EFFECT UPON GROUND-WATER LEVELS OF PROPOSED SURFACE-WATER STORAGE IN FLATHEAD LAKE, MONT.

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ABSTRACT

The area under consideration is a deltalike alluvial plain, having an area of about 25 square miles, at the northern end of Flathead Lake, where the Flathead River enters it. During most of the year the river and lake maintain fairly constant levels, but in the late spring they rise to flood peaks and promptly begin to subside. By means of readings of the water level in 40 observation wells over a period of nearly 10 years, it has been found that the ground-water levels in the vicinity of the lake and river rise and fall in response to the annual change of stage. Those wells that are nearest the lake and river show the greatest and promptest rise and fall of water level, but in the interior of the area this effect disappears.

It has been proposed to regulate the level of the lake in such a way that a moderate flood stage may be maintained for a longer period of time than under natural conditions. The purpose of this study is to determine the effects of this regulation on the ground-water levels in the delta area. The problem is approached by devising a graphic analysis of the effect of certain floods on the water table at various distances from the lake and river. From this analysis it is possible to predict in some detail the effects of a stillstand of the lake level at a moderate flood stage. A rise of the water table is indicated as a result of regulation as it has been proposed, and the probable manner in which the rise will take place, its magnitude, and the length of time required for it to be realized in various parts of the area are shown graphically.

The proposed regulation of the lake and river levels will probably result in some local changes in the use of the delta lands. As shown on plate 10, some tracts will be rendered unfit for agriculture owing to the rise of the water table, some tracts will become marginal, some may even be improved, but most of the land will be unaffected by the rise.

INTRODUCTION

On May 29, 1928, the Geological Survey was authorized by the Federal Power Commission to make an investigation of ground-water levels in the alluvial area at the head of Flathead Lake. The work of putting down test wells was begun in a few days by engineers of the Geological Survey, and since their completion observations of the water levels have been made at regular intervals. Measurements were made in 40 wells that were put down especially for observation and in

7 abandoned domestic wells. These observation wells are identified by number. Seven staff gages are maintained by the Geological Survey on the river and lake in the area under discussion. They are identified by letter (see pls. 3, 4, 5, 6, and 10). The task of locating, constructing, and measuring the wells and of collecting and assembling the measurements was supervised by A. H. Tuttle, engineer in the district office of the Geological Survey at Helena. Several preliminary reports on the study were made by Mr. Tuttle, and a memorandum was prepared late in 1929 by O. E. Meinzer, geologist in charge of the division of ground water, and L. T. Jessup, of the United States Department of Agriculture. Although in this memorandum the authors made a preliminary analysis of the problem, they concluded that until sufficient data had accumulated final conclusions were not feasible.

In the autumn of 1937 a request was made by the Federal Power Commission for a report based on the records of the water levels that had accumulated during the period of 9½ years. The writer was detailed to the project and spent a few days inspecting the area. During 1938 he studied the well records and assembled the information upon which this report is based.

The ground-water measurements from 1928 through 1935 have been published in Water-Supply Paper 777; those for 1936, in Water-Supply Paper 817; and those for 1937, in Water-Supply Paper 840.[1]

NATURE OF THE PROBLEM

The area under consideration is a deltalike alluvial plain at the northern end of Flathead Lake, where the Flathead River enters it. The river flows toward the southeast until it reaches the northwest corner of the area under consideration, which is about 5 miles north of the lake. There it makes a bend and flows about 5 miles toward the east and thence turns southward and enters the lake. Thus the area has somewhat the form of a square, bounded on the west by the mountainous side of the valley, on the north and east by the Flathead River, and on the south by the lake. It comprises about 25 square miles. During most of the year the river carries a rather uniform quantity of water, but in the late spring and early summer it reaches a high stage, usually called the flood stage, due to the melting of snow in the mountains. The lake also rises during the flood. The Rocky Mountain Power Co. proposed to regulate the outflow of the lake at its south end for the production of electric power. This proposed regulation would prolong the high stages of the lake and of the river in the stretch near the lake and would

[1] Available water-supply papers are sold by the Superintendent of Documents, Washington, D. C.

retard the recession from the high stage. It would raise the average level of the lake about 4 to 6 feet. Fear was expressed by local interests that much of the fertile land in the area under consideration would cease to be productive, to the economic detriment of both the land owners and the business interests depending in part on them. The ground-water study, therefore, was designed to provide a basis for estimating the damage to crops to be expected from the regulation of the lake level.

GENERAL FEATURES OF THE AREA

During low stages the surface of the lake and river stands at an altitude of about 2,882 feet. The land, which is very flat, rises from the lake shore to an altitude of only about 2,900 feet within the first mile and remains at about that altitude as far north as the river. The southwest corner of the area is the highest, being from 2,910 to 2,915 feet above sea level. Near the river east of the eastern border of secs. 20, 17, and 8, T. 27 N., R. 20 W., the land is rather low, most of it being between 2,890 and 2,894 feet. The rise of the land from the lake is not uniform because of the existence about half a mile from the low-water line of a definite beach deposit 6 to 8 feet high, which follows approximately the 2,893-foot contour line. The descent of the land surface to the river on the northern and eastern sides of the area is very abrupt—in many places the bank is vertical.

Several small features of the area are of considerable importance in any detailed study of the ground-water problem. These are the oxbow lakes and other deserted river channels, the channels of extinct tributary streams, and one small existing stream, Ashley Creek. Feenan and Church Sloughs and two other unnamed sloughs situated respectively near the northwest and northeast corners of the area, influence the movement of ground water. Other channels, most of which do not contain standing water, are sites of ground-water evaporation and transpiration. Although the largest and most numerous of these channels are in the western part of the area, one small channel runs north and south across the eastern part of the area, and another, parallel to it, passes nearly through the center of the area. The last two are noteworthy chiefly because they are in the part of the arable land where wells are numerous. Besides these relatively prominent topographic features there are several undrained depressions, some of which are lower than the present water table. One of special interest is in the northwestern part of sec. 18, and another is near well 20. In almost all parts of the area the land surface is cut by shallow drainage channels, many of which are recognizable on the topographic maps though they are not evident to the observer on the ground.

Logs of 26 of the test wells provide information on the composition and arrangement of the earth materials that underlie this alluvial area. Typically the surface soil is underlain by silt with varying quantities of clay or sand. This fine-grained overburden may be as much as 10 feet thick or as little as 1 foot, but it averages from 3 to 4 feet. It is thinnest along the shore of the lake. Below this is likely to be sand of fine or medium texture, with silt a prominent constituent in some wells. Typically this fine or medium sand is from 3 to 5 feet thick, but it may be as little as 1 foot or as much as 8 feet. In some wells a thin layer of clay is at the bottom of this sand, and where it occurs it lies at an altitude of about 2,890 feet. Most of the wells end below the level of the clay bed in a coarse sand that contains interbedded thin laminae of clay. As none of the present wells went deep enough to pass through this lower sand its thickness is not known. It is encountered in most localities at an altitude of about 2,890 feet. Two of the 26 wells, however, failed to encounter it at all. The deep depression in sec. 18 is floored with dark clay, which, if continuous, may underlie the coarse sand, but this is only a possibility. The coarse, permeable sand overlain by an overburden of fine sand, silt, and clay thus constitutes a semiartesian aquifer, and, as will be shown later, the water in it under certain conditions may transmit changes in hydrostatic pressure in the manner of an artesian water body.

NATURAL GROUND-WATER CONDITIONS

During most of the year the water table is high in the central part of the area and slopes off toward the north, east, and south as the water moves into the river and lake. Although wells are lacking on the west side of the area, the presence of marshes, together with the perennial character of the flow of Ashley Creek, indicates that the water tables rises toward the valley wall. Ground-water is discharged locally through channels cut below the general land surface and in areas of rapid evaporation and transpiration. When the lake and river reach high stages, wells near them show a sympathetic rise. The magnitude and promptness of this rise diminish abruptly in wells farther from the lake and river. In wells that are more than 2,500 feet from the lake or river, or from sloughs connected with them, the maximum water levels are attained early in the spring through recharge by the local melting of the snow. In some wells a rise of the water level occurs in response to autumn rains and to the cessation of losses through transpiration at the end of the growing season; these rises, however, are relatively small. Some wells at intermediate distances from the lake or river show a double peak—one early in spring and the other during the flood stage.

Wells nearest the river and lake exhibit the greatest range of fluctuation through the year. Of the wells far from the river and lake, those in which the water level lies deepest below the land surface show the least fluctuation, whereas wells in parts of the area where the water table is at shallow depth, such as No. 19, respond quickly and abruptly to surface recharge.

Comparison of well hydrographs indicates yet another difference. Some wells that were abundantly recharged in a certain year, such as those that were nearly covered by the flood waters of 1928 and 1933, show a net decline year after year until their previous base is reached. This is evidence that the percolation of ground water laterally from the area is very slow. Many other wells in the interior maintain a constant level throughout the period of record.

