FLUCTUATIONS OF HANFORD WATER LEVELS

By

William H. Bierschenk

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INTRODUCTION

Ground disposal of low-level radioactive wastes is of basic importance to the operation of Hanford chemical operating plants due to the huge volumes and economics involved. The estimated volume of low-level radioactive contaminants discharged to ground since plant startup in 1944 through June 1957 is approximately 2.9 billion gallons. In addition, about 26.7 billion gallons of relatively uncontaminated cooling waters from separations processes have been discharged to open disposal areas in and near operating facilities. Periodic process difficulties allowing trace quantities of radioactive material to enter effluent streams cause these "swamp" areas also to be considered disposal sites for radioactive wastes.

Although some of the liquid effluents is lost through evapotranspiration to the atmosphere, and some is retained in the pores of the sediments in the zone of aeration, most percolates down to the water table and enters the zone of saturation. As a result of this recharge to underlying aquifers, two groundwater mounds have formed above the regional water table (1), and water levels in wells more than 15 miles from separations areas have shown a progressive rise.

The upper level of the zone of ground-water saturation is considered to be represented by the level of water standing in wells, although forces other than actual changes in ground-water conditions may cause fluctuations of level in such wells. It is the purpose of this report to present the principal causes of water-level fluctuations and to give quantitative data of the magnitude of such fluctuations, and calculations from these data relating to the average porosity of the saturated sediments.

SUMMARY

Long-term hydrographs of water levels in 44 wells at Hanford show that water-table fluctuations are controlled primarily by the artificial recharge of aquifers by infiltrating liquid effluents, although locally some natural fluctuation is caused by alternate seepage into and from the Columbia River. In addition, the observed water level in certain wells may fluctuate due to changes in atmospheric pressure or due to earthquake shocks.

Between 1944 and 1957 an estimated 4 billion cubic feet of plant effluents have saturated approximately 62 billion cubic feet of sediments. The average wetted porosity of the affected sediments is thus calculated to be about 6.4 percent. This newly-saturated zone contains essentially all the infiltrated waste water.

WATER-BEARING PROPERTIES OF GEOLOGIC UNITS

Permeability is the property earth materials have of allowing fluids to pass through them; here, permeability to water and to liquid plant effluents and the capacity for storage are relevant. In quantitative ground-water studies, field pumping tests yield comparatively reliable values for the coefficients of permeability and storage, terms that need not be defined here.

The lithologic character and water-bearing properties of the several major geologic units occurring in the Hanford Works area are summarized in the table below. For more complete descriptions of the physical and hydraulic characteristics of the geologic formations, the reader is referred to earlier reports on Hanford geology and hydrology (2) (3) (4).

GROUND-WATER HYDROLOGY

The Water Table and Movement of Water

The water table is defined as the upper surface of the zone of saturation, except where that surface is formed by an impermeable body. The water table may also be considered as the boundary between the zone of saturation and the zone of aeration. It is not a static, plane surface but generally has many irregularities owing to differences in thickness and permeability of the water-bearing materials (aquifers), and normally it fluctuates up and down in response to local differences in the gain or loss of water.

At Hanford the regional water table is largely within the Ringold formation and to a lesser extent in the glacio-fluviatile deposits. These latter, where

Major geologic units in the Hanford Works area and their water-bearing properties

Geologic unit	Material	Water-bearing properties
Fluviatile and glacio-fluviatile sediments (200 ft thick)	Sands and gravels occurring chiefly as glacial outwash. Unconcolidated, tending toward coarseness and angularity of grains; essentially free of fines.	Where below the water table, such deposits have very high permeability and are capable of storing vast amounts of water. Highest permeability value determined is 66,700 gallons a day per square foot of cross section under a hydraulic gradient of unity (4).
Ringold formation (1,200 ft thick)	Well-bedded lacustrine silts and sands and local beds of clay and gravel. Poorly sorted, locally semi-consolidated or cemented.	Has low permeability; values range from 10 to 1,400 gpd/sq ft. Storage capacity correspondingly low. In very minor part, a few beds of gravel and sand are sufficiently clean that permeability is moderately large; on the other hand, some beds of silty clay or clay are sensibly impermeable under hydraulic gradients of ordinary magnitude.
Columbia River basalt series (> 7,000 ft thick)	Basaltic lavas with interbedded sedimentary rocks; considerably deformed. Underlie the unconsolidated sediments.	Rocks are generally dense except for numerous shrinkage cracks, interflow scoria zones, and interbedded sediments. Presumably has low to perhaps moderate permeability. Contained water may be either confined or unconfined.

below the water table, are highly permeable and occur as channels along both the northern and southern flanks of Gable Mountain and extending southeastward from the western side of Gable Mountain toward the Columbia River, and as narrow irregular zones paralleling the river.

Figures 1 and 2 are maps showing ground-water contours. Figure 1 shows the shape and position of the water table prior to plant operations, and Figure 2 shows the water table as of June 1957. The contours represent lines of equal altitude on the water table expressed in feet above mean sea level and, in the latter case, are based on the measured altitude of the water surface in 117 wells. The general direction of movement of ground water is at right angles to the contour lines in the direction of the downward slope. Thus, throughout much of the area the general movement of water was formerly northeastward and eastward (Figure 1) but the slope and direction of movement were significantly altered by plant operation (Figure 2), particularly in and near the areas of the two ground-water mounds. Whereas the natural hydraulic gradient beneath the present mounds originally was about 5 feet or less per mile northeasterly and easterly toward the Columbia River, the mounds locally reversed and increased the gradient. Consequently, ground water currently flows radially outward from the mounds under the influences of an average gradient of about 25 feet per mile in the west and a maximum of 15 feet per mile in the east.

Irregularities in the shape and slope of the water table, shown on Figure 2, are caused largely by recharge of the ground-water reservoir by plant effluents, by local differences in the thickness and permeability of the deposits, and by recharge from or discharge into the Columbia River.

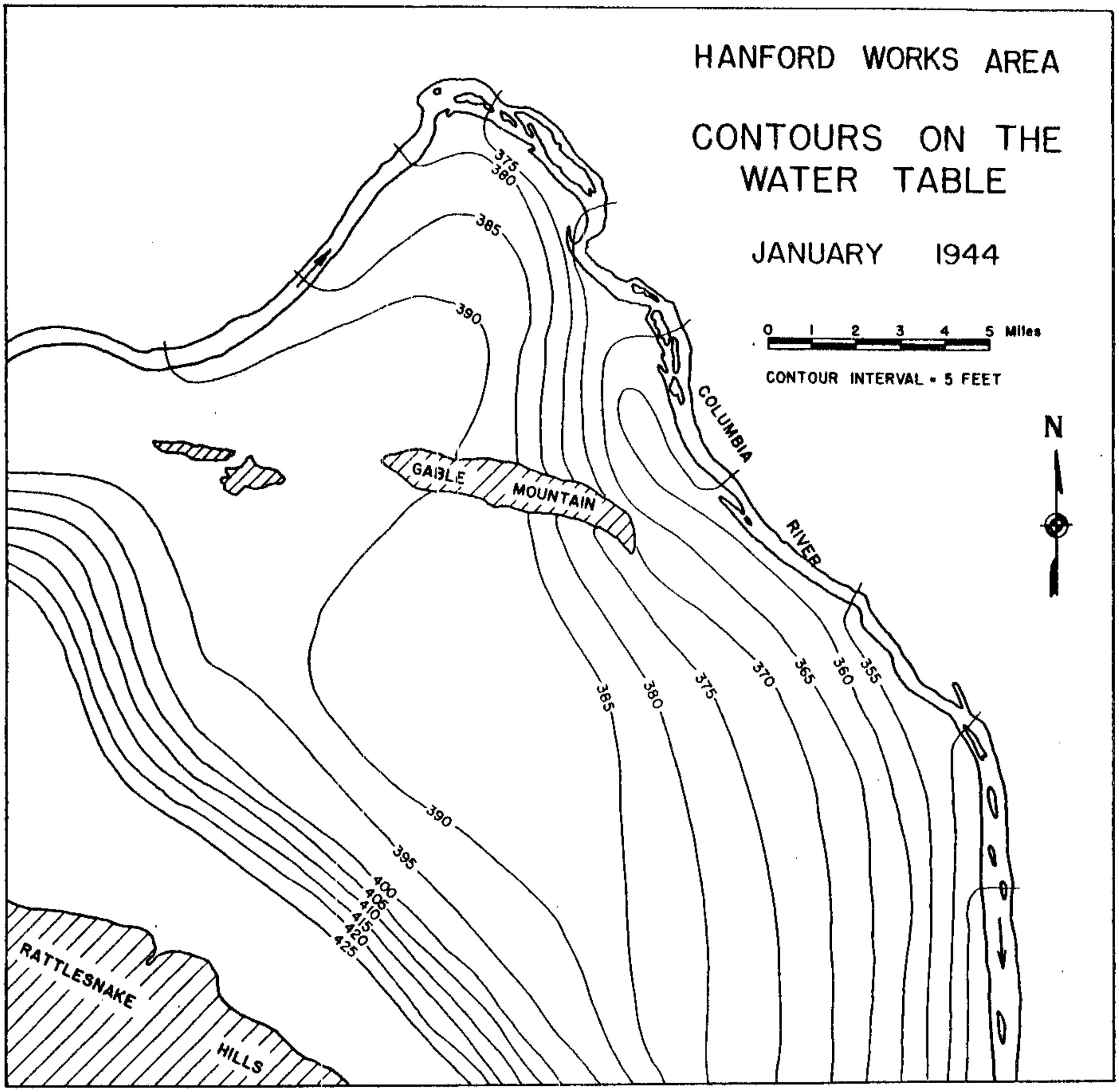

Figure 1

Map showing ground-water contours as inferred for January 1944, prior to plant operations.

