A MULTI-COMPONENT HYDROGEOLOGIC EVALUATION OF A SHALLOW GROUNDWATER FLOW SYSTEM IN GLACIAL DRIFT

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ABSTRACT

A multi-component analysis of a shallow groundwater flow system in glacial drift at the Whiteshell Nuclear Research Establishment, Manitoba is described. The investigation included geologic test drilling, definition of the hydraulic potential distribution, hydrochemical analysis, studies of the temperature distribution in the groundwater zone, radioactive tracer studies of groundwater flow, observations of secondary permeability characteristics and mathematical modelling of the geohydrologic regime.

The stratigraphic section consists of seven glacial deposits which are: a lacustrine sand and gravel unit, a lacustrine silt unit, a lacustrine clay unit, a clay-loam till, a basal sandy drift, an undifferentiated sandy till, and a lacustrine sand unit. The glacial deposits rest on Precambrian metamorphic and intrusive rock.

The groundwater flow system is bounded on the east by a topographic high formed by the lacustrine sand, on the west by the Winnipeg River and in the subsurface by relatively impermeable Precambrian bedrock. Groundwater potential distribution exhibits four major geohydrologic zones. From east to west these are: an upland recharge area consisting of the topographically high lacustrine sand unit, a strong central discharge area, a strong central recharge area and a lowland discharge area confined to the banks of the Winnipeg River. Predominantly lateral flow occurs in the more permeable basal sandy drift with lateral potential gradients existing only locally in the overlying units. Maximum horizontal tracer velocities detected at three sites are less than 10 feet per year. Groundwater flow through the less permeable upper clay-loam till and glacio-lacustrine silt and clay units occurs via joints and sand laminae.

Variations in electrolytic conductivity and distribution of Ca^{++}, Mg^{++}, Na^{+}, and $SO_4^{=}$ exhibit distinct increases in the directions of groundwater movement. The increase in major-ion concentrations with distance along the flow path in the lacustrine sand unit and the basal sandy drift is less pronounced than in the clay-loam till and the glacio-lacustrine silt and clay units due to a more active flow system and limited availability of soluble minerals in the sandy deposits.

Results of the modelling suggest that the location of the boundary between the central recharge area and the central discharge area is a result of a pronounced thinning of the basal, highly permeable, sandy drift. Strong recharge gradients in the central recharge area could not be simulated in the model.

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INTRODUCTION

The objective of this study is to define the groundwater regime in the Environmental Control Area, Whiteshell Nuclear Research Establishment (WNRE), Pinawa, Manitoba. Since May, 1968, field and laboratory investigations have been conducted to provide hydrogeologic information as a basis for design and location of radioactive liquid and solid waste disposal facilities in the glacial drift which underlies the area. Drift thickness ranges from 30 to 75 feet. The drift is underlain by relatively impermeable Precambrian crystalline rock.

The field study included investigations of the geologic framework, subsurface permeability distribution, hydraulic potential distribution, temperature distribution in the groundwater zone, groundwater-flow velocities and major-ion distribution in the groundwater zone. A two-dimensional, steady-state model of the groundwater flow system was used to refine the field interpretation of subsurface permeability distribution.

The WNRE is located 65 miles east-northeast of Winnipeg on the Winnipeg River (Fig. 1). The Environmental Control Area (Fig. 2) occupies 4 square miles of the WNRE site. Radioactive waste is presently being disposed of in only a small portion of the area (Fig. 2).

This thesis reports on the hydrogeologic environment of the area. Specific application of the results to radioactive waste disposal will be the subject of a future report.

Four previous geotechnical studies of the plantsite have been conducted. Shawinigan Engineering Limited (1960) summarized the results of an initial geological and geophysical investigation of the WNRE site. Charron (1964) conducted a reconnaissance survey of the radioactive waste disposal capabilities of the groundwater regime. Zwarich (1968) is continuing studies on ion exchange characteristics of the glacial drift in the Environmental Control Area. Lund (1967) investigated groundwater flow velocities at one location using a tritiated heavy-water tracer. Apparent anomalies in the results of her study were partially responsible for prompting the present investigation.

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Chemical analyses were conducted by the Soil Science Chemistry Laboratory, University of Manitoba, under the supervision of Dr. M. Zwarich and the Analytical Chemistry Branch, WNRE. The use of tritiated heavy water was supervised by the Radiation and Industrial Safety Section, WNRE. Drilling was completed under contract by Great Plains Augering Limited, Saskatoon in 1968 and 1969 and by Mobil Augers and Research Limited, Edmonton, in 1970.

The investigation was conducted in 1968 with direct financial support of the Environmental Control Section, WNRE, at which time I was a summer research assistant on the project. The study was continued through 1969-70 by the University of Manitoba under research contract with Atomic Energy of Canada, Limited. During this period I was employed on the project as a research assistant.

GEOMORPHIC AND HYDROLOGIC SETTING

The Environmental Control Area is located on the western edge of the Canadian Shield. Sedimentary terrain in the area originated from Wisconsinan glaciations of the Pleistocene Epoch and associated episodes of Glacial Lake Agassiz (Elson, 1966, McPherson, 1968; 1970). Deglaciation of the area occurred between 11,700 and 13,000 years BP with subsequent inundations by Glacial Lake Agassiz prior to 7300 years BP (Elson, 1966).

Relief in the Environmental Control Area varies between 905 feet and 840 feet above mean sea level (Fig. 3). The regional topography (Fig. 2) is a plain with isolated highs. Aerial photographs of the WNRE site and surrounding area (Fig. 4 and Appendix A) illustrate the low relief and marshy character of the terrain. Oblique modified infra-red photographs (Fig. 5 and Appendix A) show vegetation patterns delineating areas of both bog and sand outcrop.

In relation to worldwide climatic conditions, WNRE is within the region Dfb. (Koppen and Geiger, 1936), characterized by areas near the center of a continent with temperature extremes greater than the world average for the latitude. Recorded temperature extremes at WNRE are -53.5° F. and 108° F. (A. Reimer, personal communication). Mean daily temperature drops below 32° F. during the first part of November and rises above 32° F. near the end of March with an annual mean daily temperature of approximately 35° F.

Precipitation varies greatly with a mean of 20 inches per year, the greatest portion occurring during the summer months (Smith and Ehrlich, 1967). Recorded extremes are a low of 12.5 inches in 1961 and a high of 26.6 inches in 1968 (A. Reimer, personal communication).

METHODS OF INVESTIGATION

During the initial stages of the study, a base map prepared by Shawinigan Engineering Limited (1960) was used in conjunction with standard 1:16,000 aerial photographs to coordinate field studies. The field studies were conducted during the April-September periods of 1968, 1969 and 1970.

Physical Character of Glacial Drift

The geologic framework in the Environmental Control Area was defined by 76 test holes drilled by a truck-mounted hydraulic drill equipped with a six-inch diameter solid-stem auger flights. Disturbed samples were collected from auger flights, with sample depths estimated to within ± 1 foot. A small portable power drill (Mobil Augers Limited, Minuteman Model) equipped with three-inch auger flight was used for two preliminary test holes but its use was discontinued due to the bouldery character of the glacial till and poor quality of samples. Geologic logs of test holes with interpretations are listed in Appendix B.

Shelby tube cores 0.25 feet inside diameter and two feet in length were taken to define in detail the texture of the glacial drift and to investigate the frequency and character of joints and fractures. Immediately after sampling the cores were sealed using plastic sheeting in the tubes. The samples were then stored at room temperature until inspection could be made. A fluorescent dye, sodium fluorescein, was injected into the glacial drift prior to coring in an attempt to study the physical character of the joints.

Inspection of cores in which sodium fluorescein was thought to be present was conducted under ultraviolet light.

Piezometer Design and Installation

To define the hydraulic potential distribution in the glacial drift, 60 observation sites consisting of 210 piezometers and water table observation wells were installed in the glacial drift. Water levels were measured periodically.

Piezometers of the standpipe design (Fig. 6) were constructed of polyvinylchloride (PVC) pipe. Piezometers installed in 1968 and 1969 had an inside diameter of 0.94 inches and those installed in 1970 had an inside diameter of 0.80 inches. The bottom two feet of the standpipes were perforated and screened with fine-mesh stainless stell screen in 1968 and 1969 and with fine-mesh fibreglass matte in 1970. The intake area was packed with coarse silica sand. Bentonite or very fine silica sand was then placed above the coarse sand pack as a seal against grout. The hole was sealed by a grout mixture of sulphate-resistant cement.

Three piezometers using mild steel standpipes were installed in 1969. These piezometers were not entirely satisfactory because of difficulty preventing silt and sand from entering the standpipe as well as corrossiveness of the groundwater to mild steel. The PVC piezometers generally attained equilibrium within a week after installation (Fig. 7 and Appendix C) and were subsequently flushed and tested for response and return to equilibrium. The use of PVC standpipes made the installations ideal for hydrochemical purposes. Representative piezometer hydrographs are shown in Figures 8 - 10. Hydrographs of all other piezometers installed from 1968 to 1970 are included in Appendix C. Piezometer locations and elevations were determined by transit and level with horizontal control of approximately 10 feet and vertical control of 0.1 feet.

Hydraulic conductivities of the glacial drift were obtained from piezometer response tests using the methods of Hvorslev (1951; 1954).

Hydrochemistry and Geothermometry

Groundwater samples were collected from the screened zone of piezometers using a narrow-diameter downhole sampler and by vacuum pump. Samples were isolated from the atmosphere immediately after sampling and stored in polypropylene bottles until analyses were made.

The results of analyses for Ca^{++}, Mg^{++}, Na^{+}, Cl^{-}, and $SO_4^{=}$ are tabulated in Appendix D. Concentrations of HCO_3^{-} and $CO_3^{=}$ were calculated by the procedure discussed by Barnes (1964) from titration data and are listed with total dissolved solids in Appendix D. Field pH measurements were obtained using a null-balance pH meter (Radiometer Model pHM-4) following the procedure of Barnes (1964). Electrolytic conductivities were measured in the water at the intake area of piezometers using an extended-cable down-hole conductivity cell (Solubridge Model B3-338). Field pH and conductivity results are also listed in Appendix D. Groundwater temperatures were measured at intervals in piezometers with an extended-cable thermistor (Whitney Model TC-5A) and are summarized graphically in Appendix E along with meteorological summaries for 1968, 1969 and 1970 obtained from the Environmental Control Section, WNRE.

Heat transfer from the thermistor and connecting cable into the narrow-diameter standpipes resulted in difficulties in obtaining reproducible values. Conduction of heat from surface down the standpipe and convection within the standpipe are also believed to greatly reduce the reliability of the data.

Tracer Injection Experiments

Groundwater flow velocities were studied by injecting tritiated heavy water into the glacial drift at three locations in the study area (Fig. 3). The injection experiments were initiated in July, 1969 at a site immediately north of the present Active area. Injections at the other two sites were made in August, 1969. Each injection site comprises one 3.5 inch-diameter injection well and up to 40 sampling tubes concentrated predominantly in the anticipated direction of a flow. Sampling tubes were constructed and installed in the same manner as piezometers except that the perforated area was increased to 3 or 5 feet, depending on the sampling zone desired. The locations of injection wells and sample tubes are shown in Figures 11 - 13.

Samples were obtained from sample tubes by vacuum lines set in the perforated area of the sampling tube. Tritium analyses were conducted using a liquid scintillation counter supplied by the Environmental Control Branch, WNRE. Beta activity fluctuations for selected sample tubes are presented in Appendix F.

Prior to injection of tritium, hydraulic connection of all sample tubes to the injection well was confirmed by pressure injection of pure water. At injection site No. 1, a trial injection of sodium fluorescein was conducted to test injection and sampling procedures.

An injection well was also installed approximately 5 feet east of piezometer nest No. 20. Only sodium fluorescein was injected at this point, the primary purpose of the experiment being to take Shelby tubes within the injection zone as a means of investigating secondary permeability characteristics of the fine-grained deposits.

Steady-State Mathematical Modelling of the Groundwater Regime

A computer program initially prepared by Morris (1968; 1969) for IBM Systems 360-65 using the finite-element techniques outlined by Zienkiewicz and Cheung (1966) was used in the analysis of the groundwater flow pattern and subsurface permeability distribution. The program solves the two-dimensional steady-state flow equations for groundwater flow in saturated, anisotropic, heterogeneous porous media with an irregular water table and impermeable flow boundaries or their equivalent. The program was adapted for specific application to the flow regime in the WNRE area with solutions for the hydraulic potential distribution being plotted by a Calcomp plotter. Program listings and comments on the program are compiled in Appendix G.

STRATIGRAPHY

The stratigraphic section in the Environmental Control Area, WNRE, consists of seven units overlying Precambrian bedrock. These are: a lacustrine sand and gravel unit, an interbedded lacustrine silt, a lacustrine clay, a carbonate-rich, clay-loam till, a basal sandy drift rich in Precambrian-derived pebbles and boulders, a sandy till, and a unit of predominantly fine to medium-grained sand. The total thickness of these units overlying the Precambrian bedrock varies between 30 and 75 feet. The surficial geology is shown in Figure 14 and geologic cross sections are shown in Figures 15 - 17.

The stratigraphic section in the upland area is much more variable than in the western plain. As shown in Figure 15, the northwestern portion of the upland is underlain by only one stratigraphic unit, a thick deposit of relatively uniform fine to medium-grained lacustrine sand. The unit includes a few thin interbeds of silt and clayey silt which are probably discontinuous. This deposit extends westward beneath the clay-loam till and is terminated in the northeastern portion of the upland by the unit which appears to be a sandy and in places silty till. Figure 16 shows that the southern portion of the upland is underlain by a much different stratigraphic sequence. The thick section of sand shown in Figure 15 is not present, and a lacustrine sand and gravel deposit overlies the lacustrine clay.

West of test hole 48 (Fig. 16) the surficial sand and gravel deposits pinch out and the section consists of, in descending order, lacustrine clay, clay-loam till, and a basal unit of fine to coarse-grained sand.

The stratigraphic sequence east of the upland has not been defined by test drilling. However, based on the topographic setting, the poorly drained character of the terrain, and the continuity of both the clay-loam till unit and the lacustrine clay under the upland (Fig. 16) it appears likely that the area is underlain by both of these units.

A north-south geologic cross section (Fig. 17) illustrates the relatively uniform character of the stratigraphy in the more central portions of the Environmental Control Area.

Lacustrine Sand and Gravel Unit

The lacustrine sand and gravel unit consists of up to 15 feet of fine to coarse-grained sand with minor silt beds and gravel. The deposit is restricted to an isolated topographic high in the southeastern portion of the area (Fig. 15). Grain-size characteristics suggest relatively high hydraulic conductivities, probably in the range of 1×10^{-5} to 1×10^{-2} fps.

Lacustrine Silt Unit

The lacustrine silt unit observed in the Environmental Control Area represents a late phase shallow-water deposit of Glacial Lake Agassiz (McPherson 1968). This unit consists of massive to laminated very fine sands, sandy silts, silts, clayey silts and silty clays with a maximum thickness of 15 feet occurring near the Winnipeg River, and wedges out in the central portion of the area. Where the unit is less than two feet thick, it is somewhat obscured by the effects of soil formation.

Easily eroded masses resembling primary bedding structures were recognized in cores of this unit (Fig. 18). The structures are generally one to three inches in length and less than 1/2 inch in thickness. They may represent scours subsequently filled with coarser silt. They were not observable unless the cores were washed with a high pressure stream of water. The lower contact of the silts to the deep-water clays appears gradational over several feet.

In the poorly drained western part of the Environmental Control Area underlain by the lacustrine silt unit, perched water table conditions frequently exist. Water-table observation wells located adjacent to areas frequently covered by water indicate that the water table lies three to five feet below ground level. This ponding is thought to be due to local interbeds of silty clay near the soil zone which retard downward percolation of surface water.

Lacustrine Clay Unit

The lacustrine clay unit was deposited during a high-water phase of Glacial Lake Agassiz (McPherson, 1970). The thickness has a maximum of 25 feet near the Winnipeg River. Carbonate pebbles are present throughout this unit but become more common in the lower portions. Fragments of till-like material up to 10 inches in diameter (Fig. 19) were noted in isolated cases. Angular buff-coloured calcareous silt clasts are very common

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near the bottom of the unit (Fig. 20). The pebbles, till and silt clasts are probably due to ice rafting although Weller (1960), Hills (1963) and Elson (1966) have discussed possible alternate origins for such features.

Laminae of fine to very fine sand are present throughout the unit at angles up to 90° to the bedding (Fig. 21). These laminae may cut horizontal or shallow dipping laminae of clay and silty clay or may be conformable to them. A probable origin of the sand laminae is infilling of slump or dessication cracks formed by fluctuations in the lake level.

The lower contact of the clay is marked by a stratified zone up to three feet thick of pebbly, sandy silt, and silty sandy clay (Fig. 22).

Grain-size analyses of the glacio-lacustrine clays conducted by Zwarich (1968) on five samples collected from drill holes near the present radioactive disposal area (Fig. 2) indicate a 60:30:10 ratio of clay, silt and sand, respectively. It is expected that the largest portion of the silt and sand occur as laminae within the clay unit rather than a homogeneous unit of clay, silt and sand.

Inspection of Shelby tube cores taken near piezometer nest No. 20 (Fig. 2) indicate well-defined jointing throughout this unit. The joints may appear as thin dark lines cutting laminae (Fig. 23) or as planes coated with carbonate and gypsum precipitates (Fig. 24). Rootlets follow the joint surfaces as deep as 14 feet (Fig. 20).

The results of Hvorslev response tests indicate that the lacustrine clay unit is characterized by hydraulic conductivities in the range of 1×10^{-10} to 1×10^{-7} fps at depths below ground surface greater than 14.5 feet and by conductivities in the range of 1×10^{-10} to 1×10^{-5} fps at depths less than 14.5 feet below ground surface. Laboratory tests conducted by Templeton Engineering Company Limited (1960) on small samples obtained from the lacustrine clay near the plant (south half, section 21) yielded values in the range 1×10^{-10} to 3×10^{-9} fps. This suggests that joints, fractures or other secondary in situ characteristics of the lacustrine clay unit significantly increase the hydraulic conductivity. A more detailed analysis of the hydraulic conductivities associated with the lacustrine clay is discussed in a later section.

Clay-loam Till Unit

The lacustrine clay unit grades through a stratified zone of pebbly, sandy silt, and silty sandy clay, a few feet thick into a pebbly, carbonate-rich, clay-loam till. The deposit ranges from 0 to 30 feet in thickness. Grain-size analyses (Zwarich, 1968) of composite samples show approximately equal proportions of clay, silt and sand near the upper contact with the sand content increasing to over 50 per cent near the lower contact. Pebbles and cobbles are predominantly dolomitic with the remainder commonly being highly weathered Precambrian material. The lower contact is marked by a pavement of Precambrian cobbles and boulders. Considerable difficulty penetrating this layer was encountered at many locations. This unit correlates with the Libau Drift mapped and described by McPherson (1968) in the area west of the Winnipeg River.

Joint planes coated with carbonate precipitates (Fig. 25) were commonly observed in Shelby tube cores taken near the upper contact of this unit.

The results of Hvorslev response tests indicate that the clay-loam till is characterized by hydraulic conductivities in the range of 1×10^{-7} to 1×10^{-4} feet per second (fps). Joints appear to account for a significant secondary permeability network although only a few irregular joint-fracture features were observed in the Shelby tube samples from this unit. A more detailed analysis of the hydraulic conductivities associated with this unit is presented in a later section.

Basal Sandy Drift Unit

The basal sandy drift unit underlies the clay-loam till unit in the western third of the study area (Figs. 15 - 17). The deposit varies in thickness from 0 to 15 feet. Texturally, it varies from a silty till to unsorted gravel and sand to a well sorted fine to coarse-grained sand with few, if any, till-like features. Compositionally the unit is characterized by angular rock fragments of Precambrian Shield lithologies. Sedimentary rock fragments were observed only in isolated cases. The upper contact of the basal sandy drift with the clay-loam till is defined by a boulder pavement.

McPherson (1970) states:

> The main basis for distinguishing the Belair Drift is its occurence on surface as a sandy end moraine or outwash, its characteristic mineralogy indicating it was primarily derived from acid igneous rocks, and its stratigraphic position in the subsurface being stratigraphically lower than Lake Agassiz sediments and Libau Drift.

By this definition, the basal sandy drift unit can be stratigraphically correlated with the Belair Drift.

The results of Hvorslev response tests indicate that the basal sandy drift is characterized by hydraulic conductivities in the range of 1 x 10^{-7} to 1 x 10^{-4} fps. A detailed analysis of the hydraulic conductivities associated with this unit is presented in a later section.

Undifferentiated Sandy Till

In the eastern portion of the area the lacustrine sands are overlain by a deposit which is apparently a sandy and in places silty till. Only limited test hole data is presently available in this area, making correlation of this unity to the western portion of the area impossible.

Lacustrine Sand Unit

The lacustrine sand unit consists of up to 60 feet of fine to medium-grained sand in the northeastern portion of the area (Fig. 15). In the lower portions, several interbeds of silt and clay, often containing angular carbonate rock fragments. The lacustrine sand unit is overlain by the clay-loam till, although its stratigraphic relationships to the basal sandy drift are not clear.

The results of Hvorslev response test indicate hydraulic conductivities in the range of 1 x 10^{-7} to 1 x 10^{-5} fps, hydraulically similar to the basal sandy drift.

Precambrian Bedrock

Underlying the glacial drift in the WNRE area are granite and granodiorite of Precambrian age (Templeton, 1960). The bedrock contact defined in Figs. 15 - 17 has been assumed to occur within a foot or two of the maximum depth penetrated at each of the test holes drilled to refusal. This assumption is supported by the results of a geophysical investigation of the Environmental Control Area by Pakiriah (1970), by the relative uniformity of penetration depths within most portions of the area. The similarity of the steady-state mathematical model and the field data also support this location for the impermeable lower bounding surface.

Templeton Engineering Company Limited (1960) concluded on the basis of four diamond-drill holes in the southern half of section 21 that a deposit of "broken and weathered granite bedrock rather than glacial till" rests on the solid bedrock surface. Results of the present investigation indicate that this is a misinterpretation of the deposit here referred to as the basal sandy drift.

Although the overall bedrock surface in the Environmental Control Area has been defined to be gently rolling, local relief of over 20 feet over a horizontal distance of 10 feet was observed at tritium injection site No. 2. McPherson (1970) noted local relief on the bedrock surface in drift covered areas near Pinawa, Manitoba in excess of 100 feet.

The bedrock is assumed to have negligible permeability. Examination of outcrops near WNRE and the steady-state mathematical model support this assumption.

FIELD STUDIES OF GROUNDWATER FLOW

The objective of this portion of the investigation was to define the geohydrologic regime in the Environmental Control Area by interrelating studies of fluid potential distribution, hydrochemistry, subsurface temperature variations, groundwater flow velocities and fracture flow characteristics.

Groundwater Flow Pattern

A piezometer network of 210 piezometers and water-table observation wells was utilized to establish the hydraulic potential distribution (Figs. 26 - 28) and the magnitude of transient head variations generated within the system by water-table fluctuations. Representative piezometer hydrographs (Figs. 8 - 10) illustrate the response to seasonal precipitation and indicate short term reversals in hydraulic potential gradients in the central discharge area due to water-table fluctuations. A corresponding increase in recharge head is observed in the central recharge area. These transient effects would not be expected to affect the flow pattern as the condition is short-term and rapidly returns to the original gradient direction.

Data used for preparation of flow diagrams (Figs. 26 - 28) were taken from piezometer hydrographs (Figs. 8 - 10 and Appendix C) as an average value for 1969 and 1970. Values for 1968 were discarded due to abnormally high rainfalls which resulted in highly fluctuating values (Appendix C).

The flow pattern interpretations (Figs. 26 - 28) were made according to the methods of van Everdingen (1963) to account for a 10:1 vertical exaggeration and Freeze (1969) to approximate refractions of equipotential lines at permeability field boundaries defined by test drilling. The potential distribution indicates two areas of recharge referred to as the upland and the central recharge areas and two areas of discharge referred to as the central and lowland discharge areas (Fig. 29). The upland recharge area occurs within the outcrop area of the lacustrine sand and gravel. The lowland discharge area is confined to the banks of the Winnipeg River. Vertical discharge gradients in the central discharge area have a maximum of 0.3 ft/ft with a head avove the average water-table level of up to 12 feet and vertical recharge gradients in the central recharge area have a maximum of 0.2 ft/ft. Horizontal potential gradients are restricted to the basal sandy drift and the lacustrine sand with a local horizontal gradient existing in a narrow zone along the boundary between the central discharge and central recharge areas.

A flow pattern interpretation (Fig. 28) along a north-south cross section along the western boundary of Section 28 indicates recharge to the basal sandy drift except near the northern edge of the study area. The sandy drift unit pinches out and small discharge gradients are present.

The hydraulic potential distribution suggests two scales of flow regimes in the Environmental Control Area. The smallest scale 'local' flow systems consists of recharge in the upland recharge area and discharge in the central discharge area, and recharge in the central discharge area discharing into the Winnipeg River (Fig. 29).

The larger scale 'regional' flow system consists of recharge in the upland recharge area and discharge into the Winnipeg River with lateral ground-water flow continuing under the central discharge area. This co-existence of flow systems has been described by Meyboom (1962) and Tóth (1966), as well as others.

The seasonal stability of recharge-discharge boundaries was studied in detail by installing a line of piezometers at closely spaced intervals across the central discharge-central recharge area boundary in section 28 (Fig. 29). During the period of study from summer, 1968 to fall, 1970, this boundary was not observed to vary significantly. On the basis of these data, it has been assumed that the recharge-discharge boundaries are stable with respect to seasonal fluctuations of precipitation, evapotranspiration, and freezing.

Hydrochemistry

The major-ion chemistry of groundwater in a shallow flow system results from numerous geochemical processes. The results of studies by such investigators as Meyboom (1962), Tóth (1966), Parsons (1967), Rozkowski (1967), Charron (1969), van Everdingen (1970), and Cherry, et al (1971), suggest that the most important geochemical influences are: (a) generation of gases in the soil zones of recharge areas, (b) solution of porous media minerals, (c) precipitation of mineral phases within the pore network, (d) ion exchange between the pore solution and clay minerals in the porous medium, and (e) oxidation-reduction reactions. These processes are interdependent and are affected by mineral associations in the porous media, the relative order of geologic units along the groundwater flow path rate of groundwater flow and the length of the groundwater flow path. Using these guidelines, the major-ion distributions and electrolytic conductivity in the groundwater regime in the Environmental Control Area were investigated as a means of refining the flow system interpretation based on the hydraulic potential distribution.

Hydrochemical cross sections (Figs. 30 and 31) were prepared for Ca^{++}, Mg^{++}, Na^{+}, Cl^{-}, HCO_3^{-}, CO_2^{-} and $SO_4^{=}$ and electrical conductivity and exhibit hydrochemical patterns which correlate very closely with the flow pattern interpretations obtained from hydraulic head data (Figs. 26 - 28). In recharge areas the conductivity increases downwards to a maximum of 600 millimhos/cm. In the central discharge area conductivity increases from a minimum of 10 millimhos/cm near the Precambrian bedrock to greater than 680 millimhos/cm near the water table. A complex hydrochemical pattern is developed in a zone along the boundary of the central recharge and central discharge boundary (Figs. 30 - 32). This is probably due to a sluggish flow regime with long groundwater residence times resulting from low hydraulic potential gradients coupled with low permeability material, as well as short-term reversals of groundwater potential distribution west of this zone.

Groundwater in the lacustrine sand deposit and the basal sandy drift up to the central recharge-central discharge area boundary has very low concentrations of dissolved solids. Samples taken from shallow piezometers in the upland recharge area indicate that essentially all the dissolved solids are picked up in or near the soil zone. The subsequent lack of major variations in the dissolved mineral load in these deposits is due to the low remaining H_2CO_3 agressivity as well as the lack of relatively soluble salts in the predominantly quartzo-feldspathic sand. The more permeable deposits would also tend to allow a more active flow regime with resulting shorter residence time and therefore fresher water.

West of the central discharge-central recharge area boundary in the basal sandy drift, conductivity increases over several hundred yards to a maximum of 450 millimhos/cm. This rapid increase results from downward influx of highly mineralized water from the upper units, possibly enhanced by increased availability of fine-grained soluble materials in the drift unit.

In the lacustrine clay and clay-loam till units in the central recharge area, downward seepage is accompanied by increases in Na^{+}, Ca^{++}, Mg^{++}, Cl^{-}, and $SO_4^{=}$. In the central discharge area, upward seepage is accompanied by similar increases. This is attributed to the availability of soluble sulphate and chloride salts in the fine grained units.

The hydrochemical patterns (Figs. 30 and 32) indicate that precipitation infiltrates in the lacustrine sand and moves downward and laterally with dissolved solids remaining below 50 mg/l. A portion of the water in the central discharge area is forced upwards into the overlying upper till and lacustrine deposits with total dissolved solids reaching 200 mg/l near the water table.

Water infiltrating in the central recharge area rapidly picks up a maximum of 6000 mg/l dissolved solids as it descends to the basal sandy drift unit where it is somewhat diluted by the fresher westward lateral flow from the upland recharge area. The combined flows travel over the Precambrian surface to discharge in and near the Winnipeg River.

Field pH data have been obtained (Appendix D) and will be incorporated in a future report dealing more intensively with the hydrogeochemical regime in the WNRE area.

Groundwater Temperature Distribution

Groundwater temperature variations with depth and time were studied during the spring and summer of 1969. Typical variations (Fig. 32 and Appendix E) indicate that seasonal temperature variations affect the groundwater temperature through the full section of glacial drift at WNRE.

There is an apparent correlation of the range of temperatures and discharge-recharge zones. From graphical results (Appendix E) of 13 piezometer nests in discharge areas and 8 nests in recharge zones it was found that the mean of groundwater temperatures were 1.1 C° and 1.6 C° respectively for the first week of July, 1969. At this time the approximate mean groundwater temperature was 5.2° C. Temperature data from water-table observation wells was not included in this test.

Tracer Velocity Studies

To obtain real values of horizontal groundwater flow velocity, tritiated heavy water was injected into the flow system at three selected locations (Figs. 11 - 13) in the Environmental Control Area. Injection site 1 (Fig. 11) was installed in the basal sandy drift in the central discharge area. During the injection process the tracer was observed to arrive at sample points 13 and 15 located approximately 8 feet from the injection point. Arrivals of the tracer at other sample points located

8 to 48 feet from the point of injection were not observed during the period July, 1969 to August, 1970 although fluctuations in tritium concentration were noted in the active sample points. The movement of the tritium is confirmed by the gradual decrease in tritium concentration (Appendix F) at the injection point. Hydraulic connection of all sample tubes to the injection point was confirmed prior to injection of the tracer by pressure testing.

The tracer is known to have been successfully injected into the groundwater flow regime in the basal sandy drift. The data show that the lateral rates of groundwater movement have not been sufficient to move the tracer completely away from the area of injection. Hydraulic potential data require that the tracer front move westward and it is very unlikely that the tracer front could move undetected between the sample tubes to the west. Since sample tubes are present from 8 to 15 feet west of the injection site, it can be safely assumed that west-lateral groundwater velocities are considerably less than 10 feet per year at this location.

Injection site 2 (Fig. 12) was installed in the basal sandy drift in the central recharge area. Arrivals of the tracer during injection was observed in sample tubes 26 - 43, 1 and 4. Arrivals of the tracer at other sample tubes located 8 to 58 feet from the point of injection were not observed during the period August 1969 to August, 1970, although decreases in tritium concentrations were observed in the active sample tubes and the injection well. The procedures and results were very similar to those observed at injection site 1. This indicates a maximum horizontal flow velocity of less than 10 feet/year.

Injection site 3 (Fig. 13) was installed adjacent to injection site 2 in the central recharge area and bracketed the contact of the lacustrine clay and the clay-loam till units. Arrival of the tracer was observed in sample tube 6 during injection. Arrivals of tritium at sample tubes 8 and 48 feet from the injection point were not observed during the period August, 1969 to August, 1970. However, very low tritium levels did occur sporadically in various sample tubes, probably due to contamination during sampling. Similarly to injection sites 1 and 2, this indicates maximum westward horizontal flow velocities of less than 10 feet/year.

The experiment was designed to detect horizontal flow velocities and was not capable of detecting vertical flow. The sampling and injection methods resulted in a large mass of tritiated water (Figs. 11 - 13) which, if moving horizontally, would necessarily pass through at least one sample point.

The possibility of hydraulic fracturing due to the pressure injection method would increase the flow velocity because of increased permeability and would not have caused an anomalously low value for the flow rate. Movement of the tracer was confirmed by fluctuating tritium levels in active holes (Appendix F).

A previous tracer study in 1967 by B. Lund (1967) gave a horizontal flow velocity of 430 feet per year. The study was conducted from surface to a depth of 20 feet in the centre of section 28 (Fig. 3) in an area of extremely low lateral hydraulic potential gradients. The velocity determined by here is now thought to be due to flow in the unsaturated zone as a result of a groundwater 'mound' built by the injection of tritiated heavy water rather than flow through the saturated zone.

Tracer Investigations of Secondary Permeability Characteristics

Joints in the lacustrine clay and clay-loam till units were observed in Shelby tube cores and disturbed samples. In an attempt to define the effects of the joints on permeability in the fine-grained deposits, a fluorescent dye, sodium fluorescein was injected into these units and then Shelby tube cores were taken of the injected material.

Examination of cores under ultraviolet radiation showed no visible dye on joint surfaces or in the bulk of the material. The most permeable joints are coated with carbonate accumulations and the coating may mask the presence of the dye. Intergranular flow of groundwater in the clay unit and upper carbonate till unit is probably negligible with respect to flow through joints. Photographs of fractures (Figs. 19 - 25 and Appendix A) support this view.

Further study on the problem of quantitative determination of fracture flow is being considered. This aspect is very important to radioactive waste disposal as ion exchange capacities of a geologic medium will be drastically reduced if waste solutions do not have access to intergranular pore spaces.

Hvorslev Response Tests

Of the 210 piezometers installed in the area of investigation, 170 were subjected to response tests based on the principles and methods described by Hvorslev (1951; 1954). The ratios of vertical versus horizontal permeabilities were assumed unity for all the hydrostratigraphic units. Data summarized by Davis and DeWiest (1966) and Bakhtiari (1970) suggest that this assumption is normally acceptable within 50 per cent for sandy unconsolidated deposits not containing fine-grained interbeds or oriented platy mineral orientations. The K_v/K_h ratios for the fine grained deposits were assumed to be unity due to the relatively orthogonal orientation of joints and laminae prominent in these deposits, although the actual value of K_v/K_h was not determined.

Hydraulic conductivities obtained from water-level response tests can be affected by: (1) water-intake geometry, (2) textural variations within the intake zone, (3) disturbances of the formation during piezometer installation (4) nature and efficiency of the grout seal above the intake zone, (5) gas accumulations in the intake zone, (6) any artificial restriction or enhancement of the hydraulic conductivity of the formation or intake zone resulting from piezometer installation. Because of these and other factors involved in water-level response tests, the resulting hydraulic conductivities are likely not reliable to more than one order of magnitude.

Figures 33 and 34 summarize the permeabilities calculated from the water-level response tests. Data which appear to have been significantly affected by one or more of the above factors have been omitted. The exclusion of results was usually based on obvious evidence of sedimentation or clogging or poor graphical correlations of water-level recovery with time.

All of the 7 piezometers in the lacustrine sand unit from which reliable water-level response data were obtained yielded hydraulic conductivities in the range 1×10^{-7} to 1×10^{-4} fps. Of the 34 piezometers in the basal sandy drift from which reliable data were obtained, 22 yielded values in the range 1×10^{-7} to 1×10^{-5}. The remainder of the conductivities are in the range 1×10^{-7} to 5×10^{-10}. Auger samples from these units have been compared visually to glacial sands from southwestern Manitoba. The visual textural correlations support the conclusion that conductivities in the range 1×10^{-7} to 1×10^{-5} are characteristic of most zones within the two units.

Of the 36 piezometers in the clay-loam till from which reliable water-level response data were obtained, 20 yielded hydraulic conductivities in the range of 1×10^{-9} to 1×10^{-7} pfs. Of the remainder, 9 are in the range 1×10^{-7} to 9×10^{-6} and 9 in the range 1×10^{-9} to 1×10^{-10} fps. There is little doubt that joints in the clay-loam till account for most, if not all, of the hydraulic conductivities larger than about 1×10^{-8} fps and that the wide range of the data reflects heterogeneous characteristics in the permeability system. Variability in the character and frequency of joints in till at numerous locations in western Canada has been observed by A. Vonhof (personal communication, 1970).

Hydraulic conductivities in the lacustrine clay unit vary within the relatively wide range of 1×10^{-10} to 1×10^{-5} fps. Fig. 35 indicates that 10 of the 31 piezometers located in this unit at depths between 5 and 14.5 feet below ground surface yield hydraulic conductivities greater than 1×10^{-7} fps. Of the 14 piezometers in this unit at depths below 14.5 feet, only one yielded a hydraulic conductivity greater than 1×10^{-7} fps. The hydraulic conductivity data suggest that the lower portion of the lacustrine clay and the clay-loam till have rather similar hydraulic properties.

The significantly higher frequency of larger hydraulic conductivities nearer the ground surface can be accounted for by the increased occurrence of joints, dessication cracks, and channels cuased by plant roots and burrowing animals. The seasonal water-table fluctuations in the area underlain by the lacustrine clay is between 2 and 7 feet below ground surface. Decline of the water table below 7 feet probably occurs during years of exceptionally low precipitation. The clay fraction of sediments in the Lake Agassiz basin generally contain abundant montmorillonite (Kushnir, 1970) which characteristically undergoes major volume changes on wetting and drying. The zone of water-table fluctuation is subject to numerous cycles of wetting and drying and is therefore commonly a zone in which dessication cracks and joints develop.

STEADY-STATE MATHEMATICAL MODEL OF THE FLOW REGIME

The steady-state mathematical model (Morris, 1969) was used to: (a) refine the interpretation of the groundwater flow pattern, (b) test and refine the field interpretation of the subsurface permeability distribution, (c) test the sensitivity of the flow regime to water-table fluctuations, (d) test the assumption of an impermeable bedrock contact and (e) determine if this mathematical model was useful in predicting flow patterns as a method of initial stage planning of hydrogeologic models.

The boundary conditions defining the limits of the model (Fig. 35) are: (a) the bedrock surface is a lower bounding impermeable surface, (b) the lateral bounding surfaces are vertical and coincide with the topographic high of the lacustrine sand to the east and the Winnipeg River to the west, (c) the water table is constant and acts as a free-surface and (d) steady-state conditions exist.

The models tested include isotropic and anisotropic homogeneous, isotropic and anisotropic 2-layer and isotropic and anisotropic 2-layer with variations in permeability within the basal sandy drift and the lacustrine sand and gravel. Most combinations of permeability ratios from one to 10,000 were modelled. In all cases the lacustrine silt unit, lacustrine clay and clay-loam till were considered to have unit vertical permeability.

By using a water-table configuration determined from the observation well network (Fig. 26) a model was developed which very closely approximated the conditions observed in the field. This model (Fig. 35) was developed using unit permeability for the clay-loam till, clay and silt deposits and a permeability of 1,000 for the sandy drift and lacustrine sand deposits. This model does not, however, simulate the magnitude of recharge gradients existing in the central recharge area, although all other features are very similar.

Studies currently in progress are attempting to determine whether improved correlations between the model and the flow system can be obtained. The modelling technique is also being used in an analysis of cross section B-B' (Fig. 27). The results described above indicate that (a) although from a small-scale viewpoint each hydrostratigraphic unit is heterogeneous in texture and permeability, it is only the large scale permeability contrasts between the units which are the dominant internal factor in the development of the flow pattern, (b) the initial assumption that the bedrock is relatively impermeable is acceptable and (c) the location of the bedrock contact as indicated by the drilling data is reasonable. Although many different conductivities have been assigned to the basal sandy drift and the lacustrine sand, the results obtained from the model using a uniform conductivity continue to be the closest representation of the head distribution.

SUMMARY OF CONCLUSIONS

The stratigraphic section found in the WNRE Environmental Control Area conforms generally to the Pleistocene stratigraphic succession defined by McPherson (1968, 1970).

The glacial drift sequence includes a lacustrine sand and gravel deposit, a late-phase deposit of Glacial Lake Agassiz silts, a deep-water deposit of clay and silty clay, a clay-loam till, a basal sandy drift rich in Precambrian-derived pebbles and boulders, an undifferentiated sandy till, and a uniform lacustrine sand. The glacial drift is underlain by relatively impermeable Precambrian granite and granodiorite.

The groundwater flow pattern is characterized by a westward flow to the Winnipeg River with four zones of recharge and discharge. From east to west these are: an upland recharge area consisting of an outcrop of the lacustrine sand and gravel which act, as a groundwater divide, a central discharge area, a central recharge area and a lowland discharge area confined to the banks of the Winnipeg River which is the groundwater divide to the west. Tracer studies at three locations suggest maximum groundwater flow velocities to be less than 10 feet per year.

Ca^{++}, Mg^{++}, Na^{+}, $SO_4^{=}$ and electrolytic conductivity increased in the directions of apparent groundwater movement and correlated with flow directions interpreted from the hydraulic potential distribution. Values increased laterally in the more permeable basal units from the upland recharge area in the east to the Winnipeg River. Values in the till and lacustrine units increase upwards in the central discharge area and downward in the recharge areas. A more complex hydrochemical pattern has developed along a zone between the central discharge and central recharge area boundary due to stagnant flow conditions. The excellent correlations of hydrochemistry and groundwater flow pattern are due to the relatively active flow regime in the Environmental Control Area, lack of solubility constraint for most major ions, and highly contrasting hydrochemical facies in each geologic unit. Hydrochemistry confirmed flow pattern interpretations which would otherwise have required considerably more detailed instrumentation.

Laboratory studies of cores taken from the lacustrine and upper till units indicate that groundwater flow is occurring mainly along joint surfaces and sand laminae. This is supported by the accumulation of carbonate precipitates on joint surfaces and oxidized zones. Attempts to quantitatively describe joint-fracture flow by means of fluorescent dye tracing was not successful.

A steady-state mathematical model of the groundwater flow regime using boundary conditions defined by test drilling and the hydraulic potential distribution suggests a permeability ratio between the lacustrine clays and clay-loam till deposits and the basal sandy drift and lacustrine sand and gravel units of 1:1000. The model supports the conclusion that the water-table conditions and the discharge-recharge boundaries are relatively stable. The use of this model with preliminary hydrostratigraphic data may allow a more economical approach to simple hydrogeologic investigations.

The complementary use of several hydrogeologic techniques has allowed a relatively detailed interpretation of the shallow groundwater flow system in glacial drift at WNRE. Some of the more general conclusions resulting from the investigation are summarized as follows:

1) A comprehensive understanding of the stratigraphic framework is a prerequisite to the design of a piezometer network and the interpretation of the resulting potential distribution.

2) Hydrochemical patterns are a result of flow patterns and stratigraphy and may be used in some cases to aid in groundwater flow interpretations.

3) Influence of joints and small sand laminae increase hydraulic conductivities of otherwise low-permeable materials.

4) A finite-element steady-state model of groundwater flow may refine interpretations of field data and reduce the cost of detailed field study.

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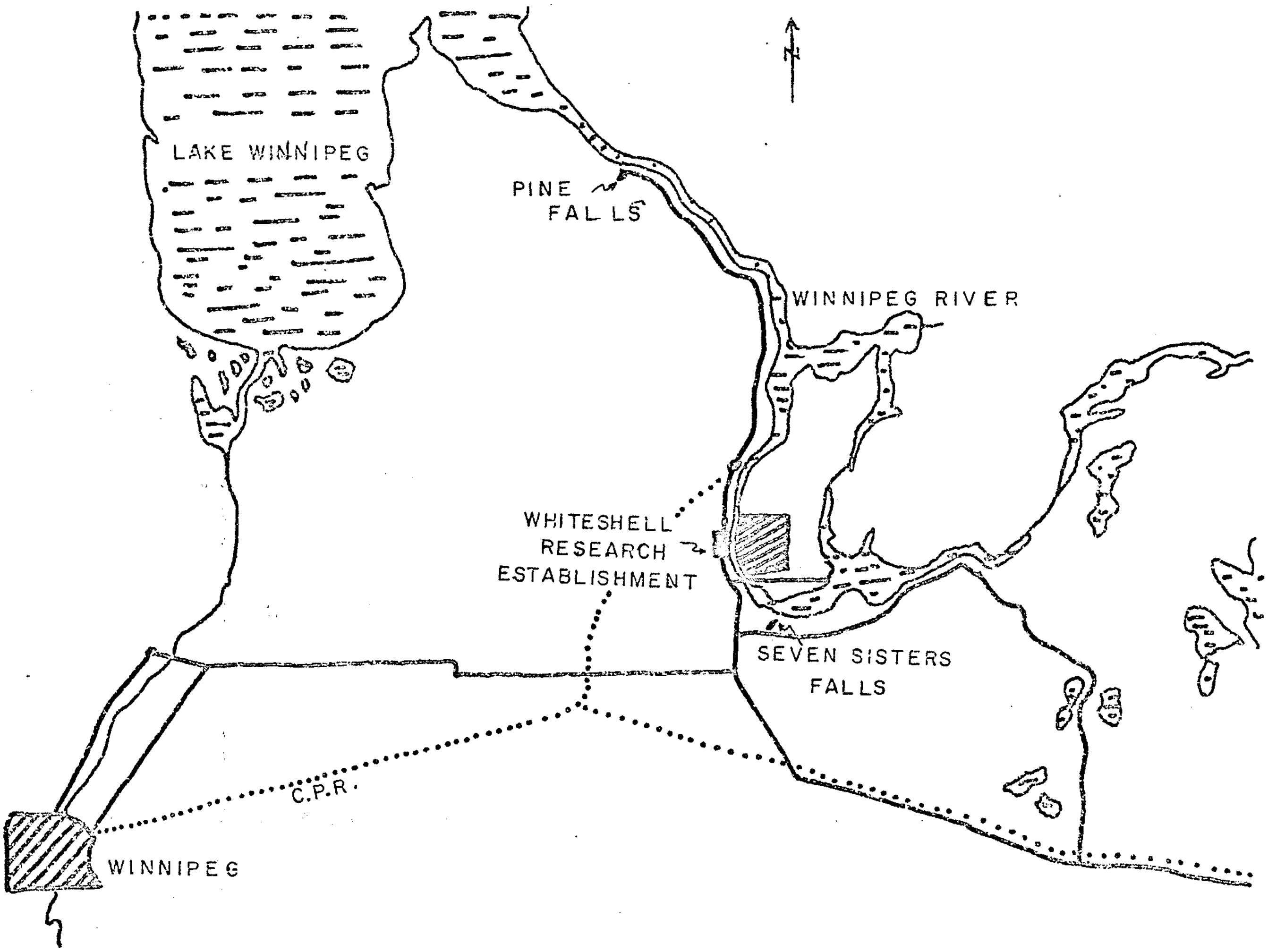


FIG. 1. Vicinty Map-Whiteshell Nuclear Research Establishment

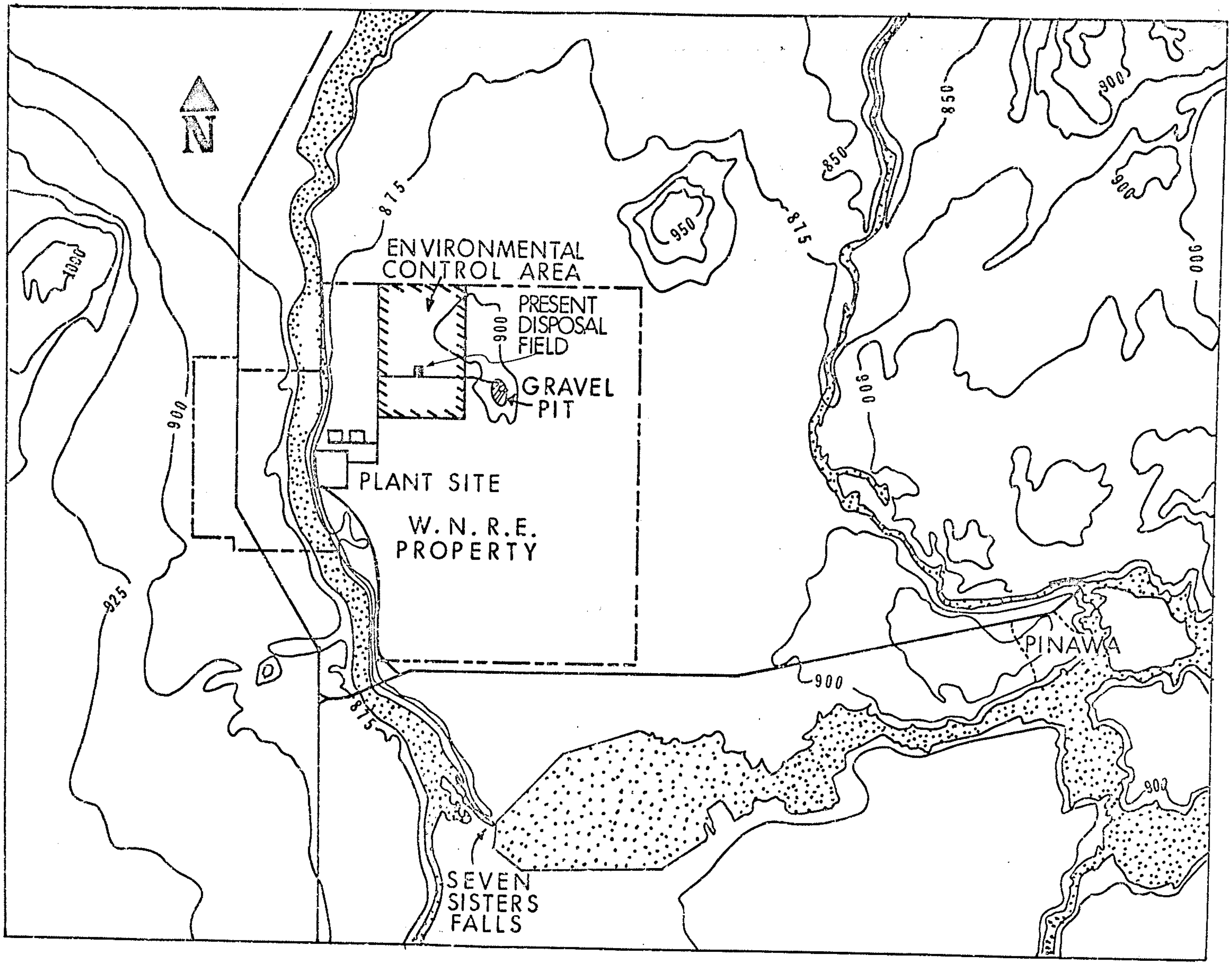


Fig. 2   Environmental Control Area and present radioactive disposal field, WNRE.

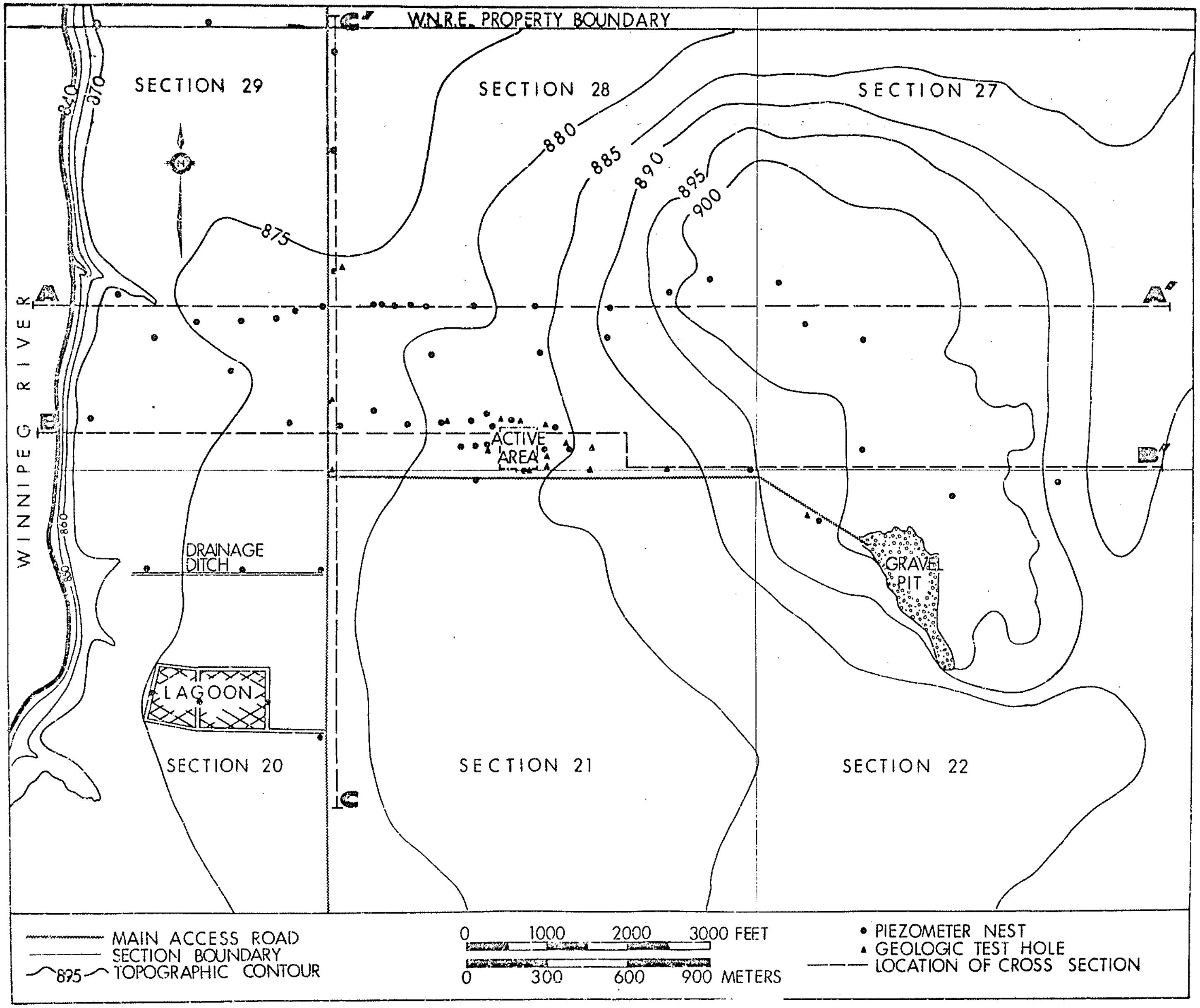


Fig. 3 Topography and location of instrumentation.

Fig. 4 Looking west towards Winnipeg River over portion of Environmental Control Area.

Fig. 5 Modified infra-red photograph of the upland area of recharge.

