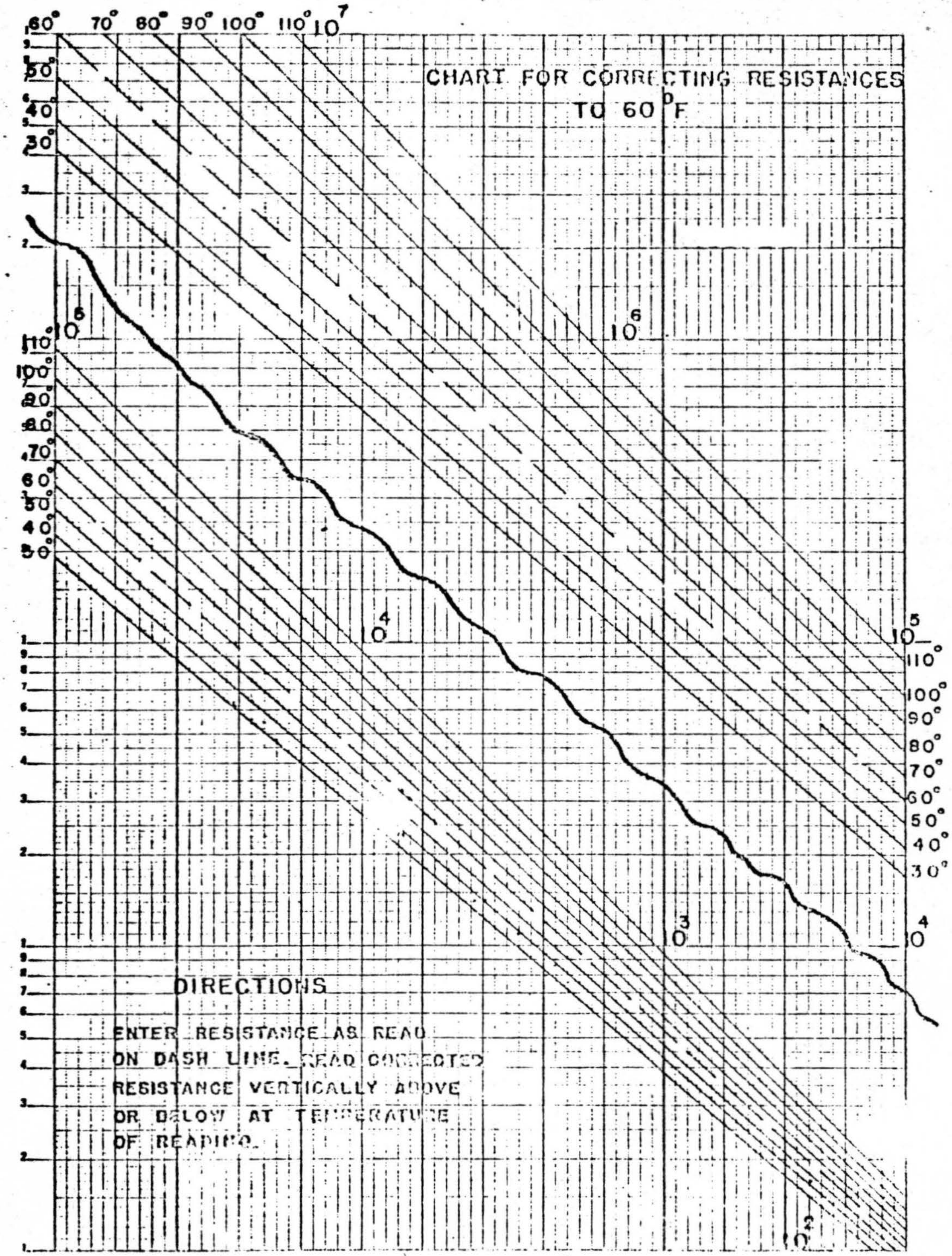


Figure 7.- Chart for correcting soil-unit resistance measured at field temperature to resistance at 60° F.

