Effect of Controlled River Level On Yield of Irrigation Wells Near Jefferson, Oregon

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EFFECT OF CONTROLLED RIVER LEVEL ON THE YIELD OF
IRRIGATION WELLS NEAR JEFFERSON, OREGON
by
J. W. Wolfe*, with review by J. E. Sceva**

SUMMARY

A ground water investigation was made along the Santiam River near
Jefferson, Oregon during the 1958 irrigation season. The principal
objective was to determine whether or not raising the river level would
be a feasible method of increasing the ground water supply for irrigation
pumping. Nine agencies cooperated in the investigation.

An area comprising about two and one-half square miles, bounded by the
river bend between Jefferson and Greens Bridge, was selected for concentrated
study. Water level in most available wells was measured at frequent intervals
throughout the summer. The river level was raised one foot for a seven-day
period at the end of July by releasing water from storage. At the end of
the season pumping tests were made to determine the hydrologic properties
of the aquifer. Resulting data include ground surface contours, ground
water contours, ground water profiles, drowdown cones, river hydrographs,
and well hydrographs. Computations were made to compare maximum consumptive
use rate with rate of flow through the aquifer.

Results showed that fluctuations in the river level caused corresponding
fluctuations in the ground water table, but that considerably more than a
week was required to reach equilibrium. Efficiency of this method for
increasing irrigation water supply is low. Increasing the number of
irrigation wells is a recommended method for increasing the available supply
during the water-short period.

SCOPE AND OBJECTIVES OF THE STUDY

The Problem

Ground water supply for irrigation has become increasingly short in the
region of the recent alluvial deposits along the Santiam River, including
its north and south tributaries. Early in the season the supply in each
well apparently is adequate, but by the last week in July several wells
fail to meet the demand. It is necessary to reduce the number of sprinklers
operating from these particular wells. Unfortunately, this period of reduced
supply coincides exactly with the period when crops require the most water.

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Initiation of Study

Farm operators in the area have observed a relationship between height of water in the Santiam River and height of water in their wells. They raised the question whether or not their problem could be solved by release of water from storage during the period of short supply. With the help of the county agents of Marion and Linn Counties, they met twice in 1957 to discuss the possibility of a cooperative study. At the November meeting they selected a committee from their number which was authorized to negotiate with other interested organizations for a cooperative study. This committee (Santiam Irrigation Water Supply Committee) signed an agreement with five cooperating agencies in July, 1958. Later, three additional organizations contributed. The project thus was initiated in time to obtain data during the 1958 season.

Cooperation

The following organizations signed a cooperative agreement to share responsibility for conducting the study:

1. The Santiam Irrigation Water Supply Committee, and the large group of growers they represent.

2. U. S. Army Corps of Engineers

3. Oregon State Engineer

4. Soil Conservation Service, U.S.D.A.

5. Extension Service, Marion and Linn Counties and Oregon State College

6. Agricultural Engineering Department, Oregon State College

The following additional organizations were called on for assistance:

1. Oregon State Water Resources Board

2. Pacific Power & Light Company

3. U. S. Geological Survey

Objectives

The following objectives were agreed upon by the cooperating agencies:

1. To determine the relationship between height of water in irrigation wells and the level of the Santiam and North Santiam Rivers.

2. To estimate the efficiency of the use of water released in the North Santiam River for the purpose of raising the height of water in wells.

3. To determine the principle factors limiting yield of wells between Jefferson and Greens Bridge.

PROCEDURE

Area Selected for Study

The study was concentrated along a two mile reach of the North Santiam and Santiam Rivers between Jefferson and Greens Bridge. Figure 1 shows that this area is bounded on the west, south, and east by the river, and on the north by an escarpment in older, fine textured material. The land slopes westward about 18 feet per mile. This area was selected because it was believed representative of the North Santiam and Santiam flood plains, it contained many wells, and it contained two recording river gaging stations. It will be referred to as the "Jefferson area" in this report. Only enough wells were measured upstream and downstream to ascertain that it is representative of the valley.

The only aquifer supplying the Jefferson area is a gravel alluvium which extends to a maximum depth of about 25 feet. It is underlaid by a relatively impermeable clay and silt and is bounded on the north by an aquiclude of similar fine and medium-fine textured material. The lower three to five feet of the aquifer are believed to be relatively free of fine material. The aquifer is overlaid with about two to six feet of medium textured soil which supports a luxuriant growth. Explorations to deeper depths have failed to reveal any other aquifers.

Well Measurements

The locations of most of the measured wells are shown in Figure 1. Fifty-six wells in the Jefferson area were selected. These included irrigation, domestic, and 1¼ inch observation wells. In addition, fifteen wells upstream and downstream were measured as a check to be sure the Jefferson area was typical of the entire alluvial valley.

Daily measurements were made on a few wells by farm operators. In addition, twice weekly measurements were made on all other wells shown in Figure 1 by the Agricultural Engineering Department. Outlying wells were measured by farm operators or by the Soil Conservation Service. Measuring a well consisted of measuring the vertical distance down from a reference point at the ground surface to the level of the water in the well. In almost all cases, the ground surface reference point was the top of the well casing. Four wells were fitted with automatic recorders, most of which were supplied by the State Engineer. Charts on recorders were changed weekly by the Agricultural Engineering Department.

Release of Water From Storage

During the last week in July, sufficient water was released from storage from Detroit Reservoir by the Corps of Engineers to raise the level of the river one foot at Greens Bridge. River level at Greens Bridge and at Jefferson was continuously recorded by the U. S. Geological Survey. The river level was also measured twice weekly at two intermediate points by the Agricultural Engineering Department.

Figure I.

Elevation of Wells

Sea level elevation of a reference point at each of the measured wells between Jefferson and Greens Bridge was determined by the Soil Conservation Service. Top of the well casing was used as a reference point whenever it was accessible. Assistance on this task was given by the Santiam Irrigation Water Supply Committee.

Transmissibility of Aquifer

Transmissibility or permeability of the aquifer was determined by pumping tests at three locations at the close of the irrigation season. These tests were conducted cooperatively by the State Engineer's Office and the Agricultural Engineering Department, with the assistance of the State Water Resources Board, Pacific Power & Light Company, and the respective farm operators. The power company furnished power for the test, and the farm operator furnished pump and pipe and assisted in preparation for the test.