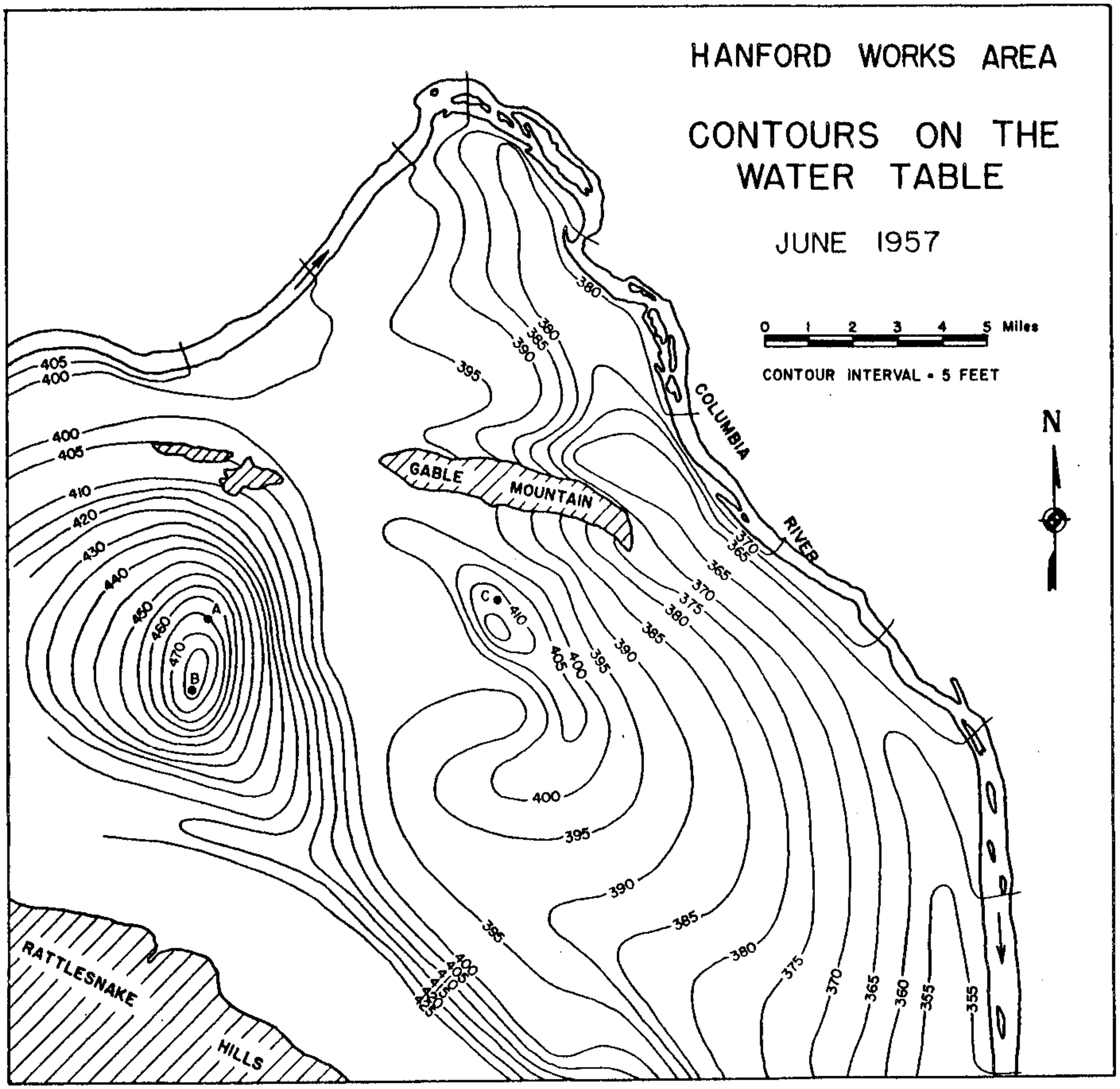

Figure 2
Map showing ground-water contours as of June 1957. A, B, and C are located near open disposal swamps.

Ground-Water Recharge

Ground-water recharge is the addition of water to the ground-water reservoir, and at equilibrium is equal to the total average discharge from the reservoir. Recharge of Hanford aquifers by plant effluents is an artificial recharge imposed upon a system that had previously been in approximate equilibrium and causes the system to become unbalanced. Before the system can reach a new equilibrium, water levels must rise throughout the aquifers enough to increase the natural discharge by an amount equal to the amount recharged. Until this new equilibrium can be established, water must be taken into storage in the aquifers.

Natural recharge of the Hanford aquifers occurs by subsurface inflow from the southwest and west. A perennial source of recharge exists at the foot of Rattlesnake Hills (see Figure 1) and Yakima Ridge (not shown) from several creeks which flow intermittently following heavy rains or melting of snows. Ordinarily, the surficial flow does not reach beyond the mouths of the respective canyons, but sinks into the floor of the valley at the foot of, and paralleling, Rattlesnake Hills. Recent studies indicate that the underflow is interrupted by a buried extension of Yakima Ridge which parallels Rattlesnake Hills at a distance of about 2 miles, and which rises above the water table; however, the details of this are as yet not completely known. More dispersed recharge doubtless is received from Yakima Ridge and Rattlesnake Hills by subsurface percolation.

Figure 1 implies that all natural movement in the regional body of unconfined water is toward the Columbia River with discharge into, but no recharge from that stream. Such is generally true for normal or low stages of the river, but as the river rises during the yearly snow-melt flood in the spring, a zone adjacent to the river is annually saturated by bank storage (see Figure 2). This zone, which commonly extends at least a mile and locally as much as three miles or more from the river, is drained as the river level decreases.

Ground-Water Discharge

Ground water is discharged from Hanford aquifers through seepage into the Columbia River, the main discharge occurring during the falling stages of the river (see above). The discharge of ground water through evaporation and transpiration of plants and by pumping from wells is considered negligible.

FLUCTUATION OF WATER LEVELS

The water table does not remain static but fluctuates much like the water level of a surface reservoir. The fluctuations of the water table underlying Hanford Works were determined by measuring the water levels in selected observation wells. The periodic measurement of the water levels resulted in a series of hydrographs, a comparison of which showed that ground-water levels in different parts of the area fluctuated with different periods and by different amounts. Hydrographs showing fluctuations of water levels in 44 wells are given in the appendix; well locations are shown in Figure 3. (In all cases the well-prefix 699- has been omitted from the Figure). The fluctuations were plotted showing the altitude of water level in feet above mean sea level.

Four types of fluctuations, one artificial and three natural, are shown by the records of water levels. The artificially caused fluctuation, largely a progressive rise, of the water table is the result of recharge of aquifers by liquid plant effluents which were sent to ground through various disposal facilities. Natural fluctuations are caused by changes in the stage of the Columbia River, by changes in atmospheric pressure, and by earthquake shocks.

Fluctuations Caused by Effluent Disposal

Approximately 29.6 billion gallons of liquid effluents have been discharged to ground at Hanford since 1944. As a result the water table has risen substantially within most of the area. Figure 3 depicts the size and shape of the zone newly saturated as a result of plant disposal operations; that is, the zone between the water-table surfaces shown in Figures 1 and 2. The contours shown represent lines of equal change in water-table elevation from 1944 to 1957. The greatest part of this artificially saturated volume is included in (a) the roughly cone-shaped ground-water mound beneath 200-West Area swamps, (b) the elongated mound beneath 200-East Area swamps, and (c) a lower saturated zone connecting the two mounds.

The total volume of sediments affected by the rise of water levels, as determined by graphical integration with a planimeter, was measured to be approximately 62 billion cubic feet. Assuming that all the process water wasted to ground since 1944 is still in the zone depicted (none discharged to the Columbia River), the above volume of sediments has been saturated with roughly 30 billion gallons of water, or about 4 billion cubic feet. Thus, the average wetted porosity of the affected sediments is about 6.4 percent. Previous estimates of this value for limited volumes, derived by the U. S. Geological Survey, averaged about 8.3 percent (2) (3). The saturated sediments of the western mound are ascribed an average porosity value of 6.0 percent, and those of the eastern mound a value of 7.2 percent. A given volume of effluent, then, upon reaching the water table in the east will not cause nearly as great a rise as it will in the west; the rise in water level being inversely proportional to the porosity.

As depicted by long-term hydrographs (Plates 1-13), the general trend of ground-water levels is upward, indicating continuing infiltration of effluents to the aquifers. The relative rise of levels in wells is controlled by the extent and hydraulic characteristics of the aquifers, the distance from the point of recharge, and the rate and volume of effluent disposed.

The fluctuations of water levels in wells 699-32-77, 699-35-78, and 699-39-79 are shown on Plate 1. Well 699-35-78, which defines the current apex of the western ground-water mound (Figures 2 and 3), has shown a steady rise of about 55 feet during the 9-year period of record in response to artificial recharge. A rise of comparable magnitude has occurred in wells 699-32-77 and 699-39-79. The inferred net rise in levels for all wells since 1944 is shown in Figure 3.

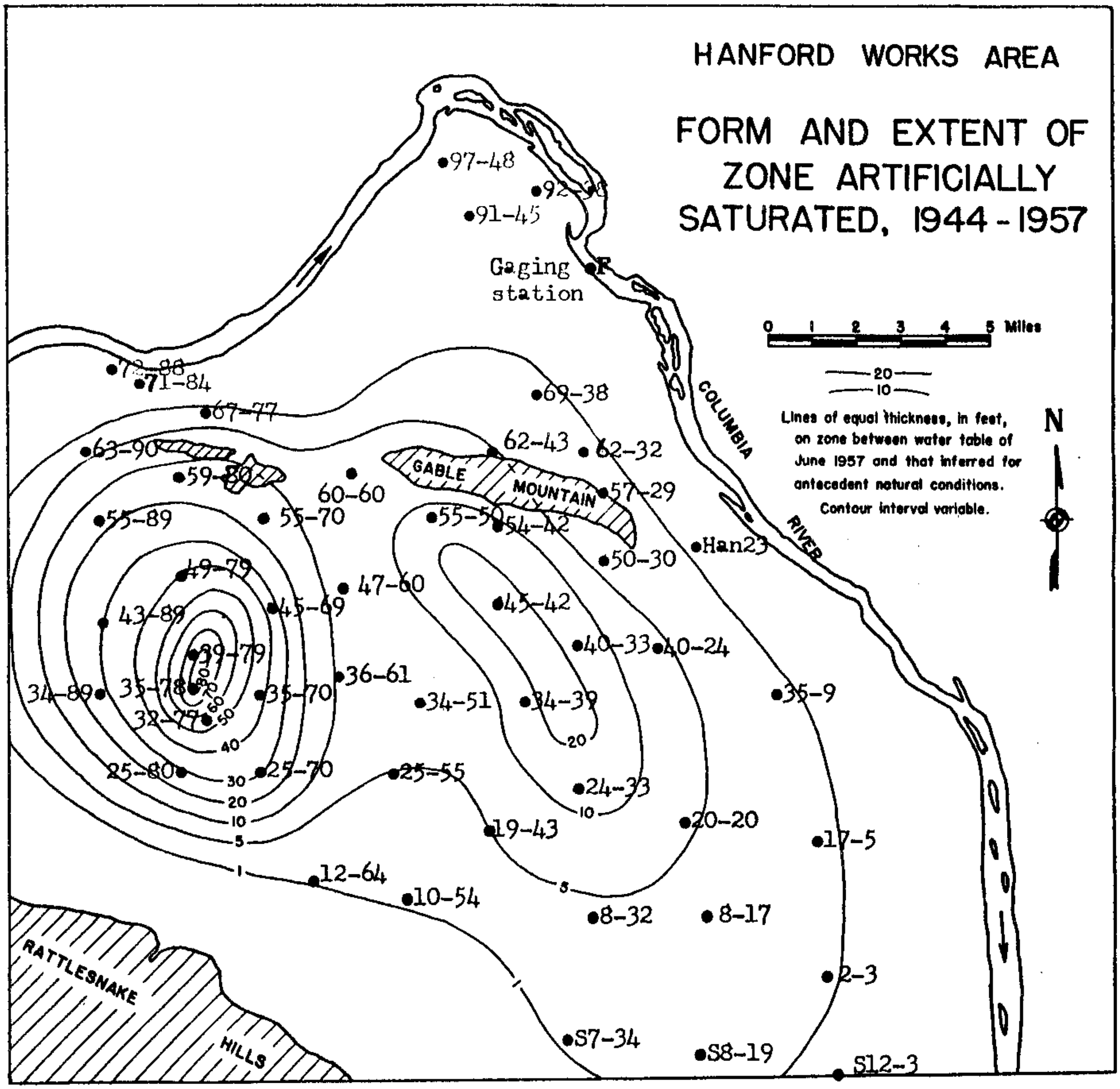

Figure 3

Map showing size and shape of newly saturated zone and locations of observation wells.