WATER LEVELS IN 1933

Because in 1933 very high stages were reached by the river and lake, and measurements of the wells were more frequent than in any other year, that year was chosen for a detailed study of the yearly ground-water and surface-water cycle. A series of contour maps of the water table shows specifically the features that were described above in general terms. Plate 3 shows the position of the water table on February 20, 1933, when the lake level was 2,882.38 feet above sea level. On that date the water table in the southwest corner of the area, near well 45, stood at 2,889 feet. Lack of wells makes it impossible to draw contours on the west-central part of the area, but it is almost certain that the water table rises toward Ashley Creek. The gradient southward toward the lake is gentle as far as well 5, but thereafter it steepens greatly and presumably falls from an altitude of 2,888 to about 2,882.5, the approximate altitude of the lake surface within a horizontal distance of less than half a mile. In the eastern half of the area the water table lies at an altitude of about 2,887.5 feet. On each of the three margins of the area bordered by water the flattish surface of the water table dips suddenly toward the river or the lake. The contours indicate a rather decided gradient into the channel in which well 19 is situated. There seems to be a similar sharp slope toward the channel that follows the west boundary of secs. 17, 8, and 5, but no wells provide control for the east side of this channel. In the vicinity of well 32 the water table stands at an altitude of 2,888.5 feet. This figure is taken from the readings on a single well, which appears to be sluggish in its response to recharge and drainage. It is possible that the water in this well has not very free interchange with the ground water outside. The gradient of the water table north of Ashley Creek is very steep. In the southeast corner of the area the water table is low—about 2,885 feet—and the gradient is very flat.

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In the spring of 1933 the lake began its rise late in April and by the middle of June had reached a peak of about 2,896 feet. The river was somewhat higher, as gage D at Damon Ranch showed a stage of over 2,900 feet. Some of the lands were inundated, chiefly on the lake shore, in the eastern part of secs. 5 and 32, in the vicinity of Church Slough, and in the vicinity of Ashley Creek. The ground-water contour map for June 11 (pl. 4) shows the advance of the inflowing water. Wells 25 and 26 have as yet shown only a slight rise, but wells near Church Slough have shown a marked rise. The advancing waters have affected wells near the shore of the lake above the level covered by flood waters, but in the southeast corner of the area the rise has been only slight. Elsewhere in the area the ground-water has continued to percolate from the high points of the water table toward the lake or river or toward places of local ground-water discharge. In the vicinity of well 45 the ground water was recharged in April from the melting of snow, but as it shows a very slight rise corresponding to the rise of the lake it indicates either direct influence of surface water in nearby channels or else a backing up of the centrifugal ground-water drainage. The latter explanation is plausible because other wells that are distant from bodies of surface water are likely to show a slight rise when the lake and river are at high stage; also the semiartesian character of the ground-water body may allow a transmission of pressure from the periphery during floods that is distinct from an actual movement of water to these wells.

The third map (pl. 5) based on the measurements of August 7, 1933, shows conditions during the recession of the flood and the draining of the bank storage. On August 7 the lake level was 2,885.58 feet above sea level. Large ground-water ridges would be expected where the bank storage moving inland was left unsupported when the flood waters receded. Such a ridge is actually defined by control wells near the lake shore. Wells 5 and 9 define the crest at 90.5 feet and the gradient inland, and well 10, in which the water level is lower than the other two, suggests the reverse gradient toward the lake. Meantime, water is still moving inward from these ridges as well as percolating from high points in the interior toward the periphery and local points of ground-water discharge. The channels running south from well 19 and along the eastern part of the area, which before the rise of the lake and the river functioned as avenues of ground-water discharge, have changed, however, to paths along which the invading bank storage moves.

The map showing the water table on October 15, 1933, when the lake level was 2,882.84 feet above sea level (pl. 6), indicates further dissolution of the ground-water ridges along the margins of the area. The persistence they exhibit is significant, for in some of the wells whose water levels rose to unusually high stages the decline toward their former positions goes on for several years. Wells 25 and 26 and wells 1, 2, and 3, in the southeast corner of the area, are good examples.

TRENDS OF THE WATER LEVELS

As a preface to a discussion of the trends that the wells have shown from season to season and from year to year during the period of observation, it is necessary to describe the trends of the lake and river stages and the precipitation. Two very high flood stages, each about 2,896 feet, were reached by the lake—one in 1928 and the other in 1933. The stage reached in 1929 was lower by about 5 feet than that of the previous year, and in 1930 and 1931 the highest stages were only about 2,889 feet. In 1932 a reversal of this trend occurred, and the peak reached was about 2,892.6 feet. Following the high peak of 1933 there was another tapering off—the 1934 peak was about equal to that of 1932; the 1935 and 1936 peaks were about 2,892 feet; and the 1937 peak was only about 2,889.5. The low stages of the lake are also variable. Autumn rains interrupted the recession from flood stage in 1933 and to a less extent in 1928, 1932, 1934, and 1937. Extreme low stages of 2,981.5 or less were reached in the autumn of 1929, 1935, and 1936. Thus in each of the two 5-year periods of record, the highest flood stages were reached at the beginning of the period, and there was a diminution during the ensuing years.

As precipitation is not directly a controlling factor in the level of the water table over most of the area, no elaborate analysis of it seems necessary. The year 1928 had moderate precipitation and was conspicuous chiefly for a 2.5-inch rainfall in June; 1929 was very dry except for a wet January and December; in 1930 precipitation was abundant in the early summer and autumn; 1932 had nearly average conditions, with the major part of its precipitation in the spring and autumn; 1933 was conspicuous for abnormally high precipitation both in May and in late autumn and winter, especially in December; and 1934 had dry months alternating with wet ones and a very dry summer. In 1935 and 1936 the distribution of precipitation was nearly normal—that is, heaviest in winter—but the amount was considerably below the average. During the first half of 1937 the precipitation was low, but it was heavy in July and also in the autumn. Some of the wells definitely not affected by the flooding of nearby land during periods of high water in 1928 and 1933 show in their base lines a slight variability that corresponds to the annual march of precipitation. In the hydrograph of these wells, however, the variability is not so impressive as the stability during the period of record. A closer correlation of ground-water levels and precipitation would probably appear if 2-year or 5-year running averages of precipitation and stage of the water levels were used.

EFFECT OF TEMPERATURE

Temperature exerts control of two kinds over the ground-water levels. Primarily it determines the thawing of the winter snow, and secondarily it controls the rate and duration of evaporation and transpiration of the ground water in shallow-water localities. For example, well 20 rose about 0.25 foot in September-October 1929 in spite of the fact that the rainfall was less than in any other similar season during the period of record. On the other hand, the heavy precipitation in December of that same year—almost 3 inches—did not produce any appreciable recharge. It is not possible to state categorically that the autumn rise was due entirely to the cessation of transpiration losses, but such an interpretation is reasonable, as wells whose water levels lie at greater depth below the land surface generally continued to decline during these months. Well 20 showed a rise early in the spring of 1930 but only after a decided thaw that occurred in March. The water level in well 19 rose nearly a foot in the autumn of 1929, and it rose also in the other autumns when the rainfall was considerably heavier, but the rise was about the same as in 1929; late in August, however, the rate of recession of the water level was abruptly retarded about the time a rain of 0.13 inch fell. As the first killing frost at the Weather Bureau Station at Kalispell came on September 6, it is possible that well 19 showed recharge of the ground water in response to very small rains. If this is so, one would infer that the capillary fringe reaches the ground surface. The additional soil moisture furnished by the rain might have tended to satisfy the needs of the vegetation so that they used less ground water. In other parts of the country observation wells where the water table is near the land surface indicate a rise of the water table after the first killing frost. Well 19 has the greatest fluctuation of water level of all wells in the area except those that are affected by the floods of the lake. As the chief recharge comes in March, the height that the water level reaches is controlled by the amount of precipitation in the previous winter.

The hydrographs of wells 19, 23, and 36, presented in plate 7, typify certain contrasts in the behavior of the water levels. Well 23 shows best the conformity of water levels with changes in the level of the river; well 36 is typical of wells far removed from the influence of the lake and river; and well 19 is the best example of a well in which the water level is near the land surface.