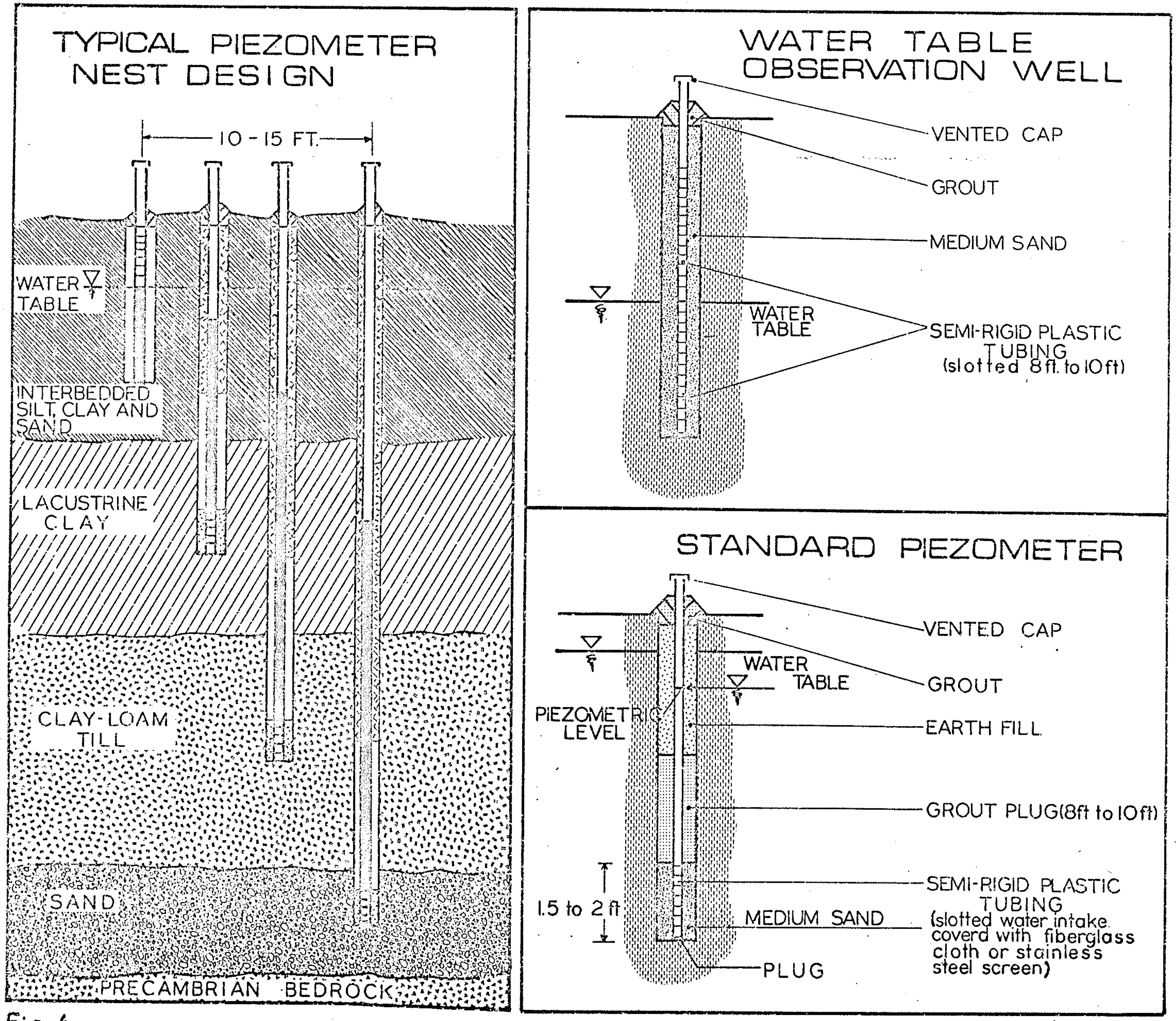

TYPICAL PIEZOMETER NEST DESIGN
10 - 15 FT.
WATER TABLE
INTERBEDDED SILT, CLAY AND SAND
LACUSTRINE CLAY
CLAY-LOAM TILL
SAND
PRECAMBRIAN BEDROCK
WATER TABLE OBSERVATION WELL
VENTED CAP
GROUT
MEDIUM SAND
WATER TABLE
SEMI-RIGID PLASTIC TUBING (slotted 8ft. to 10ft)
STANDARD PIEZOMETER
VENTED CAP
WATER TABLE
GROUT
PIEZOMETRIC LEVEL
EARTH FILL
GROUT PLUG(8ft to 10ft)
1.5 to 2 ft
SEMI-RIGID PLASTIC TUBING (slotted water intake coverd with fiberglass cloth or stainless steel screen)
MEDIUM SAND
PLUG

Fig. 6

P-13-5, P-13-12.4, P-13-20, P-13-31 installed 25/7/68 SHEET #1to 14/8/68

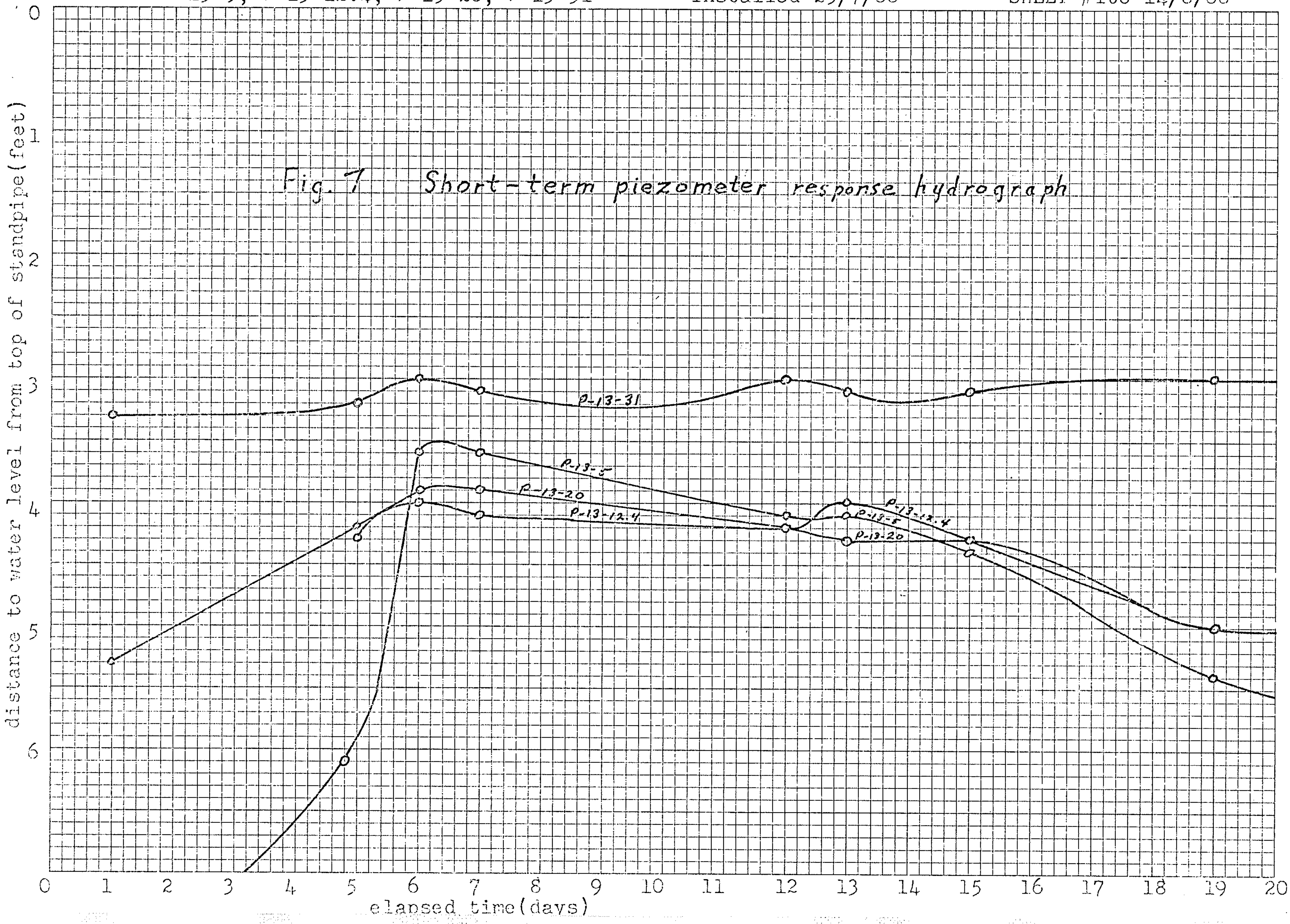


Fig. 7 Short-term piezometer response hydrograph

last point 14/8/68

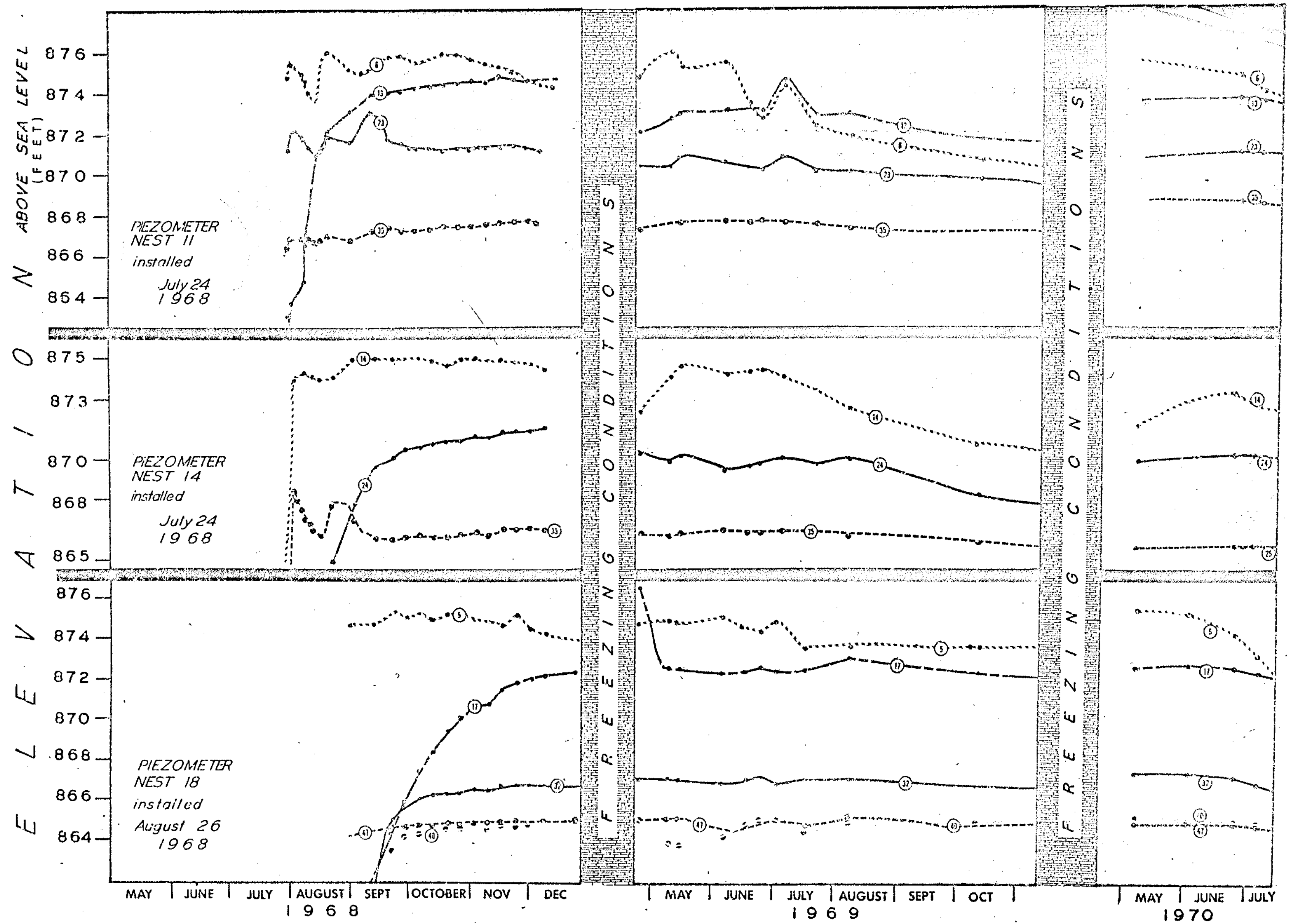


Fig. 8 REPRESENTATIVE PIEZOMETERS IN CENTRAL RECHARGE AREA

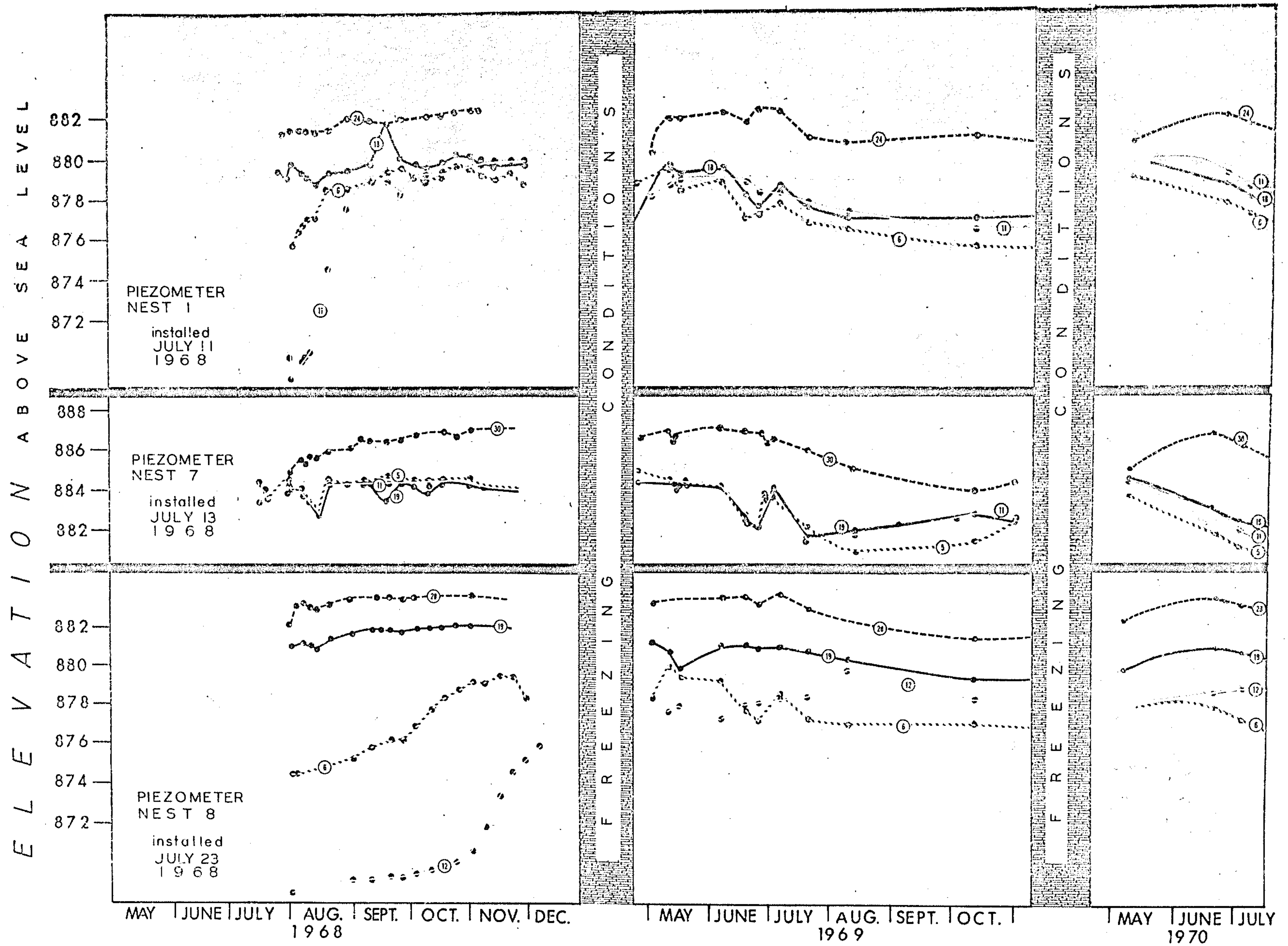


Fig. 9 REPRESENTATIVE PIEZOMETERS IN CENTRAL DISCHARGE AREA

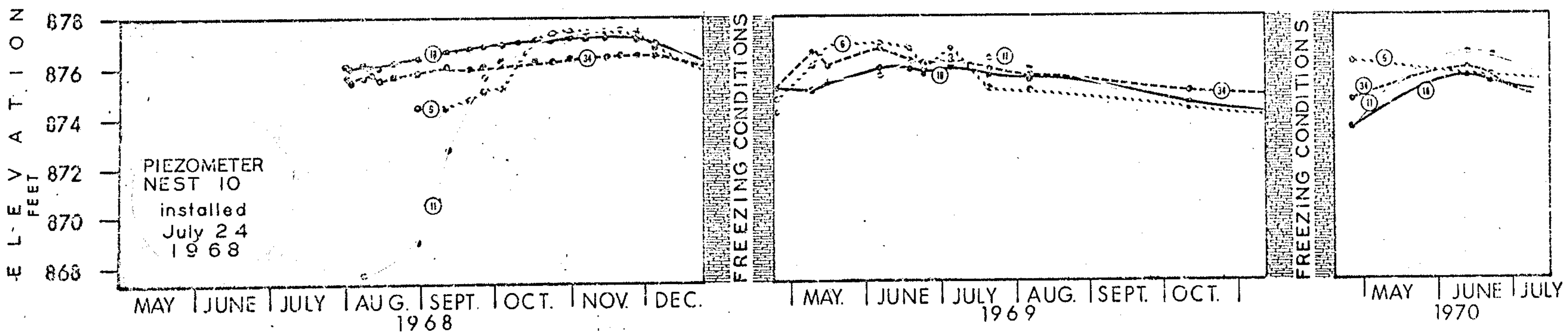
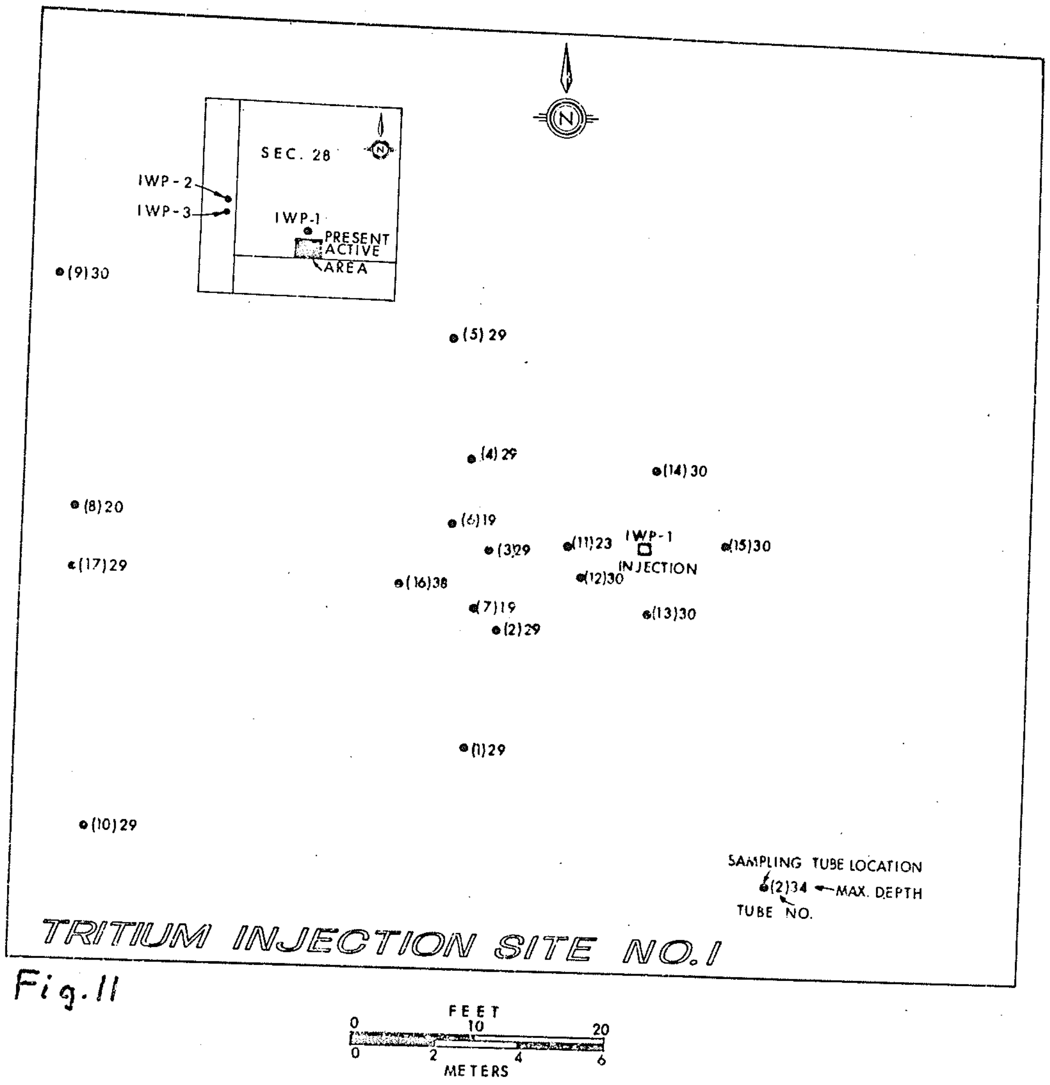


Fig. 10 Piezometer nest in transition zone between central recharge area and central discharge area



TRITIUM INJECTION SITE NO. I

Fig. 11

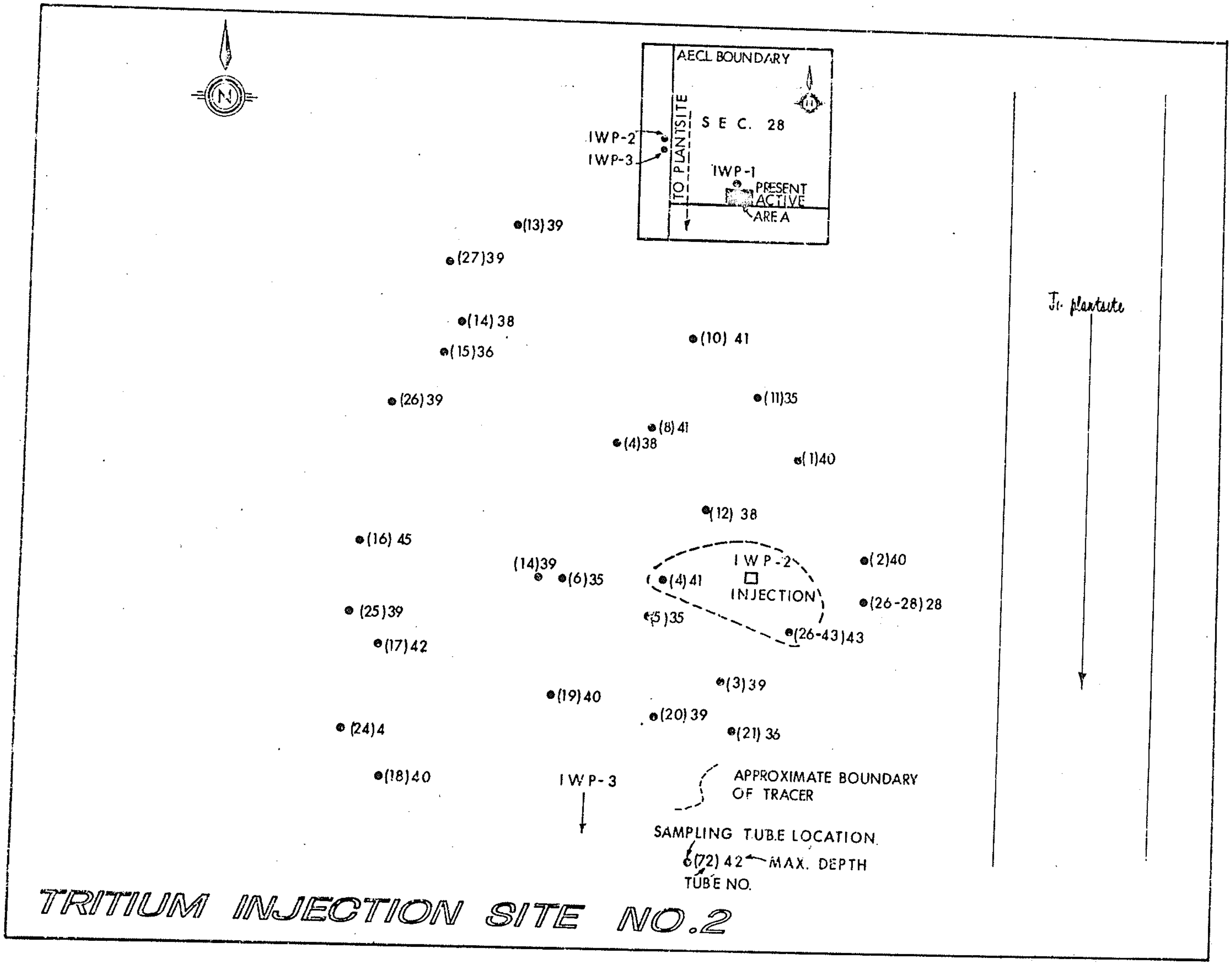


Fig. 12 Layout of tritium injection site No. 2.

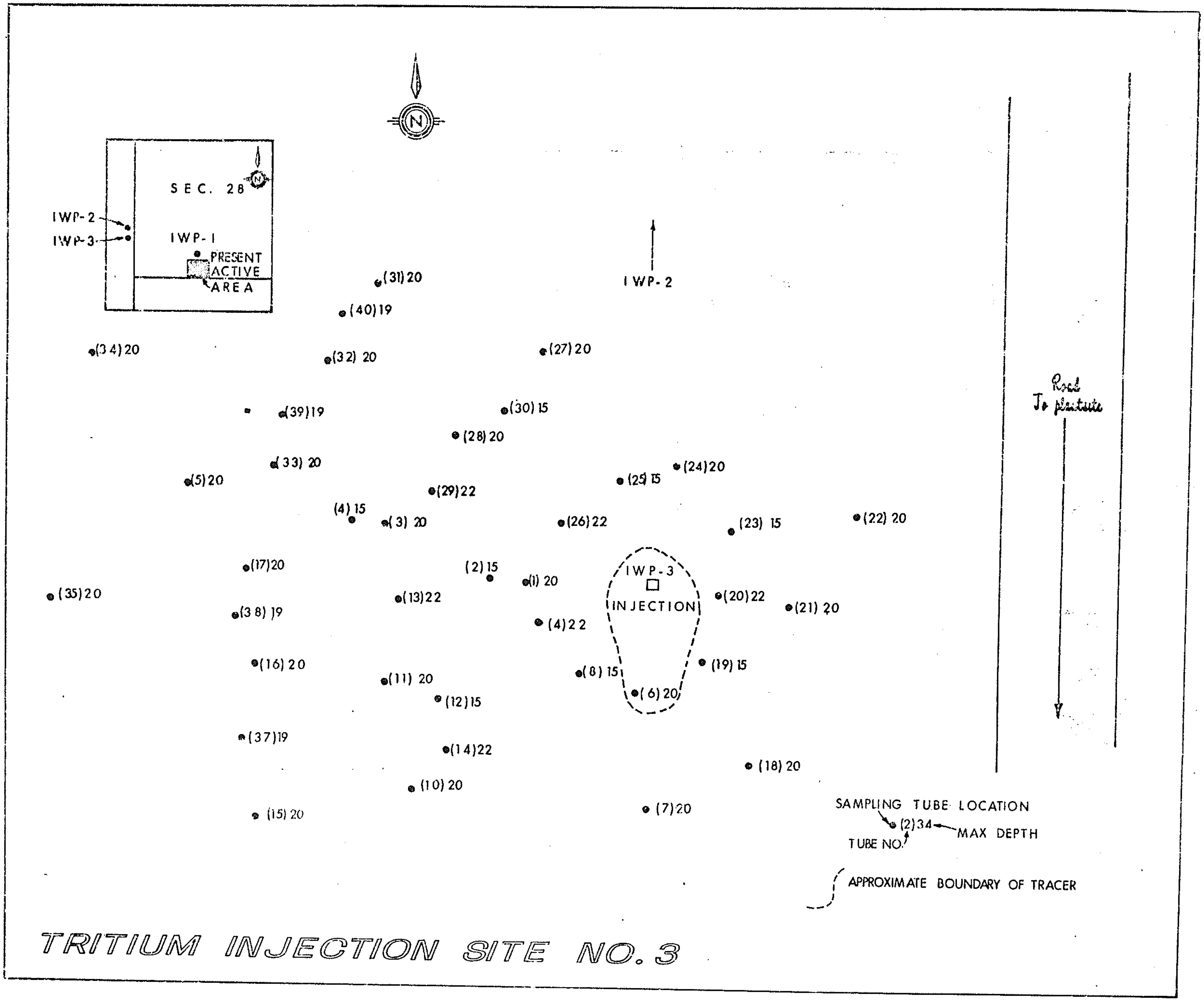


Fig. 13 Layout of tritium injection site No. 3.

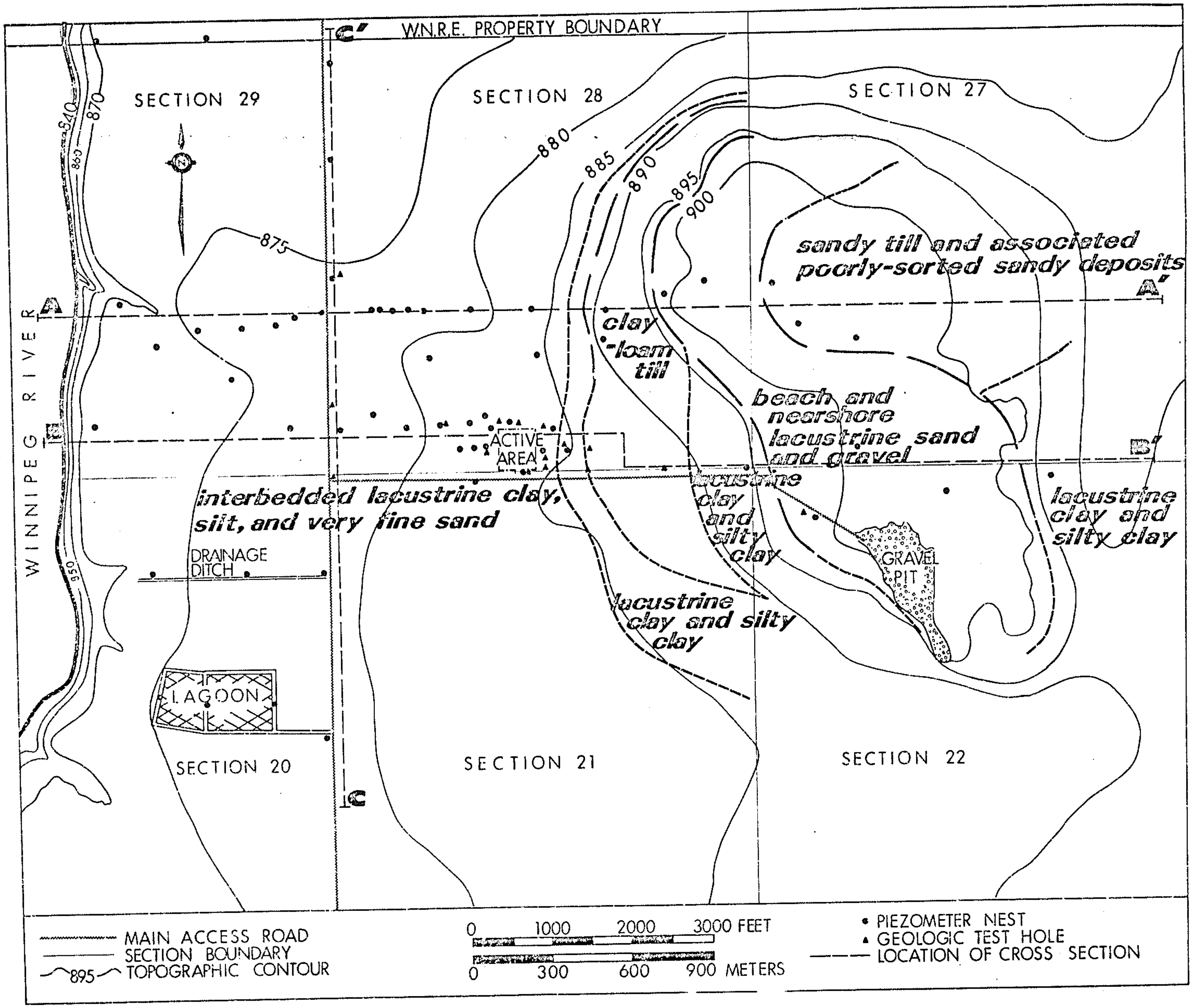


Fig. 14 Surficial geology - Environmental Control Area.

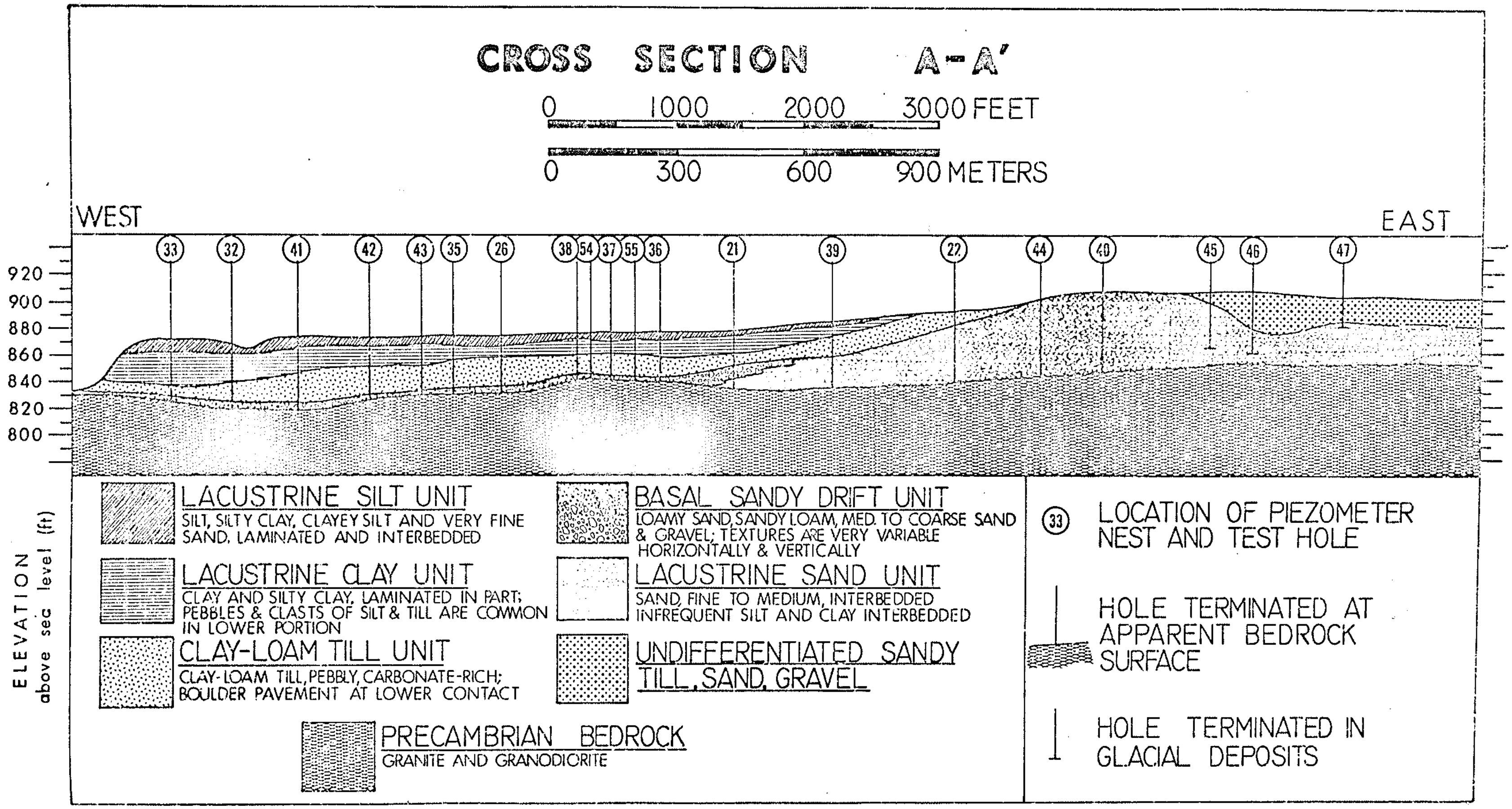


Fig. 15 Geologic cross section A-A'

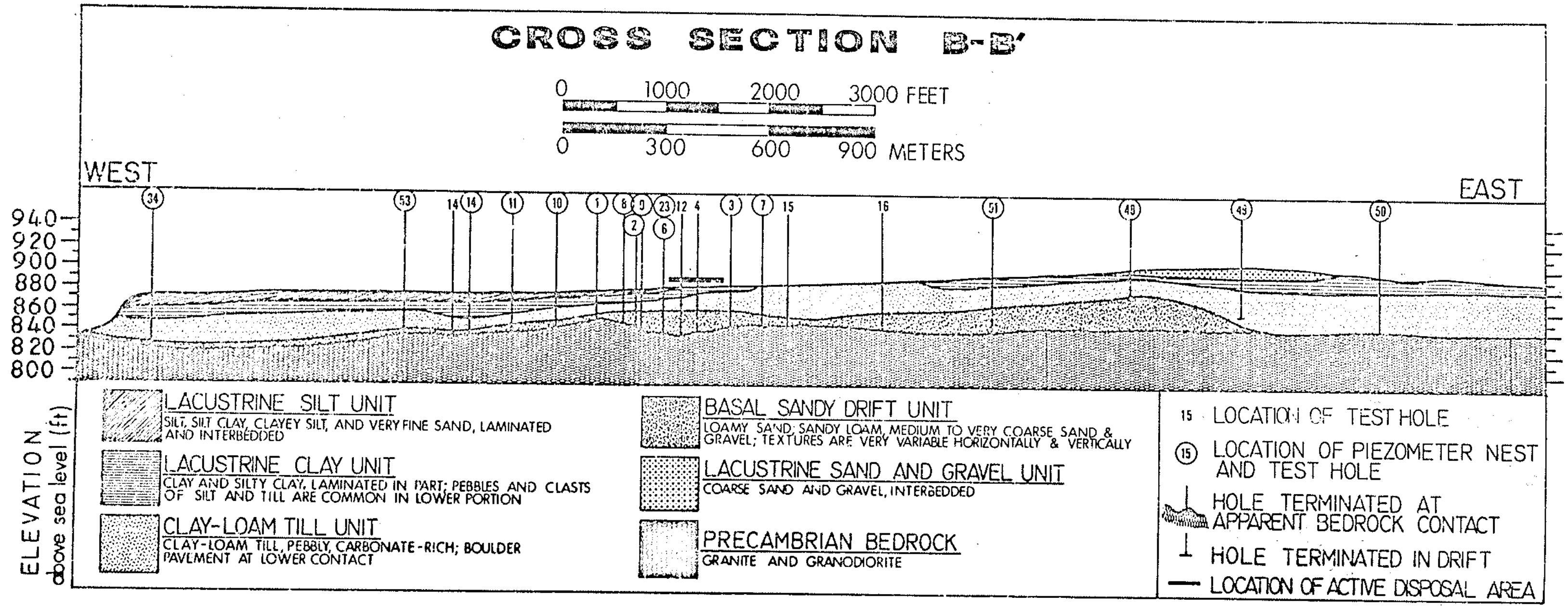


Fig. 16 Geologic cross section B-B'

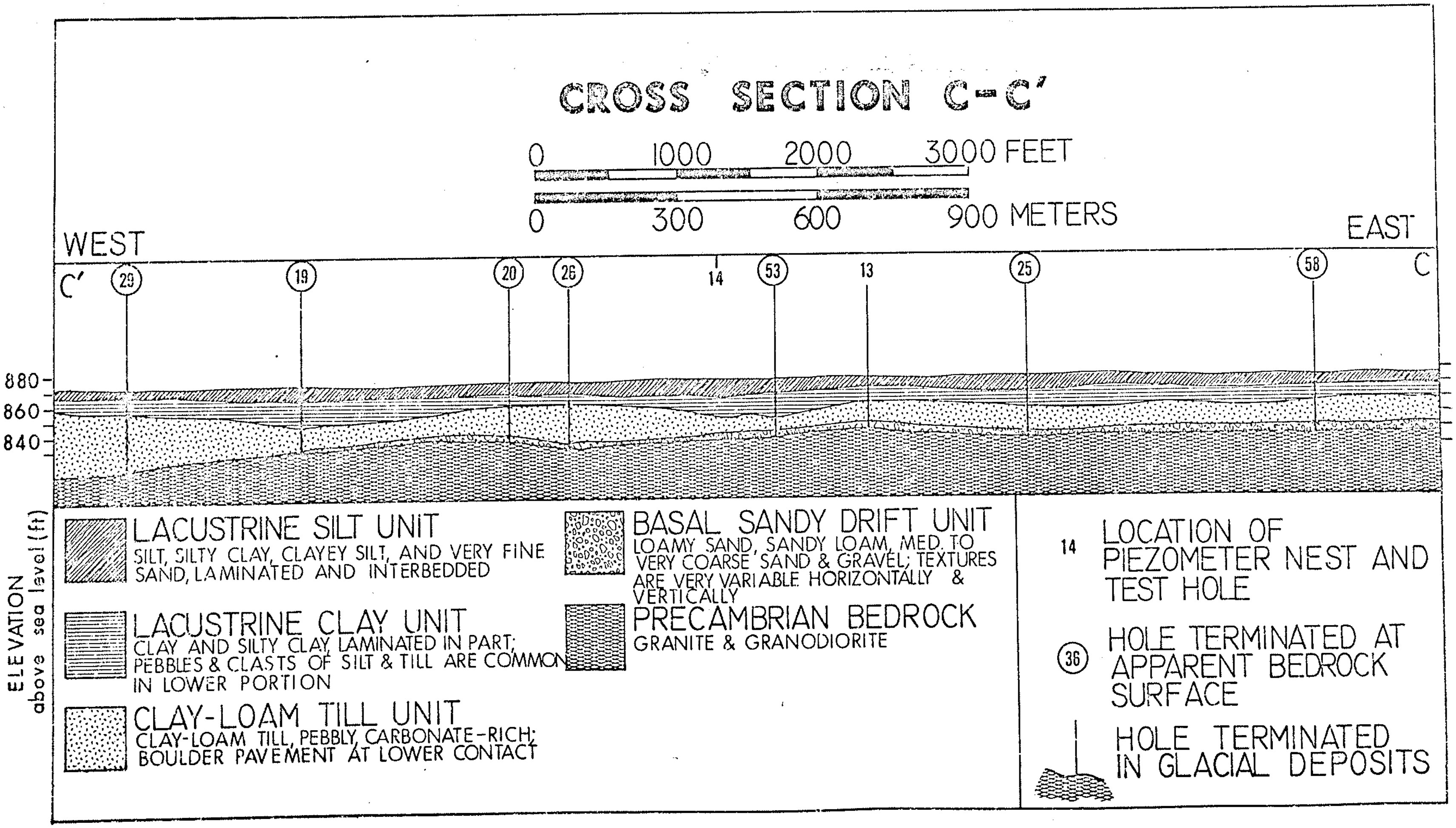


Fig. 17 Geologic cross section C-C'

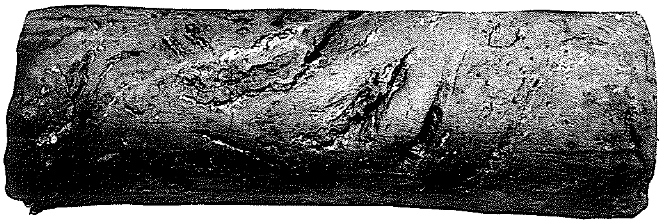


Fig. 18 Soft pockets of easily eroded silt in the upper unit - possibly primary bedding structure. Sample taken from a depth of 5 feet.

Fig. 19 Ice rafted till fragment in lacustrine clay unit. This photo taken at bottom of a 9 foot cut.

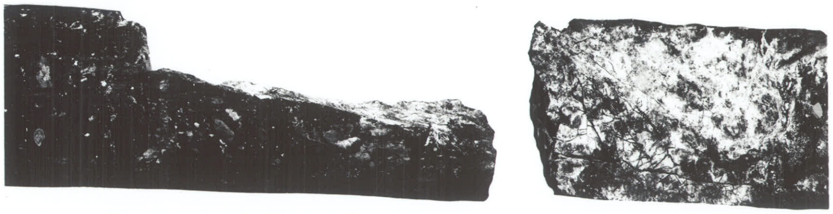


Fig. 20 Angular calcareous silt fragments embedded in lower part of the clay unit – also note precipitates and rootlets on joint surfaces. This sample taken from a depth of 14 feet.

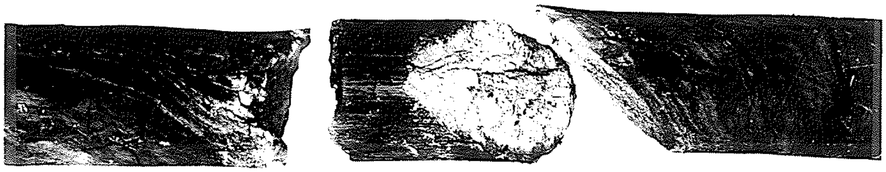


Fig. 21 Steeply dipping laminae of very fine sand in clay unit - carbonate precipitates give a whitish tone to the laminae. Bedding is essentially horizontal.

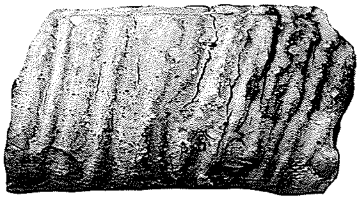


Fig. 22 Stratified transition zone between lacustrine clay unit and the clay-loam till.

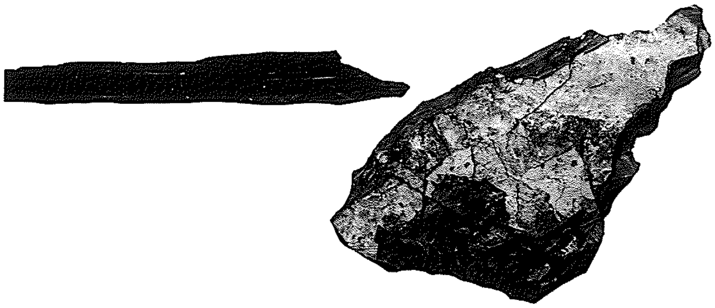


Fig. 23 Joints cutting laminae in clay unit. Joints have been accentuated artificially for illustrative purposes.

Fig. 24 Carbonate and gypsum precipitates on vertical fracture in lacustrine clay unit.

Fig. 25 Carbonate precipitates on joint surface in clay-loam till unit. Sample taken from a depth of 20 feet.

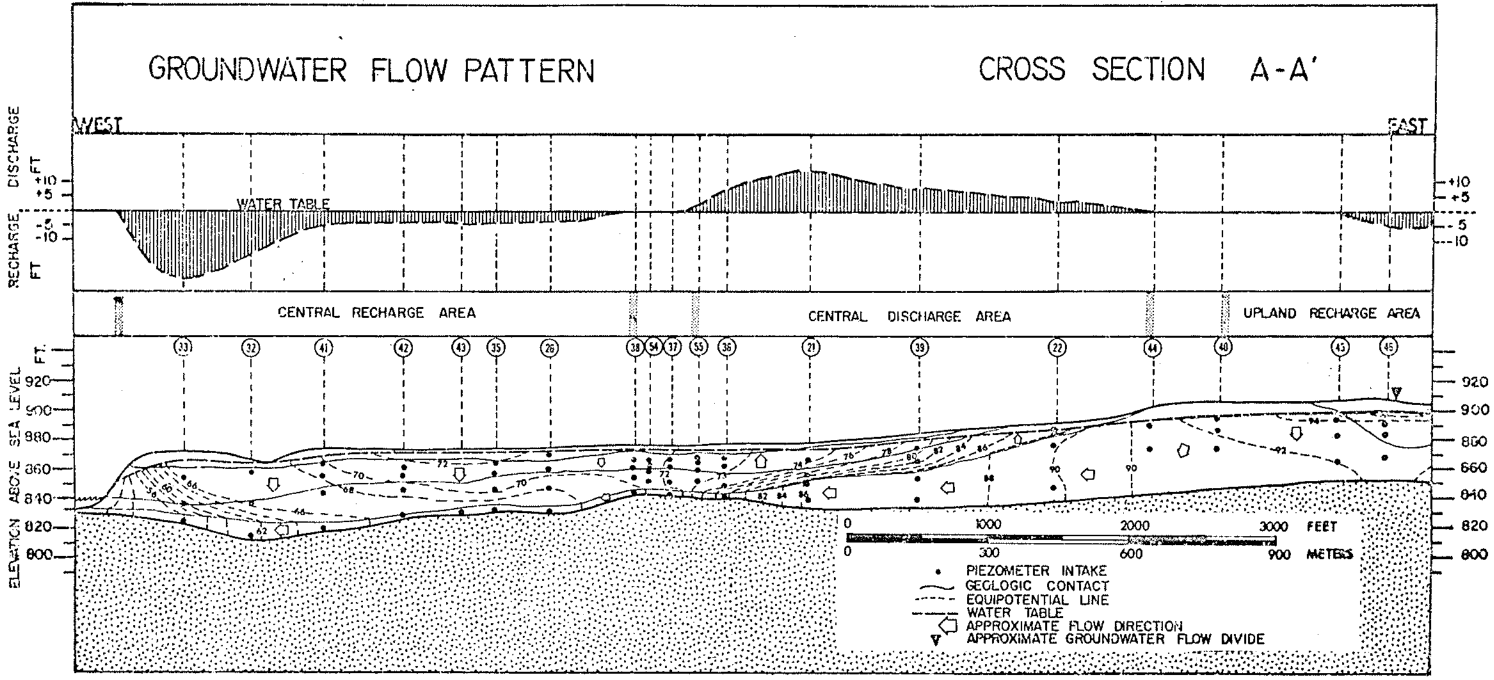


Fig. 26 Flow pattern interpretation based on the hydraulic potential distribution
Cross section A-A'

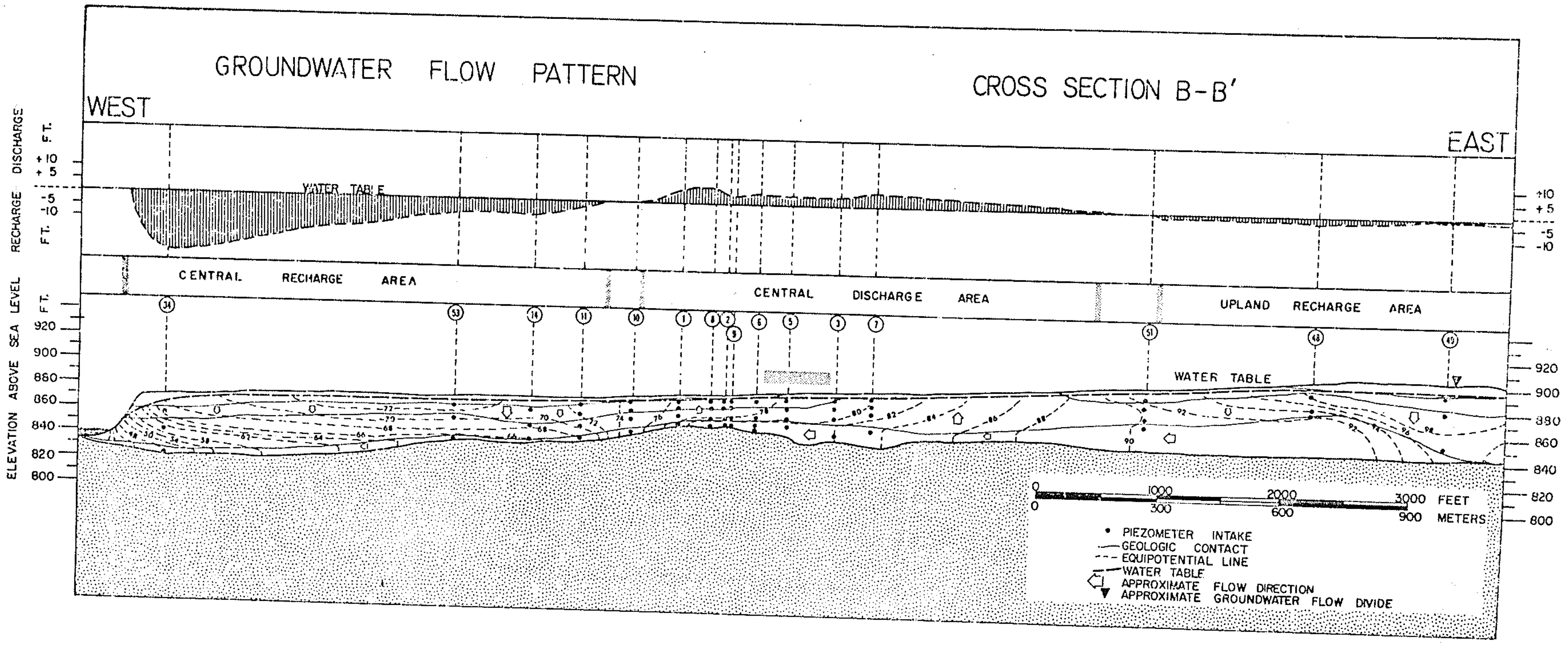


Fig. 27 Flow pattern interpretation based on the hydraulic potential distribution
Cross section B-B'

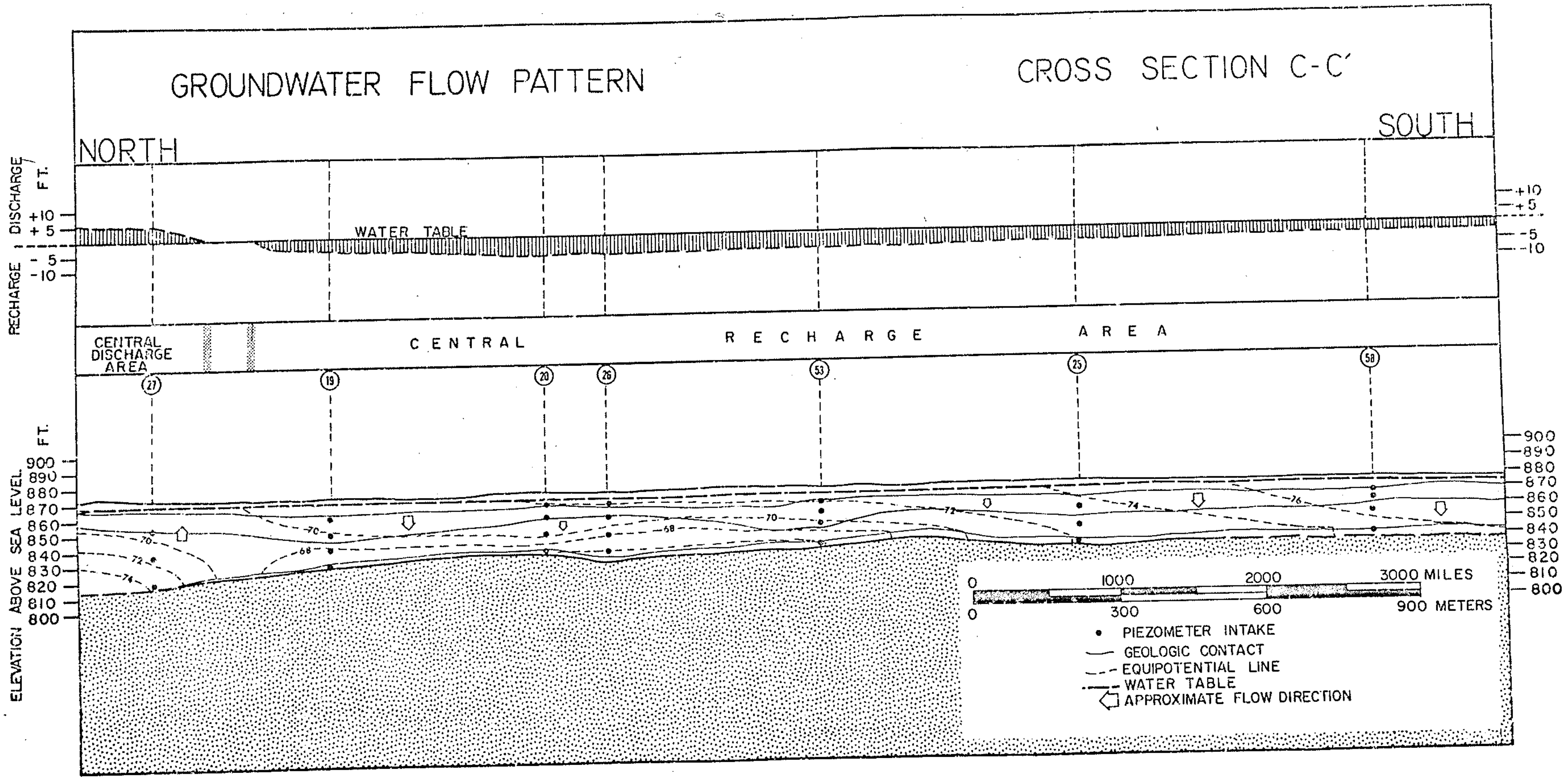


Fig. 28 Flow pattern interpretation based on the hydraulic potential distribution
Cross section C–C'

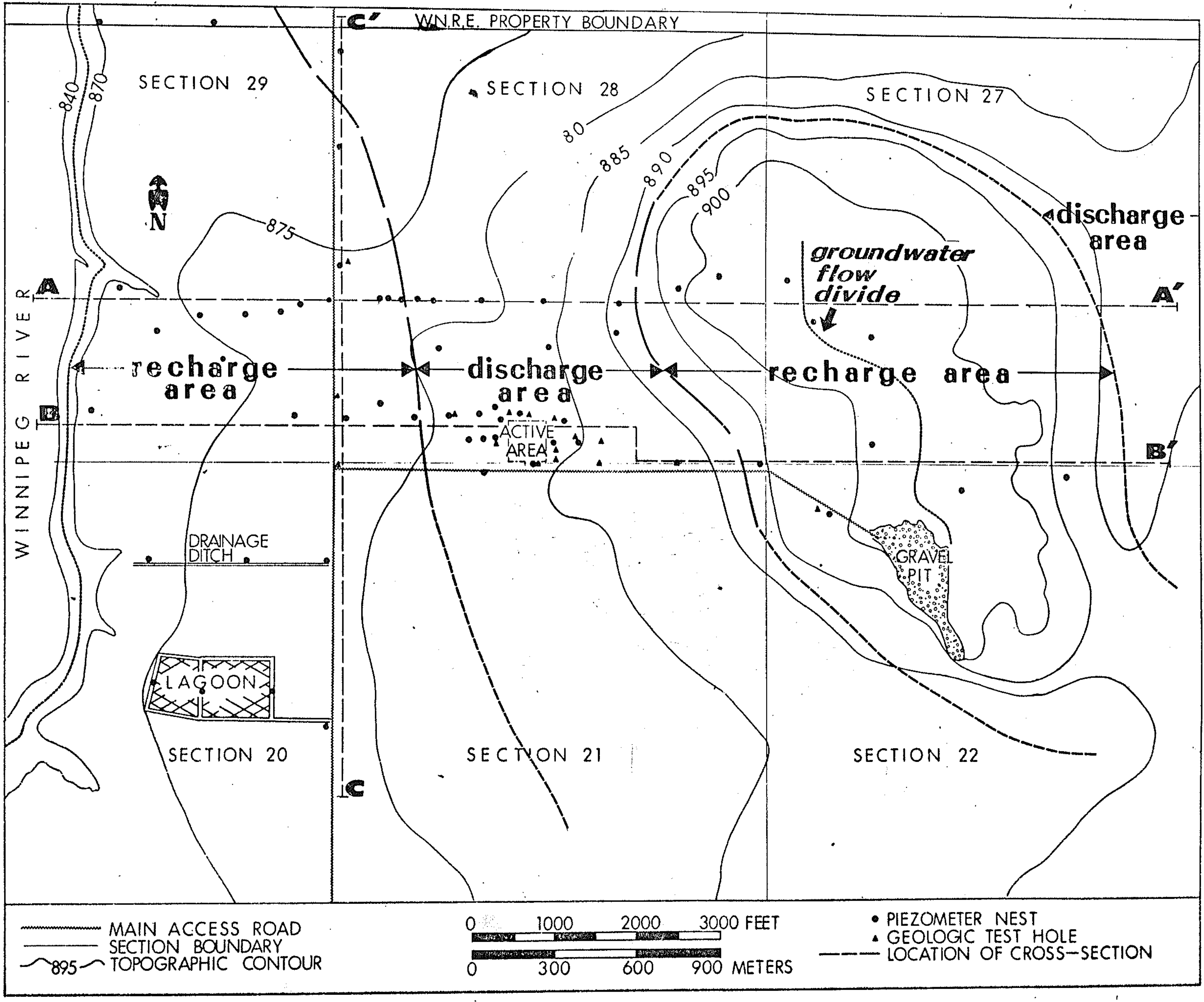


Fig. 29. Areal distribution of recharge-discharge areas.

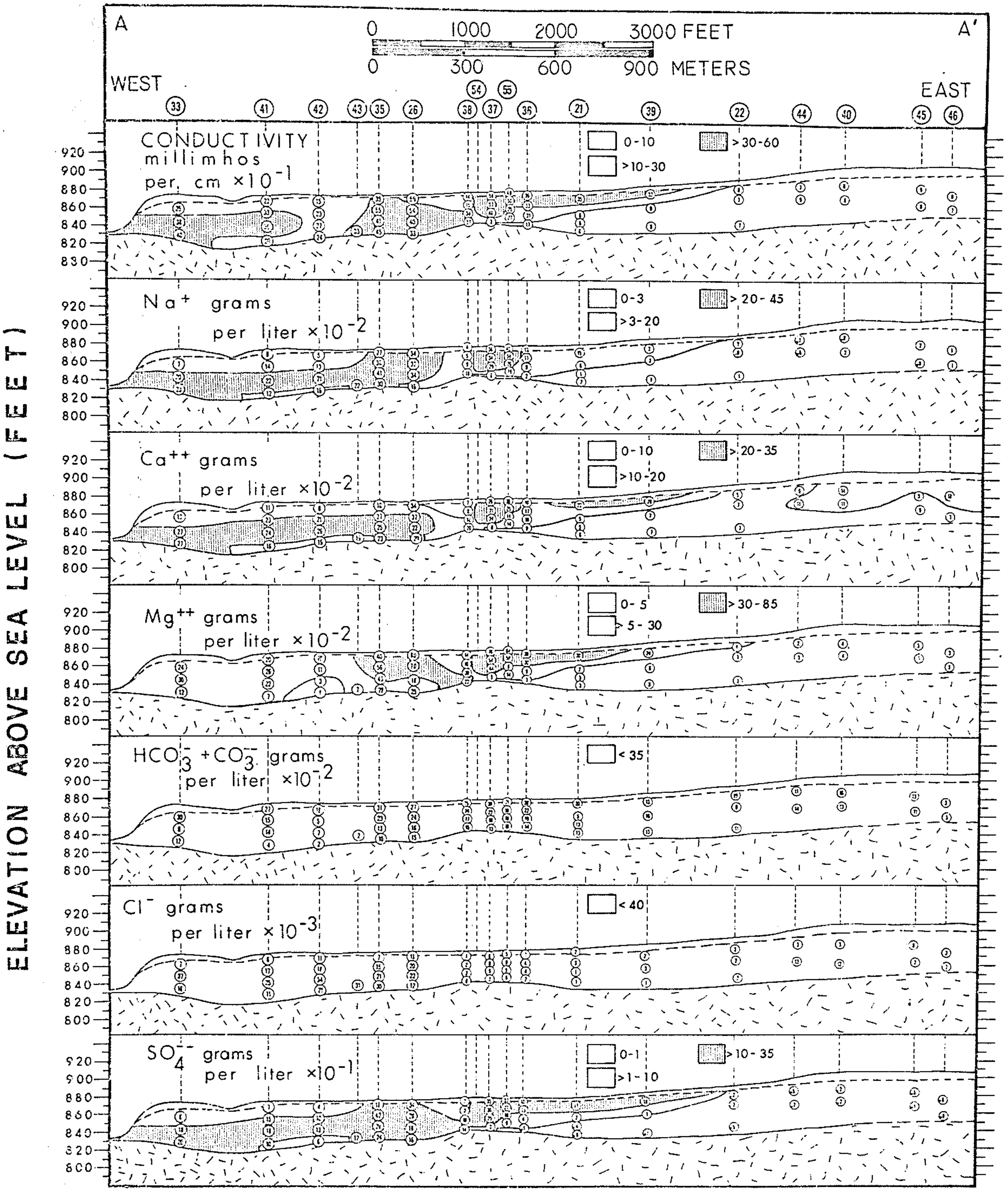


Fig. 30 Hydrochemical patterns - Cross Section A-A'

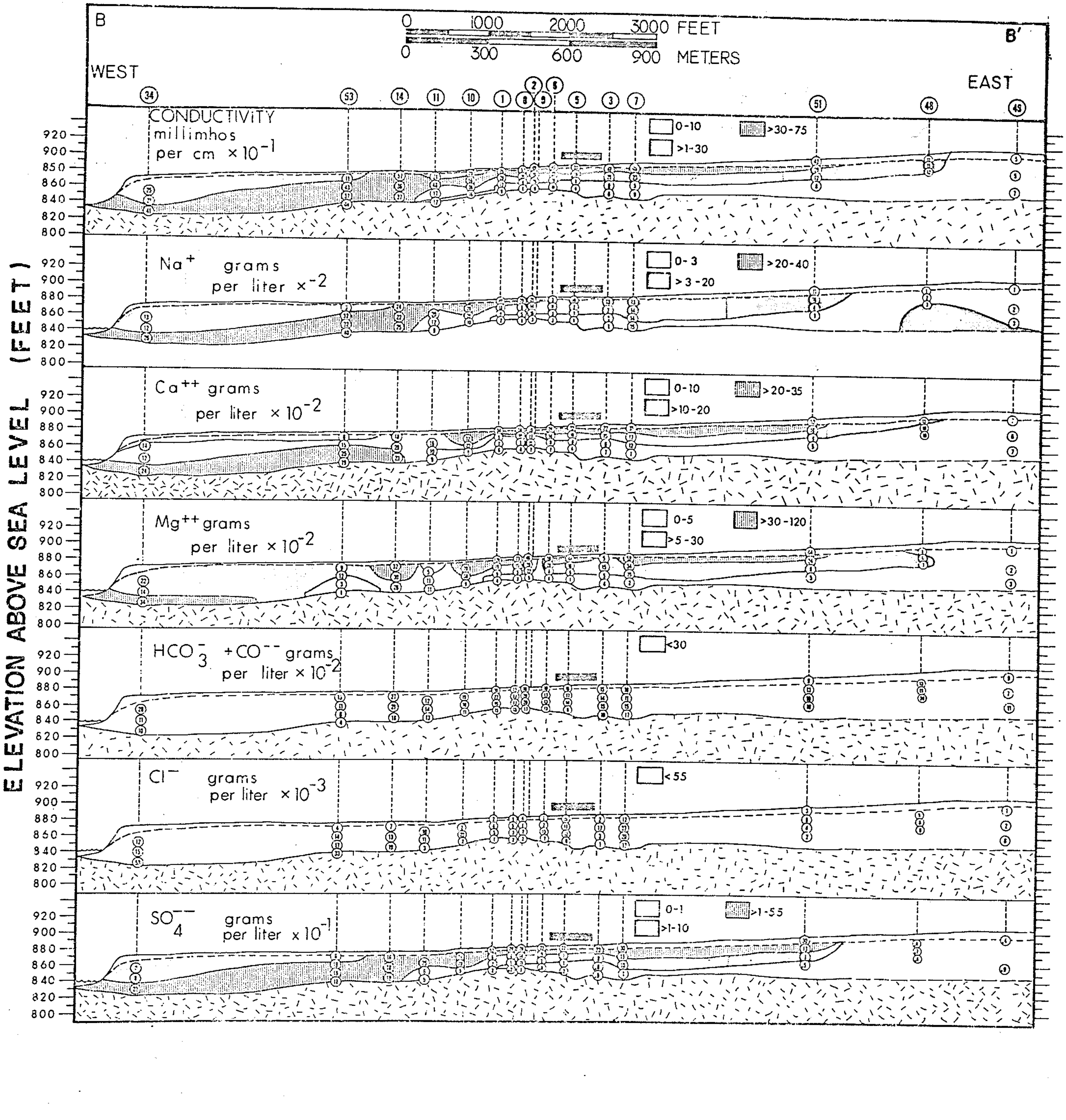


Fig. 31 Hydrochemical patterns - cross section B-B'

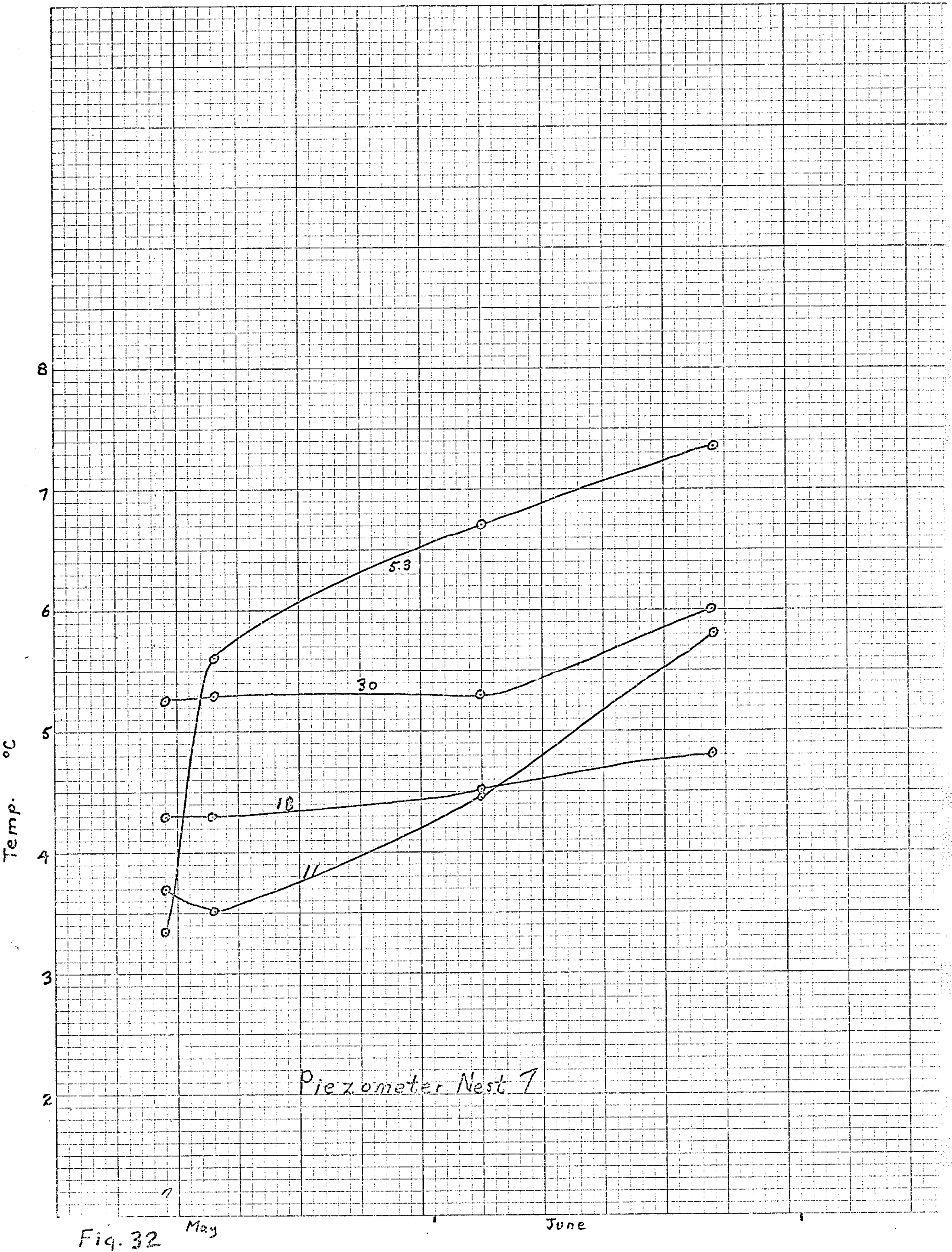
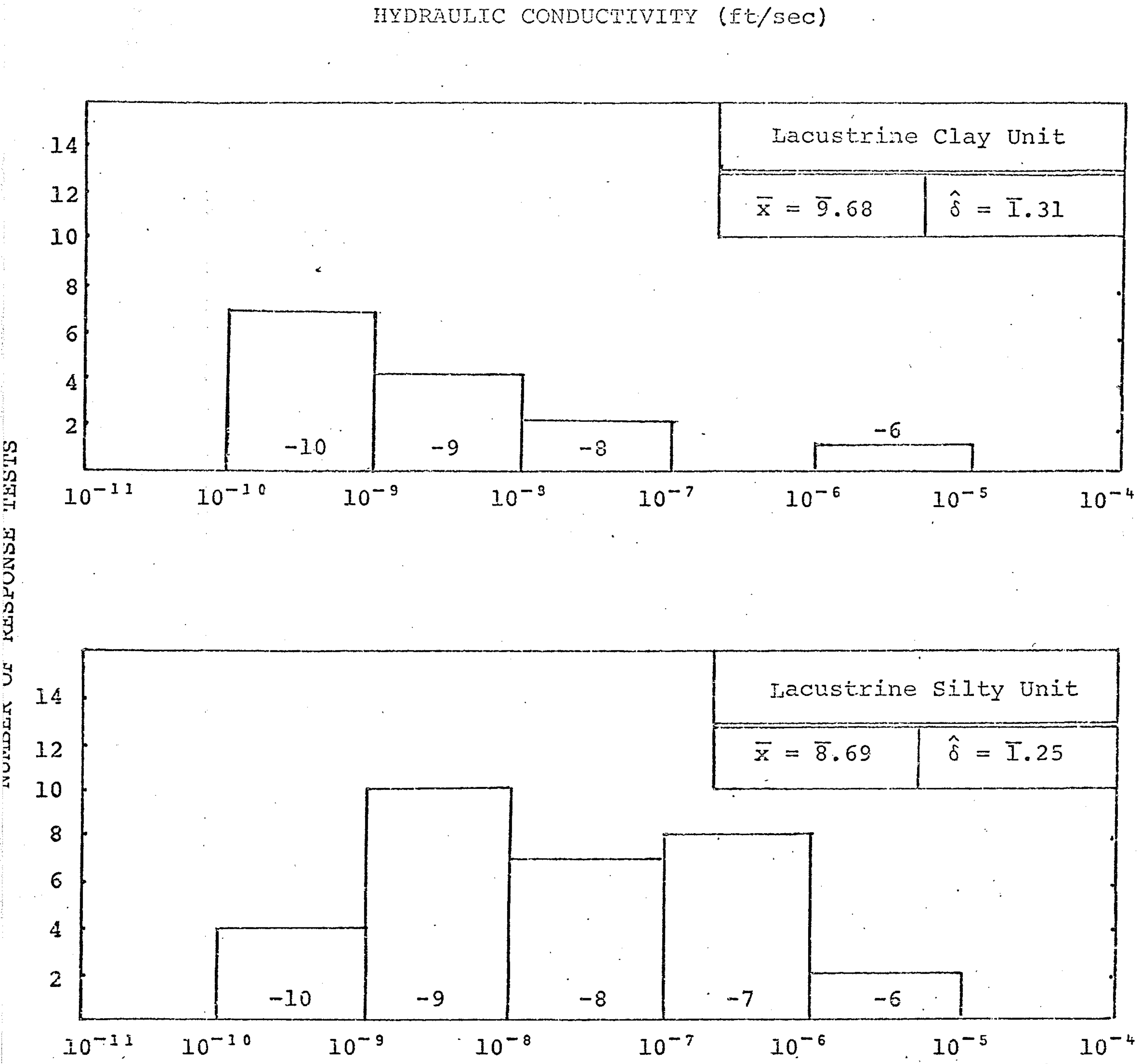


Fig. 32



$\bar{x}$ = Unbiased estimate of logarithmic mean.

