STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

A PRELIMINARY REPORT

ON THE

GEOLOGY AND GROUND-WATER RESOURCES

OF THE

DUCK LAKE AREA
OKANOGAN COUNTY, WASHINGTON

By Eugene F. Wallace *

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INTRODUCTION

Purpose and Scope of Investigation

This study was initiated on March of 1958 by the Division of Water Resources of the Department of Conservation as part of a continuing program for the collection and interpretation of basic data concerning the ground-water supply of the State of Washington. The need for such a study first became apparent in June, 1954 when the directors of the Okanogan Irrigation District went on record as opposing the granting of any future ground-water permits in the Duck Lake storage area, which, as designated by the district, includes the W½ of Sec. 11; E½ of Sec. 10; NE¼ of Sec. 14, all being in T. 34 N., R. 26 E.W.M.

The petition submitted by the district resulted from a ground-water permit being granted to Mr. Emmet Smith for the withdrawal of 800 gpm limited to 528 acre-feet annually for the irrigation of 132 acres. The well is located in the NW¼ of Sec. 11 and the district felt that the withdrawal of water from the Smith well had a definite effect on the water level of Duck Lake. Consequently, they believed that should additional ground-water rights be perfected in the Duck Lake storage area, a potentially critical situation could develop. That is, in the event of a prolonged drought, the storage area would be so depleted by ground-water withdrawals that it would not be possible for the district to fully exercise its right to pump from Duck Lake.

Another need for the study evolved from a review of the records of the Division of Water Resources. In this review it was noted that most ground-water rights in the Duck Lake area were granted with a certain degree of apprehension--the thought being that during normal water years such as have been exhibited for the most part since the early thirties, there would be ample water for all users. However, the question of availability of water during a series of dry years has led the division to a cautious approach, and in most rights granted, the applicant has been advised of possible regulation of withdrawal on a priority basis if the need should arise.

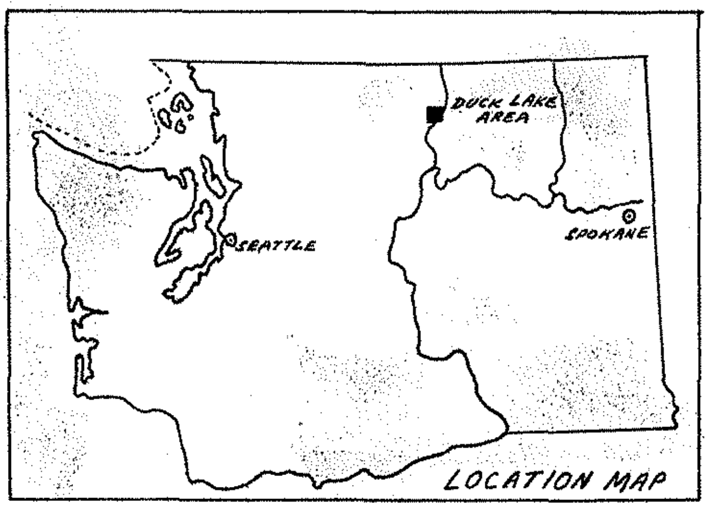
The purpose of this investigation was to ascertain the present availability of water in the Duck Lake area and to determine the proper plan for future development and utilization of the water. The scope of the study was initially set to include several determinations. The principal aims were as follows:

1. Determination of present availability of water by completing a quantitative analysis of the area.
2. Determination of approximate extent of Duck Lake storage area.
3. Determination of interference relationships between ground-water withdrawals and lake level of Duck Lake.
4. Discussion of possible adverse effects that further appropriations might incur upon appropriators with existing rights.
5. Discussion relative to recommendations for planning for future development and utilization of the water. This includes policy of Division of Water Resources toward future applications for permit to appropriate ground water.

The study has consisted of a general geologic reconnaissance of the area, measuring of representative wells for depth and water level, setting up an observation well network, obtaining information from the Okanogan Irrigation District, and interpretation of the various data.

Location and Extent of the Area

The Duck Lake area of this report has been expanded from the original designation of the Duck Lake storage area, as set forth by the Okanogan Irrigation District, to include about fourteen square miles, being specifically Sections 1, 2, 9, 10, 11, 12, 13, 14, 15, 16, 21, 22, 23 and 24 of Township 34 North, Range 26 East Willamette Meridian lying immediately north of the town of Omak in Okanogan County, Washington.



Omak lies geographically near the center of the county and is readily accessible by U.S. Highway 97. The Duck Lake area is covered with a network of gravel and paved roads which afford excellent accessibility. The area in general is bounded on the east by U.S. Highway 97, on the north by Johnson Creek, on the west by a surfaced road running from Omak to Conconully and on the south by the break in the bench above Omak.

The base map (Fig. 1) used in this report includes parts of two U.S. Geological Survey 15 minute quadrangles--the Omak Lake and Okanogan quadrangles. Contour intervals on the maps are 40 feet.

Acknowledgments and Previous Investigations

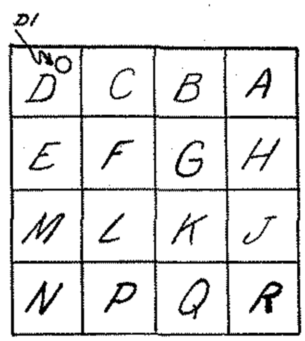
There has been no previous ground-water study made in the area although some well records and miscellaneous well data were available from water-right applications made to the Division of Water Resources. The remaining well information used in the preparation of this report was collected from the individual well owners, and their cooperation is gratefully acknowledged.

The writer wishes to express special thanks to David P. Brown, Manager of the Okanogan Irrigation District, and to Dale Thorp, Okanogan County Watermaster, for the great amount of information and assistance they provided throughout the period of study.