The water level in well 23 ranges from an extreme low point of 2,882 feet, in the spring of 1937 to somewhat more than 2,898 feet in 1933 (the peak of the rise was not measured). The land surface at the well is 2,901.58 feet above sea level. The record of this well was begun in July 1928 and shows the decline from the extremely high stage it evidently reached in the spring of that year. From then on the well hydrograph follows that of the lake and river. The flood of 1929 was lower than that of 1928 by about 5 feet; and so with the well. The floods of 1930 and 1931 were still lower and failed to reach the peak of 1929 by about 2 feet; the peak of the well hydrograph for each of these years was about 1 foot lower than that of 1929, but the measurements are not frequent enough to define the peaks exactly. In 1932 when the lake level was about 2 feet higher than that in 1929, the peak in the well was about 2 feet higher than that of 1929. The flood of 1933 was accompanied by an extremely high stage in the well. A subsidiary rise of the lake in October and November 1933 was accompanied by a rise in the well. The lake rose to about 2,892 feet in 1934, 1935, and 1936, when the water level in the well rose to stages of from 2,893 to nearly 2,895. But here again the hydrograph of the well is imperfectly delineated. Both the lake level and the ground-water level were about 2 feet lower in 1937 than in the previous 3 years. An important observation to make is that this well appears to be relatively as sensitive to changes in stage of the lake and river when at low levels as at high stage. Thus the subsidiary peaks shown by the hydrograph of the lake and river in 1930, 1932, 1936, and 1937 are reproduced in the well hydrograph. The small rises of the lake and river during their low stages in 1932, 1933, 1934, and 1937 appear also in the well hydrograph. The sensitivity of the ground water in the vicinity of well 23 to low-stage fluctuations of the lake and river indicates that the ground water does not rest on an impermeable floor above the low-water level of the lake and river. This observation, however, need not necessarily apply to the area as a whole. This well does not show evidence of recharge from the surface; such recharge doubtless occurs but is masked by major fluctuations.

The hydrograph of well 36 is subdued and shows little variability from one year to the next. The water level lies at an altitude of 2,886 to 2,887 feet, whereas the land surface at that point has an altitude of 2,902.82 feet. Thus any recharge that reaches the water table from the surface is likely to be spread over a considerable length of time—months instead of weeks. A slight decline from an abnormally high stage can be observed from 1928 to 1931, probably as a result of flooding of adjacent land during the high water of 1928. The high flood peak reached by river and lake in 1933 had a scarcely perceptible effect upon this well, doubtless because flooding of the land was prevented by dikes. In all years except 1936 the annual fluctuation was 0.4 foot or less. In 1936 exceptional recharge was effected by some means not clear, and the increased storage persisted into 1937. Perhaps steady rains in the first 4 months and in June of that year provided an unprecedented opportunity for recharge, although 1936 seems not to have been unusually rainy. In most years the highest stage of the water level is reached in April or May, a fact that suggests a lag in the recharge of between 1 and 2 months behind the precipitation and thawing that caused it. In 1936 a lag of about the same duration seems to have prevailed in the rise of the water level after the rains in the spring. The rise in June was dissipated promptly, however, for the water level dropped rapidly, in marked contrast to the rate of decline in other years.

Some of the features of the behavior of the water level in well 19 have already been mentioned. The water level at the high stages comes within a foot of the land surface and at its low stages is not more than 6 feet below the surface. The rate at which it rises to its peak in the spring and at which it falls from the peak is rapid. Thus in 1929 the water level rose 2 feet in less than a month. Not uncommonly it declines at a rate of about 1 foot a month. The rise lags only a very short time behind the rain or thaw that occasions the recharge, probably only a few days, as in August 1929. As would be expected, a rain in the nongrowing season is more effective in causing recharge than a rain falling during the growing season. Thus a rain of nearly 1 inch in May 1932 caused a rise in water level of about 0.8 foot (taking into account the falling stage at that time), whereas in October 1935 a rain of about half an inch was chiefly instrumental in causing a rise of about 1 foot (a rain of about 0.25 inch in mid-September may have accounted for some of the recharge). The behavior of this well suggests that the capillary fringe extends at least 5 feet above the water table, for the prompt and decided rise of water level from low stages to high probably means that the fine-grained silt and clay that overlie the water-bearing sand are partly filled with capillary water throughout most or all of the period of record. Another possibility is that the channel in which the well is situated was cut through the fine-grained overburden and into the water-bearing sand, so that recharge of ground water is unobstructed, and the water level in the well is determined by the level at which accumulated surface water stands in the channel. Records of other wells in the area, however, indicate as a general relation that where the water level is not affected by the level of the lake and river its fluctuation is greater the nearer it is to the land surface. When the water level in certain wells is declining from an extremely high stage, as in 1928, the fluctuation is greatest in the years when the average stage is highest and becomes less in succeeding years as the average stage declines.

SUMMARY OF RELATIONS OF WATER LEVEL IN WELLS TO RISE AND FALL OF RIVER AND LAKE

The water level in wells in the periphery of the area fluctuates in harmony with the rise and fall of the lake and river. The highest stage is reached in years when the flood stages of the river and lake are highest. The farther a well is from the lake and river the more subdued are the fluctuations and the greater the lag. Wells farther in the interior of the area are scarcely affected by floods of the lake and river, and thus they have only one peak, which comes in the winter and spring. These wells show a fluctuation whose magnitude varies inversely with the depth of the water level below the land surface. In an intermediate belt the well hydrographs exhibit a double peak each year, one about April and the other in June or July.

ADJUSTMENT OF GROUND-WATER LEVELS TO REGULATION OF THE LAKE

Water that has reached the zone of saturation by seeping from the surface in the interior of the area is at present percolating toward the river or lake. But owing to the annual rise and fall of the river and lake level, water moves a short distance into the periphery of the area and temporarily obstructs the centrifugal ground-water percolation. Thus it appears that the water levels back from the river and lake are determined by the average annual level of the lake, and to foresee the effects of regulating the lake it would be necessary merely to compute the new average annual level of the lake and to adjust the ground water level to it. This relation would be very simple, direct, and logical were it not for the possibility that the ground water might rest upon a relatively impermeable floor of fine-grained material. The ground-water levels then would not have any direct relation to the lake and river levels during such low stages when the lake and river stood lower than this floor. It was decided to attempt some other method of predicting the adjustment of the water table that would avoid this uncertainty and to retain the use of average levels as a check. As is shown later, however, the two methods gave comparable results.

In general terms, the method chosen to picture the changes occurring in the ground-water body as a result of regulation of the lake was to systematize the relations existing between fluctuations of the lake and well levels under natural conditions and to apply these relations rigidly to the proposed artificial regime. Three elements were separated out of the continuous behavior of the wells and lake and treated individually: (1) The lag of the fluctuations of the wells behind the fluctuations of the lake level, (2) the rise of the water levels to their peaks, and (3) the recession from the peaks to the low stages.

The initial step in the process was to select several wells whose behavior seemed regular and simple. Because of the flooding of the lands near the lake the type wells were chosen from among those along the river in the northern part of the area. The distance of each well from the river or the slough connected with the river was plotted graphically on the base line of the figure (see pl. 8, *B*). Then three flood periods were chosen—a low one, an intermediate one, and a high one. The lake rose to about 2,889 feet in 1931, to about 2,892.6 feet in 1932, and to about 2,896 feet in 1933; and as these years are in chronologic order, these three floods were chosen. The floods of the river are plotted on the zero point of the "distance-base," whereas the rise of each well is plotted from its appropriate point on the distance-base. The maximum stage reached by each well in a certain year, as 1931, is plotted directly above the point of origin on the distance-base according to the vertical scale constructed to express altitude of gage height. The duration of the rise to this stage is expressed as a horizontal line from the point at its appropriate gage height in accordance with a second horizontal scale—that of duration in days. The gage heights of the river and the rises of the wells chosen, as plotted for the years 1931, 1932, and 1933, indicate that the highest rise of the river lasted the longest and that the wells farther from the river rose less, but over a longer period of time than the others. Curved lines connecting the gage-height point and the duration point for each year were then drawn from the river through each well plotted. For convenience the curve connecting the gage-height points will be called the "B-curve," and that connecting the duration points of the rises will be called the "A-curve." Inasmuch as a small flood of long duration should have about the same effect on water levels in nearby wells as a high flood lasting but a short time, it is possible to estimate the effect upon selected wells of a hypothetical flood whose gage height and duration are postulated. With respect to the gage height existing before the beginning of a flood, it may be stated that the maximum stage reached by a river when a given quantity of floodwater is being discharged through its channel is, within limits, practically independent of the stage at which the river stood before the flood began. Thus a flood coming at a time when the river is at moderate stage will not be superimposed upon that stage but will rise to some stage similar to that attained by a potentially equal flood coming when the river is at a lower stage. For the sake of simplicity it can be assumed that the preflood stage has no effect upon the ultimate flood stage. Similarly, with wells, it is assumed that the potential rise of a well will have the same time relation to the river flood that caused it and will attain the same stage without regard to the stage of the water level before the rise began. The records of wells in the area indicate that this assumption involves an error but apparently not a serious one. It is essential to the method that the approximate rate at which the river and each of the wells rises to each of the three peaks be represented. Thus an average low stage was chosen for the river and each well, and a diagonal line was drawn from this stage at the zero point on the duration scale to the point at the end of the duration line at the appropriate gage height.