$\hat{\delta}$ = Population logarithmic standard deviation.

Fig. 33 Statistical summary of the Hvorslev hydraulic conductivity data from the lacustrine clay unit grouped according to depth intervals.

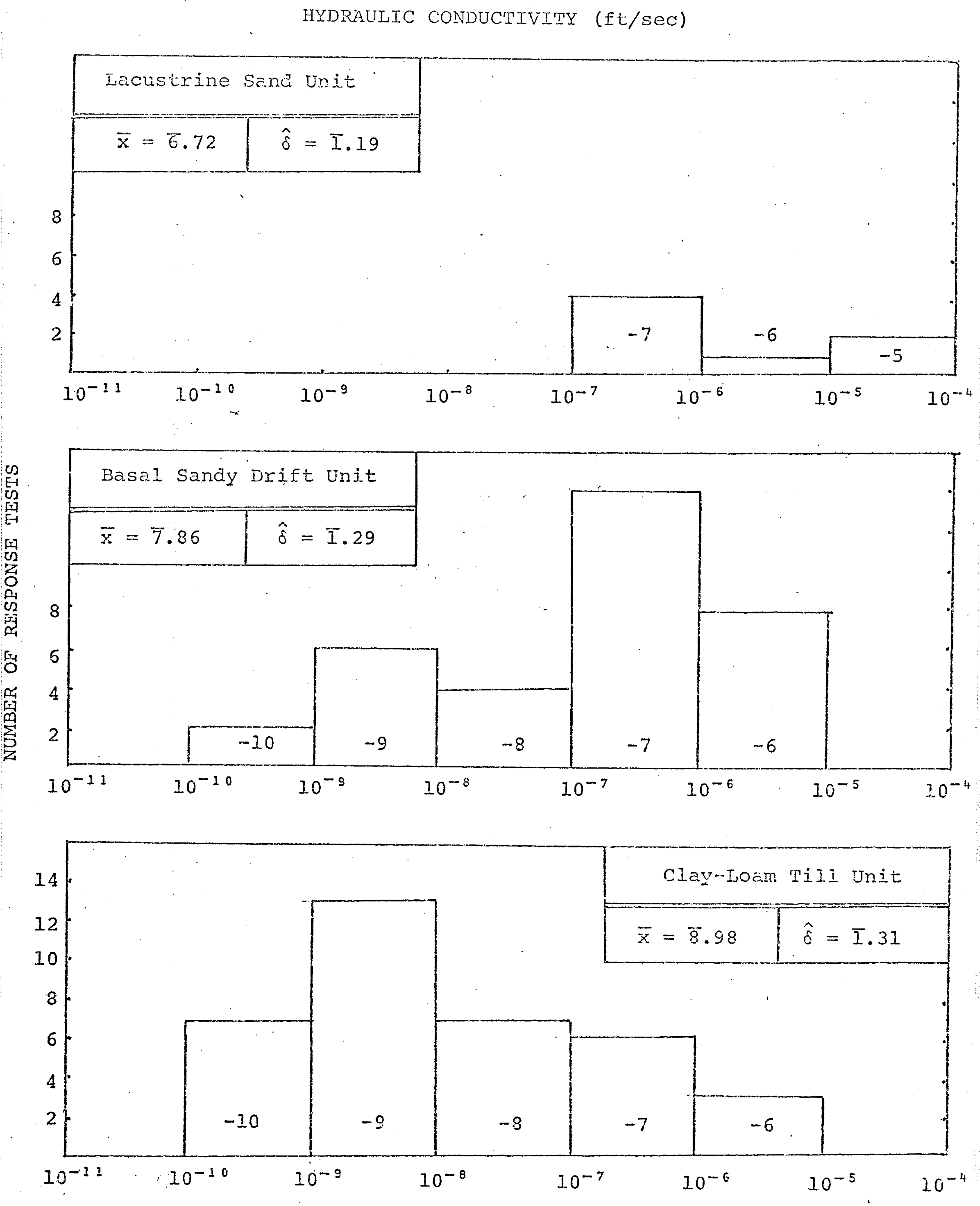


Fig. 34 Statistical summary of Hvorslev hydraulic conductivity data grouped according to hydrostratigraphic units.

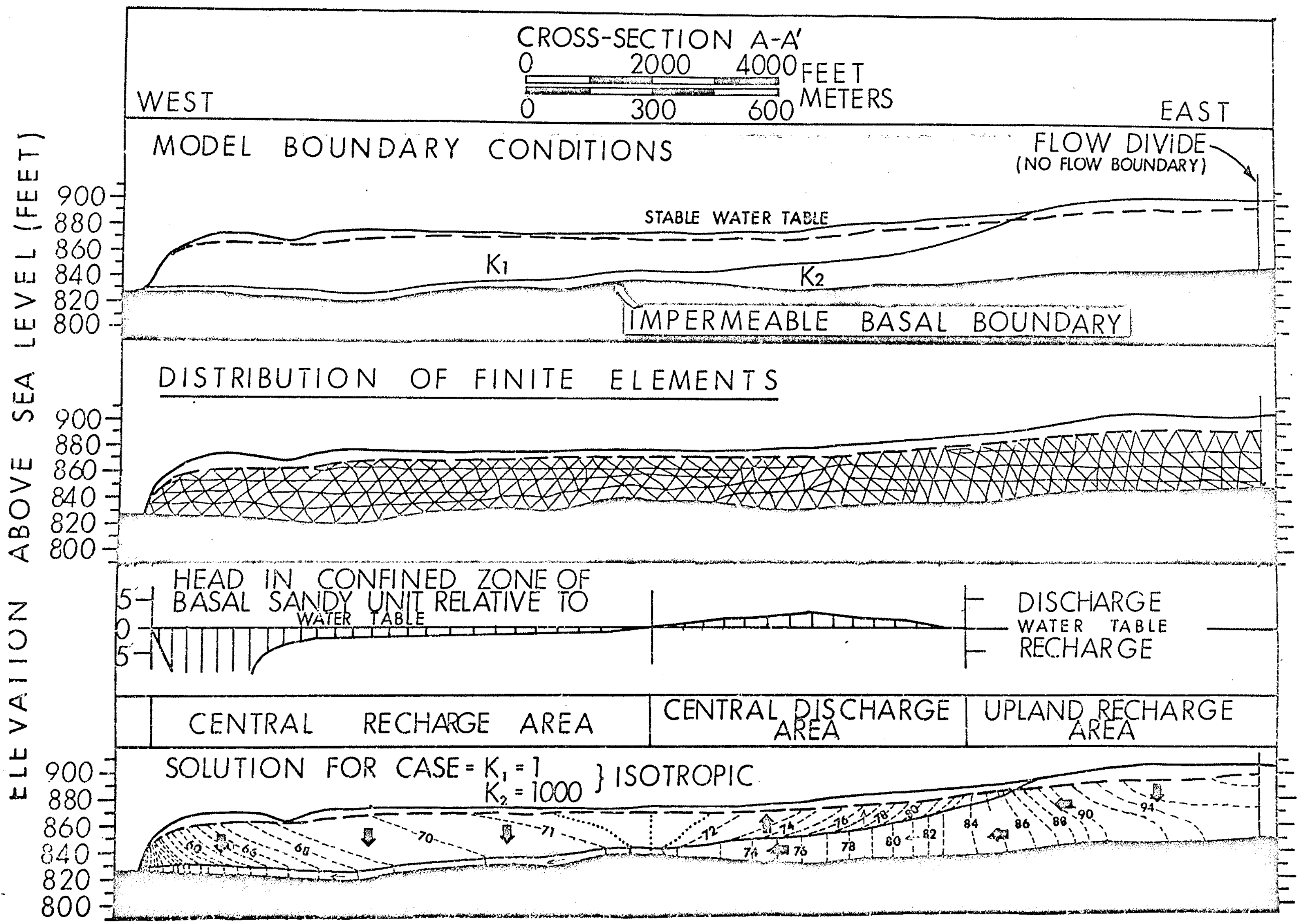


Fig. 35 'Best fit' model of the hydraulic potential distribution.

APPENDIX A

COMPILATION OF PHOTOGRAPHS

Fig. 1A Modified infra-red photograph looking east over Environmental Control Area. Outcrop of lacustrine sand and gravel unit is on the left. Present waste disposal area is in top centre.

Fig. 2A Caissons for subsurface disposal of radioactive wastes.

Fig. 3A Winter conditions in Environmental Control Area

Fig. 4A Parting along bedding in lacustrine silty unit.

Fig. 5A Jointing in lacustrine clay unit with precipitates on joint surfaces.

Fig. 6A Jointing in lacustrine clay unit without visible precipitates.

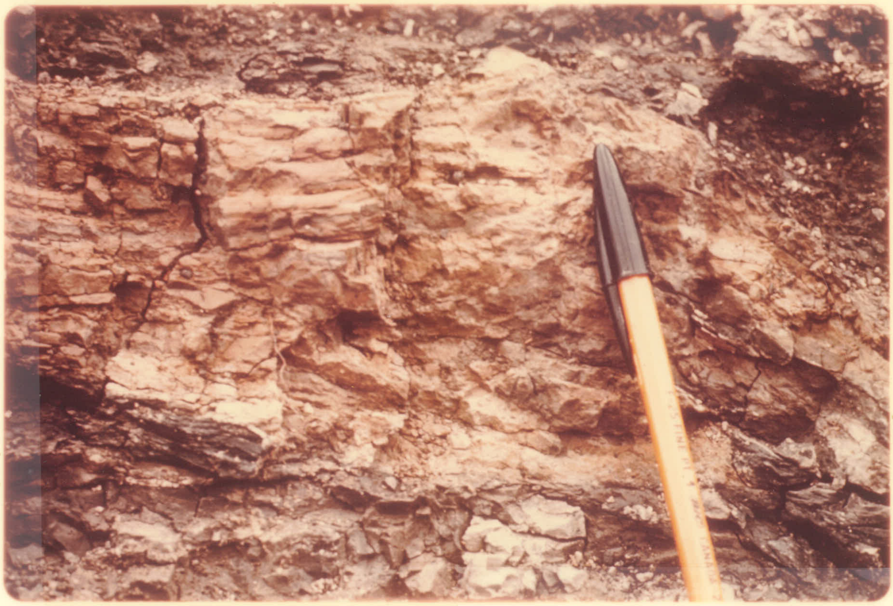


Fig. 7A Ice-rafted clayey-silt fragment embedded in lacustrine clay unit.

Fig. 8A Clay-loam till unit.

Fig. 9A Installation of piezometers in central discharge area.

Fig. 10A Installation of piezometers in upland recharge area.

Fig. 11A PVC piezometer with intake zone wrapped with fine mesh screen.

Fig. 12A Reading water levels in piezometers in late fall after water-table freezing begins.

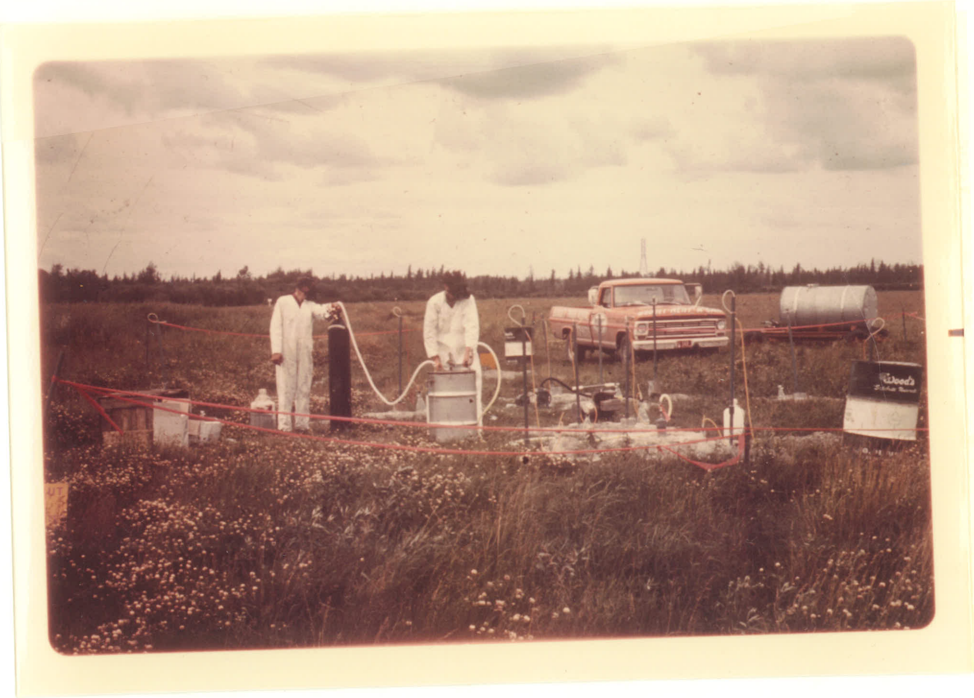


Fig. 13A Injection of tritium tracer at injection site No. 1.

Fig. 14A Injection vessel with level gauge.

Fig. 15A Sampling for tritium at injection site No. 1. Colouring of the water sample due to sodium fluorescein remaining in the groundwater from a trial injection.

Fig. 16A Injection site No. 2 in late fall.

APPENDIX B

GEOLOGIC LOGS OF TEST HOLES

TEST HOLE #1

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-15	Finely laminated clay and silty clay; gypsum flakes and iron concretions present throughout; colour 2.5Y browns and olive browns.	lacustrine clay unit
15-16	Interlayered sandy, pebbly clay, sandy silts.	
16-36	Sandy, silty, clayey till; carbonate pebbles; colour 2.5Y light olive brown and yellowish brown near 16 feet becoming 2.5Y4/2 below.	clay-loam till
36-39	Till and interbedded medium to coarse sand; igneous pebbles and quartzo-feldspathic sand.	basal sandy drift
39	End of hole on rock.	

TEST HOLE #2

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-12	Complexly laminated clay with carbonate pebbles and sand grains common in upper few feet; gypsum flakes common in upper five feet; colour 2.5Y4/2 dark grey brown with lighter grey laminae, mottled 2.5Y shades in upper 5 feet.	lacustrine clay unit
12-13.5	Layered silty sands; gradational from clay to till-like material.	
13.5-28	Silty sandy clayey till with carbonate rock fragments; silt content increases slightly downward; colour 2.5Y4/2 becoming 2.5Y4/4 near 28 feet.	clay-loam till

TEST HOLE #2 Cont'd.

28-40	Very poorly sorted gravelly sands with till-like interbeds; rock fragments and sand of igneous origin; colour 5Y4/2 olive grey.	basal sandy drift
40	End of hole due to auger breakage.	

TEST HOLE #3

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-12	Laminated clay with isolated pebbles and sand grains in upper portion; occasional laminae of very fine sand between 5 and 10 feet; silt content increased slightly near 12 feet; colour 2.5Y/3/2.	lacustrine clay unit
12-21	Sandy silty clayey till with carbonate pebbles; colour 2.5Y4/4.	clay-loam till
21-21.5	Coarse gravel and cobbles.	basal sandy drift
21.5-24	Medium to coarse pebbly sand, colour 5YN3.	
24-30	Very sandy slightly silty till; colour 5YN3.	
30	End of hole on rock.	

TEST HOLE #4

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-7	Laminated silty clay; pebble content increases with depth; till-like zones; gypsum flakes common; colour 2.5Y greys.	lacustrine clay unit
7-10	Highly variable sand-silt-clay layered complex.	

TEST HOLE #4 Cont'd.

10-23	Sandy silty clayey till with carbonate pebbles; colour 2.5Y3/2.	clay-loam till
23-42	Quartzo-feldspathic sand, medium to fine, with clay interbeds a few inches thick in lower 15 feet; colour 5YN/3.	basal sandy drift
42	End of hole on rock.	

TEST HOLE #5

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-3	Clay; laminated; pebbles common; colour 2.5Y5/4.	lacustrine clay unit
3-21	Till; carbonate pebbles predominate; colour 2.5Y5/4 grading downward to 5Y5/4.	clay-loam till
21-46	Sand; medium to fine poorly sorted gravelly; igneous origin; sandy till-like layer near the upper contact and clay interbed believed present near bottom; colour 5YN3.	basal sandy drift
46	End of hole on rock.	

TEST HOLE #6

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-6	Clay; laminated; silty, pebbly; colour 2.5Y4/2.	lacustrine clay unit
6-28	Till; carbonate pebbles predominate; becomes progressively more sandy downwards; pebble content decreases downwards; colour 2.5Y4/4 becoming 5YN/3 around 15 feet.	clay-loam till

TEST HOLE #6 Cont'd.

28-47	Very poorly sorted medium, gravelly sand, igneous origin; below 40 feet driller reported till-like drilling condition but samples were not obtained due to boulders.	basal sandy drift
47	End of hole on rock.	

TEST HOLE #7

Depth (ft)	Characteristics	Interpretation
0-1	Top soil.	
1-31	Sandy silty clayey till with carbonate pebbles; sand and silt content increasing downward; colour 2.5Y4/2.	clay-loam till
31-37	Silt, sand, pebbles, boulders; colour 5YN/3.	basal sandy drift
37	End of hole on rock.	

TEST HOLE #8

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-5	Laminated, mottled, clay; carbonate pebbles present; colour 5Y4/3.	lacustrine clay unit
5-23	Normal; till with carbonate pebbles; colour 5Y4/3 grading to olive grey.	clay-loam till
23-36	Sand; medium very poorly sorted; many cobbles; lower few feet become very fine silty sand; colour 5YN/4.	basal sandy drift
36	End of hole.	

TEST HOLE #9

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-5	Laminated, mottled, clay; gypsum flakes common; colour 5Y4/2.	lacustrine clay unit
5-26	Normal till with carbonate pebbles; becomes more silty in lower portions; colour 5Y5/4.	clay-loam till
26	End of hole on rock. NOTE: second hole drilled five feet from TEST HOLE #9 also ended at 26 feet on rock.	

TEST HOLE #10

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-5	Laminated, mottled, clay; carbonate pebbles present; colour 2.5Y light browns.	lacustrine clay unit
5-23	Till; normal; colour 2.5Y4/4.	clay-loam till
23	End of hole on rock. NOTE: second hole drilled five feet away from TEST HOLE #10 also ended at 23 feet on rock.	

TEST HOLE #11

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-11	Clay; massive, mottled; pebbles absent; colour 2.5Y3/2.	lacustrine clay unit
11-17	Till; normal; colour 2.5Y4/4.	clay-loam till
17	End of hole on rock.	

TEST HOLE #11 Cont'd.

	New hole started 4 feet away.	
13-22	Till; normal; carbonate pebbles predominate.	clay-loam till
22-30	Sand; fine to very fine well sorted, no pebbles; colour 5YN/4.	basal sandy drift
30	End of hole on rock.	

TEST HOLE #12

Depth (ft.)	Characteristics	Interpretation
0-2	Road fill.	
2-11	Clay; laminated, mottled, light grey silt balls (angular fragments) in dark clay.	lacustrine clay unit
11-22	Till; normal; colour 5Y4/3 grading to 5YN/4.	clay-loam till
22-40	Sand; upper three feet is coarse poorly sorted silty; 25 to 40 is fine well sorted dense clean sand; colour 5YN/4.	basal sandy drift
40	End of hole, no more auger available.	

TEST HOLE #13

Depth (ft.)	Characteristics	Interpretation
0-4	Road fill.	
4-7	Very fine sand and silt.	lacustrine silty unit
7-16	Clay; massive; no pebbles noticed; many gypsum flakes; colour 5Y4/3.	lacustrine clay unit
16-18	Transition zone.	
18-29	Till; normal; carbonate pebbles predominate; colour 5Y5/3.	clay-loam till

TEST HOLE #13 Cont'd.

29-35	Sand; very fine silty sand interlayered with black silty clay; becomes gravelly in last foot.	basal sandy drift
35	End of hole on rock.	

TEST HOLE #14

Depth (ft.)	Characteristics	Interpretation
0-3	Road fill.	
3-29	Clay; layered massive and laminated zones; pebbled content increasing with depth; angular silt fragments increase with depth; gypsum flakes concentrated around 20 feet; laminae of very fine sand; colour 5Y5/4 and 5Y4/3, sand laminae 5Y7/1.	lacustrine clay unit
29-30	Clay; massive; very compact; slightly sandy; colour 5Y4/3.	lacustrine clay unit
30-38	Till; hard, very silty; carbonate and granitic pebbles; very bouldery in the last foot.	clay-loam till
38	End of hole on rock.	

TEST HOLE #15

Depth (ft.)	Characteristics	Interpretation
0-4	Road fill.	
4-11	Clay and silty clay; fine sand laminae present, pebbly.	lacustrine clay unit
11-25	Till; upper portion has deficiency of sand but approaches equal proportions near lower boundary.	clay-loam till
25-30	Till; slightly less clay than above and very bouldery; some portions drill like sand.	basal sandy drift
30	End of hole on rock.	

TEST HOLE #16

No drilling log available.

TEST HOLE #17

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-8	Sand and gravel, interbedded.	lacustrine sand and gravel unit
8-16	Silty clay and clay; laminated, pebbly; colour 5Y greys and olives.	lacustrine clay unit
16-42	Till; carbonate pebbles predominate; colour 5Y4/1 dark grey.	clay-loam till
42-45	Till; slightly more silty than above; drills very bouldery.	basal sandy drift

TEST HOLE P-1

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-2	Silty sand.	lacustrine silt unit
2-15	Clay; laminated; many gypsum flakes and much iron staining; pebbles absent near surface but become common near 15 feet.	lacustrine clay unit
15-15.5	Gravelly layer.	
15.5-23	Till; mottled, with carbonate pebbles; upper two feet silty and gravelly, lower material normal till composition; dark grey fine sand layers present in upper 4 feet.	clay-loam till
23-30	Sand; clean fine grained with minor gravel; becomes silty and clayey near 27 and resembles a sandy till near 30 feet.	basal sandy drift
30	End of hole for piezometer installation.	

TEST HOLE P-2

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-8	Clay; laminated; many gypsum flakes and iron staining; carbonate pebbles predominant over highly weathered igneous pebbles; colour 2.5Y3/2.	lacustrine clay unit
8-21	Till; normal with dark grey fine sand layers less than 0.1 inches thick; near 8 feet till appears banded with sand and gravel; colour 2.5Y4/2.	clay-loam till
21-29	Sand; poorly sorted, gravelly; igneous fragments.	basal sandy drift
29-30	Sandy till.	

TEST HOLE P-3

Same as Test Hole #8.

TEST HOLE P-4

Same as Test Hole #10

TEST HOLE P-5

Same as Test Hole #4.

TEST HOLE P-6

Same as Test Hole #11.

TEST HOLE P-7

Same as Test Hole #6.

TEST HOLE P-8

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-14	Clay; laminated; gypsum flakes common; dark grey brown.	lacustrine clay unit
14-21	Till; silty; igneous and carbonate pebbles.	clay-loam till
21-27	Sand; very poorly sorted, gravelly, bouldery, silty; possibly sandy till.	basal sandy drift
27-29	Till; normal; mainly carbonate pebbles.	
29	End of hole on rock.	

TEST HOLE P-9

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-9	Clay; mottled, laminated; dark grey brown.	lacustrine clay unit
9-15	Clay-till transition; based on drilling feel and samples.	
15-23	Till; normal; olive brown.	clay-loam till
23-30	Sand; very coarse gravelly dirty; in bottom three feet approaches a sandy till.	basal sandy drift
30-41	Sand; gravelly, bouldery; less silt and clay than above.	
41	End of hole due to difficult drilling in boulders.	

TEST HOLE P-10

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-13	Clay; generally non-mottled massive; no silt fragments; slightly silty; minor gypsum flakes.	lacustrine clay unit
13-15	Transition to till.	
15-23	Till; normal; olive brown.	clay loam till
23-32	Sand; silty, clayey; gravelly; possibly a sandy till; upper three feet are very till-like.	basal sandy drift
32	End of hole on rock.	

TEST HOLE P-11

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-18	Clay; laminated; lacks usual mottling and silt fragments; patches of white and grey material; colour 5Y4/3.	lacustrine clay unit
18-27	Till; normal; carbonate pebbles predominate; colour 5Y4/3.	clay-loam till
27-30	Till; becomes very sandy near 30 feet; colour 5Y5/4.)	basal sandy drift
30-36	Sand; very coarse to coarse, gravelly, slightly silty; colour 5Y5/2.)	
36	End of hole.	

TEST HOLE P-12

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-6	Clay; laminated, mottled; many gypsum flakes and angular silt fragments; colour olive grey 5Y4/3 and 5Y4/4.	lacustrine clay unit
6-21	Till; normal; carbonate and igneous pebbles; colour 5Y4/3 grading downward to 5Y4/1.	clay-loam till
21-25	Sand and gravel; very poorly sorted; angular pebbles and sand grains; granitic.	basal sandy drift
25-37	Sand; very fine to fine well sorted; a dense silt or very fine sand layer encountered at 36 feet.	
37-42	Gravel; based on drilling feel; no samples obtained.	
42	End of hole on rock.	

TEST HOLE P-13

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-11	Clay; massive, non-mottled; occasional pebbles; fissile; colour 5Y4/2.	lacustrine clay unit
11-13	Clay-till transition.	
13-25	Till; more silty than normal; carbonate and igneous pebbles; colour 5Y4/3.	clay-loam till
25-30	Till; slightly more sandy and silty than normal; colour 5YN4.	clay-loam till
30-33	Sand; silty gravelly, resembling sandy till.	basal sandy drift
33	End of hole due to auger breakage.	

TEST HOLE P-14

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-22	Clay; laminated in some portions; fine sand layers at angles to layering; some silt fragments in lower portion; pebble content increases with depth; colour 5Y4/2 to 5Y4/3.	lacustrine clay unit
2-35	Till; normal; seems abnormally soft in places but no visible variation in grain size ratios; colour 5YN4.	clay-loam till
35	End of hole on rock.	

TEST HOLE P-15

Same as Test Hole #12

TEST HOLE P-16

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-16	Till; igneous and carbonate pebbles; occasional slightly silty zone; colour 2.5Y4/4 grading to 5Y3/1 near 16 feet.	clay-loam till
16-49	Sand; very fine to fine well sorted; drills as if layered possibly with clayey interbeds; colour 5YN4.	lacustrine sand unit
49-52	Silt and clay; interbedded; colour 5YN4.	
52-55	Sand; granitic, very coarse, poorly sorted.	
55	End of hole on rock.	

TEST HOLE P-17

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-13	Clay; laminated; many gypsum flakes; silt fragments increase near 13 feet; colour 2.5Y3/2.	lacustrine clay unit
13-21	Till; normal; colour 2.5Y5/4.	clay-loam till
21-34	Sand; very fine; well sorted; silt and clay interbeds; colour 5YN4; sand becomes coarse and poorly sorted from 31-34 feet.	basal sandy drift
34	End of hole on rock.	

TEST HOLE P-18

Depth (ft.)	Characteristics	Interpretation
0-4	Top soil and fill.	
4-11	Clay; laminated to massive; colour 5Y6/2, 5Y5/4 and 5Y4/3.	lacustrine clay unit
11-27	Silty clay; very soft; appears bedded; colour dark grey 5Y4/1.	
27-36	Till; more silty than normal; very plastic; colour 5Y4/1.	clay-loam till
36-48	Sand; from 36 to 41 feet very fine silty sand, well sorted from 41 to 48 feet medium poorly sorted silty pebbly sand with boulders; definitely not a till.	basal sandy drift
48	End of hole on rock.	

TEST HOLE P-19

Depth (ft.)	Characteristics	Interpretation
0-5	Top soil and road fill.	
5-27	Silty clay and clay; upper 10 feet somewhat till-like; colour 5Y5/3; below 10 feet generally massive; pebbles common; colour 5Y5/3 and 5Y4/1.	lacustrine clay unit
27-42	Till; less clay than normal; carbonate and igneous pebbles common; colour 5Y5/1.	clay loam till
42-44	Sand?; driller reported sand but no sand sample was obtained.	basal sandy drift
44	End of hole on rock.	

TEST HOLE P-20

Depth (ft.)	Characteristics	Interpretation
0-3	Top soil.	
3-17	Clay; massive to slightly laminated; silt fragments common.	lacustrine clay unit
17-36	Till; normal; igneous and carbonate pebbles; colour 5Y4/1.	clay-loam till
36-39	Till; very bouldery and sandy; sand interbeds suspected.	basal sandy drift
39	End of hole on rock.	

TEST HOLE P-21

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-17	Clay; many selenite crystal concentrations; laminated grading to more massive in lower portions; occasional pebble; colour 5Y5/4 and 5Y4/1.	lacustrine clay unit

TEST HOLE P-21 Cont'd .

17-25	Till; normal; igneous and carbonate pebbles; colour 5Y4/1 dark grey.	clay-loam till
25-45	Sand; silty coarse very poorly sorted; layered; colour 5YN5.	basal sandy drift
45	End of hole on rock.	

TEST HOLE P-22

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-9	Till; normal; igneous and carbonate pebbles; colour 5Y5/3.	clay-loam till
9-10	Boulders.)	lacustrine sand unit
10-43	Sand; fine, well sorted; colour 5Y5/1.)	
43-53	Sand; granitic; coarse pebbly; no silt or clay.)	
53	End of hole on rock.	

TEST HOLE P-23

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-9	Clay.	lacustrine clay unit
9-11	Clay-till transition.	
11-21	Till; normal; colour 5Y4/3.	clay-loam till
21-24	Bouldery.	
24-37	Sand; coarse very poorly sorted; gravelly, bouldery; possible slightly silty; igneous origin.	basal sandy drift

TEST HOLE P-23 Cont'd.

37-41	Till; very bouldery; more sandy and silty than normal; colour 5YN4.	basal sandy drift
41	End of hole on rock.	

TEST HOLE P-24

Depth (ft.)	Characteristics	Interpretation
0-3	Fill.	
3-10	Silt and clayey silt; laminated; occasional pebble; colour -- greys and olives 5Y.	lacustrine silt unit
10-24	Clay and silty clay; no pebbles apparent; laminated.	lacustrine clay unit
24-51	Till; silty; less pebbles than usual; colour - dark grey.	clay-loam till
51-56	Sand; isolated pebbles and cobbles; slightly silty; has appearance of till in places in terms of pebble distribution.	basal sandy drift
56	End of hole on rock.	

TEST HOLE P-25

Depth (ft.)	Characteristics	Interpretation
0-3	Fill.	
3-10	Silts and clayey silts; laminated; greys and olives 5Y.	lacustrine silt unit
10-23	Clays and silty clays; grades into above; laminated.	lacustrine clay unit
23-38	Till; slightly more silty and less clayey than usual; colour 5Y4/1.	clay-loam till
38-43	Till; very silty and sandy; igneous pebbles; bouldery; difficult drilling.	basal sandy drift
43	End of hole on rock.	

TEST HOLE P-26

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-10	Silty and clayey silt; laminated; occasional pebbles and silt fragments; colour - greys and olives 5Y.	lacustrine silt unit
10-15	Clay and silty clay; grades into above; calcite concentrations (?).	lacustrine clay unit
15-42	Till; normal; igneous and carbonate pebbles; colour 5Y4/1.	clay-loam till
42-45	Sand; medium, pebbly; medium to poorly sorted; clean to slightly silty; some boulders or coarse gravel.	basal sandy drift
45	End of hole on rock.	

TEST HOLE P-27

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-27	Clay and silty clay; laminated; colour 5Y4/2 and 4?4 becoming 5Y4/1 near base; upper few feet are very silty.	lacustrine clay unit
27-56	Till; clayey silty sandy; carbonate pebbles predominant; in places clay content drops; colour 5Y4/1.	clay-loam till
56-59	Till; very pebbly, sandy, bouldery; igneous material.	basal sandy drift
59	End of hole on rock.	

TEST HOLE P-28

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-8	Silt and silty clay; laminated; olive 5Y colouring.	lacustrine silt unit
8-24	Clay and silty clay; laminated in places; oxidized near 8 feet grading rapidly to 5Y4/1 unoxidized.	lacustrine clay unit
24-75	Till; generally normal with minor variations in silt-sand-clay ratios as well as pebble content; pebbles mainly carbonate; no sign of sand or gravel interbeds.	clay-loam till
75-77	Clay; laminated; occasional pebble; gypsum concentrations.	
77	End of hole on rock.	

TEST HOLE P-29

Depth (ft.)	Characteristics	Interpretation
0-4	Road Fill.	
4-19	Clay and silty clay; laminated to massive; occasional pebble; gypsum flakes; olive 5Y colouring.	lacustrine clay unit
19-56	Till; carbonate pebbles predominate; colouring 5Y4/1.	clay-loam till
56	End of hole on rock.	

TEST HOLE P-31

Depth (ft.)	Characteristics	Interpretation
0-3	Top soil and peat.	

TEST HOLE P-31 Cont'd.

3-15	Silt and clayey silt; olives and yellow browns; massive.	lacustrine silt unit
15-37	Clay; soft, slightly silty; grades into the above; dark grey 5Y.	lacustrine clay unit
37-42	Till; normal; soft; dark grey 5Y.	clay-loam till
42-45	Bouldery; no sample, auger broke in hole.	basal sandy drift
45	End of hole due to auger breakage.	

TEST HOLE P-32

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-10	Silt and sand; very fine sands and silts; laminated; iron oxide staining; olive, yellow, and yellow brown colour.	lacustrine silt unit
10-32	Clay; slightly silty; silt fragments; generally massive.	lacustrine clay unit
32-46	Till; normal; mainly carbonate pebbles; soft; dark grey 5Y.	clay-loam till
46-59	Till; sandy, silty, becoming very sandy near bottom; igneous pebbles and sand grains predominate; dark grey 5Y; very bouldery.	basal sandy drift
59	End of hole on rock.	

TEST HOLE P-33

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-10	Silt and clayey silt; very fine sand laminations; yellow and yellow brown colouration.	lacustrine silt unit

TEST HOLE P-33 Cont'd.

10-35	Clay; slightly silty; dark grey 5Y.	lacustrine clay unit
35-42	Till; normal; mainly carbonate pebbles; soft; dark grey 5Y.	clay-loam till
42-48	Till; sandy, silty becoming very sandy near bottom; igneous pebbles, bouldery; dark grey 5Y.	basal sandy drift
48	End of hole on rock.	

TEST HOLE P-34

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-13	Silt and very fine sand; olives, yellows, and yellow brown.	lacustrine silt unit
13-24	Clay; slightly silty.	lacustrine clay unit
24-46	Till; silty, sandy slightly clayey; very soft; dark grey.	clay-loam till
46-49	Till; sandy, silty; igneous pebbles; contact noted due to sudden increase in boulder content.	basal sandy drift
49-51	Till; as above but very pebbly.	

TEST HOLE P-35

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-8	Silts and very fine sand; laminated; yellows, browns, olives.	lacustrine silt unit
8-15	Clay; slightly silty; many silt fragments and gypsum flakes.	lacustrine clay unit

TEST HOLE P-35 Cont'd.

15-17	Transition to till.	
17-38	Till; clayey, silty, sandy; dark grey unoxidized; soft.	clay-loam till
38-43	Till; sandy (medium to fine) slightly silty, pebbly, bouldery; igneous pebbles.	basal sandy drift
43	End of hole on rock.	

TEST HOLE P-36

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-6	Silts and very fine sand.	lacustrine silt unit
6-19	Clay; laminated; oxidized olives 5Y; many silt fragments; selenite concentrations; occasional pebble; becoming oxidized dark grey 5Y near bottom.	lacustrine clay unit
19-22	Clay-till transition.	
22-31	Till; clayey silty, sandy; carbonate pebbles predominate; dark grey 5Y.	clay-loam till
31-37	Till; sandy, silty, pebbly; silt content decreased downwards; igneous pebbles.	basal sandy drift
37	End of hole on rock.	

TEST HOLE P-37

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-8	Silt; laminations of very fine sand and clay.	lacustrine silt unit

TEST HOLE P-37 Cont'd.

8-16	Clay; slightly silty; occasional pebble; silt fragments; selenite concentrations; oxidized olives 5Y.	lacustrine clay unit
16-17	Transition to till.	
17-34	Till; clayey silty sandy; very soft; mainly carbonate pebbles.	clay-loam till
34-36	Till; silty, pebbly, bouldery; igneous pebbles.	basal sandy drift
36	End of hole on rock.	

TEST HOLE P-38

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-4	Silt and very fine sand; laminated.	lacustrine silt unit
4-14	Clay; slightly silty; occasional pebble; silt fragments.	lacustrine clay unit
14-16	Transition to till.	
16-31	Till; normal; mainly carbonate pebbles;	clay-loam till
31-33	Till?; very bouldery; no samples as auger broke in hole.	basal sandy drift
33	End of hole in boulders.	

TEST HOLE P-39

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-4	Silts and very fine sand.	lacustrine silt unit

TEST HOLE P-39 Cont'd.

4-8	Clay; silty; silt fragments common; oxidized olive 5Y.	lacustrine clay unit
8-24	Till; normal; carbonate pebbles predominate.	clay-loam till
24-42	Sand; layered very fine silty sand and medium sand; no pebbles; occasional thin clay interbed.	lacustrine sand unit
42-46	Medium to coarse well-sorted sand.	
46	End of hole in boulders.	

TEST HOLE P-40

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-56	Sand; clean, well sorted fine to medium sand; no pebbles; oxidized to 18 feet.	lacustrine sand unit
56-57	Clay; layered, very silty, black; angular carbonate pebbles.	
57	End of hole on rock.	

TEST HOLE P-41

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-7	Silty clay, clayey silt and very fine sand; interbedded, laminated; oxidized.	lacustrine silt unit
7-20	Clay, lacustrine massive.	lacustrine clay unit
20-50	Till, clayey, silty, sandy, with carbonate pebbles; 5Y5/1 grey.	clay-loam till
50-54.5	Till, very sandy silt; igneous pebbles.	basal sandy drift
54.5	End of hole on solid rock.	

TEST HOLE P-42

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-6	Silt, silty clay and very fine sand; interbedded, laminated; gradational lower contact.	lacustrine silt unit
6-18	Clay, lacustrine; olive grey 5Y becoming dark grey; occasional pebble and silt ball.	lacustrine clay unit
18-22	Transition to till.	
22-43	Till; olive grey 5Y4/2 grading to dark grey 5Y4/1; clayey, silty, sandy; very plastic.	clay-loam till
43-45.5	Till; silty sandy; igneous pebbles.	basal sandy drift
45.5	End of hole in boulders.	

TEST HOLE P-43

Depth (ft.)	Characteristics	Interpretation
0-1	Topsoil.	
1-6	Silt, clayey silt and very fine sand; interbedded, laminated; oxidized.	lacustrine silt unit
6-18	Clay, lacustrine.	lacustrine clay unit
18-23	Transition to till.	
23-40	Till; silty, sandy, slightly clayey; carbonate pebbles.	clay-loam till
40-44	Sand, medium, poorly sorted; upper foot bouldery; slightly pebbly.	basal sandy drift
44	End on solid rock.	

TEST HOLE P-44

Depth (ft.)	Characteristics	Interpretation
0-53	Sand, very fine to fine; massive, poorly sorted; no pebbles, few fines.	lacustrine sand unit

TEST HOLE P-45

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-6	Till; silty, sandy, slightly clayey; igneous pebbles.	
6-43	Sand; fine to very fine; poorly sorted, no fines; oxidized to 20 feet; no pebbles; no clay interbeds observed.	lacustrine sand unit

TEST HOLE P-46

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-4	Sand; coarse to medium with occasional pebble; oxidized.	undifferentiated sandy till
4-8	Sand; coarse; very poorly sorted; pebbly, slightly silty; oxidized.	
8-17	Silt; sandy, pebbly; and sand; fine, silty; oxidized olive 5Y; pebbly.	
17-30	Silt and sand; interlayered; unoxidized dark grey 5Y.	
30-40	Sand; medium to coarse; pebbly, no fines.	
40-47.5	Sand; fine, poorly sorted; slightly pebbly, no fines.	

TEST HOLE P-47

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-10	Till; silty, sandy, slightly clayey; oxidized olive 5Y; gypsum and carbonate concentrations.	Undifferentiated sandy till
10-18	Till; as above but more sandy and bouldery; very little clay.	
18-21	Sand; very coarse, pebbly, bouldery; oxidized.	
21	End of hole in boulders.	

TEST HOLE P-48

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-4	Sand; medium to coarse; moderately sorted; no fines.	
4-7	Clay; lacustrine; occasional pebble; massive to slightly laminated; silt balls.	lacustrine clay unit
7-24	Till; silty, sandy, slightly clayey;	clay-loam till
24-26	Sand; silty, pebbly, bouldery; dark grey 5Y	basal sandy drift

TEST HOLE P-49

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-10	Sand; upper 5 feet medium grained moderately sorted, 2.5YR3/6; lower 4 feet slightly silty with occasional pebble.	lacustrine sand and gravel unit
10-23	Clay, lacustrine; massive; dary grey 5Y3.5/1.	lacustrine clay unit
23-53	Till; clayey, silty, sandy; very plastic.	clay-loam till

TEST HOLE P-50

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-8	Clay; lacustrine; massive to laminated; abundant silt balls; occasional pebble.	lacustrine clay unit
8-15	Transition to till.	
15-47	Till; clayey, silty, sandy; carbonate and igneous pebbles; olive 5Y to 20 feet and dark grey 5Y below.	clay-loam till
47	End of hole on boulder or bedrock.	

TEST HOLE P-51

Depth (ft.)	Characteristics	Interpretation
0-3	Road fill.	
3-7	Clay; lacustrine; silt balls and occasional pebble; gypsum concentrations; massive to slightly laminated.	lacustrine clay unit
7-10	Transition to till.	
10-25	Till; clayey, silty, sandy; igneous and carbonate pebbles.	clay-loam till
25-27	Boulders.	
27-50	Sand; medium grading to coarse near bottom; pebbly; poorly sorted near bottom; no fines.	basal sandy drift
50	End of hole in boulders.	

TEST HOLE P-52

Depth (ft.)	Characteristics	Interpretation
0-2	Road fill.	

TEST HOLE P-52 Cont'd.

2-12	Silty clay and clay; laminae of very fine sand; pebbly with silt balls.	lacustrine silt unit
12-30	Clay; lacustrine; silt balls and occasional pebble; massive to slightly laminated.	lacustrine clay unit
30-40	Till; clayey, silty, sandy; plastic and soft.	clay-loam till
40	End of hole on boulder.	

TEST HOLE P-53

Depth (ft.)	Characteristics	interpretation
0-2	Top soil.	
2-7	Clayey silt and silty clay; laminae of very fine sand.	lacustrine silt unit
7-12	Transition to well sorted clay.	
12-27	Clay; laminated to massive; silt balls and occasional pebble.	lacustrine clay unit
27-35	Till; clayey, silty, sandy; very soft.	clay-loam till
35-37	Till and boulders; very sandy.	basal sandy drift
37	End of hole in boulders.	

TEST HOLE P-54

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-5	Clayey silt with laminations of very fine sand.	lacustrine silt unit
5-14	Clay; lacustrine; silt balls and occasional pebble; massive to slightly laminated.	lacustrine clay unit
14-26	Till; clayey, silty, sandy.	clay-loam till
26	End of hole on boulder.	

TEST HOLE P-55

Depth (ft.)	Characteristics	Interpretation
0-2	Top soil.	
2-3	Clayey silt.	lacustrine silt unit
3-15	Clay; lacustrine; silt balls and occasional pebble; secondary gypsum concentrations.	lacustrine clay unit
15-27	Till; clayey, silty; soft, oxidized.	basal sandy drift

TEST HOLE P-56

Depth (ft.)	Characteristics	Interpretation
0-7	Silty clay and clayey silt; laminae of very fine sand; lower portion has less silt, occasional pebble and silt balls.	lacustrine clay unit
7-23	Till; clayey, silty, sandy.	clay-loam till
23-26	Boulders and sand.	basal sandy drift
26	End of hole on rock.	

TEST HOLE P-57

Depth (ft.)	Characteristics	Interpretation
0-4	Silty clay and clayey silt; laminated with very fine sand.	lacustrine silt unit
4-10	Clay; massive with occasional pebble.	lacustrine clay unit
10-19	Till; clayey, silty, sandy.	clay-loam till
19-30	Till; very sandy silty; mixed pebble composition; moist; soft.	
30-41	Sand; possibly silty, very sandy till.	basal sandy drift

TEST HOLE P-58

Depth (ft.)	Characteristics	Interpretation
0-1	Top soil.	
1-8	Silty clay.	lacustrine silt unit
8-17	Clay; lacustrine; silt balls and gypsum concentrations; laminated.	lacustrine clay unit
17-35	Till; silty, sandy.	clay-loam till

TEST HOLE P-59

Depth (ft.)	Characteristics	Interpretation
0-2	Road fill.	
2-10	Clay; slightly silty.	lacustrine clay unit
10-25	Clay; lacustrine; silt balls; high gypsum content.	
25-59	Till; very clayey, silty, sandy.	clay-loam till

TEST HOLE P-60

Depth (ft.)	Characteristics	Interpretation
0-2.5	Road fill.	
2.5-13	Clay; silty; laminated with silt balls.	lacustrine clay unit
13-23	Clay; lacustrine; silt balls and gypsum concentrations.	
23-40	Till; very clayey, slightly silty, sandy.	clay-loam till

APPENDIX C

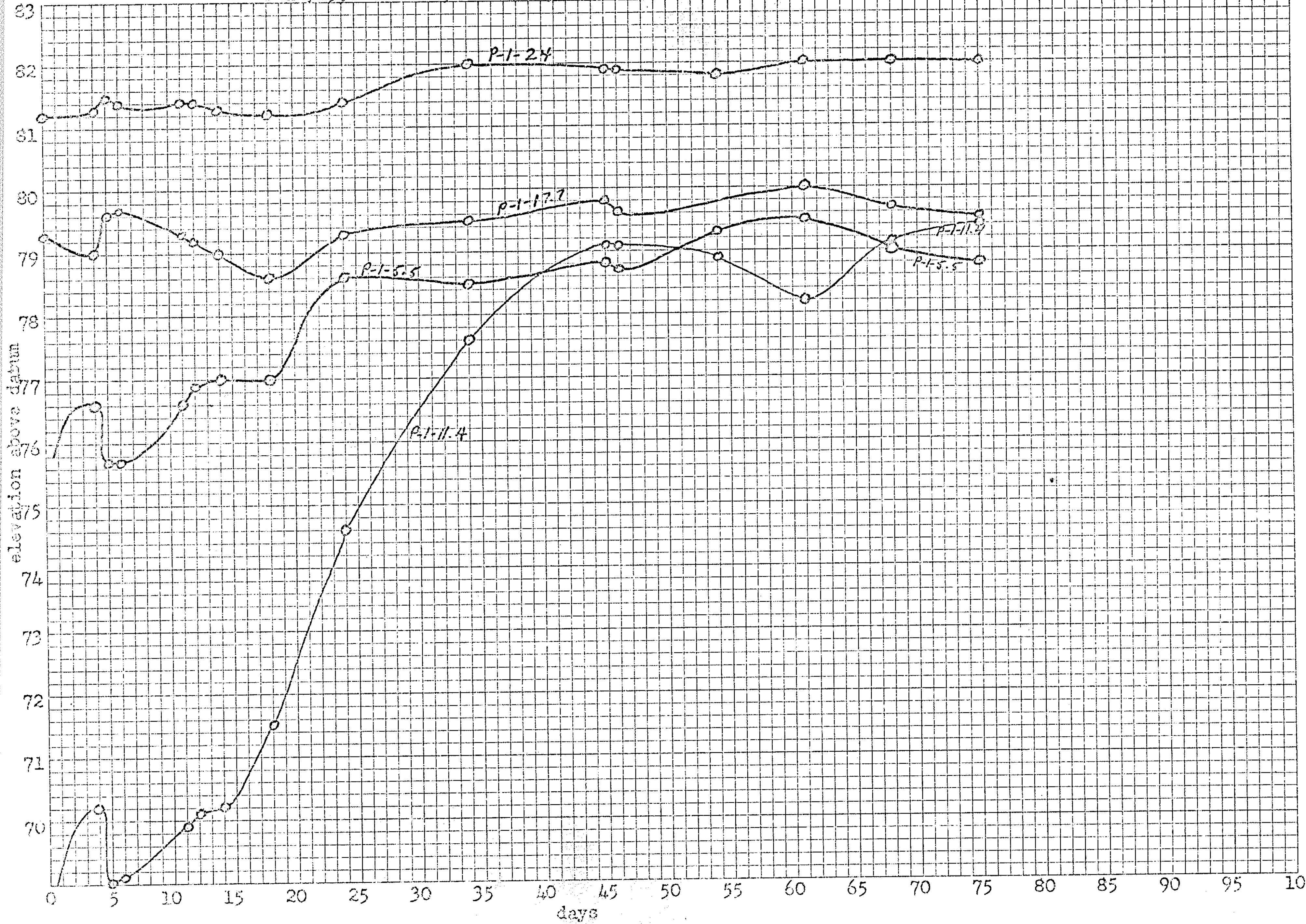
PIEZOMETER HYDROGRAPHS

The first group of hydrographs is arranged so that, for each nest, a 20-day hydrograph is followed by a 100-day hydrograph. This allows a more convenient comparison of the initial stabilization period to a seasonal fluctuation. These hydrographs were prepared only for piezometer nests 1 through 14 installed during the summer of 1968. The 20-day hydrographs were prepared before survey data was available and list water levels from the top of the standpipe rather than an elevation. However, they are useful in illustrating short-term response characteristics.

Two-year hydrographs of piezometer nests 1 through 40 were prepared to illustrate seasonal and annual fluctuations. Precipitation bar graphs indicate the relative sensitivity of each hydrograph to short-term and long-term variations in precipitation.