Robert H. Russell, Assistant Supervisor of the Division of Water Resources, provided much background information which aided in the geologic reconnaissance of the area. Additionally, he accompanied the author on a one day field trip through the report area to check specific outcrops.

Well Numbering System

Well numbers used by the U.S. Geological Survey and the Washington State Division of Water Resources show locations of wells according to the rectangular system for subdivision of public land, indicating township, range, section, and 40-acre tract within the section. An example is the well numbered 34/26-11D1 owned by Emmet Smith. The part preceding the hyphen indicates successively the township and range (T. 34 N., R. 26 E.) north and east of the Willamette base line and meridian. The first number after the hyphen indicates the section (Sec. 11) within that township and the letter (D) gives the 40-acre subdivision of the section as shown in the diagram. The last number (1) is the serial number of the well in that particular 40-acre tract and is the first well recorded there. The second well recorded would have the number 34/26-11D2.



Topography and Drainage

The topography of the Duck Lake area is for the most part an upland bench which drops off rather abruptly towards the Okanogan River on the east and south and abuts against the uplands on the west and north. The surface of the bench is about 400 feet above the town of Omak. Numerous kettles and glacial wash channels are present throughout the area.

There is no prominent surface drainage from the bench comprising the area, so most of the local precipitation that is not lost by the process of evapotranspiration percolates downward to the ground-water table.

GENERAL GEOLOGY AND GEOLOGIC HISTORY OF AREA

A general geologic reconnaissance indicates that the physiographic features and rock units in the Duck Lake area represent the end product of some very complex geologic processes. From a purely academic viewpoint, it would be desirable to map the geology in detail and describe the various rock units in addition to determining the geologic history of the area. However, for the purposes of this report it is thought best to discuss only those geological aspects which directly pertain to the ground-water conditions in the project area. For the reader who is interested in the overall geologic picture and descriptions of various rock units, there is an unpublished report entitled "Preliminary Geologic Report of Limestone Belt, Okanogan County, State of Washington" by Robert H. Russell. The report includes much of the area just north of Johnson Creek and is available for loan from the Division of Water Resources.

Within the scope of the present study, the rock units need only be divided into two groups. The more important group is that one which includes the glacially derived sands and gravels of Pleistocene age. These are the most recent rocks deposited in the area, and the unit as a whole serves as the only important aquifer. The second unit will in most cases be referred to merely as bedrock. It includes numerous rock types--porphyritic rhyolite, porphyritic andesite, lime-silicate gneiss, some quartzite and cherty quartz, metamorphosed sediments, dolomitic limestone and also some weathered granitics. However, because most of these rock types are discussed in the previously mentioned report by Robert H. Russell and since they are all essentially impermeable, they can reasonably be discussed as a single unit with minor exceptions and need not be described individually. This second unit constitutes all the pre-glacial or older materials in the Duck Lake area and of these rocks, the rhyolite and andesite proved most valuable in attempting to delineate the extent of the aquifer in the project area.

The rhyolite and andesite apparently developed as extrusive flows in Tertiary time which places them chronologically younger than the various other types of bedrock previously mentioned and older than the Pleistocene glacial deposits. The older bedrock is exposed only in the northern and western fringe areas and consequently is thought to serve as lateral boundaries for the Duck Lake aquifer on the north and west. The rhyolite probably flowed onto a relatively uneven terrain and (or) was subjected to a considerable period of erosion prior to the advent of the Puget ice sheet and now serves as a limiting factor both in depth of the Duck Lake aquifer and flow of ground water within it.

Thus far we have a sequence of the surface of old bedrock being covered in part by the extrusive flows of rhyolite and andesite. This was followed by a period of erosion. Then in Pleistocene time the entire area was covered by a vast ice sheet from the north which in this paper is referred to as Puget. The sand and gravel deposits which presently blanket the project area, except for numerous nunataks (small islands of bedrock which extend through the surface of the younger glacial deposits), were laid down by recessional outwash streams as the ice receded to the north. In some instances large blocks of ice became isolated and engulfed at least partially in the outwash materials. When these ice blocks melted, depressions or kettles remained, and where the right water-table relationship existed, lakes were formed. This type of relationship is believed to have been the geologic process responsible for the occurrence of Duck Lake, Fry (Loon) Lake and Proctor Lake, In cases where these kettles were formed above the water table, dry depressions remained. There are examples of such depressions north of Duck Lake in Sections 2, 10, and 11.

GROUND WATER

Occurrence and Present Availability of Ground Water within the Duck Lake Area

As indicated previously, the principal aquifer underlying the Duck Lake area is made up of the glacially derived sand and gravel deposits of Pleistocene age. Although the lateral extent of this aquifer has been generally delineated, it has not been possible to complete a definitive quantitative analysis in the area because the configuration of the bedrock surface underlying the aquifer materials is not known.

A reflectograph study to obtain the necessary information had been contemplated, but the equipment brought into the state and tested by Robinson and Roberts, consulting geologists from Tacoma, Washington, did not show the sensitivity desired for the study. The cost of a seismic study was prohibitive and as a consequence, only a very general approximation of aquifer storage capacity was obtained.

The procedure for obtaining the recoverable storage capacity of the aquifer was established such that a reasonably certain minimum capacity would be determined. The depth of the aquifer penetrated for 67 of the wells checked in this study was tabulated and the average depth penetrated was 16 feet. The specific yield of an aquifer, which is the ratio of the volume of water a saturated rock will yield, by gravity, to the total volume of the rock, was assumed to be 15 percent, which is conservative for a good sand and gravel aquifer. The surface area of the aquifer was approximated at 4000 acres, whereas it may actually exceed 4500 acres. Utilizing the preceding figures, the available storage capacity of the Duck Lake aquifer under existing conditions is calculated to be a minimum of 9600 acre-feet.