The lag of wells behind the river is subject to two variables—distance from the river and height of river stage. In using the floods of 1931, 1932, and 1933, the distance from the river was measured off on the ordinate and the time lag was measured on the abscissa (see pl. 8, A). As the flood of 1931 was shorter than the other two floods and differed from them in its trend, some arbitrary adjustments had to be made. The reason for the discrepancy seemed to be that whereas the floods of 1932 and 1933 hesitated in the early part of their rise, the flood of 1931 seemed not to hesitate. Lines connecting the points representing the lag, exhibited by wells at different distances from the river, curve in such a way as to be convex upward. Presumably this is because the river has receded by the time the ground-water wave has extended inland, and the wave thenceforth weakens as it travels. The higher the flood, the less is the lag of the rise in the well.

As the more distant wells rose to their yearly peaks more slowly and the peaks were lower, so also the decline after the peaks were reached was slower. A rather definite relation seemed to exist between river, nearby wells, and more distant wells. Therefore it was possible to plot the recession curves of the river and the wells, to compute the proportional relation among the various rates of decline, and thus to carry this proportional relation over to the much slower rate of decline of the regulated river (see pl. 8, *C*).

The Rocky Mountain Power Co. submitted to the Federal Power Commission a series of hydrographs of the levels of Flathead Lake, on which were shown the levels that would have prevailed if the regulation had been in force during the period 1928 to 1936. The lake level was held at the 2,893-foot stage longest in 1928, after a high flood had occurred. As a flood of about the magnitude of that of 1928 occurred again in 1933 it was assumed that the regulated levels of 1928 might prevail frequently in the future, but the regulated levels in 1933 were lower than those in 1928. Average levels taken from the "Statement of Rocky Mountain Power Co. concerning the effect of its proposed power development on the water elevation of Flathead Lake," dated May 1, 1928, were used in the present study because they are somewhat higher than the monthly average shown on the hydrograph mentioned above but lower than those computed for 1928.

The foregoing discussion indicates that the elements for constructing hypothetical well hydrographs for the regulated period are available. It now remains to apply the method. A well 800 feet from the river (well 27) is used as an example. The monthly levels of the regulated lake (the regulated levels of the river near the wells would be practically identical) are sketched on the figure showing gage heights and duration of flood peaks for that period when the lake is rising toward 2,893 feet and while it remains at that level. By consulting the proper curve it is found that the beginning of the rise in well 27 lags 25 days behind the beginning of the rise of the river level. The "A—curve" and "B—curve" are constructed so as to conform as nearly as possible to the curves drawn for actual flood periods. The curve that represents the stand of the river level at 2,893 feet, which is analogous to the "A—curve" showing the duration of the rise to that level, is designated the "A′—curve" of the river. Whereas the level of the river with regulation may not necessarily reach so high a peak as under natural conditions, the longer duration of high water should effect a rise of the ground-water levels about equal to that of the flood of 1933. In 1931 the river reached a peak of about 2,893 feet (not to be confused with the maximum lake level of that year) so that the "B—curve" for the regulated river almost coincides with that of 1931, and the gage height resulting from the rise of the river to its 2,893-foot level is about equal to that resulting from the flood of 1931. The effect of the river's maintenance of that level for several months will be considered a little later. The gage height reached by well 27 is about 2,888 feet. By drawing the horizontal duration line from this gage height until it intersects the "A—curve" of the regulated river we find that the rise of the river from a stage of 2,885 to 2,893 feet, taking place in a period of about 60 days, will cause a rise in well 27 to a stage of 2,888 feet in 78 days. Now the river remains at its maximum stage for a period of about 90 days, and the well ought to continue to rise until it reaches the lake level, but at a diminishing rate. This second phase in the rise of the well ought to prevail through a period that is in the same proportion to the first phase as the rise of the lake to 2,893 is to its stillstand. Then, 60:90 as 78:x, or, x equals about 120 days. As this means that for 120 days well 27 should rise toward 2,893 feet, we lay out a point at the 2,893 gage-height level 120 days from the point where the rise of the well intersected the "A—curve" of the regulated river, and we construct a line between these two points. It intersects the "A′—curve" of the regulated river at a gage height of 2,889.8 feet on September 12, which means that at that stage of the water level, and at that time after the beginning of its rise, the well should begin to show the effect of the decline of the lake level. The peak of the well hydrograph should round off, and to express a rounding-off, the arbitrary procedure of sketching the recession of the river on the time scale of the well rise and of extending the rise from the "A′—curve" to the intersection is followed. Beyond this point the well will be at a higher level than the river. The well rise meets the recession curve of the river at a gage height of 2,891.5 feet on October 25. It happens that the well is now at about the same stage as at the peak of the flood of 1932. In that year the well started definitely downward 37 days after the river began its recession. Thus we carry the well rise horizontally for a period of 37 days at the gage height of 91.5 feet. From here the well begins its decline.

At the beginning of the recession of the well on December 2 the water level stands at 91.5 feet. On the recession curve for a well 800 feet from the river the elevation of 91.5 feet was located with respect to the point representing December 2 and followed down the curve to a point 25 days after the river began its next rise (May 10). The well will fall to a stage of 2,871.1 feet in that length of time. We now return to the curve depicting the rise of river and wells and begin the new rise in the well from 2,887.1 feet. The rise from 2,887.1 feet is carried parallel to the rise of the preceding year, and the point at which it meets the "A—curve" of the river is 2,889.1 feet; it is assumed that it reaches this point on the same date as in the previous year (July 28). Counting back to the beginning of the rise on the time scale, we find that the rise began on June 16. The interval between the end of the recession on May 10 and the beginning of the rise on June 16 is expressed as a horizontal line—a standstill of the water level. This is, of course, not quite correct, for actually the recession has been tapering off gradually. That part of the rise between the "A—curve" and the "A′—curve" for the current year will also be drawn parallel to the corresponding part of the rise of the previous year. It reaches the "A′—curve" at an elevation of 91.4 feet on September 20. Again it is carried beyond the "A—curve" until it intersects the recession curve of the river (which must be sketched in for each year's operation) and then run horizontally for 37 days from this point, as was described above for the rise of the previous year. The next recession is determined in like manner. Thus each year the stage at the beginning of the rise becomes higher and begins later, so that the rise ultimately will become limited and will be equaled by the amount of recession. When that condition prevails the ground-water recharge and drainage will have become stabilized.

The hydrograph of the well situated 1,500 feet from the river was prepared in like manner with one variation. The rise was drawn from the preregulation stage to the "A—curve" of the river. The end point was found to fall on January 27. In this case the rise was continued without a break in slope, for the stage reached on January 27 was below that of the lake, namely, about 2,889.7 feet. This simply means that the rise was much slower owing to the greater distance from the river, and the adjustment between inflow of bank storage to outflow of ground waters was attained considerably later.

Plate 9 shows the hydrographs of wells that are 200, 800, 1,500, and 2,500 feet from the river. The nearest well rises in the first year of regulation from a low stage to about 2,892 feet by the middle of October, drops off to 2,886.3 feet the following spring, rises to 2,893 feet by early October, drops to 2,887.3 feet in the spring, and finally attains stability in the third year of regulation, reaching 2,893 in mid-September, beginning to decline near the end of November, and declining again to 2,887.3 by early May. After that, the well hydrograph is repeated year after year if the regulated river levels are the same. The well 800 feet from the river rises the first year to 2,891.5 feet, declines to 2,887.1 feet by the following spring, rises to 2,891.9 feet, and so on until in the fourth year it has reached a stable form—a rise to 2,892.2 feet in the autumn and a decline to 2,887.9 feet in the spring. The well 1,500 feet from the river rises to 2,889.7 feet in the first year, declines to 2,887.4 feet, and in each succeeding year reaches a higher level and declines less. This general rise of the water level, however, diminishes through the years. In about the eighth year, having reached a stable form, it will rise from a stage of 2,888.8 feet to 2,891.3 feet and then recede to its former level. The well 2,500 feet from the river rises about a foot the first year and gradually attains a level of 2,889.1 feet in the spring of about the eighteenth year, rising about 0.25 foot and subsiding that much again in the course of the year. The yearly fluctuation is small and very much delayed. It is doubtful whether the delay would be so great in nature, for as the water-bearing sand is filled closer and closer to the overburden of fine-grained material the pressure occasioned by the rise of the lake and river would be transmitted in the manner of artesian pressure rather than as a transfer of unconfined ground water. Also, if this were so, the number of years required to reach the new stable level would be considerably diminished. The hydrographs of course should be drawn as curves so that the straight lines will be tangent to them.