P-1-5.5, P-1-11.9, P-1-17.7, P-1-24 installed 24/7/68 SHEET #1 to 13/8/68

last point 13/8/68

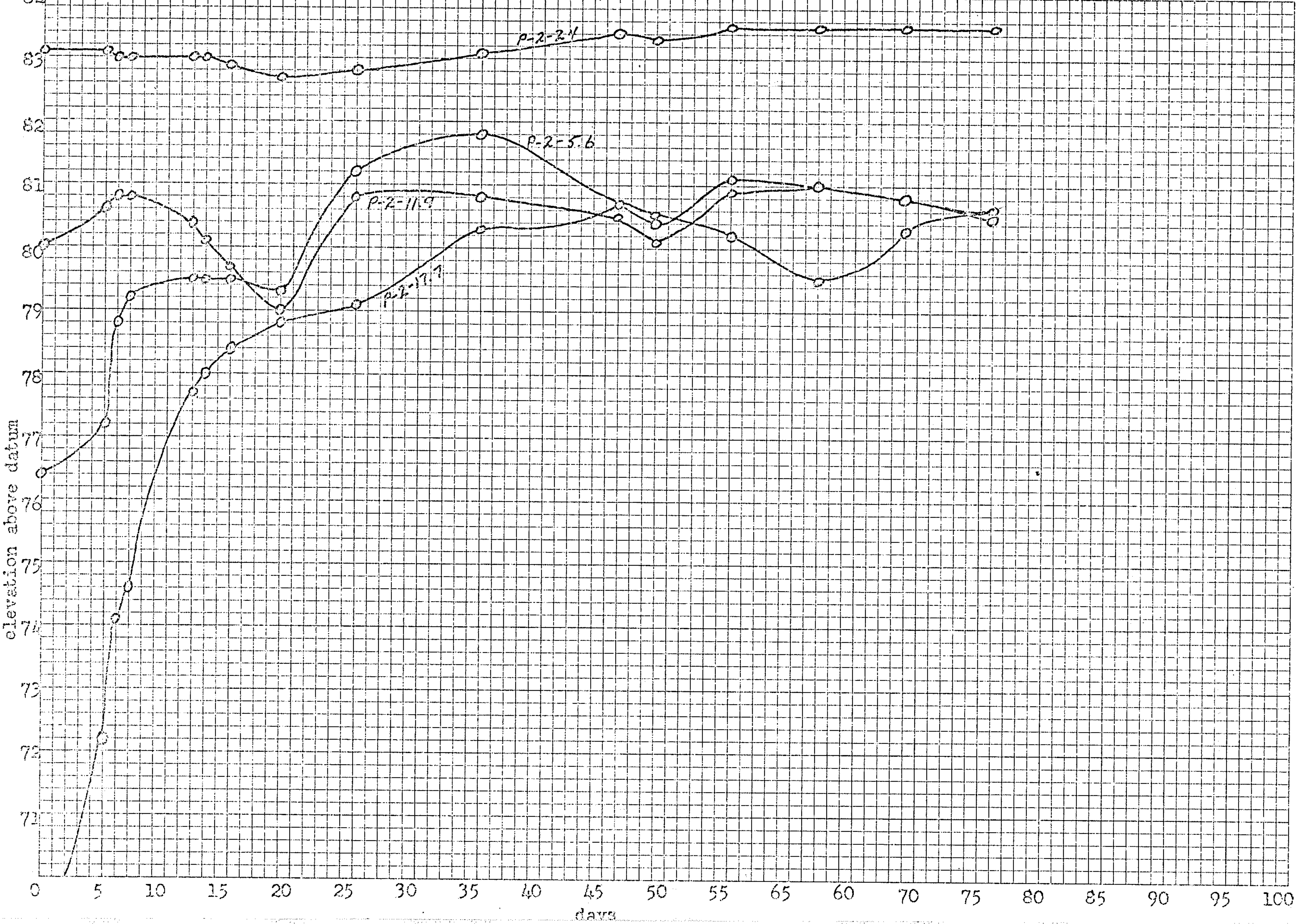


P-1-5.5, P-1-11.4, P-1-17.7, P-1-24

P-2-5.4, P-2-11.9, P-2-17.7, P-2-24 INstalled 24/7/68 SHEET #1 to 13/8/68

last point 13/8/68

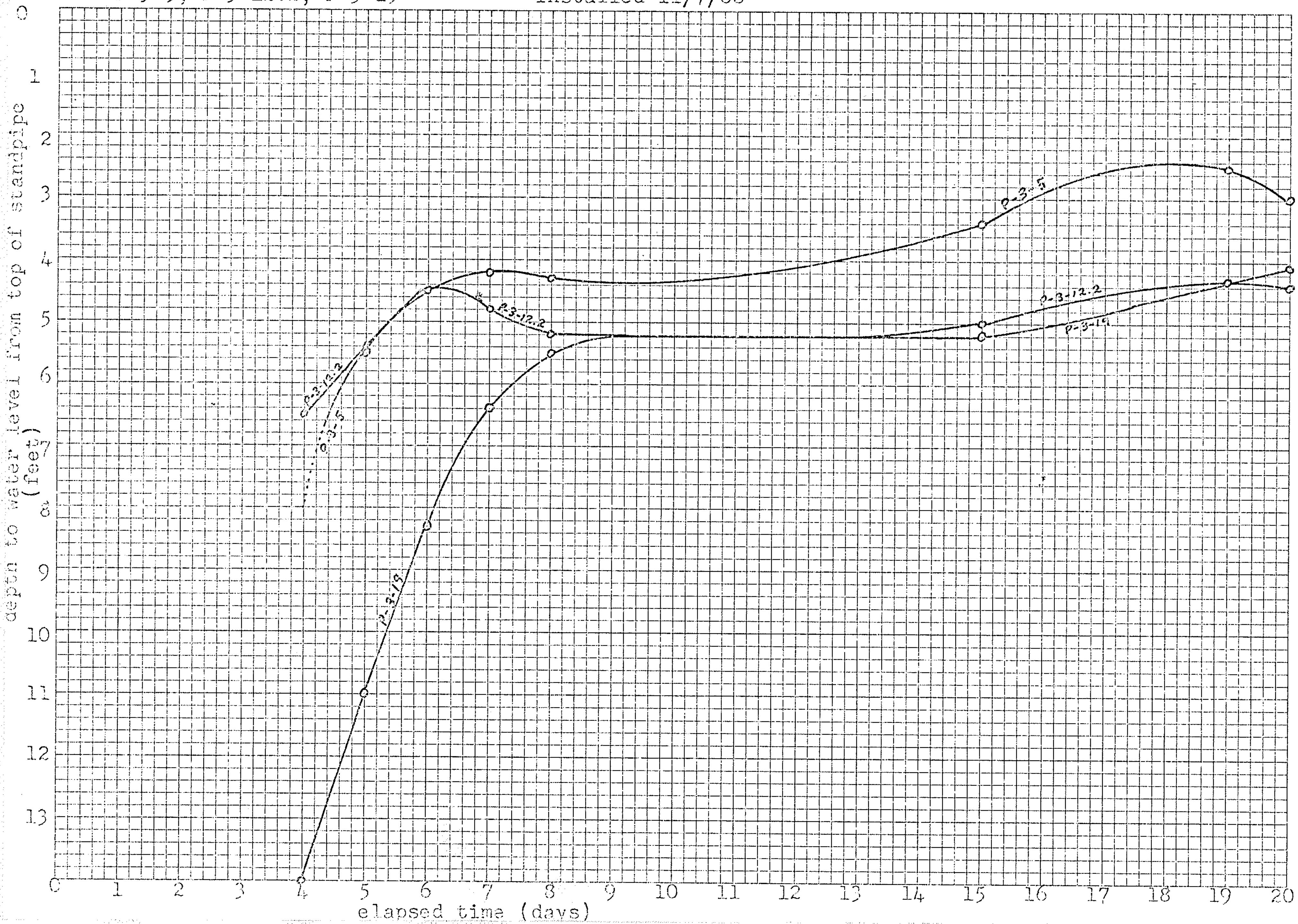
P-2-5.6, P-2-11.9, P-2-17.7, P-2-24



SHEET #1

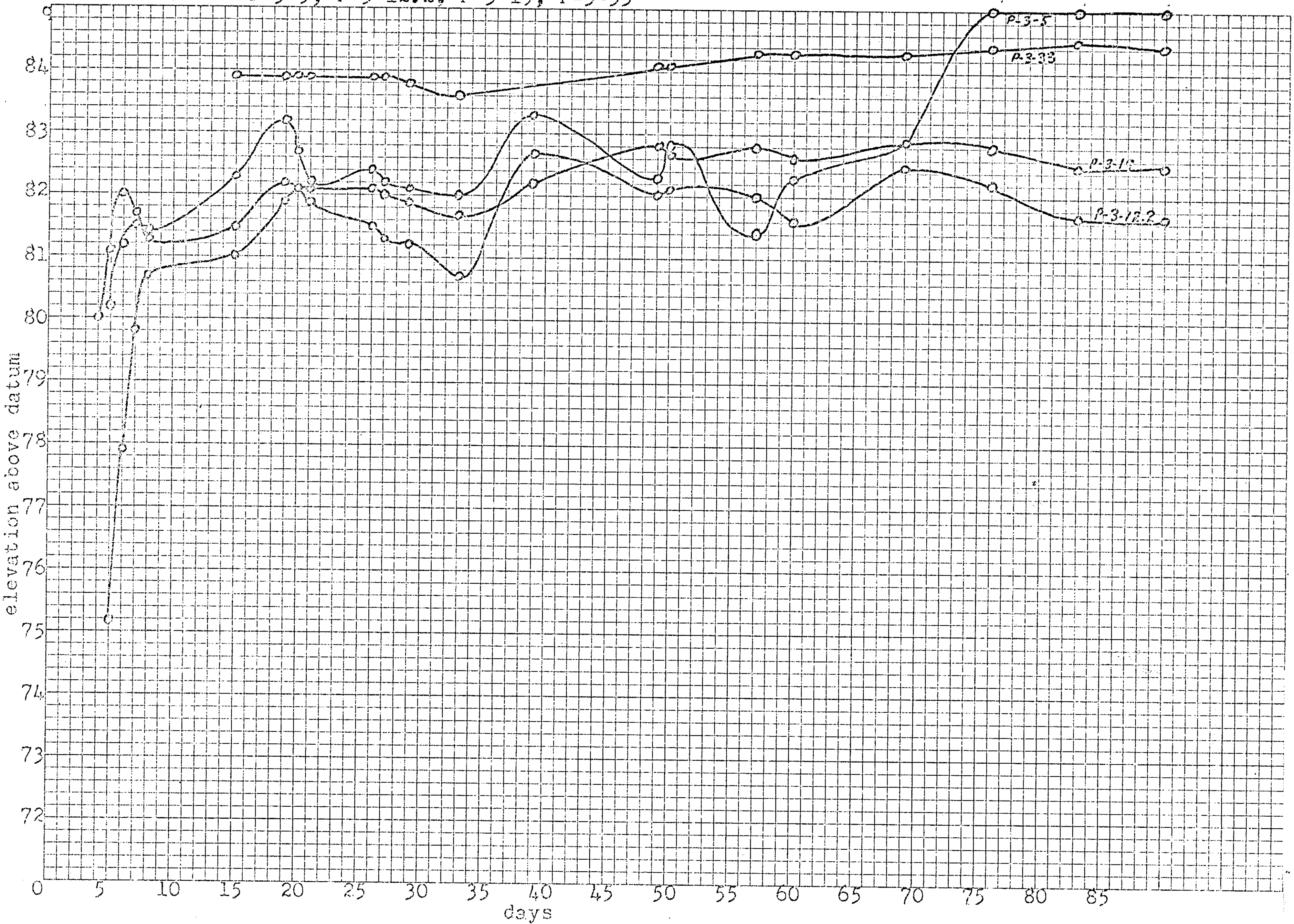
P-3-5, P-3-12.2, P-3-19

installed 11/7/68

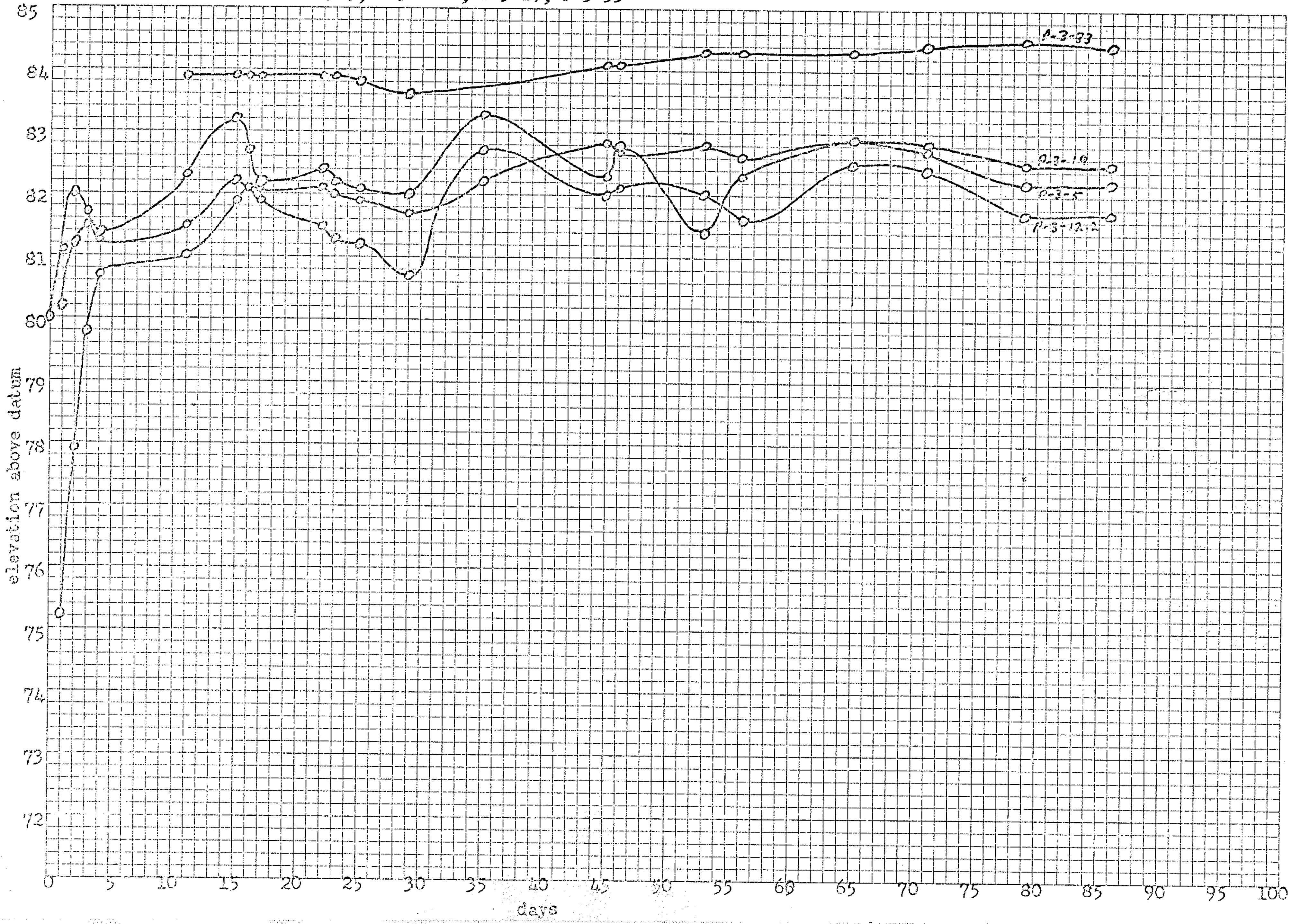


last point 31/7/68

P-3-5, P-3-12.2, P-3-19, P-3-33



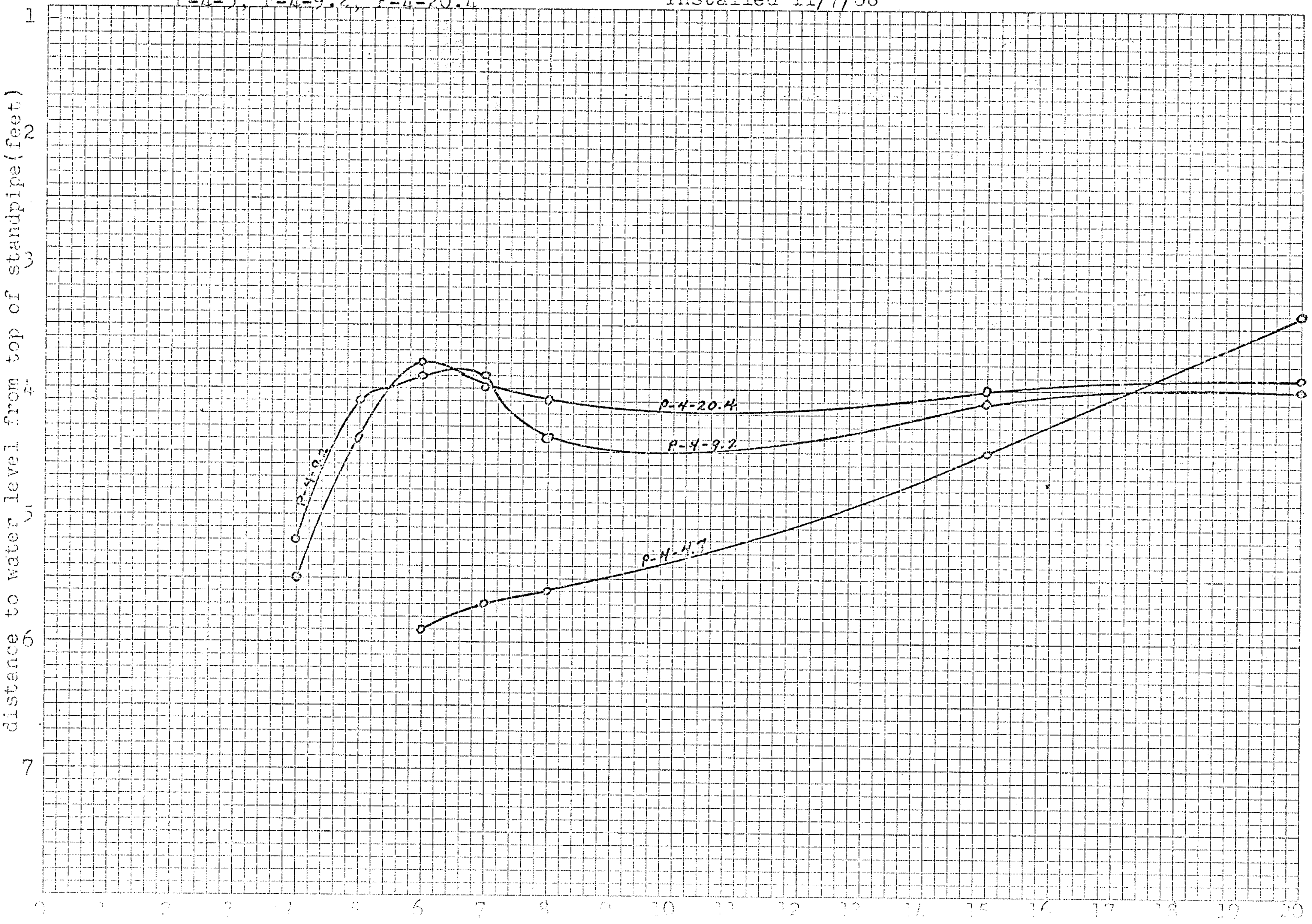
P-3-5, P-3-12.2, P-3-19, P-3-33



SHEET #1 to July 31

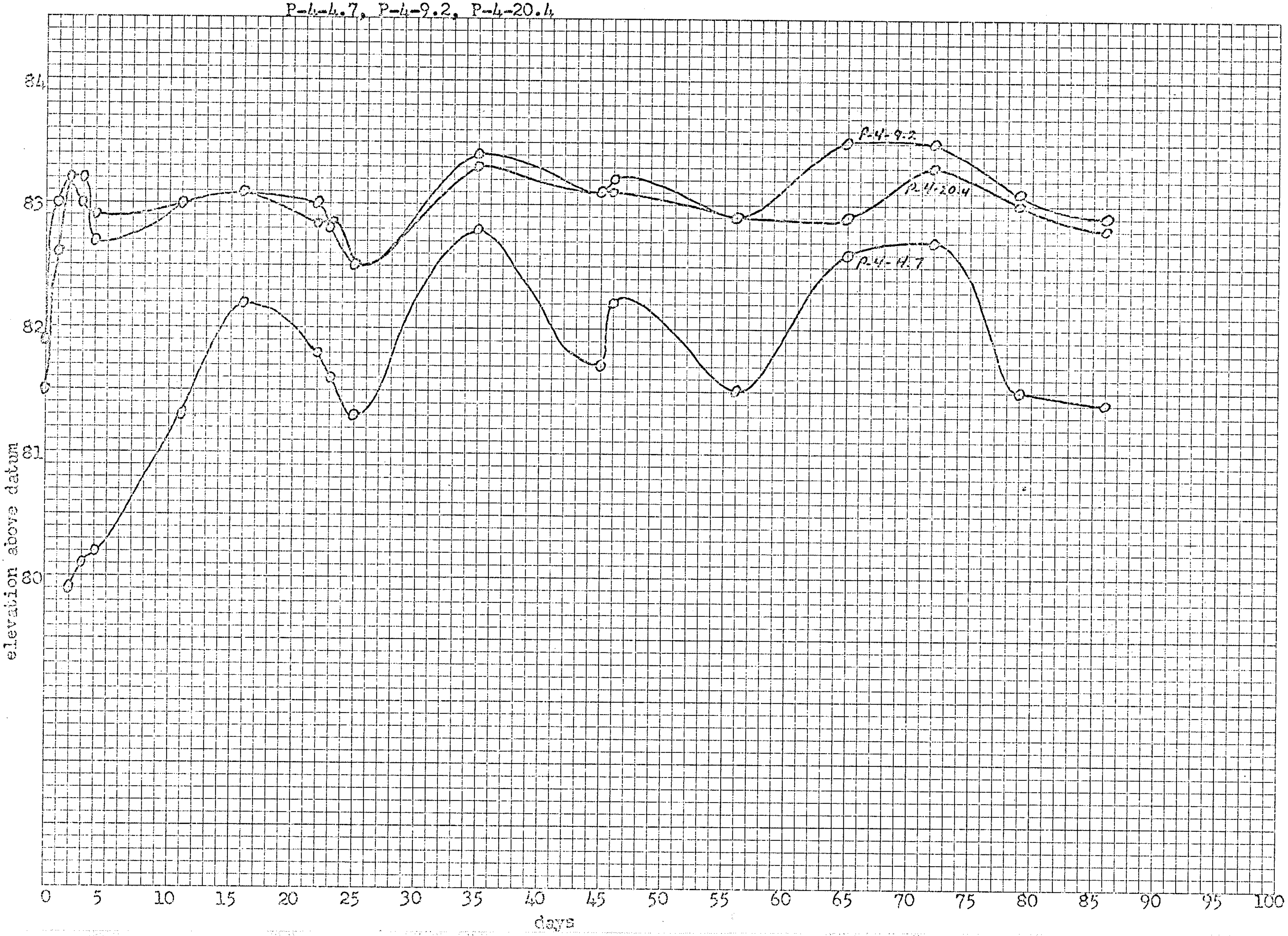
P-4-5, P-4-9.2, P-4-20.4

installed 11/7/68



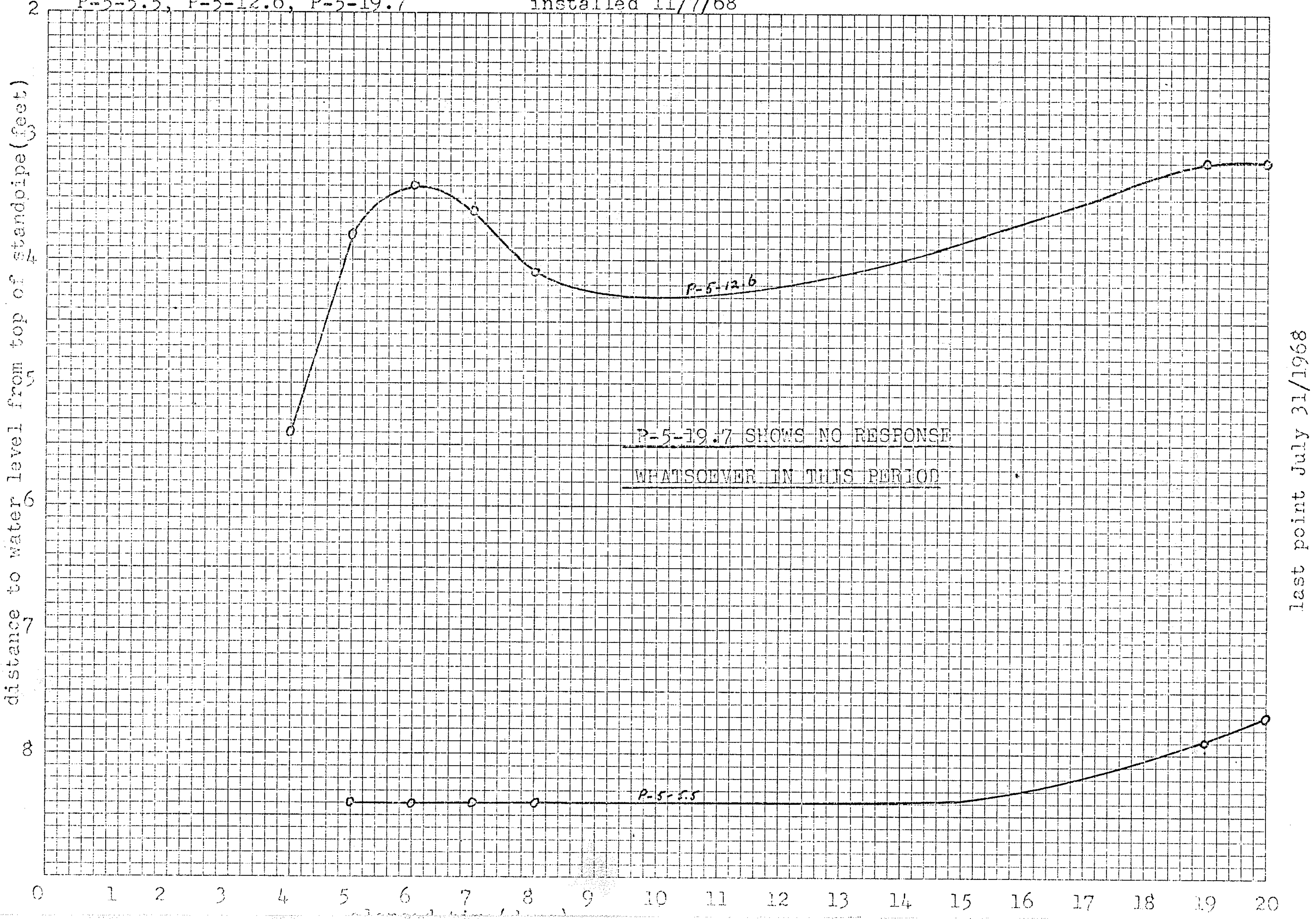
last point 31/7/68

P-4-4.7, P-4-9.2, P-4-20.4

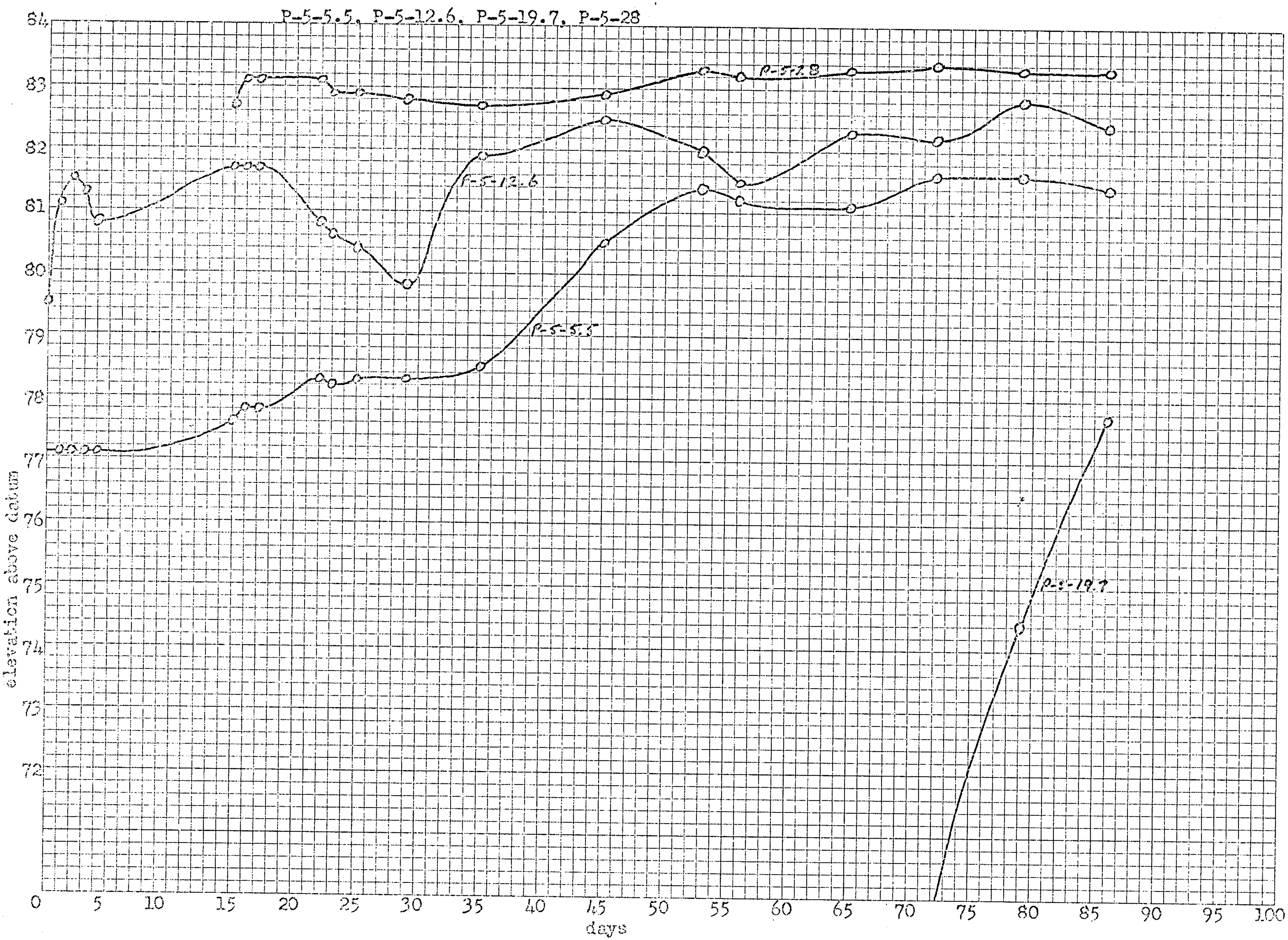


SHEET #1 to July 31/1968

P-5-5.5, P-5-12.6, P-5-19.7 installed 11/7/68



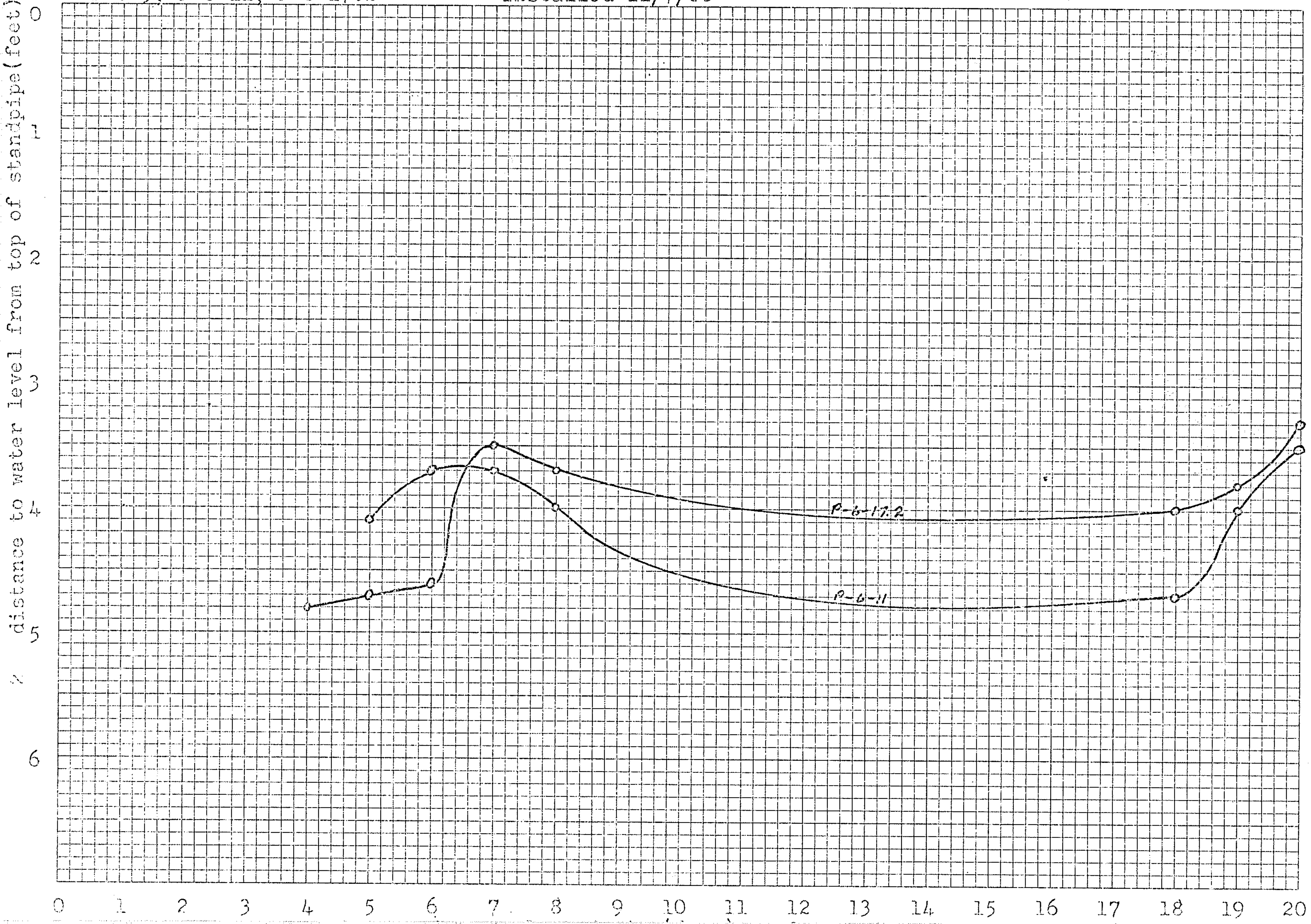
P-5-19.7 SHOWS NO RESPONSE WHATSOEVER IN THIS PERIOD


P-5-5.5, P-5-12.6, P-5-19.7, P-5-28

5 X 5 PER HALF INCH MADE IN U. S. A.

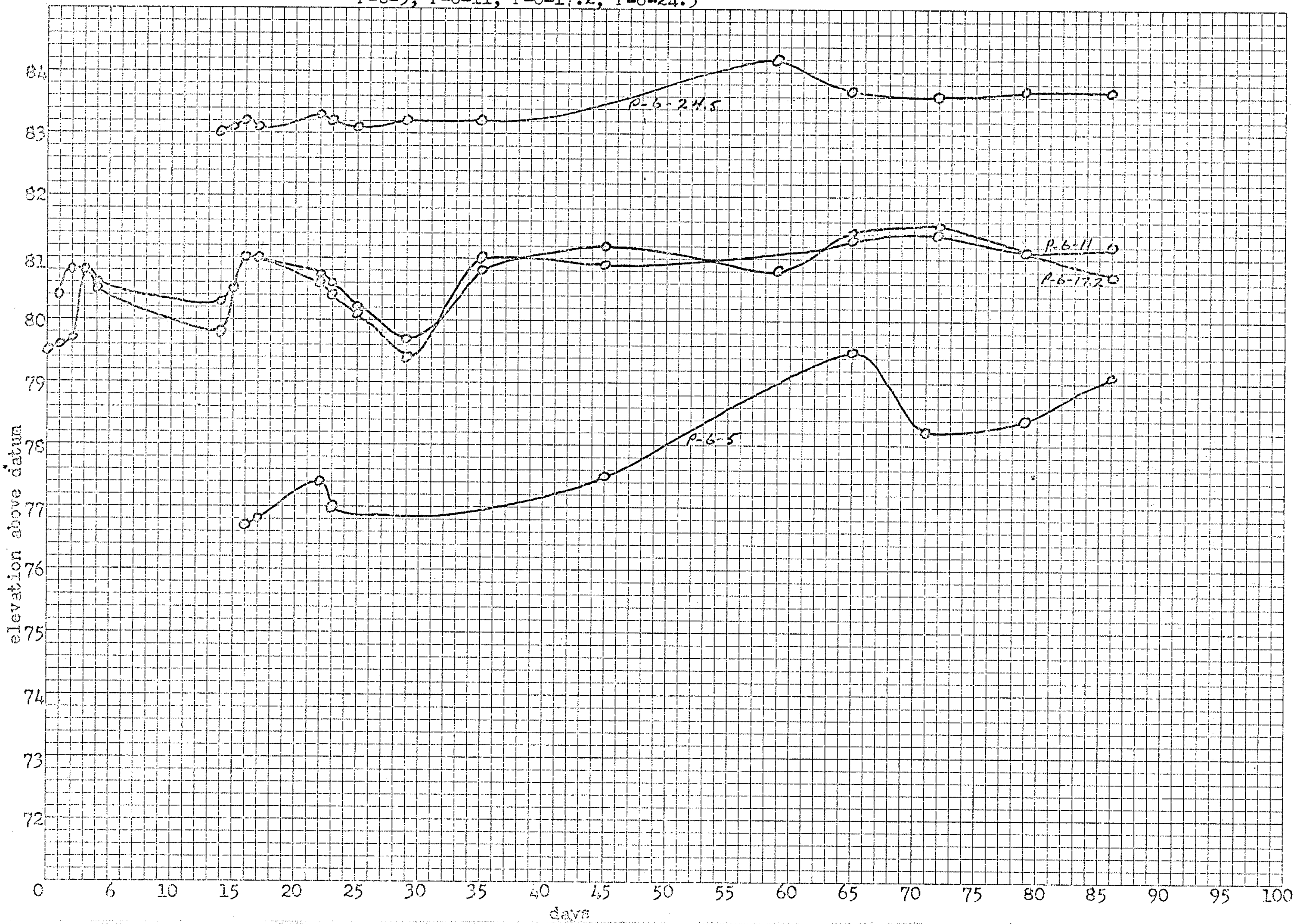
SHEET #1 to July 31/1968

P-6-5, P-6-11, P-6-17.2 installed 11/7/68

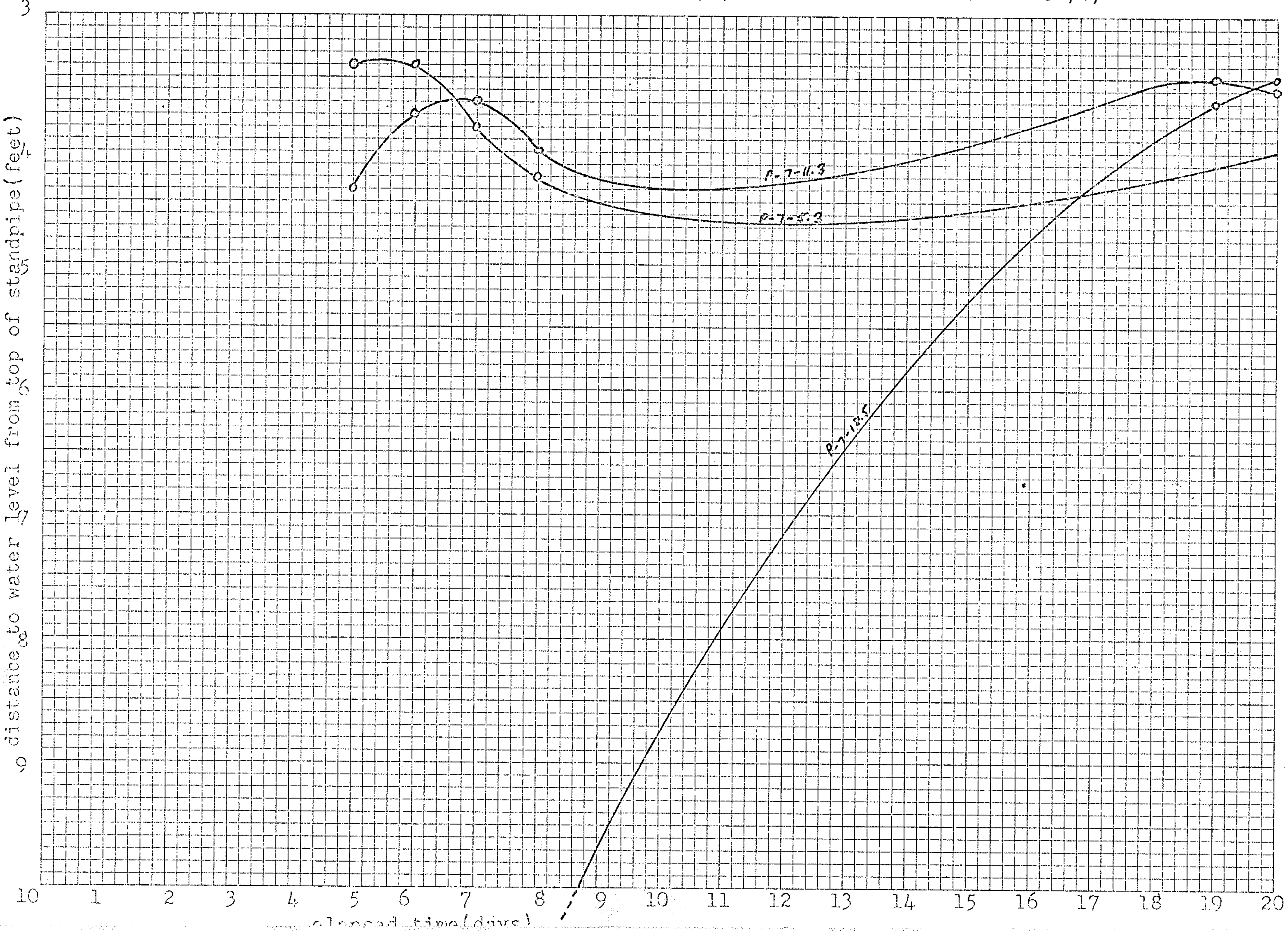


last point 31/7/68

P-6-5, P-6-11, P-6-17.2, P-6-24.5

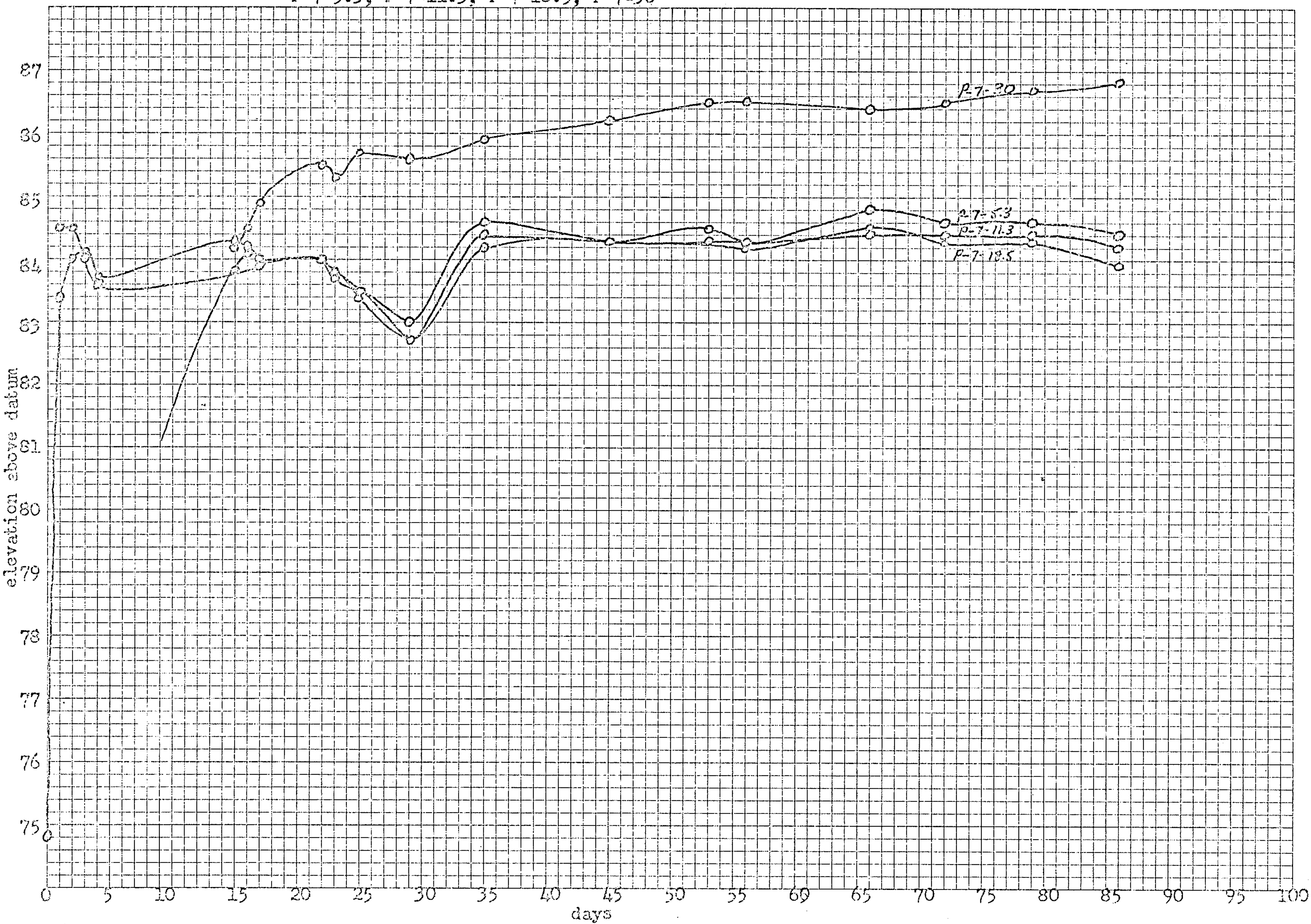


P-7-5.3, P-7-11.3, P-7-18.5 installed 11/7/68 SHEET #1 to 31/7/68



last point 31/7/68

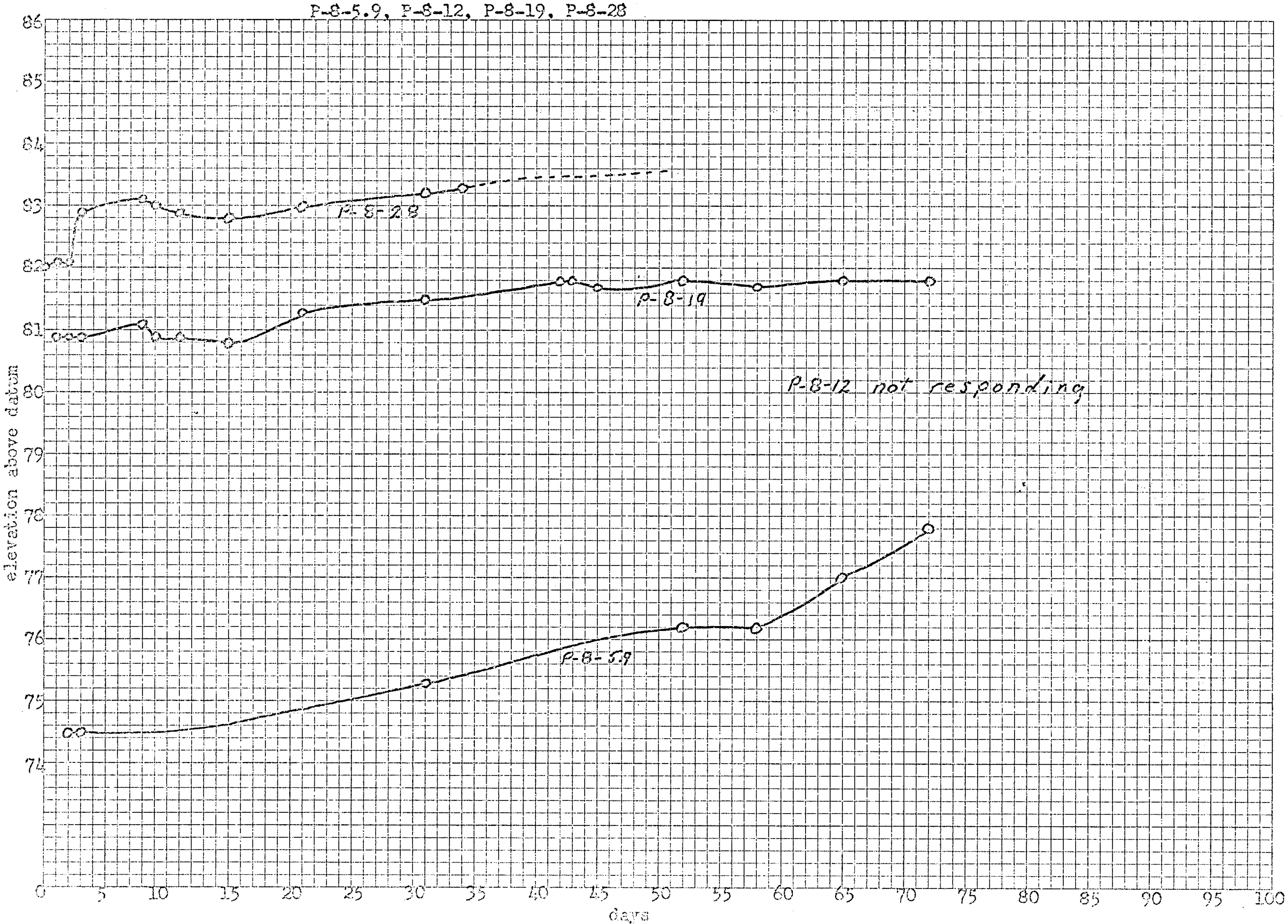
P-7-5.3, P-7-11.3, P-7-18.5, P-7-30



P-8-5.9, P-8-12, P-8-19, P-8-28 installed 24/7/68 SHEET #1 to 13/8/68

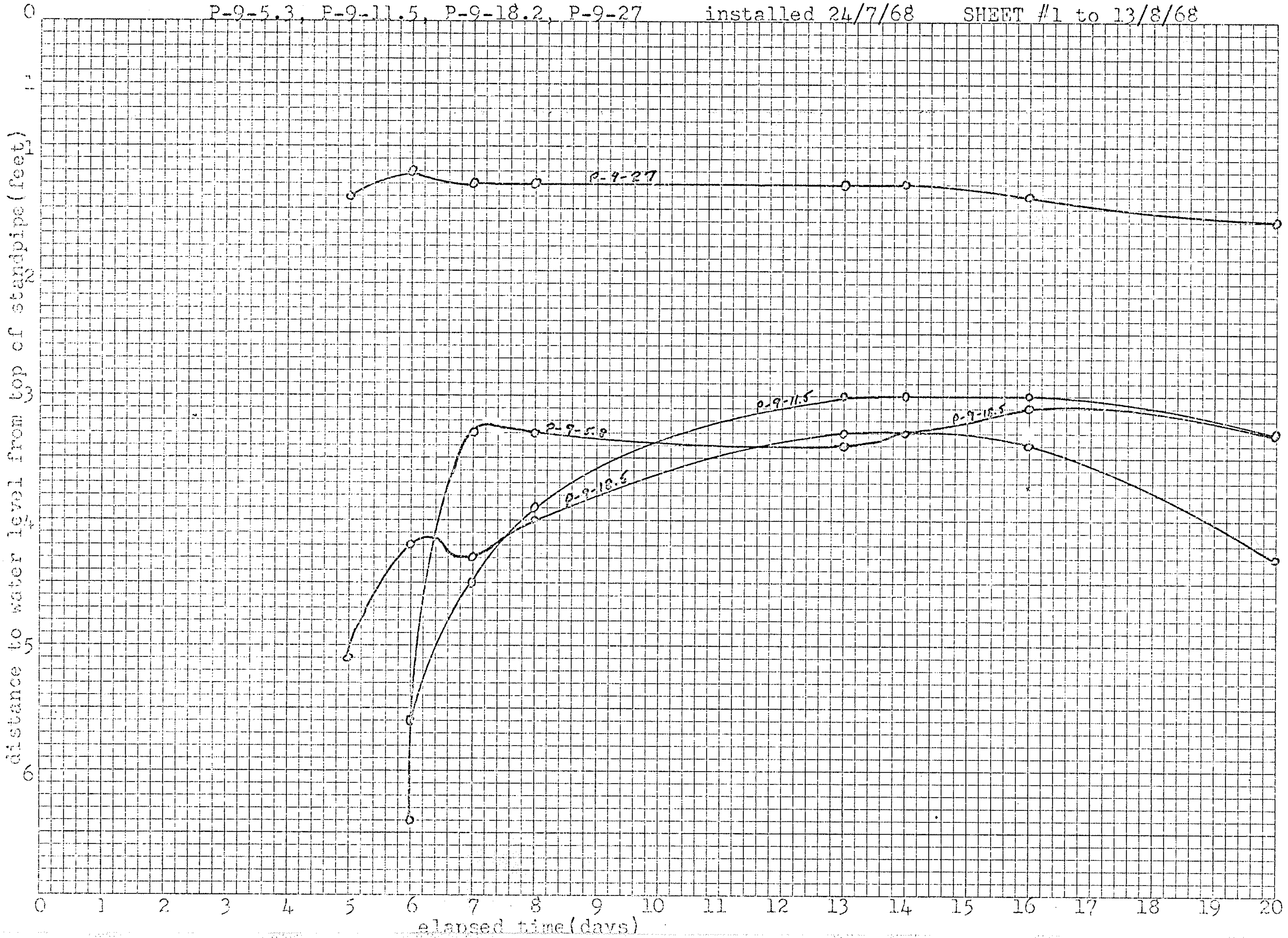
P-8-5.9 and P-8-12 show no response through this period

last point 13/8/68



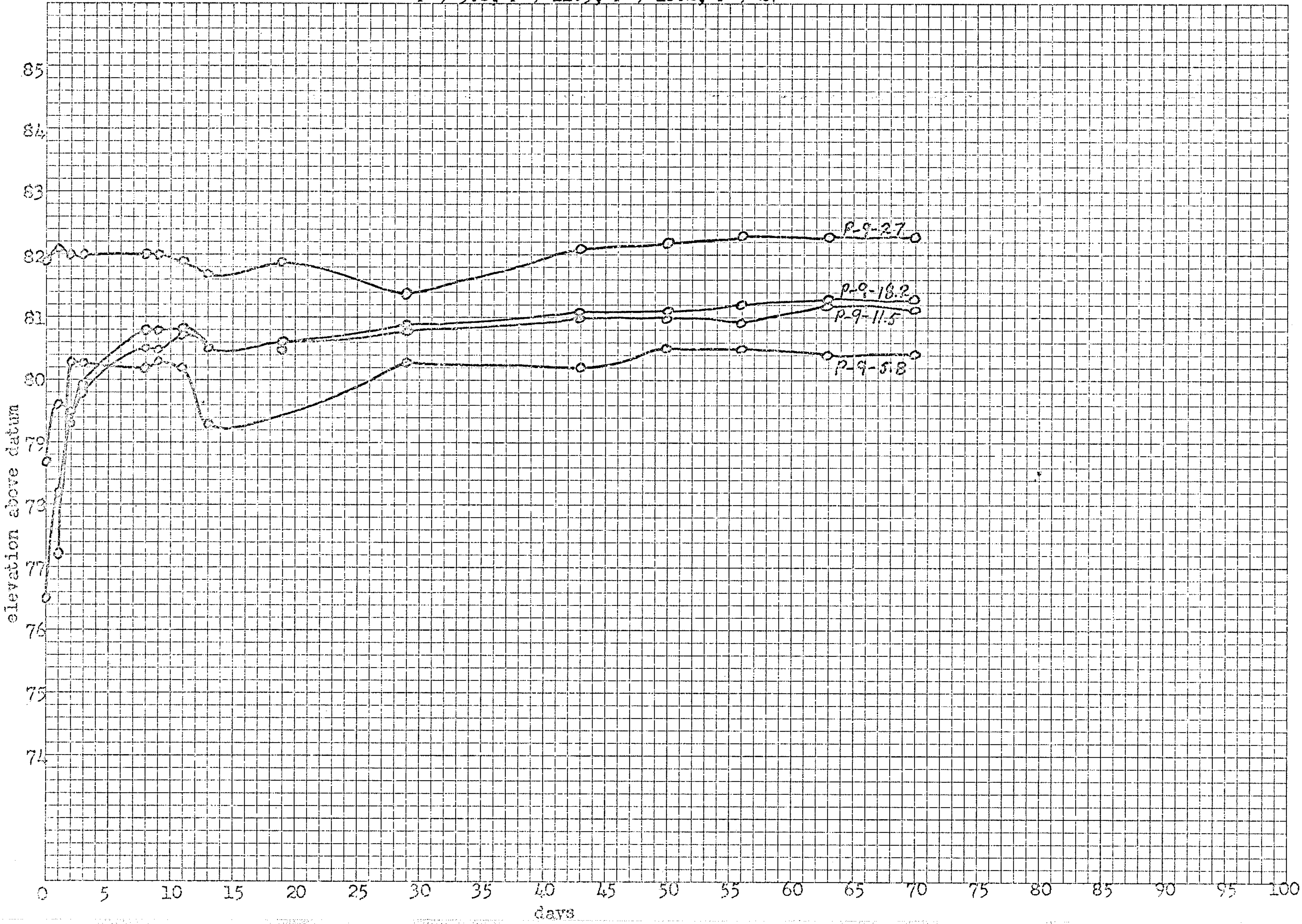
P-8-5.9, P-8-12, P-8-19, P-8-28

P-9-5.3, P-9-11.5, P-9-18.2, P-9-27 installed 24/7/68 SHEET #1 to 13/8/68

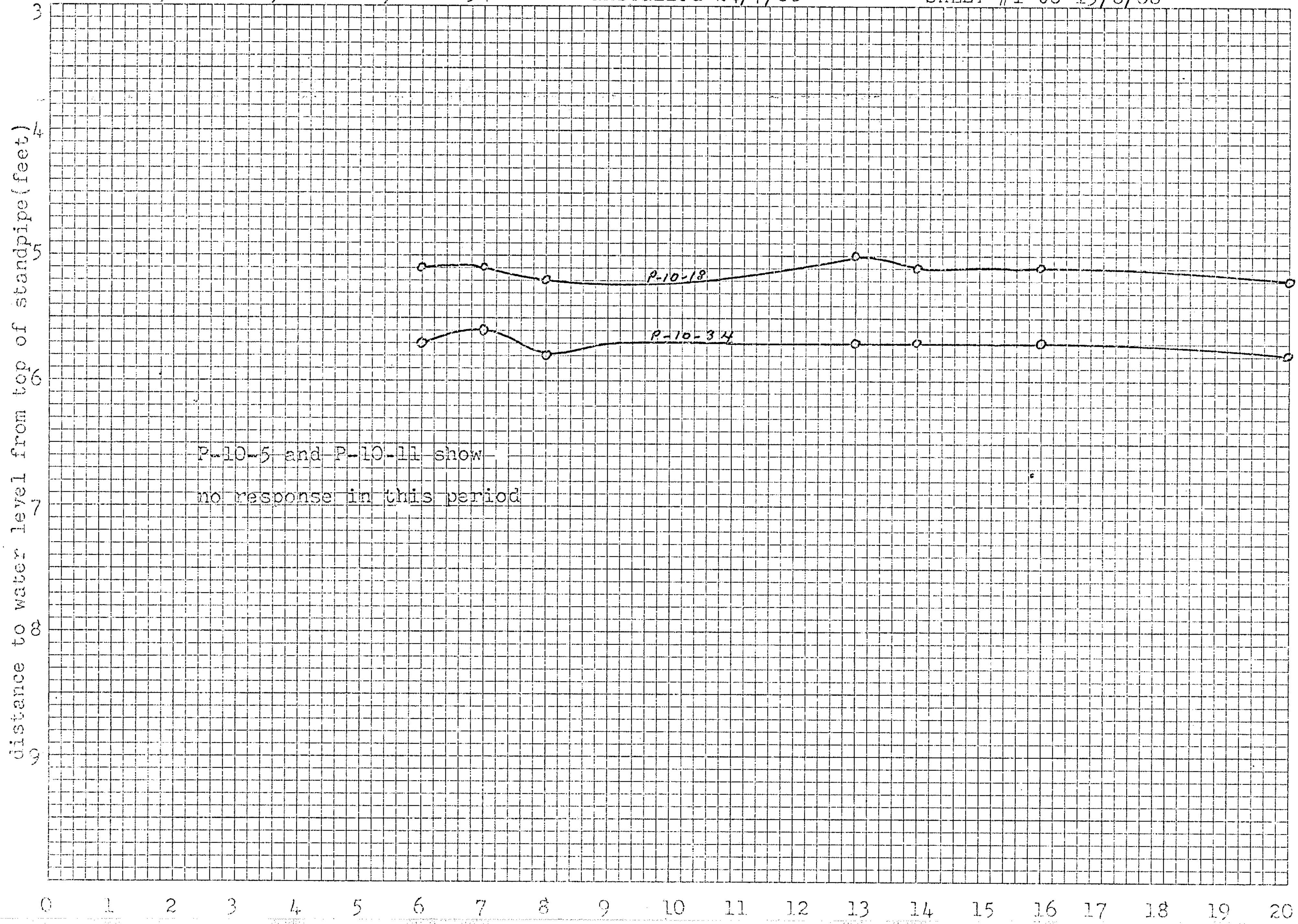


last point 13/8/68

P-9-5.8, P-9-11.5, P-9-18.2, P-9-27



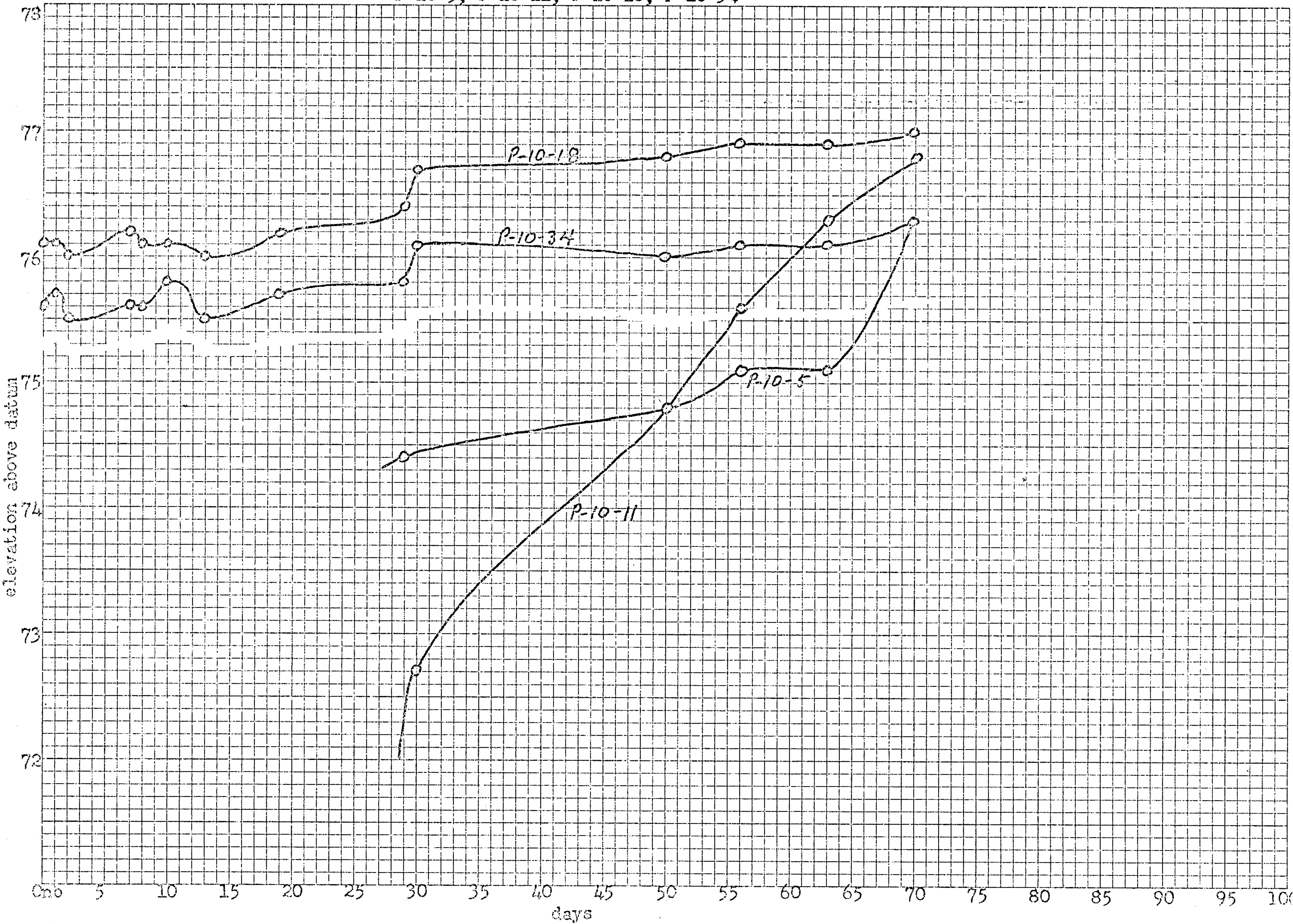
P-10-5. P-10-11, P-10-18, P-10-34 installed 24/7/68 SHEET #1 to 13/8/68



