Progress Report No 1

Laboratory Investigation of the removal of Salt Water from a Two-part aquifer using Tile drains installed in the upper member.

Hydraulics Branch Report No. HYD-520

June 27, 1963

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DEPARTMENT OF THE INTERIOR
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Office of Chief Engineer
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Laboratory Report No. Hyd-520
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Subject: Progress Report No. 1--Laboratory Investigation of the Removal of Salt Water from a Two-part Aquifer Using Tile Drains Installed in the Upper Member

SUMMARY AND TENTATIVE CONCLUSIONS

A 1:40 scale model of an idealized portion of the Gila Valley was constructed and tested to determine the hydraulic action of tile drain(s) placed 8 feet below the ground surface. An upper aquifer, 40 feet thick, composed of fine sand was placed over a lower aquifer, 40 feet thick, composed of coarse sand having a permeability 50 times as great as the fine sand, in a testing tank 16 feet long and 2.5 feet wide and deep. The lower aquifer (and in some tests the upper aquifer also) was charged with salt water, colored blue for visual identification. Fresh water was applied to the upper aquifer surface and the drain effluent was regularly sampled, analyzed, and used to determine the flow of waters in the model. The model was operated continuously for days, keeping a continuous supply of fresh irrigation water flowing into the upper aquifer and a continuous flow of drainage water from the drain(s).

The statements made below are tentative conclusions based on thoughts extrapolated from five tests made in the Bureau of Reclamation Hydraulic Laboratory in Denver, Colorado. Conclusions of this type may seem premature, but the need for information on the salt water problem in the Gila Valley is urgent. There are no previous tests or precedent to guide the testing procedures or the drawing of conclusions. Yet it is believed that the conclusions stated below are valid and that future investigations will prove them to be true.

Data from the five tests described in this report indicate that:

1. A tile drain (or drains) placed 8 feet below the top surface of a two-member aquifer (top member fine sand 40 feet thick; lower member coarse material 50 times as permeable and 40 feet thick) will not intercept and discharge fresh water if the lower aquifer contains salt water. The drain will discharge

salt water having a salt content up to about two-thirds or three-fourths of the salt content of the lower aquifer.

2. Reducing the horizontal distance between drains reduces the upper limit of salt content in the drain effluent, but it does not appear to be economically possible to reduce the drain spacing sufficiently to obtain a fresh water (or nearly fresh) effluent. A greater number of drains does reduce the time required to flush the aquifer free of the salt water that can be moved to the drains. Drain spacings ranging from about 1, 280 feet to 320 have been investigated.

3. The reduced quantity of salt water which flows to the drains from the lower aquifer as a result of decreasing the drain spacing is associated with a corresponding increase in the amount of salt remaining in permanent storage in the aquifer. From visual estimates the salt remaining in permanent storage for a 1, 280-foot drain spacing is very small, for 640 feet is about one-sixth of the original volume, and for 320-foot spacing is about one-fourth of the original volume.

4. The aquifers are flushed substantially free of salt water when the quantity (volume) of fresh water applied to the ground surface (irrigation water) becomes equal to the volume of salt water originally present in the aquifer. Based on model test results and using an estimated time correction factor to account for nonirrigated areas, the time necessary to accomplish this in the Gila Valley would be of the order of 12 to 18 years. The time scale is one 24-hour model day equals 4.5 prototype years.

5. The path followed by fresh water from the aquifer surface to the tile drain located in the upper aquifer is, in general, vertically downward through the upper aquifer, horizontally through the more permeable lower aquifer to a point approximately beneath the drain, then vertically upward to the drain. Only slight mixing of the fresh and salt waters occurs during the flushing process. The fresh water tends to drive the salt water ahead of it to the drain.

6. In all of the tests performed thus far, there has resulted a permanent storage of a portion of the original salt water contained in the aquifer. The reason for this is that the saline water is heavier than the fresh water and a balance of forces develops in which the saline water reaches a condition of complete stagnation. Along the curved and sloping interface between the fresh and saline waters the greater hydrostatic pressure of the saline water is counterbalanced by the dynamic forces producing flow along the interface on the fresh water side. A similar balance exists in coastal areas where the seaward moving ground waters

come in contact with the saline ocean water. This balance is a very delicate one and is influenced by the ratio of densities of the salt and fresh waters and by the rates at which water is supplied to the area between drains.

7. The present experiments have been made to clarify some of the aspects of salt removal which were of immediate concern. Much more experimentation will need to be done to evaluate the influences of density differentials and flow rates. Some analytical work will be needed to clarify the effects of flow and density variations and to reduce them to quantitative values.

The conclusions reported here are limited to the case of a two-part aquifer having certain geometric and physical characteristics. The more common case of a uniform aquifer will need to be studied as will other combinations of two-or-more-part aquifers before general conclusions can be made regarding aquifer clearing processes.

HISTORY

The Wellton-Mohawk area in Arizona is located in the valley of the Gila River near the junction of the Gila and Colorado Rivers. The irrigated lands in this area are located in the river valley which is, on the average, about 4 miles wide and extends for about 40 miles along the valley floor. These relationships are shown on the map of Figure 1.

The river valley occupies a trench eroded in part through lacrustine sediments of an earlier geologic era, and in part passes around and through the boundaries of crystalline rocks. The higher mesa lands which border the river valley along a part of its southern boundary represent the old lake deposits in which the present valley is incised. These beds are also present below the alluvial fill which now exists below the valley floor. The bottom member of this alluvial fill consists generally of coarse sands and gravels; the upper member is generally composed of fine sands and silts. The nature of these deposits is shown in Figure 2.

Beginning about 1915, irrigation of valley lands was started using water obtained from wells. By about 1934, the salinity of the well water had increased to detrimental levels, the water table had sunk alarmingly, and it was apparent that supplemental irrigation water from the Colorado River must be used if irrigation was to continue. By May 1, 1952, water diverted from the Colorado River at Imperial Dam was being delivered and used in the Wellton-Mohawk area. These facilities were constructed by the Bureau of Reclamation.

Continued application of the imported waters caused a rise of the water table, and by about 1959 it was apparent that drainage works would be necessary for control of the water table. To provide the required drainage a concrete-lined channel was constructed traversing the full length of the valley, and 69 wells with pumps were installed to lift the drainage water into the drainage channel. The channel has a maximum capacity of 300 cubic feet per second and discharges into the Colorado River. The effluent originally had a salt content of about 6,000 parts per million by weight (ppm).

During the winter months the water delivered via the Colorado River to Mexico at the northern boundary may be as little as 900 cubic feet per second. At such times, the salinity of the delivered water may rise to about 2,700 ppm, making it undesirable for use as irrigation water. The Mexican people have protested sufficiently against delivery of water having such a high salt content that the President of the United States and the President of Mexico met and agreed to appoint panels to study the possibilities for reducing the salinity of the waters being delivered to Mexico. The United States panel promptly prepared a report outlining certain measures which could be taken to reduce the salt content of the water being delivered. One suggestion was to install drainage tile or construct open drains at relatively shallow depths to intercept the water being drained from the land before it became salty. It seems to have been supposed that the drains would collect substantially all of their flow from percolations coming into the upper part of the aquifer and leave the lower saline waters in permanent ground-water storage. Investigations described in this report show that this assumption is not confirmed.

PURPOSE OF TESTS

Previous studies of the behavior of fresh water sea water interfaces in coastal areas and construction of a flow net indicated that the selective type of drainage operation proposed for the Gila Valley might not be realized. Because of this uncertainty it was decided to design, build, and test in the laboratory, a model including the aquifers and a drainage system. As far as can be determined there are no previous investigations of this type and consequently there were no established principles to offer guidance in designing or testing a model. Construction and testing procedures were therefore modified as necessary before, during, or after accomplishment in an attempt to develop techniques.

THE MODEL

Model Construction

The model was constructed to a linear scale of 1:40 in a glass-walled tank. This tank is 2.5 feet wide and deep and has transparent plastic walls on both sides. Of the entire length, a portion 16 feet long was isolated and used to represent half the distance between two drains. To scale, this would represent a drain spacing of 1,280 feet. To represent the two-part Wellton-Mohawk aquifer, two laboratory prepared sands were selected having, respectively, the permeability of the lower gravel in the Gila Valley and the permeability of the upper sand and silt member in the Gila Valley. The sands were selected on the basis that the coarse sand was 50 times as permeable as the finer sand. The coarse sand was placed in the bottom of the tank to a depth of 11 inches, and the fine sand was placed over this to an additional depth of 1 foot, Figure 3. Between these layers a sand of intermediate size, about 1 inch in thickness, was installed to prevent the upper fine sand from working down into the coarse sands below. As placed, these sands represent prototype depths of about 40 feet each and a total aquifer depth of 80 feet.

In the Gila Valley, the aquifers vary somewhat in thickness, as shown in Figure 2, but the model is believed to provide an approximate representation of the major portion of the Wellton-Mohawk aquifer. In making these decisions, it was considered more important to idealize the problem and establish flow and drainage principles, than to represent precisely the aquifer and flow condition at some selected spot in the Wellton-Mohawk area.

In an idealized model using homogeneous aquifers it can be assumed that there is no flow across the zone midway between drains; therefore, the midpoint of the drain spacing could be represented by an impermeable bulkhead (a plane of symmetry), and a vertical section at the drain could be represented by an impermeable bulkhead, Figure 3. For the same reason there is no flow across a vertical section passing through the centerline of a drain. The drain itself was represented by a perforated copper tube about five-eighths inch in diameter, wrapped with a single layer of fine brass screen, to prevent clogging of the holes. A "T" section at midlength of the copper tube was connected to a short length of pipe which was passed through the bulkhead. The pipe conveyed the drainage flows through the bulkhead to permit sampling, flow measurement, and disposal. On the aquifer side of the bulkhead, the copper drain tube was placed closely against the bulkhead and a small quantity of the intermediate sand was placed around the pipe and against the bulkhead to effectively locate the exact point of drainage at the face of the bulkhead.

Prior to placing the aquifers, piezometer taps had been installed on the centerline of the floor of the tank at each end, in the middle, and between the middle and each end, Figure 3. Flexible plastic tubes attached to these taps were connected to five glass manometer tubes mounted vertically on the middle supporting post of the tank. These manometers are visible in all the photographs. A scale behind the tubes permits reading of the pressures on the bottom of the tank. Directly above each of the piezometer taps an observation well was installed consisting of a short, open-end glass tube extending down into the upper aquifer, Figure 3. The position of the water table during a test could be read by a point gage mounted on a traveling carriage and lowered into the tube from above. A 1-inch layer of coarse sand was placed on top of the upper sand aquifer and served to distribute uniformly the water applied to the aquifers during a test and to prevent erosion of the fine sand. A valved pipe distribution system was also installed along the centerline of the bottom of the flume to introduce salt water into the tank at approximately the one-third points of the model.

Model Operation

To simulate field conditions as they are believed to exist in the Gila Valley, the lower aquifer was saturated with salt water before irrigation water was applied to the surface of the upper aquifer. To facilitate visual observations of the salt water movements in the lower aquifer the salt water was dyed blue. Sodium chloride (NaCl) was the salt added to provide the proper density; potassium chloride (KCl) was added to provide means for quick flame photometer analysis of drain samples. The mixture varied slightly from test to test but the salt water contained approximately, by weight,

250 ppm patent blue dye
6,000 ppm sodium chloride
100 ppm potassium chloride.

The salts and dye in powder form were added to water in a 50-gallon drum and thoroughly mixed using a pneumatic propeller mixer. The mixture from the drum was fed into the valved distribution system at the bottom of the testing tank and allowed to slowly rise to displace the air in the lower aquifer interstices and the film of moisture covering each sand particle. Several hours were required to raise the level of the blue salt water to near the top of the lower aquifer. To prevent capillary action from pulling salt water up into the upper aquifer, the flow of blue salt water was stopped before it reached the separating sand layer. Fresh water was then added to the surface of the upper aquifer and allowed to permeate the upper sand. The lower salt water flow was then restarted, the process being repeated until the lower aquifer was full of blue salt water and the upper aquifer was full of fresh water up to the level of the drain, 0.2 foot below the surface. Figure 4 (H-1480-10) shows the bottom aquifer almost full of blue salt water and the upper aquifer almost wetted with fresh water.

In the first test, water, representing the irrigation water applied to crops, was applied to the surface of the upper aquifer by means of a sprinkling can. Three gallons were applied in less than a minute at 1-hour intervals. The water was carefully distributed over the entire surface of the model and the quantity was sufficient to raise the water table about 0.1 foot above the level of the drain. The water table level was closely observed and was never allowed to reach the top of the upper sand.

In later tests, a perforated garden hose was used to provide a uniform and continuous supply of irrigation water, 3 gallons per hour, rather than the hourly application of 3 gallons. The hose was laid on the longitudinal centerline of the model on the coarse sand covering previously described; the water issued from pinholes uniformly spaced along the underside. The fine sand aquifer was left bare for about 6 inches across the width of the tank at the drain end of the model to insure that no free water ever was present in this zone.

Measurements were systematically made of the levels in the observation wells throughout the period of the test. Samples of the drain effluent were taken at scheduled times for chemical and colorimetric analysis to find the quality (salt content) of the drain effluent. Measurements of the rate of flow from the drain were made at regular intervals, and photographs on 35-mm color film and 4- by 5-inch black and white film were taken at frequent intervals. A 16-mm time-sequence motion picture film was also made; individual frames were taken at 1-, 3-, or 6-minute intervals, day and night throughout the test.

In later tests another drain assembly was placed at the other bulkhead to represent a field problem with a drain spacing of 640 feet; a third drain was placed at the center of the test tank to represent a drain spacing of 320 feet. Irrigation water rate of application was increased to 12 gallons per hour and other modifications were made to the model and testing procedures as testing progressed. Variations are discussed as they occur in each test, but in general procedures were as described.

THE INVESTIGATION

Results of Tests 1 and 2

Test 1.--Almost immediately after the first application of 3 gallons of water to the top aquifer, the saline (blue) water began to flow through the fine sand layer, toward and out of the drain, Figure 5 (H-1480-13). After a few hours a blue wedge had formed near the drain in the upper aquifer. It assumed a triangular shape with the hypotenuse at an angle of about 45° to the horizontal. After 11 hours the hypotenuse began to show a convex shape. This configuration was maintained until sufficient water had been added to the upper aquifer (50 hours) to begin the flushing out of the lower aquifer with fresh water, Figure 6 (H-1480-23). As the testing proceeded, the blue water came to be confined to a narrow wedge in the lower sand and a very narrow band in the upper sand. After 4 days of operation most of the blue saline water had been flushed out of the lower aquifer except close to and below the drain where the height of the blue wedge in the lower sand always occupied the full depth of the lower sand. The face of this wedge was concave upwards. Two more days of operation failed to dissipate the wedge.