It is noted that the 9600 acre-feet figure has been determined using the average depth of aquifer penetrated by existing wells so in a sense this is another assumption setting the bottom of each well at the bottom of the aquifer which obviously is not the case. The fact is that very few of the representative wells are penetrating the entire depth of the aquifer. This point is stressed in order to emphasize that the 9600 acre-feet is a safe figure for the minimum available storage capacity of the aquifer.

A possible maximum available storage capacity of the aquifer has been determined in much the same manner as was used in determining the minimum capacity. Probable maximum figures were substituted for the minimum figures previously used with the exception of surface area of the aquifer (4000 acres). The depth of the aquifer is based on the depth of water in Duck Lake which is about 40 feet when the lake is full. The altitude of the lake at this stage is about 1250 feet above mean sea level. The specific yield has been increased from 15 percent to 25 percent. With the new set of data, a maximum available storage capacity of 40,000 acre-feet is obtained. It is noted that this is considerably more water than can be stored in Salmon Lake and Conconully Reservoirs combined (23,500 acre-feet).

To completely utilize the entire 40,000 acre-feet would require an extensive program of new development because the existing wells are not of sufficient depth to withdraw water from the entire depth of the aquifer. A cross-section drawn south from Duck Lake indicates there would still be water available from Duck Lake after most of the existing wells were pumped dry.

In summary, it is concluded that the available storage capacity of the Duck Lake aquifer ranges between 9600 acre-feet and 40,000 acre-feet. These figures could be refined considerably with a more comprehensive study of the aquifer including a seismic or reflectograph study in addition to a test-hole drilling program.

Extent of Aquifer

The glacially derived sand and gravel deposited on the rough rhyolite and andesite surface are of low to moderate permeability throughout most of the Duck Lake aquifer. In delineating the extent of the aquifer, it can safely be assumed that its depth or thickness is controlled by the bedrock underlying the gravel.

It is bounded on the north and west by older bedrock; the east boundary is less perfectly defined, but it is thought that an almost continuous buried ridge of andesitic or rhyolitic material extends northerly from Coleman Butte, thereby forming at least a partial barrier to ground water flowing easterly. The evidence for this is seen in the road cuts on nearly every road which runs east from the flat down to Airport road. The southern boundary is perhaps the most questionable, but the flow of ground water to the southwest is apparently impeded by another buried ridge of rhyolite which extends in a general northwesterly direction from the Duck Lake-Conconully Road Y through the center of Sec. 22, T. 34 N., R. 26 E. This is indicated by a scattering of exposures of rhyolite along this line in addition to a variance of water levels in wells on opposite sides of the assumed ridge.

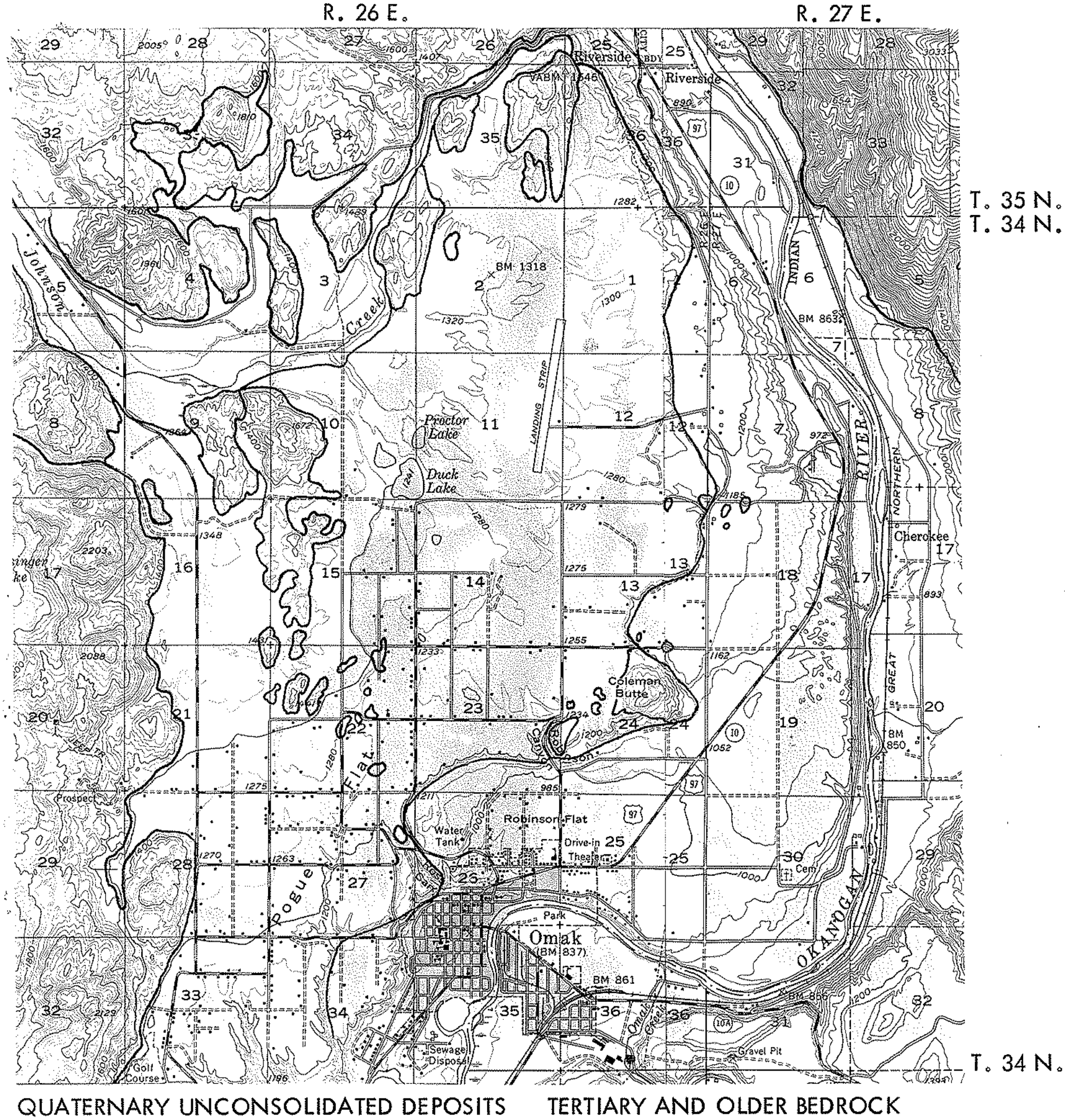
The most doubtful boundary occurs in Section 23, where well information is limited and there is no field evidence that a barrier to ground-water movement exists. It has been reported that one hole was drilled about 1000 feet east of the center of the section to a depth of 300 feet without penetrating anything but a sand so fine that water could not readily be withdrawn from it. There are indications that the water table drops abruptly in this area so it appears that a continuous barrier is probably non-existent and the water is passing downward to a level below that of Robinson Flat. From Robinson Canyon easterly to Coleman Butte an effective andesite barrier exists. This is verified as being almost continuous by surface exposures of the bedrock.