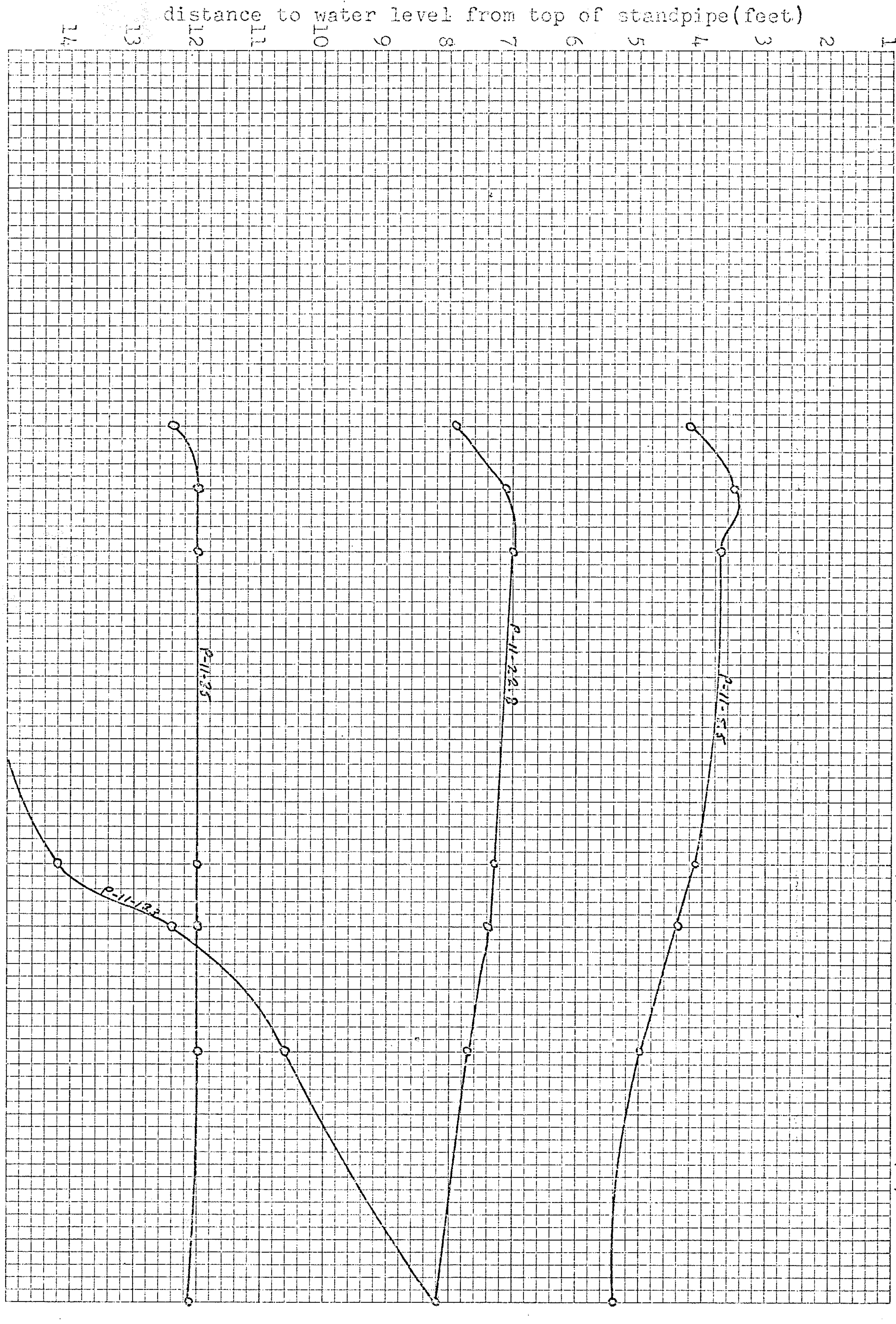
P-10-5 and P-10-11 show
no response in this period

last point 13/8/68

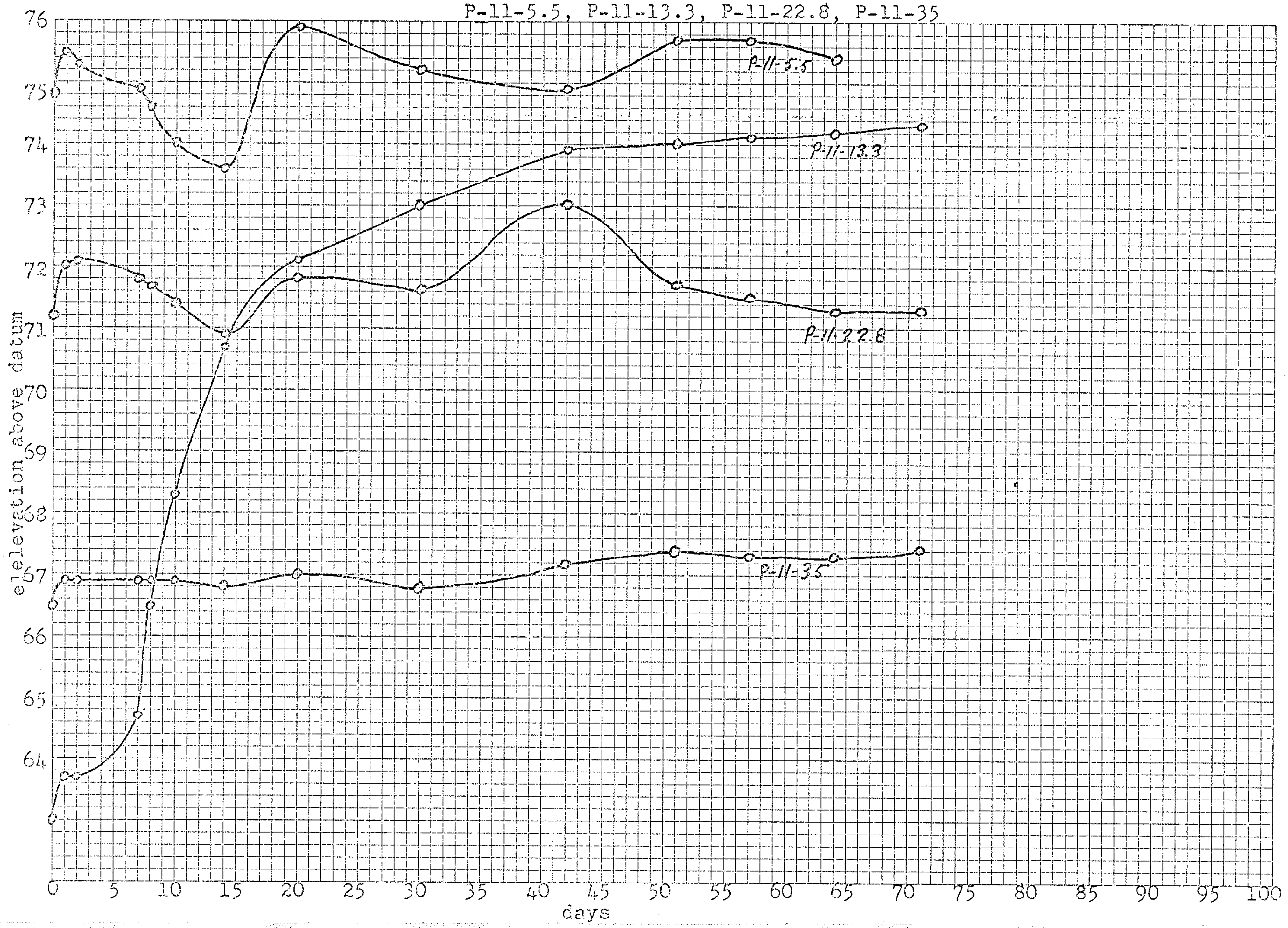
P-10-5, P-10-11, P-10-18, P-10-34



P-11-5.5, P-11-13.3, P-11-22.8, P-11-35 installed 24/7/68 SHEET #1 to 13/8/68

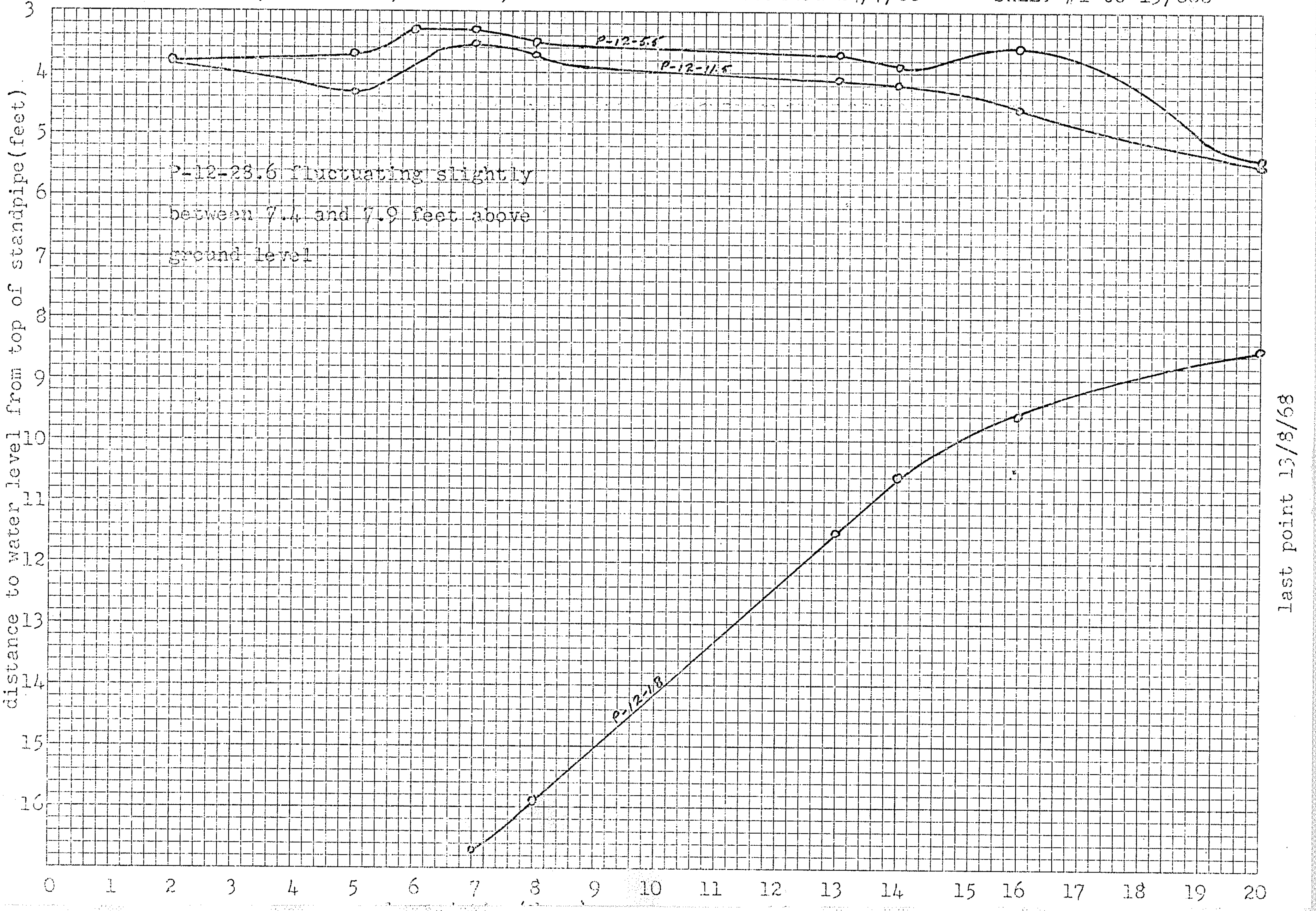


last point 13/8/68



P-11-5.5, P-11-13.3, P-11-22.8, P-11-35

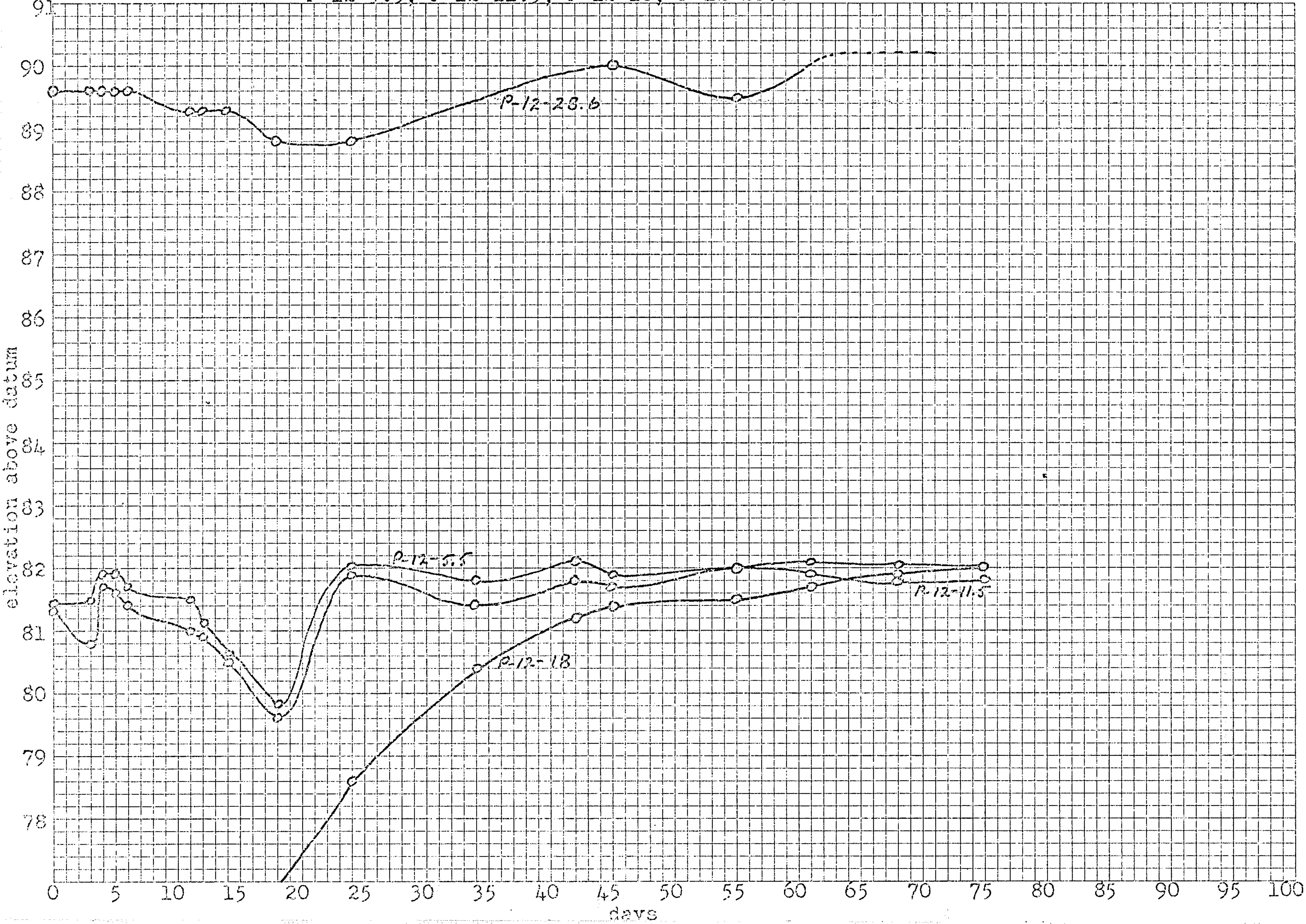
P-12-5.5, P-12-11.5, P-12-18, P-12-28.6 installed 24/7/68 SHEET #1 to 13/868



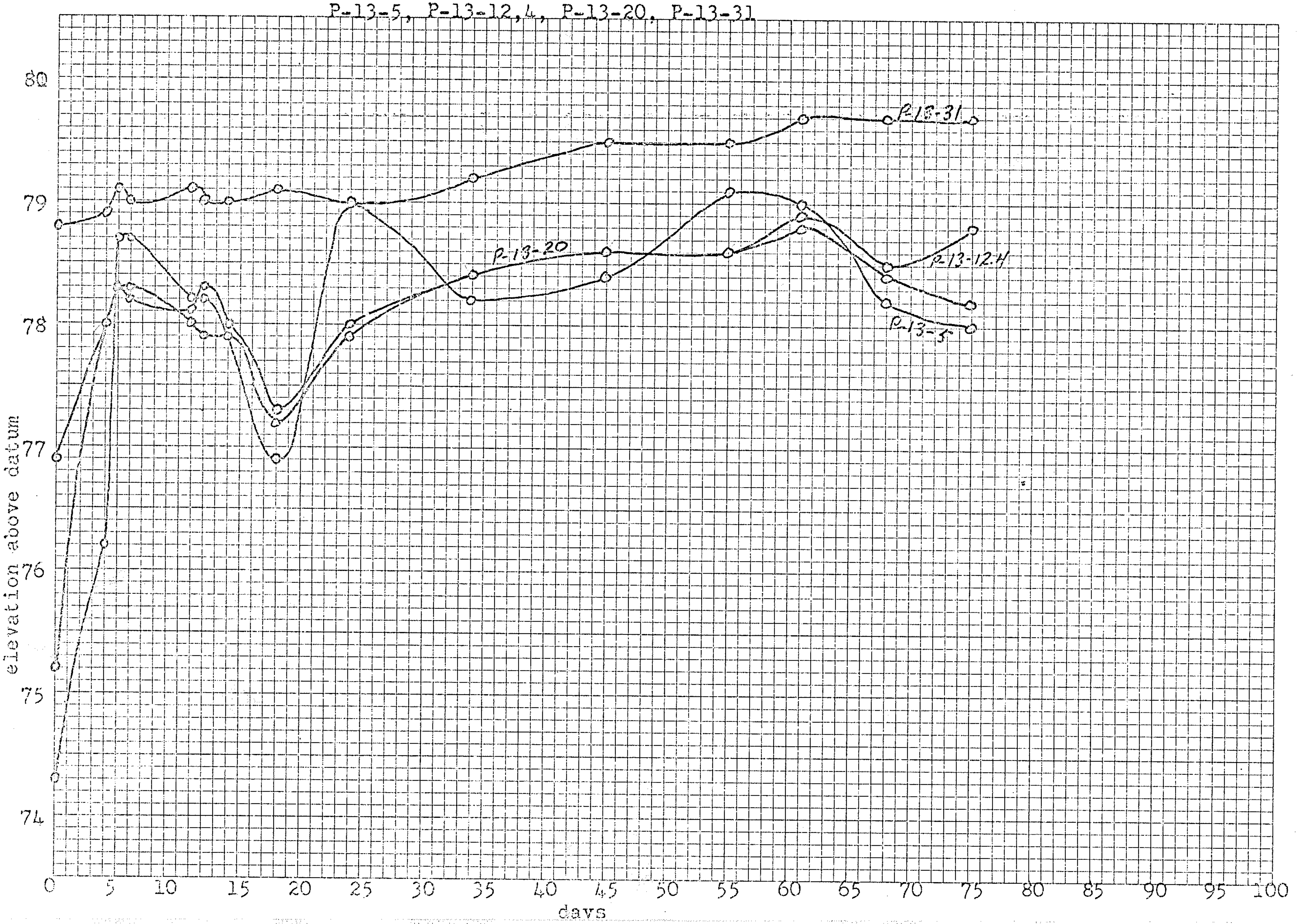
P-12-28.6 fluctuating slightly between 7.4 and 7.9 feet above ground level

last point 13/8/68

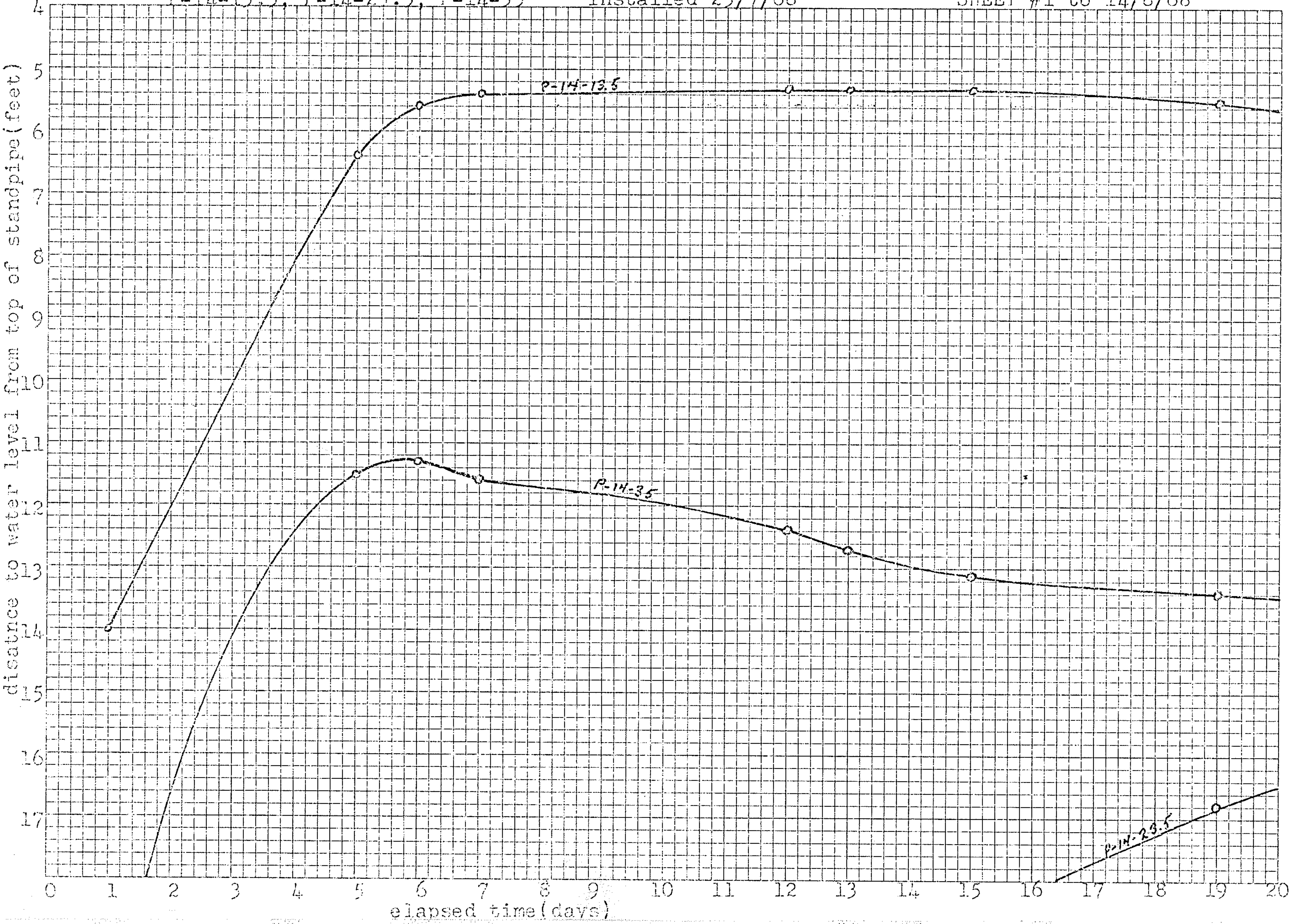
P-12-5.5, P-12-11.5, P-12-18, P-12-28.6



P-13-5, P-13-12,4, P-13-20, P-13-31



P-14-13.5, P-14-23.5, P-14-35 installed 25/7/68 SHEET #1 to 14/8/68



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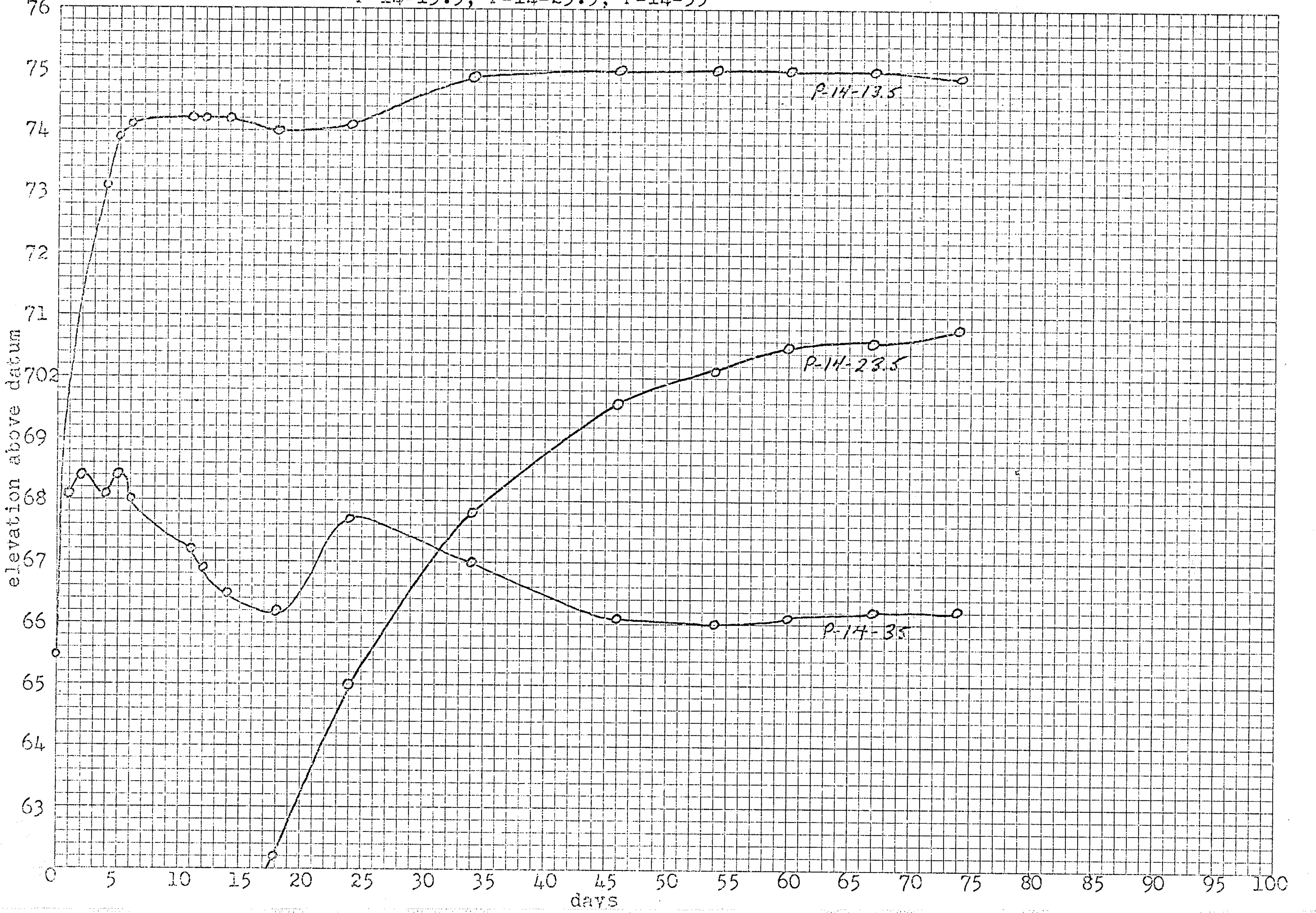


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P-2, 1969

PRECIPITATION 1969


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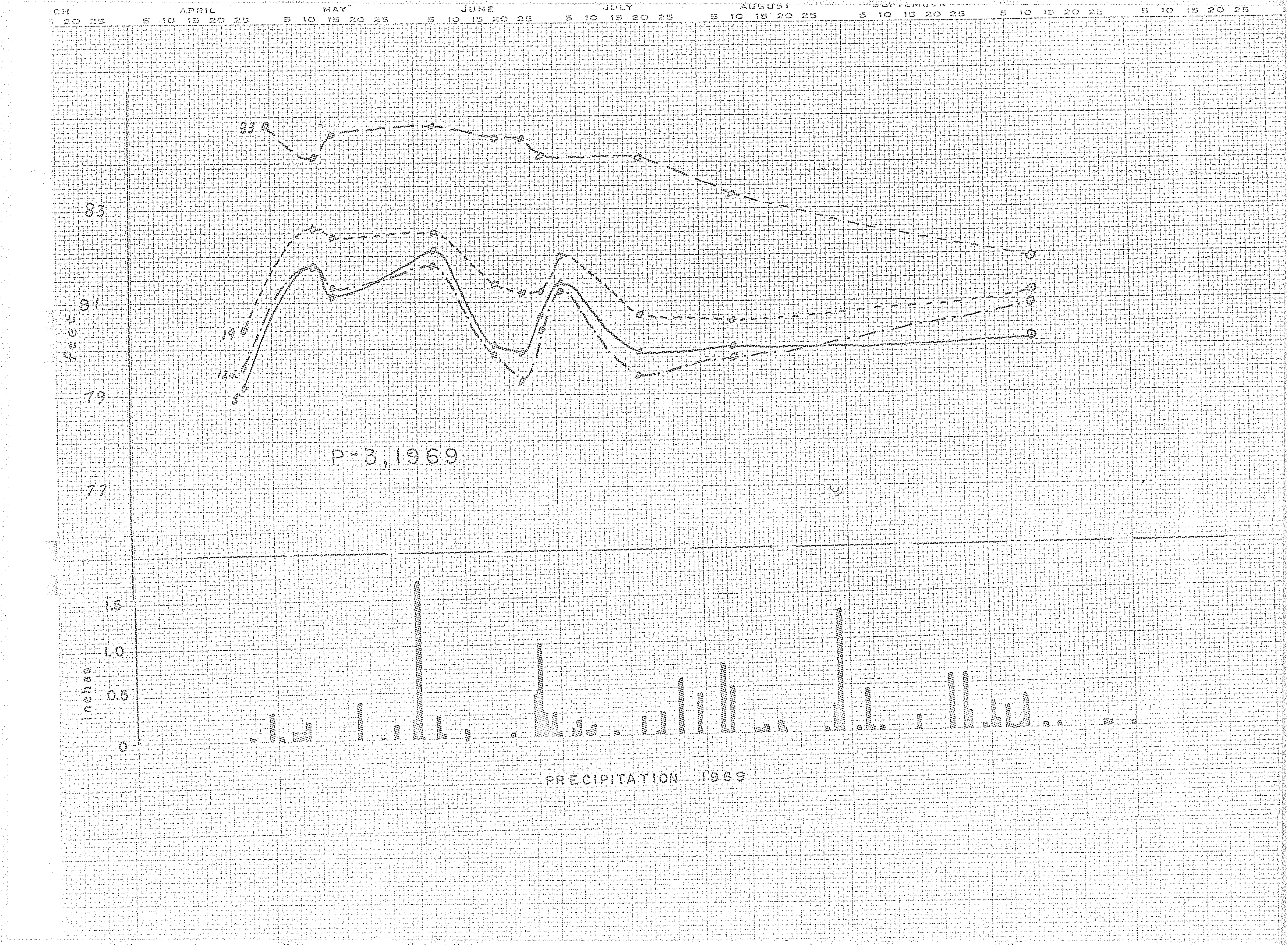
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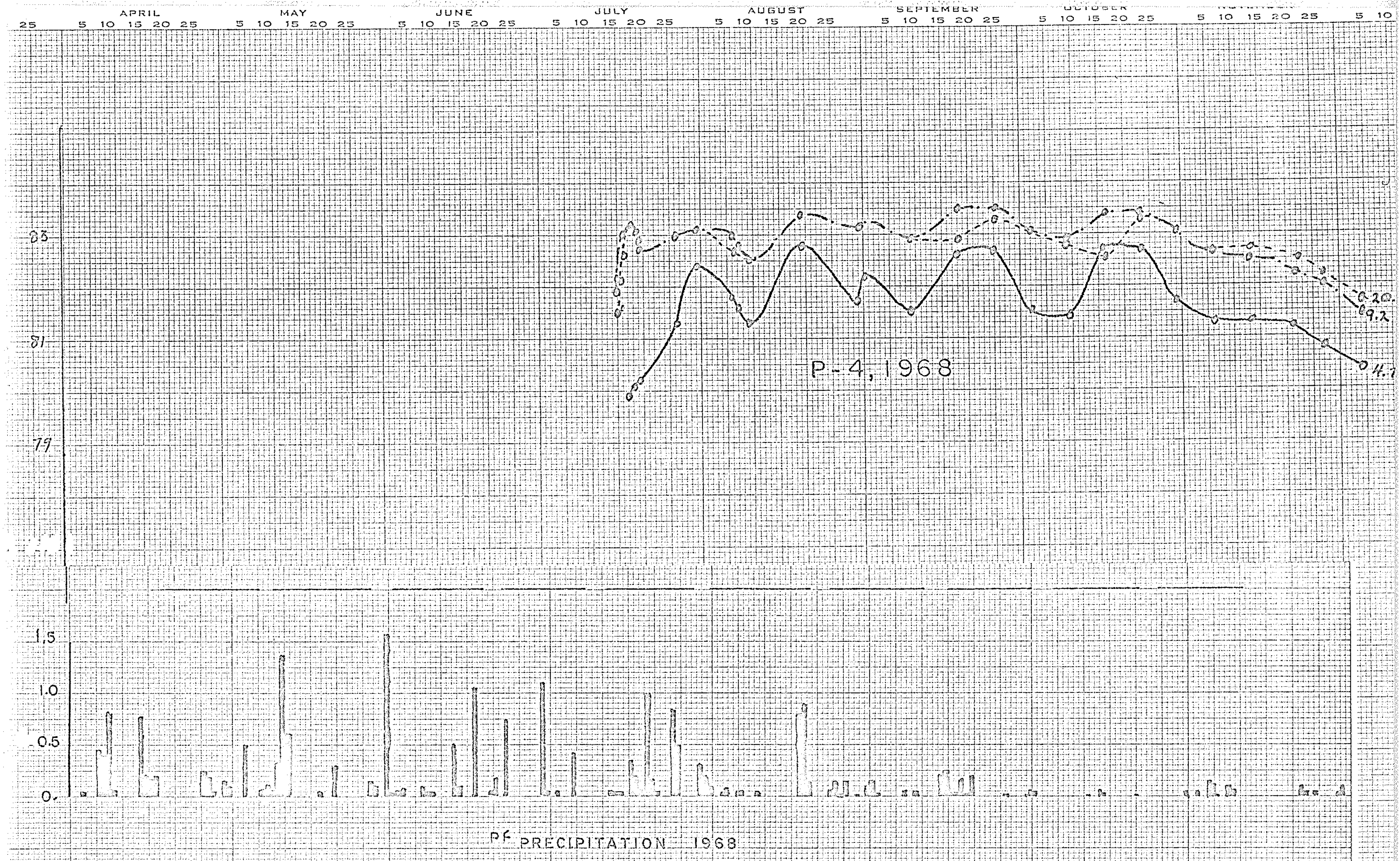
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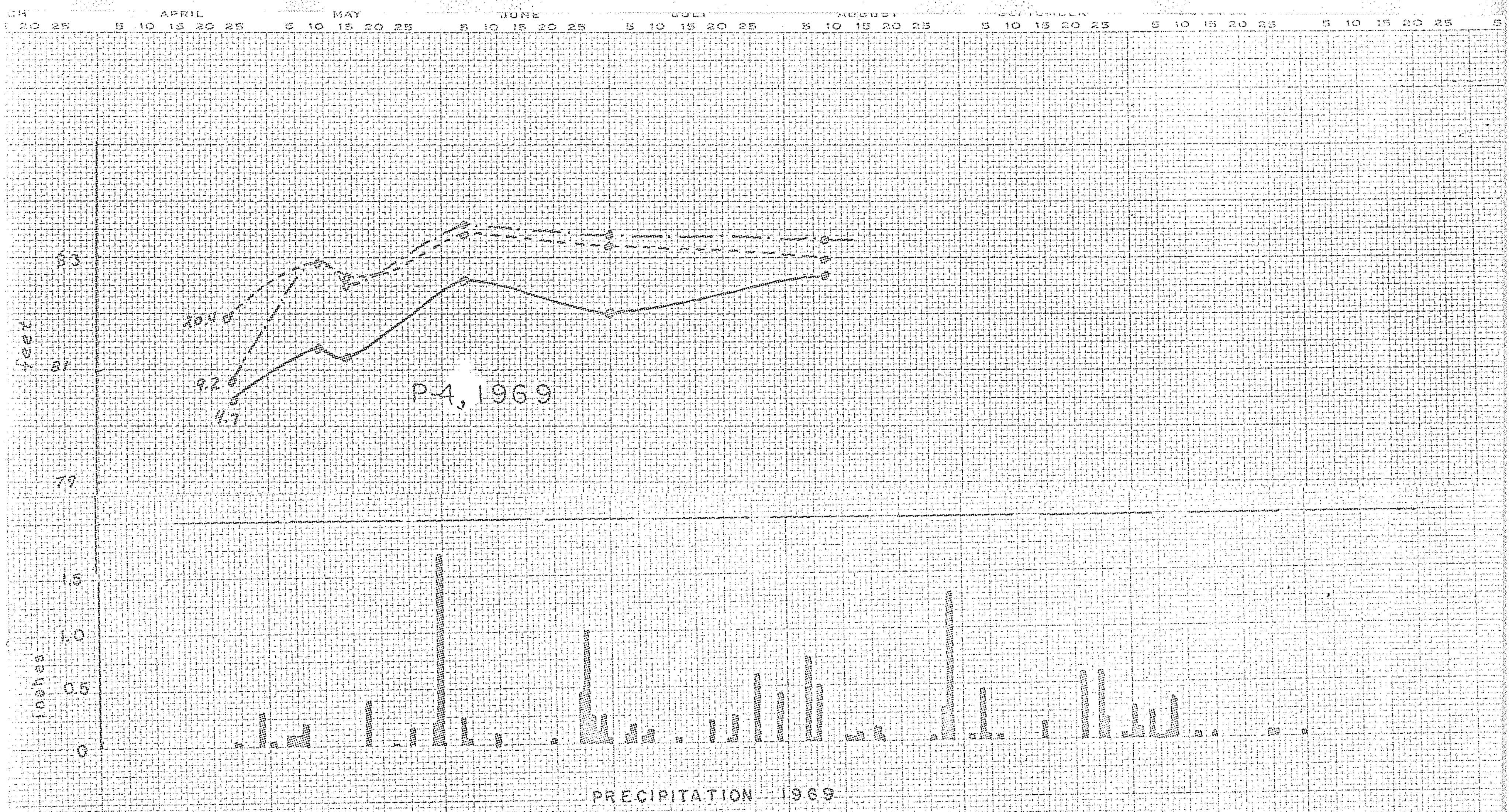
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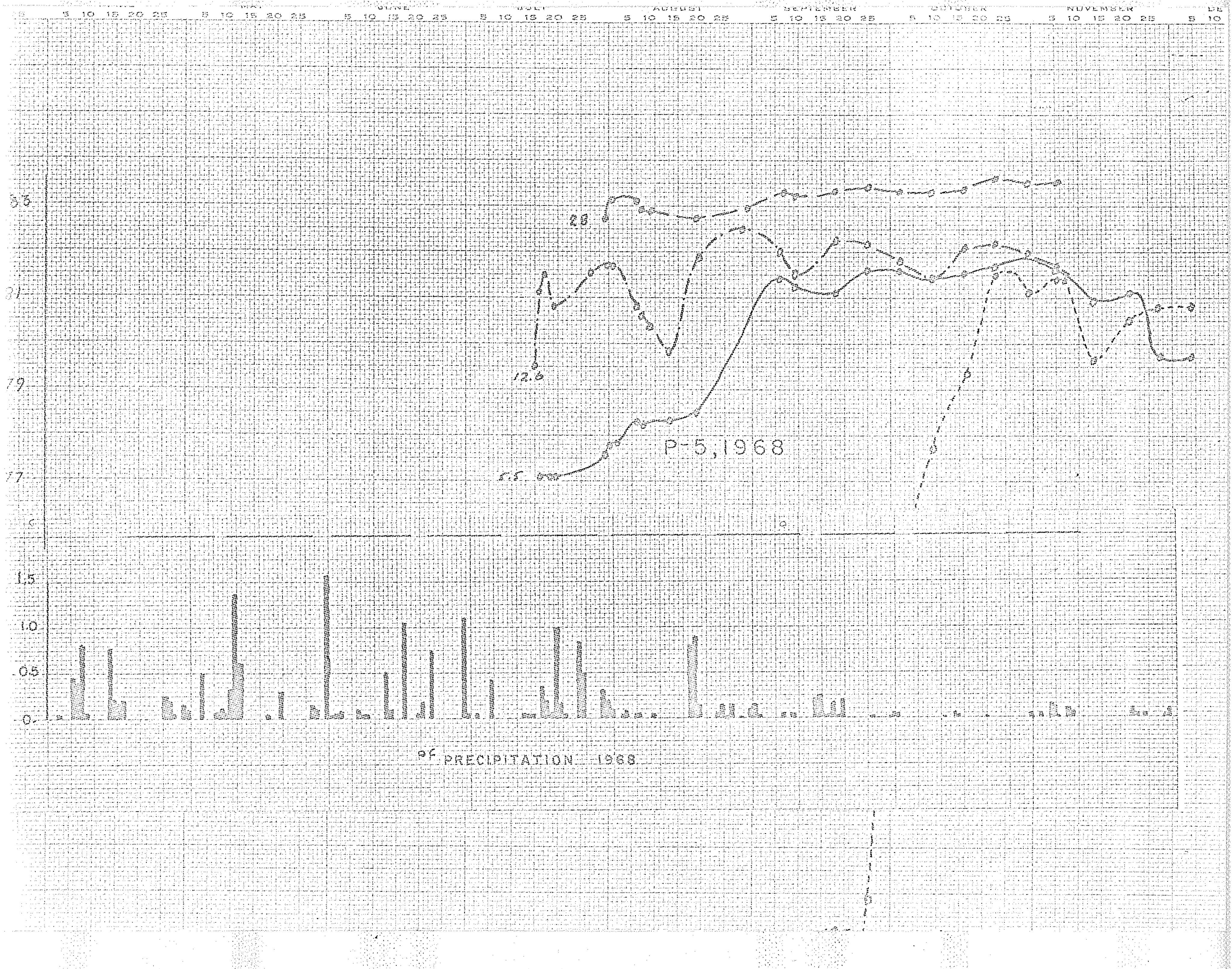
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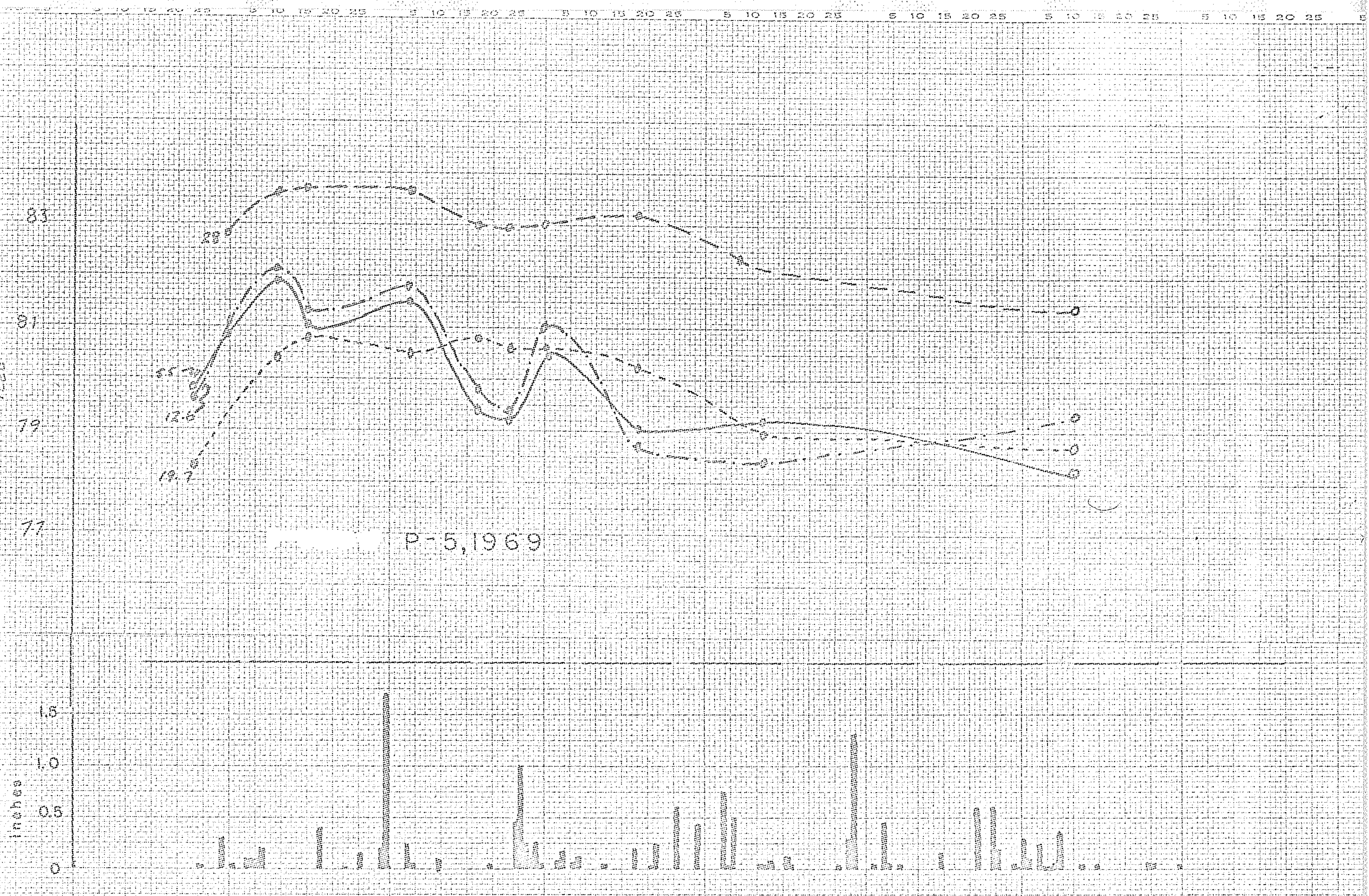

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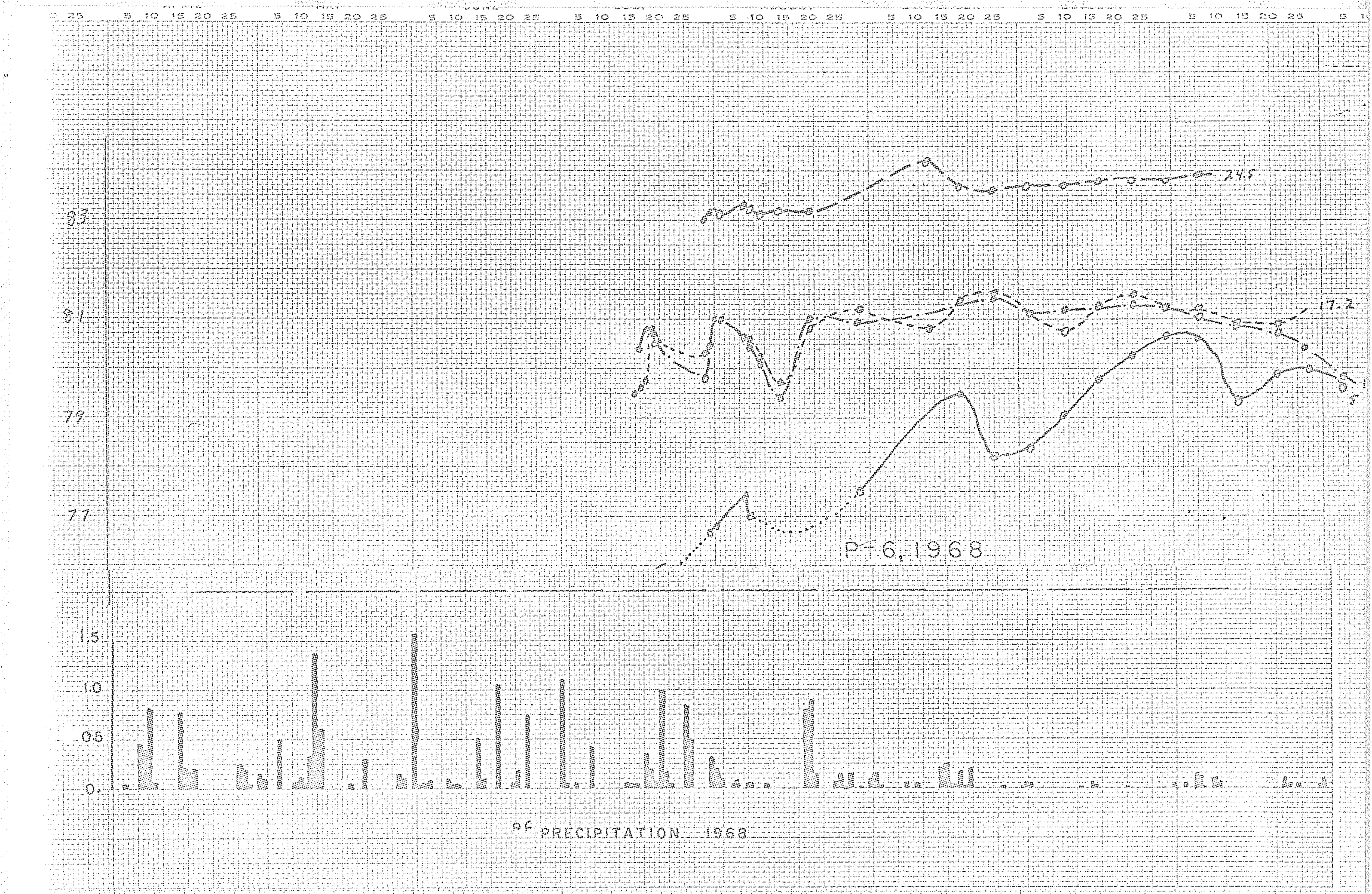

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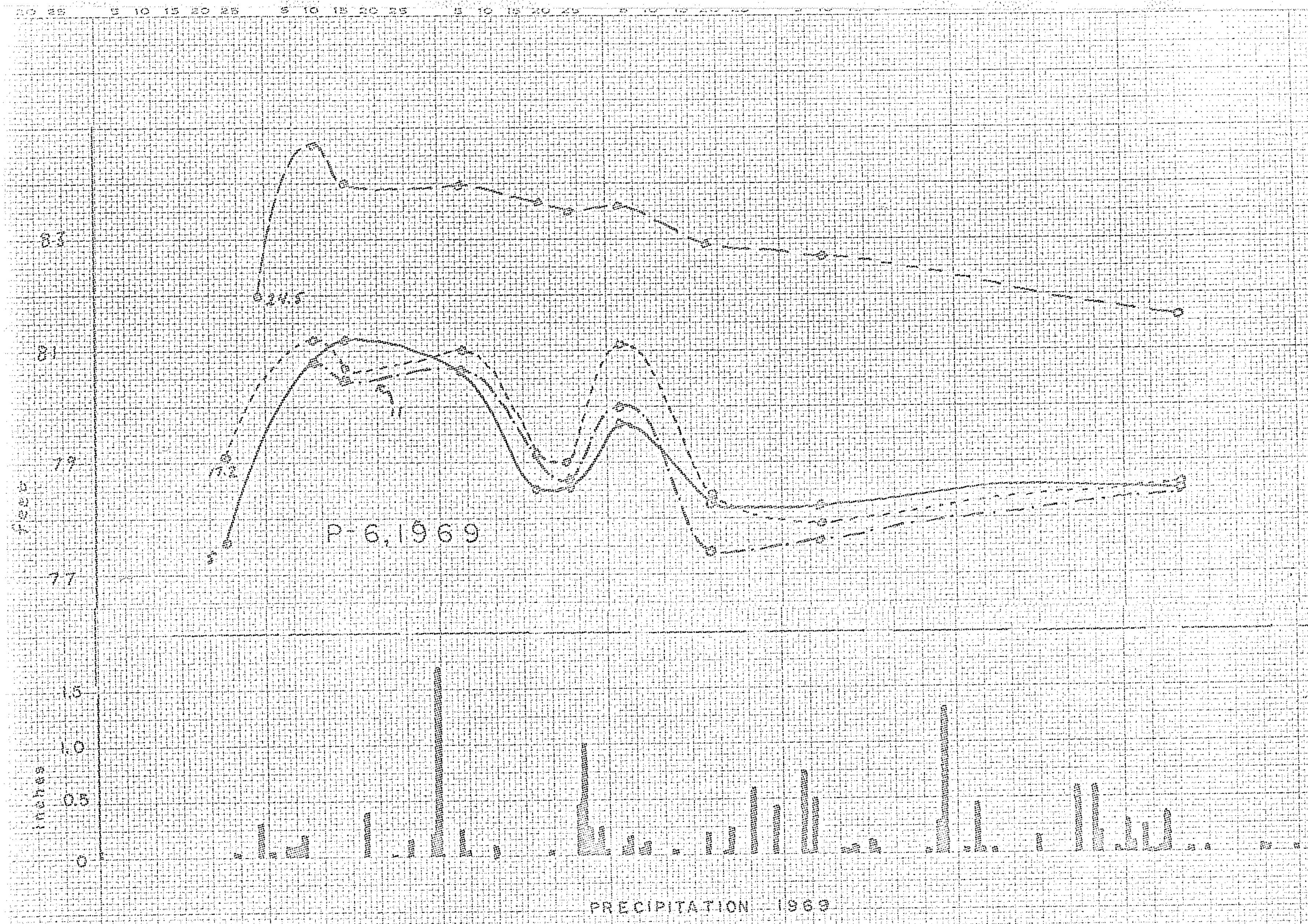
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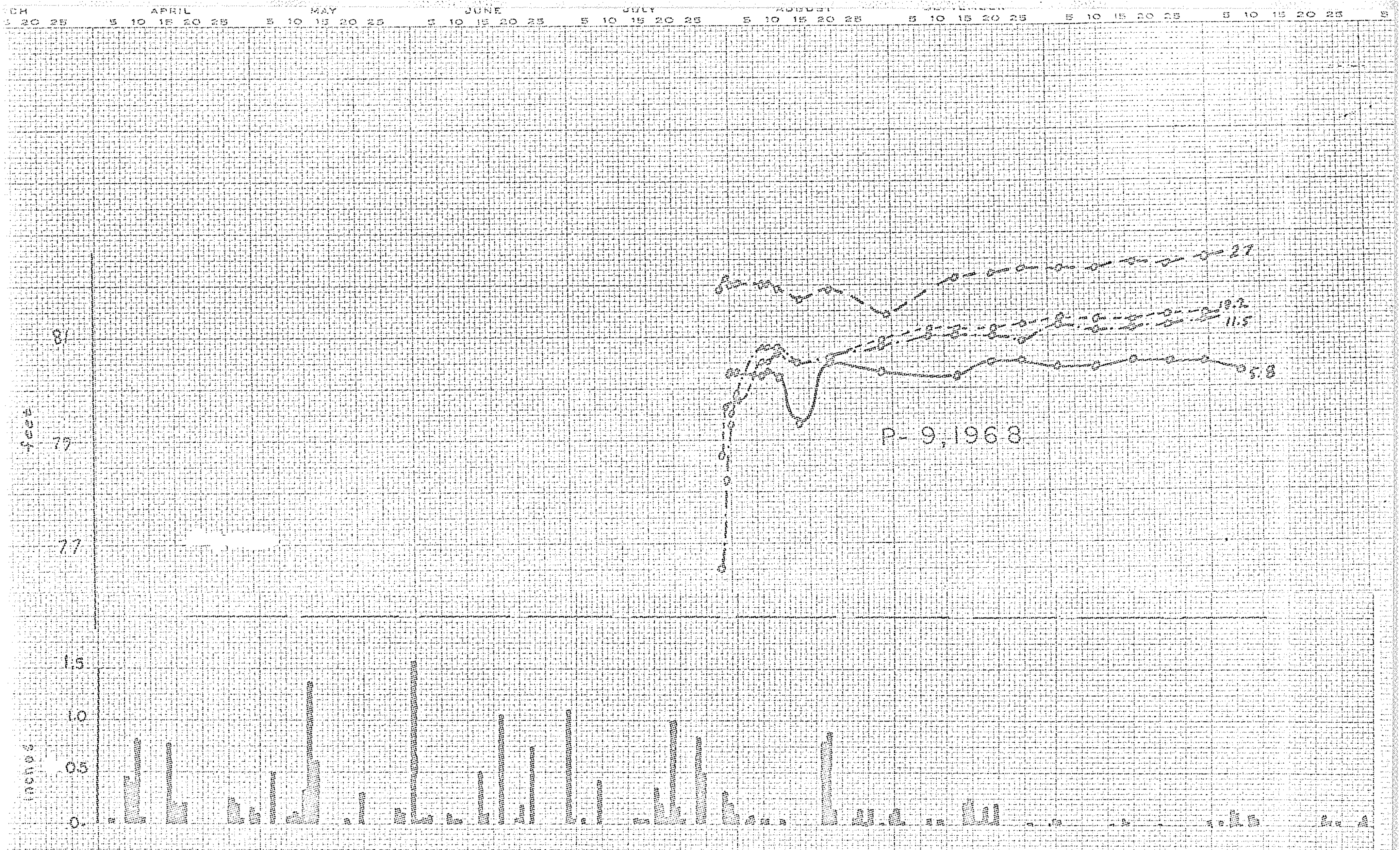

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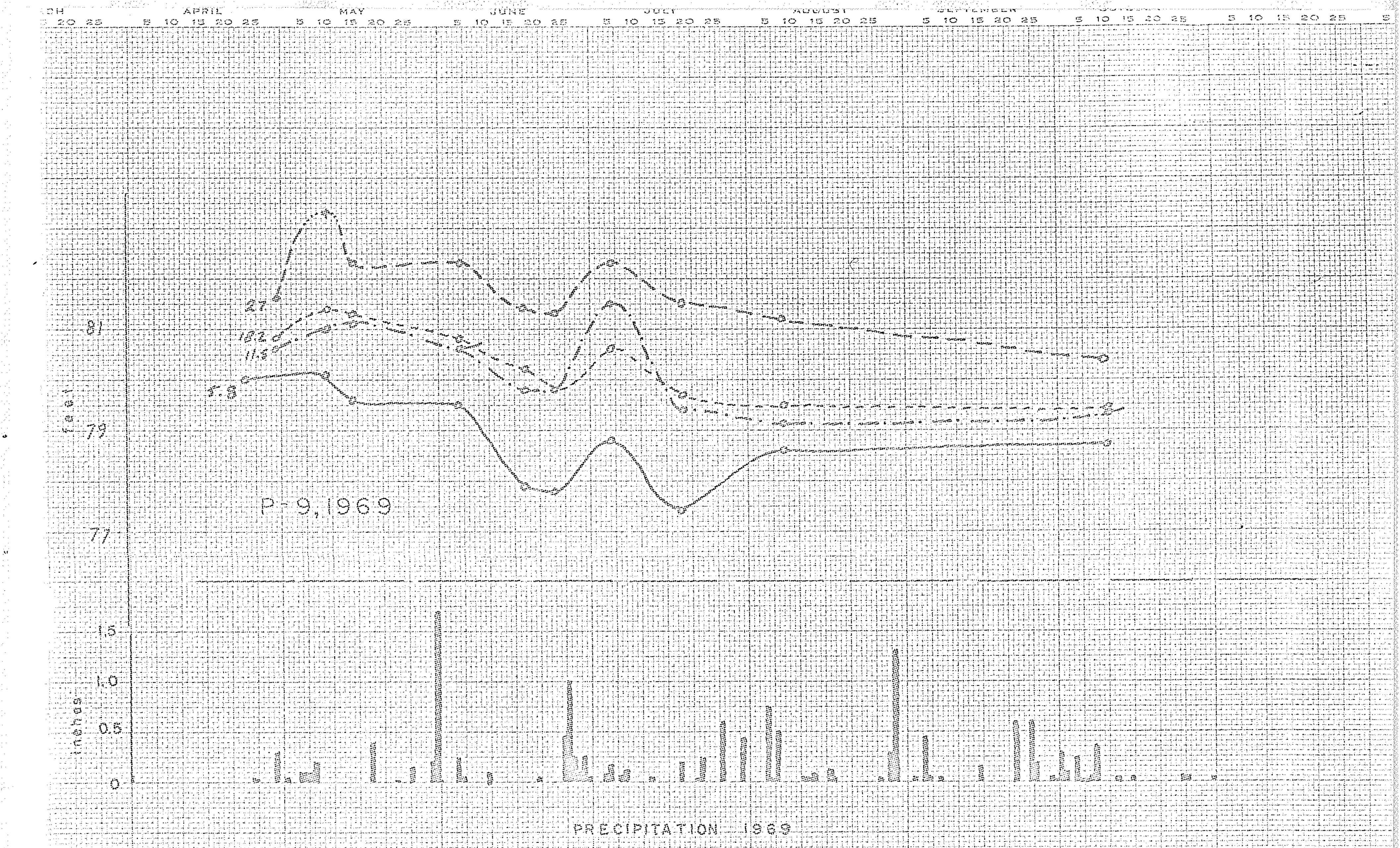
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PRECIPITATION 1969


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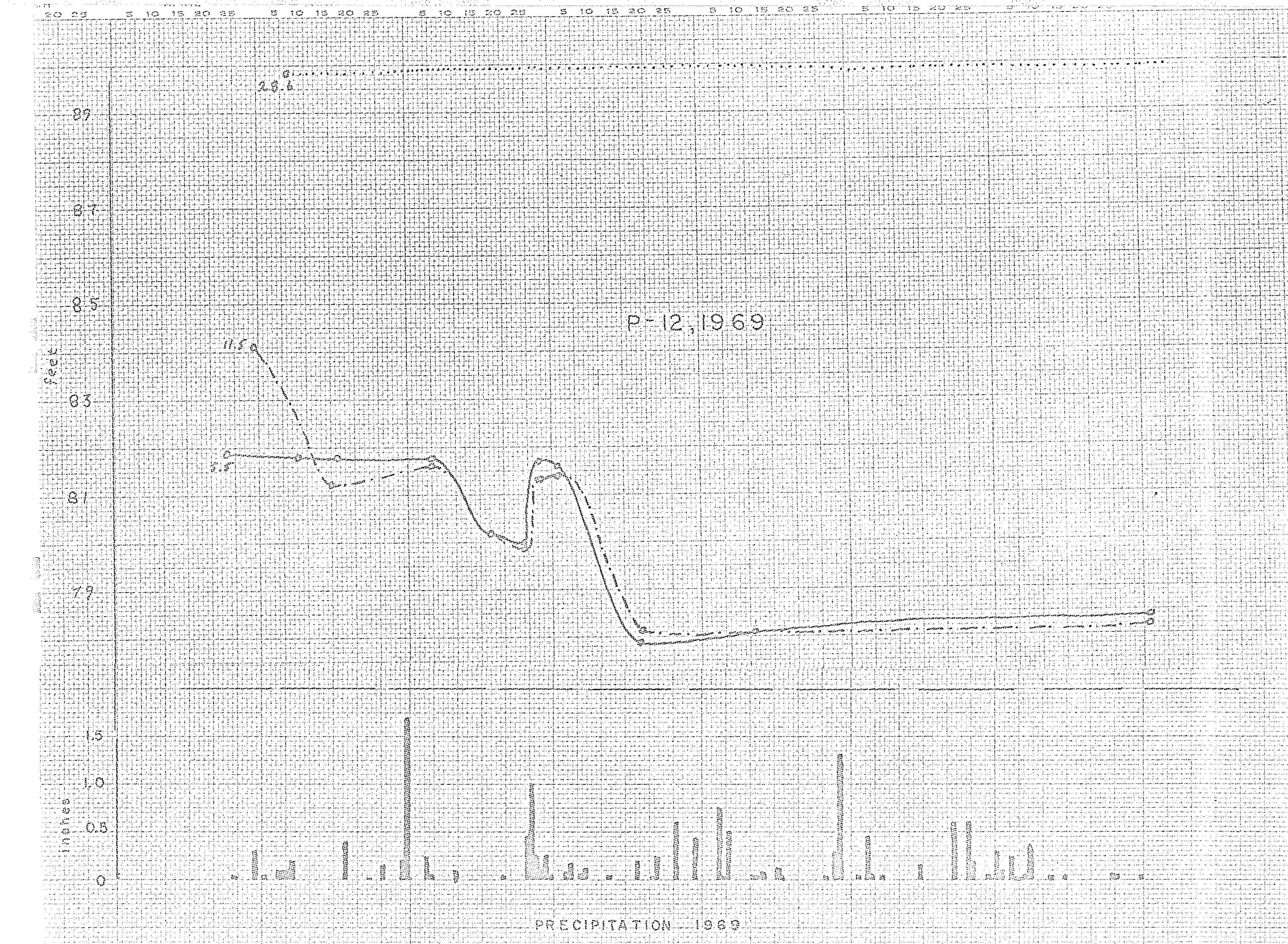
PF PRECIPITATION 1968



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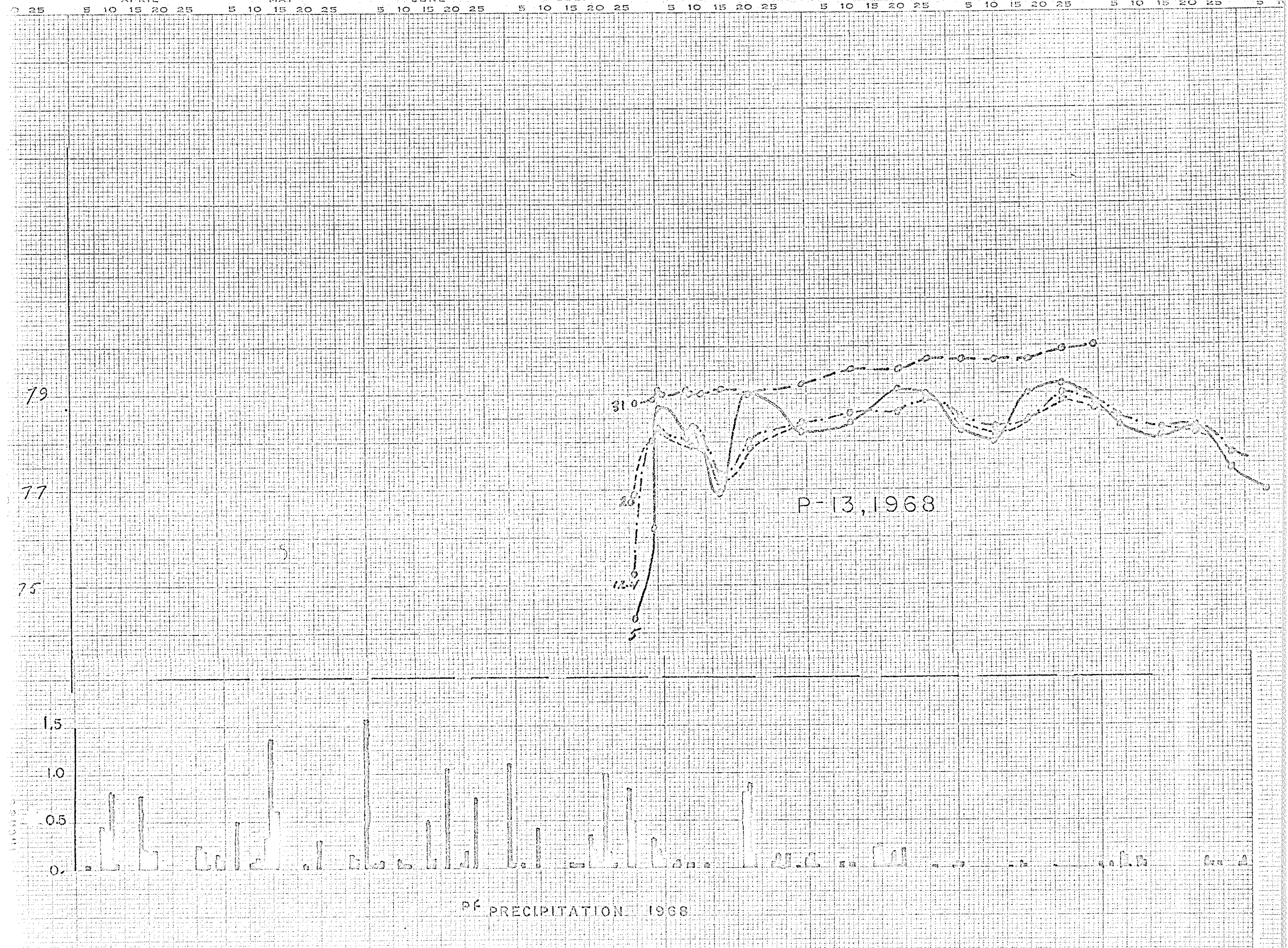
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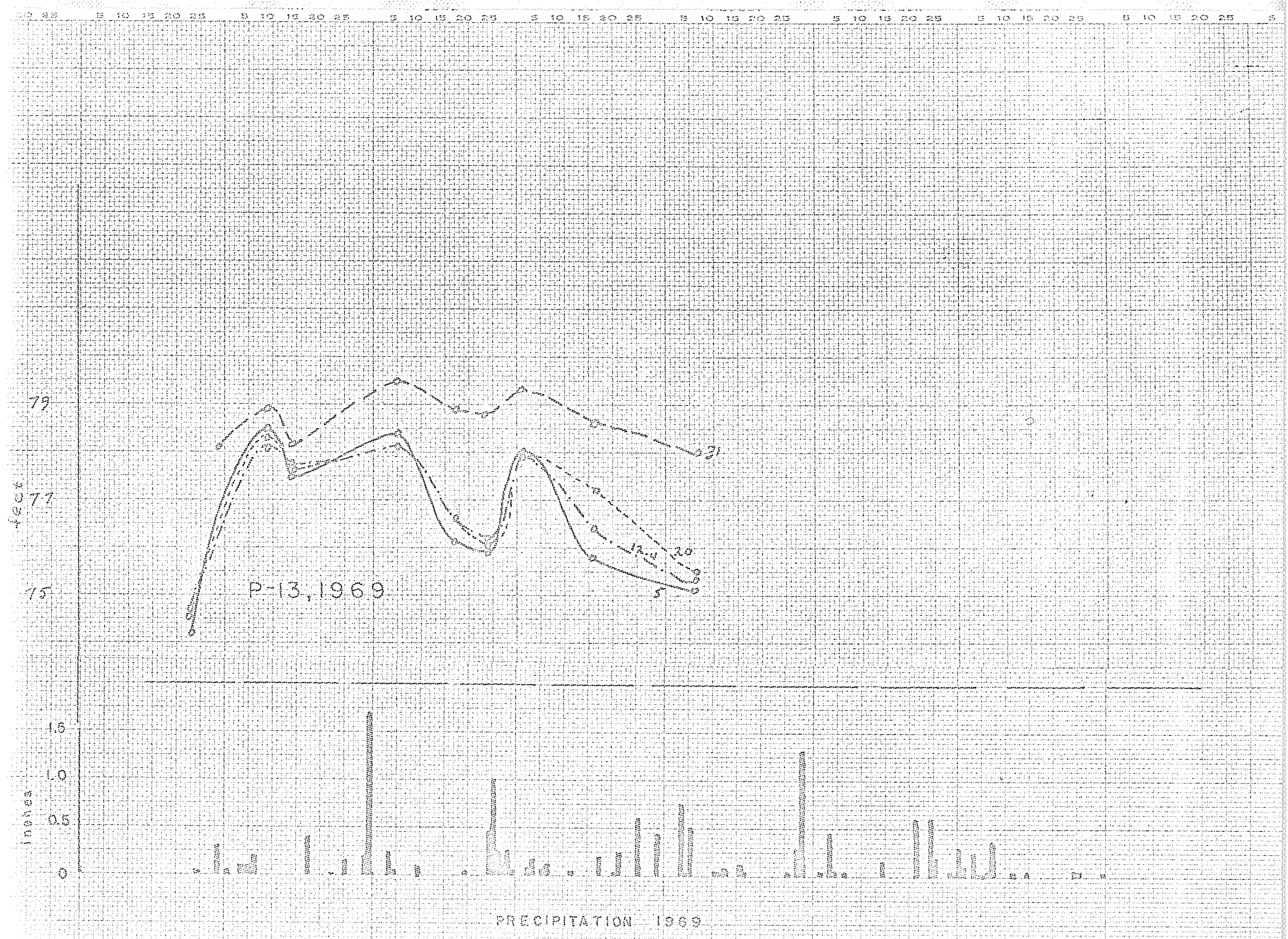P-13, 1969
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PRECIPITATION 1969
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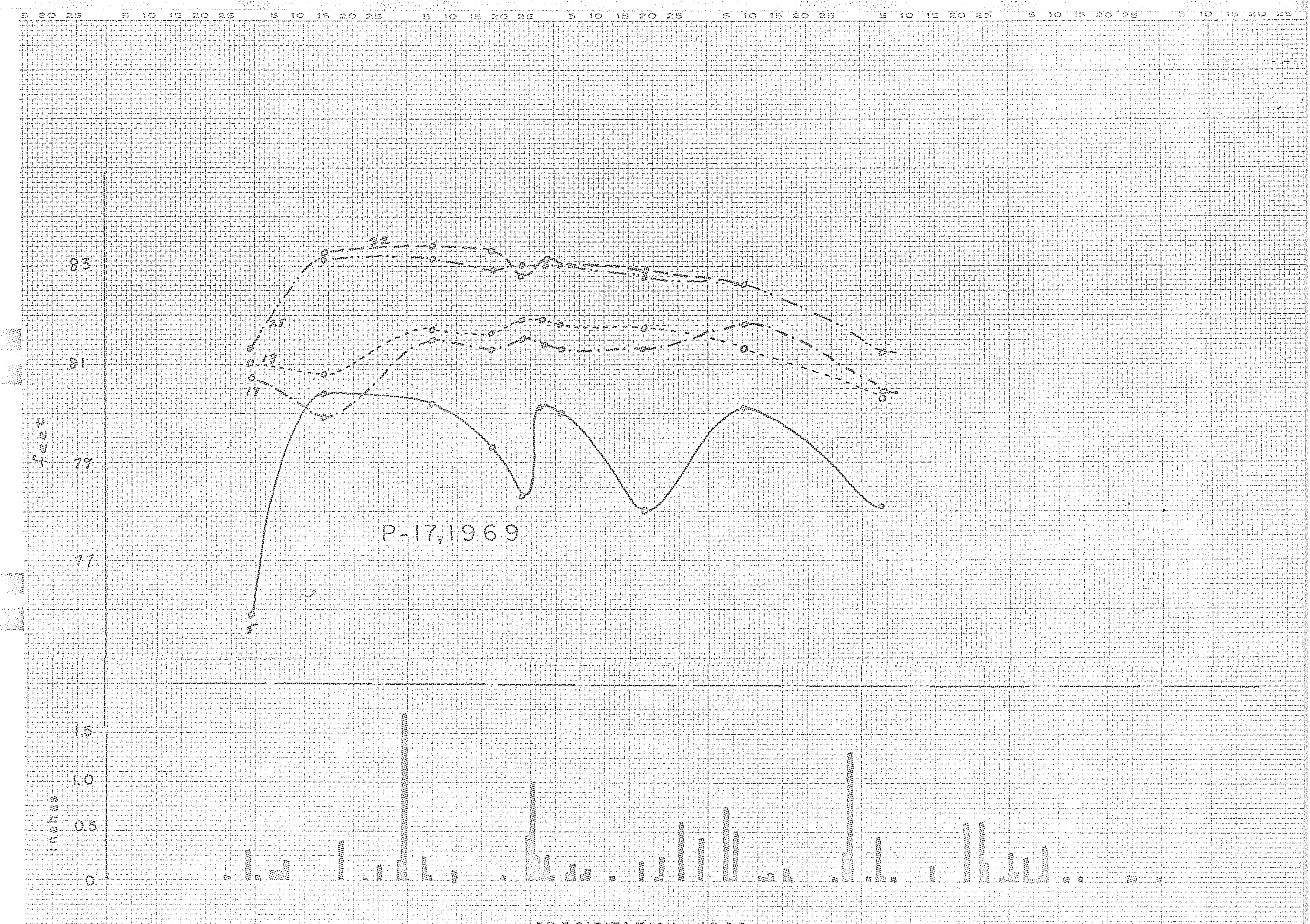


PRECIPITATION 1969

PF PRECIPITATION 1968

P-20,1969

PRECIPITATION 1969

APPENDIX D

HYDROCHEMICAL ANALYSES

The hydrochemical analyses listed in Table 1 were conducted by the Whiteshell Nuclear Research Establishment, Research and Development Branch, in 1968 on samples obtained from relatively newly installed piezometers. The analyses listed in Table 2 were obtained in 1969 after piezometers had been stabilized, flushed, and drained, allowing true formation waters to be sampled with a minimum of contamination. Analyses for anions of the 1968 samples were conducted by the University of Manitoba, Department of Agriculture under the supervision of Dr. M. Zwarich, and the results are available although not listed in this appendix.