Figure 7 is a record of Test 1 operations and results plotted against the days of the month (which indicate the duration of the testing). The water application curve (also water discharge curve) indicates that water was added during the regular working hours on the 19th, 20th and 21st of March 1963; no water was added during the 16 off hours. Starting on the afternoon of March 21, water was added day and night; every hour 3 gallons of water was sprinkled over the surface. The drain effluent sodium chloride concentration curve shows that the salt content of the drain water rose rapidly for the first 2 days of the testing, fell off at a rather rapid rate for about 3 days, then gradually approached a clear water condition, although a fully clear condition was not reached after 8 days of testing. The potassium chloride curve indicates a similar action. Figure 8 shows water surface profiles as determined from water surface observations made in the wells during one water cycle application. The scale sketch at the bottom of the figure shows the stations at which wells were located, the drain location, and the relative height of the water level change in terms of the total depth of aquifers.

The upper curves in the figure show the water surface plotted to an exaggerated vertical scale. The top curve labeled "zero minutes" indicates the water table surface, beneath the surface of the upper aquifer, immediately after application of 3 gallons of water over the upper aquifer surface. The next curve below was taken 15 minutes later, the next 45 minutes later, and the bottom curve 60 minutes later. At this time the cycle was repeated and more measurements were taken.

The convex upward curve of the water surface found in all profile measurements was a reality and was not the result of poor measuring techniques. No explanation for the curvature has yet been found. The rise in water surface indicated between the upstream bulkhead and the high point in the water surface was about one-eighth inch in the model.

The results of Test 1 indicate that a single drain placed 8 feet below the surface of the upper aquifer will not, as might be expected, intercept the fresh water applied to the upper aquifer surface. This is true even when there is a sufficient quantity of fresh water to raise the average water table level above the level of the drain. Instead, the fresh water tends to follow a path of least resistance by working its way into the lower aquifer, where flow resistance is considerably less, and pushing salt water up through the upper aquifer to the drain. The drain effluent is thereby contaminated with salt. Analysis of the drain effluent indicates that the salt concentration rose as high as 4,500 ppm, and for a period of over four model test days stayed above 1,500 ppm.

Test 2.--Test 2 was, after inspecting the results, a rerun of Test 1. In this test water was applied to the upper aquifer continuously at a uniform rate (3 gallons per hour) through a perforated garden hose laid along the centerline on the top of the model. The water application and discharge curves are shown in Figure 9. Salt concentration in the drain effluent was practically the same as for Test 1 and the overall test results were practically identical. For a direct comparison of Tests 1 and 2 the salt concentration curve for Test 1 has been replotted in Figure 10, after making time adjustments to compensate for the differences in the method of application of the fresh water. The slight displacement of the curves of Tests 1 and 2 is not significant in drawing general conclusions from these tests.

Figure 9 shows the drain effluent discharge rate in gallons per hour plotted against model time in days. Although the rate of water application should have been constant, the variations indicated are the result of needle-valve-control clogging, line pressure variation, etc. The large sudden increase at noon on April 8 was caused by opening the needle valve to clear the clogging prior to resetting of the desired quantity. A study of these two curves indicates that there is, in general, an increase in salt concentration when there is an increase in fresh water discharge, and that the effect is apparent almost immediately. It may therefore be concluded that the rate of application of fresh water has some effect on the salt concentration in the drain effluent.

Near the end of the second test, crystals of potassium permanganate were used to indicate flow direction in various parts of the model. The crystals were placed against the glass wall of the tank by inserting a glass tube, through the sand until the bottom was at the desired elevation, dropping the crystals down the tube and then withdrawing the tube so that the sand closed in around the hole. Flow past the crystals left color trails which, if inspected and traced at regular intervals, indicated flow direction and velocity. Crystals introduced within the boundary of the blue wedge below the drain indicated flow toward the drain. Elsewhere, the dye streaks indicated the flow to be downward through the upper sand to the lower land, horizontal flow through the lower sand, and upward flow to the drain. Such a flow path represents essentially the flow path of least resistance. Figure 11 (H-1480-65) shows three vertical dye traces, one in each of the three upstream panels, and two dye traces in the downstream panel approaching the drain. The third dye trace in the downstream panel shows flow downward through the upper aquifer into the lower aquifer even though the starting point for this flow trace was just off the end of the blue wedge, which indicated flow directly to the drain, similar to that in Figure 5.

Time Correlation

Although the linear scale of the model is 1:40 the time scale is not the same. Correlation of model and prototype times must be made on the basis of comparative volumes. The prototype aquifer, 80 feet deep, with a 40 percent gross porosity would contain (80)(0.4) = 32 feet of water. Deep percolation of 3 feet per year would replace the original water content in a period of 32/3 = 10-2/3 or, say, 11 years. The model is 16 feet long, 2.5 feet wide, and 2 feet deep. The volume is (16)(2.5)(2) = 80 cubic feet. With a gross porosity of 40 percent the water content would be (80)(0.4) = 32 cubic feet. An inflow of 3 gallons per hour for an 8-hour period would supply $\frac{(3)(8)}{8}$ = 3 cubic feet using the approximation that there are 8 gallons in a cubic foot (actually 7.4805 gallons per cubic foot). On this basis, the time required to replace the original water content in the model would be 32/3 = 10-2/3 ≈ 11 (approximately) periods of 8 hours each. A comparison of these values will indicate that about 8 hours of model time represent a year of prototype time. It should be noted, however, that this comparison is for a completely irrigated area. Since the entire Wellton-Mohawk Valley is not irrigated, the water replacement process in the Gila area may be expected to take somewhat longer than indicated by the above calculations. It may be reasonable to increase the time by 50 percent to obtain a realistic prototype time estimate. Thus the 8 days of testing indicated in each of Tests 1 and 2 would probably represent 25 to 35 years of prototype time. However, the salt was substantially removed in 4 days which represents perhaps as little as 12 years in the prototype.

Results of Test 3

For Test 3 a drain was installed at the bulkheads at each end of the tank and another was installed at the middle. With three drains the model extended throughout two adjacent drain spacings. With reference to the prototype the drain spacing would be about 320 feet. Test 3 was run with a continuous and uniform water supply at a rate of about 13 gallons per hour applied through the perforated hose. The initial depth of blue salt water introduced into the lower aquifer was 1 foot.

After the fresh water flow was initiated the salinity of the effluent from Drains A and C located on the bulkheads, Figure 3, quickly rose to a peak of about 2,700 ppm, as shown on Figure 12 and then declined. The original concentration of the saline solution was 6,200 ppm.

The average discharge from Drain A was 3.42 gallons per hour; from Drain C, 2.87 gallons per hour. The average discharge from Drain B (middle) was 6.74 gallons per hour. The middle drain could draw water from both horizontal directions, which accounts for its larger discharge. The effluent from Drain B reached a maximum concentration of only 2,250 ppm. Plotted data for Drains B and C are not submitted but appear to be consistent with the curves of Figure 12. Figure 13 shows water table surface profiles for times and dates as indicated. The variations in profile shape are minor and indicate the probable range of profile differences throughout the testing period. Figure 14 (H-1480-97) shows the blue salt water approaching the center drain only 1 hour and 5 minutes after the start of the test. Figure 15 (H-1480-99) shows the blue wedges at the drains 1 hour and 30 minutes later. Figure 16 (H-1480-107) shows the reduction in color in the wedges and the beginning of the sharp interface in the lower aquifer, indicating a complete displacement of salt water.

At the completion of the test (after almost 4 days) a sharp interface was present in the lower gravel layer, Figure 17 (H-1480-115). The blue salt solution remaining below the interface occupied about half of the volume of the gravel layer, or one-fourth the volume of the entire model. At this time the effluent still contained over 100 ppm of salt. This test indicated that a closer spacing of drains does reduce the salt concentration of the drain effluent, but a very close spacing would be required to produce a salt-free effluent.

Results of Test 4

The three drains described in Test 3 were also operating in Test 4. In this test, however, the salt water level was brought to the upper surface of the upper aquifer and initially occupied the entire volume of the model.

The initial concentration of salt used in this test was 6,000 ppm, by weight. The fresh water application rate was 3 gallons per hour, applied through the perforated hose. By comparing the results obtained from this test with those obtained from Test 3, it was hoped to get some indication of the effect of different initial amounts of salt and of different fresh water flow rates.

As expected, immediately after the start of the test on May 10, a salt concentration of 6,000 ppm appeared in the drain effluent. The behavior of the model proved erratic since the right-hand end of the model (as seen in the photographs) cleared first. The reason for this, determined after the conclusion of the test, was that inadvertently the hose was delivering more than half of the water to the right half of the model. Figure 18 (H-1480-130) shows the erratic clearing of the blue salt water from the upper aquifer and the beginning of the formation of a visible flow pattern at the middle "B" drain and right "C" drain, May 12, 1963. By May 20, 1963, a well established pattern for Drain A was apparent, and the C drain pattern was no longer visible. By May 28, 1963, the A and B drain flow patterns were beginning to disappear, and the position of the salt water in the lower aquifer was sharply defined, Figure 19 (H-1480-155). Testing was then discontinued. Figure 20 shows the salt concentration in the effluent from the three drains plotted against model time.

Results of Test 5

The middle drain (see Test 4) was plugged for this test, leaving the two end drains operative. This arrangement of the model represents a prototype spacing between drains of about 640 feet. The entire depth of both aquifers was saturated with blue salt water, as in Test 4. The fresh water flow rate was maintained at about 3 gallons per hour. The test is still running at the time of this writing and complete data have not been obtained, but a clearly defined interface is present as shown in Figure 21. It is believed that the interface has reached approximately its final configuration. There is some salt water remaining midway between the drains. The permanent salt water storage, as estimated visually, would be about one-third of the volume of the lower aquifer and one-sixth the volume of the entire model. The other five-sixths were removed between June 11, 1963, and June 20, 1963, a prototype time of perhaps 27 to 40 years. Most of the salt would be removed long before this time, however.