As an aid to understanding the previous discussion, a generalized geologic sketch map has been prepared with bedrock outcrops indicated where they bound the aquifer or extend through the overlying glacial deposits (Fig. 1). The scattering of outcrops should give the reader a good idea of the unevenness of the bedrock surface underlying the sand and gravel deposits.

Other Aspects

Although the boundaries of the Duck Lake aquifer, as designated in the preceding paragraphs, is thought to be essentially correct both from field reconnaissance and collected well data, some additional aspects should be considered. First, it is noted that the water-table conditions as they exist in the Duck Lake area today are not natural. This is due to the recharge program of the Okanogan Irrigation District and recharge incidental to irrigation of project lands (see page 8). However, the lakes which serve as a receptacle for recharge are natural and the Duck Lake aquifer is natural, so it must be assumed that the aquifer is either bounded on all sides having accumulated its water over a period of many years through local precipitation or is not a perfect basin but rather a basin with an inlet which receives ground-water recharge annually from outside the immediate area.

Regarding the latter, it appears possible that considerable ground water could gain entrance to the aquifer from the northwest or diagonally across Section 10. If this were so, the water would be passing under Johnson Creek. The evidence for such a theory is far from conclusive--however, comparative elevations and topographic conditions do not preclude such an idea. It appears possible that at some time in the past an old drainage channel did exist through Section 10. If such were the case and the channel was later partially filled by aggradation of the stream, the ground water could now flow southeasterly into the Duck Lake area. This could be verified by test drilling in the suspected channel and comparing water levels in the test holes with the level of Duck Lake.



QUATERNARY UNCONSOLIDATED DEPOSITS

Alluvium, flood plain and terrace deposits, undifferentiated

Glacial drift (glacially derived sand and gravel deposits)

TERTIARY AND OLDER BEDROCK

Principally Paleozoic(?) and Mesozoic metamorphic rocks of the Limebelt Series (metamorphosed marine sediments) with associated Tertiary rhyolite and andesite flows.

Pogue Mountain granitic complex

Colville gneiss complex containing coarse crystalline granitics in Omak Lake area.

Fig. 1 Geologic sketch map of Duck Lake Area showing general relationship of bedrock to Quaternary unconsolidated deposits of sand and gravel.

In the other case, if the Duck Lake aquifer is confined to a true basin without the possibility of annual recharge from fringe areas, it must be assumed that all natural recharge is resultant of precipitation on the immediate land surface of the basin. Stuart E. Shumway, meteorologist for the State Department of Conservation, has reported that the data made available through the McFarland weather station indicate such recharge would be slight in a normal water year. Consequently, it would take many years to fill the basin initially and sustained pumping of any appreciable quantity would cause a continuous lowering of the water table and depletion of the available water in the aquifer. Thus, if the Duck Lake aquifer were in a perfect basin, it would have to be assumed that most of the available water in this aquifer results from artificial recharge from Salmon Creek and Johnson Creek or recharge incidental to irrigation.

Recharge and Discharge

Generally, unconfined aquifers such as that underlying the Duck Lake area are principally recharged by local precipitation. As indicated previously, direct precipitation has only minimal importance in recharge of the Duck Lake aquifer although precipitation over the general area north of Johnson Creek possibly contributes considerable water.

The two sources that are definitely known to be major contributors to the recharge of the aquifer are artificial recharge by the Okanogan Irrigation District and recharge incidental to irrigation of the project lands by water from Salmon Lake and Conconully Reservoirs.

In years when surplus run-off water is available, the Okanogan Irrigation District diverts water into Duck Lake from Salmon Creek and Johnson Creek. Duck Lake is a ground-water lake in that its waters commingle with the ground water of the Duck Lake aquifer. Consequently, any recharge water put in Duck Lake also recharges the surrounding ground-water body. The Okanogan Irrigation District recharged Duck Lake under the schedule shown on page 9 during the years 1958, 1959 and 1960.