Plates 2, 3, and 4 include hydrographs for wells closely identified with the western mound, and as such show rises of level ranging from about 12 feet in well 699-55-89 to about 30 feet in well 699-25-70 for the respective periods of record. The downward trend shown for well 699-49-79 (Plate 3) since early 1956 is the result of a large reduction in the amount of effluent being discharged to the swamp located less than a mile to the southeast (1). Prior to 1956 the apex of the western mound was located near this well.

Plate 4 includes the hydrograph of well 699-45-42 which is near the apex of the eastern ground-water mound. Its water level fluctuates in direct response to disposal practices. For example, during the period 1949-1952 the peak of the mound was nearly stabilized, but early in 1952 the effluent discharge rate was reduced from about 2 million gallons daily (mgd) to 0.1 mgd. The water level in the well subsequently fell about 9 feet. Early in 1956 the rate of discharge increased to more than 6 mgd and the water level rose about 13 feet to a point higher than that previously reached (5). The apex of the eastern mound currently is located about one mile to the south of well 699-45-42.

Plates 5-12 include hydrographs for wells more remote from the two ground-water mounds, and consequently show correspondingly smaller net rises of water level although the progressive rises are everywhere attributed to artificial recharge.

Natural Fluctuations

The hydrographs of wells 699-63-90, 699-92-38, and 699-Han. 23 (Plate 13) illustrate the type of fluctuation where seepage to and from the Columbia River is the controlling factor. The hydrographs show that water levels rose during the early spring of each year, reached a peak about June-July, and declined thereafter. This is in accord with the annual rise and fall of the river (see river hydrograph, Plate 13).

The water level in wells 699-57-29, 699-62-32, 699-67-77, 699-71-84, 699-72-88, 699-91-45, and 699-97-48 (located on Figure 3) also fluctuate in response to sinusoidal changes in river stage.

In addition to fluctuations caused by addition or withdrawal of water, minor short-range fluctuations caused by changes in atmospheric pressure and by earthquake shocks are observed in some wells. Wells that penetrate water-bearing formations having a relatively impermeable bed above the zone of saturation may fluctuate inversely as the barometer fluctuates. The pressure on the water surface in a well increases directly as the increase in atmospheric pressure. If this increase in pressure is not transmitted uniformly to the ground-water body because there is no direct communication between the atmosphere and the water table, but acts only on the exposed water surface in the well, the water level in the well fluctuates according to the changes in pressure. If the pressure is transmitted freely through the pore spaces of the soil to the water table, the water level will reflect no appreciable barometric effect.

Daily hydrographs of wells 699-39-79, 699-45-42, and 699-49-79, obtained from automatic water-stage recorders, are shown on Plate 14. The plate also presents the contemporary record of barometric pressure, as recorded by a microbarograph. The maximum water-level fluctuation thus observed was 0.8 feet. The barometric efficiency of well 699-45-42 is shown to be about 50 percent.

Fluctuations in water levels due to earthquakes have been observed in several wells at Hanford equipped with water-stage recorders (6). Where an aquifer is affected by shock waves of an earthquake there will first be an abrupt increase in water pressure followed by an abrupt decrease. In attempting to adjust to the pressure changes, the water level in the well first rises and then falls. Plate 15 gives daily hydrographs of wells 699-25-70 and 699-50-30 showing fluctuations caused by an earthquake shock at Ketchikan, Alaska. The maximum fluctuation observed was 0.2 feet. These are superimposed upon diurnal fluctuations caused by atmospheric pressure changes.

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(2) Parker, G. G. and Piper, A. M., Geologic and Hydrologic Features of the Richland Area, Washington, Relevant to Disposal of Waste at the Hanford Directed Operations of the Atomic Energy Commission, U. S. Geol. Survey, Interim Report No. 1, July 1949.

(3) Newcombe, R. C. and Strand, J. R., Geology and Ground-Water Characteristics of the Hanford Reservation of the Atomic Energy Commission, Washington, U. S. Geol. Survey, Interim Report No. 2, 1953.

(4) Bierschenk, W. H., Hydraulic Characteristics of Hanford Aquifers, HW-48916, March 3, 1957.

(5) Bierschenk, W. H., The Effect of Ground-Water Mounds on the Purex Operation, HW-49728, April 18, 1957.

(6) McConiga, M. W., The Detection of Earthquakes by Water-Level Recorders, HW-37711, November 1955.

APPENDIX

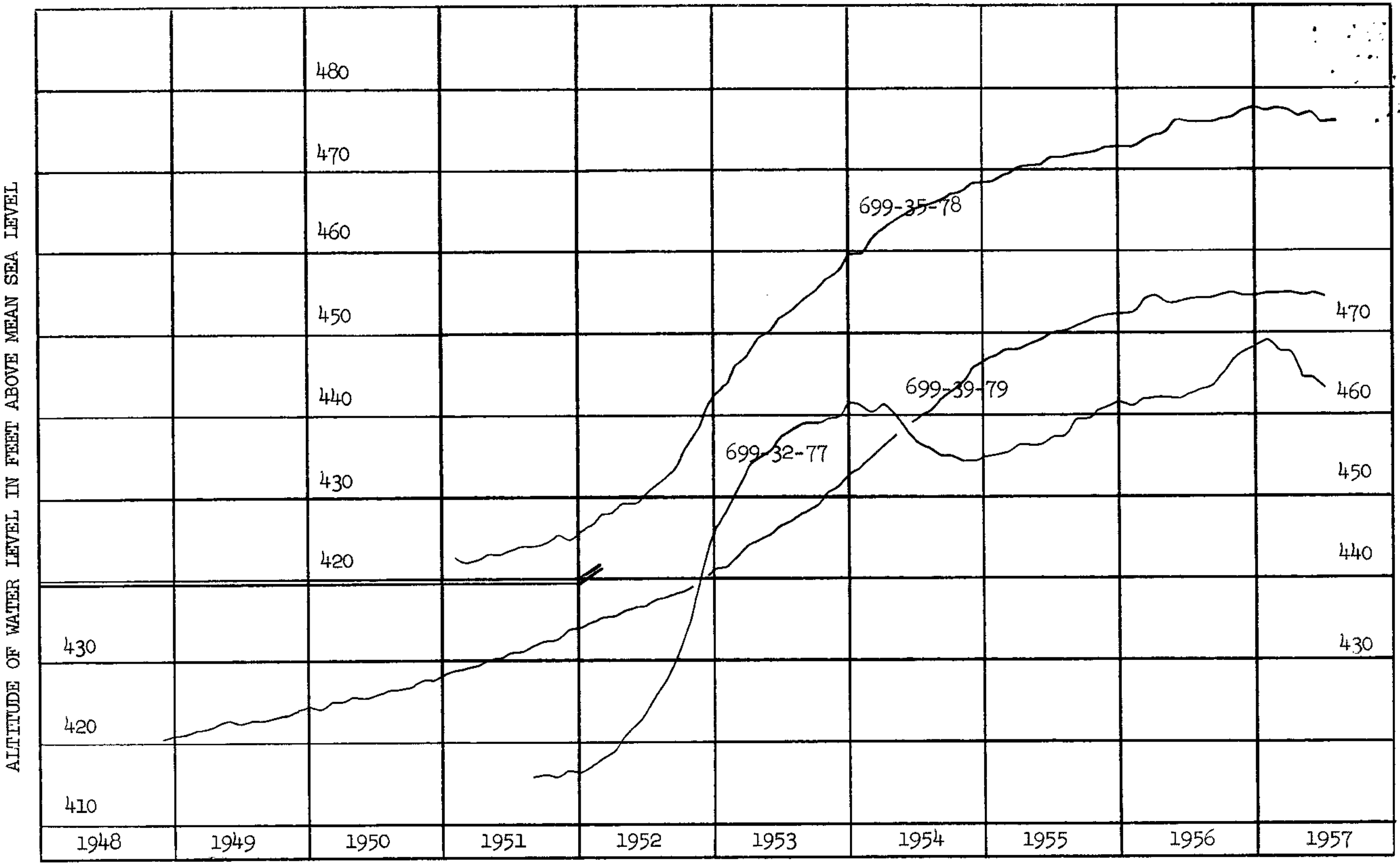

Plate 1.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-35-78, 699-39-79, and 699-32-77.