Transmissibility determinations were made by the Theis non-equilibrium method. The procedure includes measurement of the cone of depression of the water table as it was gradually lowered with sustained pumping.

In order to observe the cone of depression as it progressed out from the well, small diameter observation wells were driven. Some of these were about ten feet from the pumped well and others were out about 100 to 200 feet. Similar observation wells were installed by several farm operators about ten feet from their pumped wells. In two cases, records kept by farm operators were so complete it was possible to estimate transmissibility of the aquifer at their locations without making a special test at the end of the season.
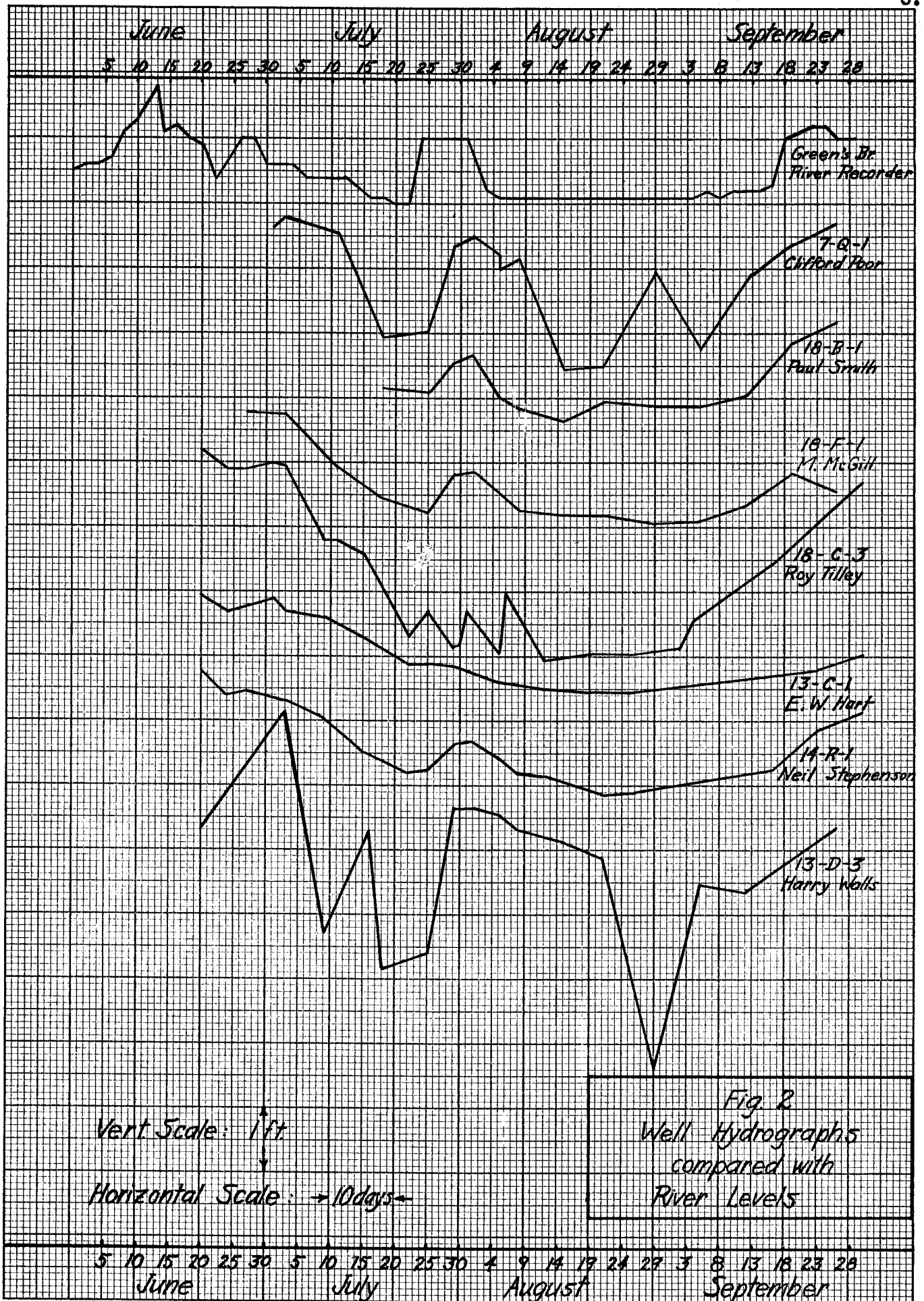
Coordination and Completion

Coordination and communication on the project were provided by the Oregon State Extension Service. At season's end, data was compiled by the Agricultural Engineering Department, and after considerable study, tentative conclusions were reached jointly by representatives of the State Engineer's Office and of the Agricultural Engineering Department. This report has been prepared by the Agricultural Engineering Department and reviewed by Jack Sceva from the Office of the State Engineer.