Recharge incidental to the irrigation of project lands within the Okanogan Irrigation District is an important secondary source of recharge to the Duck Lake aquifer. In years of normal precipitation, most of the project lands are irrigated with water from Salmon Lake and Conconully Reservoirs. The water is released at the reservoirs and flows down Salmon Creek to a point in Section 31, T. 34 N., R. 26 E.W.M. where it is diverted by canal to serve district lands in the Duck Lake area as well as lands outside the report area. Most of the irrigation water that is not taken up by evaporation or consumed by the crops eventually percolates down to the water table.

Ground-water discharge from the Duck Lake aquifer occurs in minor amounts through springs and seeps along the south and east side of the area. Additionally, it is thought that a considerable quantity of water passes laterally and downward to a lower aquifer below Robinson Flat. Most of the remaining discharge occurs as a result of withdrawal by wells, although some evapotranspiration losses occur where the ground-water table is very shallow. The amount of water withdrawn by wells is variable depending upon the program of the Okanogan Irrigation District. There are presently about 460 acres covered by primary ground-water rights in the area. Figuring an application of 4 acre-feet per acre per year, the annual withdrawal would be about 1840 acre-feet assuming all rights were being used

RECHARGE DATA FOR DUCK LAKE, 1958, 1959, 1960

1958

4 c.f.s. from Johnson Creek into Frye Lake Oct. 15, 1956 to Apr. 15, 1958
6 months or approximately 180 days at 8 acre-feet per day = 1440 acre-feet

20 c.f.s. from Salmon Creek into Duck Lake May 10 to June 15
35 days at 40 acre-feet per day = 1400 acre-feet

0.5 c.f.s. from Salmon Creek into Duck Lake during summer months
4 months or approximately 120 days at 1 acre-foot per day = 120 acre-feet

1440 acre-feet
1400 acre-feet
120 acre-feet
2960 acre-feet total recharge

1959

4 c.f.s. from Johnson Creek into Frye Lake Oct. 15, 1958 to Apr. 15, 1959
6 months or approximately 180 days at 8 acre-feet per day = 1440 acre-feet

20 c.f.s. from Salmon Creek into Duck Lake May 15 to June 31
48 days at 40 acre-feet per day = 1920 acre-feet

0.5 c.f.s. from Salmon Creek into Duck Lake during summer months
4 months or approximately 120 days at 1 acre-foot = 120 acre-feet

1440 acre-feet
1920 acre-feet
120 acre-feet
3480 acre-feet total recharge

1960

4 c.f.s. from Johnson Creek into Frye Lake Oct. 15, 1959 to Apr. 15, 1960
6 months or approximately 180 days at 8 acre-feet per day = 1440 acre-feet

10 c.f.s. from Salmon Creek into Duck Lake May 29 to June 18
21 days at 20 acre-feet per day = 420 acre-feet

0.5 c.f.s. from Salmon Creek into Duck Lake during summer months
4 months or approximately 120 days at 1 acre-foot per day = 120 acre-feet

1440 acre-feet
420 acre-feet
120 acre-feet
1980 acre-feet total recharge

Average 2806 acre-feet annually
for 1958, 1959, 1960

and the district was obtaining all their required water from surface water sources. Following years of below normal precipitation, the demands on the aquifer are greatly increased because during these periods the district pumps from Duck Lake and many wells with supplementary rights are utilized.

Discussion of Relationship between the Water Levels in Wells and Duck Lake -- Hydrographs

In order to determine the relationship between the water table and the water level of Duck Lake as designated on the water-table contour map (Fig. 2), an observation well network was set up in March of 1958 and terminated on July 1, 1960 providing a record of over two years. The network consisted of five wells measured semi-monthly for about a year and monthly during the remainder of the period. The water level of Duck Lake was recorded monthly. Hydrographs of these measurements have been included in this report and individual records are referred to by name and well number (Figs. 3 and 4). Prior to discussion of the hydrographs, it is pointed out that a two-year data record is insufficient to determine any specific trends of the water levels as they may be related to one another. However, it is an adequate period to determine similarity or dissimilarity between the individual hydrographs.

Of the five observation wells, three hydrographs show a definite similarity to the Duck Lake hydrograph. The remaining two will be discussed first. The Roger Holt well (34/26-22K2) shows a high water level near the first of October for the two years of record. The natural low water level is not known because of pumping operations in the summer. The high level in October could be indicative of recharge to the aquifer by percolating irrigation water and the slight time lag would be normal. The hydrograph seems to have no direct correlation with that of Duck Lake which for the period of record has shown a high level in April, May or June and a low in September. This dissimilarity tends to substantiate the previously mentioned belief that a buried bedrock ridge, extending from the Duck Lake - Conconully Road Y northwest through the center of Section 22, serves at least as a partial barrier to the passage of ground water from northeast to southwest out of the Duck Lake aquifer.

The Dean Carlton well (34/26-24D1) is not pumped for irrigation purposes and has a high water level in late October and November with a low in May and June. This hydrograph is not directly correlative with the Duck Lake hydrograph although the well is thought to be tapping the Duck Lake aquifer. Working within the limitations of our short term record, this variance between hydrographs can be explained. The Carlton well is almost one and one half miles from Duck Lake and the degree of influence of the artificial recharge is considerably diminished by the time water can move laterally through that distance. There should be a definite time lag between the high lake level and the high water level in the Carlton well. This would depend greatly on the transmissibility of the aquifer and it would not be abnormal if the entire variance of the hydrographs resulted from a time lag. However, another factor may be recharge incidental to irrigation. This, as in the Holt well, probably affects the water table near the Carlton well. Regardless of the cause, the dissimilarity of hydrographs is not an unusually startling occurrence and cannot by itself stand as a criterion for exclusion of the Carlton well from the basin.