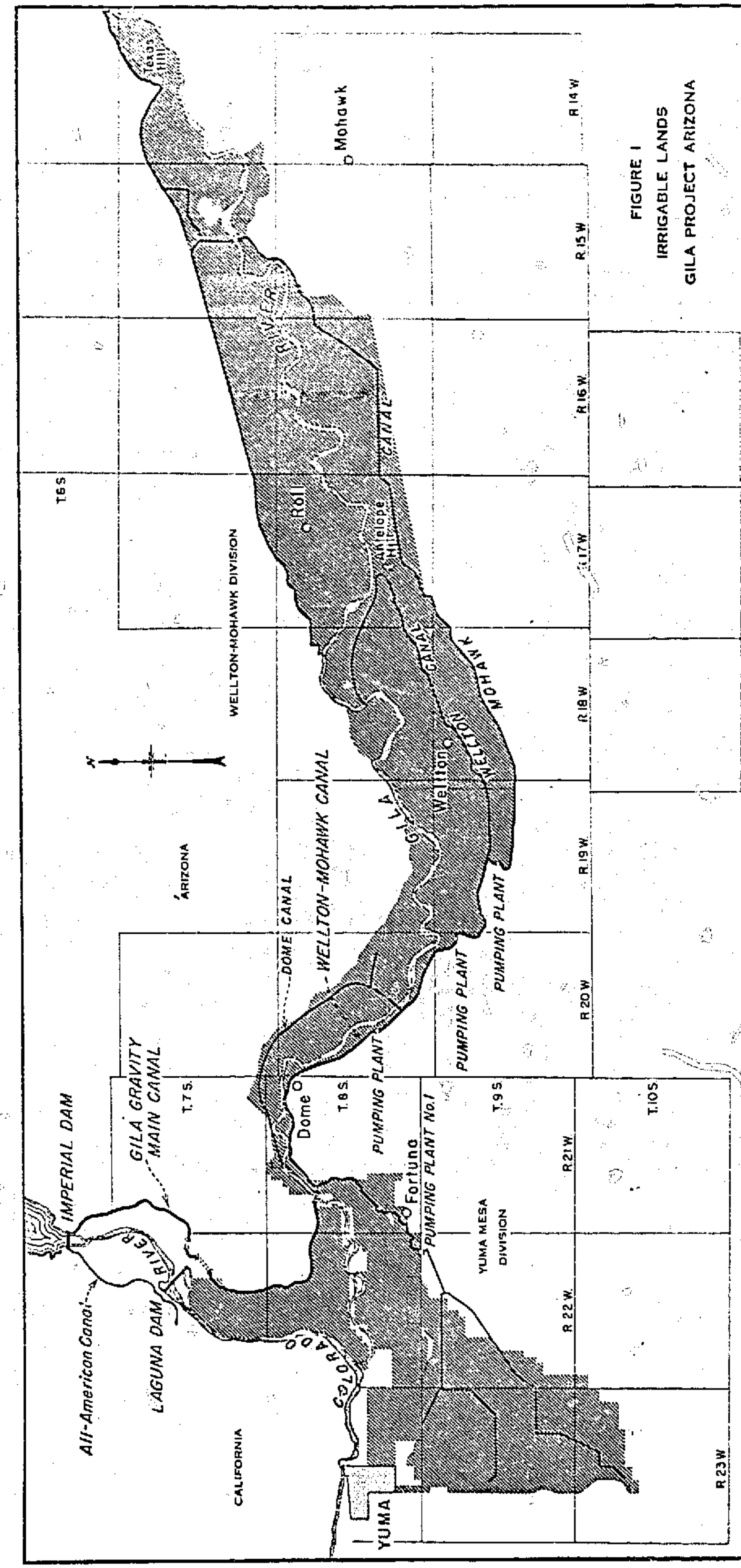
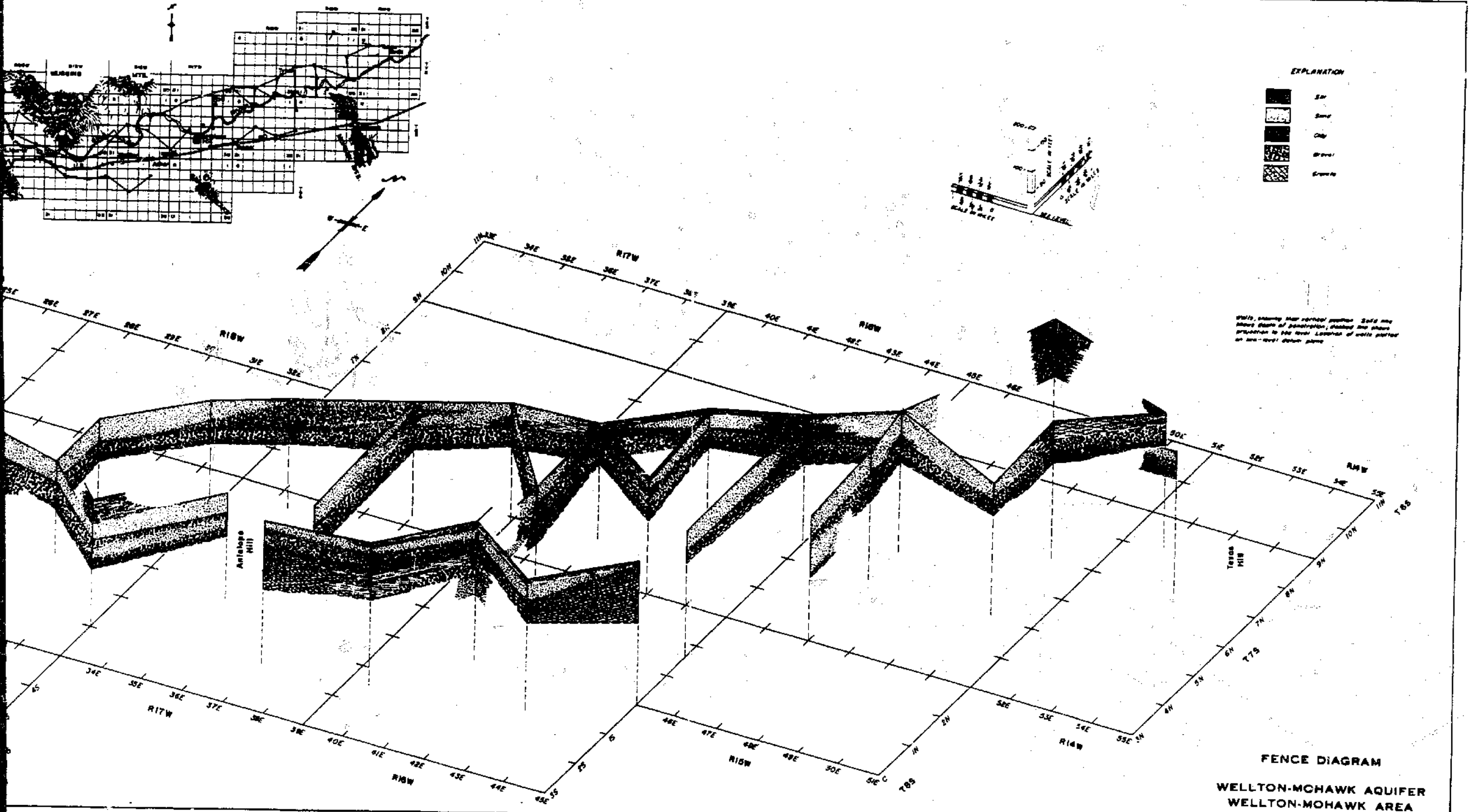
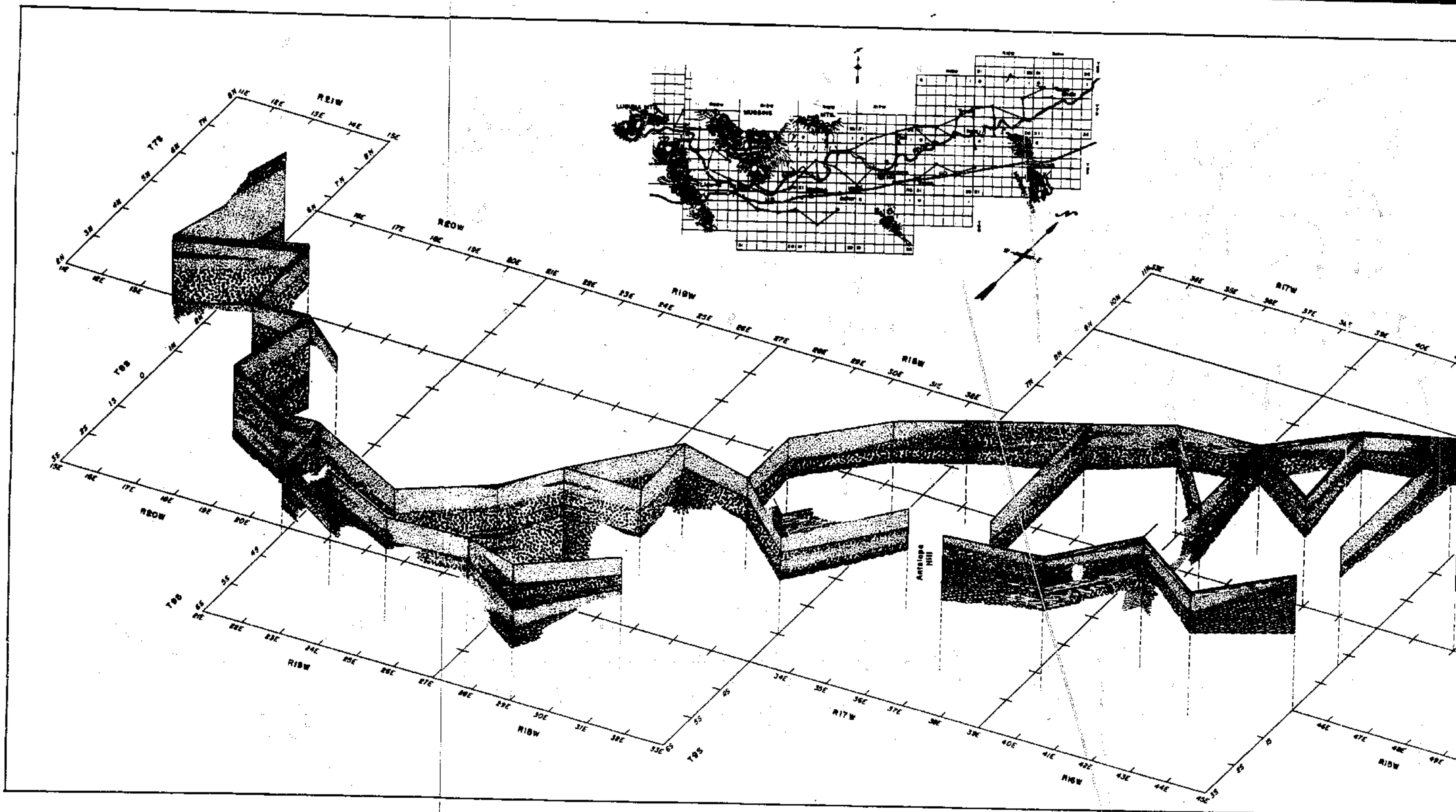


FIGURE 1
IRRIGABLE LANDS
GILA PROJECT ARIZONA



FENCE DIAGRAM

WELLTON-MOHAWK AQUIFER
WELLTON-MOHAWK AREA



FRAME 2

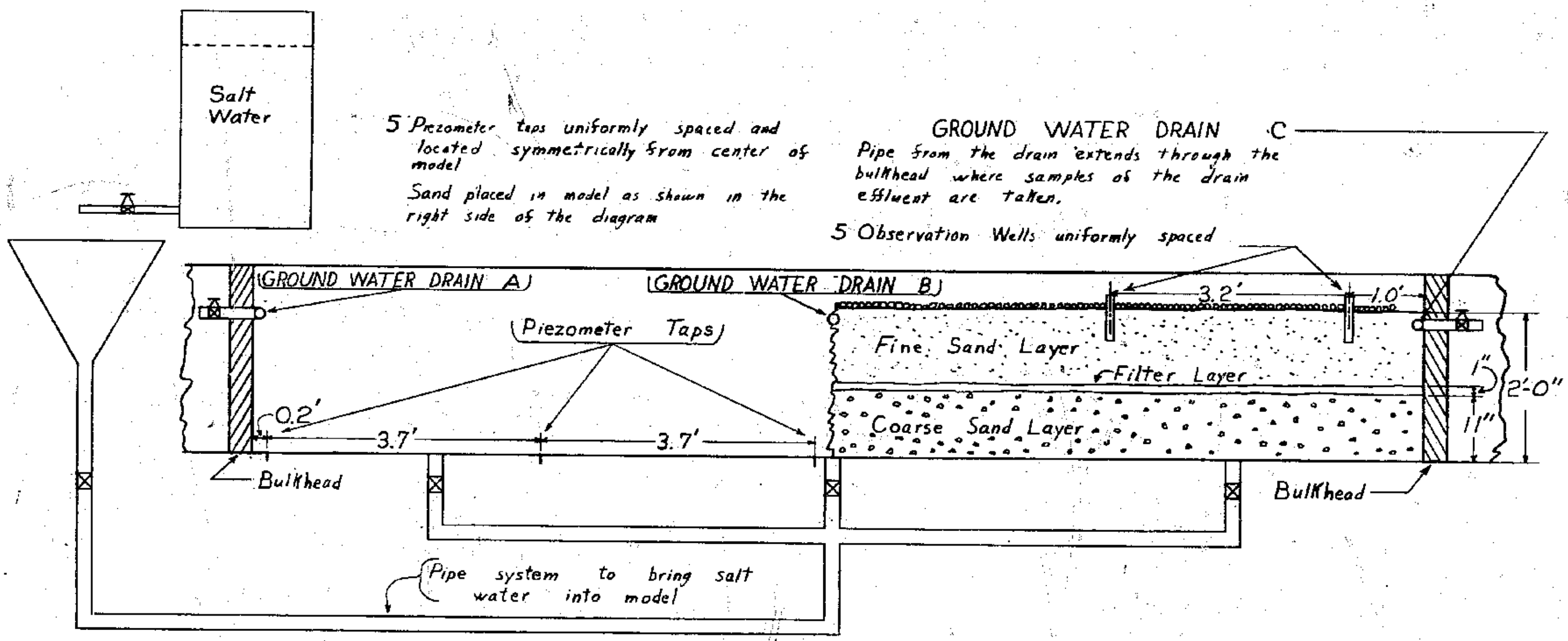
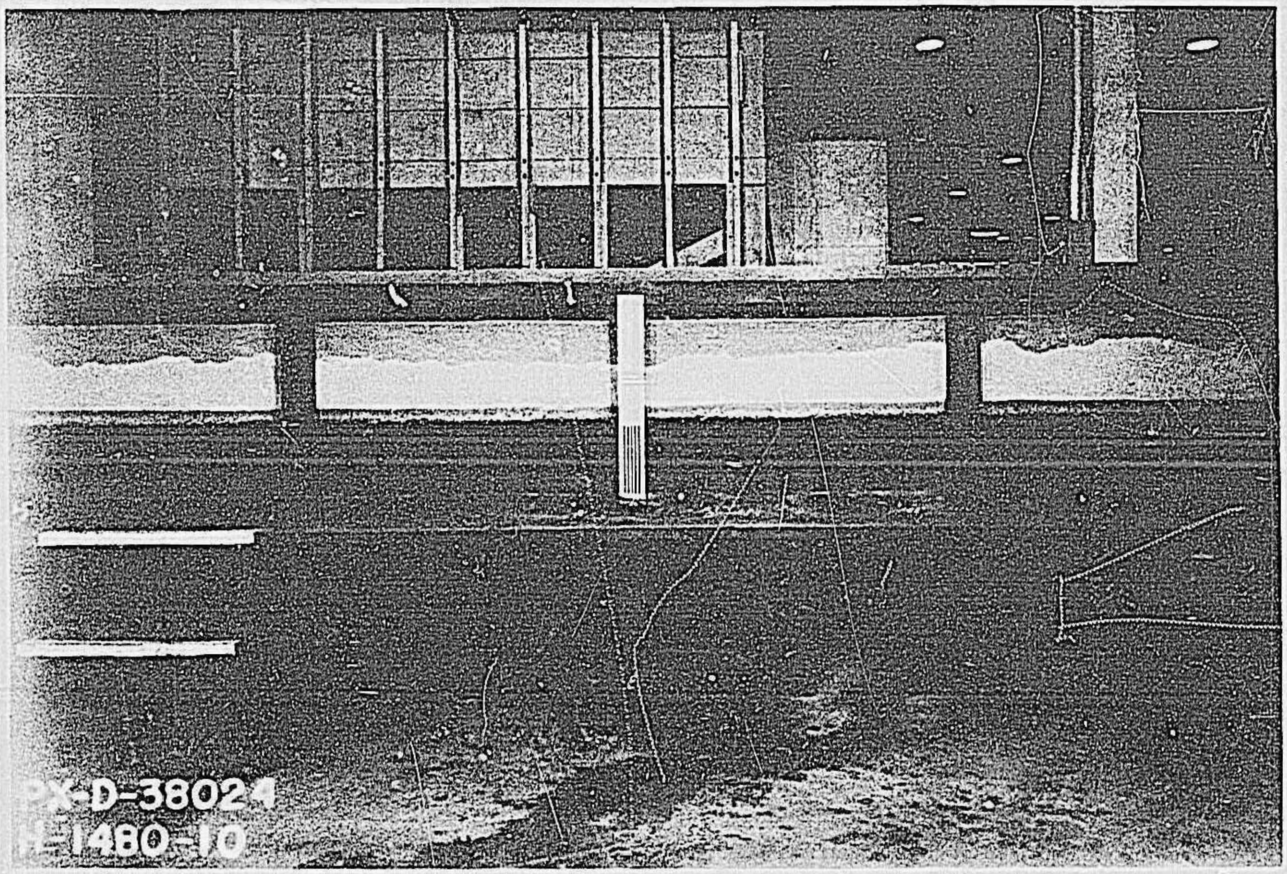


DIAGRAM OF THE
GILA VALLEY GROUND WATER MODEL

ERZ 6-24-63



Lower aquifer of coarse sand is almost filled with blue salt water and upper aquifer of fine sand is partially wetted with fresh water, prior to start of Test 1. Manometer tubes indicate the level of the salt water.