RESULTS AND DISCUSSION

Rise in Water Level in Wells

Figure 2 shows a number of well hydrographs. They show the fluctuations of the water table during the irrigation season. The hydrographs shown were selected because they best show the general trend. Some of those not shown have so much fluctuation, due to intermittent pumping, that they were difficult to interpret.
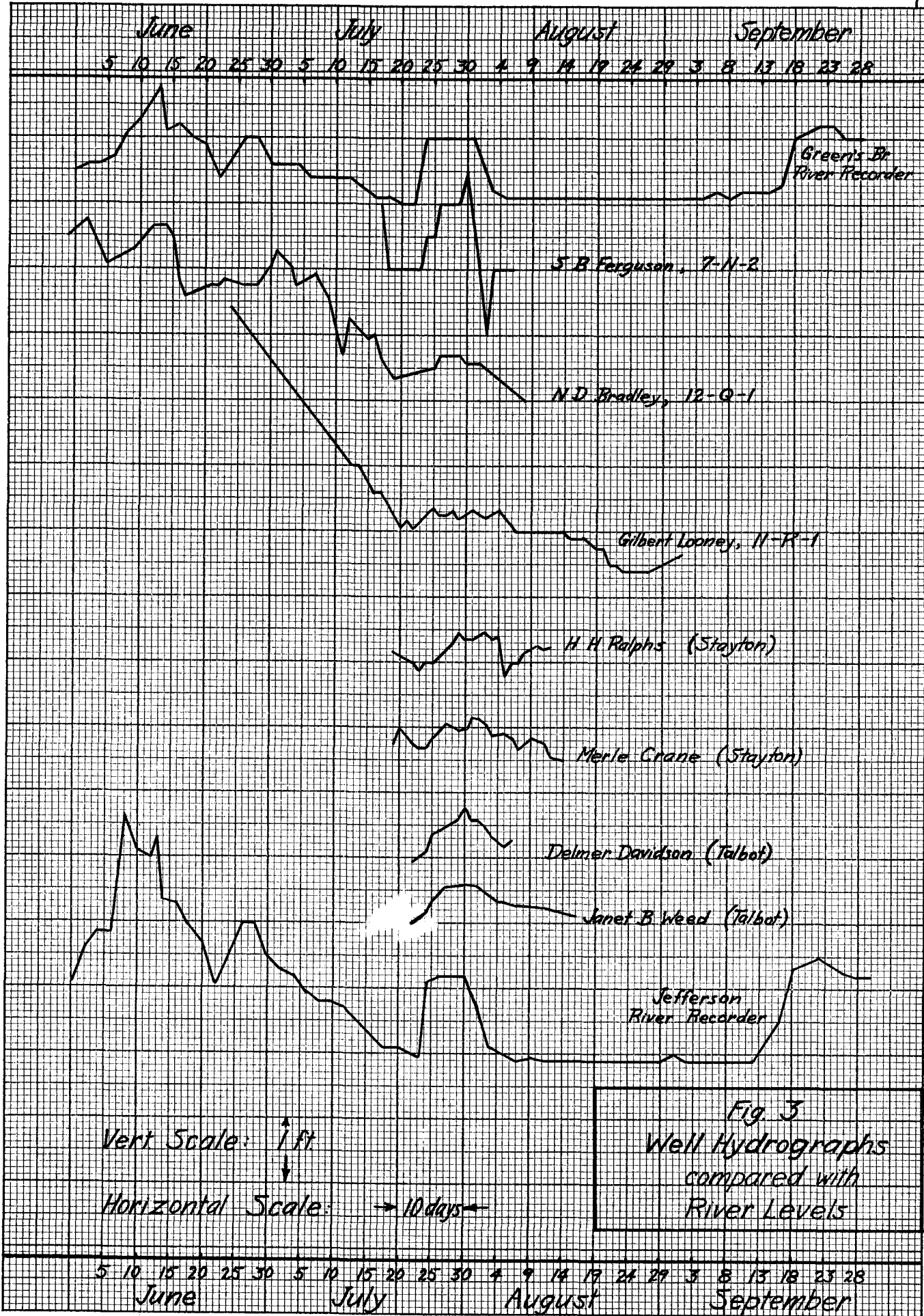
Fig. 2

Well Hydrographs compared with River Levels

Vert. Scale: 1 ft.

Horizontal Scale: →10 days←

Fig. 3
Well Hydrographs
compared with
River Levels

Vert Scale: 1 ft

Horizontal Scale: →10 days←

Maximum rise shown on any well as a result of the one-foot rise in the river is a little more than 0.5 foot. Illustrative of this maximum rise is well number 14-R-1 (Neil Stephenson), in Figure 2. This well is located in the southwest portion of the study area very near the river. It was an unpumped well and was measured with an automatic recorder during the irrigation season. A more detailed hydrograph of this well is shown in the Appendix, along with hydrographs of three other wells on which recorders were maintained and the river hydrograph. Among probable reasons why this well showed such a significant rise are its proximity to the river, apparent absence of pumped wells in the immediate vicinity, and the fact that the river rise was a little greater near Jefferson. Even so, the fact that the rise in the well level was only about half the rise in the river, in a one week period, tends to indicate there is considerably more than a one week lag between river level and ground water level at this point.

The opposite trend is illustrated by the hydrograph for well number 13-C-1 (E. W. Hart). No rise was observed in the level of water in this well during the period of river rise. There are several probable reasons for this reaction. This well is one of the more distant from the river, thus probably requiring more time to reach equilibrium. Perhaps more important, it is apparently not located in a gravel aquifer, as evidenced by the fact that it was an abandoned irrigation well. A study of the curve reveals that even though the well level did not rise during the period of river rise, it did definitely reduce its rate of decline. This leveling off period appears to anticipate the period of river rise by about three days both at the start and at the end. It may be concluded therefore that this fluctuation was caused by some factor entirely unrelated to the river level.

Between these two extremes, there is quite a variation in results. Wells number 18-B-1 (Paul Smith) and 18-F-1 (Mervin McGill) are quite close to the river and both seem to show the same sort of rise as did well number 14-R-1 (Neil Stephenson). On the other hand, well number 11-R-1 (Gilbert Looney) does not show the same degree of rise even though it also is close to the river. The apparent failure to respond is probably due to rather continual pumping during this period. All of the other well hydrographs in Figure 2 and 3 show a tendency to rise during the period of river rise, but relationships are somewhat indistinct because fluctuations due to pumping are more prominent than the rise caused by the river.

Figure 3 also shows the hydrographs from two wells located upstream and two located downstream from the Jefferson area. The similar shape of these hydrographs tends to indicate that data obtained in the Jefferson area will be applicable to the flood plain of the Santiam River.

Transmissibility of the Aquifer

After the irrigation season, determination of the hydrologic properties of the aquifer were made by pumping tests at three wells. These wells were selected where it was believed they would give the best estimate of the transmissibility of the entire aquifer. The three wells are numbered 13-F-1, 13-B-1, and 7-N-2 and are operated by E. W. Hart, Leland Wells, and S. B. Ferguson, respectively. In addition, the records kept by Gilbert Looney and O. D. Stephenson on well Nos. 11-R-1 and 18-D-1, respectively, were in sufficient detail that transmissibility could be estimated approximately without making an additional pumping test. Results of all of these determinations are shown in Table 1.

Table 1. Transmissibility Measurements

Well designation	Owner	Radial distance from measured point to center of pumped well, ft.	Transmissibility	
			cu. ft. per sec. per ft. of width per unit hydraulic gradient	gallons per day per ft. of width, per unit hydraulic gradient
11-R-1	Gilbert Looney	7.4	0.247	160,000
18-D-1	O.D. Stephenson	0.33	0.80	519,000
13-F-1	E.W. Hart	100	1.59*	1,030,000*
"	"	6.8	1.12**	725,000**
"	"	6.8	1.59	1,030,000
"	"	0.42	1.38	892,000
13-B-1	Leland Wells	10	0.166	107,700
"	"	0.33	0.149	96,300
7-N-2	S.B. Ferguson	93	0.194	125,500
"	"	91.5	0.250	161,500
"	"	10	0.180	116,200
"	"	0.42	0.169	109,300
	Average		0.653	423,100

*Mean of measurements on two observation wells on opposite side of pumped well.
**Result obtained by a shorter computation of the non-equilibrium method using the same figures as in the line below. All other transmissibility figures were computed by the Theis non-equilibrium method.