There probably is no particular need to enter into a detailed discussion of the possible errors involved in the method used in constructing the hypothetical hydrographs. Following is a list of arbitrary steps taken so that some relation that in nature appeared to be obscure could be applied consistently to all wells considered: (1) Drawing the rises after the first year parallel to the rise in the first year is probably not strictly correct. As the water level reaches higher and higher levels under a constant force (the rise of the lake and its standstill) the rate of rise should diminish somewhat. This diminution was not shown in the figures, for straight lines are much simpler and easier to handle. (2) Assuming that the well rise reaches its peak at a fixed date every year (when the same fluctuations of the lake are postulated year after year) is undoubtedly somewhat in error, for each higher peak should be reached a little later each year. If that had been done the rise in average stage from year to year would have been somewhat more rapid. (3) Carrying the rise out beyond its intersection with the "A′—curve" of the river to its intersection with the recession curve of the river is conventional, for in reality the fact that the river recedes to a lower level than the well at that time would have no such immediate effect on the well as has been shown. It merely adds another point by which the peak is rounded off. (4) When the peak of the rise of a well lies a considerable distance above the actual recession curve of that well as taken from observed data, the water level would probably fall off at a greater rate than the curve indicates, so that if the peak were 1 foot above the curve in the autumn, by spring it would be less than a foot above it. This relation was too intricate to be dealt with in this study, and the error involved is undoubtedly small. It would have the effect of diminishing the time required for the water levels to attain stability; the fluctuation would be larger, and the apparent average gage height for the year would be slightly lower.

The previous paragraphs have dealt with the manner and rate of change of the gradient of the ground water away from the river toward the interior of the area when the average yearly water level is raised through regulation of the lake. What remains to be considered is what becomes of the water that seeps down to the zone of saturation from the land surface in the interior of the area. For with the gradients reversed, this increment cannot then drain into the river and lake. Obviously, most of it must remain as stored water until the water table has risen sufficiently to reestablish the former gradient.

By inspection it was found that wells in the interior of the area in which the water level lies at a distance of more than about 6 feet below the surface showed an average annual rise of about 0.35 foot due to recharge from the surface. There was not a very wide discrepancy between wells in this respect. This increment to the ground water would tend to remain, as it could not drain out to the river. No way was found to distinguish between the loss of ground water from the area by drainage to the river and lake and the loss due to evaporation and transpiration from the zone of saturation. Consequently this loss was ignored. It affects chiefly not the altitude but the rate at which the stable form of the water table will be attained. One complication entered the problem that could not be ignored. As the increment is added each year and the water level approaches its final stage, the water will start percolating toward the river and lake during the yearly peaks, more and more as the average water level approaches equilibrium. The average yearly net increment must therefore be cut down as stability is approached. This was done by finding the rate at which the hypothetical hydrographs tapered off and applying that proportion roughly to the increment. No very accurate way of doing this was found, but great accuracy was not necessary because the basis of estimating the ultimate ground-water levels had already been arrived at in the preceding process. The ground-water increments have been plotted on the hydrographs, and the resulting figures show approximately what happens to the peripheral wells under the regulation. The interior wells should bear approximately the same relation to the peripheral wells as they do before regulation begins.

After the hypothetical hydrographs have been adjusted to take account of the increment to the ground water derived from surface recharge, the main outline of what happens along the periphery of the area after the postulated regulation begins can be fairly well understood. A well 200 feet from the river or lake will have risen to about 2,893.8 feet in the autumn of the third year and thenceforth will fluctuate between that high level and a low of about 2,888 feet; the average stage for the year will be about 2,891 feet. A well 800 feet from the river or lake will have risen to about 2,893.2 feet in the autumn of the fourth year and thenceforth will fluctuate between that stage and about 2,889 feet. A well 1,500 feet from the river and lake will have risen to slightly less than 2,893 feet in the eighth year of regulation and will fluctuate between that stage and 2,890.6 feet. A well 2,500 feet from the river will rise ultimately to about 2,893 feet, though apparently this rise will not be fully attained for some years. This distant well will have a yearly fluctuation of only about 0.3 to 0.6 foot, except where the water level is near the land surface.

The results of this method of analysis indicate that if the average annual stage of the lake is raised through regulation from about

2,884 feet to 2,890 feet, the average annual stage of a well 2,500 feet from the lake or river will be raised from about 2,887 feet to about 2,893 feet. It indicates likewise that at other points in the interior of the area the ground-water levels will rise about the same amount that the average lake level is raised by regulation. The gradients after they have been adjusted to the regulated lake and river levels will thus be carried landward from the water levels in the peripheral wells essentially as they exist under present natural conditions. Thus the water level in the well, 2,500 feet from the river or lake stands at an altitude of about 2,887 feet under present conditions but will rise to an altitude of about 2,893 feet after the regulation as postulated has been in force for some time. Similarly the average water level of the other wells in the interior of the area was raised about 6 feet, and the new contours of the water table were given the higher values. As has been repeatedly brought out, this 6-foot rise of the water levels will prevail only insofar as the postulated regulation is approximated. Insofar as the regulated levels resemble the regulated levels determined by the Rocky Mountain Power Co. for the period 1928 to 1936, inclusive, the ground-water levels will rise about 4 feet over the area.

AREAS SUBJECT TO DAMAGE BY RISE OF GROUND-WATER LEVELS

Maps prepared for land use when the topographic survey was made indicate that the land under cultivation is rather uniformly distributed over the area. Areas where damage is most likely to occur as a result of regulation of the lake levels, however, are among the least intensively cultivated. The channels cutting through the area that are neither swampy nor subject to overflow are used chiefly for grazing. The gradually sloping lake shore, the southeast corner of the area, and the lands near Feenan Slough are used in part for the cultivation of crops but also to a considerable degree as grazing lands, or else they are abandoned to brushwood. Roughly half of the acreage in these areas is cultivated. Only in secs. 8, 9, and 17 are large tracts of cultivated land subject to damage by the rise of the ground-water levels.

Before outlining the areas where the ground-water levels will be raised dangerously near the land surface it is necessary to adopt some criterion upon which estimates of possible damage to land can be based. Land can be damaged by shallow-lying ground water in three ways—by the drowning of crops, by the deposition of harmful salts in the soil, and by being rendered unworkable. Damage from salts to any considerable extent is not probable because there is frequent downward movement of water from the land surface, chiefly during autumn and spring. This water would probably flush any accumulating salts out of the soil and subsoil. At least there is no evidence of salt damage to vegetation in any of the depressions in the land where ground water is being discharged by evaporation and transpiration. It is likely that plowing in spring would be made difficult by a rise of the ground-water level to a depth of 2 or 4 feet below the land surface, but to what extent it is not easy to say. The possible drowning of crops is the chief concern in this area. It is very probable that lands where the water table lies 1 or 2 feet below the surface during the growing season will be rendered unsuitable for the growing of ordinary crops. Jessup,[2] in his study of the relation of crop production to the ground-water levels in the Kootenai River Valley found that the yield of lands decreased markedly when the water table was 1.75 feet below the surface in May. He also found that the production of wheat was greatest where the water table lay between 2 and 4 feet below the surface in May. After comparing the description of the soils in the Kootenai Valley with those in the area under consideration it was assumed that a similar relation would hold. In this study then, chiefly as a consequence of Jessup's findings, those areas where the water table would lie at a depth of 2 feet or less at some time during the growing season were outlined and designated as almost certain to be seriously damaged (see pl. 10). Areas where the water table would lie at some time during the growing season at a depth of from 2 to 4 feet below the surface were outlined and designated as marginal. The probable status of the marginal lands will be discussed more fully later.

The areas where the water table will rise within 4 feet of the land surface will include essentially all the deeper channels that are now dry. These are the large channels in the western part of the area, the two in the central and eastern parts of the area, and many small ones; the undrained depressions near well 44, the large depressions north of it, and the depression near well 20; the channel of Ashley Creek; and a belt of land along the lake shore south of a line running roughly from Somers to the center of sec. 8 and thence over to the southern part of sec. 9. A line showing the parts of the area where the water levels will be within 2 feet of the land surface nearly coincides with the 4-foot line except for a considerable part of sec. 9 and an area between Feenan Slough and the river.

Most of the channels and depressions may be considered as likely to be damaged to such a degree as to render them unfit for productive use

[2] Jessup, L. T., Effects of proposed regulated river levels of Kootenai River on crop production, prepared for presentation to International Joint Commission; application of West Kootenai Power & Light Co., Ltd.

after regulation has been established. In the southern part of the area, however, the ground-water levels will be more complex. Where the water level will be from 2 to 4 feet below the land surface the base of the silty layers above the water-bearing sand will be saturated, according to almost all the logs of wells that give any information on the subsurface materials. Available data [3] indicate that, in silt, water will rise by capillary attraction about 8 feet above the water table. Samples of material taken from the area under consideration, as shown in the accompanying table, consist chiefly of silt and clay. Where the capillary fringe reaches the land surface, water will move upward into the root zone as it is evaporated and transpired but not in sufficient quantity to saturate the soil. When the subsoil is partly full of capillary water a rather small amount of rain water or melted snow moving down to the zone of saturation will cause a decided rise of the ground-water level. The record of well 19 suggests that in these areas of shallow-lying ground water the water level will be very near the surface in the early spring, probably late in March and April in most years, and that it will decline rapidly through the summer and autumn. Although the record of well 19 does not suggest it, there is some possibility that summer rains will recharge the ground water and bring the water levels near enough to the surface to drown a growing crop.