In Table 2, the samples listed under 'Special Samples', were isolated under low pressure from the atmosphere immediately after sampling.

Table 3 lists the field conductivities obtained by downhole methods during 1970.

Sample Number	Na^+ mg/l	K^+ mg/l	Mg^{++} mg/l	Ca^{++} mg/l
P- 1- 5	291.0	3.7	850.0	226.0
P- 1-11	109.5	6.05	182.5	110.0
P- 1-17	61.0	5.7	100.5	96.0
P- 1-24	31.5	6.3	50.0	51.7
P- 2- 5	205.0	5.25	530.0	268.0
P- 2-11	144.0	8.4	345.0	220.0
P- 2-17	149.5	12.3	215.0	210.0
P- 2-24	23.5	5.8	55.0	79.0
P- 6- 5	118.5	7.0	650.0	492.0
P- 6-11	71.0	16.65	210.5	197.0
P- 6-17	65.0	48.0	70.0	128.5
P- 6-24	22.5	5.9	79.0	92.0
P- 8- 5	223.5	5.5	650.0	354.0
P- 8-12	138.5	5.5	130.0	122.0
P- 8-19	127.0	5.25	66.0	78.0
P- 8-28	18.0	7.3	35.0	31.0
P- 9- 5	75.0	5.8	366.0	304.0
P- 9-11	34.0	5.85	25.0	62.5
P- 9-18	75.0	15.6	49.0	92.0
P- 9-27	44.0	5.85	149.0	139.0
P-21-12	271.0	595.0		726.0
P-21-22	181.5	817.5		137.0
P-21-28	71.0	162.5		850.0
P-21-39	14.5	9.35	24.0	17.4
P-23-19	109.5	117.0	155.0	139.0
P-23-28	21.0	10.4	46.5	45.5
P-23_1-32	22.0	8.85	48.5	49.0
P-23_2-32	20.0	9.0	48.5	62.5

Table 1. Analyses by AECL, 1968.

Sample Number	Na^+ mg/l	K^+ mg/l	Mg^{++} mg/l	Ca^{++} mg/l	$SO_4^=$ mg/l	$CO_3^=$ mg/l	HCO_3^- mg/l	Cl^- mg/l	TDS mg/l	Lab Conductivity (umhos/cm)
P-1-5.5	330	4	670	180	2800		844.2	3.0	4881	
-11.4	75	4	160	70	485		473.4	6.0	1273	
-17.7	55	5	85	85	65		502.6	6.5	804	
-24	10	5	90	65	1180			2.0	1352+	
P-2-5.6	160	5	300	135	1490		392.8	3.5	2487	
-11.9	160	8	280	180	1440		466	5.0	2539	
-17.7	130	9	185	185	50		361	7.5	928	
-24	15	5	50	40	225		373	3.5	712	
P-3-5	165	5	535	235	2830		241.6	4.0	4016	
-12.2	135	7	145	135	840		307	5.0	1574	
-19	20	7	45	40	65		334	8.0	519	
-33	5	8	15	55	40		210	3.0	331	
P-4-4.7	130	6	370	270	2180		359	4.0	3319	
-9.2	135	9	320	335	2250		268	4.5	3322	
-20.4	125	7	140	105	610			5.0	610+	
P-5-5.5	105	7	305	265	1820		366	3.5	2872	
-12.6	65	8	165	105	770		405	5.5	1524	
-19.7	30	9	60	70	185		368	7.5	730	
-28	5	-	35	70	70		364	3.5	543	
P-6-5	160	25	520	235	2800		293	3.0	4036	
-11	175	9	180	40	950		346	4.5	1705	
-17.2	35	27	70	100	30		425	5.0	692	
-24.5	20	7	45	68	50		427	3.5	621	
P-7-5.3	105	11	455	385	2540		381	6.0	3883	
-11.3	165	8	440	265	1960		401	8.0	3247	
-18.5	155	15	215	195	1260			10.0	1850+	
-30	235	25	25	60	30		447	9.0	831	
P-8-5.9	240	5	40	370	3650		439	4.0	4748	
-12	105	5	165	50	685		632	5.5	1648	
-19	30	4	625	140	80		339	5.0	1223	
-28	5	7	35	90	110		295	2.0	539	

Table 2. Analyses by AECL, 1969

Sample Number	Na^+ mg/l	K^+ mg/l	Mg^{++} mg/l	Ca^{++} mg/l	$SO_4^=$ mg/l	$CO_3^=$ mg/l	HCO_3^- mg/l	Cl^- mg/l	TDS mg/l	Lab Conductivity (umhos/cm)
P- 9-5.8	70	4	335	390	2130		322	4.0	3255	
-11.5	20	6	40	70	25		383	6.5	551	
-18.2	55	14	40	95	215		332	9.0	760	
-27	15	4	50	9	135		342	4.5	560	
P-10-5	210	2	190	80	745		639	2.5	1869	
-11	265	9	600	375	3390		564	7.5	5211	
-18	165	10	330	290	1850		625	5.5	3276	
-34	115	-	25	10	250		405	3.5	809	
P11-5.5	45	2	150	75	530		444	2.5	1249	
-13.3	210	13	435	320	2530		683	11.0	4202	
-22.8	375	19	140	145	1300		396	7.0	2376	
-35	165	14	200	215	1330		298	9.5	2231	
P-12-5.5	75	3	255	190	1630		229	1.0	2383	
-11.7	5	6	30	70	150		107	-	363	
P-13-5	435	5	1110	205	4220		561	14.0	6550	
-12.4	230	15	400	340	2490		307	11.0	3793	
-20.0	200	10	30	225	1730		532	5.0	2732	
-31	20	5	220	65	20		327	2.5	660	
P-14-13.5	195	11	290	240	1210		805	16.0	2767	
-23.5	220	16	260	270	1640		566	19.0	2991	
-35	220	15	200	75	1380		503	19.0	2412	
P-15-4	10	6	40	145	30		493	3.0	727	
P-16-6	45	6	170	145	860		337	4.0	1567	
-10	105	9	235	310	1770		244	5.0	2678	
-14.5	30	7	165	155	955		229	5.0	1546	
-20	15	7	50	70	55		415	2.5	615	
-34	55	9	40	80	100		327	3.0	564	
P-17-5	140	3	275	15	710		712	4.5	1860	
-13	15	4	50	50	40		361	7.0	527	
-17	15	5	45	55	30		346	7.0	507	
-25	20	10	50	60	40		425	5.5	602	
-32	5	7	40	60	10		366	3.0	481	

Table 2, continued

Sample Number	Na^+ mg/l	K^+ mg/l	Mg^{++} mg/l	Ca^{++} mg/l	$SO_4^=$ mg/l	$CO_3^=$ mg/l	HCO_3^- mg/l	Cl^- mg/l	TDS mg/l	Lab Conductivity (umhos/cm)
P-18-5	10	6	150	125	195		854	9.5	1349	
-17	145	-	125	170	705		630	22.0	1797	
-32	230	-	140	165	1190		444	22.0	2191	
-39.5	190	36	230	270	1680		464	34.0	2904	
-47	95	16	150	165	705		512	13.0	1656	
P-19-12	100	35	160	115	560		732	12.0	1714	
-22	190	225	125	160	1010		512	15.0	2237	
-32	210	130	115	155	1190		205	18.0	2023	
-44	95	120	65	35	265		454	6.0	1040	
P-20-5	475	7	850	35	3650		693	5.5	5716	
-15	430	60	560	285	3690		522	20.0	5567	
-25	400	17	600	350	3560		590	32.0	5549	
-38.5	270	16	370	310	2230		434	37.0	3667	
P-22-5	5	2	50	55	5		376	2.5	491	
-8	10	4	55	60	40		376	4.5	550	
-16	10	5	25	65	10		273	3.0	391	
P-23-17	70	11	115	95	540		307	7.0	1145	
-28	20	7	40	70	60		342	6.0	545	
-32.5	25	5	40	65	115		288	5.0	543	
Special Samples										
P- 7-30	170	10	15	30	110		429	7.0	771	770
P-11-22.8	215	15	110	150	930		351	7.0	1778	1850
P-11-34	95	15	125	140	760		332	5.0	1472	1500
P-12-23.6	5	11	30	95	5		434	1.0	571	540
P-13-12.9	250	3	450	325	2700		459	5.0	4192	3810
P-13-31	15	10	30	65	30		337	2.0	489	470
P-14-13.5	240	14	210	190	1210		581	17.0	2462	2400
P-14-23.5	205	14	270	340	1790		537	17.0	3173	2990
P-14-35	265	18	210	320	1800		420	18.0	3051	2950

Table 2, continued

Sample Number	Na$^+$ mg/l	K$^+$ mg/l	Mg^{++} mg/l	Ca^{++} mg/l	SO$_4^=$ mg/l	CO$_3^=$ mg/l	HCO$_3^-$ mg/l	Cl$^-$ mg/l	TDS mg/l	Lab Conductivity (umhos/cm)
P-16-14	35	7	165	350	905		356	4.0	1822	1640
P-16-20	5	5	50	95	40		468	3.0	661	670
P-16-34	5	6	50	100	80		473	3.5	713	690
P-20-15	350	17	65	335	3670		488	27.0	4952	5100
P-21-22	60	23	15	90	310		132	6.5	637	740
P-21-28	10	3	25	70	5		337	1.0	446	460
P-21-39	5	3	25	70	5		342	1.5	447	460
P-22-16	15	17	35	90	15		449	6.0	627	640
P-26-28	365	355	245	290	2340		259	35.0	3889	4100
P-26-43	180	14	200	270	2320		249	17.0	2320	2530
P-27-58	115	80	4	520	1250		464	18.0	2451	3200
P-28-18	175	34	380	390	2290		781	12.0	4062	3650
P-28-40	225	275	4	200	1080		181	20.0	1985	2250
P-28-71	110	-	70	135	820		166	37.0	1338	1630
P-29-18	130	10	300	495	2140		429	8.0	3512	3340
P-29-35	140	14	275	475	2050		356	9.0	3319	3000
P-29-54	135	13	245	490	1980		342	7.5	3213	3000
P-31-10	25	3	90	140	200		468	5.0	931	3350
P-31-25	145	35	145	345	1290		400	18.0	2378	2250
P-31-44	255	36	190	285	1400		454	13.0	2633	2800
IWP-3-20	435	15	360	530	2590		634	21.0	4585	4000
IWP-3-(11-15)	380	18	505	455	3590		439	29.0	5416	5000
IWP-3-(15-20)	350	14	470	500	3270		698	29.0	5331	4700
IWP-3-15	245	12	345	550	2600		615	16.0	4383	3900
P-33-18	50	4	200	105	1644		976	20.0	1644	1600
P-33-35	305	26	80	300	1600		97.6	37.0	2446	2800
P-33-48	305	39	250	370	1990		288	44.0	3286	3200
IWP-2-(20-36)	320	15	495	410	3190		547	29.0	5006	4500
IWP-2-8	325	29	0.1	190	575		786	7.5	1913	3400
P-35-9	160	4	190	120	885		405	5.0	1769	1800
P-35-17	390	20	550	230	3360		791	20.0	5360	5000

Table 2, continued

Sample Number	Na^+ mg/l	K^+ mg/l	Mg^{++} mg/l	Ca^{++} mg/l	$SO_4^=$ mg/l	$CO_3^=$ mg/l	HCO_3^- mg/l	Cl^- mg/l	TDS mg/l	Lab Conductivity (umhos/cm)
P-35-27	410	45	425	250	2800		254	21.0	4205	4200
P-35-42	385	480	240	275	2350		205	34.0	3969	4000
P-39-19	35	17	65	100	220		405	7.0	849	920
P-40-20	5	4	25	80	15		327	2.5	454	510
P-40-45	5	3	20	60	25		220	2.5	331	370
P-36-15	130	17	260	210	1360		700	8.0	2685	2800
P-36-24	110	2	60	75	595		229	10.0	3766	4390
P-36-36	5	4	25	55	5		339	2.5	431	450
P-37-10	345	6	700	300	3540		917	8.5	5817	5300
P-37-15	310	11	510	345	3010		732	10.0	4928	4600
P-37-25	270	13	405	340	2550		644	11.5	4337	4050
P-37-36	65	10	55	45	260		268	5.5	709	790
P-38-15	45	12	125	125	1416		859	5.0	1416	1400
P-38-22	80	9	225	290	1210		725	3.0	2542	2500
P-38-33	240	25	185	235	1670		215	14.0	2584	3000

Table 2, continued

APPENDIX E

GRAPHICAL PRESENTATION
OF GROUNDWATER TEMPERATURE
VARIATIONS

53, 1966

ANNUAL METEOROLOGICAL SUMMARY

1968

WNRE, Pinawa, Manitoba

Health and Safety Branch Environmental Control Section

	Temperature (°F)							Heating Degree Days	Wind	
nth	Mean Max.	Mean Min.	Mean	Ex-treme Max.	Date	Ex-treme Min.	Date		Average Speed (M.P.H.)	Pre-vailing Directio
n.	8.1	-10.1	- 1.0	42	Jan. 21	-42	Jan. 6	2046	6.4	SSE
b.	12.4	-11.4	0.5	34	Feb. 3, 29	-34	Feb. 22	1870	6.3	NNW
rch	35.1	13.5	24.3	57	Mar. 26	-18	Mar. 11	1261	6.6	N
ril	48.8	26.7	37.8	76	Apr. 11	8	Apr. 5	817	7.1	NNW
y	58.6	37.7	48.2	78	May 1	17	May 5	522	8.1	NNW
ne	67.6	48.8	58.2	84	June 3	37	June 14	210	6.7	NNW
ly	73.3	52.5	62.9	88	July 6	39	July 9	102	6.1	NNW
g.	67.7	51.1	59.4	80	Aug. 5	35	Aug. 17	190	6.3	WNW
pt.	65.2	46.1	55.7	82	Sept. 14	34	Sept. 9	290	5.3	SSE
t.	49.6	35.1	42.3	66	Oct. 13	23	Oct. 24	703	8.3	NNW
v.	32.9	21.4	27.2	50	Nov. 3	1	Nov. 29	1135	6.4	SSE
c.	14.5	0.0	7.3	36	Dec. 2	-29	Dec. 25	1791	5.6	N
ar	44.5	26.0	35.2	88	July 6	-42	Jan. 6	10,937	6.6	

Precipitation (Inches)

onth	Rain	Snow	Total Precipi-tation*	Greatest 24 Hour Precipitation			
				Rain	Date	Snow	Date
nuary	0.10	16.5	1.75	.09	Jan. 24	5.1	Jan. 11
bruary	0.01	2.6	0.27	.01	Feb. 26	1.2	Feb. 5
rch	0.15	7.7	0.92	.10	March 30	3.9	Mar. 19
ril	0.78	3.5	1.13	.39	Apr. 20	2.5	Apr. 1
y	3.27	4.2	3.69	.78	May 8	2.2	May 17
ne	5.23	-	5.23	1.54	June 30	-	-
ly	4.40	-	4.40	1.11	July 29	-	-
gust	4.31	-	4.31	1.01	Aug. 18	-	-
ptember	2.46	-	2.46	0.89	Sept. 16	-	-
tober	1.40	0.3	1.43	0.26	Oct. 15	0.2	Oct. 26
vember	0.03	2.2	0.25	0.03	Nov. 1	1.1	Nov. 12
cember	-	7.9	0.79	-	-	1.7	Dec. 4
Year	22.14	44.90	26.63	1.54	June 30	5.1	Jan. 11

* Sum of rainfall plus one-tenth of snowfall

ANNUAL METEOROLOGICAL SUMMARY

1969

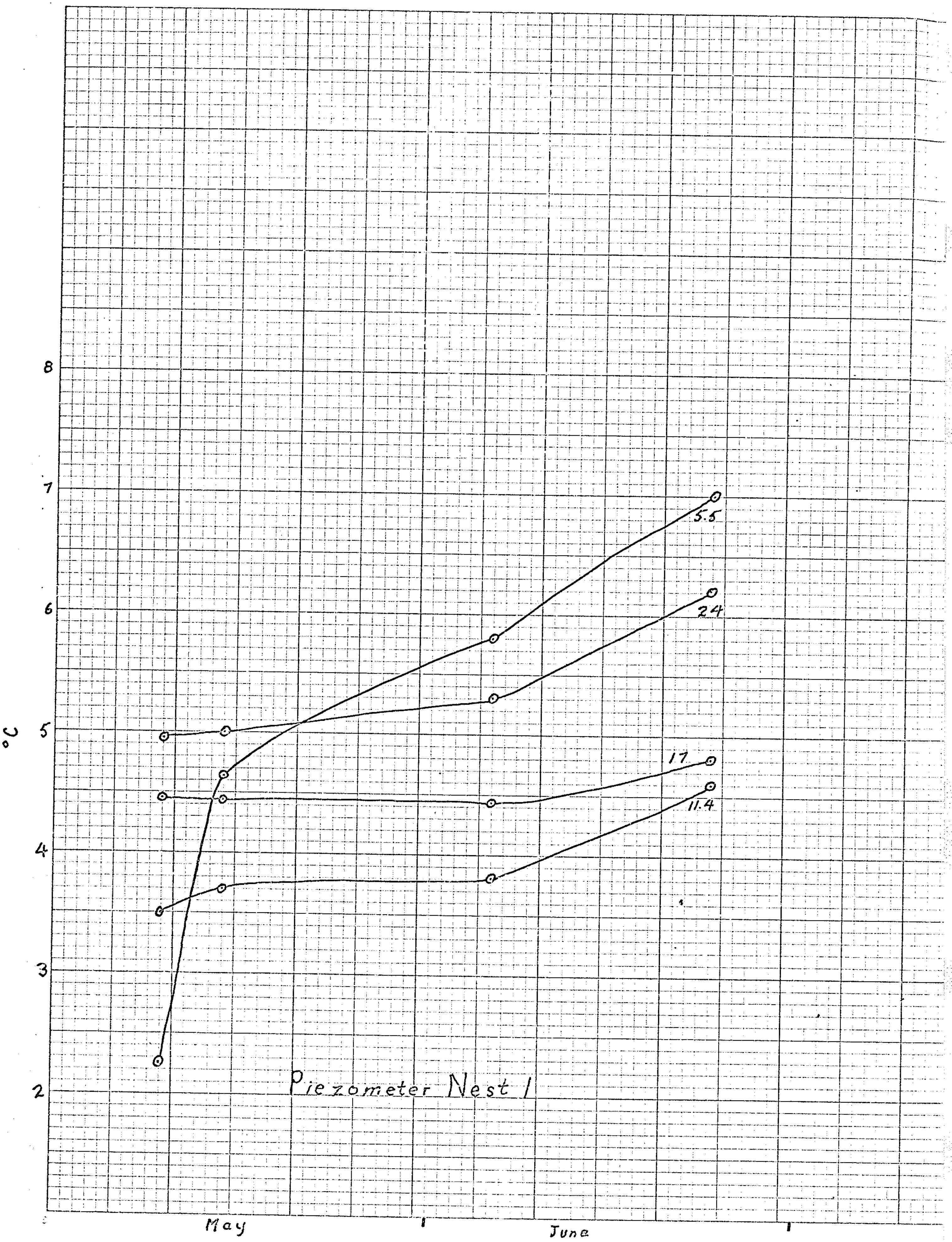
WNRE, Pinawa, Manitoba

Health and Safety Branch   Environmental Control Section

	Temperature							Heating Degree Days	Wind	
nth	Mean Max.	Mean Min.	Mean	Extreme Max.	Date	Extreme Min.	Date		Average Speed	Prevailing Directio
an.	4.9	-13.4	-4.2	27	Jan. 15	-38	Jan. 26	2147	6.5	NNW
eb.	20.0	- 1.6	9.2	36	Feb. 23	-40	Feb. 3	1562	5.0	SSE
ar.	26.0	4.0	15.0	41	Mar. 21	-15	Mar 29	1549	5.6	N
pr.	54.6	29.4	42.0	70	Apr. 25	- 2	Apr 2	691	6.1	S
ay	60.8	39.4	50.1	85	May 26	21	May 19	474	7.8	NNW
une	62.9	41.1	52.0	77	June 9	30	June 13	390	6.6	N
uly	74.5	53.5	64.0	93	July 12	38	July 6	87	5.0	SSE
ug.	79.2	56.6	67.9	90	Aug.22	46	Aug. 1	35	5.4	SSE
ept	64.1	45.5	54.8	84	Sept13	28	Sept.28	331	5.5	SE
ct.	41.2	30.0	35.6	54	Oct. 3	15	Oct. 23	913	5.9	SSE
ov.	33.4	18.8	26.1	59	Nov. 6	- 3	Nov. 20	1167	7.1	NW
ec.	20.3	8.7	14.5	50	Dec. 1	-19	Dec. 22	1566	5.1	SSE
ar	45.2	26.0	35.6	93	July 12	-40	Feb. 3	10,912	6.0	SSE

	Precipitation						
				Greatest 24 Hour Precipitation			
onth	Rain	Snow	Total Precipitation*	Rain	Date	Snow	Date
nuary	0.01	27.7	2.78	0.01	Jan.14	5.6	Jan. 15
bruary	-	3.1	0.31			0.7	Feb. 10
rch		1.9	0.19			0.8	March 7
ril	0.35		0.35	0.28	April30		
y	2.72	1.5	2.87	1.54	May 31	1.5	May 31
ne	2.60		2.60	0.98	June 26		
ly	2.06		2.06	0.62	July 26		
gust	3.29		3.29	1.33	Aug. 29		
ptember	2.46		2.46	.60	Sept.24		
tober	.91	1.3	1.04	.31	Oct. 7	0.4	Oct.24-2
vember	.01	3.7	0.38	.01	Nov. 11	0.8	Nov. 23
cember		11.9	1.19			2.6	Dec 7
ear	14.41	51.10	19.52	1.54	May 31	5.6	Jan. 15

* Sum of rainfall plus one-tenth of snowfall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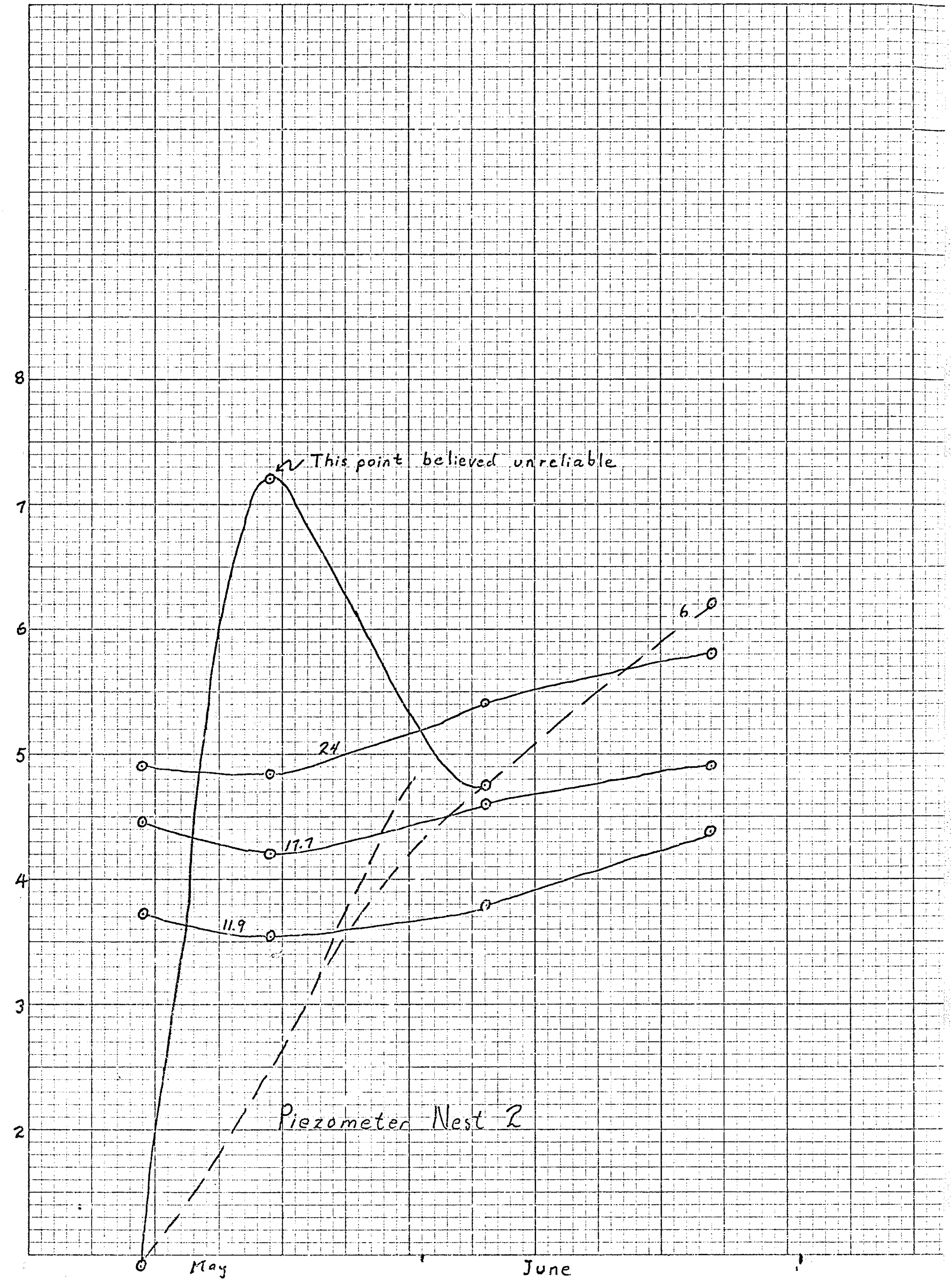
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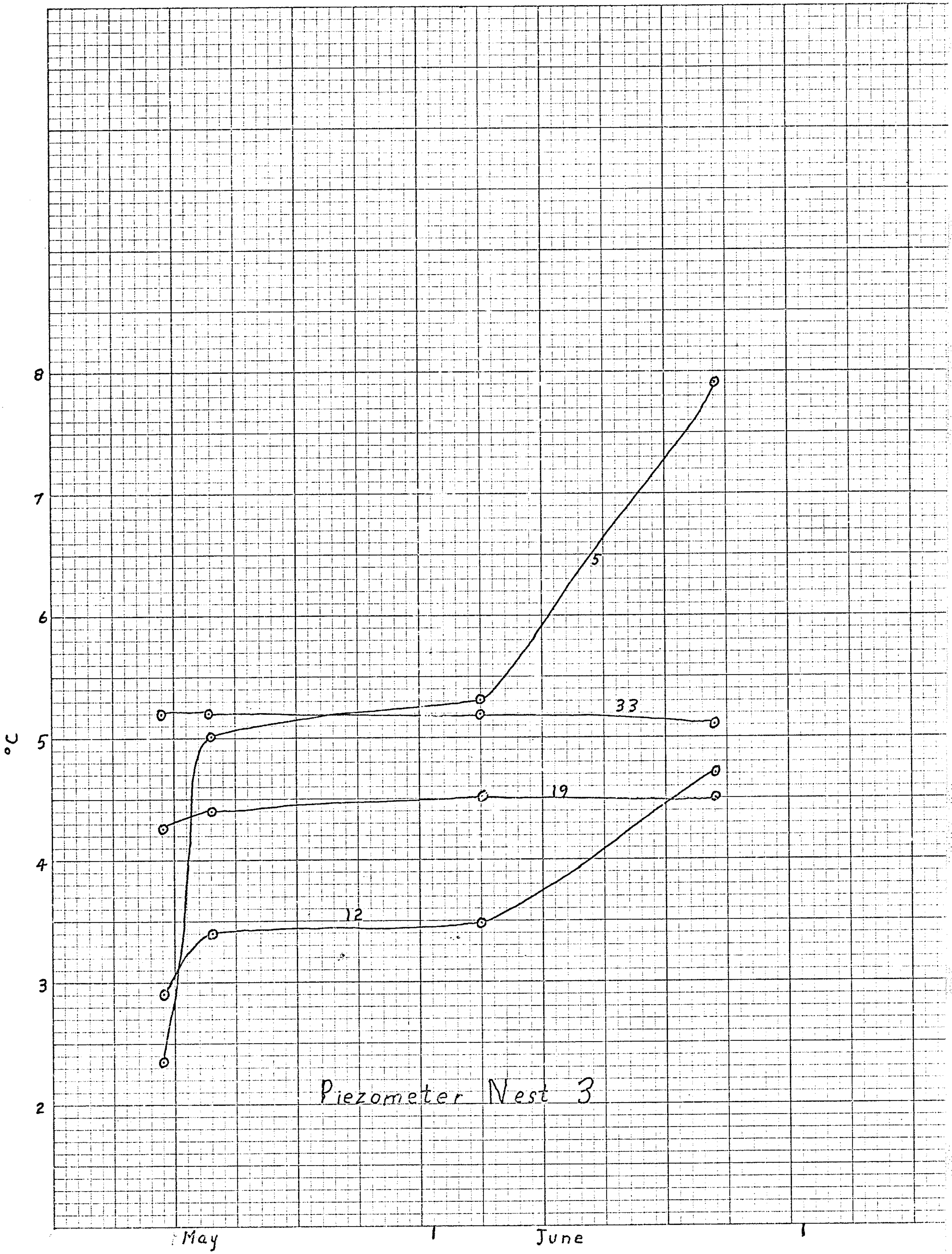
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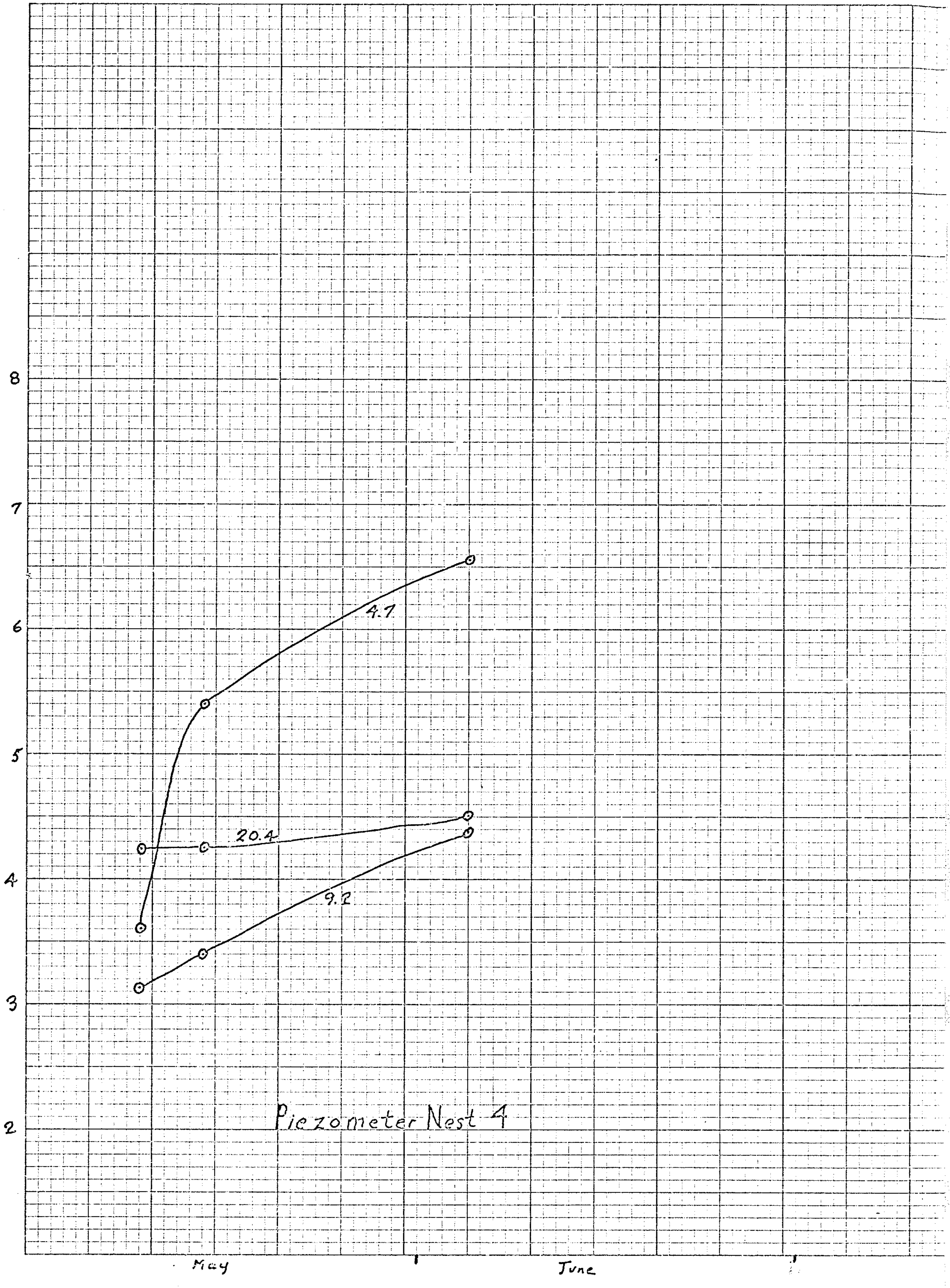
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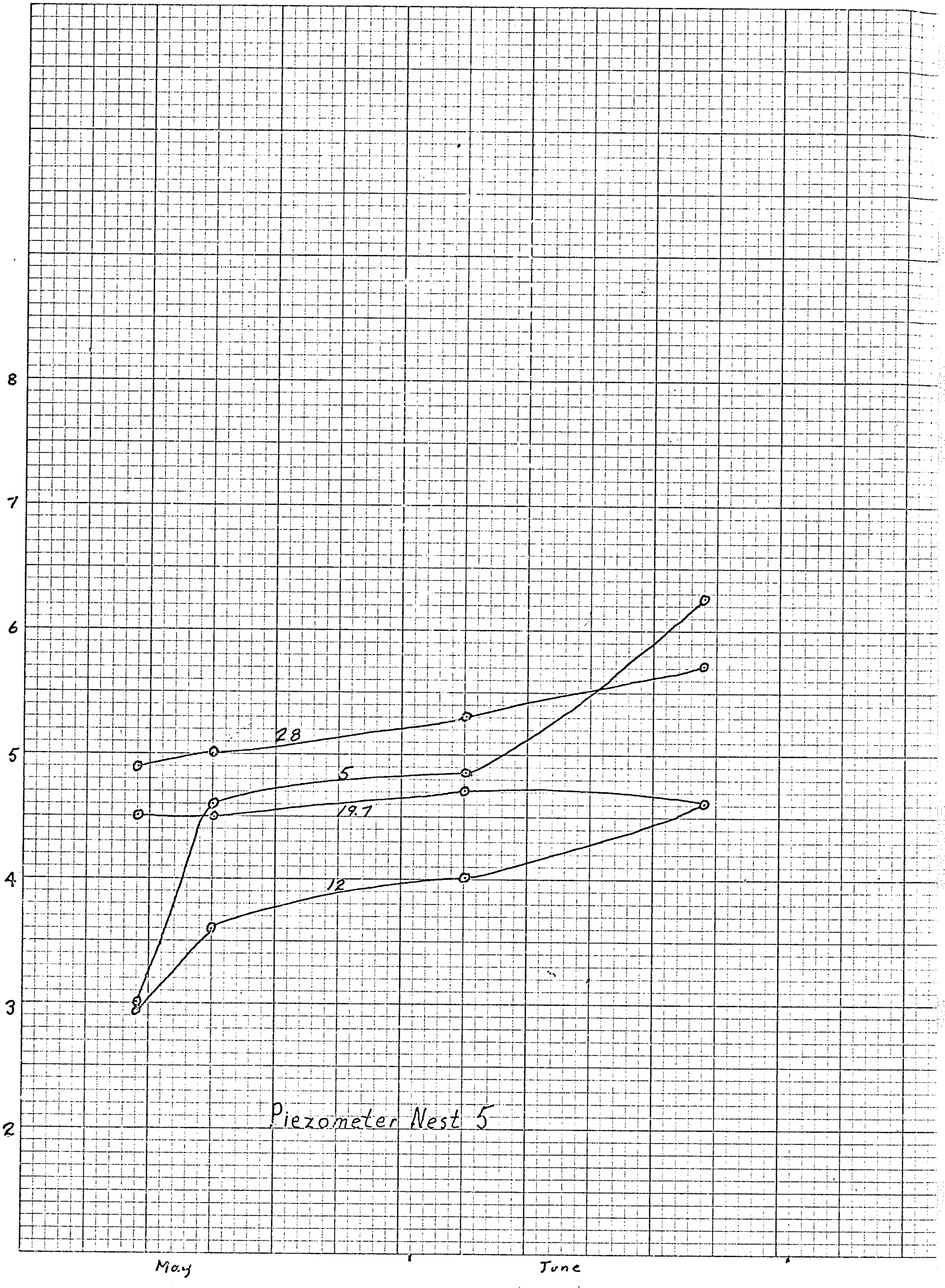
KEUFFEL & ESSER CO.



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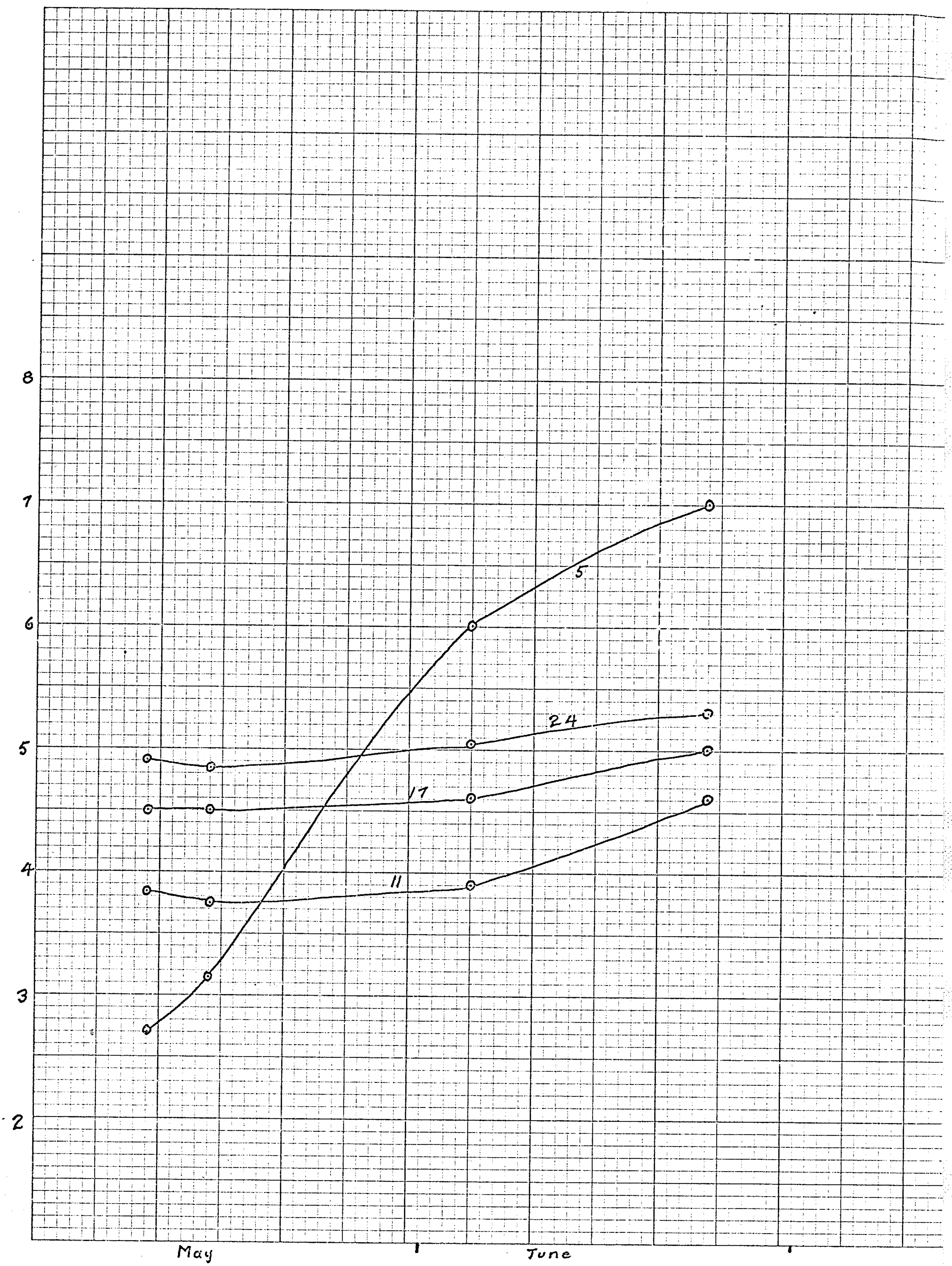
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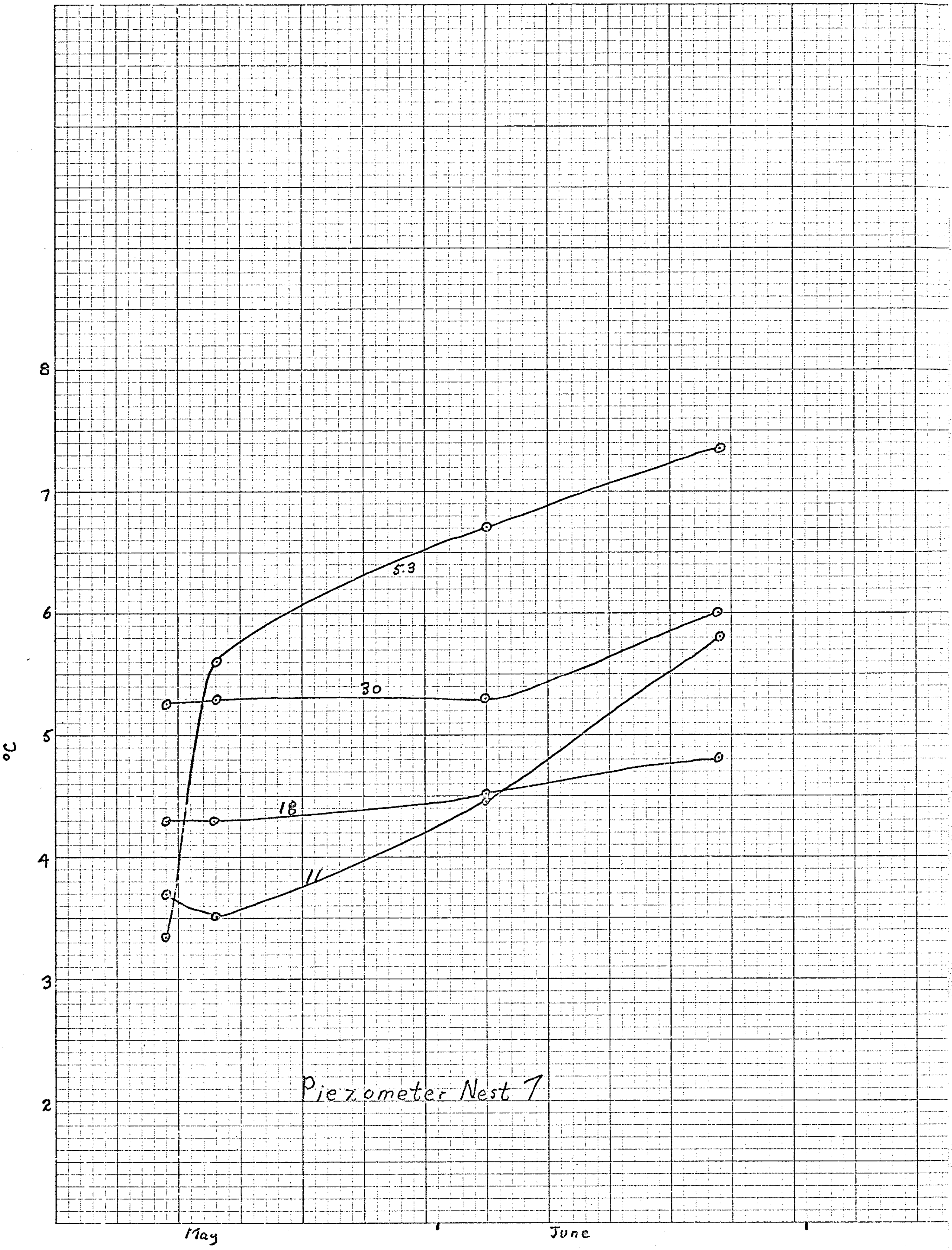

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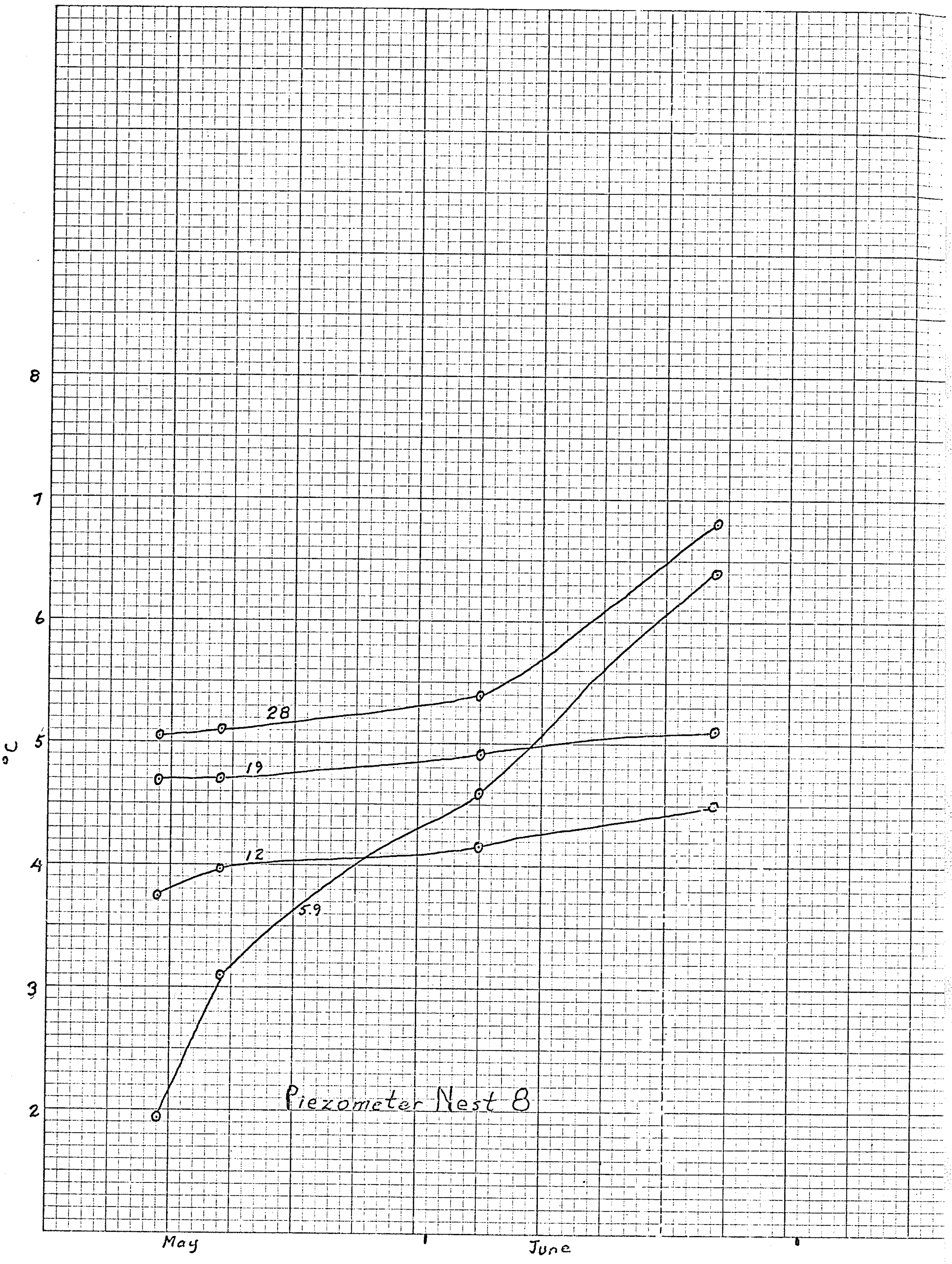
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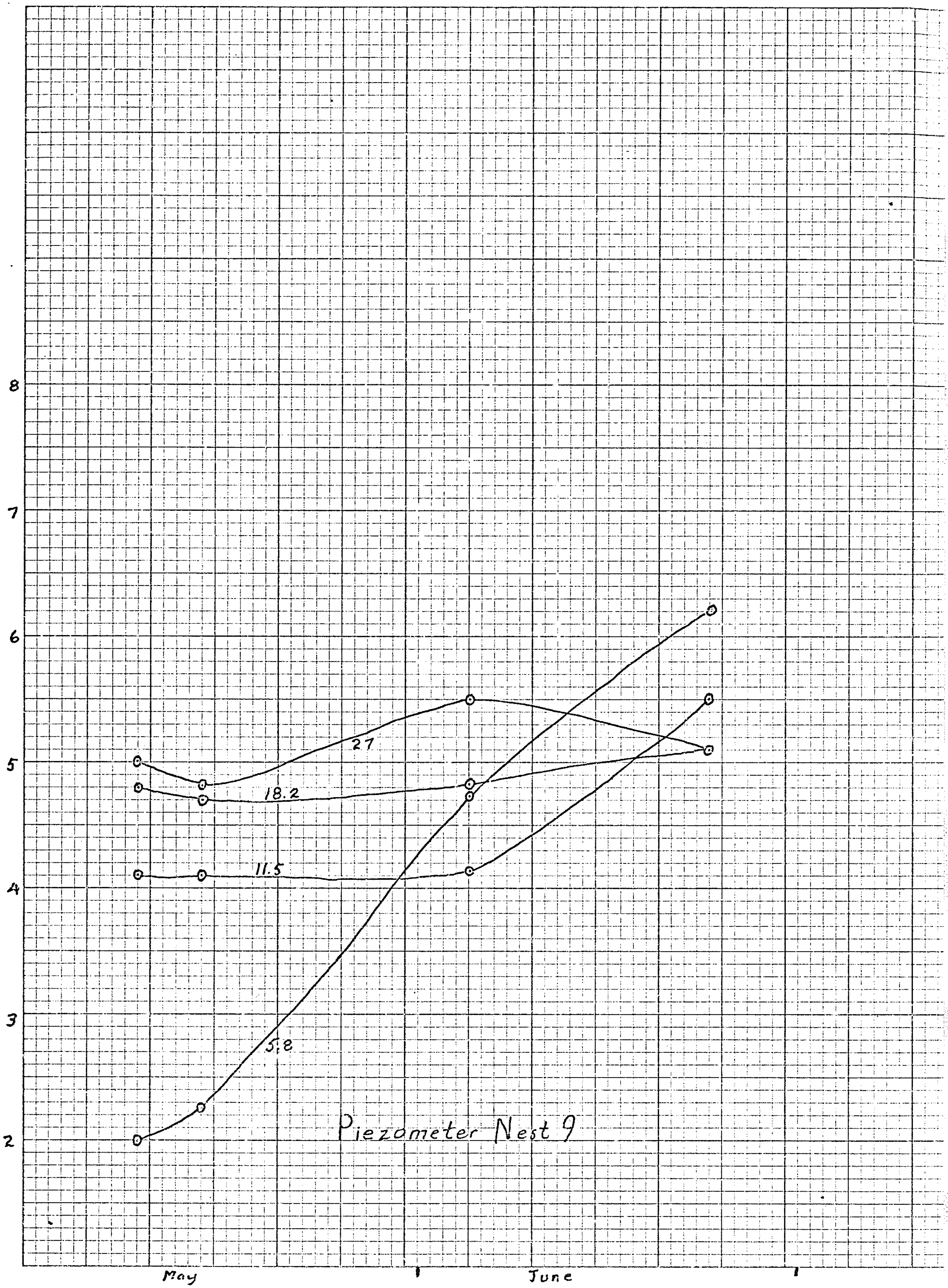

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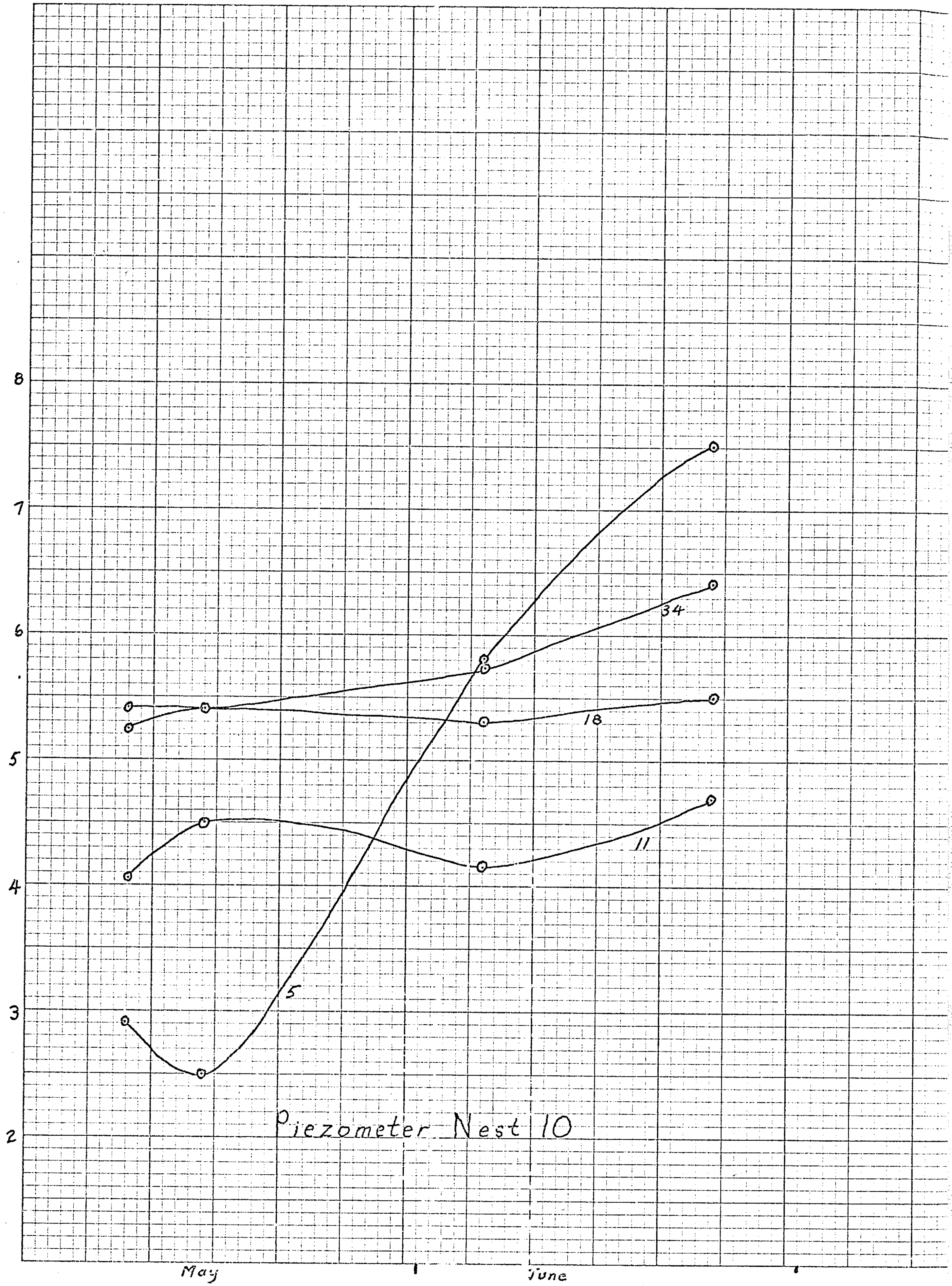