Well tests were conducted by pumping at a steady discharge for a period of 9 to 24 hours. Drawdown measurements were made in the pumped well, in an observation well located about 6 to 10 feet from the pumped well, and in two observation wells located 90 or 100 feet from the pumped well in opposite directions. During the test on well 13-B-1 the drawdown in the wells at 100 foot radius was not consistant, probably indicating that a rise in the general level of the water table was offsetting the drawdown from pumping. No transmissibility computation was made for these points.

Table 1 shows transmissibility of the aquifer near well 13-F-1 was almost ten times that near well 13-B-1. All other measurements ranged between these two extremes. The ten-fold variation represents a high variability in the nature of the aquifer within the Jefferson area. It is extremely doubtful that the number of determinations made were sufficient to give an accurate estimate of the overall transmissibility of the aquifer in view of this variation. In spite of this doubt, a mean value of all transmissibility determinations has been used in subsequent computations. Most of the variability is probably due to variation in size of the particles comprising the aquifer, but part of it is also caused by variation in thickness and in proximity to relatively impermeable islands or boundaries of finer textured material. Computations of coefficient of storage of the aquifer made in conjunction with the transmissibility computations, in general, give very small values. Several were in the range of 0.003, but some were much lower and one or two were much higher. Coefficient of storage is defined as the ratio of the volume of water which will drain from saturated soil to the volume of the saturated soil, as the water table is lowered past the point in question. The low values obtained indicate that water is flowing under conditions essentially artesian in nature. In other words, it appears that most water supplying the wells is flowing through the lower portion of the aquifer, perhaps the lower 2 to 4 feet. Apparently the layers above this are less permeable, and the quantity of water they contribute directly to the flow into the well is much less significant. Under these conditions, the coefficient of storage is more accurately described as a measure of consolidation of the aquifer as pressure within it is reduced by pumping.

The transmissibility figures in Table 1 represent the quantity of water which will flow through a one foot wide section of the aquifer with a hydraulic gradient of one foot per foot of length. In the zone where the aquifer is thicker, it should have a higher transmissibility. On the other hand, if the presumption that most of the water moves through the lower more permeable part of the aquifer if correct, total thickness is less important than thickness of the lower layer. If recorded depth of well is an accurate estimate of depth of the aquifer, thickness below the water table averages about 13.5 feet and ranges between 10 and 17 feet during the pumping season. The water table during the 1958 pumping season ranged from about 6 feet to 18 feet below ground surface.

Examination of Figures 5 and 6 show that ground water contour lines are at right angles to the general direction of river flow. Water in the aquifer flows at right angles to these contour lines or in a direction generally parallel to the river. The total quantity of water flowing through

the aquifer can be estimated from the equation

$$Q = TIW$$

where T = transmissibility in cfs (cubic feet per second) per foot of width per unit of hydraulic gradient.

I = hydraulic gradient in feet per foot (slope of water table)

W = width of aquifer in feet (average)