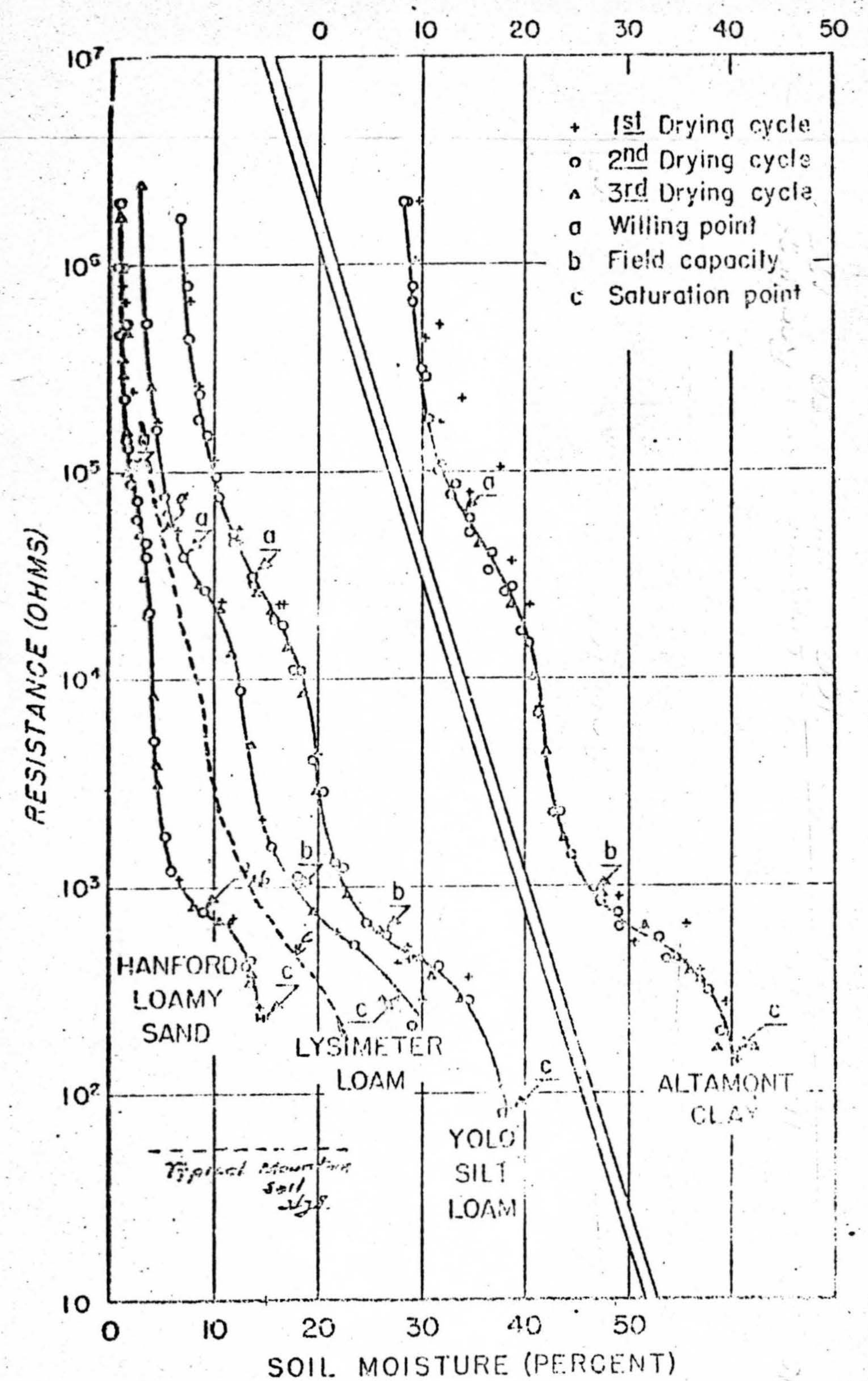


Figure 8. - Sample calibration curves for three California soils. (Soil moisture for the Altamont clay is read on the top abscissa.)