Figure 5
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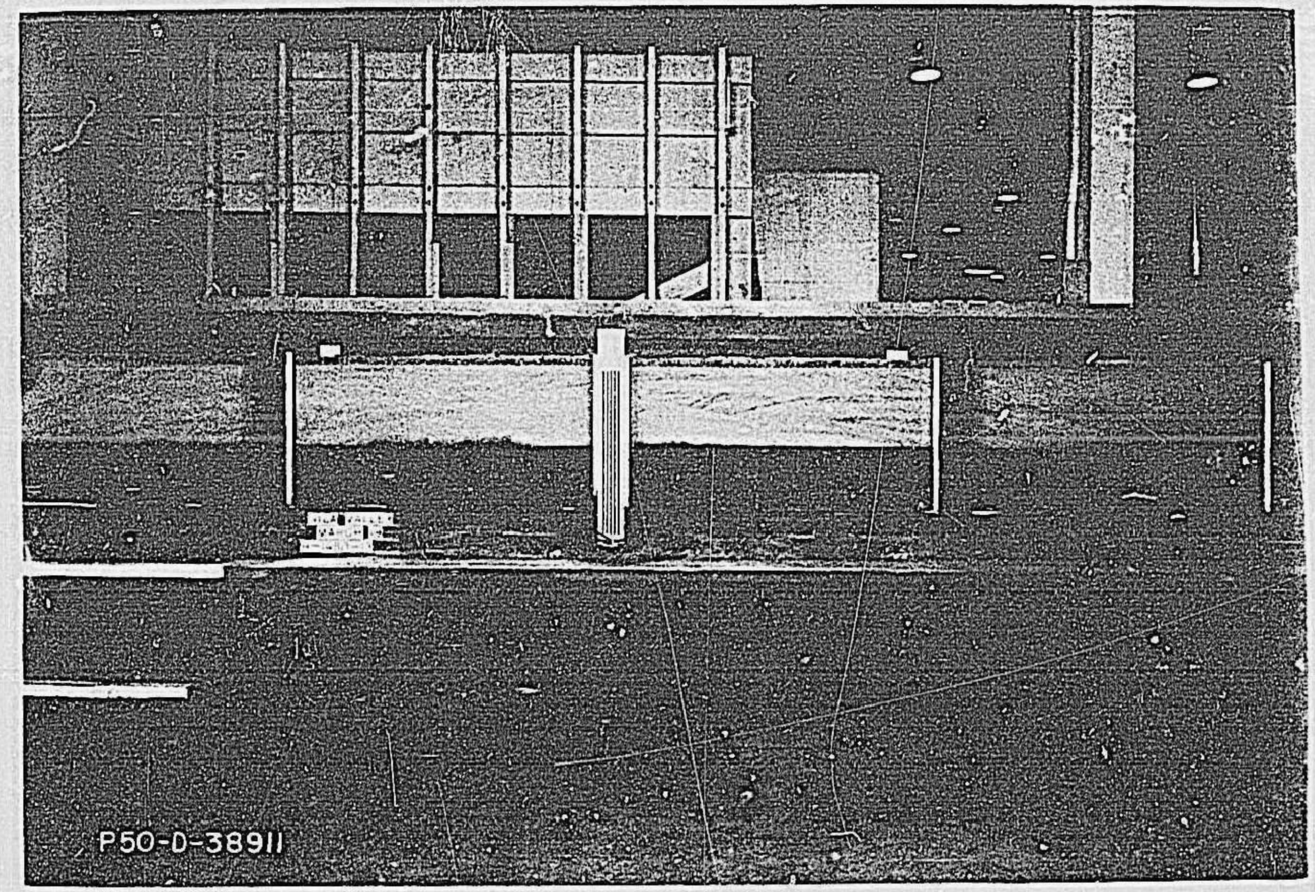
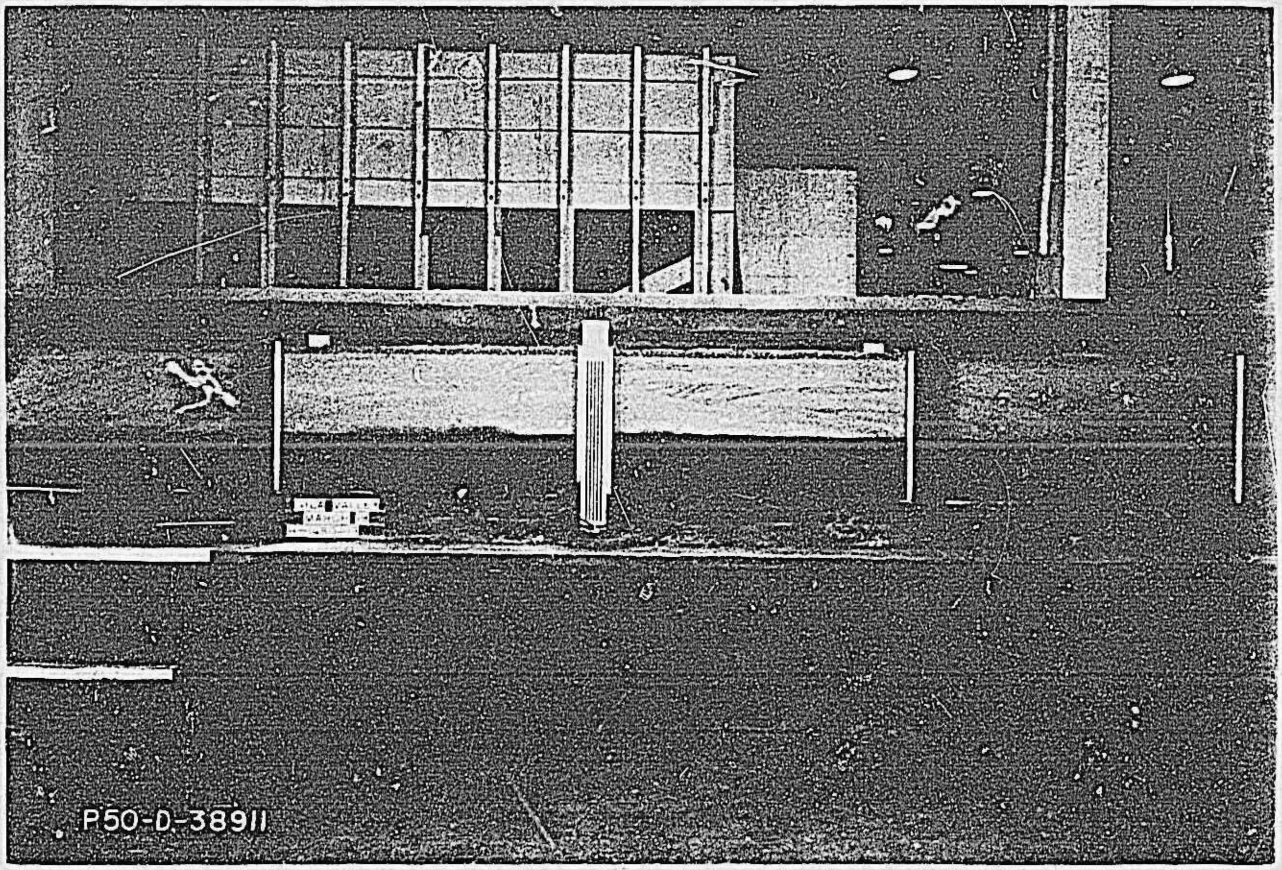


Flow pattern of salt water through upper aquifer to drain is well established only a few hours after the start of Test 1. Manometers indicate the level of the water in the aquifers.



Flow pattern of salt water through upper aquifer to drain is well established only a few hours after the start of Test 1. Manometers indicate the level of the water in the aquifers.

Figure 6
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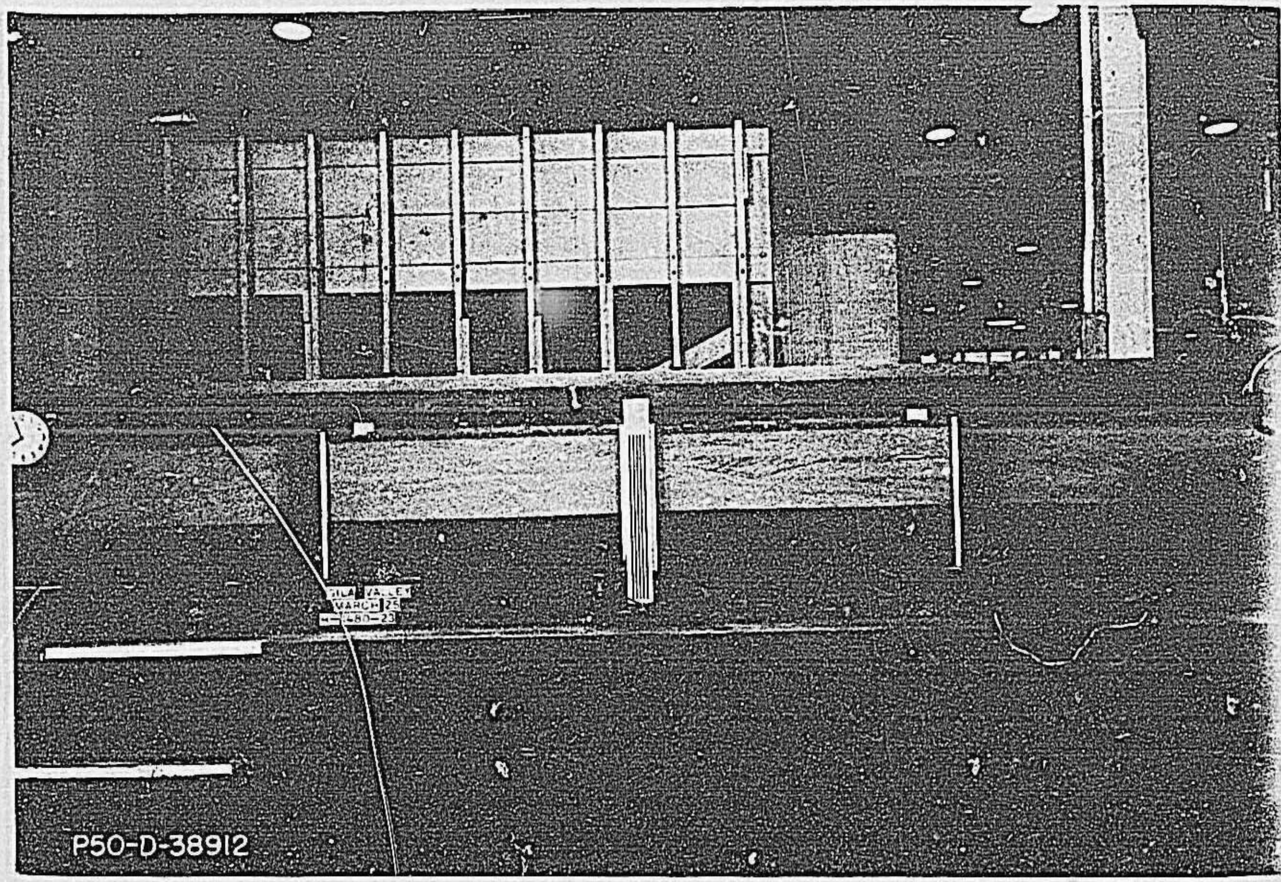


Flow of salt water to drain continues after 67 hours of operation, Test 1. Lower aquifer is being flushed with fresh water.