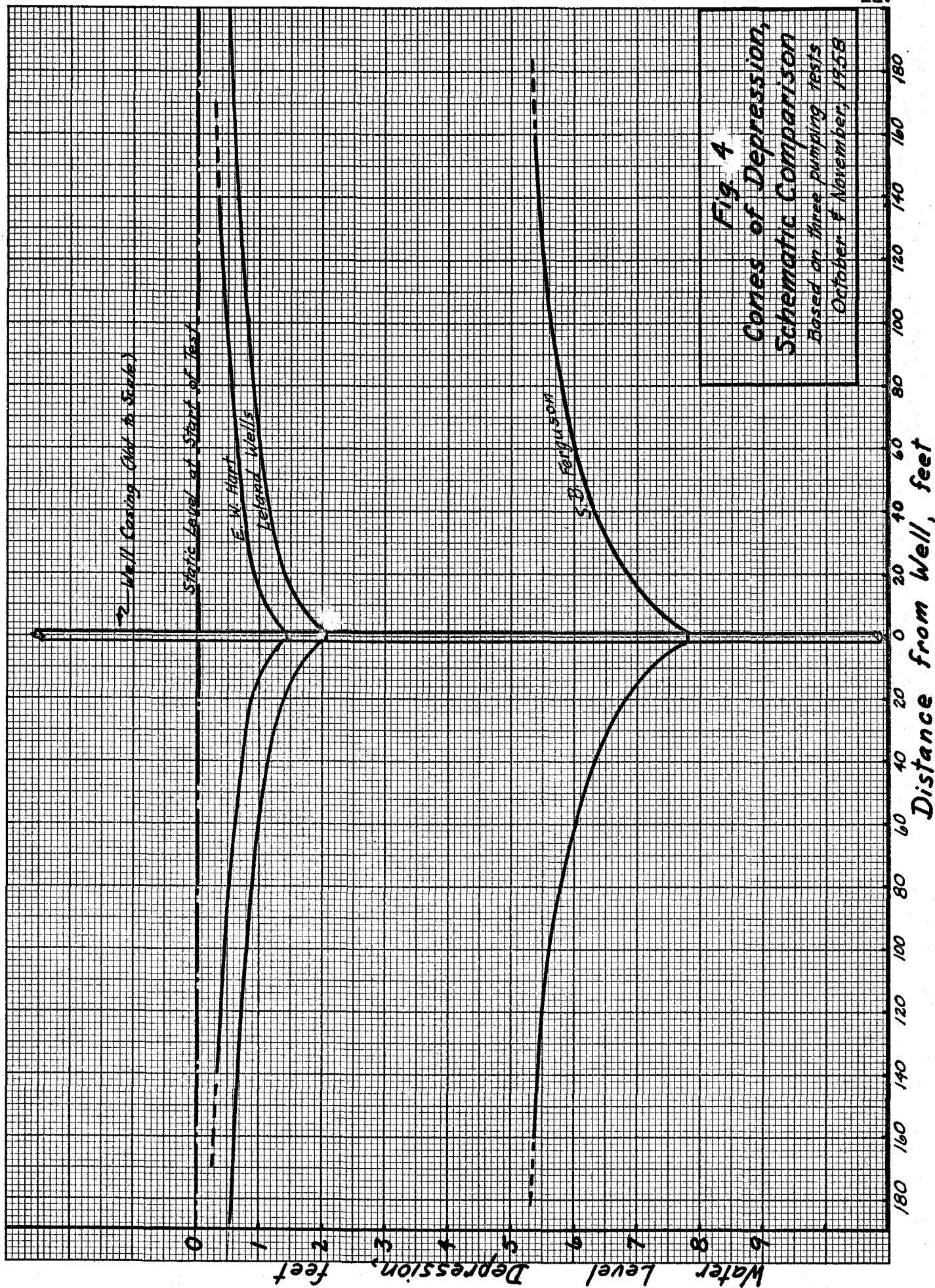so that $Q = (0.653)(0.00345)(5,500)$

= 12.4 cfs

This quantity of water should be essentially all available for pumping. While it is true that some will always escape to the lower river section on the west, lowering of the water table by pumping will increase inflow from the east. A 6 foot lowering of the entire water table at the center of the area should increase the inflow by at least one-third, and possibly by more than half.

Figure 4 shows a schematic comparison of cones of depression around each of the three wells pumped for transmissibility determinations. Cone shapes are quite similar. The cone at the Ferguson well is much greater and the drawdown is greater. The quantity of water pumped from the Ferguson well was 650 gallons per minute, from the Hart well 550 gallons per minute, and from the Wells well 180 gallons per minute. Since the transmissibility of the Ferguson well and the Wells well were determined to be approximately equal, we can assume that pumping 650 gallons per minute from the Wells well would produce a cone of depression very similar to that shown for the Ferguson well. A slight difference would be expected because the Ferguson well is located near a relatively impermeable boundary so water flows into the well effectively from only about half the circumference of the drawdown cone. In other words, had the Ferguson well been located farther from the boundary, a slightly higher and probably more accurate measure of transmissibility would have been obtained at the test. During the pump test at the Ferguson well it was interesting to note that water level in the observation well about 90 feet away from the pumped well began to drop immediately as the pumping commenced, dropping 0.4 foot in 30 seconds. This observation lends support to the theory that an artesian condition exists in the lower layer of the aquifer. The immediate drop in the well 90 feet away could only have occurred as a drop in pressure. It could not have resulted from a de-watering of the aquifer.

Ground Water Contours

Figures 5 and 6 show ground water contours as of July 18 and August 1, respectively. The contours were interpolated from the ground water elevation data also shown on the map. Considerable estimating was necessary when shaping the contours, particularly in the vicinity of a well which was being pumped at time of measurement. Figure 5 shows the situation six days before the river level was raised. Figure 6 shows the situation at the end of the one-week period of river rise when the effect was at a maximum.

Comparing Figure 5 with Figure 6, it is apparent that a slight displacement of ground water contours has occurred. The displacement is much more evident close to the river and tapers off rather rapidly as the interior of the area is approached. It is also quite apparent from this comparison that pumping has a greater effect on location of specific point on a contour

Fig. 4
Cones of Depression,
Schematic Comparison
Based on three pumping tests
October & November, 1955

Distance from Well, feet

Water Level Depression, feet

o Well Location.

□ River Level Station.

● Well Being Pumped At Time Of Reading.

000.00 Ground Water Contour Elev., Feet Mean Sea Level.

SANTIAM GROUND WATER INVESTIGATION

Ground Water Contours
As Of July 18 1958
Contour Interval 2.0 Ft.
Scale Approx.

Mile

Figure 5.

o Well Location.
□ River Level Station.
⊗ Well Being Pumped At Time Of Reading.
⌒000.00⌒ Ground Water Contour Elev., Feet Mean Sea Level

SANTIAM GROUND WATER INVESTIGATION

Ground Water Contours As Of Aug. 1 1958
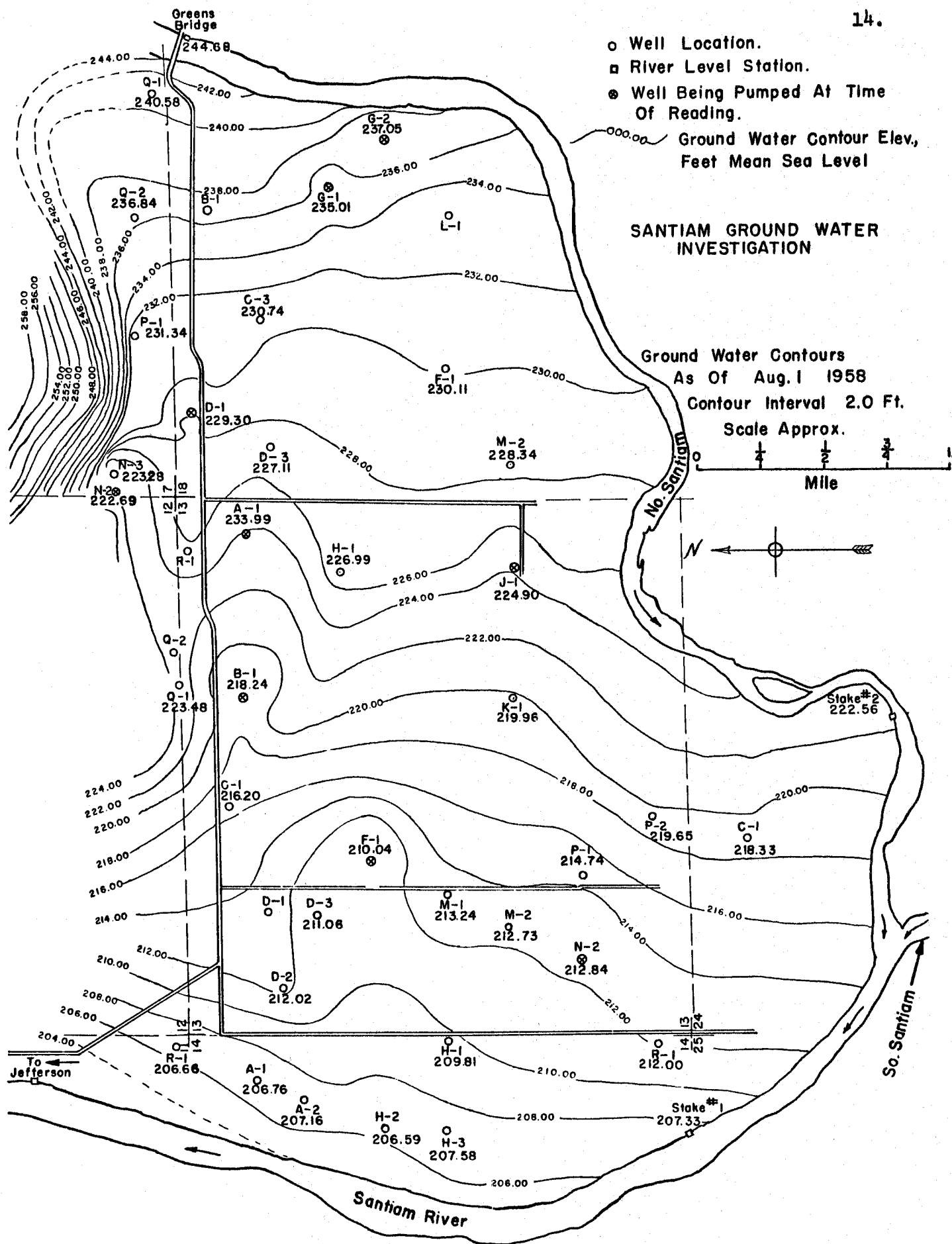Contour Interval 2.0 Ft.
Scale Approx.