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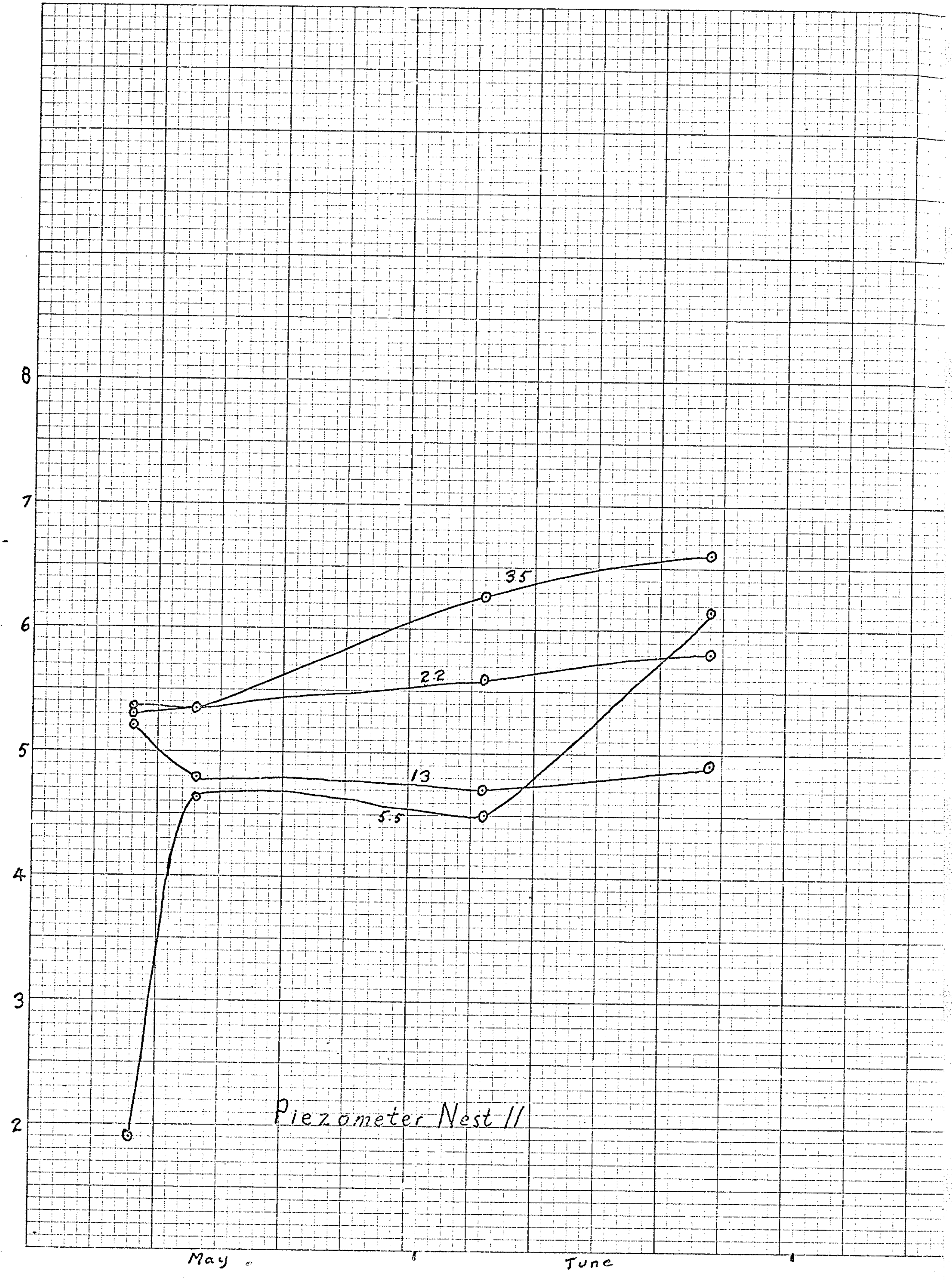

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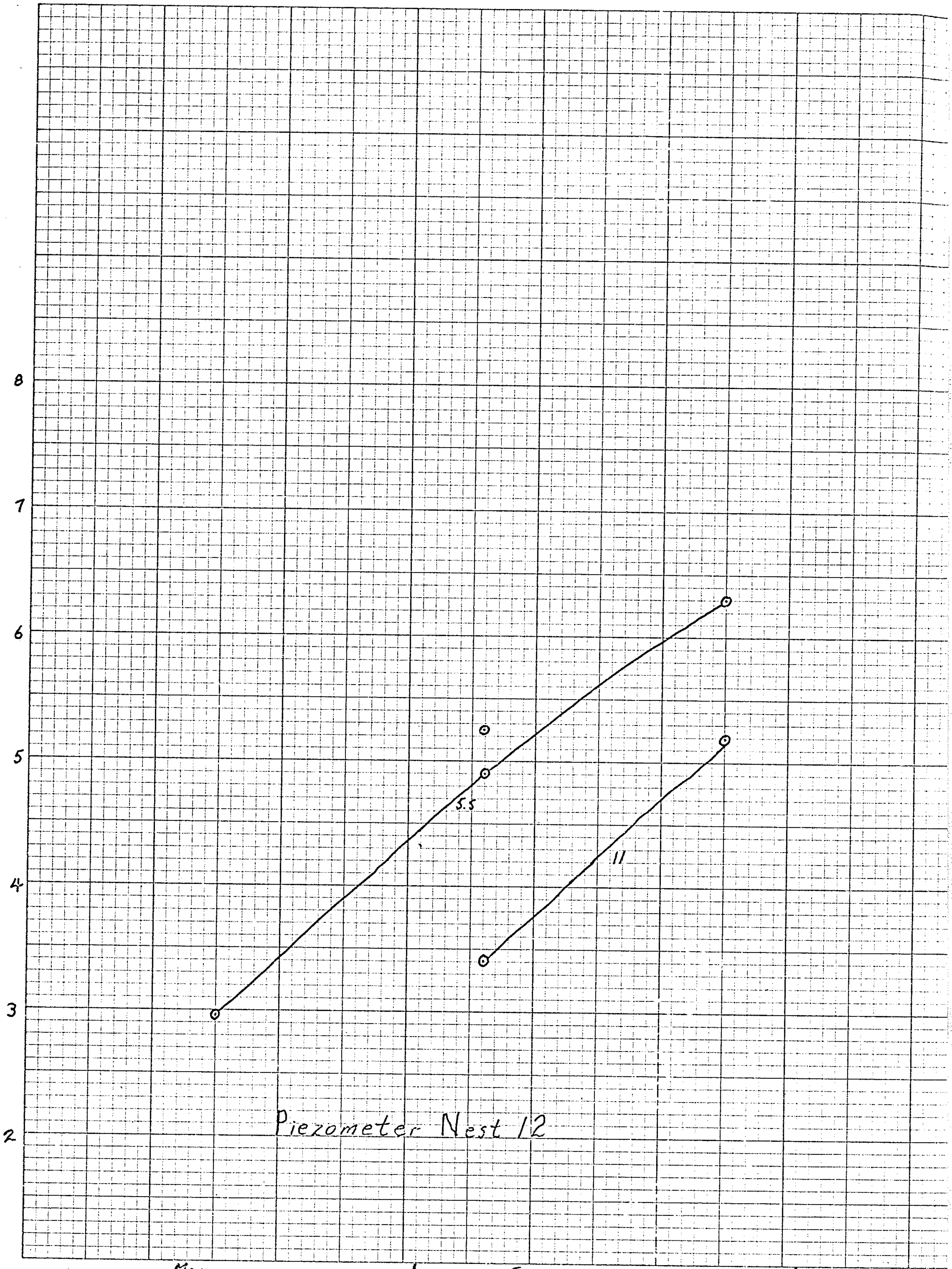

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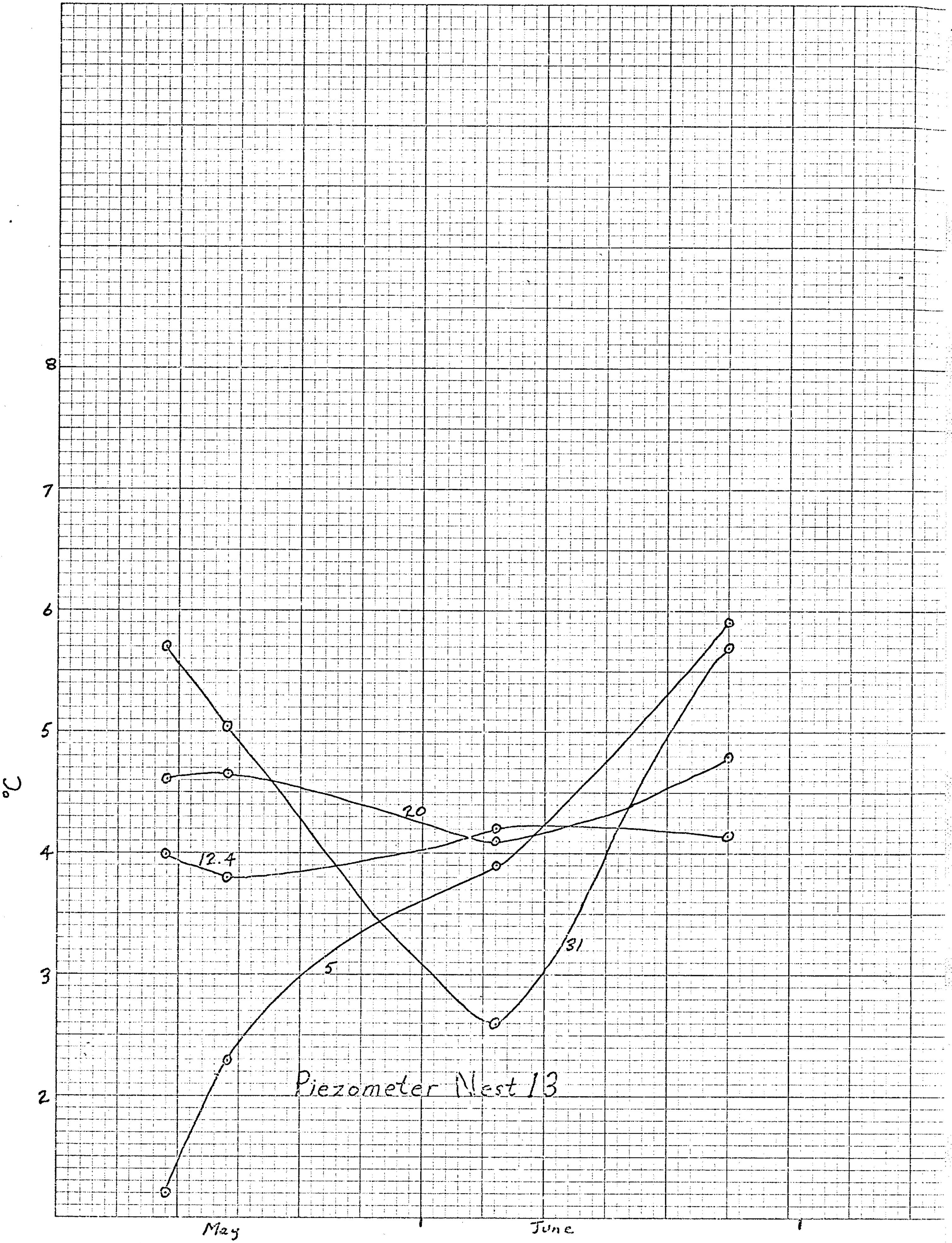
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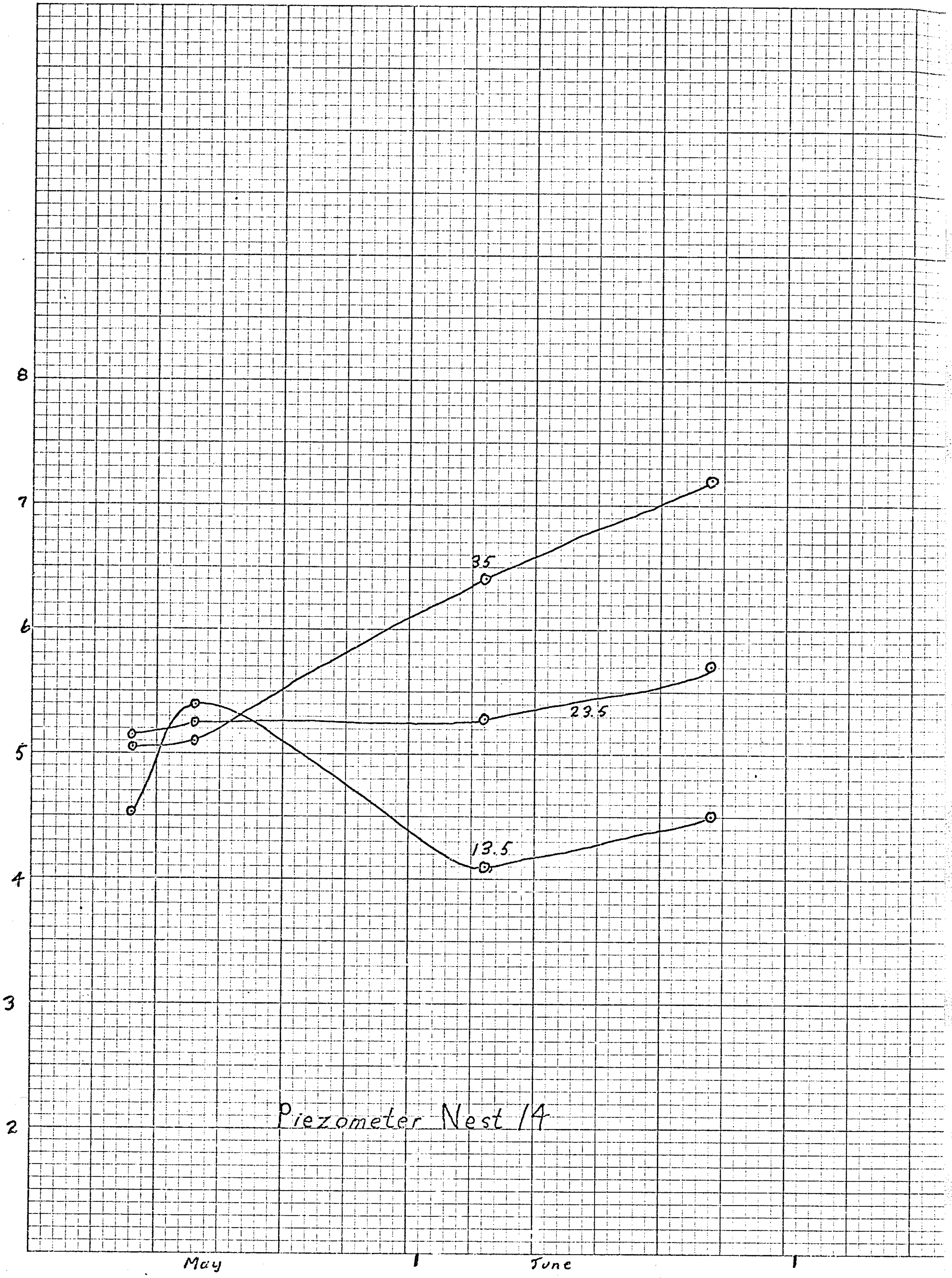
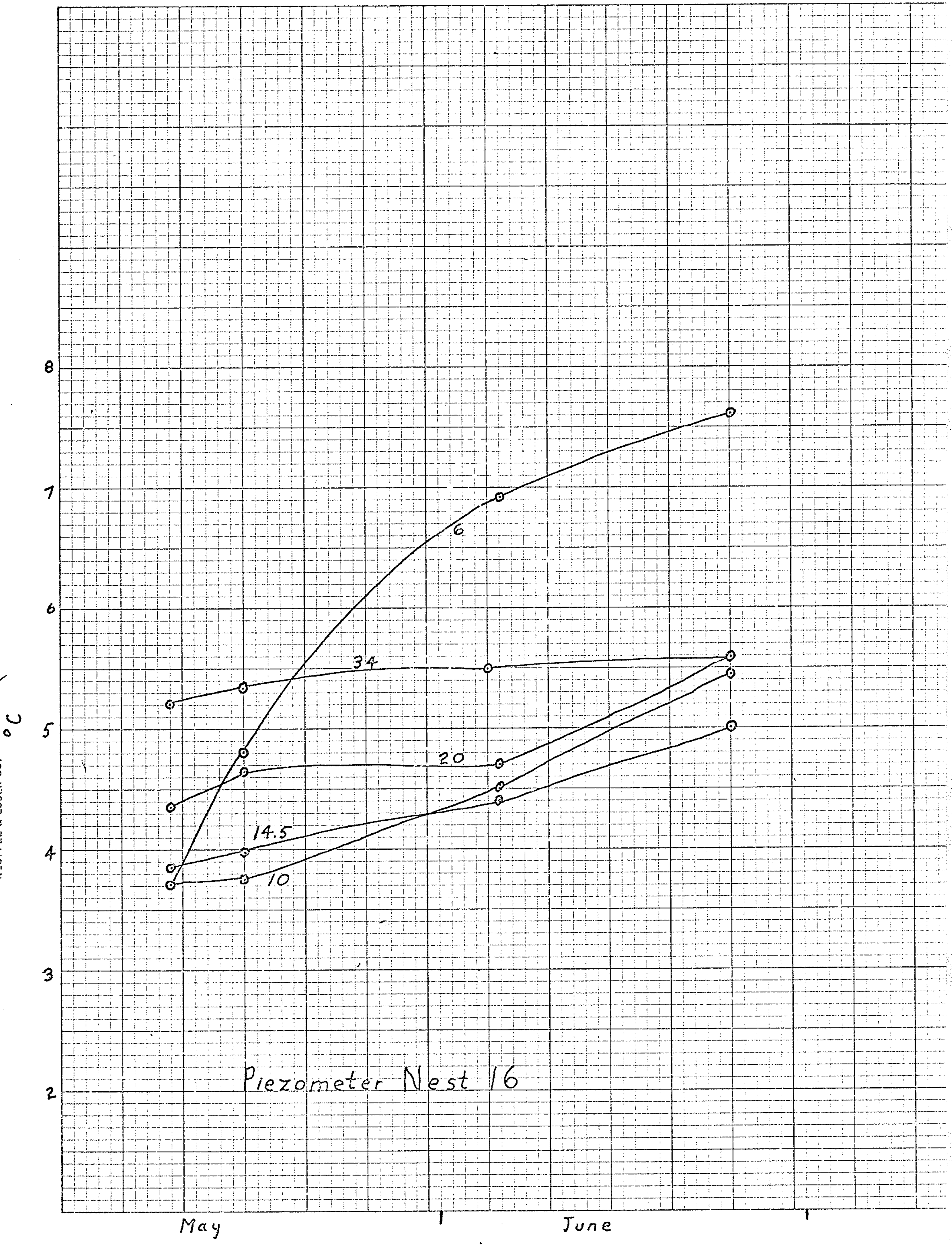


Piezometer Nest 14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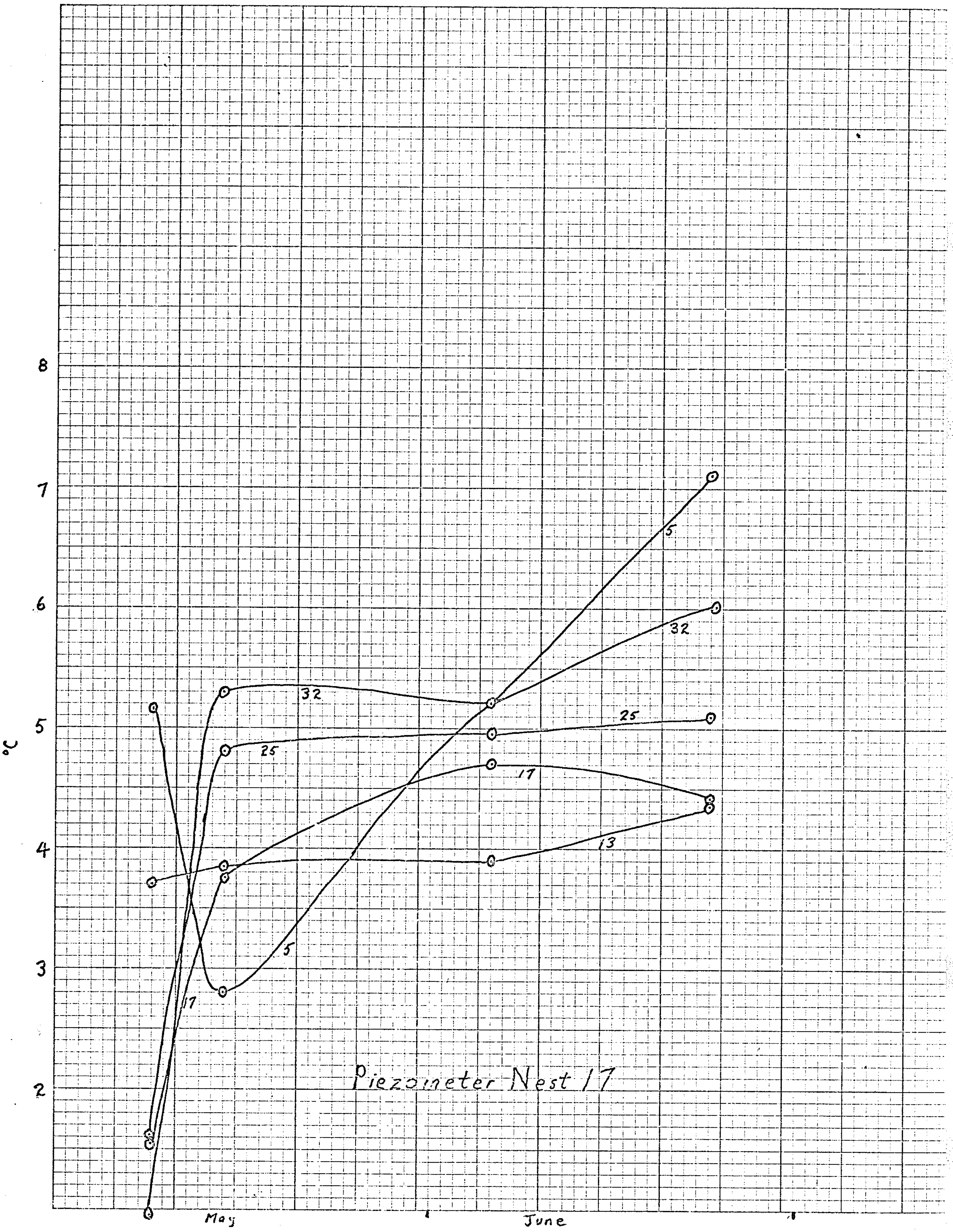
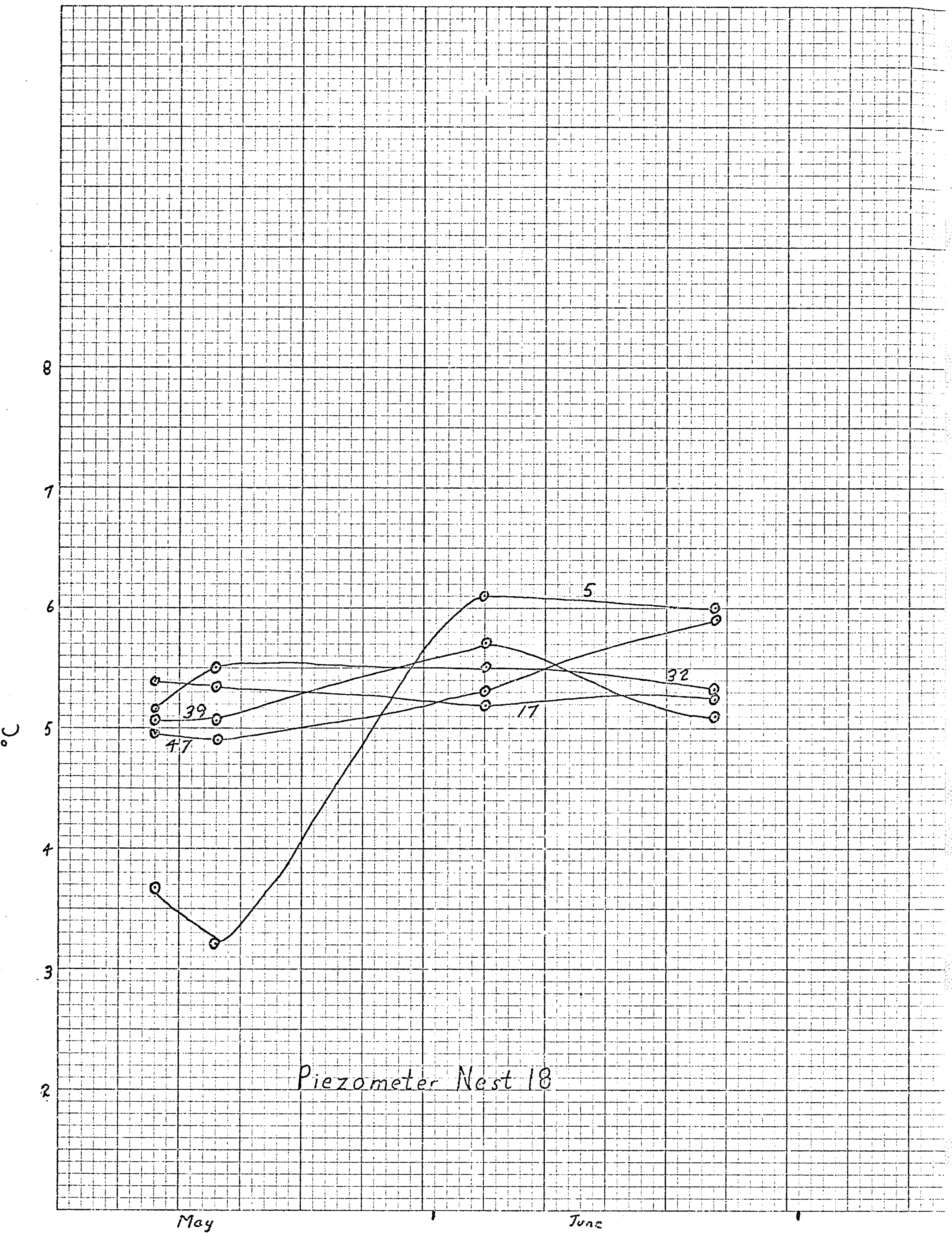
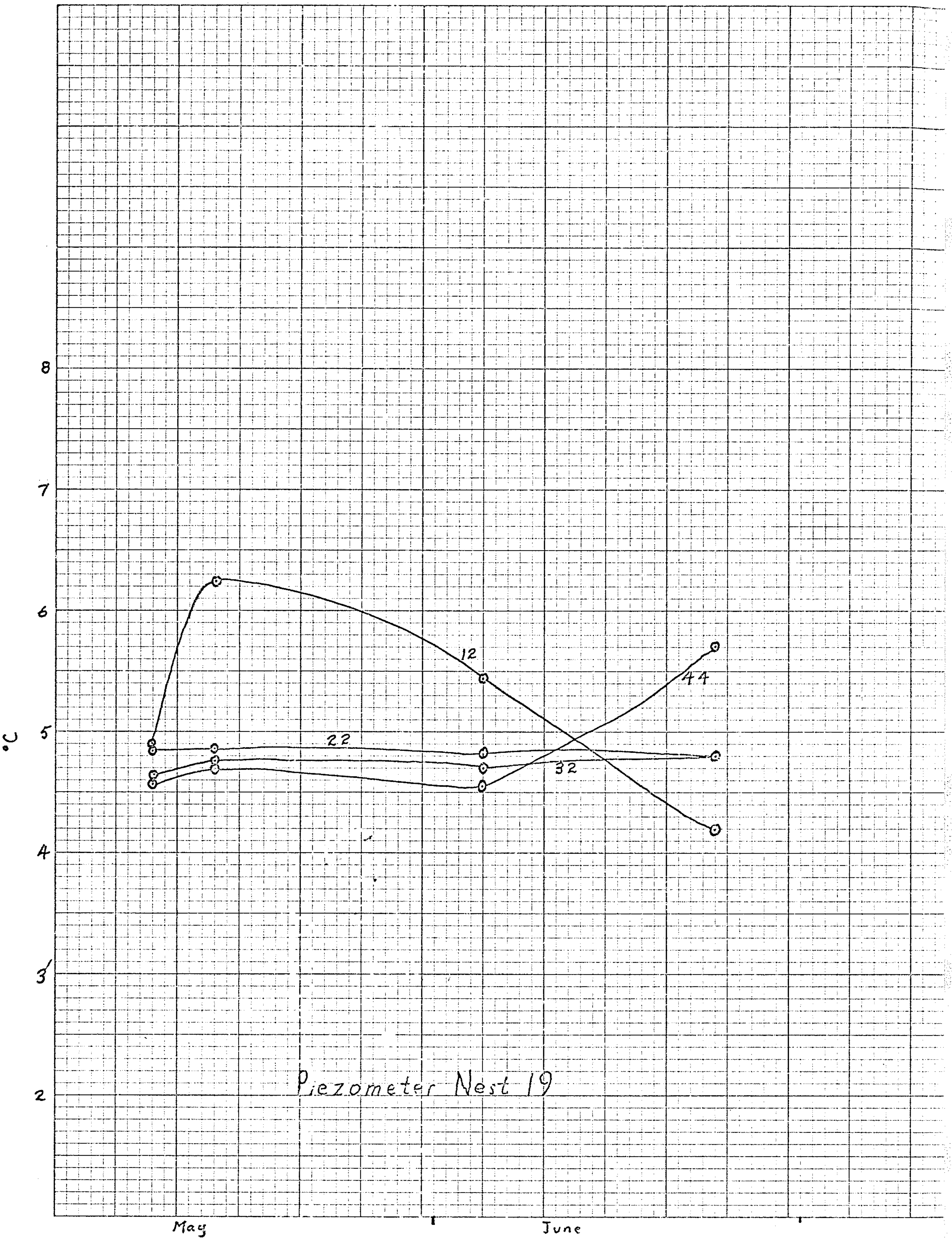


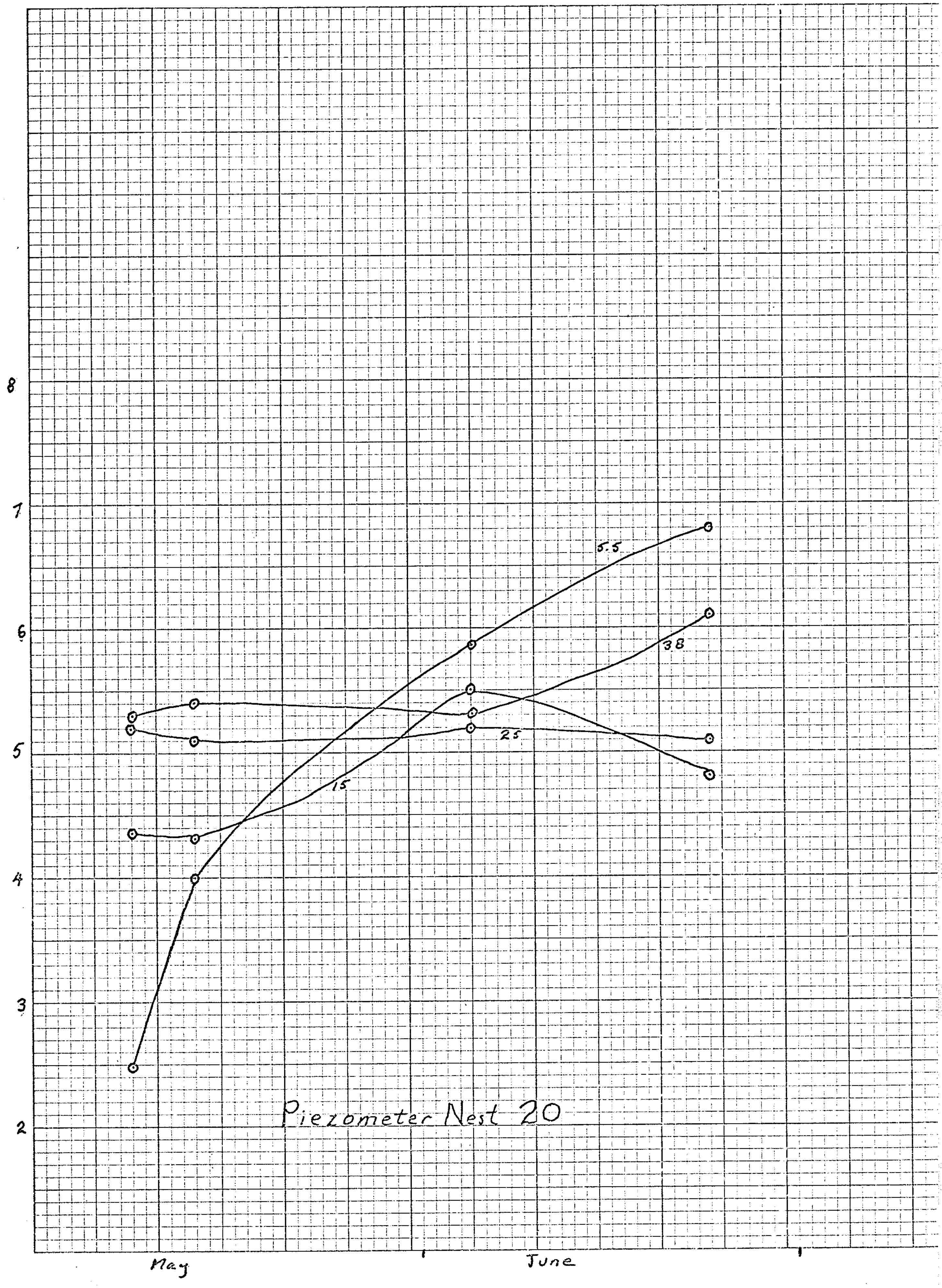
Piezometer Nest 17



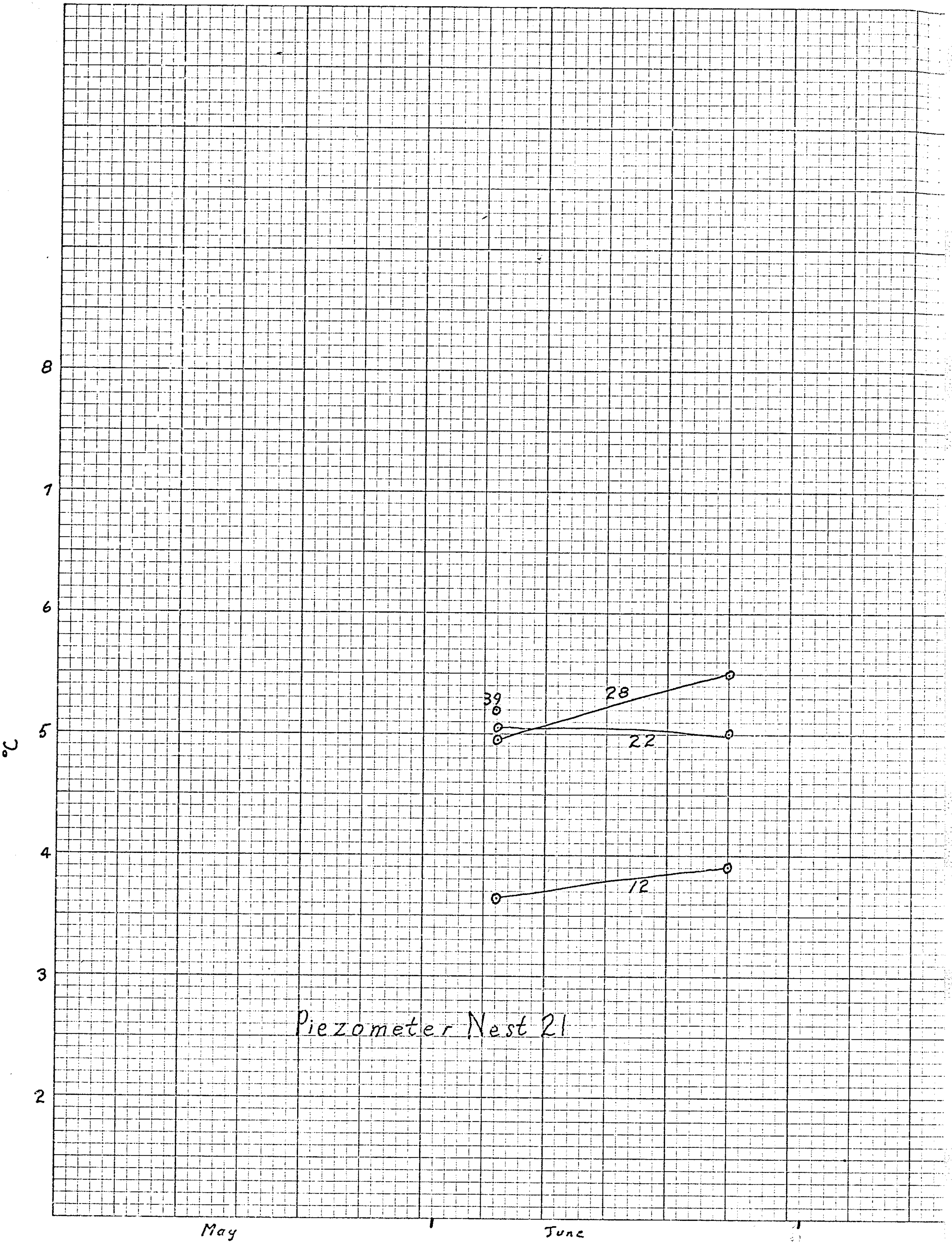
Piezometer Nest 18

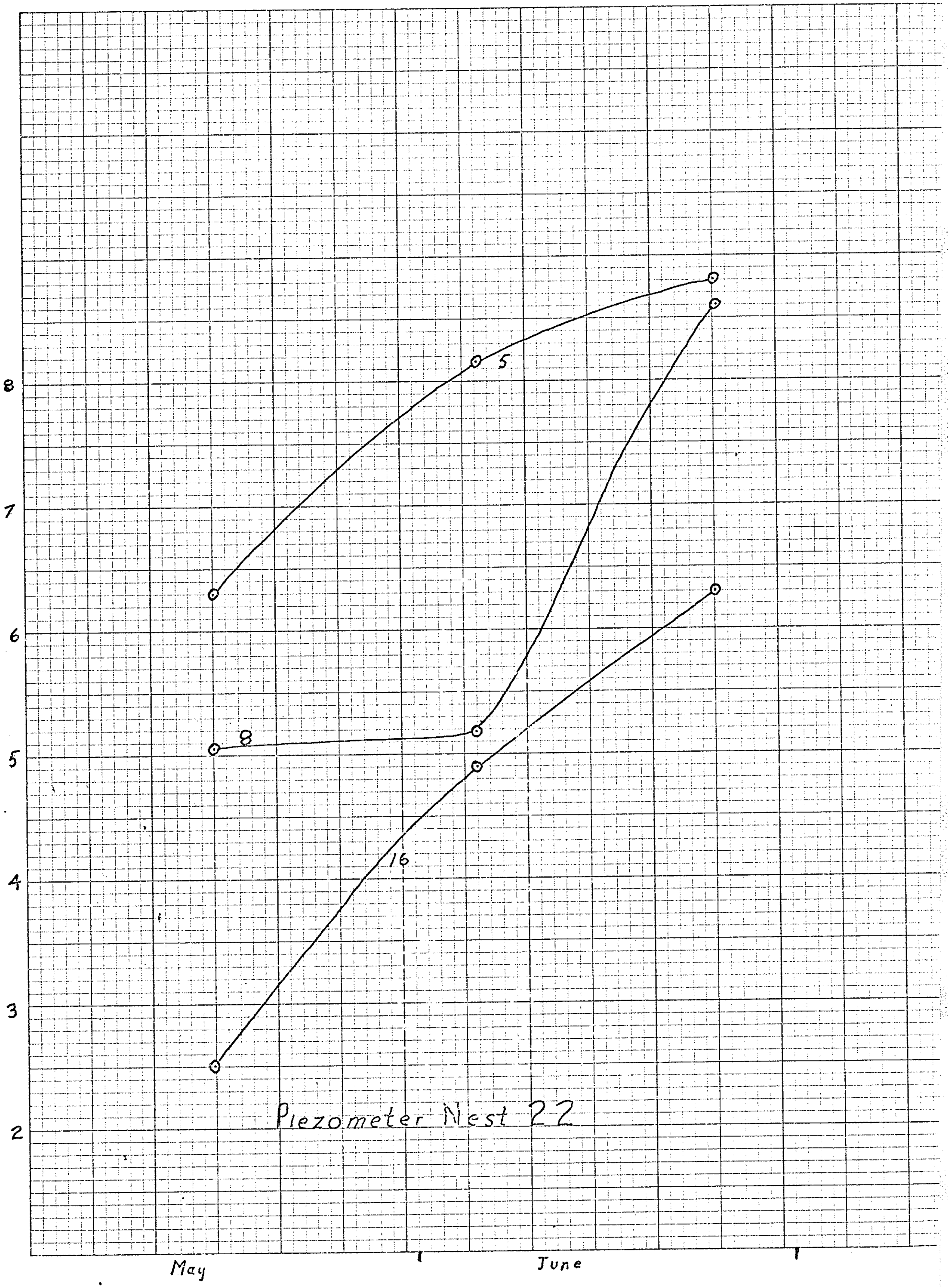


Piezometer Nest 19



Piezometer Nest 20


Piezometer Nest 21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APPENDIX F

TRACER VELOCITIES IN GROUNDWATER

Tritiated heavy water was injected into the flow regime under pressures of less than 10 psi. A schematic of the injection system is shown in figure 13A.

Samples were taken with a vacuum pump connected to flasks in which a 20 - 50 ml sample was collected. To ensure a fresh sample for every sampling period, a 100 ml aliquat was taken and discarded prior to final sampling. A down-hole sampler identical to that used for the geochemical samples (Fig. 11) was used for the initial few samples but the difficulty of preventing contamination resulted in a modification of sampling technique. Each sample point was given individual vacuum lines and a vacuum flask was used for sampling (Fig. 15A).

For analysis, an aliquot of sample was placed in 20 ml of Chicago Nuclear NE220 liquid scintillator in 25 ml scintillation counter (low sodium) glass vials and counted by a Chicago Nuclear 3-channel scintillometer for beta activity. Results were printed and stored on paper tape and counts repeated to ensure reliable values. Background radiation was not considered because of its relatively stable 18-25 cpm during the period of study. Decay of the tritium was not considered because of the relatively short period of study relative to the 12.26 year half-life of tritium.

Tabulated activity counts are given only for sample tubes considered active or for those indicating contamination.

INJECTION SITE #1

July 2, 1969 - injection of 20 gallons solution of 20.3 gms fluorescein at 10 psi to ensure adequate safety precautions for tritium injection. Immediate response of water level in all sample tubes noted when pressure applied. Injection rate @ 10 psi approximately 2 gpm.

July 9, 1969 - 1 curie tritium diluted in 20 gallons water and injected under less than 10 psi.followed by 20 gallons water to flush all tritium into the formation. All sample tubes were corked during injection to prevent overflow due to pressure. Fluorescein noted in sample tube 15 immediately after injection. Samples taken immediately after injection showed IWP-1-15 to have count of 210 cpm. Samples taken periodically over the next 96 hours showed a rapid increase to 148,000 cpm/ml. A peak count in sample tube 15 of 826,445 cpm/ml was recorded on August 15, 1969. By November 5, the count had fallen to 675,675 cpm/ml.

The injection well samples indicated counts of 4.78×10^3 cpm/ml (top) and 3.15×10^5 cpm/ml (bottom) on July 21. The difference was a result of the injection of pure water following the tritium. A peak of 3.65×10^6 cpm/ml was reached on August 22, 1969 and by May 15, 1970 the count had fallen to 3.9×10^5.

Sample tube 13 began to show above background beta activity 8 hours after injection. Values fluctuated but reached a peak of 4,470 on August 17, 1969. A value of 12,300 cpm/ml on July 19 is felt to be in error. By November 5, 1969 the value fell off to 460 cpm/ml.

No other sample tubes indicated the presence of tritium.

TRITIUM ANALYSES RECORD - IWP-1-INJ

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
21/7	4.780×10^3	6/ 8	--
21/7	3.150×10^5	6/ 8	1.462×10^6
22/7	4.149×10^5	7/ 8	2.084×10^6
23/7	6.493×10^5	8/ 8	1.429×10^6
24/7	7.751×10^5	10/ 8	1.916×10^6
25/7	9.708×10^5	11/ 8	2.080×10^6
28/7	--	13/ 8	1.770×10^6
28/7	1.405×10^6	14/ 8	2.220×10^6
29/7	1.456×10^6	15/ 8	1.740×10^6
30/7	7.619×10^5	17/ 8	1.870×10^6
31/7	9.709×10^5	18/ 8	1.585×10^6
1/8	9.346×10^5	22/ 8	5.55×10^5
3/8	1.0×10^6	29/ 8	3.65×10^6
4/8	--	7/ 9	1.136×10^6
4/8	1.550×10^6	17/ 9	7.368×10^5
5/8	--	8/10	8.620×10^5
5/8	1.417×10^6	5/11	5.848×10^5

TRITIUM ANALYSES RECORD - IWP-1-15

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
9/7	210	28/ 7	529,100
10/7	51,400	29/ 7	549,450
10/7	70,600	30/ 7	552,485
10/7	95,000	31/ 7	537,633
10/7	119,000	1/ 8	502,500
11/7	102,000	3/ 8	507,613
12/7	100,000	4/ 8	526,315
13/7	148,000	5/ 8	518,134
14/7	168,500	6/ 8	490,195
15/7	170,000	7/ 8	555,555
15/7	177,600	8/ 8	588,234
16/7	290,000	10/ 8	609,755
16/7	293,000	11/ 8	653,594
17/7	288,000	13/ 8	704,224
18/7	357,000	14/ 8	781,249
19/7	367,000	15/ 8	826,445
20/7	385,000	22/ 8	734,607
21/7	426,000	17/ 8	793,650
22/7	438,000	18/ 8	793,650
23/7	448,430	29/ 8	757,120
24/7	462,962	7/ 9	775,193
25/7	487,804	17/ 9	813,674
27/7	490,195	8/10	746,268

TRITIUM ANALYSES RECORD - IWP-1-13

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
9/7	7	29/ 7	910
10/7	36	30/ 7	775
10/7	91	31/ 7	940
10/7	134	1/ 8	850
10/7	303	3/ 8	850
11/7	453	4/ 8	1,325
12/7	535	5/ 8	950
13/7	540	6/ 8	1,565
14/7	508	7/ 8	2,060
15/7	435	8/ 8	1,755
15/7	235	10/ 8	2,095
16/7	375	11/ 8	3,171
16/7	625	13/ 8	2,899
17/7	625	14/ 8	2,436
18/7	2,225	15/ 8	2,650
19/7	12,300	22/ 8	3,200
20/7	4,700	17/ 8	4,467
21/7	2,750	18/ 8	2,330
22/7	1,675	29/ 8	1,782
23/7	875	7/ 9	1,494
24/7	1,175	17/ 9	1,289
25/7	1,025	8/10	816
27/7	1,125	5/11	460
28/7	655		

INJECTION SITES #2 & #3

The procedure used for injection #1 was followed for injections 2 and 3 with the exception that the fluorescein test was not used. In injections 2 and 3 only 10 millicuries of tritium was injected rather than the 1 curie used at 1.

Serious sample tube contamination occurred in injection site 3 in sample tube 20 and 24. It probably resulted from contamination during the initial few sampling periods before a routine sampling procedure was developed. The anomalous values are not felt to be true indicators of the subsurface movement of tritium because the values are very low relative to what would be expected from the 10 mCi injection.

A series of peaks and declines in beta activity in the active holes is felt significant, although of what is not certain.

TRITIUM ANALYSES RECORD - IWP-3-INJ

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
20/8	495,282	3/ 9	226,244
20/8	686	5/ 9	204,498
20/8	248	10/ 9	182,546
20/8	26,404	13/ 9	168,960
24/8	189,907	17/ 9	147,547
28/8	252,650	20/ 9	163,335
22/8	93,023	24/ 9	307,666
25/8	225,733	1/10	184,162
27/8	264,550	8/10	112,935
30/8	226,244	17/10	49,799
4/9	222,222	24/10	28,778
1/9	220,264	5/11	16,446
2/9	228,310	24/11	12,492

TRITIUM ANALYSES RECORD - IWP-3-6

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
20/8	20	13/ 9	1,948
20/8	13,298	17/ 9	1,846
24/8	13,872	20/ 9	1,267
22/8	25,203	24/ 9	1,444
26/8	14,464	1/10	1,046
27/8	9,292	8/10	1,350
30/8	8,069	17/10	6,277
4/9	4,842	24/10	6,925
5/9	3,887	5/11	7,096
2/9	6,589	24/11	6,809
10/9	2,689	6/ 5/70	4,525

TRITIUM ANALYSES RECORD - IWP-3-18

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
24/8	32	4/9	52
28/8	30	5/9	23
30/8	34	10/9	30

TRITIUM ANALYSES RECORD - IWP-3-20

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
20/8	29	2/ 9	73
20/8	45	10/ 9	74
24/8	74	1/10	67
22/8	73	8/10	59
26/8	93	17/10	100
27/8	72	24/10	82
30/8	94	5/11	77
4/9	135	24/11	94

TRITIUM ANALYSES RECORD - IWP-3-24

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
20/8	20	17/ 9	161
20/8	24	24/ 9	101
24/8	27	1/10	114
28/8	77	8/10	106
30/8	82	17/10	100
4/9	20	24/10	86
5/9	144	5/11	82
10/9	168	24/11	101

TRITIUM ANALYSES RECORD - IWP-2-INJ

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
21/8	57,735	10/ 9	116,157
21/8	349,950	13/ 9	106,951
21/8	6,000	17/ 9	83,756
24/8	5,007	20/ 9	85,917
26/8	9,454	24/ 9	76,915
28/8	106,593	1/10	59,245
30/8	138,979	8/10	53,248
1/9	137,363	17/10	41,119
3/9	132,626	24/10	37,825
4/9	132,978	5/11	32,873
5/9	130,208	24/11	33,213

TRITIUM ANALYSES RECORD - IWP-2-26-43

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
24/8	28,926	13/ 9	46,168
28/8	37,059	17/ 9	42,706
21/8	28	20/ 9	45,241
22/8	16,239	24/ 9	44,339
26/8	35,844	1/10	41,098
30/8	30,754	8/10	40,919
4/9	43,195	17/10	37,900
1/9	42,444	24/10	37,797
3/9	46,749	5/11	36,416
5/9	42,633	24/11	43,370
10/9	42,047		

TRITIUM ANALYSES RECORD - IWP-2-4

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
24/8	102,499	10/ 9	27,120
28/8	99,087	13/ 9	27,901
21/8	15,836	17/ 9	25,177
22/8	100,678	20/ 9	27,865
23/8	106,461	24/ 9	27,282
30/8	98,597	1/10	22,663
4/9	52,402	17/10	19,523
1/9	77,869	24/10	19,627
3/9	60,961	5/11	20,006
5/9	42,890	24/11	20,538

TRITIUM ANALYSES RECORD - IWP-2-1

Date	Activity (cpm/ml)	Date	Activity (cpm/ml)
24/8	853	13/ 9	963
28/8	2,389	17/ 9	695
21/8	221	20/ 9	744
23/8	679	24/ 9	650
30/8	1,794	1/10	545
4/9	1,322	8/10	649
5/9	1,301	17/10	511
1/9	1,488	24/10	521
3/9	1,373	5/11	550
10/9	1,070	24/11	625

APPENDIX G

LISTING OF AND COMMENTS ON INPUT AND OUTPUT FOR THE STEADY-STATE MODEL

The first program includes a complete set of data input and output.

The second program includes print checks for debugging new data decks.

```
      THIS PROGRAM CALCULATES TOTAL HEAD AT ALL NODES IN A REGION
      WHEN GIVEN HEADS AT SPECIFIED BOUNDARY NODES
      REAL NL(352),KX(576),KY(576)
      COMMON M,CJ(352,2),IE(576,3),L1,L2,L3,  T,ST(3),KL,KX,KY,S(576)
      DIMENSION LIST(353),A(353), ISR(576),HDG(20)
      DIMENSION STORE(6000),                 NEIN(353),NI(353,8)
      DIMENSION G(3,6),DISPL(6),STRESS(576)
      EQUIVALENCE (NE,NN)
—     JRD=5  1
—     JWT=6  3
      READ JOB TITLE
    1 READ(JRD,510,END=9999)(HDG(I),I=1,20)
      WRITE(JWT,512)(HDG(I),I=1,20)
  512 FORMAT('1'//20A4)
  510 FORMAT(20A4)
      WRITE(JWT,600)
  600 FORMAT(/' TWO DIMENSIONAL SEEPAGE PROBLEM'//'  INPUT DATA'//)
      READ NUMBER OF ELEMENTS, NUMBER NODES,NUMBER SPECIFIED NODAL
      HEADS, THICKNESS
      ALL INPUT PRINTED OUT FOR CHECKING PURPOSES
      READ(JRD,500) NEL,NE,NBD,T
      IF(T.EQ.0.) T=1.
      WRITE(JWT,601) NEL,NN,NBD,T
  601 FORMAT(I4,'  ELEMENTS'I4,' NODES'I4,' SPECIFIED NODAL HEADS'//'  E
     1LEMENT THICKNESS ='F8.3//)
  500 FORMAT(3I5,F10.3)
      READ COORDINATES OF NODES
      READ(JRD,501)((CJ(J,I),I=1,2),J=1,NN)
      WRITE(JWT,602)
  602 FORMAT(///'  NODAL COORDINATES  (FT)'   //'  NODE      X COORD
     1  Y COORD')
      DO 99 J=1,NN
   99 WRITE(JWT,694)J,CJ(J,1),CJ(J,2)
  501 FORMAT(6F10.3) -
      ZERO CONSTANT VECTOR
  191 DO 39 J=1,NN
   39 NL(J)=0.

      GENERATE NODAL INCIDENCE TABLE

      WRITE(JWT,686)
  686 FORMAT(//'  ELEMENT INCIDENCE TABLE'//'  ELEMENT      NODE 1    NOD
     1E 2  NODE 3      KX          KY       SLOPE'//)
      SS=0.
      DO 17 M=1,NEL
      READ(JRD,505)(IE(M,I),I=1,3),XK,YK,SL ————
  505 FORMAT(3I5,3F10.3)
      IF(XK.NE.0.)XX=XK
      IF(YK.NE.0.)YY=YK
      IF(SL.NE.0.) SS=SL
      S(M)=SS
      KX(M)=XX
      KY(M)=YY
   17 WRITE(JWT,687)M,(IE(M,I),I=1,3),XX,YY,S(M)
  687 FORMAT(4I9,3F10.3)
      DO 18 J=1,NN
      NEIN(J)=0
```

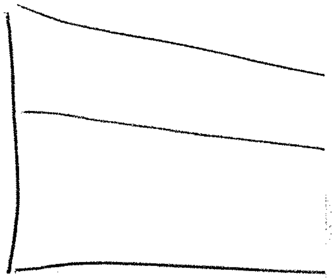
```
      DO 18 M=1,6
   18 NI(J,M)=0
      DO 19 M=1,NEL
      DO 19 K=1,3
      J=IE(M,K)
      NEIN(J)=NEIN(J)+1
      L=NEIN(J)
   19 NI(J,L)=M
  694 FORMAT(I5,6F12.4)
      READ ANY PRESCRIBED NODAL HEADS
      DO 376 J=1,NN
  376 ISR(J)=0
      WRITE(JWT,596)
  596 FORMAT(///'  PRESCRIBED NODAL HEADS'//'  NODE  PRESCRIBED HEAD'//)
      DO 574 I=1,NBD
      READ(JRD,694)J, NL(J)
      ISR(J)=1
  574 WRITE(JWT,694)J, NL(J)
      GENERATION AND ELIMINATION OF NODAL EQUILIBRIUM EQUATIONS
      GENERATE I TH  ROW OF STIFFNESS MATRIX AND STORE IN A TEMPORARILY
  172 LIST(1)=1
      DO 100 I=1,NE
      NON ZERO BAND OF ROW I IN STIFFNESS IS FROM KL TO KH. KL = LOWEST
       NODE NO FOR NODES INCIDENT ON ELEMENTS INCIDENT ON NODE I, KH = HIGHEST
      KL=I
      KH=I
      IM=NEIN(I)
      DO 5 J=1,IM
      M=NI(I,J)
      DO 5 K=1,3
      JF=IE(M,K)
      IF(JF-NE)10,10,5
   10 IF(JF-KH)14,14,12
   12 KH=JF
      GO TO 5
   14 IF(JF-KL)16,5,5
   16 KL=JF
    5 CONTINUE

      ZERO ALL A MATRICES IN NON - ZERO BAND
      K=KH-KL+1
      DO 29 J=1,K
   29 A(J)=0.
      INSERT STIFFNESS MATRICES INTO NON ZERO BAND
      DO 200 J=1,IM
      M=NI(I,J)
      DO 20 L=1,3
    →IF(I-IE(M,L))20,22,20
   22 KI=IE(M,L)
      L1=L
      L2=L+1-3*(L/3)
      KJ=IE(M,L2)
      L3=L+2-3*(L/2)
      KK=IE(M,L3)
   20 CONTINUE
      CALL STIFF
      NNI, NJ AND NK ARE NODES I, J AND K FOR ELEMENT M - (POSITION IN ROW I
      RELATIVE TO KL = 1
```

```
    NNI=I-KL+1
    INSERT STIFFNESS MATRIX I
    A(NNI)=A(NNI)+ST(1)
    TEST WHETHER NODE NJ IS A FIXED SUPPORT
    IF(KJ-NE)47,47,6
    INSERT STIFFNESS MATRIX J
 47 NJ=KJ-KL+1
    A(NJ)=A(NJ)+ST(2)
    TEST WHETHER NODE NK IS FIXED SUPPORT
  6 IF(KK-NE)8,8,200
  8 NK=KK-KL+1
    INSERT STIFFNESS MATRIX K
    A(NK)=A(NK)+ST(3)
200 CONTINUE
    MODIFY EQUATION IF SPECIFIED HEAD AT NODE I
    IF(ISR(I).EQ.0) GO TO 497
    A(NNI)=10.**25
    NL(I)=NL(I)*10.**25
497 LINC=KH-I
    FOR FIRST EQUATION, BYPASS ELIMINATION
    IF(I-KL)60,60,50
    PERFORM ELIMINATION FOR ROW I TO ZERO BELOW MAIN DIAGONAL
 50 KU=I-1
    DO 256 K=KL,KU
    IK = PIVOTAL COLUMN RELATIVE TO  KL = 1
    IK=K+1-KL
    IM=LIST(K+1)-LIST(K)
    IJ=K+IM-I-LINC
    IF NON ZERO BAND FOR PIVOTAL EQ ENDS TO RIGHT OF THAT FOR EQ I, EXTEND
    FOR EQ I
     IF(IJ.LE.0.) GO TO 82
    KK=LINC+I-KL+2
    LINC=LINC+IJ
    LL=IJ+KK-1
    DO 83 L=KK,LL
 83 A(L)=0.
 82 IF(IM.LE.0.) GO TO 256
    DO 55 J=1,IM
    IJ=IK+J
    KJ= LIST(K)+J-1
    IF(ABS(STORE(KJ)).LE.10.**(-10)) STORE(KJ)=0.
 55 A(IJ)=A(IJ)-A(IK)*STORE(KJ)
256 NL(I)=NL(I)-A(IK)*NL(K)
    NORMALIZE ROW I. JJ = PIVOTAL ELEMENT RELATIVE TO KL = 1
 60 JJ=I+1-KL
    IJ=JJ


    LIST(I+1)=LINC+LIST(I)
    IF(LINC)75,75,65
 65 DO 70 J=1,LINC
    IJ=IJ+1
    IK=LIST(I)+J-1
 70 STORE(IK)=A(IJ)/A(JJ)
    NORMALIZE HEAD AT NODE I
 75 NL(I)=NL(I)/A(JJ)
100 CONTINUE
    START BACK SUBSTITUTION
```

Water table



$$\begin{tikzcd} 90 \arrow[r, bend right, leftrightarrow] & 114 \end{tikzcd}$$ 97