FIGURE 7
REPORT HYD 520

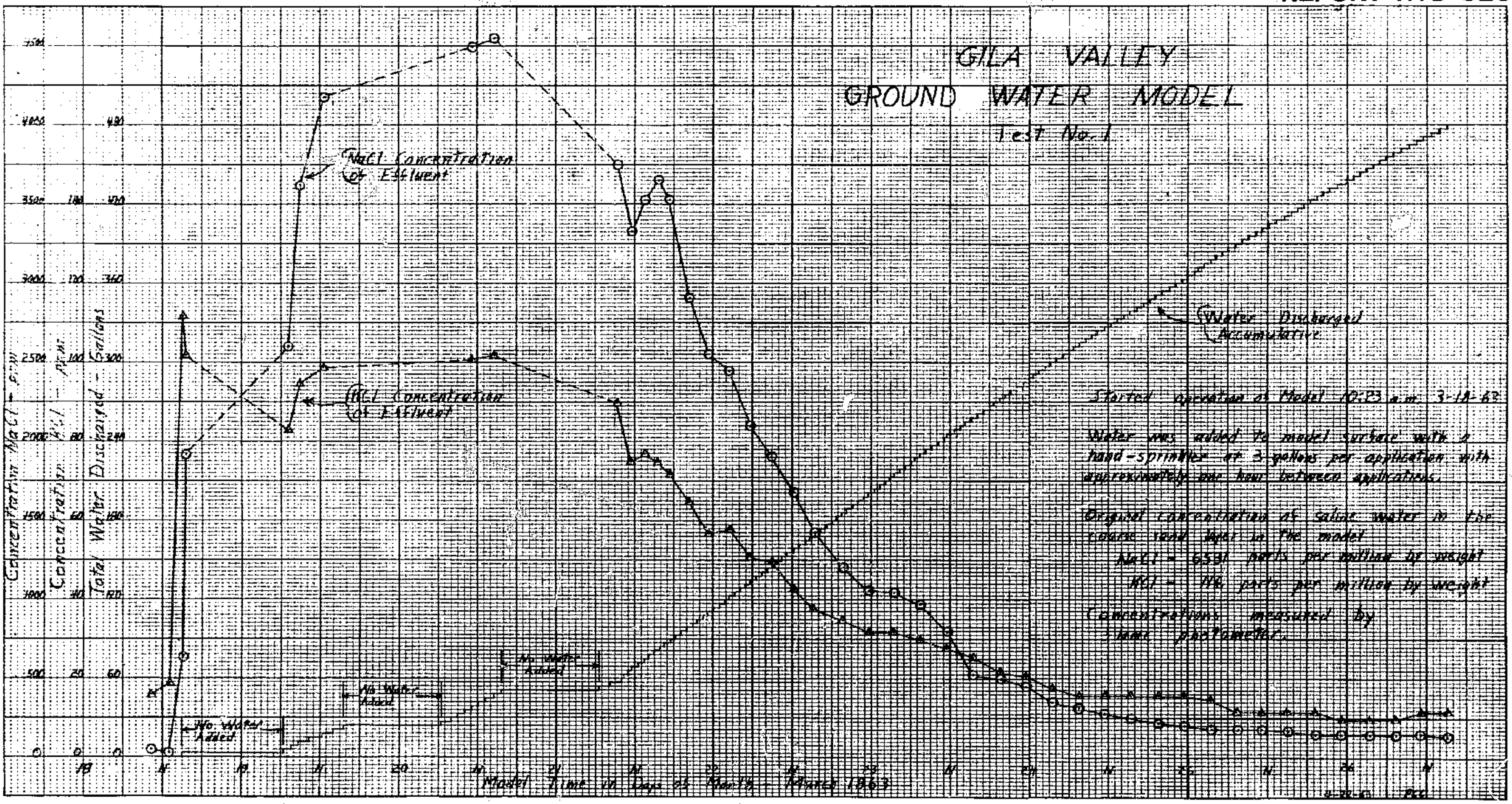


FIGURE 8
REPORT HYD 520

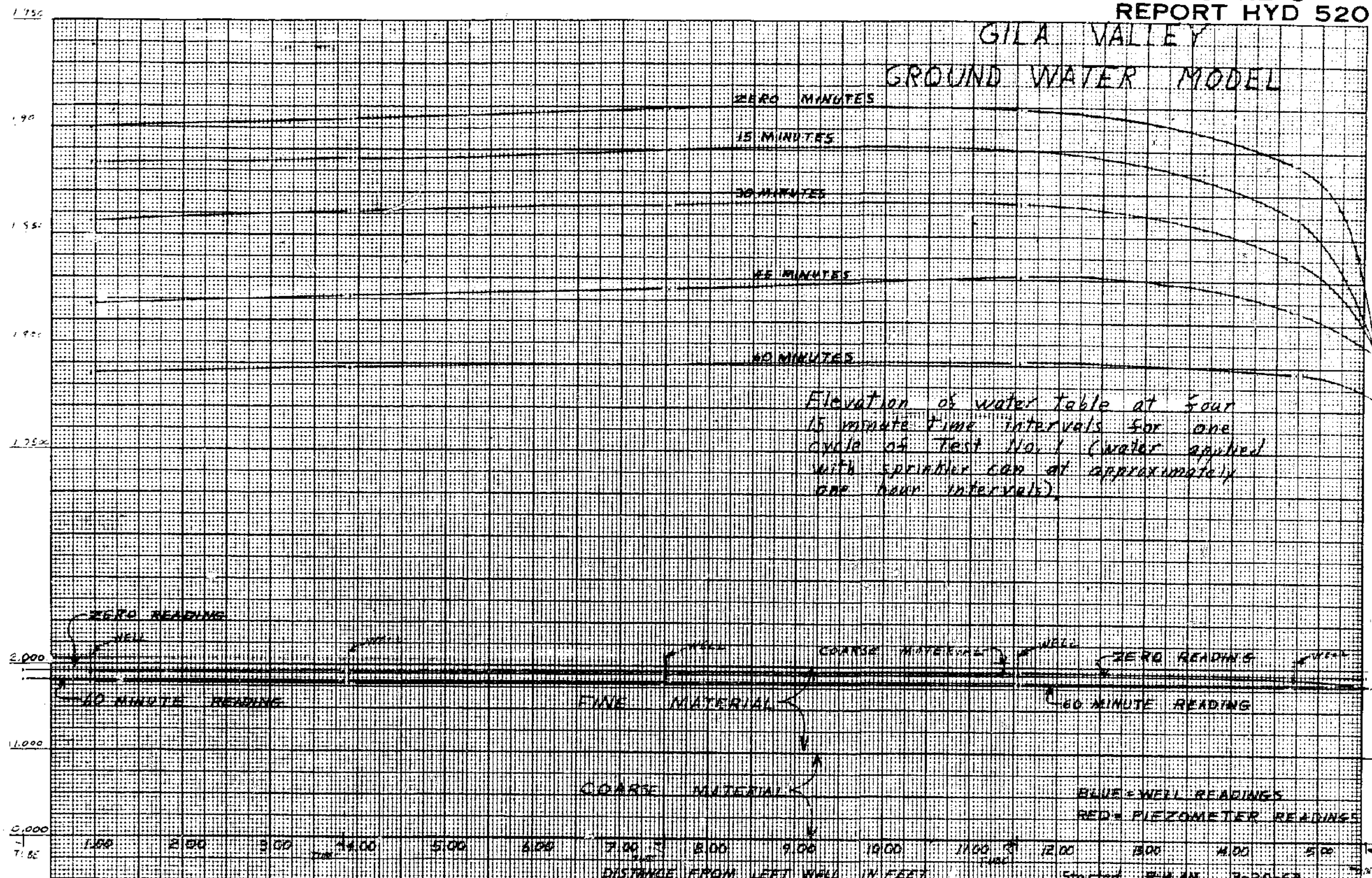


FIGURE 9
REPORT HYD 520

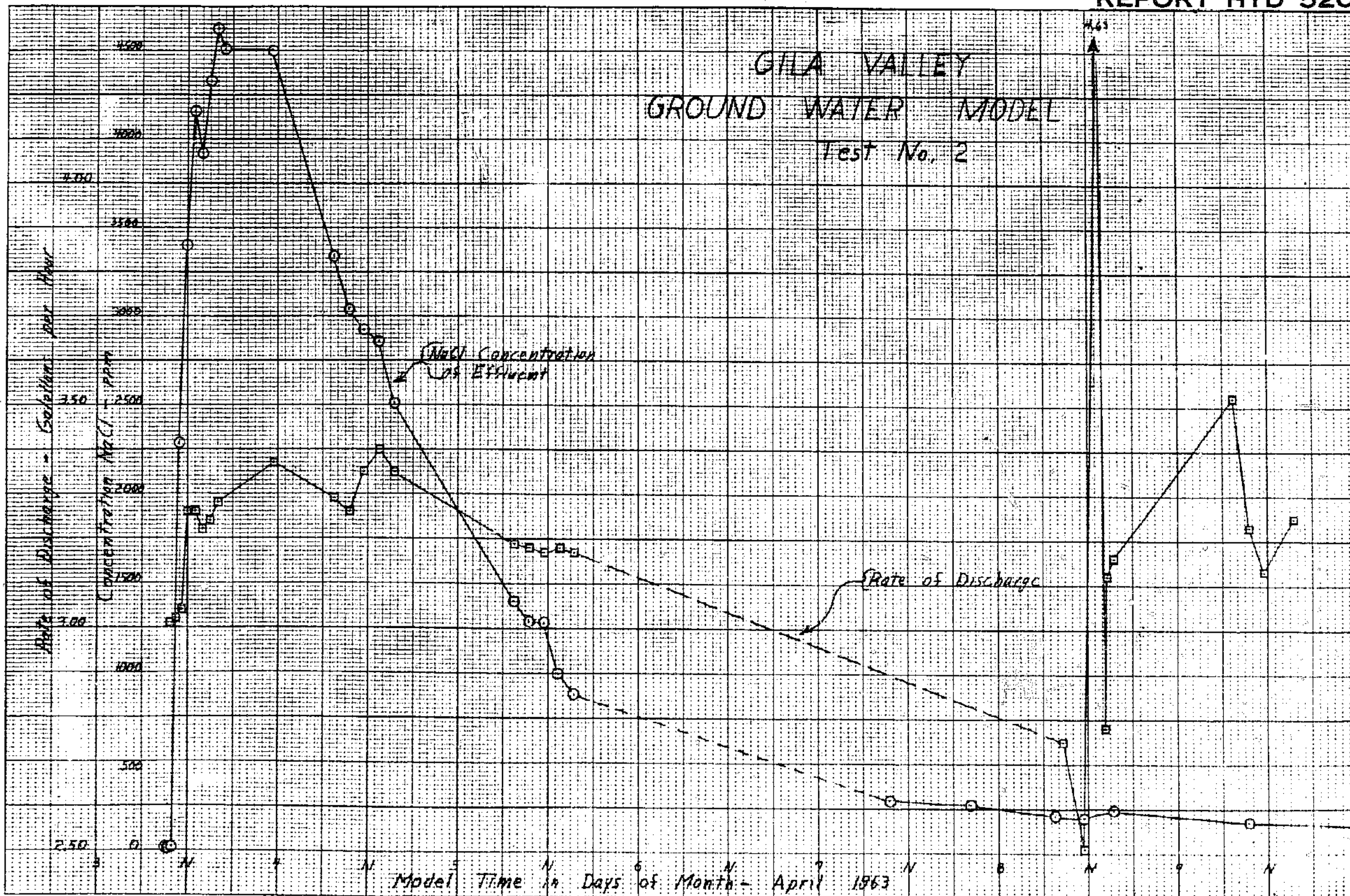
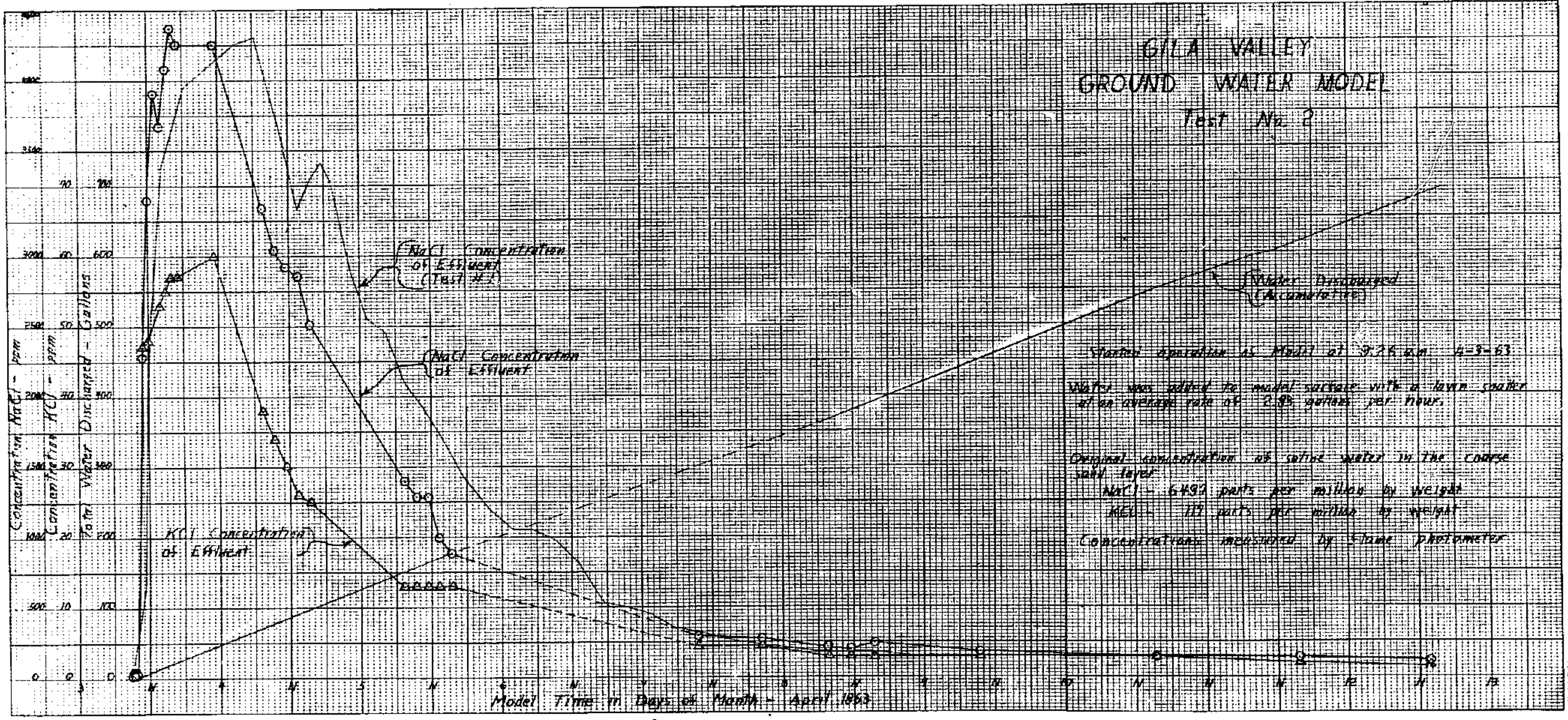
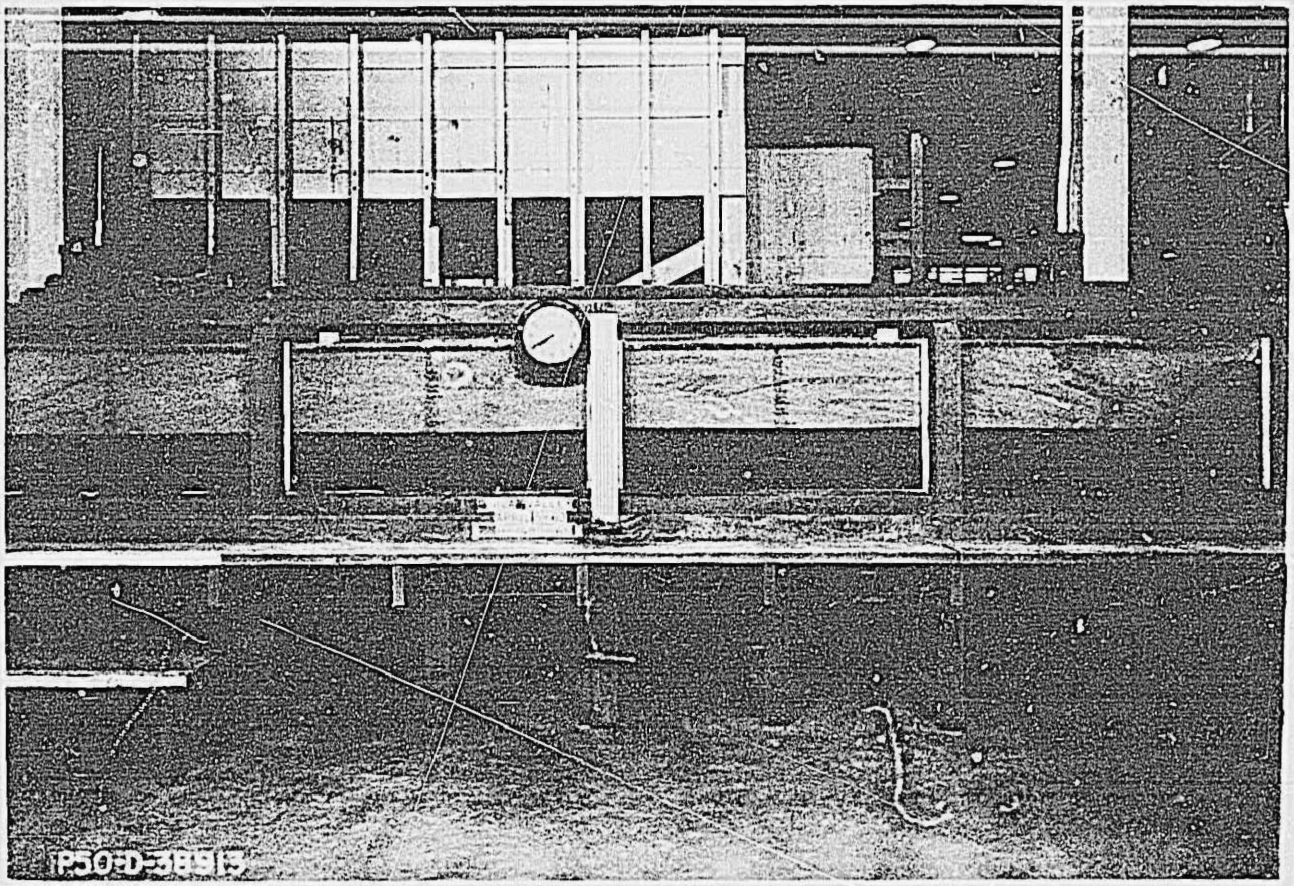