Figure 6.

than does elevation of the river, but the effect from pumping a single well is confined to a relatively small area.

A few small diameter observation wells were driven to a depth of about 20 feet in the aquiclude which forms the north boundary of the Jefferson area (Ferguson farm) and is situated above the level of the flood plain. Purpose of these wells was to determine the relationship between the water table on the higher lands and the level of the river. Result of a typical reading is shown at the north edge of Figure 6. The water table remained within reach of these 20 foot wells, even during the lowest water period. Note, however, that contours are extremely close together, indicating a steep gradient. These measurements show that water continues to flow from the hill lands toward the river all summer. The steep gradient shown in Figure 6 could only exist through such a long period of no rainfall if the transmissibility of this material is very low. We can conclude, therefore, that even though a contribution from the hill lands continues throughout the summer, the quantity of water supplied from this source is very small compared with the quantity flowing through the aquifer in the direction of river flow.

Ground Water Profile

Figure 7 shows the profile of the ground surface and the ground water surface along a line essentially parallel to the direction of maximum gradient of the river valley, or in other words, parallel to the general direction of river flow. The location of this profile is shown in Figure 7 and is designated as Profile "A". Ground water profiles are shown for July 18 and August 1, 1958 and for March 26, 1959. The first two correspond to the data presented in Figure 5 and 6 and represent the situation before and during the period of river rise respectively. Note the cones of depression shown in the water table at some of the wells. This indicates the well was being pumped when measurement was made. Cone shape was only estimated.

Examination of Figure 7 shows that the average elevation of ground water surface is higher on August 1 than on July 18. Such is not the case, however, for wells 13-B-1 and 13-A-1. These two were both being pumped at the time of the August 1 measurement and hence show lower values. No reading was available for August 1 on well 13-D-1 so that point on the profile is not necessarily correct.

If a straight edge is laid from the river level at Greens Bridge to the river level near Jefferson, it is observed that most of the water elevations in the wells lie very close to this line of uniform gradient. Two exceptions are the levels in well 18-C-3, which is below the line, and in well 13-D-2, which is above the line. These slight deviations are undoubtedly caused by changes in the transmissibility of the underground strata, or in other words, by the underground barriers of finer textured material. Furthermore, the profile for March 26, 1959 has a shape almost identical to that during the previous irrigation season. These profiles conclusively place two facts in evidence. First, average elevation of ground water surface is dependent more upon river level than it is upon pumping or upon inflow from adjacent hills to the north. Secondly, quantity of pumping (together with transmissibility of the aquifer at the point) has a large influence on ground water surface elevation in the immediate vicinity of the pumped well.

Fig. 1.

Profile "A"

Showing Well Locations,
Surface & Water Table Gradients
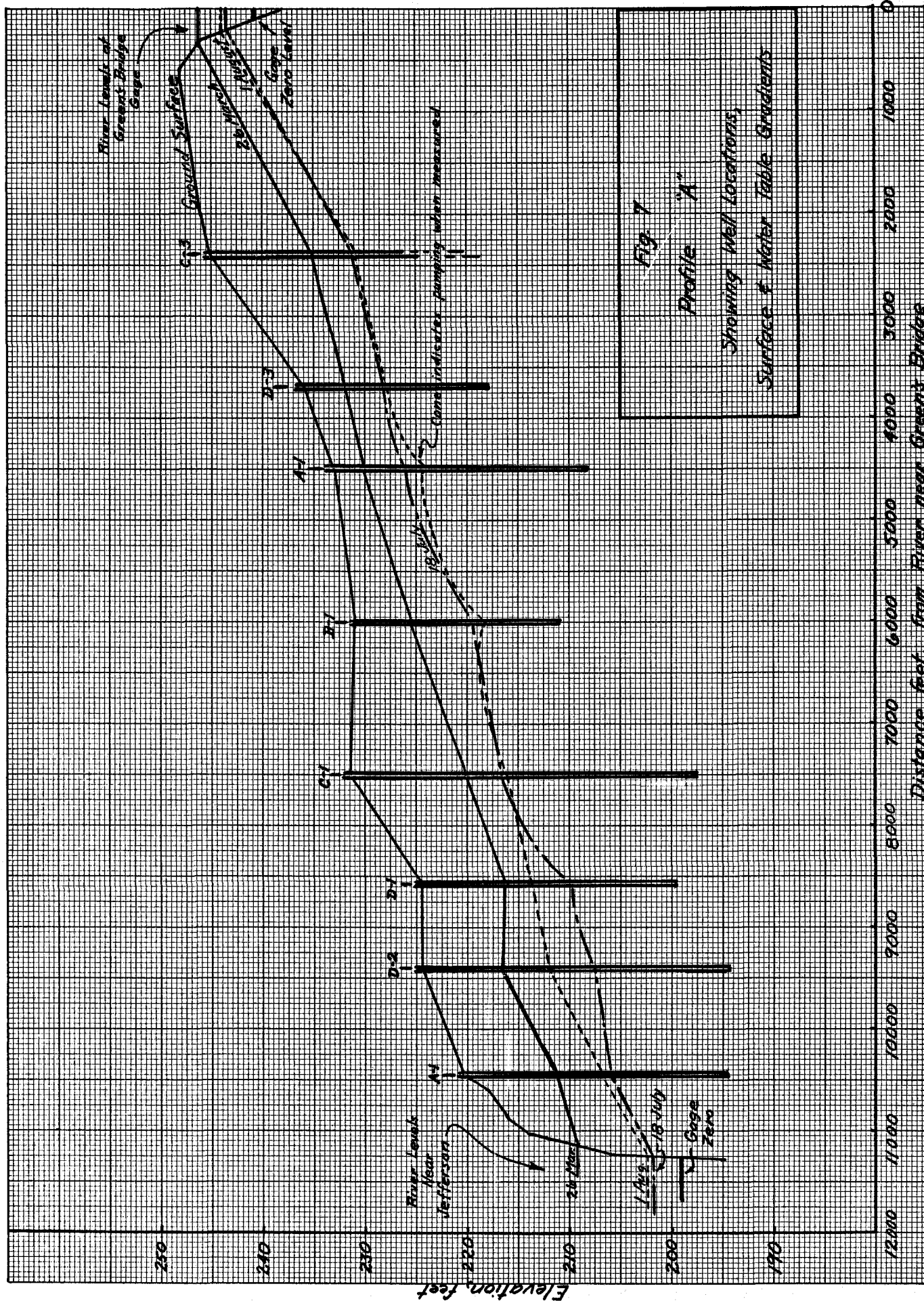
Consumptive Use