1

576

$$\begin{tikzcd} 90 \arrow[r, bend right, leftrightarrow] & 130 \end{tikzcd}$$

1
4
9
13
18

A(IT)

```
    N2=NE-1
    IF(N2)210,210,220
220 DO 250 K=1,N2
    I=NE-K
    KU=LIST(I+1)-LIST(I)
    SUM=0.
    DO 240 J=1,KU
    IK=LIST(I)+J-1
    IJ=I+J
240 SUM=SUM+STORE(IK)*NL(IJ)
250 NL(I)=NL(I)-SUM
    WRITE NODAL HEADS
210 WRITE(JWT,560)(HDG(I),I=1,20)
560 FORMAT('1'//20A4,//'  RESULTS'//'  NODAL HEADS'//'  NODE  HEAD (FT
   1)'//)
    DO 397 L=1,NN
397 WRITE(JWT,694)L,NL(L)
    CALL PLOTER(NL)
999 CALL EXIT
    GO TO 1
    END
```

```
      SUBROUTINE STIFF
      THIS SUBROUTINE DEVELOPS STIFFNESS MATRICES II,IJ AND IK FOR
      CONSTANT STRAIN TRIANGLE I-J-K
      REAL NL(352),KX(576),KY(576)
      COMMON M,CJ(352,2),IE(576,3),L1,L2,L3,  T,ST(3),KL,KX,KY,S(576)
      DIMENSION A(3),B(3)
      SL=ABS(S(M)/57.2958)
      COSA=COS(SL)
      SINA=SIN(SL)
      IF(S(M).LE.0.) SINA=-SINA
      I=IE(M,1)
      J=IE(M,2)
      K=IE(M,3)
      A(1)=(CJ(K,1)-CJ(J,1))*COSA+(CJ(K,2)-CJ(J,2))*SINA
      A(2)=(CJ(I,1)-CJ(K,1))*COSA+(CJ(I,2)-CJ(K,2))*SINA
      A(3)=(CJ(J,1)-CJ(I,1))*COSA+(CJ(J,2)-CJ(I,2))*SINA
      B(1)=(CJ(J,2)-CJ(K,2))*COSA-(CJ(J,1)-CJ(K,1))*SINA
      B(2)=(CJ(K,2)-CJ(I,2))*COSA-(CJ(K,1)-CJ(I,1))*SINA
      B(3)=(CJ(I,2)-CJ(J,2))*COSA-(CJ(I,1)-CJ(J,1))*SINA
      DET=CJ(J,1)*CJ(K,2)-CJ(K,1)*CJ(J,2)-CJ(I,1)*CJ(K,2)+CJ(K,1)*CJ(I,2
     1)+CJ(I,1)*CJ(J,2)-CJ(J,1)*CJ(I,2)
      ST(1)=(KY(M)*A(L1)*A(L1)+KX(M)*B(L1)*B(L1))/2./DET
      ST(2)=(KY(M)*A(L1)*A(L2)+KX(M)*B(L1)*B(L2))/2./DET
      ST(3)=(KY(M)*A(L1)*A(L3)+KX(M)*B(L1)*B(L3))/2./DET
      RETURN
      END
```

```
      SUBROUTINE PLOTER(Z)
      COMMON M,CJ(352,2),IE(576,3),L1,L2,L3,  T,ST(3),KL,KX,KY,S(576)
      DIMENSION Z(352),IBUF(1000)
      CALL PLOTS(IBUF,1000)
      CALL PLOT(0.0,-11.0,-3)
      CALL PLOT(1.0,1.0,-3)

      DRAW AXES

      CALL AXIS(0.,0.,'JOR320',-6,40.,0.,0.,200.)
      CALL AXIS(0.,0.,' ',1,6.,90.,800.,20.)

      SCALING

      DO 20 I=1,352
      A=CJ(I,1)/200.
      B=(CJ(I,2)-800)/20.

      PLOT POINTS

      CALL SYMBOL(A,B,0.07,4,0.,-1)
      C=A-0.175
      D=B-0.105
      E=Z(I)-800
      CALL NUMBER(C,D,0.07,E,0.,2)
20    CONTINUE
      CALL PLOT(40.,0.,999)
      RETURN
      END
```

```
FINITE ELEMENT SEEPAGE PROGRAM BESWICK PINAWA

TWO DIMENSIONAL SEEPAGE PROBLEM

 INPUT DATA


576  ELEMENTS 352 NODES  57 SPECIFIED NODAL HEADS

 ELEMENT THICKNESS =    1.000




 NODAL COORDINATES  (FT)

 NODE       X COORD        Y COORD
   1       1.0000     839.0000
   2      70.0000     849.0000
   3      95.0000     839.0000
   4       1.0000     830.0000
   5     120.0000     830.0000
   6     205.0000     848.0000
   7     225.0000     839.0000
   8     200.0000     860.0000
   9       1.0000     822.5000
  10     200.0000     822.0000
  11     300.0000     830.0000
  12     390.0000     821.0000
  13     485.0000     830.0000
  14     420.0000     839.0000
  15     375.0000     848.0000
  16     320.0000     859.0000
  17     340.0000     865.0000
  18     450.0000     868.0000
  19     400.0000     865.0000
  20     490.0000     859.0000
  21     550.0000     821.0000
  22     600.0000     839.0000
  23     650.0000     830.5000
  24     700.0000     820.0000
  25     570.0000     848.0000
  26     695.0000     859.0000
  27     570.0000     865.0000
  28     610.0000     869.0000
  29     790.0000     865.0000
  30     830.0000     869.0000
  31     880.0000     859.0000
  32     720.0000     848.0000
  33     760.0000     839.0000
  34     810.0000     830.5000
  35     900.0000     817.5000
  36     910.0000     839.0000
  37     890.0000     848.0000
  38    1000.0000     859.0000
  39     940.0000     865.0000
  40    1010.0000     869.0000
  41    1120.0000     869.0000
  42    1080.0000     865.0000
  43    1030.0000     848.0000
  44    1000.0000     828.0000
  45    1080.0000     813.0000
```

```
 47    1140.0000     839.0000
 48    1250.0000     848.0000
 49    1180.0000     859.0000
 50    1240.0000     865.0000
 51    1305.0000     869.5000
 52    1510.0000     870.0000
 53    1440.0000     865.0000
 54    1390.0000     859.0000
 55    1440.0000     848.0000
 56    1330.0000     839.0000
 57    1410.0000     828.0000
 58    1280.0000     813.0000
 59    1440.0000     815.0000
 60    1620.0000     817.5000
 61    1590.0000     829.0000
 62    1510.0000     839.0000
 63    1690.0000     839.0000
 64    1610.0000     848.0000
 65    1550.0000     859.0000
 66    1620.0000     865.0000
 67    1700.0000     870.0000
 68    1860.0000     870.5000
 69    1800.0000     865.0000
 70    1710.0000     859.0000
 71    1790.0000     848.0000
 72    1820.0000     839.0000
 73    1740.0000     829.5000
 74    1790.0000     820.0000
 75    1880.0000     829.5000
 76    1970.0000     821.0000
 77    1990.0000     839.0000
 78    1920.0000     848.0000
 79    1890.0000     859.0000
 80    1950.0000     865.0000
 81    2005.0000     870.5000
 82    2150.0000     870.5000
 83    2090.0000     865.0000
 84    2020.0000     859.0000
 85    2090.0000     848.0000
 86    2140.0000     839.0000
 87    2040.0000     830.0000
 88    2160.0000     824.0000
 89    2320.0000     824.5000
 90    2225.0000     831.0000
 91    2310.0000     839.0000
 92    2250.0000     848.0000
 93    2200.0000     859.0000
 94    2250.0000     865.0000
 95    2330.0000     871.0000
 96    2515.0000     871.0000
 97    2430.0000     865.0000
 98    2380.0000     859.0000
 99    2420.0000     848.0000
100    2470.0000     839.0000
101    2400.0000     832.5000
102    2490.0000     824.5000
103    2560.0000     834.0000
104    2650.0000     825.0000
105    2610.0000     839.0000
106    2580.0000     848.0000
107    2540.0000     859.0000
108    2610.0000     865.0000
109    2695.0000     871.0000
110    2800.0000     871.0000
111    2730.0000     865.0000
```

```
113    2710.0000     848.0000
114    2810.0000     859.0000
115    2880.0000     848.0000
116    2730.0000     835.0000
117    2810.0000     825.0000
118    2990.0000     827.0000
119    2900.0000     835.0000
120    3030.0000     848.0000
121    2990.0000     859.0000
122    2890.0000     865.0000
123    2970.0000     871.0000
124    3105.0000     871.0000
125    3030.0000     865.0000
126    3200.0000     865.0000
127    3280.0000     871.5000
128    3120.0000     859.0000
129    3200.0000     848.0000
130    3060.0000     835.5000
131    3115.0000     829.5000
132    3295.0000     831.0000
133    3210.0000     839.0000
134    3310.0000     848.0000
135    3290.0000     859.0000
136    3350.0000     865.0000
137    3410.0000     871.5000
138    3520.0000     871.5000
139    3450.0000     865.0000
140    3400.0000     859.0000
141    3500.0000     859.0000
142    3420.0000     848.0000
143    3370.0000     841.5000
144    3450.0000     834.5000
145    3615.0000     836.0000
146    3540.0000     844.0000
147    3600.0000     852.5000
148    3650.0000     859.0000
149    3560.0000     865.0000
150    3610.0000     871.5000
151    3750.0000     871.5000
152    3700.0000     865.0000
153    3900.0000     871.5000
154    3840.0000     865.0000
155    3800.0000     859.0000
156    3760.0000     852.5000
157    3700.0000     845.0000
158    3790.0000     835.5000
159    3980.0000     835.0000
160    3840.0000     844.0000
161    3910.0000     852.5000
162    3970.0000     859.0000
163    4010.0000     865.0000
164    4080.0000     871.5000
165    4020.0000     842.0000
166    4100.0000     852.5000
167    4170.0000     859.0000
168    4270.0000     871.5000
169    4210.0000     865.0000
170    4120.0000     834.5000
171    4210.0000     843.0000
172    4290.0000     852.5000
173    4330.0000     859.0000
174    4390.0000     865.0000
175    4440.0000     871.5000
176    4290.0000     834.5000
177    4380.0000     845.0000
```

```
179    4500.0000     859.0000
180    4550.0000     865.0000
181    4600.0000     872.0000
182    4770.0000     872.0000
183    4700.0000     865.0000
184    4640.0000     859.0000
185    4600.0000     852.5000
186    4550.0000     846.0000
187    4440.0000     834.5000
188    4580.0000     833.0000
189    4610.0000     840.0000
190    4670.0000     832.0000
191    4720.0000     840.0000
192    4690.0000     846.5000
193    4790.0000     847.5000
194    4790.0000     859.0000
195    4880.0000     859.0000
196    4820.0000     865.0000
197    4920.0000     865.0000
198    4890.0000     872.5000
199    4990.0000     872.5000
200    5150.0000     873.0000
201    5100.0000     865.0000
202    5030.0000     859.0000
203    4980.0000     850.0000
204    4890.0000     840.0000
205    4810.0000     831.0000
206    4980.0000     830.0000
207    5030.0000     840.0000
208    5120.0000     830.0000
209    5200.0000     840.0000
210    5290.0000     830.0000
211    5350.0000     840.0000
212    5280.0000     849.5000
213    5180.0000     849.5000
214    5150.0000     855.0000
215    5190.0000     859.0000
216    5240.0000     865.0000
217    5300.0000     874.0000
218    5480.0000     875.0000
219    5400.0000     865.0000
220    5350.0000     858.5000
221    5400.0000     849.5000
222    5470.0000     830.0000
223    5500.0000     840.0000
224    5540.0000     849.5000
225    5460.0000     860.0000
226    5600.0000     859.0000
227    5610.0000     864.0000
228    5490.0000     865.0000
229    5560.0000     875.5000
230    5680.0000     877.5000
231    5830.0000     878.5000
232    6000.0000     880.0000
233    5800.0000     867.5000
234    5760.0000     859.0000
235    5710.0000     849.5000
236    5680.0000     840.0000
237    5630.0000     830.5000
238    5800.0000     831.5000
239    5820.0000     840.0000
240    5870.0000     849.5000
241    5900.0000     859.0000
242    5950.0000     870.0000
243    6120.0000     881.5000
```

```
245    6090.0000    870.0000
246    6040.0000    859.0000
247    6010.0000    849.5000
248    5980.0000    840.0000
249    5950.0000    832.5000
250    6050.0000    834.0000
251    6050.0000    840.5000
252    6170.0000    834.5000
253    6100.0000    849.5000
254    6205.0000    849.5000
255    6130.0000    859.0000
256    6230.0000    859.0000
257    6290.0000    870.0000
258    6180.0000    870.0000
259    6190.0000    874.5000
260    6210.0000    883.0000
261    6340.0000    885.0000
262    6305.0000    876.0000
263    6460.0000    886.0000
264    6440.0000    880.0000
265    6410.0000    870.0000
266    6380.0000    859.0000
267    6340.0000    849.5000
268    6300.0000    836.0000
269    6480.0000    837.5000
270    6510.0000    849.5000
271    6540.0000    859.0000
272    6580.0000    870.0000
273    6600.0000    882.0000
274    6620.0000    888.0000
275    6780.0000    889.0000
276    6770.0000    885.0000
277    6760.0000    882.0000
278    6710.0000    870.0000
279    6690.0000    859.0000
280    6670.0000    849.5000
281    6620.0000    839.0000
282    6770.0000    840.0000
283    6790.0000    849.5000
284    6810.0000    859.0000
285    6840.0000    870.0000
286    6880.0000    882.0000
287    6900.0000    888.0000
288    6900.0000    890.5000
289    7000.0000    892.5000
290    6990.0000    882.0000
291    6960.0000    870.0000
292    6920.0000    859.0000
293    6905.0000    849.5000
294    6890.0000    841.0000
295    7005.0000    842.0000
296    7110.0000    849.5000
297    7090.0000    859.0000
298    7050.0000    870.0000
299    7020.0000    882.0000
300    7120.0000    895.0000
301    7280.0000    900.0000
302    7260.0000    895.0000
303    7220.0000    882.0000
304    7200.0000    870.0000
305    7180.0000    859.0000
306    7150.0000    849.5000
307    7140.0000    842.5000
308    7280.0000    842.5000
309    7280.0000    849.5000
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```
 311    7320.0000     870.0000
 312    7360.0000     882.0000
 313    7390.0000     895.0000
 314    7410.0000     903.0000
 315    7530.0000     903.0000
 316    7510.0000     895.0000
 317    7490.0000     882.0000
 318    7450.0000     870.0000
 319    7420.0000     859.0000
 320    7400.0000     849.5000
 321    7390.0000     842.5000
 322    7510.0000     842.5000
 323    7520.0000     849.5000
 324    7550.0000     859.0000
 325    7580.0000     870.0000
 326    7600.0000     882.0000
 327    7620.0000     895.0000
 328    7650.0000     902.0000
 329    7770.0000     901.0000
 330    7740.0000     895.0000
 331    7710.0000     882.0000
 332    7690.0000     870.0000
 333    7660.0000     859.0000
 334    7630.0000     849.5000
 335    7610.0000     843.0000
 336    7710.0000     843.0000
 337    7740.0000     849.5000
 338    7780.0000     859.0000
 339    7800.0000     870.0000
 340    7830.0000     882.0000
 341    7880.0000     895.0000
 342    7890.0000     900.5000
 343    7925.0000     900.5000
 344    7925.0000     895.0000
 345    7925.0000     882.0000
 346    7925.0000     870.0000
 347    7890.0000     859.0000
 348    7925.0000     860.0000
 349    7925.0000     850.0000
 350    7925.0000     843.0000
 351    7830.0000     843.0000
 352    7870.0000     849.5000


ELEMENT INCIDENCE TABLE

ELEMENT       NODE 1      NODE 2   NODE 3      KX         KY       SLOPE


       1         51          53        52     1.000      1.000      0.0
       2         50          53        51     1.000      1.000      0.0
       3         50          54        53     1.000      1.000      0.0
       4         49          54        50     1.000      1.000      0.0
       5         48          54        49     1.000      1.000      0.0
       6         43          48        49     1.000      1.000      0.0
       7         43          47        48     1.000      1.000      0.0
       8         36          47        43     1.000      1.000      0.0
       9         36          44        47     1.000      1.000      0.0
      10         34          44        36     1.000      1.000      0.0
      11         41          50        51     1.000      1.000      0.0
      12         41          42        50     1.000      1.000      0.0
      13         40          42        41     1.000      1.000      0.0
      14         39          42        40     1.000      1.000      0.0
      15         42          49        50     1.000      1.000      0.0
      16         38          49        42     1.000      1.000      0.0
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   18       37       43       38     1.000     1.000     0.0
   19       36       43       37     1.000     1.000     0.0
   20       33       36       37     1.000     1.000     0.0
   21       33       34       36     1.000     1.000     0.0
   22       23       34       33     1.000     1.000     0.0
   23       38       42       39     1.000     1.000     0.0
   24       31       38       42     1.000     1.000     0.0
   25       31       37       38     1.000     1.000     0.0
   26       31       32       37     1.000     1.000     0.0
   27       18       19       27     1.000     1.000     0.0
   28       18       27       28     1.000     1.000     0.0
   29        5       11        7     1.000     1.000     0.0
   30        7       11       14     1.000     1.000     0.0
   31        7       14       15     1.000     1.000     0.0
   32       14       25       15     1.000     1.000     0.0
   33       15       25       20     1.000     1.000     0.0
   34       20       25       26     1.000     1.000     0.0
   35       20       26       27     1.000     1.000     0.0
   36       26       29       27     1.000     1.000     0.0
   37       27       29       28     1.000     1.000     0.0
   38       28       29       30     1.000     1.000     0.0
   39       11       13       14     1.000     1.000     0.0
   40       13       22       14     1.000     1.000     0.0
   41       14       22       25     1.000     1.000     0.0
   42       22       32       25     1.000     1.000     0.0
   43       25       32       26     1.000     1.000     0.0
   44       26       32       31     1.000     1.000     0.0
   45       26       31       29     1.000     1.000     0.0
   46       29       31       39     1.000     1.000     0.0
   47       29       39       30     1.000     1.000     0.0
   48       30       39       40     1.000     1.000     0.0
   49       13       23       22     1.000     1.000     0.0
   50       22       23       33     1.000     1.000     0.0
   51       22       33       32     1.000     1.000     0.0
   52       32       33       37     1.000     1.000     0.0
   53       19       20       27     1.000     1.000     0.0
   54       16       20       19     1.000     1.000     0.0
   55       15       20       16     1.000     1.000     0.0
   56        6       15       16     1.000     1.000     0.0
   57        6        7       15     1.000     1.000     0.0
   58        3        7        6     1.000     1.000     0.0
   59        3        5        7     1.000     1.000     0.0
   60        3        4        5     1.000     1.000     0.0
   61       17       19       18     1.000     1.000     0.0
   62       16       19       17     1.000     1.000     0.0
   63        8       16       17     1.000     1.000     0.0
   64        6       16        8     1.000     1.000     0.0
   65        2        6        8     1.000     1.000     0.0
   66        2        3        6     1.000     1.000     0.0
   67        1        3        2     1.000     1.000     0.0
   68        1        4        3     1.000     1.000     0.0
   69      287      289      288     1.000     1.000     0.0
   70      275      287      288     1.000     1.000     0.0
   71      275      276      287     1.000     1.000     0.0
   72      274      276      275     1.000     1.000     0.0
   73      273      276      274     1.000     1.000     0.0
   74      263      273      274     1.000     1.000     0.0
   75      263      264      273     1.000     1.000     0.0
   76      261      264      263     1.000     1.000     0.0
   77      261      262      264     1.000     1.000     0.0
   78      259      262      260     1.000     1.000     0.0
   79      243      259      260     1.000     1.000     0.0
   80      260      262      261     1.000     1.000     0.0
   81      232      244      243     1.000     1.000     0.0
   82      232      242      244     1.000     1.000     0.0
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  84     231     233     242     1.000     1.000     0.0
  85     230     233     231     1.000     1.000     0.0
  86     227     233     230     1.000     1.000     0.0
  87     227     230     229     1.000     1.000     0.0
  88     227     229     228     1.000     1.000     0.0
  89     225     227     228     1.000     1.000     0.0
  90     218     228     229     1.000     1.000     0.0
  91     218     219     228     1.000     1.000     0.0
  92     219     225     228     1.000     1.000     0.0
  93     219     220     225     1.000     1.000     0.0
  94     217     219     218     1.000     1.000     0.0
  95     216     219     217     1.000     1.000     0.0
  96     216     220     219     1.000     1.000     0.0
  97     214     220     216     1.000     1.000     0.0
  98     200     216     217     1.000     1.000     0.0
  99     200     201     216     1.000     1.000     0.0
 100     199     201     200     1.000     1.000     0.0
 101     197     201     199     1.000     1.000     0.0
 102     197     199     198     1.000     1.000     0.0
 103     196     197     198     1.000     1.000     0.0
 104     182     196     198     1.000     1.000     0.0
 105     182     183     196     1.000     1.000     0.0
 106     181     183     182     1.000     1.000     0.0
 107     180     183     181     1.000     1.000     0.0
 108     175     180     181     1.000     1.000     0.0
 109     174     180     175     1.000     1.000     0.0
 110     201     215     216     1.000     1.000     0.0
 111     201     202     215     1.000     1.000     0.0
 112     202     214     215     1.000     1.000     0.0
 113     202     203     214     1.000     1.000     0.0
 114     193     203     195     1.000     1.000     0.0
 115     195     203     202     1.000     1.000     0.0
 116     195     202     197     1.000     1.000     0.0
 117     197     202     201     1.000     1.000     0.0
 118     195     197     196     1.000     1.000     0.0
 119     194     195     196     1.000     1.000     0.0
 120     193     195     194     1.000     1.000     0.0
 121     192     193     194     1.000     1.000     0.0
 122     184     186     192     1.000     1.000     0.0
 123     184     192     194     1.000     1.000     0.0
 124     183     184     194     1.000     1.000     0.0
 125     183     194     196     1.000     1.000     0.0
 126     177     186     178     1.000     1.000     0.0
 127     178     186     185     1.000     1.000     0.0
 128     178     185     179     1.000     1.000     0.0
 129     179     185     184     1.000     1.000     0.0
 130     179     184     180     1.000     1.000     0.0
 131     180     184     183     1.000     1.000     0.0
 132     171     177     172     1.000     1.000     0.0
 133     172     177     178     1.000     1.000     0.0
 134     172     178     173     1.000     1.000     0.0
 135     173     178     179     1.000     1.000     0.0
 136     173     179     174     1.000     1.000     0.0
 137     174     179     180     1.000     1.000     0.0
 138     168     174     175     1.000     1.000     0.0
 139     168     169     174     1.000     1.000     0.0
 140     164     169     168     1.000     1.000     0.0
 141     163     169     164     1.000     1.000     0.0
 142     153     163     164     1.000     1.000     0.0
 143     153     154     163     1.000     1.000     0.0
 144     169     173     174     1.000     1.000     0.0
 145     167     173     169     1.000     1.000     0.0
 146     167     172     173     1.000     1.000     0.0
 147     166     172     167     1.000     1.000     0.0
 148     166     171     172     1.000     1.000     0.0
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  150       163       167       169     1.000      1.000      0.0
  151       162       167       163     1.000      1.000      0.0
  152       162       166       167     1.000      1.000      0.0
  153       161       166       162     1.000      1.000      0.0
  154       161       165       166     1.000      1.000      0.0
  155       160       165       161     1.000      1.000      0.0
  156       154       162       163     1.000      1.000      0.0
  157       154       155       162     1.000      1.000      0.0
  158       155       161       162     1.000      1.000      0.0
  159       155       156       161     1.000      1.000      0.0
  160       156       160       161     1.000      1.000      0.0
  161       156       157       160     1.000      1.000      0.0
  162       146       157       147     1.000      1.000      0.0
  163       147       157       156     1.000      1.000      0.0
  164       147       156       148     1.000      1.000      0.0
  165       148       156       155     1.000      1.000      0.0
  166       148       155       152     1.000      1.000      0.0
  167       152       155       154     1.000      1.000      0.0
  168       151       152       154     1.000      1.000      0.0
  169       151       154       153     1.000      1.000      0.0
  170       150       152       151     1.000      1.000      0.0
  171       149       152       150     1.000      1.000      0.0
  172       148       152       149     1.000      1.000      0.0
  173       141       148       149     1.000      1.000      0.0
  174       141       147       148     1.000      1.000      0.0
  175       142       146       147     1.000      1.000      0.0
  176       141       142       147     1.000      1.000      0.0
  177       142       143       146     1.000      1.000      0.0
  178       133       143       134     1.000      1.000      0.0
  179       134       143       142     1.000      1.000      0.0
  180       134       142       140     1.000      1.000      0.0
  181       140       142       141     1.000      1.000      0.0
  182       139       140       141     1.000      1.000      0.0
  183       139       141       149     1.000      1.000      0.0
  184       138       139       149     1.000      1.000      0.0
  185       138       149       150     1.000      1.000      0.0
  186       137       139       138     1.000      1.000      0.0
  187       136       139       137     1.000      1.000      0.0
  188       135       140       136     1.000      1.000      0.0
  189       136       140       139     1.000      1.000      0.0
  190       134       140       135     1.000      1.000      0.0
  191       129       134       135     1.000      1.000      0.0
  192       129       133       134     1.000      1.000      0.0
  193       129       130       133     1.000      1.000      0.0
  194       119       130       120     1.000      1.000      0.0
  195       120       130       129     1.000      1.000      0.0
  196       120       129       128     1.000      1.000      0.0
  197       128       129       135     1.000      1.000      0.0
  198       126       128       135     1.000      1.000      0.0
  199       126       135       136     1.000      1.000      0.0
  200       126       136       127     1.000      1.000      0.0
  201       127       136       137     1.000      1.000      0.0
  202       124       126       127     1.000      1.000      0.0
  203       124       125       126     1.000      1.000      0.0
  204       125       128       126     1.000      1.000      0.0
  205       121       128       125     1.000      1.000      0.0
  206       120       128       121     1.000      1.000      0.0
  207       115       120       121     1.000      1.000      0.0
  208       115       119       120     1.000      1.000      0.0
  209       115       116       119     1.000      1.000      0.0
  210       103       116       113     1.000      1.000      0.0
  211       113       116       115     1.000      1.000      0.0
  212       113       115       114     1.000      1.000      0.0
  213       114       115       121     1.000      1.000      0.0
  214       114       121       122     1.000      1.000      0.0
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  216      122      125      123      1.000      1.000      0.0
  217      123      125      124      1.000      1.000      0.0
  218      110      122      123      1.000      1.000      0.0
  219      110      111      122      1.000      1.000      0.0
  220      109      111      110      1.000      1.000      0.0
  221      108      111      109      1.000      1.000      0.0
  222      111      114      122      1.000      1.000      0.0
  223      111      112      114      1.000      1.000      0.0
  224      108      112      111      1.000      1.000      0.0
  225      112      113      114      1.000      1.000      0.0
  226      106      113      112      1.000      1.000      0.0
  227      105      113      106      1.000      1.000      0.0
  228      107      112      108      1.000      1.000      0.0
  229      106      112      107      1.000      1.000      0.0
  230       99      106      107      1.000      1.000      0.0
  231       99      100      106      1.000      1.000      0.0
  232      100      105      106      1.000      1.000      0.0
  233      100      103      105      1.000      1.000      0.0
  234      100      101      103      1.000      1.000      0.0
  235       90      101       91      1.000      1.000      0.0
  236       91      101      100      1.000      1.000      0.0
  237       91      100       99      1.000      1.000      0.0
  238       96      108      109      1.000      1.000      0.0
  239       96       97      108      1.000      1.000      0.0
  240       97      107      108      1.000      1.000      0.0
  241       97       98      107      1.000      1.000      0.0
  242       98       99      107      1.000      1.000      0.0
  243       92       99       98      1.000      1.000      0.0
  244       91       99       92      1.000      1.000      0.0
  245       86       91       92      1.000      1.000      0.0
  246       86       90       91      1.000      1.000      0.0
  247       86       87       90      1.000      1.000      0.0
  248       95       97       96      1.000      1.000      0.0
  249       94       97       95      1.000      1.000      0.0
  250       82       94       95      1.000      1.000      0.0
  251       82       83       94      1.000      1.000      0.0
  252       83       93       94      1.000      1.000      0.0
  253       93       98       94      1.000      1.000      0.0
  254       94       98       97      1.000      1.000      0.0
  255       92       98       93      1.000      1.000      0.0
  256       85       92       93      1.000      1.000      0.0
  257       85       86       92      1.000      1.000      0.0
  258       77       86       85      1.000      1.000      0.0
  259       77       87       86      1.000      1.000      0.0
  260       75       87       77      1.000      1.000      0.0
  261       83       84       93      1.000      1.000      0.0
  262       84       85       93      1.000      1.000      0.0
  263       78       85       84      1.000      1.000      0.0
  264       77       85       78      1.000      1.000      0.0
  265       72       77       78      1.000      1.000      0.0
  266       72       75       77      1.000      1.000      0.0
  267       72       73       75      1.000      1.000      0.0
  268       81       83       82      1.000      1.000      0.0
  269       80       83       81      1.000      1.000      0.0
  270       68       80       81      1.000      1.000      0.0
  271       68       69       80      1.000      1.000      0.0
  272       80       84       83      1.000      1.000      0.0
  273       79       84       80      1.000      1.000      0.0
  274       78       84       79      1.000      1.000      0.0
  275       71       78       79      1.000      1.000      0.0
  276       71       72       78      1.000      1.000      0.0
  277       63       72       71      1.000      1.000      0.0
  278       63       73       72      1.000      1.000      0.0
  279       61       73       63      1.000      1.000      0.0
  280       69       79       80      1.000      1.000      0.0
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 282      70      71      79     1.000     1.000     0.0
 283      64      71      70     1.000     1.000     0.0
 284      63      71      64     1.000     1.000     0.0
 285      62      63      64     1.000     1.000     0.0
 286      61      63      62     1.000     1.000     0.0
 287      57      61      62     1.000     1.000     0.0
 288      67      69      68     1.000     1.000     0.0
 289      66      69      67     1.000     1.000     0.0
 290      66      70      69     1.000     1.000     0.0
 291      65      70      66     1.000     1.000     0.0
 292      64      70      65     1.000     1.000     0.0
 293      55      64      65     1.000     1.000     0.0
 294      55      62      64     1.000     1.000     0.0
 295      55      56      62     1.000     1.000     0.0
 296      56      57      62     1.000     1.000     0.0
 297      46      57      56     1.000     1.000     0.0
 298      52      66      67     1.000     1.000     0.0
 299      52      53      66     1.000     1.000     0.0
 300      53      65      66     1.000     1.000     0.0
 301      53      54      65     1.000     1.000     0.0
 302      54      55      65     1.000     1.000     0.0
 303      48      55      54     1.000     1.000     0.0
 304      48      56      55     1.000     1.000     0.0
 305      47      56      48     1.000     1.000     0.0
 306      46      56      47     1.000     1.000     0.0
 307      44      46      47     1.000     1.000     0.0
 308       4       9       5     1.000     1.000     0.0
 309       5       9      10     1.000     1.000     0.0
 310       5      10      11     1.000     1.000     0.0
 311      10      12      11     1.000     1.000     0.0
 312      12      21      13     1.000     1.000     0.0
 313      11      12      13     1.000     1.000     0.0
 314      13      21      23     1.000     1.000     0.0
 315      21      24      23     1.000     1.000     0.0
 316      23      24      34     1.000     1.000     0.0
 317      24      35      34     1.000     1.000     0.0
 318      34      35      44     1.000     1.000     0.0
 319      35      45      44     1.000     1.000     0.0
 320      44      45      46     1.000     1.000     0.0
 321      45      58      46     1.000     1.000     0.0
 322      46      58      57     1.000     1.000     0.0
 323      57      58      59     1.000     1.000     0.0
 324      57      59      61     1.000     1.000     0.0
 325      59      60      61     1.000     1.000     0.0
 326      60      73      61     1.000     1.000     0.0
 327      60      74      73     1.000     1.000     0.0
 328      73      74      75     1.000     1.000     0.0
 329      74      76      75     1.000     1.000     0.0
 330      75      76      87     1.000     1.000     0.0
 331      76      88      87     1.000     1.000     0.0
 332      87      88      90     1.000     1.000     0.0
 333      88      89      90     1.000     1.000     0.0
 334      89     101      90     1.000     1.000     0.0
 335      89     102     101     1.000     1.000     0.0
 336     101     102     103     1.000     1.000     0.0
 337     102     104     103     1.000     1.000     0.0
 338     103     104     116     1.000     1.000     0.0
 339     104     117     116     1.000     1.000     0.0
 340     116     117     119     1.000     1.000     0.0
 341     117     118     119     1.000     1.000     0.0
 342     118     130     119     1.000     1.000     0.0
 343     118     131     130     1.000     1.000     0.0
 344     130     131     133     1.000     1.000     0.0
 345     131     132     133     1.000     1.000     0.0
 346     132     143     133     1.000     1.000     0.0
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  348      143      144      146      1.000      1.000      0.0
  349      144      145      146      1.000      1.000      0.0
  350      145      157      146      1.000      1.000      0.0
  351      145      158      157      1.000      1.000      0.0
  352      157      158      160      1.000      1.000      0.0
  353      158      159      160      1.000      1.000      0.0
  354      159      165      160      1.000      1.000      0.0
  355      159      170      165      1.000      1.000      0.0
  356      165      170      171      1.000      1.000      0.0
  357      170      176      171      1.000      1.000      0.0
  358      171      176      177      1.000      1.000      0.0
  359      176      177      187      1.000      1.000      0.0
  360      177      187      186      1.000      1.000      0.0
  361      186      187      189      1.000      1.000      0.0
  362      187      188      189      1.000      1.000      0.0
  363      188      190      189      1.000      1.000      0.0
  364      189      190      191      1.000      1.000      0.0
  365      186      189      192      1.000      1.000      0.0
  366      189      191      192      1.000      1.000      0.0
  367      190      205      191      1.000      1.000      0.0
  368      191      205      204      1.000      1.000      0.0
  369      191      204      193      1.000      1.000      0.0
  370      204      205      206      1.000      1.000      0.0
  371      204      206      207      1.000      1.000      0.0
  372      193      204      203      1.000      1.000      0.0
  373      203      204      207      1.000      1.000      0.0
  374      203      207      214      1.000      1.000      0.0
  375      206      208      207      1.000      1.000      0.0
  376      207      208      209      1.000      1.000      0.0
  377      207      209      214      1.000      1.000      0.0
  378      208      210      209      1.000      1.000      0.0
  379      209      210      211      1.000      1.000      0.0
  380      210      222      211      1.000      1.000      0.0
  381      211      222      223      1.000      1.000      0.0
  382      222      237      223      1.000      1.000      0.0
  383      223      237      236      1.000      1.000      0.0
  384      236      237      238      1.000      1.000      0.0
  385      236      238      239      1.000      1.000      0.0
  386      238      249      239      1.000      1.000      0.0
  387      239      249      248      1.000      1.000      0.0
  388      248      249      250      1.000      1.000      0.0
  389      248      250      251      1.000      1.000      0.0
  390      209      212      213      1.000      1.000      0.0
  391      212      220      213      1.000      1.000      0.0
  392      213      220      214      1.000      1.000      0.0
  393      209      211      212      1.000      1.000      0.0
  394      211      221      212      1.000      1.000      0.0
  395      211      223      221      1.000      1.000      0.0
  396      221      223      224      1.000      1.000      0.0
  397      223      236      224      1.000      1.000      0.0
  398      224      236      235      1.000      1.000      0.0
  399      235      236      239      1.000      1.000      0.0
  400      235      239      240      1.000      1.000      0.0
  401      239      248      240      1.000      1.000      0.0
  402      240      248      247      1.000      1.000      0.0
  403      247      248      251      1.000      1.000      0.0
  404      247      251      253      1.000      1.000      0.0
  405      250      252      253      1.000      1.000      0.0
  406      252      254      253      1.000      1.000      0.0
  407      252      268      254      1.000      1.000      0.0
  408      254      268      267      1.000      1.000      0.0
  409      267      268      269      1.000      1.000      0.0
  410      267      269      270      1.000      1.000      0.0
  411      269      281      270      1.000      1.000      0.0
  412      270      281      280      1.000      1.000      0.0
```

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  414       280       282       283     1.000     1.000     0.0
  415       282       294       283     1.000     1.000     0.0
  416       283       294       293     1.000     1.000     0.0
  417       293       294       295     1.000     1.000     0.0
  418       293       295       296     1.000     1.000     0.0
  419       295       307       296     1.000     1.000     0.0
  420       296       307       306     1.000     1.000     0.0
  421       306       307       308     1.000     1.000     0.0
  422       306       308       309     1.000     1.000     0.0
  423       309       321       320     1.000     1.000     0.0
  424       308       321       309     1.000     1.000     0.0
  425       320       321       322     1.000     1.000     0.0
  426       320       322       323     1.000     1.000     0.0
  427       322       335       323     1.000     1.000     0.0
  428       323       335       334     1.000     1.000     0.0
  429       334       335       336     1.000     1.000     0.0
  430       334       336       337     1.000     1.000     0.0
  431       336       351       337     1.000     1.000     0.0
  432       337       351       352     1.000     1.000     0.0
  433       350       352       351     1.000     1.000     0.0
  434       349       352       350     1.000     1.000     0.0
  435       347       352       349     1.000     1.000     0.0
  436       347       349       348     1.000     1.000     0.0
  437       338       352       347     1.000     1.000     0.0
  438       337       352       338     1.000     1.000     0.0
  439       323       337       338     1.000     1.000     0.0
  440       333       334       337     1.000     1.000     0.0
  441       324       334       333     1.000     1.000     0.0
  442       323       334       324     1.000     1.000     0.0
  443       319       323       324     1.000     1.000     0.0
  444       319       320       323     1.000     1.000     0.0
  445       310       320       319     1.000     1.000     0.0
  446       309       320       310     1.000     1.000     0.0
  447       305       309       310     1.000     1.000     0.0
  448       305       306       309     1.000     1.000     0.0
  449       297       306       305     1.000     1.000     0.0
  450       296       306       297     1.000     1.000     0.0
  451       292       296       297     1.000     1.000     0.0
  452       292       293       296     1.000     1.000     0.0
  453       284       293       292     1.000     1.000     0.0
  454       283       293       284     1.000     1.000     0.0
  455       279       283       284     1.000     1.000     0.0
  456       279       280       283     1.000     1.000     0.0
  457       271       280       279     1.000     1.000     0.0
  458       270       280       271     1.000     1.000     0.0
  459       266       270       271     1.000     1.000     0.0
  460       266       267       270     1.000     1.000     0.0
  461       256       267       266     1.000     1.000     0.0
  462       254       267       256     1.000     1.000     0.0
  463       254       256       255     1.000     1.000     0.0
  464       253       254       255     1.000     1.000     0.0
  465       246       253       255     1.000     1.000     0.0
  466       246       247       253     1.000     1.000     0.0
  467       241       247       246     1.000     1.000     0.0
  468       212       221       220     1.000     1.000     0.0
  469       220       221       225     1.000     1.000     0.0
  470       221       224       225     1.000     1.000     0.0
  471       224       227       225     1.000     1.000     0.0
  472       224       235       226     1.000     1.000     0.0
  473       226       234       227     1.000     1.000     0.0
  474       226       235       234     1.000     1.000     0.0
  475       227       234       233     1.000     1.000     0.0
  476       234       235       240     1.000     1.000     0.0
  477       234       240       241     1.000     1.000     0.0
  478       240       247       241     1.000     1.000     0.0
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 480     233     241     242     1.000     1.000     0.0
 481     241     246     242     1.000     1.000     0.0
 482     242     246     245     1.000     1.000     0.0
 483     242     245     244     1.000     1.000     0.0
 484     245     246     255     1.000     1.000     0.0
 485     245     255     258     1.000     1.000     0.0
 486     244     245     258     1.000     1.000     0.0
 487     244     258     259     1.000     1.000     0.0
 488     255     256     258     1.000     1.000     0.0
 489     256     257     258     1.000     1.000     0.0
 490     257     259     258     1.000     1.000     0.0
 491     256     266     257     1.000     1.000     0.0
 492     257     266     265     1.000     1.000     0.0
 493     257     265     262     1.000     1.000     0.0
 494     257     262     259     1.000     1.000     0.0
 495     262     265     264     1.000     1.000     0.0
 496     264     265     272     1.000     1.000     0.0
 497     265     271     272     1.000     1.000     0.0
 498     265     266     271     1.000     1.000     0.0
 499     264     272     273     1.000     1.000     0.0
 500     271     279     272     1.000     1.000     0.0
 501     272     279     278     1.000     1.000     0.0
 502     272     278     273     1.000     1.000     0.0
 503     273     278     277     1.000     1.000     0.0
 504     273     277     276     1.000     1.000     0.0
 505     278     279     284     1.000     1.000     0.0
 506     277     278     285     1.000     1.000     0.0
 507     276     277     286     1.000     1.000     0.0
 508     276     286     287     1.000     1.000     0.0
 509     284     292     285     1.000     1.000     0.0
 510     285     291     286     1.000     1.000     0.0
 511     285     292     291     1.000     1.000     0.0
 512     286     291     290     1.000     1.000     0.0
 513     286     290     287     1.000     1.000     0.0
 514     287     290     289     1.000     1.000     0.0
 515     289     299     300     1.000     1.000     0.0
 516     289     290     299     1.000     1.000     0.0
 517     290     298     299     1.000     1.000     0.0
 518     290     291     298     1.000     1.000     0.0
 519     291     297     298     1.000     1.000     0.0
 520     291     292     297     1.000     1.000     0.0
 521     297     305     298     1.000     1.000     0.0
 522     298     305     304     1.000     1.000     0.0
 523     298     304     299     1.000     1.000     0.0
 524     299     304     303     1.000     1.000     0.0
 525     299     303     300     1.000     1.000     0.0
 526     300     303     302     1.000     1.000     0.0
 527     300     302     301     1.000     1.000     0.0
 528     304     305     310     1.000     1.000     0.0
 529     304     310     311     1.000     1.000     0.0
 530     303     304     311     1.000     1.000     0.0
 531     303     311     312     1.000     1.000     0.0
 532     302     303     312     1.000     1.000     0.0
 533     302     312     313     1.000     1.000     0.0
 534     301     302     313     1.000     1.000     0.0
 535     301     313     314     1.000     1.000     0.0
 536     313     316     314     1.000     1.000     0.0
 537     314     316     315     1.000     1.000     0.0
 538     313     317     316     1.000     1.000     0.0
 539     312     317     313     1.000     1.000     0.0
 540     312     318     317     1.000     1.000     0.0
 541     311     318     312     1.000     1.000     0.0
 542     311     319     318     1.000     1.000     0.0
 543     310     319     311     1.000     1.000     0.0
 544     318     319     324     1.000     1.000     0.0
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     546        317        318        325        1.000        1.000        0.0
     547        317        325        326        1.000        1.000        0.0
     548        316        317        326        1.000        1.000        0.0
     549        316        326        327        1.000        1.000        0.0
     550        315        316        327        1.000        1.000        0.0
     551        315        327        328        1.000        1.000        0.0
     552        327        330        328        1.000        1.000        0.0
     553        328        330        329        1.000        1.000        0.0
     554        327        331        330        1.000        1.000        0.0
     555        326        331        327        1.000        1.000        0.0
     556        326        332        331        1.000        1.000        0.0
     557        325        332        326        1.000        1.000        0.0
     558        325        333        332        1.000        1.000        0.0
     559        324        333        325        1.000        1.000        0.0
     560        332        333        338        1.000        1.000        0.0
     561        332        338        339        1.000        1.000        0.0
     562        338        347        339        1.000        1.000        0.0
     563        339        347        346        1.000        1.000        0.0
     564        346        347        348        1.000        1.000        0.0
     565        331        332        339        1.000        1.000        0.0
     566        331        339        340        1.000        1.000        0.0
     567        330        331        340        1.000        1.000        0.0
     568        330        340        341        1.000        1.000        0.0
     569        329        330        341        1.000        1.000        0.0
     570        329        341        342        1.000        1.000        0.0
     571        341        344        342        1.000        1.000        0.0
     572        342        344        343        1.000        1.000        0.0
     573        341        345        344        1.000        1.000        0.0
     574        340        345        341        1.000        1.000        0.0
     575        340        346        345        1.000        1.000        0.0
     576        339        346        340        1.000        1.000        0.0


PRESCRIBED NODAL HEADS

NODE   PRESCRIBED HEAD


   1     839.0000
   2     849.0000
   8     860.0000
  17     865.0000
  18     868.0000
  28     869.0000
  30     869.0000
  40     869.0000
  41     869.0000
  51     869.5000
  52     870.0000
  67     870.0000
  68     870.5000
  81     870.5000
  82     870.5000
  95     871.0000
  96     871.0000
 109     871.0000
 110     871.0000
 123     871.0000
 124     871.0000
 127     871.5000
 137     871.5000
 138     871.5000
 150     871.5000
 151     871.5000
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 164     871.5000
 168     871.5000
 175     871.5000
 181     872.0000
 182     872.0000
 198     872.5000
 199     872.5000
 200     873.0000
 217     874.0000
 218     875.0000
 229     875.5000
 230     877.5000
 231     878.5000
 232     880.0000
 243     881.5000
 260     883.0000
 261     885.0000
 263     886.0000
 274     888.0000
 275     889.0000
 288     890.5000
 289     892.5000
 300     895.0000
 301     900.0000
 314     900.0000
 315     900.0000
 328     900.0000
 329     900.0000
 342     900.0000
 343     900.0000
```

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FINITE ELEMENT SEEPAGE PROGRAM BESWICK PINAWA

 RESULTS

 NODAL HEADS

 NODE  HEAD (FT)


   1     838.9998
   2     848.9995
   3     851.0352
   4     840.5310
   5     852.9375
   6     859.7358
   7     860.3801
   8     859.9998
   9     841.3079
  10     858.8625
  11     863.7202
  12     866.5659
  13     868.3914
  14     867.1941
  15     866.0562
  16     864.4456
  17     864.9998
  18     867.9995
  19     866.8091
  20     868.3201
  21     869.0432
  22     869.3037
  23     869.4353
  24     869.4233
  25     869.0679
  26     869.2236
  27     868.9602
  28     868.9995
  29     869.0750
  30     868.9995
  31     869.0200
  32     869.2710
  33     869.2639
  34     869.1909
  35     869.0786
  36     869.0361
  37     869.0376
  38     868.9929
  39     868.9902
  40     868.9995
  41     868.9995
  42     868.9946
  43     869.0417
  44     869.0420
  45     869.0916
  46     869.2551
  47     869.1563
  48     869.3413
  49     869.1831
  50     869.3196
  51     869.4998
  52     869.9998
  53     869.8462
  54     869.7170
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 56     869.5308
 57     869.7058
 58     869.4126
 59     869.7656
 60     870.0750
 61     870.0295
 62     869.9063
 63     870.1614
 64     870.0413
 65     869.9463
 66     869.9988
 67     869.9998
 68     870.4995
 69     870.3040
 70     870.1572
 71     870.2920
 72     870.3367
 73     870.2356
 74     870.2993
 75     870.3994
 76     870.4878
 77     870.5090
 78     870.4517
 79     870.4421
 80     870.5117
 81     870.4995
 82     870.4995
 83     870.5005
 84     870.4968
 85     870.5833
 86     870.6548
 87     870.5583
 88     870.6914
 89     870.8794
 90     870.7646
 91     870.8672
 92     870.7847
 93     870.6951
 94     870.7852
 95     870.9995
 96     870.9995
 97     871.0210
 98     870.9705
 99     870.9944
100     871.0188
101     870.9653
102     871.0281
103     871.0493
104     871.0432
105     871.0532
106     871.0454
107     871.0303
108     871.0117
109     870.9995
110     870.9995
111     871.0063
112     871.0171
113     871.0261
114     871.0063
115     870.9924
116     871.0256
117     871.0046
118     871.0098
119     870.9944
120     871.0132
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 122     870.9983
 123     870.9995
 124     870.9995
 125     870.9756
 126     871.2681
 127     871.4995
 128     871.1309
 129     871.2754
 130     871.0532
 131     871.1331
 132     871.4329
 133     871.2974
 134     871.4504
 135     871.4331
 136     871.5278
 137     871.4995
 138     871.4995
 139     871.5103
 140     871.5320
 141     871.5176
 142     871.5332
 143     871.5168
 144     871.5398
 145     871.5278
 146     871.5364
 147     871.5249
 148     871.5161
 149     871.5107
 150     871.4995
 151     871.4995
 152     871.5071
 153     871.4995
 154     871.5010
 155     871.5046
 156     871.5105
 157     871.5188
 158     871.5112
 159     871.5071
 160     871.5090
 161     871.5039
 162     871.5027
 163     871.5010
 164     871.4995
 165     871.5054
 166     871.5046
 167     871.4958
 168     871.4995
 169     871.4929
 170     871.4998
 171     871.5034
 172     871.4670
 173     871.4604
 174     871.4861
 175     871.4995
 176     871.5295
 177     871.4751
 178     871.5640
 179     871.7144
 180     871.8364
 181     871.9998
 182     871.9998
 183     872.0195
 184     871.9587
 185     871.9077
 186     871.8337
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188     871.8755
189     871.9155
190     871.9856
191     872.0564
192     872.0217
193     872.1685
194     872.1519
195     872.3447
196     872.1943
197     872.4441
198     872.4998
199     872.4998
200     872.9995
201     872.8330
202     872.6626
203     872.5347
204     872.3564
205     872.2092
206     872.5427
207     872.6833
208     873.0212
209     873.3674
210     873.8208
211     874.1924
212     873.8235
213     873.2786
214     873.1182
215     873.2734
216     873.5918
217     873.9998
218     874.9998
219     874.5342
220     874.2236
221     874.5020
222     875.0352
223     875.2996
224     875.6709
225     874.8840
226     876.3049
227     876.4055
228     875.1121
229     875.4995
230     877.4998
231     878.4995
232     879.9995
233     878.3367
234     877.9363
235     877.4390
236     877.1284
237     876.6292
238     878.2590
239     878.4426
240     878.8953
241     879.1448
242     879.5435
243     881.4998
244     881.2493
245     881.1284
246     880.5276
247     880.2063
248     879.9233
249     879.6379
250     880.6445
251     880.6619
252     882.4316
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254     882.9695
255     881.7590
256     883.3550
257     884.2439
258     882.5422
259     882.6936
260     882.9995
261     884.9995
262     884.4861
263     885.9998
264     885.8406
265     885.5637
266     885.2644
267     884.7783
268     884.2695
269     886.4675
270     886.7947
271     887.1038
272     887.5303
273     887.7773
274     887.9995
275     888.9998
276     888.9250
277     888.8469
278     888.5002
279     888.3616
280     888.2002
281     887.7898
282     888.9141
283     889.0950
284     889.2751
285     889.6211
286     890.2378
287     890.5105
288     890.4995
289     892.4995
290     892.2542
291     891.6790
292     890.8838
293     890.5889
294     890.3293
295     892.8464
296     895.2527
297     894.7258
298     893.6775
299     892.8164
300     894.9995
301     899.9995
302     899.4331
303     898.1677
304     897.6335
305     897.0952
306     896.3186
307     896.0415
308     899.1243
309     899.1262
310     899.3940
311     899.6335
312     900.0295
313     900.0815
314     899.9995
315     899.9995
316     900.0222
317     900.0776
318     900.1160
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 320     900.0002
 321     899.9568
 322     900.0916
 323     900.0952
 324     900.0906
 325     900.0640
 326     900.0359
 327     900.0142
 328     899.9995
 329     899.9995
 330     900.0042
 331     900.0176
 332     900.0315
 333     900.0486
 334     900.0645
 335     900.0708
 336     900.0457
 337     900.0422
 338     900.0352
 339     900.0293
 340     900.0168
 341     900.0071
 342     899.9995
 343     899.9995
 344     900.0000
 345     900.0056
 346     900.0110
 347     900.0232
 348     900.0151
 349     900.0181
 350     900.0205
 351     900.0374
 352     900.0332
```

```
    THIS PROGRAM CALCULATES TOTAL HEAD AT ALL NODES IN A REGION
    WHEN GIVEN HEADS AT SPECIFIED BOUNDARY NODES
    REAL NL(360),KX(576),KY(576)
    INTEGER ELEM(576)
    COMMON M,CJ(360,2),IE(576,3),L1,L2,L3,  T,ST(3),KL,KX,KY,S(576)
    COMMON JRD,JWT
    DIMENSION LIST(360),A(360), ISR(576),HDG(20)
    DIMENSION STORE(6000),NODE(360),      NEIN(360),NI(360,8)
    DIMENSION G(3,6),DISPL(6),STRESS(576)
    EQUIVALENCE (NE,NN)
    JRD=1
    JWT=3
    IPAGE=1
    LINE=0
    READ JOB TITLE
510 FORMAT(I4,19A4)
  1 READ(JRD,510)IDENT,    (HDG(I),I=1,19)
    IF(IDENT.EQ.0) GO TO 9999
564 FORMAT('1',100X,'PAGE ',I4)
    WRITE(JWT,564) IPAGE
    IPAGE=IPAGE+1
512 FORMAT('0',    'NO.',I5,1X,19A4)
    WRITE(JWT,512) IDENT,(HDG(I),I=1,19)
    WRITE(JWT,600)
600 FORMAT(/' TWO DIMENSIONAL SEEPAGE PROBLEM'//' INPUT DATA'//)
    READ NUMBER OF ELEMENTS, NUMBER NODES,NUMBER SPECIFIED NODAL
    HEADS, THICKNESS
    ALL INPUT PRINTED OUT FOR CHECKING PURPOSES
    READ(JRD,500) NEL,NE,NBD,T
500 FORMAT(3I5,F10.3)
    IF(T.EQ.0.) T=1.
    WRITE(JWT,601) NEL,NN,NBD,T
601 FORMAT(I4,'  ELEMENTS'I4,' NODES'I4,' SPECIFIED NODAL HEADS'//' EL
   1EMENT THICKNESS ='F8.3//)
    READ COORDINATES OF NODES
501 FORMAT(3(I5,2F10.3))
    READ(JRD,501)(NODE(J),(CJ(J,I),I=1,2),J=1,NN)
    LINE=5
    WRITE(JWT,564) IPAGE
    IPAGE=IPAGE+1
    WRITE(JWT,602)
6020FORMAT(1H0,'NODAL COORDINATES (FT) '//' NODE      X COORD      Y COO
   1RD'/)
    DO 99 J=1,NN
    WRITE(JWT,694)NODE(J),CJ(J,1),CJ(J,2)
    LINE=LINE+1
    IF(LINE.LT.60)GO TO 99
    WRITE(JWT,564) IPAGE
    IPAGE=IPAGE+1
    LINE=5
 99 CONTINUE
    LINE=4
    ZERO CONSTANT VECTOR
```

```
191 DO 39 J=1,360
 39 NL(J)=0.
    GENERATE NODAL INCIDENCE TABLE

    WRITE(JWT,564) IPAGE
    IPAGE=IPAGE+1
    WRITE(JWT,686)
6860FORMAT(1HO,' ELEMENT INCIDENCE TABLE '//'  ELEMENT   NODE 1   NODE
  1 2   NODE 3        KX     .    KY    SLOPE'/)
    SS=0.
    DO 17 M=1,NEL
505 FORMAT(I5,3I5,3F10.3)
    READ(JRD,505)ELEM(M),(IE(M,I),I=1,3),XK,YK,SL
    IF(XK.NE.C.)XX=XK
    IF(YK.NE.C.)YY=YK
    IF(SL.NE.C.) SS=SL
    S(M)=SS
    KX(M)=XX
    KY(M)=YY
    WRITE(JWT,687)ELEM(M),(IE(M,I),I=1,3),XX,YY,S(M)
687 FORMAT(4I9,3F10.3)
    LINE=LINE+1
    IF(LINE.LT.60) GO TO 2002
    WRITE(JWT,564) IPAGE
    IPAGE=IPAGE+1
    LINE=4
~~2002 IF(IE(M,1).EQ.IE(M,2)) GO TO 2000~~
    ~~IF(IE(M,1).EQ.IE(M,3)) GO TO 2000~~
    ~~IF(IE(M,2).EQ.IF(M,3)) GO TO 2000~~
    GO TO 17
~~2001 FORMAT('0','CHECK ELEMENT(',I3,') INCIDENCES')~~
~~2000 WRITE(JWT,2001) ELEM(M)~~
    ~~STOP 2000~~
 17 CONTINUE
    LINE = 5
    DO 18 J=1,360
    A(J)=0.0
    NEIN(J)=0
    DO 18 M=1,8
 18 NI(J,M)=0
    DO 19 M=1,NEL
    DO 19 K=1,3
    J=IE(M,K)
    NEIN(J)=NEIN(J)+1
    L=NEIN(J)
    NI(J,L)=M
 19 CONTINUE
694 FORMAT(I5,6F12.4)
    READ ANY PRESCRIBED NODAL HEADS
    DO 376 J=1,576
376 ISR(J)=0
    WRITE(JWT,564)IPAGE
    IPAGE = IPAGE + 1
```

elements checked
duplication of values (debug)

```
596 FORMAT('0','PRESCRIBED NODAL HEADS'//' NODE   PRES.HEAD'//)
    WRITE(JWT,596)
    DO 574 I=1,NBD
    READ(JRD,694)J, NL(J)
    ISR(J)=1
    WRITE(JWT,694)J, NL(J)
    LINE = LINE + 1
    IF(LINE.LT.60)GO TO 574
    WRITE (JWT,564)IPAGE
    WRITE (JWT,596)
    IPAGE = IPAGE + 1
574 CONTINUE
    LINE=11
    GENERATION AND ELIMINATION OF NODAL EQUILIBRIUM EQUATIONS
    GENERATE I TH  ROW OF STIFFNESS MATRIX AND STORE IN A TEMPORARILY
172 LIST(1)=1
    LINE=0
    DO 100 I=1,NE
    NON ZERO BAND OF ROW I IN STIFFNESS IS FROM KL TO KH. KL = LOWEST
     NODE NO FOR NODES INCIDENT ON ELEMENTS INCIDENT ON NODE I, KH = HIGHEST
    KL=I
    KH=I
    IM=NEIN(I)
    DO 5 J=1,IM
    M=NI(I,J)
    DO 5 K=1,3
    JF=IE(M,K)
    IF(JF-NE)10,10,5
 10 IF(JF-KH)14,14,12
 12 KH=JF
    GO TO 5
 14 IF(JF-KL)16,5,5
 16 KL=JF
  5 CONTINUE

    ZERO ALL A MATRICES IN NON - ZERO BAND
    K=KH-KL+1
    DO 29 J=1,K
 29 A(J)=0.
    INSERT STIFFNESS MATRICES INTO NON ZERO BAND
    DO 200 J=1,IM
    M=NI(I,J)
    DO 20 L=1,3
    IF(I-IE(M,L))20,22,20
 22 KI=IE(M,L)
    L1=L
    L2=L+1-3*(L/3)
    KJ=IE(M,L2)
    L3=L+2-3*(L/2)
    KK=IE(M,L3)
 20 CONTINUE
    CALL STIFF
    NNI, NJ AND NK ARE NODES I, J AND K FOR ELEMENT M - (POSITION IN ROW I
    RELATIVE TO KL = 1
```

```
      NNI=I-KL+1
      INSERT STIFFNESS MATRIX I
      A(NNI)=A(NNI)+ST(1)
      TEST WHETHER NODE NJ IS A FIXED SUPPORT
      IF(KJ-NE)47,47,6
      INSERT STIFFNESS MATRIX J
   47 NJ=KJ-KL+1
      A(NJ)=A(NJ)+ST(2)
      TEST WHETHER NODE NK IS FIXED SUPPORT
    6 IF(KK-NE)8,8,200
    8 NK=KK-KL+1
      INSERT STIFFNESS MATRIX K
      A(NK)=A(NK)+ST(3)
  200 CONTINUE
      MODIFY EQUATION IF SPECIFIED HEAD AT NODE I
      IF(ISR(I).EQ.0) GO TO 497
      A(NNI)=10.**25
      NL(I)=NL(I)*10.**25
  497 LINC=KH-I
      FOR FIRST EQUATION, BYPASS ELIMINATION
      IF(I-KL)60,60,50
      PERFORM ELIMINATION FOR ROW I TO ZERO BELOW MAIN DIAGONAL
   50 KU=I-1
      DO 256 K=KL,KU
      IK = PIVOTAL COLUMN RELATIVE TO  KL = 1
      IK=K+1-KL
      IM=LIST(K+1)-LIST(K)
      IJ=K+IM-I-LINC
      IF NON ZERO BAND FOR PIVOTAL EQ ENDS TO RIGHT OF THAT FOR EQ I, EXTEND
      FOR EQ I
       IF(IJ.LE.0.) GO TO 82
      KK=LINC+I-KL+2
      LINC=LINC+IJ
      LL=IJ+KK-1
      DO 83 L=KK,LL
   83 A(L)=0.
   82 IF(IM.LE.0.) GO TO 256
~~3000 FORMAT('0','MAIN LOOP I=',I4,'   IM=',I4,' ******',' LINC=',I4/)~~
      ~~WRITE(JWT,3000) I,IM,LINC~~            Print check for main loop (debug)
      DO 55 J=1,IM
      IJ=IK+J
      KJ= LIST(K)+J-1
      IF(ABS(STORE(KJ)).LE.10.**(-10)) STORE(KJ)=0.
      A(IJ)=A(IJ)-A(IK)*STORE(KJ)
      ~~IF(ABS(A(IJ)).EQ. 0.) GO TO 55~~
      ~~IF(ABS(A(IJ)).GT.10.**(-50)) GO TO 55~~
~~30010FORMAT(' ','   IM LOOP J=',I4,'   IJ=',I4,'   KJ=',I4,' A(IJ)=',E12.5~~
     ~~1,' A(IK)=',E12.5,' STORE(KJ)=',E12.5)~~        Print check for location of
      ~~IF(LINE.EQ.1000)GO TO 55~~                       underflow errors (debug)
      ~~WRITE(JWT,3001) J,IJ,KJ,A(IJ),A(IK),STORE(KJ)~~
      ~~LINE=LINE+1~~
   55 CONTINUE
  256 NL(I)=NL(I)-A(IK)*NL(K)
      NORMALIZE ROW I. JJ = PIVOTAL ELEMENT RELATIVE TO KL = 1
```

```
 60 JJ=I+1-KL
    IJ=JJ
    LIST(I+1)=LINC+LIST(I)
    IF(LINC)75,75,65
 65 DO 70 J=1,LINC
    IJ=IJ+1
    IK=LIST(I)+J-1
 70 STORE(IK)=A(IJ)/A(JJ)
    NORMALIZE HEAD AT NODE I
 75 NL(I)=NL(I)/A(JJ)
100 CONTINUE
    START BACK SUBSTITUTION
    N2=NE-1
    IF(N2)210,210,220
220 DO 250 K=1,N2
    I=NE-K
    KU=LIST(I+1)-LIST(I)
    SUM=0.
    DO 240 J=1,KU
    IK=LIST(I)+J-1
    IJ=I+J
240 SUM=SUM+STORE(IK)*NL(IJ)
250 NL(I)=NL(I)-SUM
    WRITE NODAL HEADS
210 WRITE(JWT,564) IPAGE
    IPAGE=IPAGE+1
    WRITE(JWT,560)(HDG(I),I=1,20)
560 FORMAT('0'1X20A4,//'  RESULTS'//'  NODAL HEADS'//'  NODE   HEAD (F
   1T)'/)
    DO 397 L=1,NN
562 FORMAT(I6,F12.4)
    WRITE(JWT,562)L,NL(L)
    LINE =LINE + 1
    IF(LINE.LT.60) GO TO 397
    WRITE(JWT,564) IPAGE
    IPAGE=IPAGE+1
561 FORMAT('0','  RESULTS CONT. '//'  NODE   HEAD (FT)'/)
    WRITE(JWT,561)
    LINE = 7
397 CONTINUE  <-- CALL PLØTER (NL) - subroutine PLØTER may be
                                    introduced at this point
563 FORMAT(//1X,'END OF RUN NO. ',I4)
    WRITE(JWT,563) IDENT
    LINE=0
    IPAGE=1
    GO TO 1
9999 STOP 1000
    END
```

```
      SUBROUTINE STIFF
      THIS SUBROUTINE DEVELOPS STIFFNESS MATRICES II,IJ AND IK FOR
      CONSTANT STRAIN TRIANGLE I-J-K
      REAL NL(360),KX(576),KY(576)
      COMMON M,CJ(360,2),IE(576,3),L1,L2,L3,  T,ST(3),KL,KX,KY,S(576)
      COMMON JRD,JWT
      DIMENSION A(3),B(3)
~~ 15 FORMAT('0','CHECK NODAL INCIDENCES$$$ I=', I4,'J=',I4,'K=',I4)~~
      SL=ABS(S(M)/57.2958)
      COSA=COS(SL)
      SINA=SIN(SL)
      IF(S(M).LE.0.) SINA=-SINA
      I=IE(M,1)
      J=IE(M,2)
      K=IE(M,3)
      A(1)=(CJ(K,1)-CJ(J,1))*COSA+(CJ(K,2)-CJ(J,2))*SINA
      A(2)=(CJ(I,1)-CJ(K,1))*COSA+(CJ(I,2)-CJ(K,2))*SINA
      A(3)=(CJ(J,1)-CJ(I,1))*COSA+(CJ(J,2)-CJ(I,2))*SINA
      B(1)=(CJ(J,2)-CJ(K,2))*COSA-(CJ(J,1)-CJ(K,1))*SINA
      B(2)=(CJ(K,2)-CJ(I,2))*COSA-(CJ(K,1)-CJ(I,1))*SINA
      B(3)=(CJ(I,2)-CJ(J,2))*COSA-(CJ(I,1)-CJ(J,1))*SINA
      DET=CJ(J,1)*CJ(K,2)-CJ(K,1)*CJ(J,2)-CJ(I,1)*CJ(K,2)+CJ(K,1)*CJ(I,2
     1)+CJ(I,1)*CJ(J,2)-CJ(J,1)*CJ(I,2)
      ~~IF(DET.NE.0.0) GO TO 16~~
      ~~WRITE(JWT,15)I,J,K~~
      ~~STOP 3000~~
~~ 16~~ ST(1)=(KY(M)*A(L1)*A(L1)+KX(M)*B(L1)*B(L1))/2./DET
      ST(2)=(KY(M)*A(L1)*A(L2)+KX(M)*B(L1)*B(L2))/2./DET
      ST(3)=(KY(M)*A(L1)*A(L3)+KX(M)*B(L1)*B(L3))/2./DET
      RETURN
      END
```

print check for nodal values (debug)