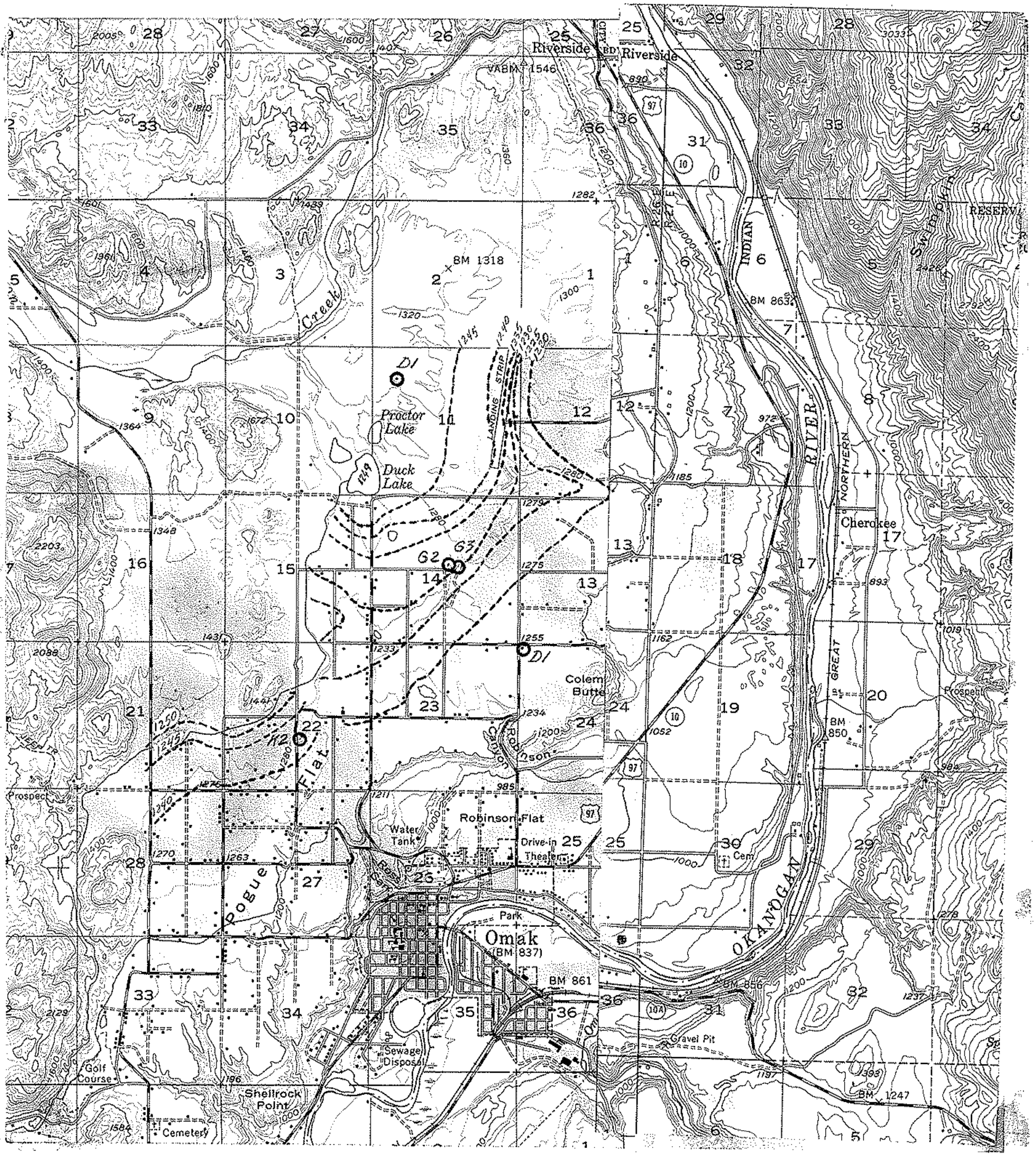


Fig. 2 Map showing water-table contours and locations of observation wells.