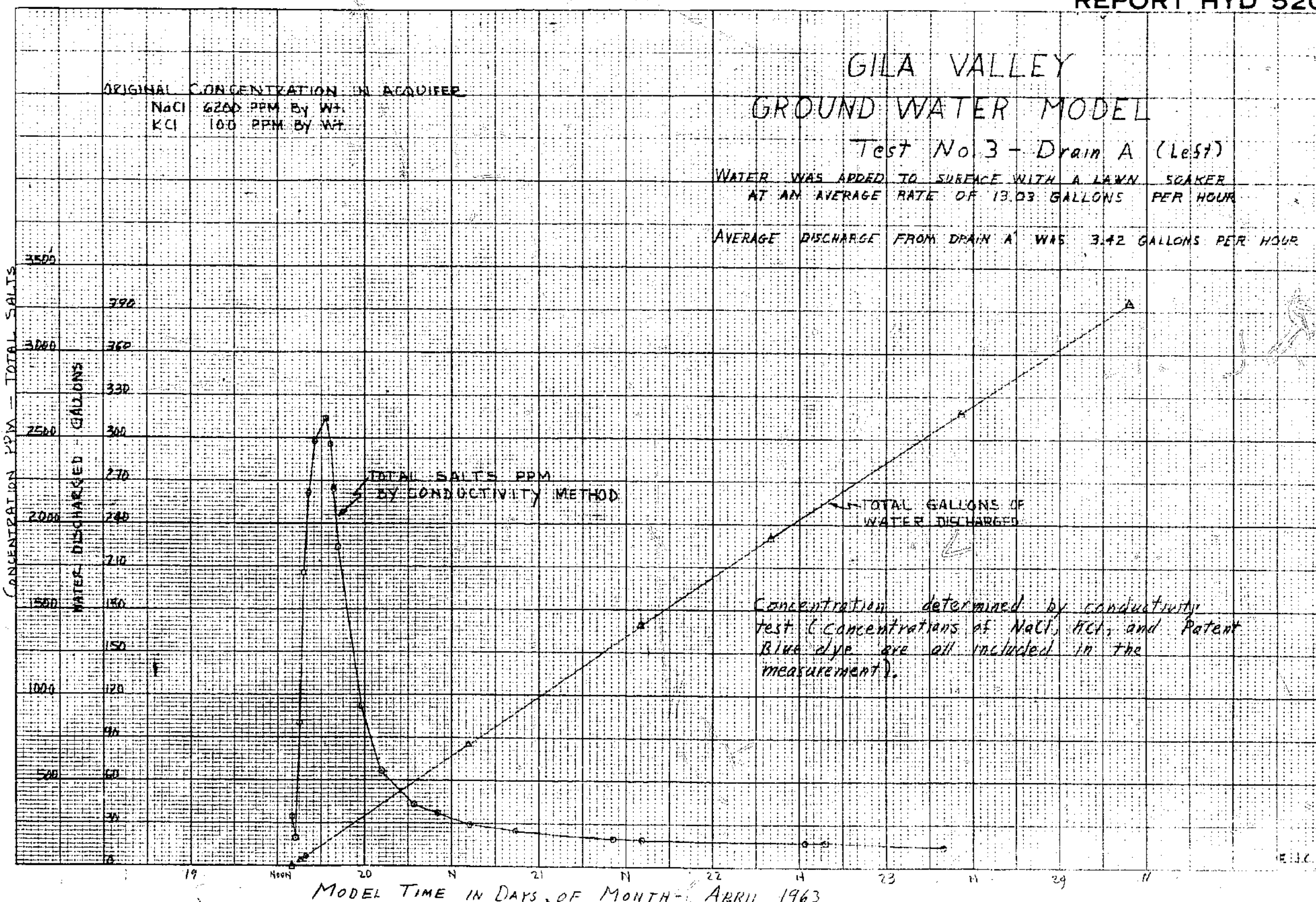
FIGURE 10
REPORT HYD 520

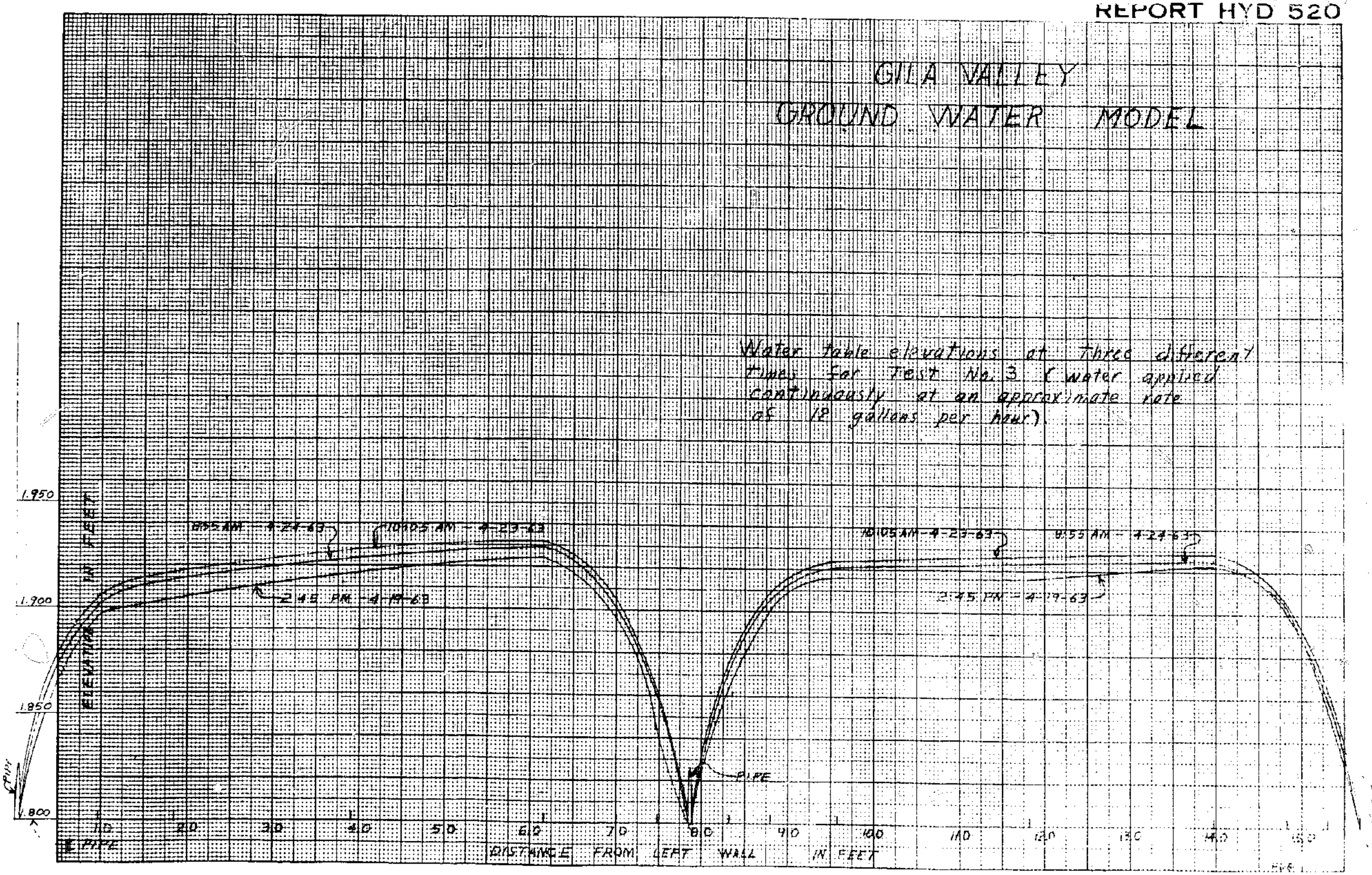


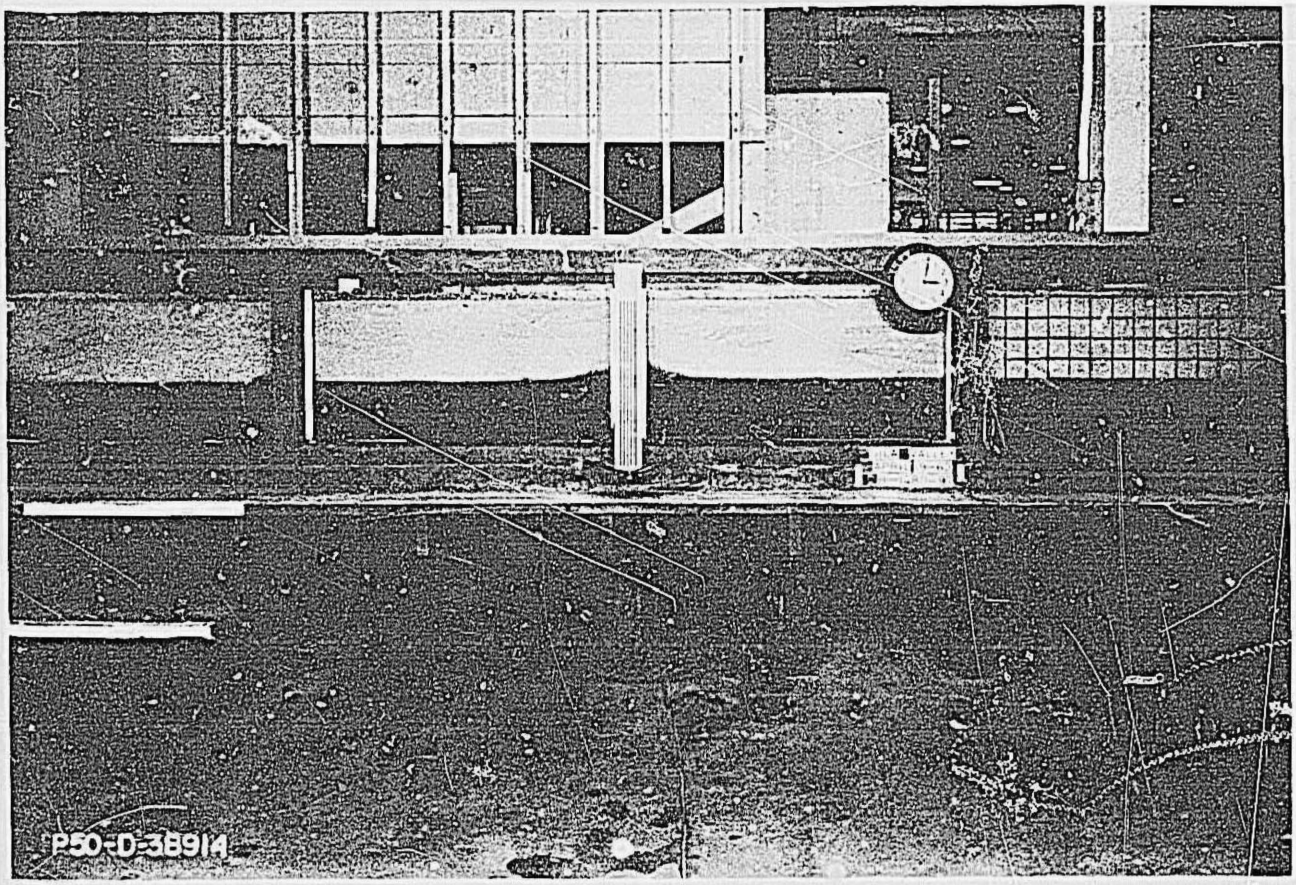


Dye crystals in three left panels show that path of fresh water is vertically downward from surface to lower aquifer, horizontally to vicinity of drain, then vertically into drain. Two dye traces at extreme right show flow from upper aquifer is directly into drain on a curved path.