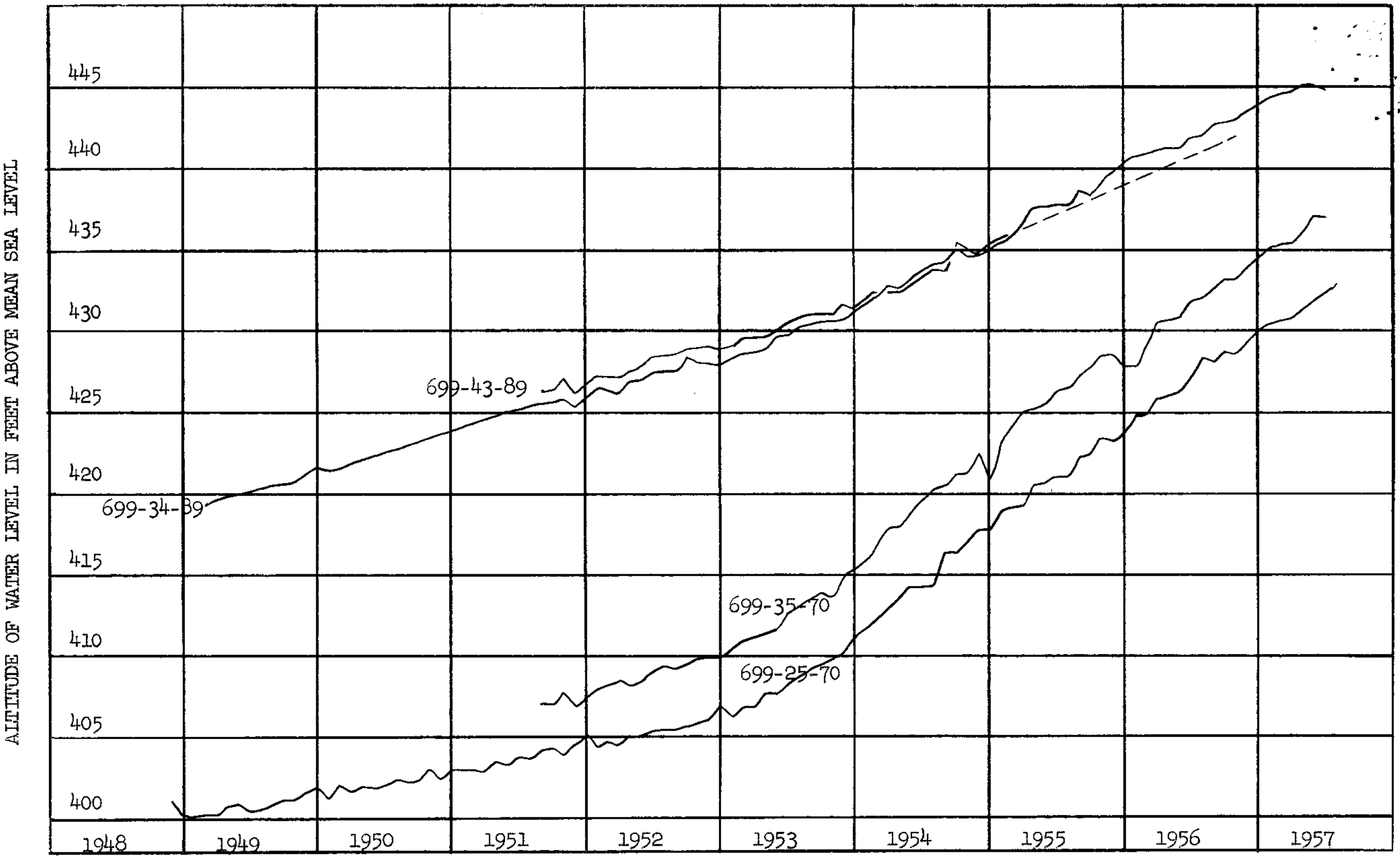

Plate 2.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-43-89, 699-35-70, 699-25-70 and 699-34-89.

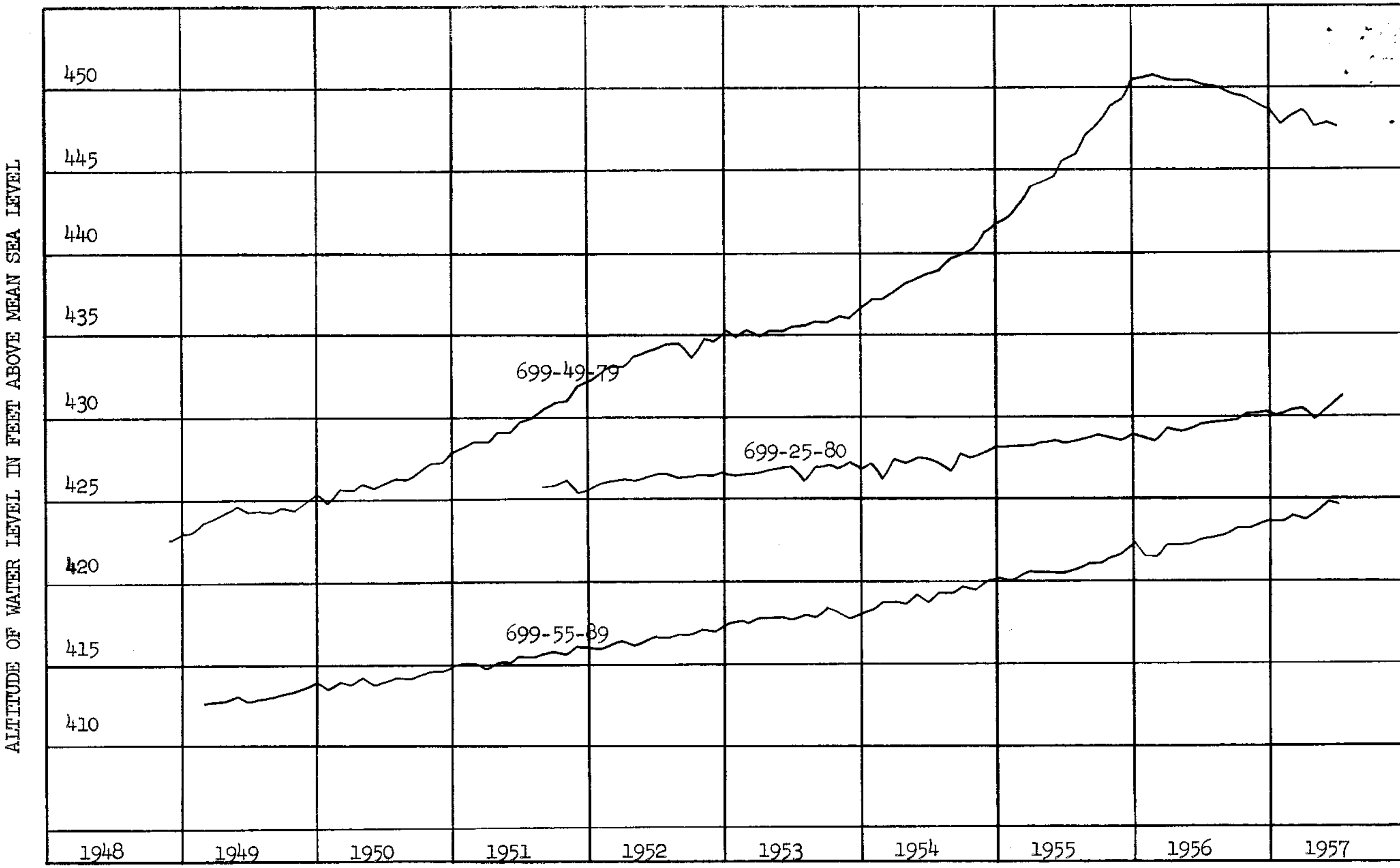

Plate 3.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-49-79, 699-25-80, and 699-55-89.

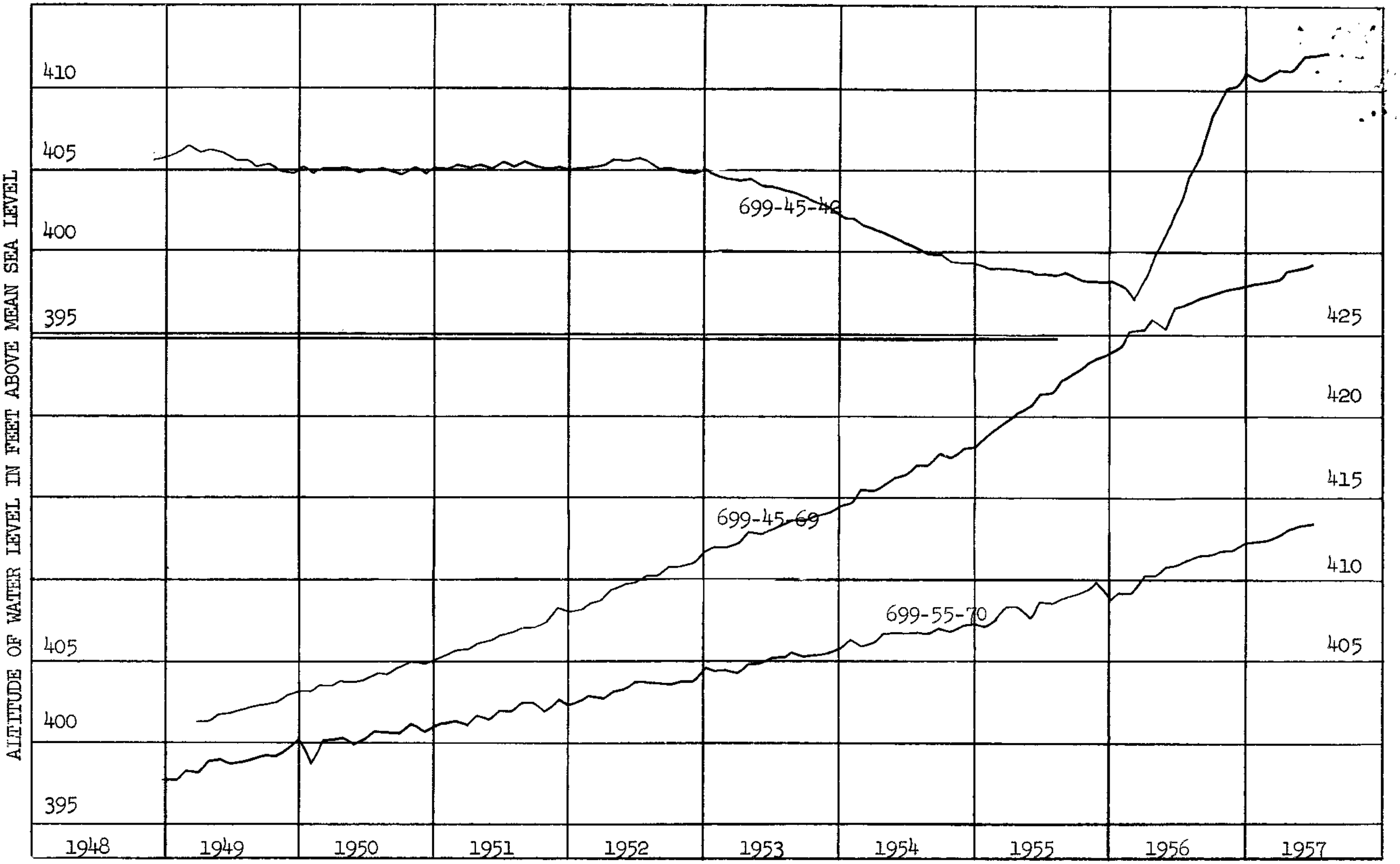

Plate 4.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-45-42, 699-45-69, and 699-55-70.