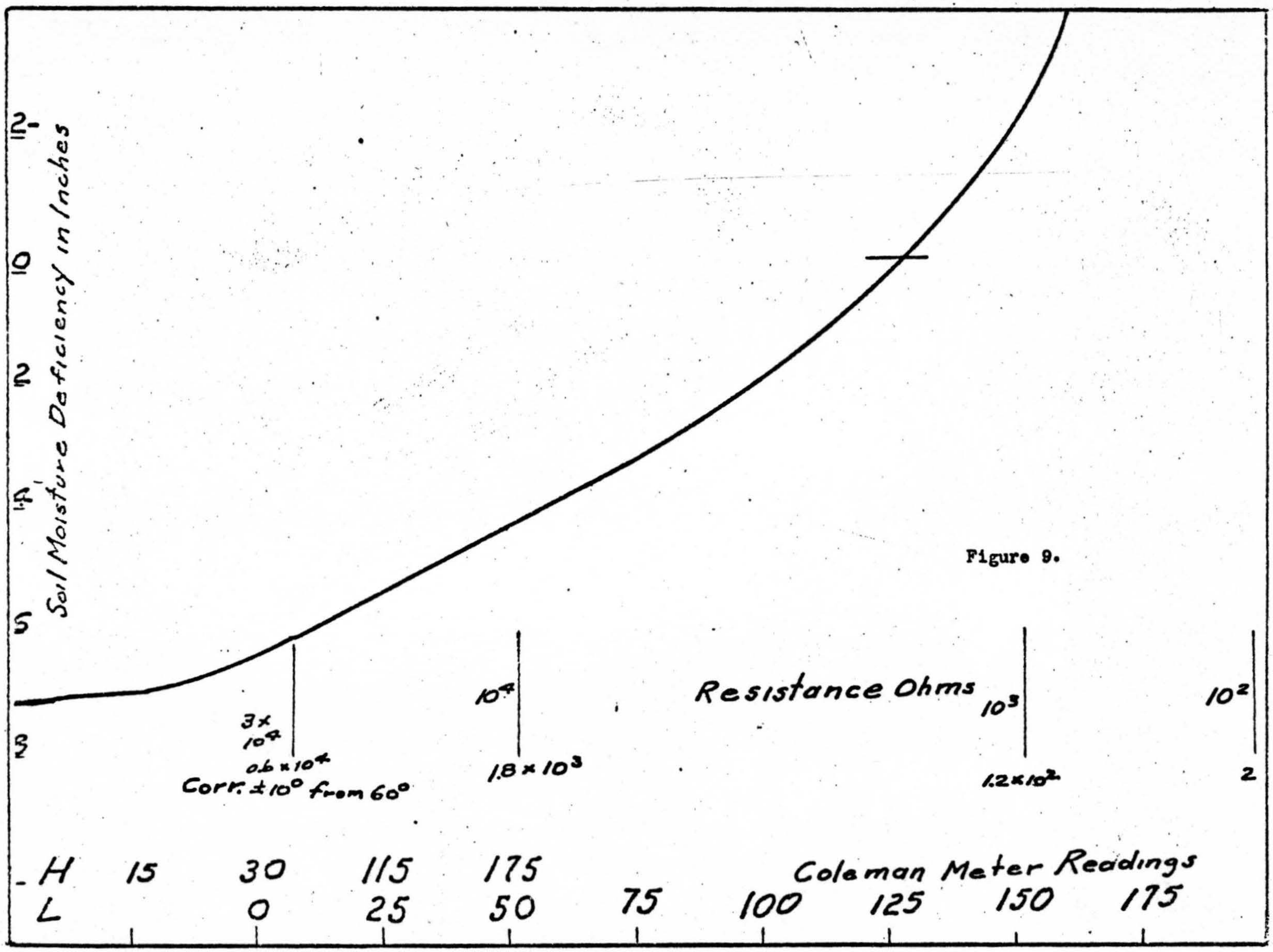

Soil Moisture Deficiency in Inches
10
Resistance Ohms
3 x 10^4
10^4
10^3
10^2
0.6 x 10^4
Corr. ±10° from 60°
1.8 x 10^3
1.2 x 10^2
2
H 15 30 115 175
L 0 25 50 75 100 125 150 175
Coleman Meter Readings

Figure 9.