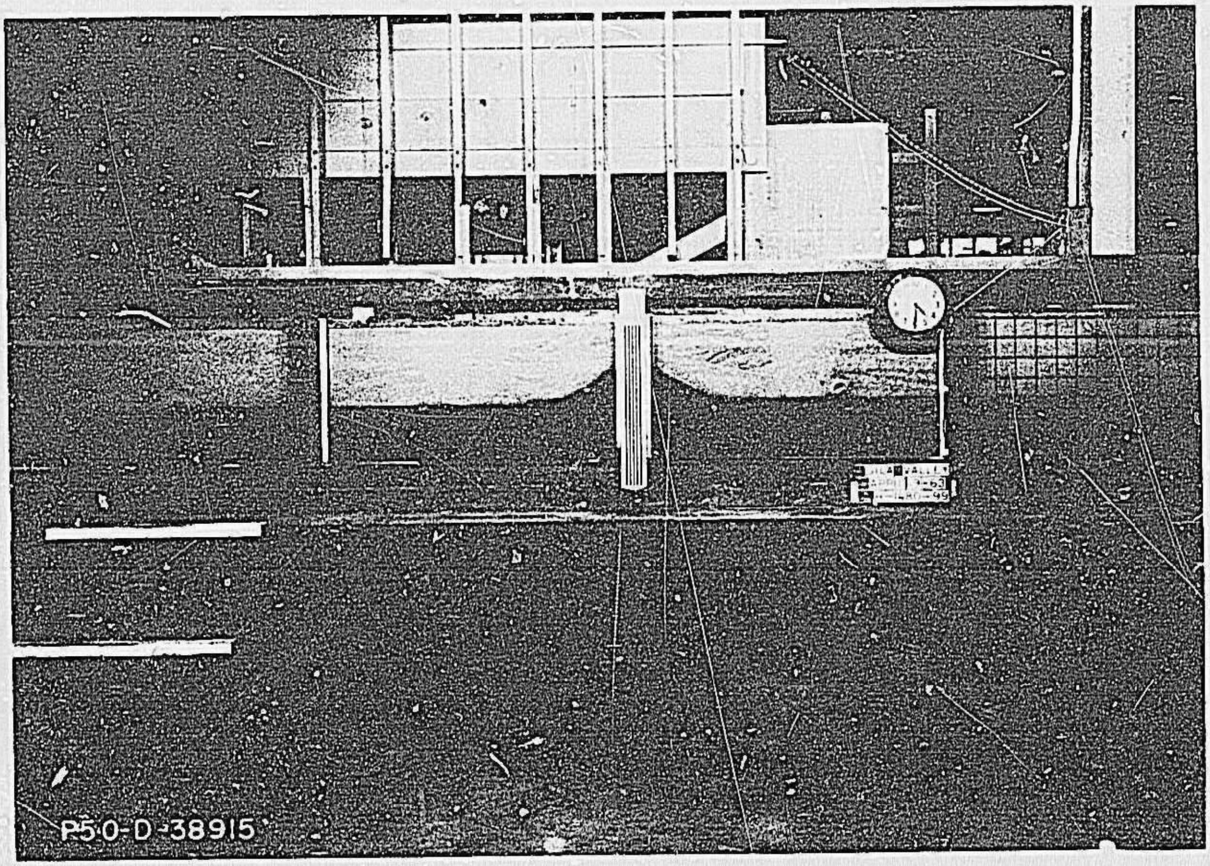
FIGURE 12
REPORT HYD 520



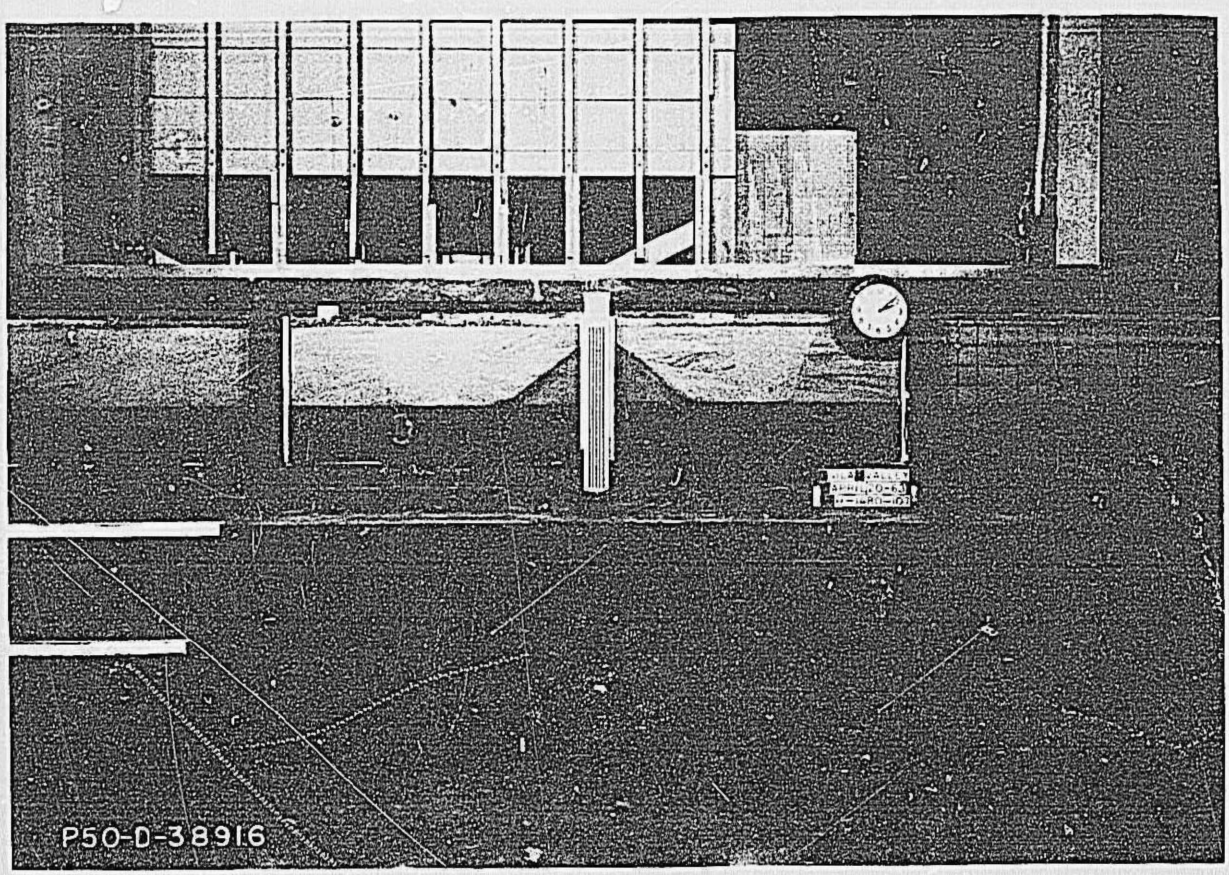

GILA VALLEY
GROUND WATER MODEL
Water table elevations at three different times for Test No. 3 (water applied continuously at an approximate rate of 12 gallons per hour).
8:55 AM - 4-24-63
10:05 AM - 4-23-63
2:45 PM - 4-19-63
10:05 AM - 4-23-63
8:55 AM - 4-24-63
2:45 PM - 4-19-63
PIPE
PIPE
1.950
1.900
1.850
1.800
ELEVATION IN FEET
℄ PIPE
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
DISTANCE FROM LEFT WALL IN FEET



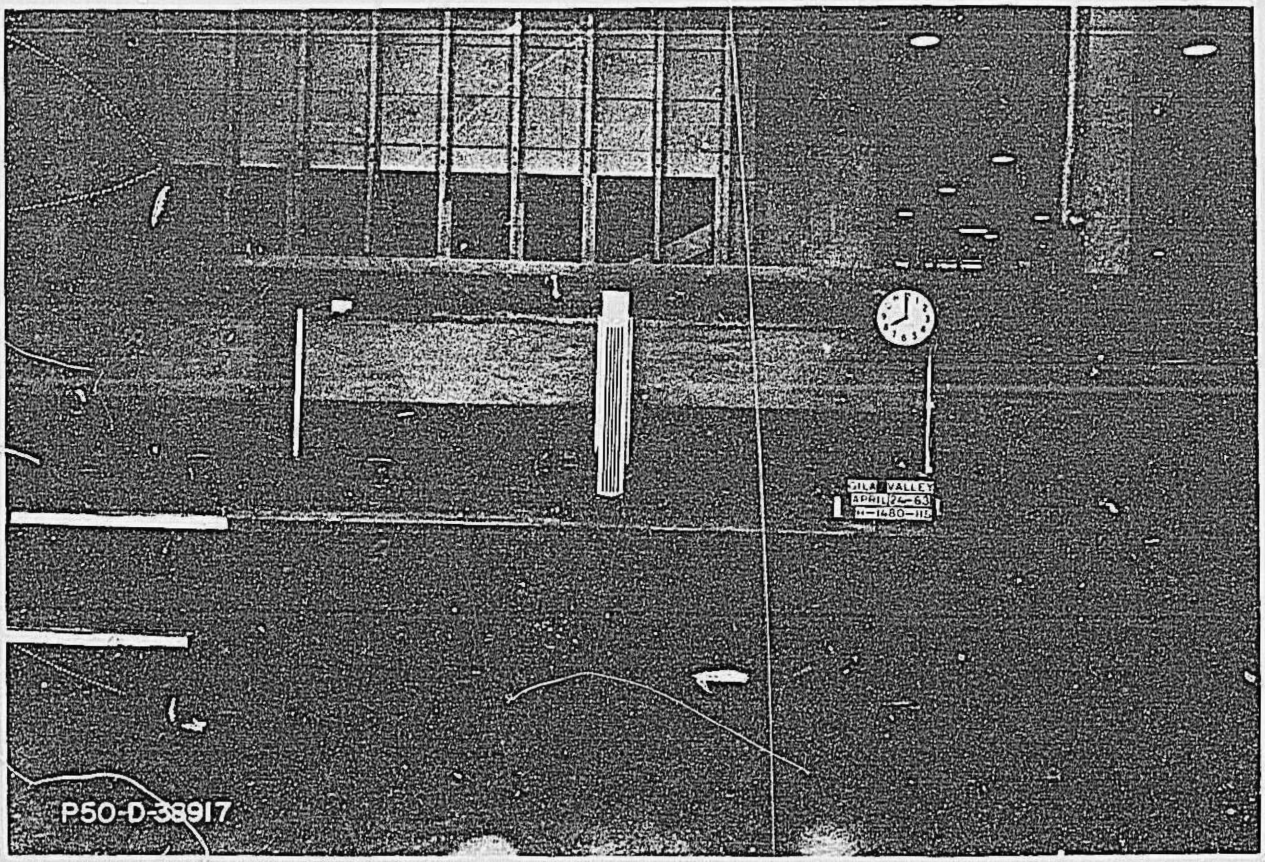
One hour and 5 minutes after the start of Test 3, the blue salt water could be seen approaching the three drains, located at each end and middle of model.



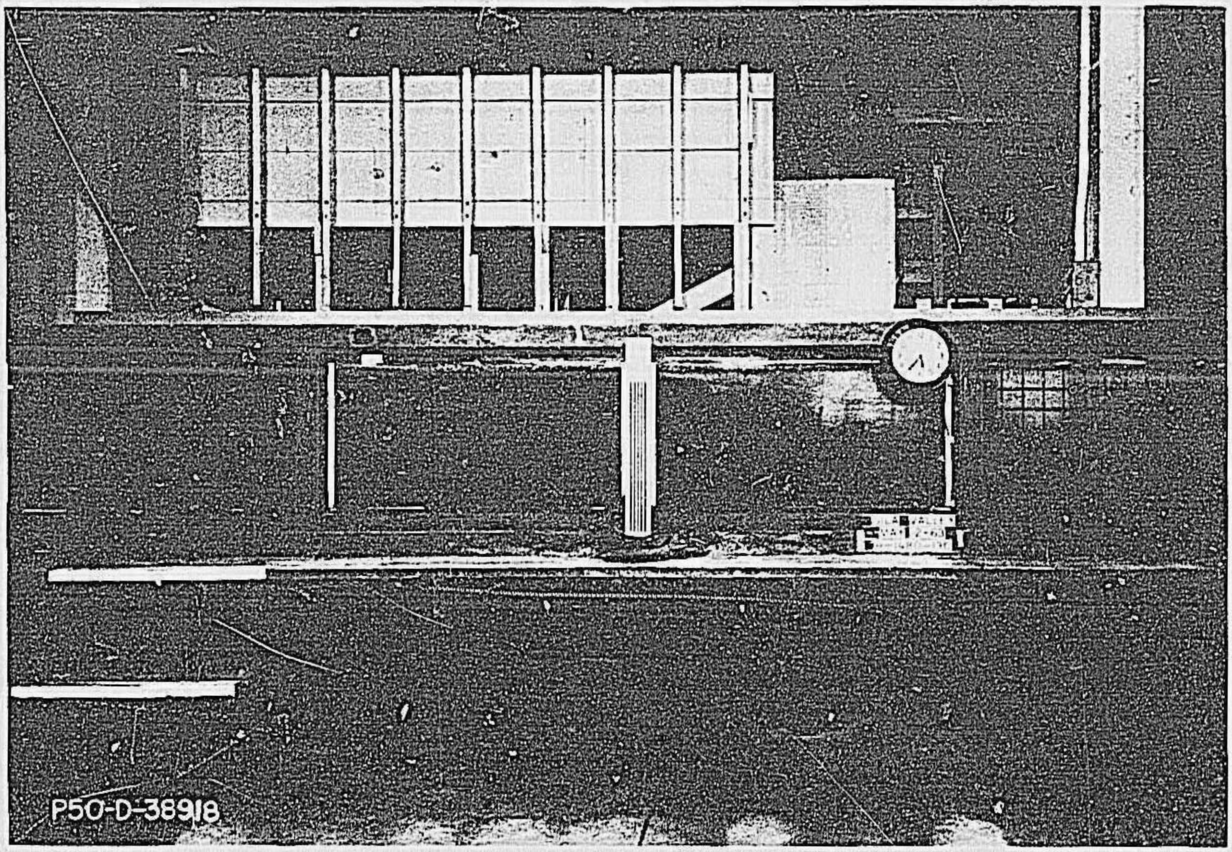
Two hours and 35 minutes after start of Test 3, a well-developed flow pattern toward the drains is evident. Clearing of the lower aquifer has begun and a curved interface is evident.



After only about 24 model hours of operation, Test 3, a great quantity of the salt water in the lower aquifer has been displaced and discharged through the drains. The characteristic sharp line of demarcation between fresh and salt water areas is evident.