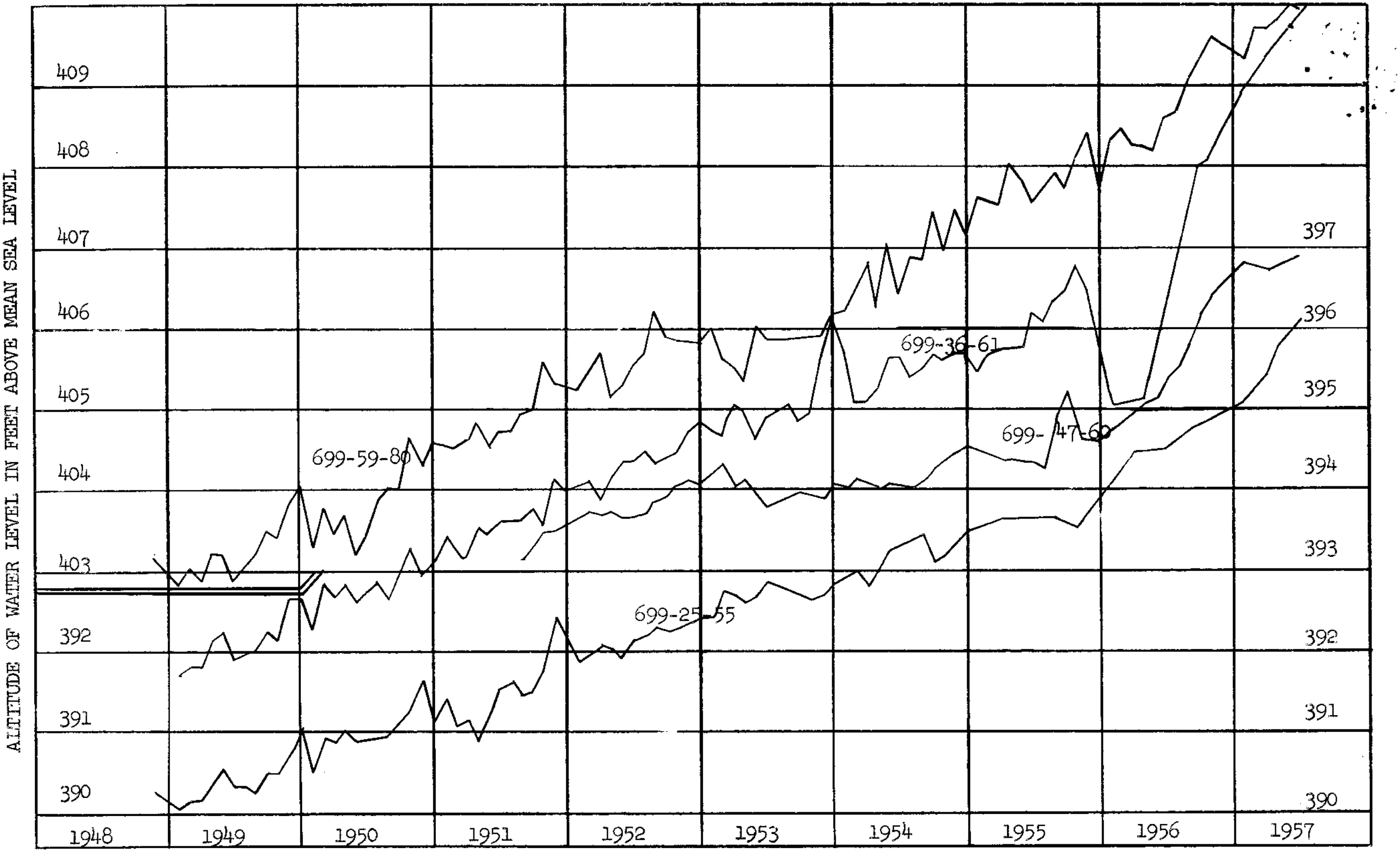

Plate 5

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-59-80, 699-47-60, 699-36-61, and 699-25-55.

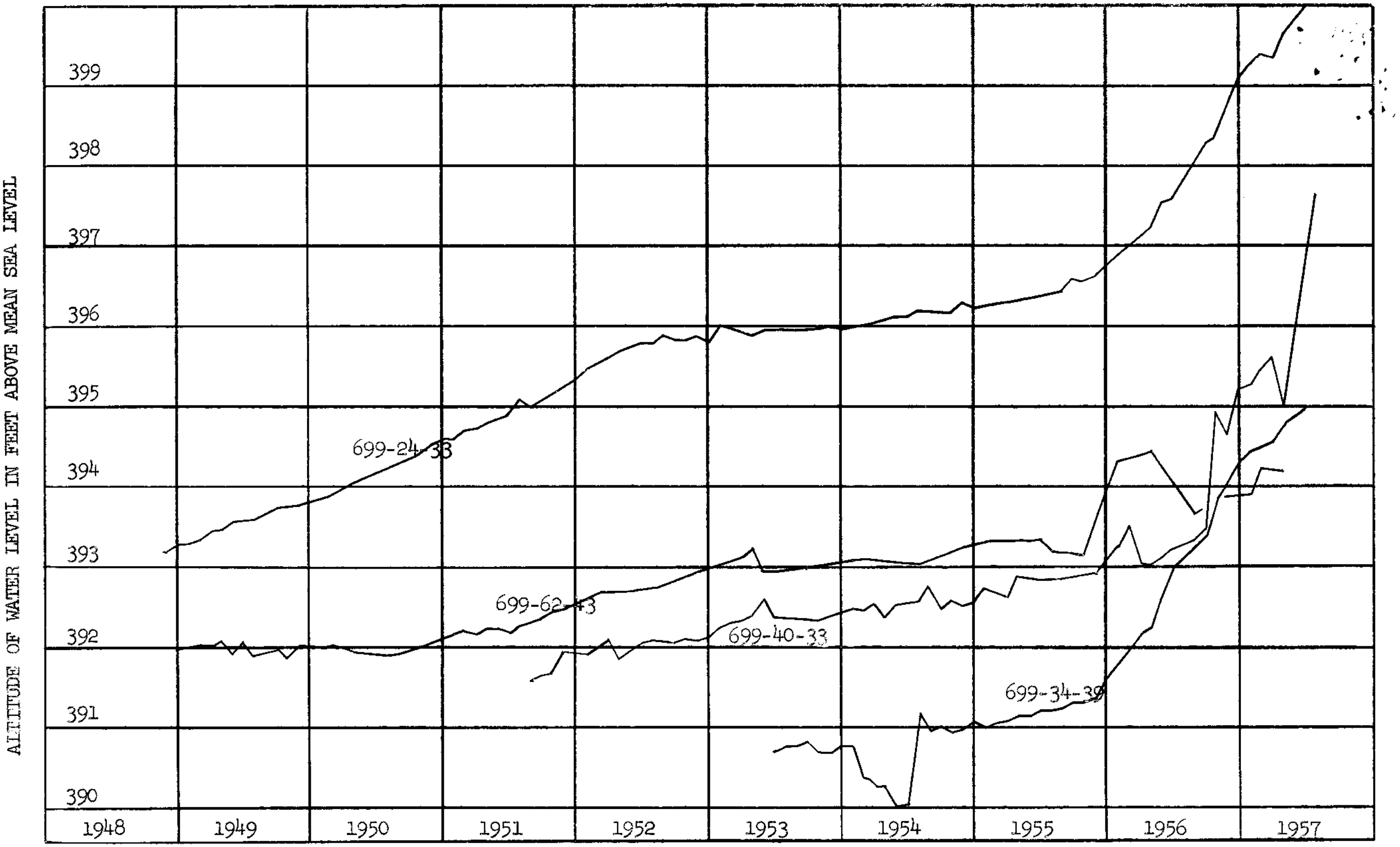

Plate 6.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-24-33, 699-62-43, 699-40-33 and 699-34-39.

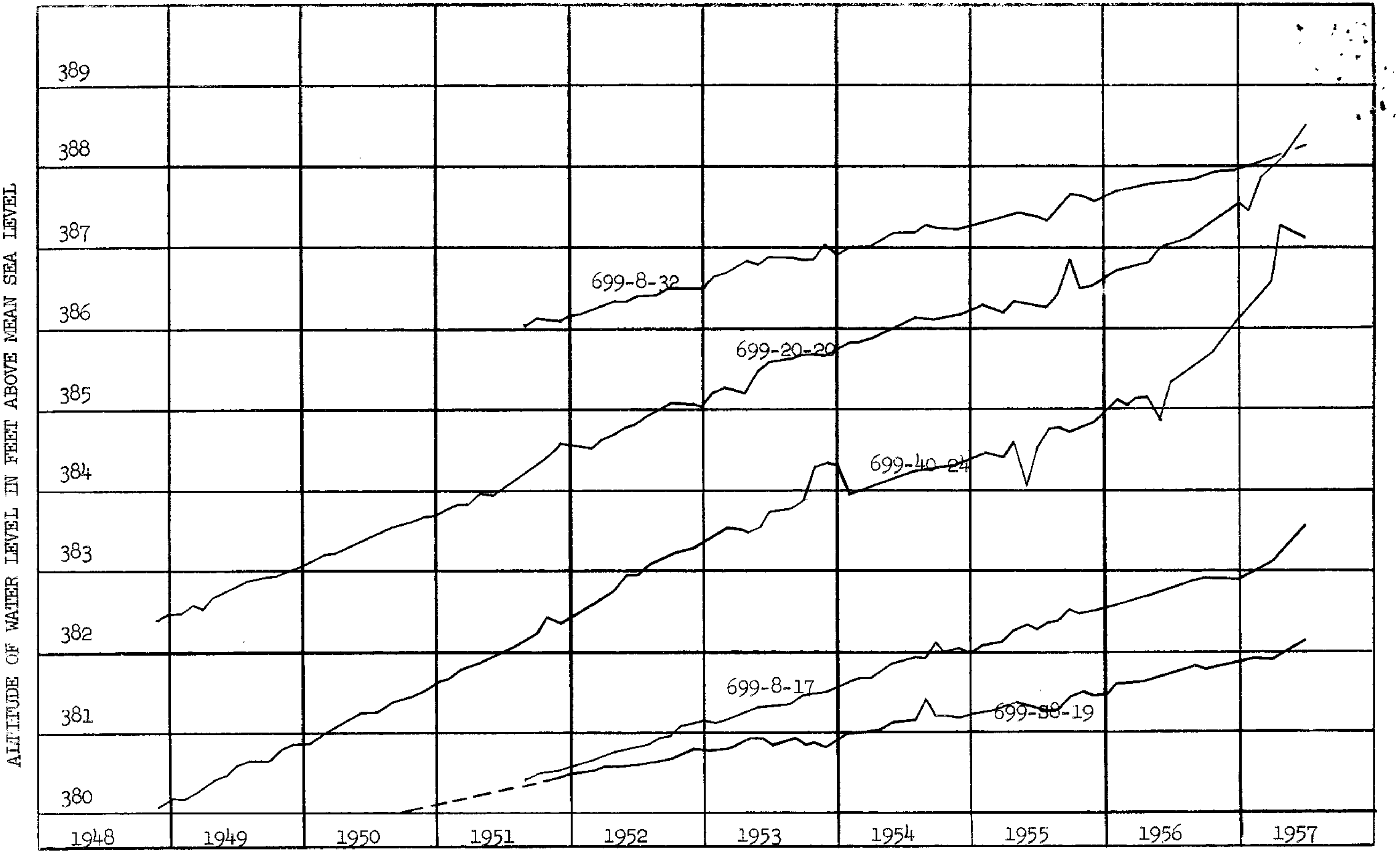

Plate 7.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-8-32, 699-20-20, 699-40-24, 699-8-17, and 699-S8-19.