Although the map (pl. 10) showing the areas where the water level will lie at depths of less than 2 feet and between 2 and 4 feet probably does not need further refinement, it should be pointed out that within the threatened areas ground-water behavior will be of two types. In a belt roughly 2,500 feet from the lake the water level will be nearest the land surface during summer, when the lake levels are highest; but back from the lake the water levels will be highest in March or April and will be declining during the remainder of the growing season. Thus in this area the productivity of the land for small grains and other crops with a shallow root system might be increased by the addition to the soil of water from the capillary fringe, and the danger that the crops would be drowned out by heavy rains in the growing season might not be very great. Nevertheless, a ruined crop only once in several years might be as disastrous economically as a chronic diminution of the yield of the land. Consequently the area within the line depicting a depth of water of 4 feet or less should probably be considered subject to damage.

Generally speaking, the line indicating a 2-foot depth to water would become the 4-foot line if the regulation of 1928–1936 prevailed through a long period of years, but the difference in area of the marginal lands is not great.

[3] See Water-Supply Paper 489, pp. 31–38.

Physical properties of water-bearing materials collected in Flathead Valley

Laboratory No.	Field No.	Location	Mechanical analysis (percent by weight)					Apparent specific gravity	Porosity	Moisture equivalent		Coefficient of permeability
			Larger than 0.25 mm.	0.25 to 0.125 mm.	0.125 to 0.062 mm.	Silt	Clay			By weight	By volume	
2275	1	Steep bank of south side of Flathead River at Jackson gage	3.2	8.4	23.2	53.7	11.8	1.44	45.1	12.6	18.1	6
2276	2	do	[1] 75.5	19.2	2.6	1.9	1.5	1.49	44.2	3.6	5.3	850
2277	3	Bank of south side of river, 150 feet north of well 23	.3	17.0	49.1	23.9	10.0	1.27	52.2	7.4	9.4	100
2278	4	Well 30, 0.5 to 2 feet deep	2.5	.9	1.0	45.3	49.3	1.20	55.5	31.2	37.4	.2
2279	5	South side of channel, 300 feet south of well 19	.8	1.3	9.2	65.2	24.4	1.36	49.2	16.9	22.9	2.0
2280	6	Well 37, 0–0.5 foot	.9	1.2	3.6	31.7	61.9	1.20	60.7	25.0	30.0	5.0
2281	7	0.5 mile east of church	.4	1.6	1.6	19.6	75.5	1.07	59.0	41.4	44.3	2.0
2282	8	100 yards west of well 5, 0–0.5 foot	8.4	26.1	15.9	20.4	28.6	1.19	54.2	18.3	21.8	20
2283	9	Near well 8, 0.5–1 foot						1.18	53.3	26.0	30.7	10
2284	10	At well 14, 0.7–2 feet						1.26	59.3	24.8	31.2	4

[1] 9.4 percent larger than 0.50 mm.

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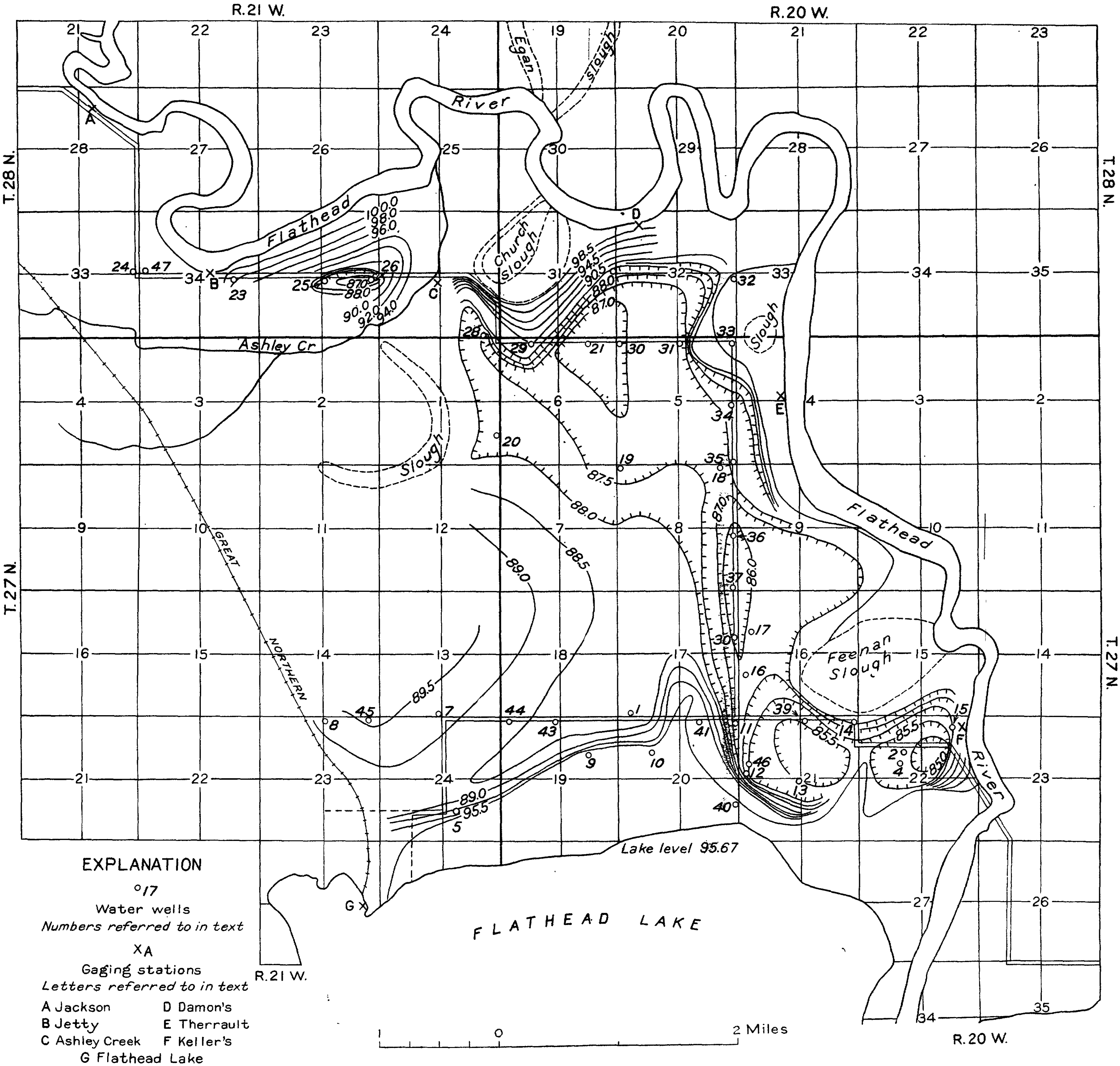
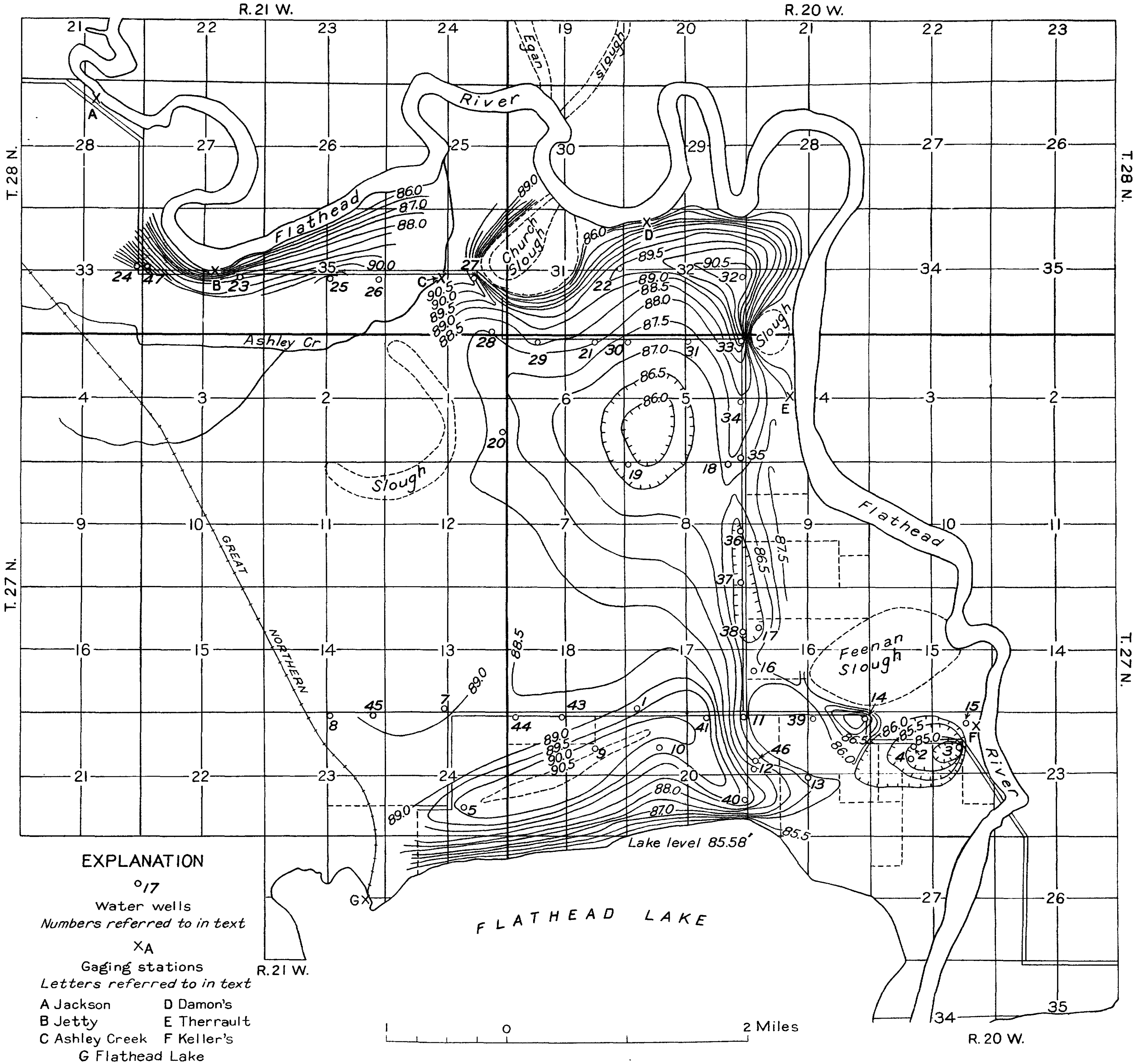
MAP SHOWING CONTOURS OF THE WATER TABLE BASED ON MEASUREMENTS OF WATER LEVEL IN WELLS ON FEBRUARY 20, 1933.