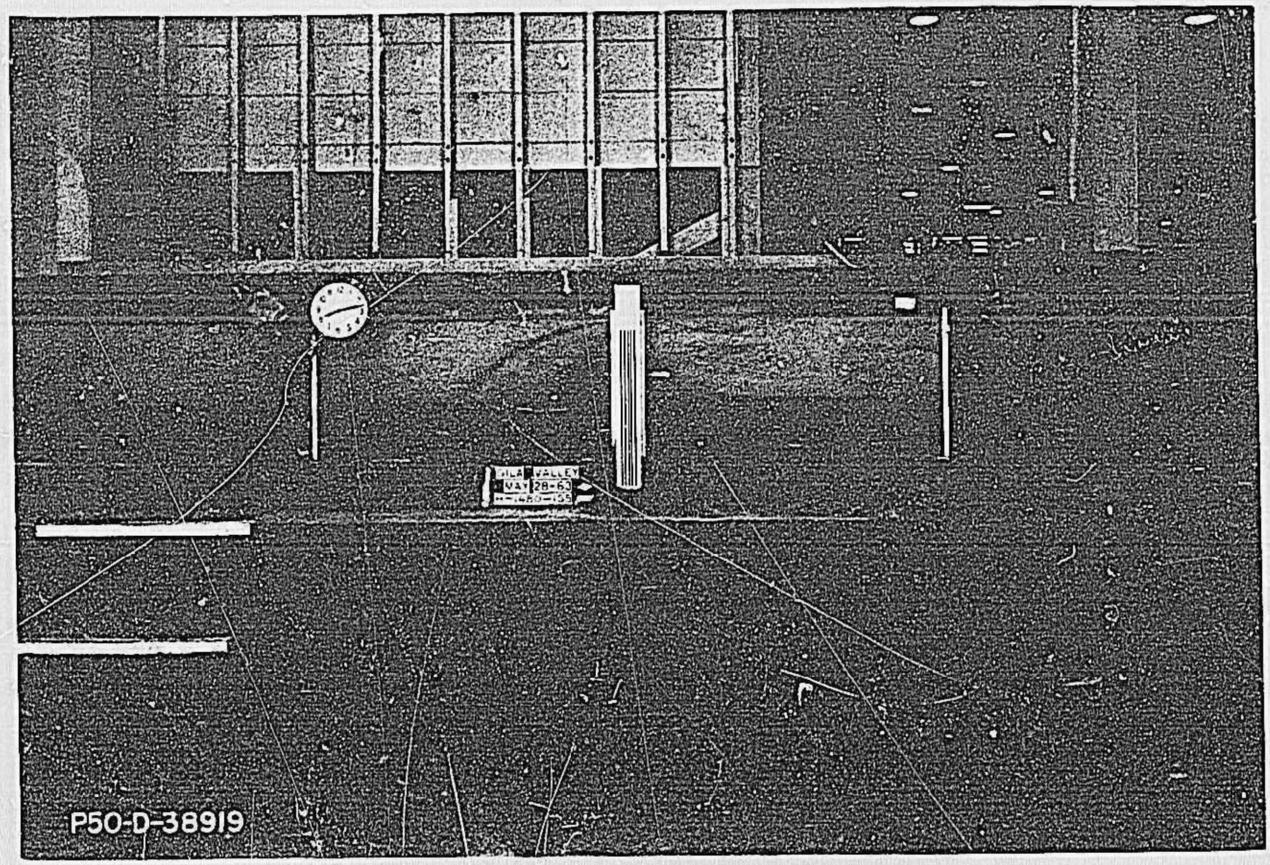


After almost 4 days of operation, Test 3, about half of the salt water in the lower aquifer has been replaced; the drain effluent still contains over 100 ppm of salt. This represents an almost stable state in the lower aquifer.



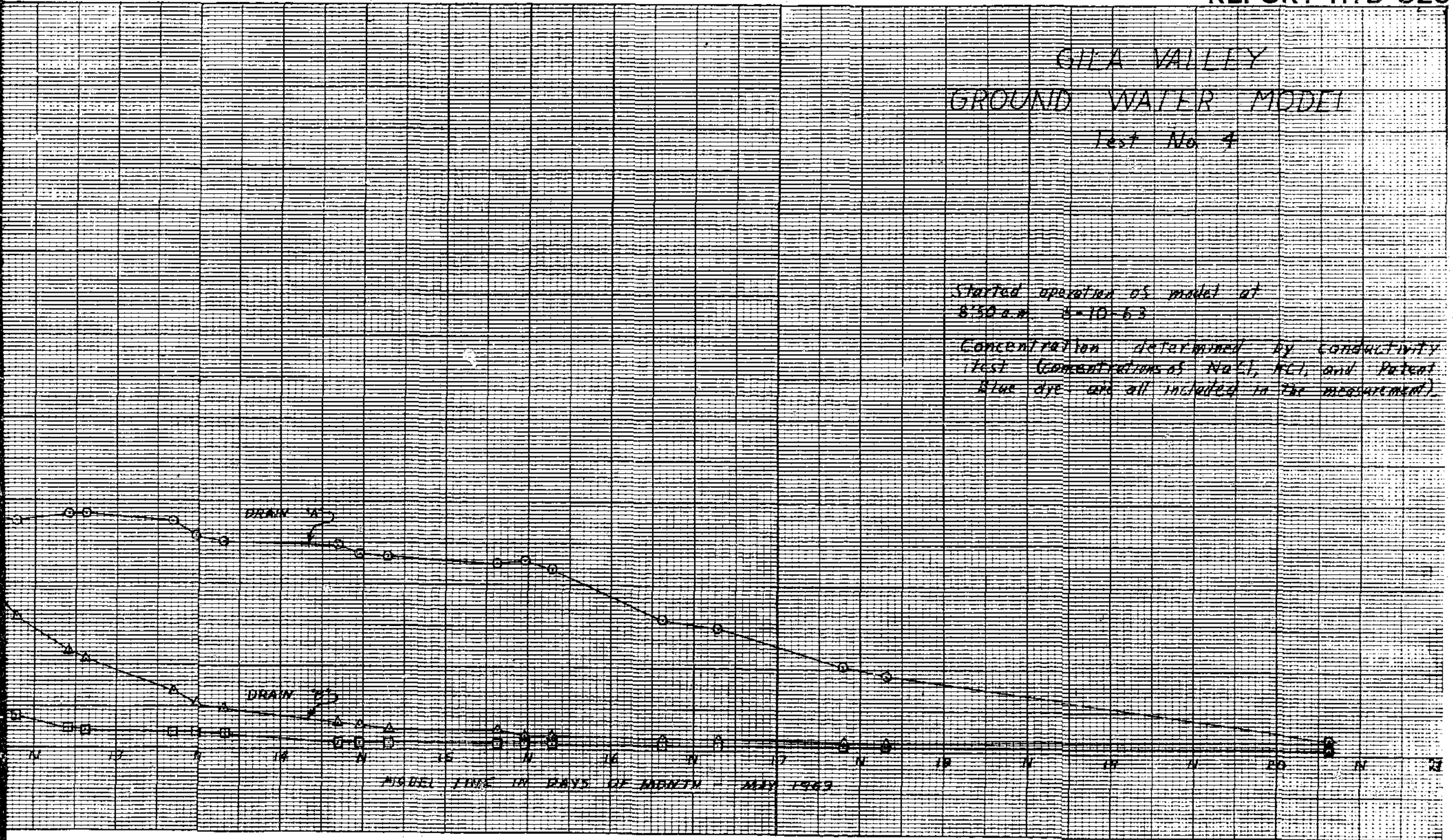
Test 4. Blue salt water which occupied entire volume of model at start of test is being cleared from upper aquifer, particularly in right-hand area. Flow patterns indicating path of salt water to drains is evident.

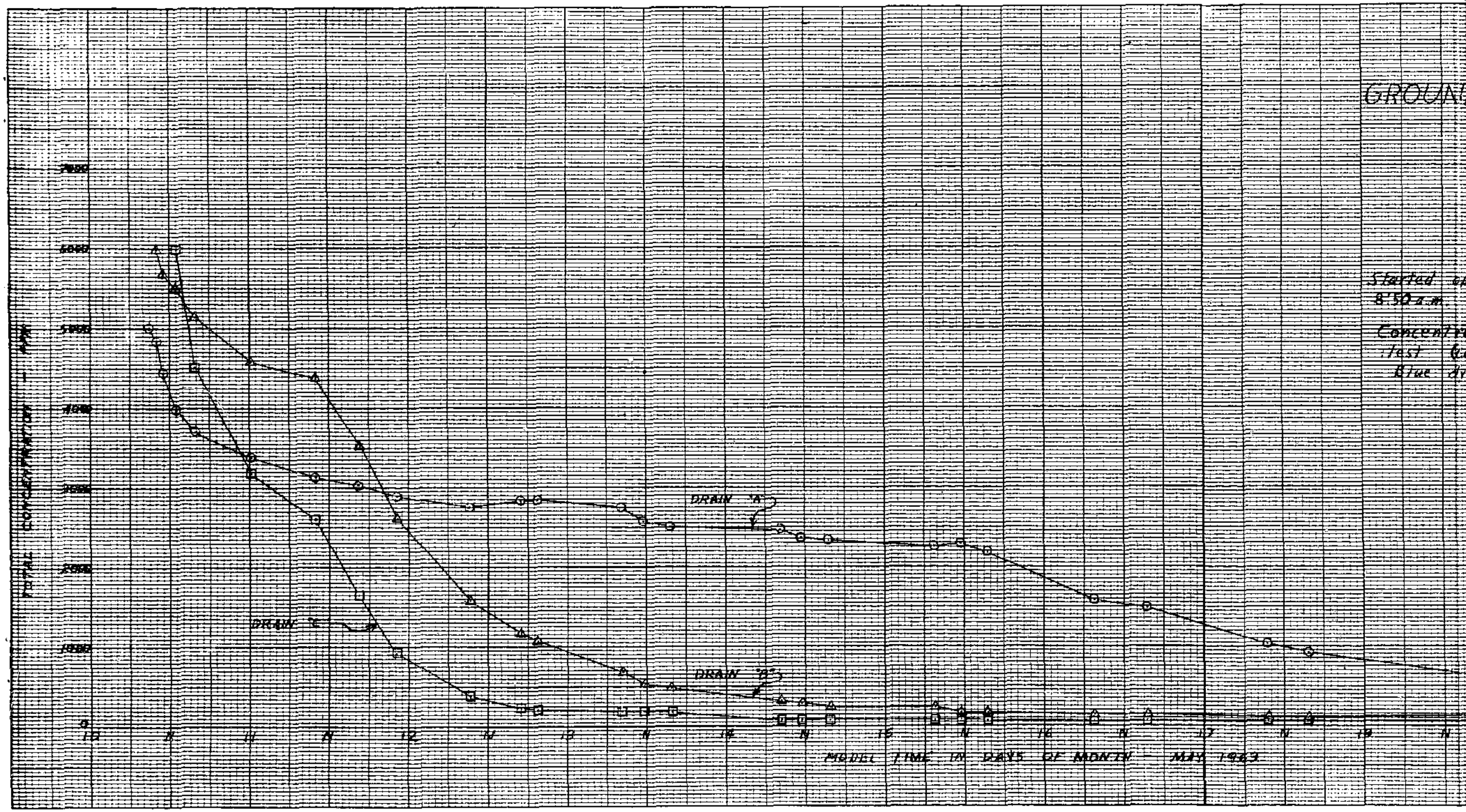
Figure 19
Report Hyd-520



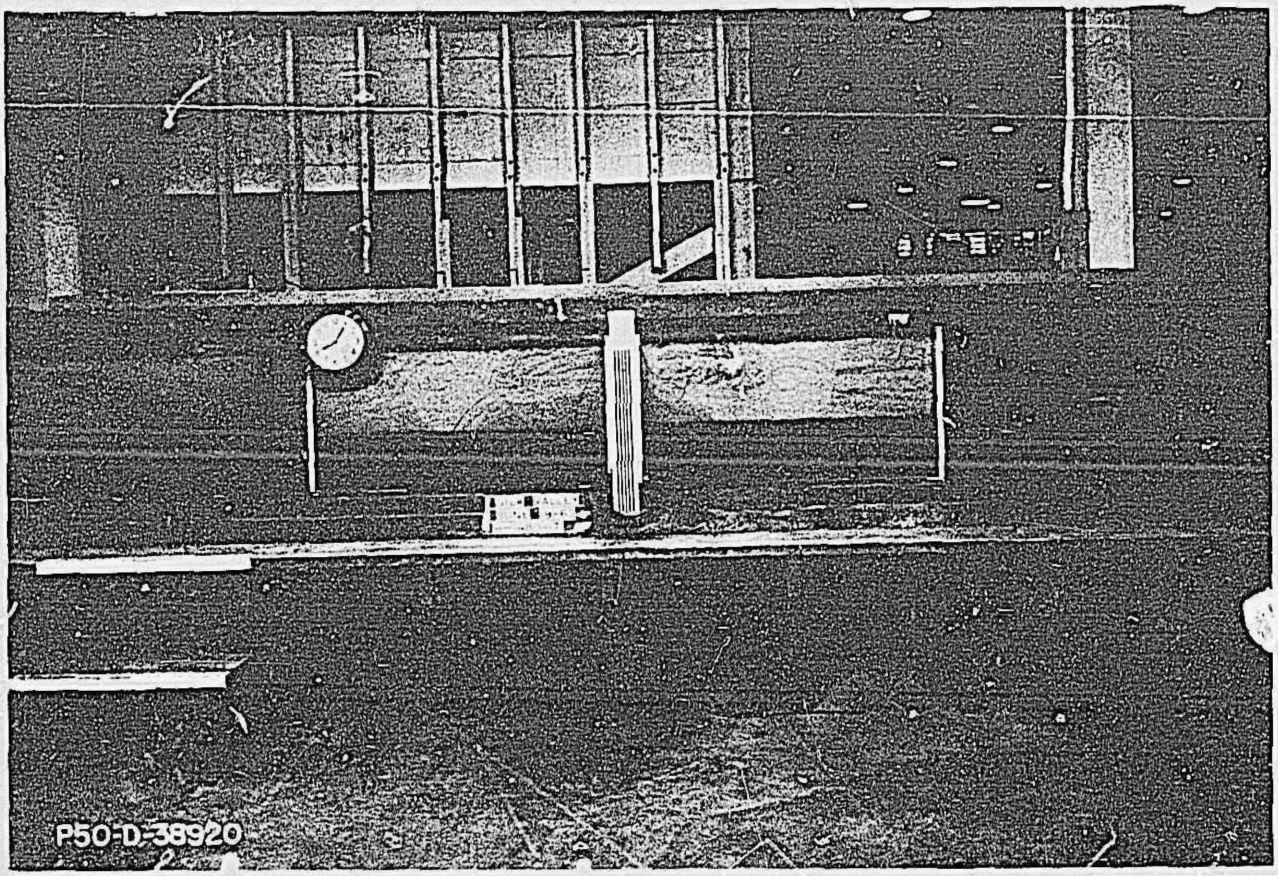
End of Test 4. Permanent storage of salt water in lower aquifer is indicated. Storage pattern in lower aquifer is not symmetrical about centerline of model because water was inadvertently applied more rapidly to right-hand side (in photograph).

FIGURE 20
REPORT HYD 520




GROUND
Started
8:50 a.m.
Concentra
Test
Blue
7000
6000
5000
4000
3000
2000
1000
0
TOTAL CONCENTRATION - PPM
DRAIN "A"
DRAIN "B"
DRAIN "C"
10
N
11
N
12
N
13
N
14
N
15
N
16
N
17
N
18
N
MODEL TIME IN DAYS OF MONTH - MAY 1963

FRAME 2



Nearing the end of operations, Test 5. About one-third of the volume of the lower aquifer will remain in permanent storage. Drain effluent still contains an appreciable quantity of salt.