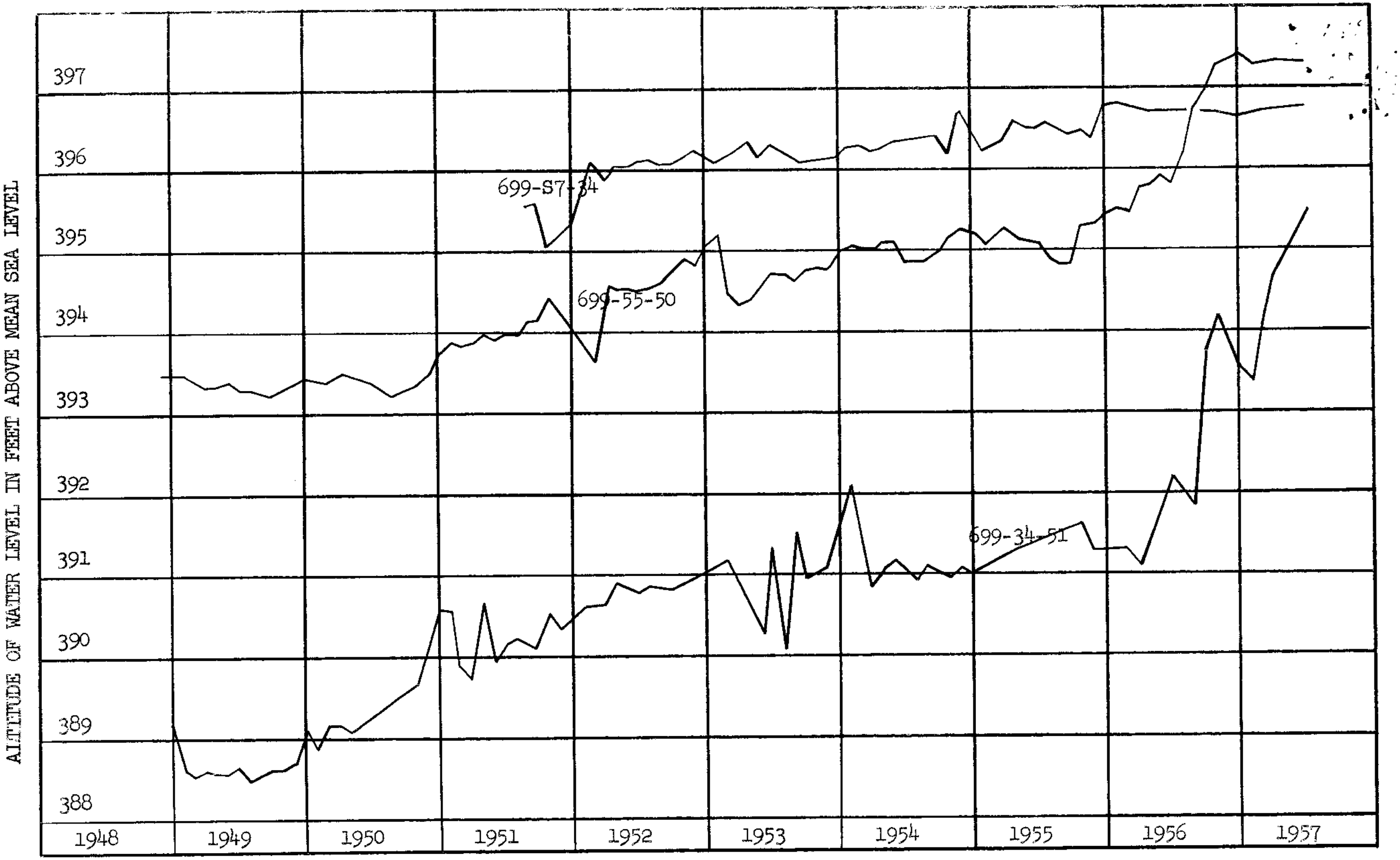

Plate 8.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-S7-34, 699-55-50, and 699-34-51.

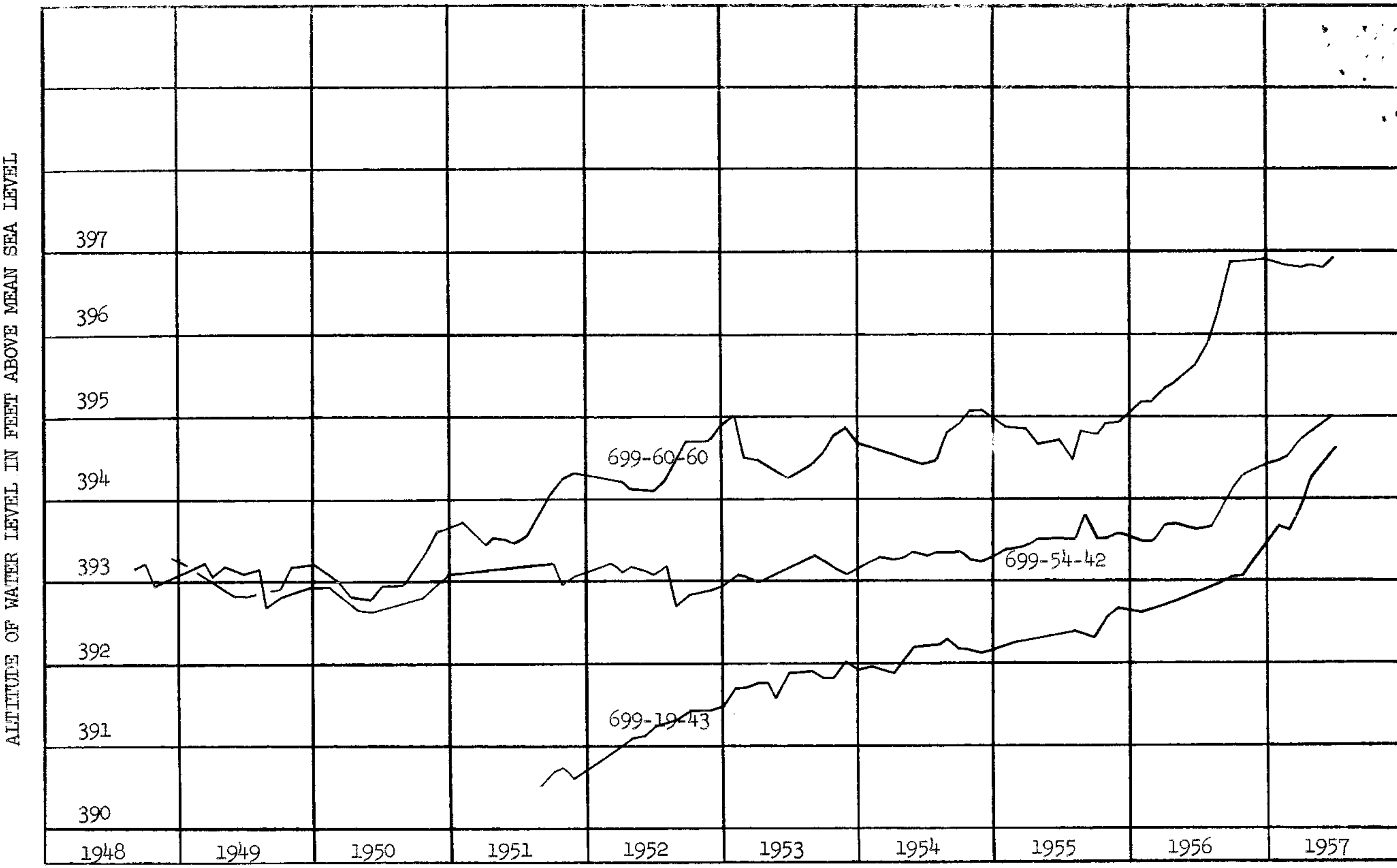

Plate 9.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-60-60, 699-54-42, and 699-19-43.