Altitude of contours above datum may be converted into altitude above sea level by adding 2,800 feet.



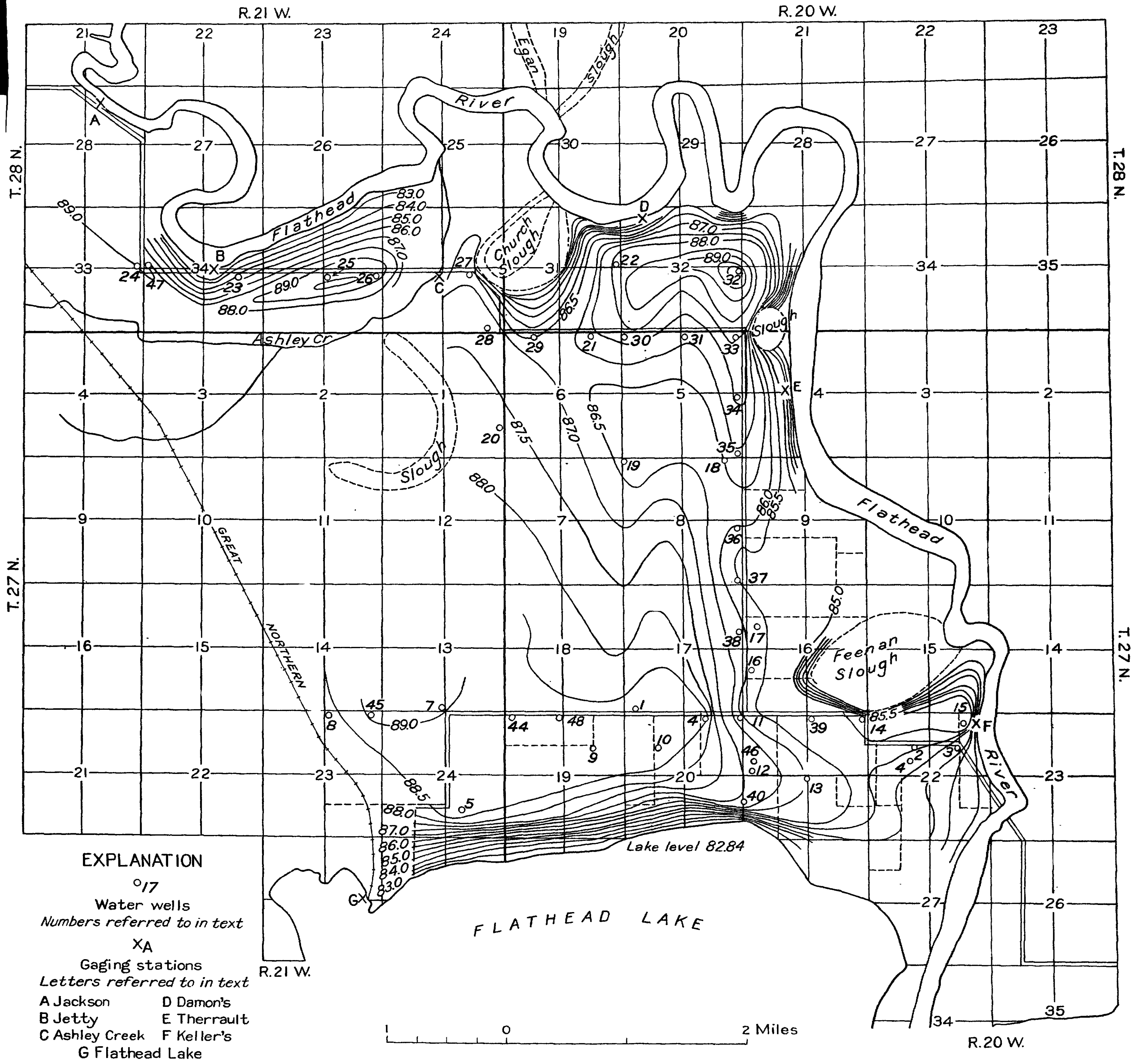
MAP SHOWING CONTOURS OF THE WATER TABLE BASED ON MEASUREMENTS OF WATER LEVEL IN WELLS ON JUNE 11, 1933.

Altitude of contours above datum may be converted into altitude above sea level by adding 2,800 feet.



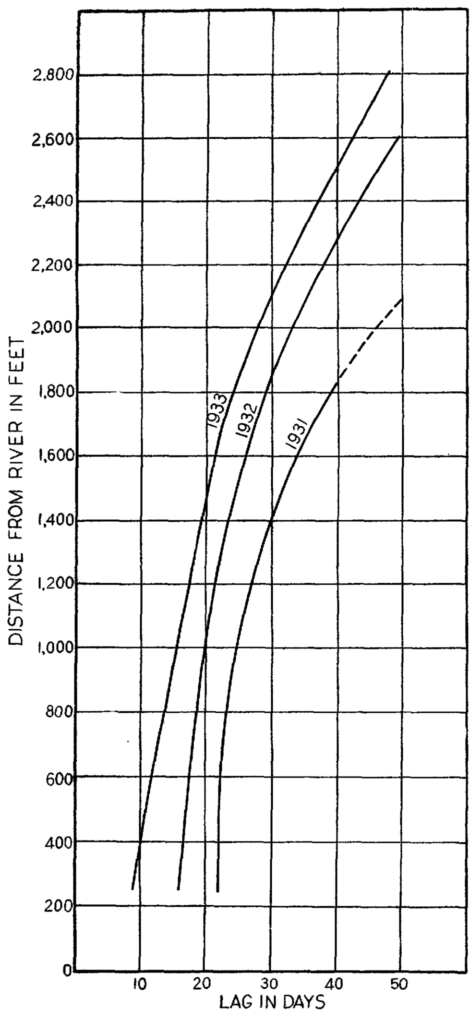
MAP SHOWING CONTOURS OF THE WATER TABLE BASED ON MEASUREMENTS OF WATER LEVEL IN WELLS ON AUGUST 7, 1933.

Altitude of contours above datum may be converted into altitude above sea level by adding 2,800 feet.