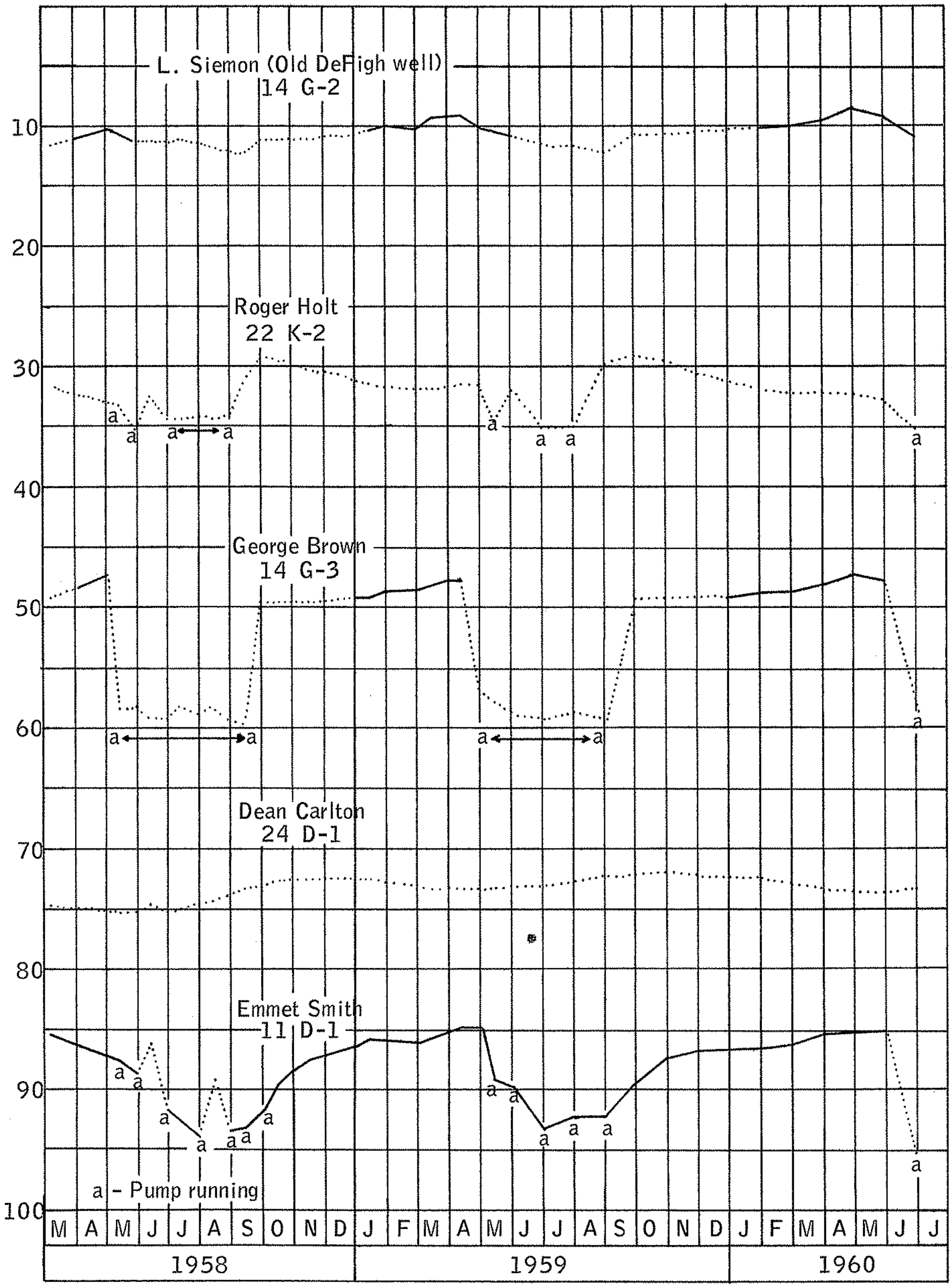


Fig. 3 Hydrographs showing fluctuations of water levels in observation wells.

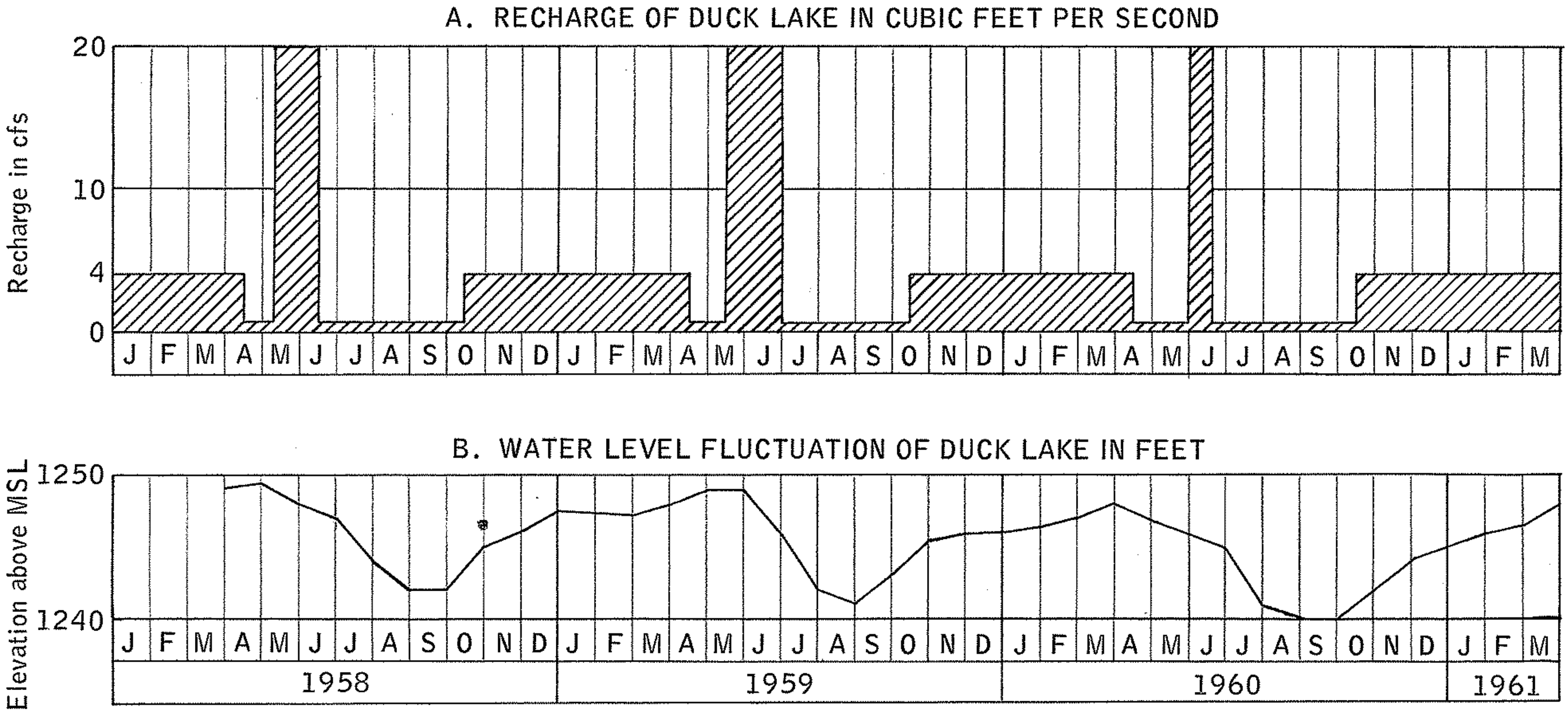


Fig. 4 A. Recharge of Duck Lake in cubic feet per second as reported by the Okanogan Irrigation District.
B. Hydrograph showing water level fluctuation of Duck Lake.