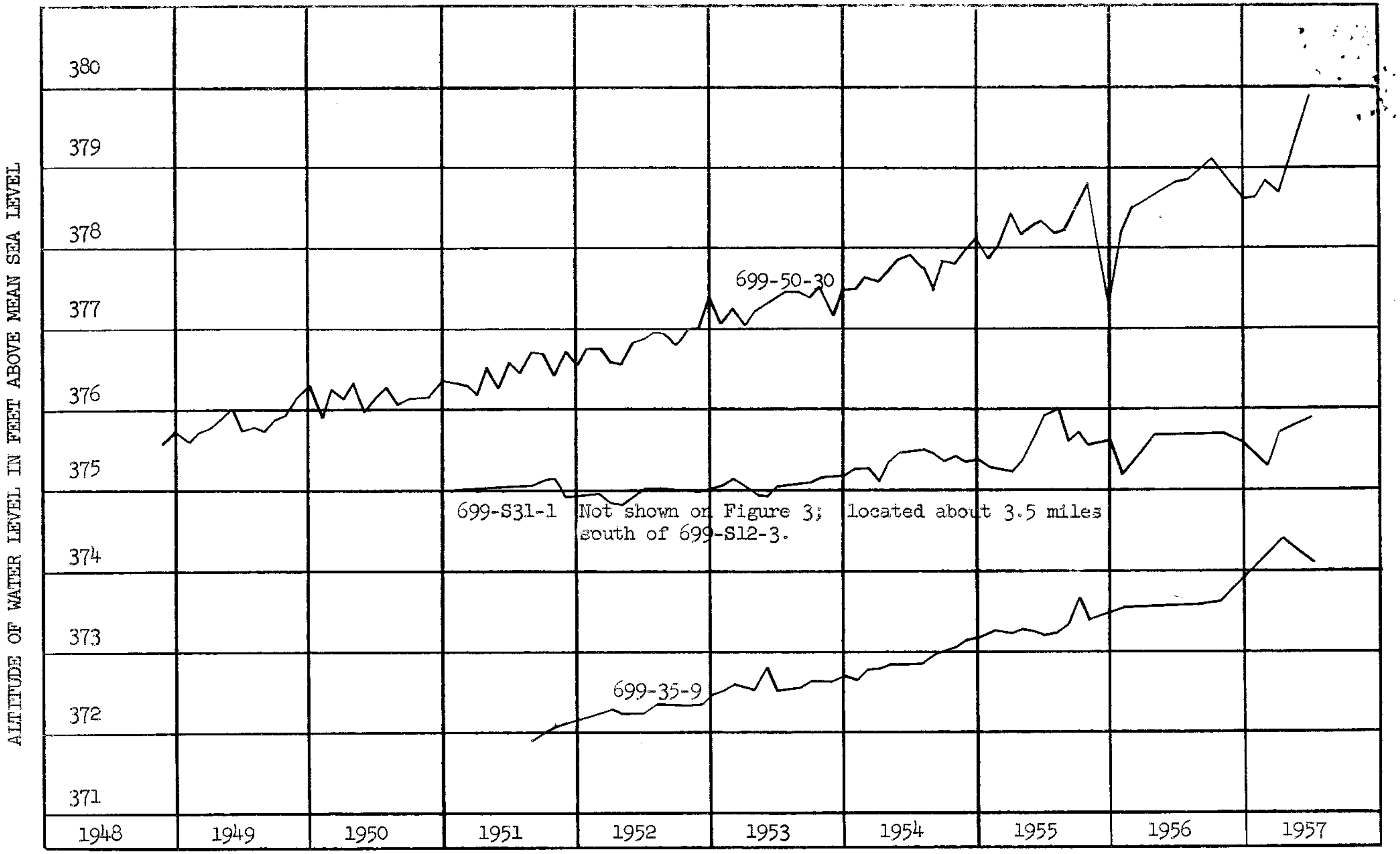

Plate 10.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-50-30, 699-S31-1, and 699-35-9.

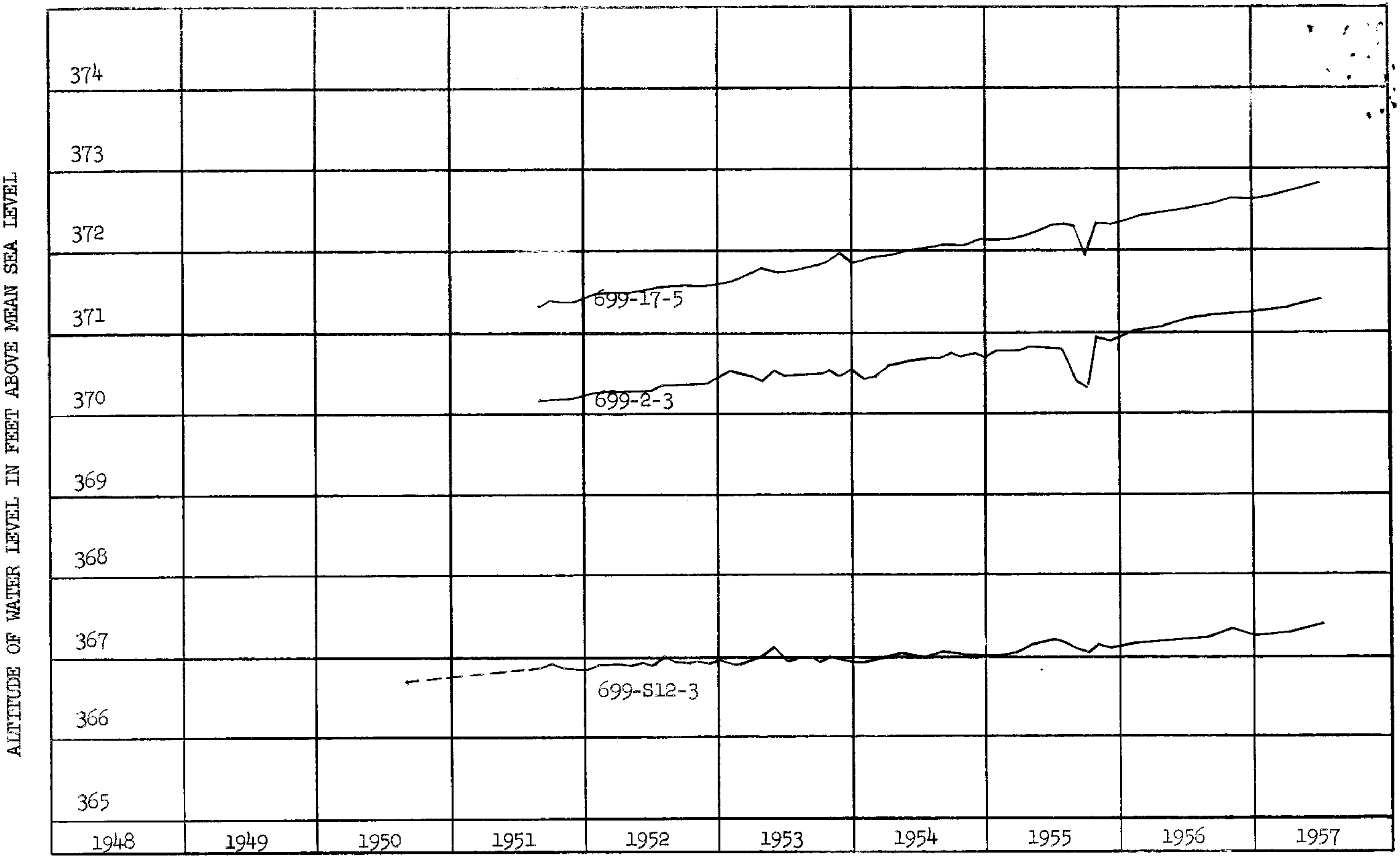

Plate 11.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-17-5, 699-2-3, and 699-S12-3.

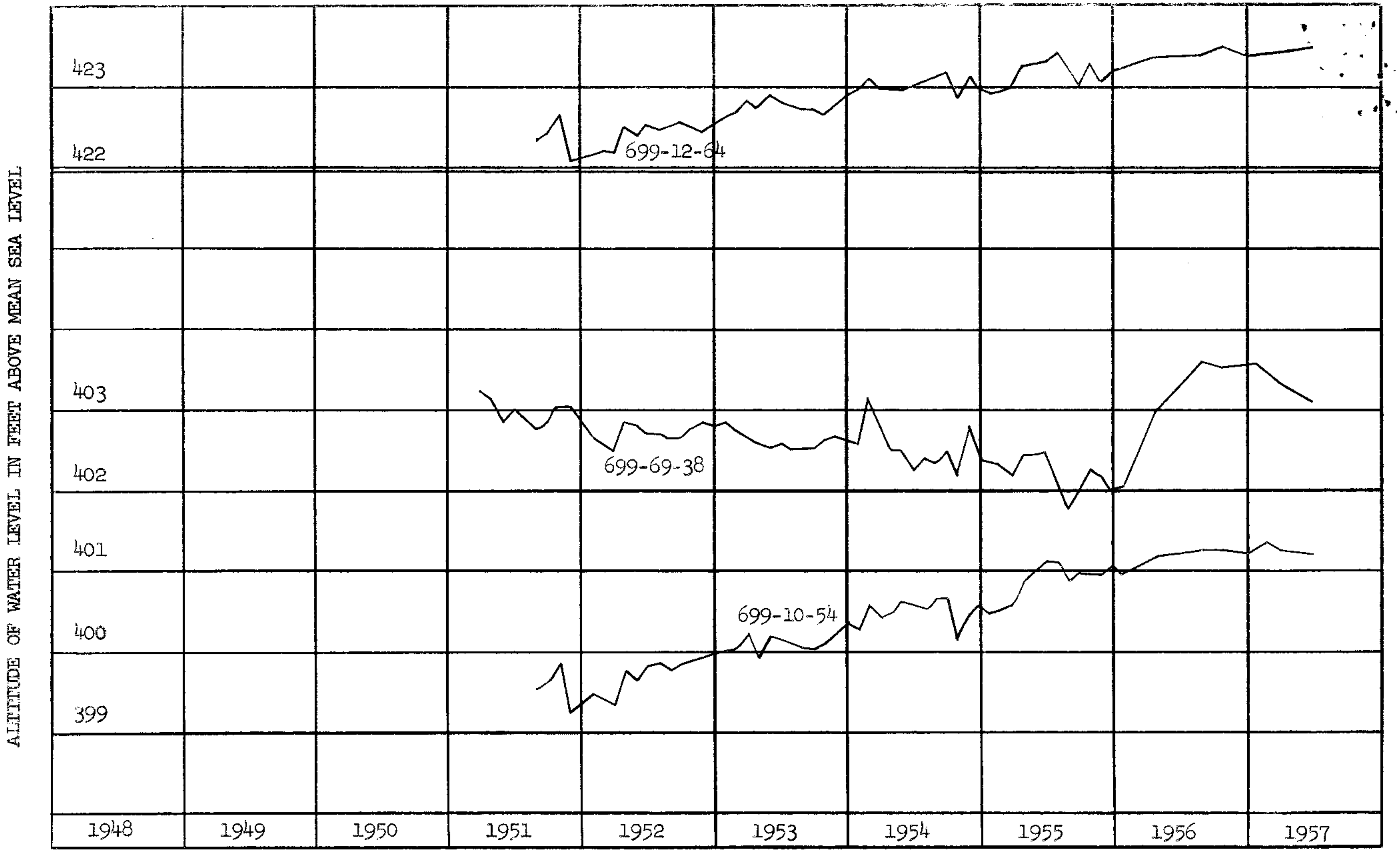

Plate 12.

FLUCTUATIONS OF WATER LEVELS IN WELLS 699-12-64, 699-69-38, and 699-10-54.