Consumptive use of all irrigated crops in the area has been estimated by the Blaney-Criddle method. The procedure involves obtaining total acreage of each crop in the area and estimating consumptive use for each by formula. Consumptive use is defined as the quantity of water transpired by plants plus that which evaporates from the bare ground surface between the plants. From data collected by the Santiam Irrigation Water Supply Committee with assistance of the County Agent, there are 929 irrigated crop acres in the Jefferson area. Mint comprises about half of this acreage and the remainder is distributed among 12 other crops.

The peak consumptive use rate during July, assuming adequate irrigation on all the irrigated acreage, was computed to be 7.75 cubic feet per second. For the sake of comparison, total potential irrigated acreage in this area was estimated as 1,450 acres. This figure includes a narrow strip of higher land believed to be within reach of economical pumping from wells in the bottom. Expanding the irrigated area to 1,450 acres would increase peak consumptive use rate to 12.1 cubic feet per second.

Purpose of estimating consumptive use was that it is considered to be a more accurate measure of actual withdrawal from the aquifer than pumping records could possibly be. When water is pumped onto land surface an un-measured amount of excess water ultimately returns to the ground water table and is available for pumping again. Consumptive use, on the other hand, represents total net water withdrawn from this underground stream flowing through the aquifer. The 12.1 cubic feet per second represents a maximum potential withdrawal, regardless of the quantity of pumping, so long as crop acreages remain in about the present relative proportion. It is also assumed that no water returns to the river over the land surface. This estimate for irrigation requirement is less than the estimated ground water moving through the Jefferson area during the period of lowest river stage.

Release from Storage

A quantity of water sufficient to raise the river level near Greens Bridge about 1.0 foot was released from storage from Detroit Reservoir by the Corps of Engineers. According to Geological Survey measurements near Greens Bridge this quantity of water was approximately 1,200 cubic feet per second, assuming the stream flow immediately prior to release would have persisted during the period. Total volume of released water passing Greens Bridge was approximately 21,000 acre feet.

Records from the Corps of Engineers indicate 1,400 cubic feet per second were released which makes a total volume of 24,000 acre feet. The difference apparently went into bank storage and diversions between Detroit Reservoir and Greens Bridge. If this released water is evaluated at 50 cents per acre foot, the cost of the water released would be about $12,000.

Increase in Well Yield to be Expected from a One Foot Rise in River Level

Two approaches have been used to estimate total potential increase in yield from wells resulting from a one foot increase in river level. The first approach is based on the assumption that the aquifer is equally

permeable throughout its vertical section. Considering effective thickness of the aquifer at present as 13.5 feet, an increase of one foot would increase the quantity of water flowing through the aquifer by 1/13.5 or about 7.4%. The 12.4 cubic feet per second estimated as flowing through the aquifer now would thus be increased to 13.3 cubic feet per second. Actually the increase would probably not be this much because the lower stratum of the aquifer is believed considerably more permeable than the remainder.

Probably the most accurate method of estimating maximum increase would be to consider the increase in gradient from the river to the area center. If we consider the center of the Jefferson area to be in the vicinity of well number 12-Q-1 the distance from the river is approximately one mile. The present gradient (in the direction of maximum gradient) in the ground water table is about 18 feet per mile. Raising the river level one foot would increase this gradient by the fraction 1/18 or about 5.6%. Potential flow would increase proportionately.

In order to estimate total quantity of additional water potentially available for pumping along the entire flood plain of North Santiam and the Santiam rivers as a result of the one foot rise, it is necessary to make some assumptions or approximations. The rise in the river is assumed to be effective over a channel 20 miles long. This distance is measured in the direction of the alluvial valley and does not include all of the meanderings of the river within the valley. Because the increase in water will cause flow from both river banks we will consider twice this distance or 40 miles. If the typical well is considered to be 1/2 mile from the river bank, and if we consider only that vector of the increased gradient in the ground water which is at right angles to the general direction of river flow, this gradient would be one foot per 1/2 mile or 0.000379 feet per foot. It is assumed that pumping would be adequate to prevent any rise in the water table at the well. Total increase in flow due to the river rise would then be

$$Q = TIL$$

$$= (0.653)(0.000379)(40 \times 5,280)$$

$$= 52.3 \text{ cfs}$$

If all assumptions are correct this means the total increase in water available for irrigation as a result of the river rise is 52.3 cubic feet per second, which is 3.7% of the 1400 cubic feet per second released.