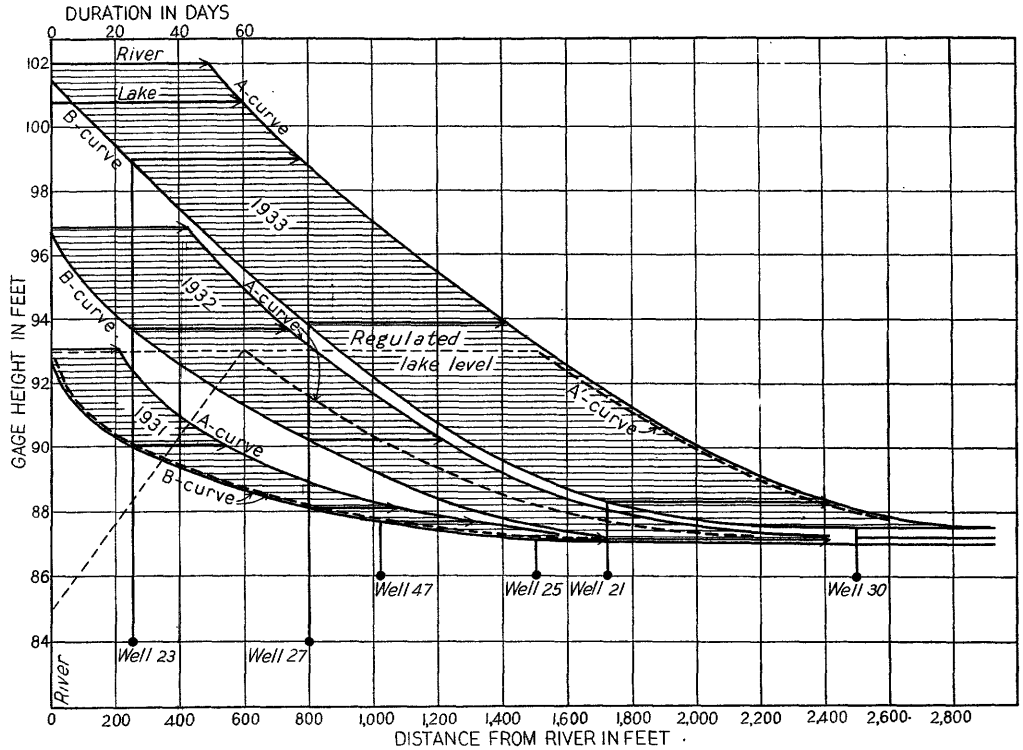


MAP SHOWING CONTOURS OF THE WATER TABLE BASED ON MEASUREMENTS OF WATER LEVEL IN WELLS ON OCTOBER 15, 1933.

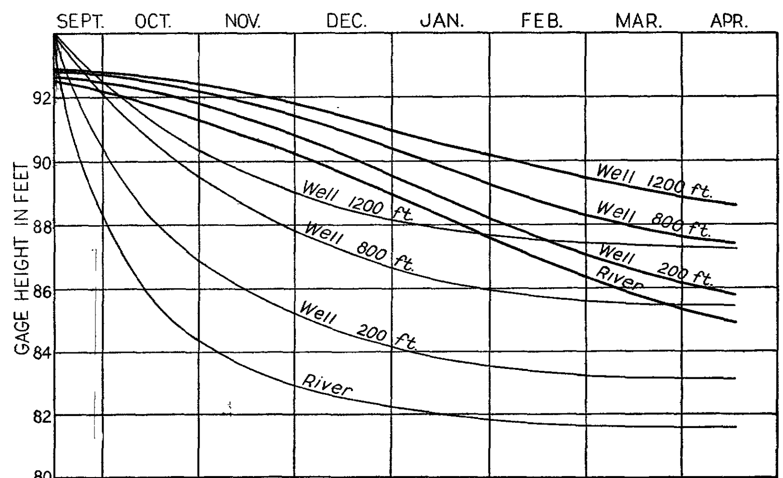
Altitude of contours above datum may be converted into altitude above sea level by adding 2,800 feet.



A



B



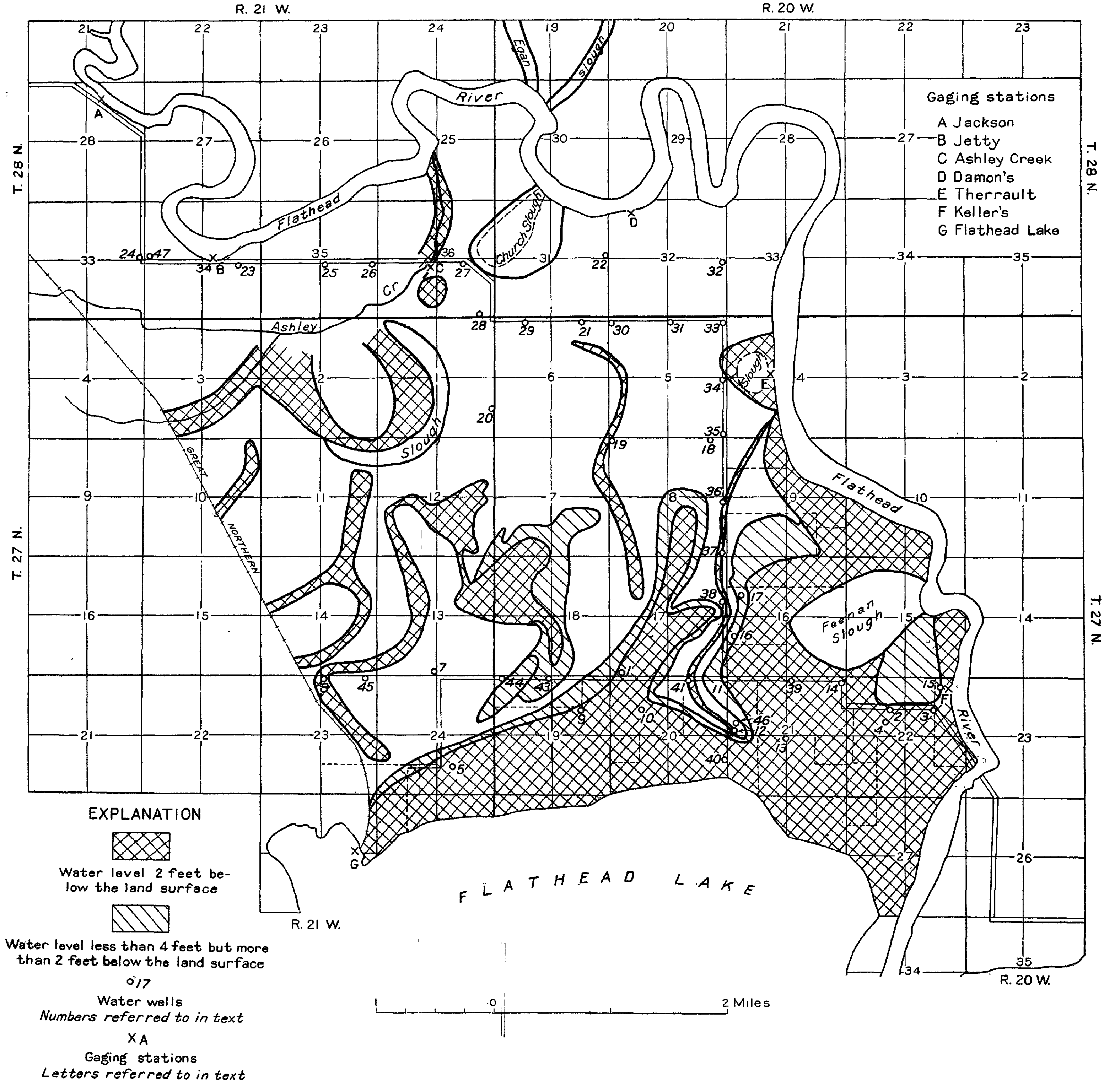
C

A. **LAG OF WATER LEVEL IN SELECTED WELLS AFTER BEGINNING OF RIVER FLOODS IN 1931, 1932, AND 1933.**

B. **MAGNITUDE AND DURATION OF RISE OF WATER LEVEL IN SELECTED WELLS IN RESPONSE TO RIVER FLOODS IN 1931, 1932, AND 1933, AND AFTER POSTULATED REGULATION OF RIVER AND LAKE LEVELS.**

The maximum levels to which the river and each of the wells rose in 1931, 1932, and 1933 are connected by lines designated as "B-curves." The points showing the duration of the rise of the river and each well, expressed as horizontal lines drawn at the proper gage heights, are connected by lines designated as "A-curves." The regulated lake levels, as postulated, are shown as light dashed lines rising from a gage height of 85 feet to a gage height of 93 feet over a period of 60 days and remaining at 93 feet for 90 days. An "A-curve" and a "B-curve" for the regulated lake levels are drawn in heavy dashed lines, and in addition an "A-curve" to express the stillstand of the lake levels at 93 feet. By means of this figure the rise of the water level in wells at various distances from the river in response to the regulation of the river and lake levels may be computed.

C. **OBSERVED COMPOSITE RATE OF RECESSION OF RIVER LEVELS AND WATER LEVELS IN SELECTED WELLS BEFORE REGULATION OF RIVER AND LAKE LEVELS (light lines) AND COMPUTED RATES OF RECESSION OF RIVER LEVELS AND WATER LEVELS IN THE SAME WELLS AFTER POSTULATED REGULATION OF RIVER AND LAKE LEVELS (heavy lines).**



MAP OF FLATHEAD LAKE PROJECT SHOWING AREAS IN WHICH THE GROUND-WATER LEVELS, ACCORDING TO THE COMPUTATIONS BASED ON THE POSTULATED REGULATION OF RIVER AND LAKE LEVELS, WILL BE LESS THAN 2 FEET BELOW THE LAND SURFACE DURING PARTS OF EACH YEAR, AND THE AREAS IN WHICH THEY WILL BE LESS THAN 4 FEET BUT MORE THAN 2 FEET BELOW THE LAND SURFACE.