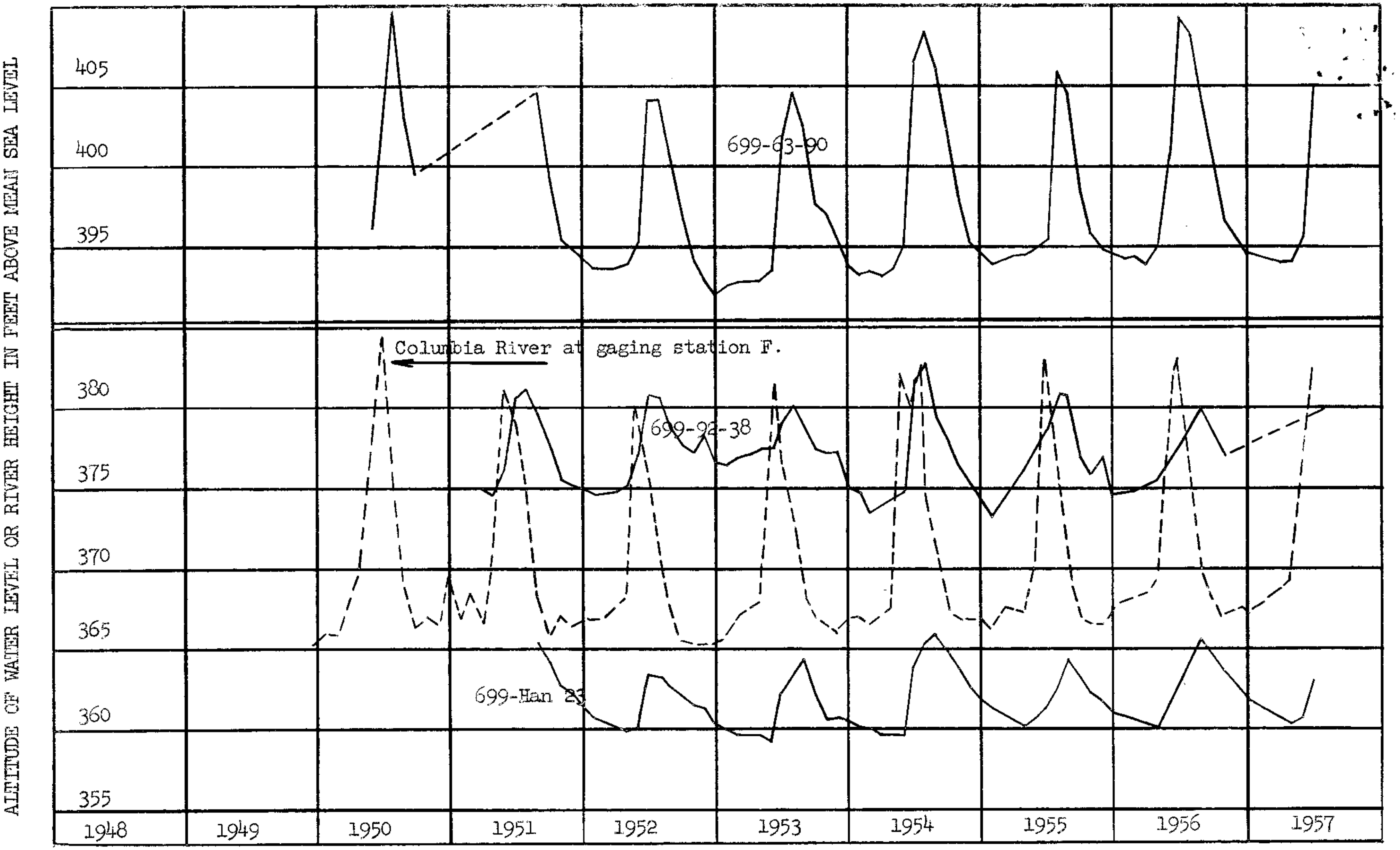

PLATE 13.

CORRELATION BETWEEN FLUCTUATION OF WATER LEVEL IN SELECTED WELLS AND OF RIVER FLUCTUATION.

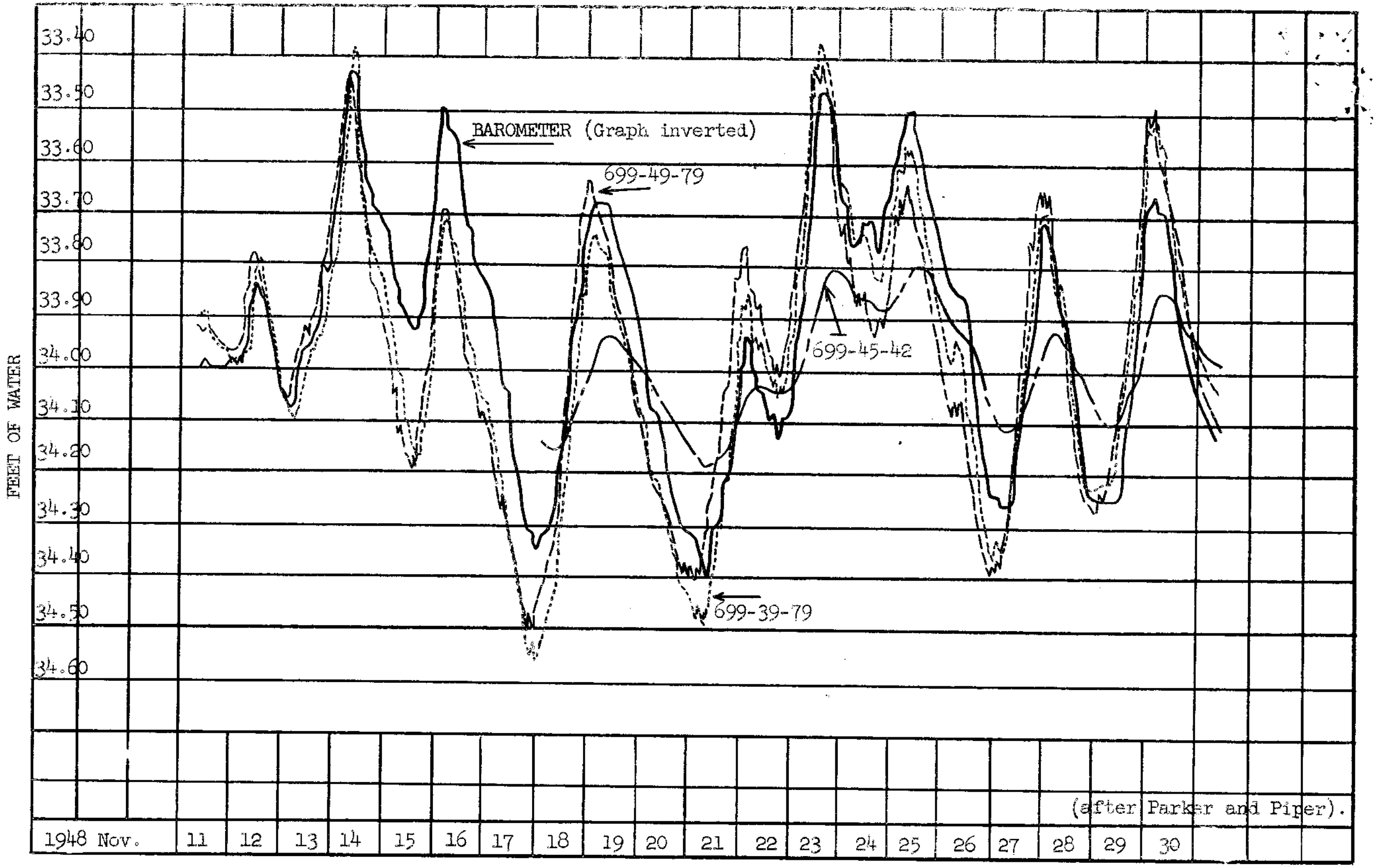

Plate 14.

CORRELATION BETWEEN FLUCTUATION OF WATER LEVEL IN SELECTED WELLS AND OF BAROMETRIC PRESSURE.

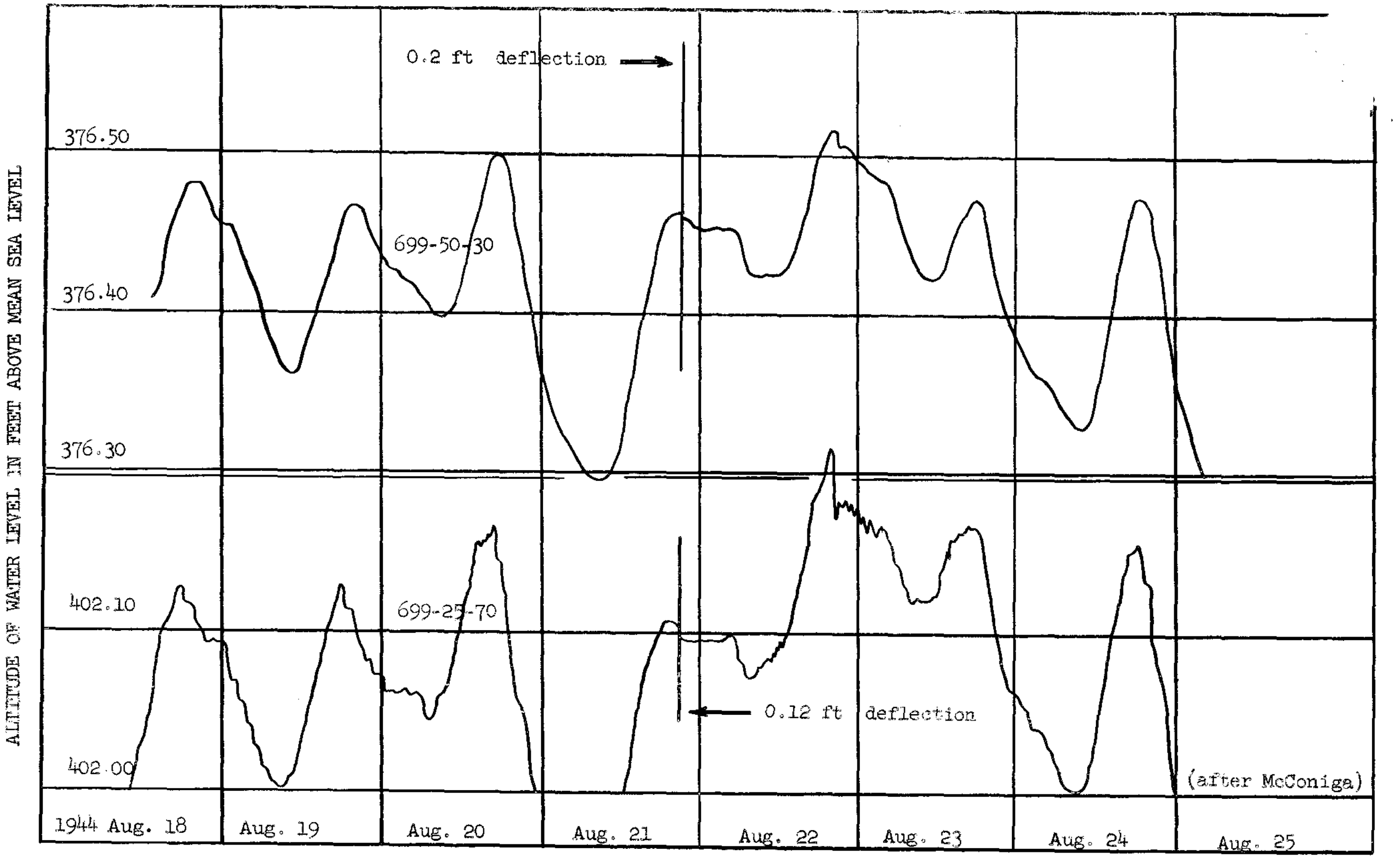

Plate 15.

THE KETCHIKAN, ALASKA EARTHQUAKE OF 8-21-49

As Shown by Water-level Fluctuations in Wells 699-50-30 and 699-25-70.