Volume of Storage in the Basin

Total volume of water contained in the aquifer could be estimated if an accurate value for coefficient of storage were available. It has been pointed out that values obtained for coefficient of storage represented only the consolidation in lower stratum of the aquifer and did not represent the volume of water contained in upper layers. A typical value of coefficient of storage for a gravel aquifer as found in the literature is 0.25. If this value can be assumed to apply to this aquifer it means that 1/4 of the total 13.5 feet depth of aquifer is water, or 40.5 inches of water. This quantity of water is approximately twice that needed to supply consumptive use for

one season, and would still leave approximately half the original depth of water in the wells.

Outlying Wells

Outlying wells measured as a supplemental part of this study extended upstream toward Stayton and downstream toward the Santiam River mouth. Four typical hydrographs of these wells are shown in Figure 3. These hydrographs show a rise during the period of river rise similar to that shown in wells in the Jefferson area. It appears from these results that data from the Jefferson area is typical, and that water level in wells situated in the entire length of the flood plain of the North Santiam and Santiam rivers is primarily controlled by water level of these rivers.

CONCLUSIONS AND RECOMMENDATIONS

Relation of Ground Water Level to River Level

General elevation of the ground water table in the flood plain deposits of the Santiam and North Santiam Rivers appears to be associated more closely with elevation of river surface than with any other single factor. When river level rises, adjacent ground water level begins to rise almost immediately but at a slower rate. Farther from the river the response is slower. Apparently there is a lag of considerably more than one week between fluctuations in river level and corresponding fluctuations in ground water level. Actual lag will depend on proximity to the river and transmissibility of the aquifer.

Pumping appears to influence water levels only in the vicinity of the pumped well. Maximum fluctuation observed in any well as a result of irrigation pumping was about six feet, or six times the river fluctuation during the test period. Most wells fluctuated much less. Total acreage affected by severe pumping drawdown at any one time is relatively small.

Direction of flow of ground water in the flood plain appears to be in a westerly direction across the Jefferson area. The elevation of the water table at any location in the Jefferson area is approximately the same as the river elevation at a point lying due south of that location.

Quantity of Increase for Pumping

In the Jefferson area probable maximum increase of ground water flow toward the area center caused by a one foot rise in river level is about 6% of existing ground water flow. Actual estimates made by two methods were 5.6% and 7.4% respectively. Estimated flow through this area during a normal pumping season is 12.4 cubic feet per second. On this basis expected increase would be about 0.8 cubic foot per second.

If results of the study in the Jefferson area are applicable to about 20 miles of flood plain of the North Santiam and Santiam Rivers, total increase in water available for pumping would be about 50 cubic feet per second. Actual computed value based on several assumptions was 52.3 cubic feet per second.

Overall Efficiency

Computations based on measurements of ground water flow and river flow indicate a release of 1400 cubic feet per second could cause an increase of 52.3 cubic feet per second available for pumping. Maximum possible overall efficiency of this operation is $\frac{52.3 \times 100}{1400}$ or 3.7%. This would be considered an extremely low project efficiency for irrigation.

Other Possible Methods for Increasing Pumping Yields of the River Basin

One method suggested for raising water level in the river is to construct a dam or series of dams in the river channel. For such a scheme to work in the Jefferson area, however, a series of dams all the way around the loop would be required because the river falls about 40 feet in this section. A study of the ground water contours makes it evident that a single dam on the east side of this area would affect the ground water level for only a short distance. Since the cost of multiple dams would be prohibitive, this method is not recommended.

Probably the most inexpensive way of increasing total pumping yield of this valley is to increase the number of wells. For two of the three wells pumped for the transmissibility determinations, depression of the water table at a distance of 100 feet from the pumped well did not exceed one foot. In the third well corresponding drawdown was about 6 feet. During all three tests more water was being pumped than the respective sprinkler systems required. A mean of these three values is 2.67 feet. If we can consider this mean value applicable to a typical well, and if two such wells were placed 200 feet apart, the total drawdown at mid point would be approximately double this, or 5.33 feet. The corresponding drawdown in the well would be about seven feet, a value that would not be excessive for most of the wells in the area. Thus it appears wells could be located as close as 300 feet without serious interference in a typical case although 400 feet would be better. As number of wells is increased, pumping from each would be decreased so the situation described would probably represent an extreme which would seldom, if ever, be reached. Along the boundary at the north edge of the Jefferson area minimum distance between wells should probably be 500 or 600 feet.

Increasing the number of wells with a corresponding decrease in quantity of water pumped from each would reduce the tendency for pumps to break suction and quit operating. It is believed that reported "cut-offs" are due to two causes. First, as pumping level drops in summer the aquifer in the vicinity of certain wells probably does not have enough transmitting capacity to supply all sprinklers of the system. When this occurs pumping level would drop to the very bottom of the well if the pump had the ability to drawdown this far. The second cause of cut-off is excess pumping lift and not insufficient water. When a lift of about 14 or 15 feet is exceeded the pump begins a noisy operation and its efficiency is reduced, so fewer sprinklers can be operated. Further increase will cause the pump to lose prime even though the foot valve may still be under the water surface. This difficulty can be eliminated by placing the pump in a pit deep enough to prevent the lift from exceeding 14 feet.

Application of Results to Other Areas

The fact that the outlying wells upstream and downstream from the area of concentrated measurement showed characteristics similar to those in the concentrated area indicates that data obtained is applicable to the entire alluvial valley of the North Santiam and Santiam Rivers. The results can probably also be applied to the South Santiam and any other valley with characteristics similar to those of the North Santiam River.

APPENDIX

Appendix fig. 1
Hydrographs
based on
Recorder Chart Data

from 1 July 1958 to 8 Oct 1958

Vert. Scale: 1 in. = 10 ft.
Horiz. Scale: 1 in. = 10 days
Transfer Point interval, 1/2 day

North Santiam R.
at
Green's Bridge

Well No. 14-R-1
N. Stephenson

Appendix, Fig 2

Hydrographs
based on
Recorder Chart Data

from 1 July to 8 Oct. 1953

Vert. Scale: 1 in. = 10 ft
Horiz. Scale: 1 in. = 10 days
Transfer Point Interval ½ day

Well No. 13-C-1
E. W. Hart

Well No. 18-C-3
Roy Tilley

Appendix - Fig. 3
Hydrographs
based on
Recorder Chart Data
Vert. Scale: 1 in. = 10 ft.
Horiz. Scale: 1 in. = 10 days

Well No. 7-N-3
J. B. Ferguson