The three remaining hydrographs are thought to be directly correlative with the Duck Lake hydrographs. However, a true interpretation of the data is complicated by the artificial recharge into Duck Lake as well as withdrawal from two of the wells in question. That part of each hydrograph where a distinct similarity is noted has been designated by a solid line and the dissimilar portion by a dotted line. The dissimilar part usually coincides with periods of pumping from the wells.

The Leland Siemon well (34/26-14G2) and George Brown well (34/26-14G3) show both a definite relationship to each other as well as a similarity in part to the water surface of Duck Lake. The two wells are less than 100 yards apart and at first observation one might expect the Siemon well, which was not pumped for irrigation purposes during the period of study, to show a greater interference effect than it does when the Brown well is operating. However, in a pump test conducted on the Brown well, it was found that the drawdown was very fast in the first few minutes,being 6 feet in the first 15 minutes and only 2 additional feet in the next two hours, at which time it appeared to be fairly well stabilized. This indicates the aquifer at this point may have a relatively low permeability, thereby having a high rate of initial drawdown and a steep sided cone of depression with a small area of direct influence. This would explain the small effect shown by the Siemon well hydrograph during the period when the Brown well is being pumped. Also, measuring both the Siemon well and the old DeFigh well (34/26-14G1) during the previously mentioned pump test showed interference only in fractions of an inch, so it appears that the Siemon well is at the fringe of the area of influence and should show only slight effects when the Brown well is being pumped. The similarity of these two hydrographs with that of Duck Lake is restricted to periods when the Brown well is not operating.

The Emmet Smith well (34/26-11D1) has the most remarkable and unexplainable hydrograph of the five observation wells. If the measurements of June 15 and August 15, 1958 were not used, the hydrograph of the Smith well would be almost identical with that of Duck Lake. A true interpretation of the data is complicated by the artificial recharge into Duck Lake by the Okanogan Irrigation District as well as the withdrawal of up to 800 gallons per minute from the Smith well authorized under Ground Water Certificate No. 1316. Under normal circumstances such outside influences should affect the hydrographs in such a manner as to obscure correlative similarities between them. It seems the opposite has occurred in this case, and without further data, this peculiarity cannot be explained. However, the fact that the Smith well does tap the Duck Lake aquifer is apparent from a comparison of the two hydrographs during periods when the Smith well is not operating.

In closing the discussion on hydrographs, it is thought that some of the peculiarities of the Duck Lake hydrograph should be mentioned. In comparing the hydrograph with the recharge schedule presented on page 9 , it is seen that the rise and fall of the water surface of Duck Lake does not correspond very well with the recharge schedule (Fig. 4). First, it is noted that the lake begins to rise before recharge is increased to 4.0 c.f.s. in the fall and secondly, when recharge is at a high of 20.0 c.f.s. in late spring, the lake level is receding. Assuming the recharge schedule is correct, the water-level characteristics of the lake have to be attributed to a combination of factors, some of which are recharge incidental to irrigation of project lands, variance in water-table gradient away from and possibly towards the lake at times during the year and a seasonal variation of the rate of movement of ground water through the aquifer. A true evaluation of the peculiarities of the Duck Lake hydrograph could only be ascertained after a carefully regulated period of study and data collecting and is not possible at this time. The writer has a tentative explanation which may be considered in future studies, but is not adaptable to this report.

PAST AND PRESENT UTILIZATION OF WATER

The history of water use will be restricted primarily to those periods when withdrawal of water from the Duck Lake area by the Okanogan Irrigation District was necessitated in order to save the crops. The Okanogan Irrigation District took over the Okanogan Project (also includes much acreage outside of report area) of the U.S. Bureau of Reclamation on January 1, 1929 and in so doing took over a project that had been plagued with water shortages almost continuously since 1918, due both to an inefficient operation and a period of low precipitation. History shows the worst years were yet to come, those being 1929, 1930 and 1931. The storage facilities in 1929 were essentially the same as those today which consist of Conconully Reservoir with a capacity of 13,000 acre-feet and Salmon Lake with a capacity of 10,500 acre-feet. However, Salmon Lake remained essentially dry until 1938 and never reached capacity until 1942. As indicated on page 8 , water from these reservoirs is carried in the natural channel of Salmon Creek to a point about three miles above the town of Okanogan where it is diverted for use on project lands which include much of the Duck Lake area. In 1929, it was necessary to use two 5 c.f.s. pumping units from Duck Lake and two government wells with a capacity of 1 c.f.s. per well for irrigation of lands in the Duck Lake area. Additionally, there were many private wells equipped to pump into the distribution system as well as numerous private plants pumping from Duck Lake, Frye Lake and Proctor Lake. All pumping plants, government owned and private, capable of pumping surplus water were used through the critical years of 1929, 1930 and 1931. Most of these plants also operated in 1932. The availability of water from the Duck Lake aquifer was the primary factor that kept both the orchards and the Okanogan Project alive during the critical low-water years. The Duck Lake pumping plants were utilized in 1934, -36, -37, -39, -40, -41, -43, -44 and -47. Interpreting the storage data presented on page 16, it appears that with the possible exception of 1947, utilization of the Duck Lake pumping plants would not have been necessary after the irrigation season of 1940. However, the use probably continued both because the equipment was available and because memories of the early thirties were slow to wane; consequently, every effort was being made to keep full reservoirs.

With the adoption of the ground-water code in 1945, many declarations of use were received by the Division of Water Resources, but most of them were supplemental in part to rights from the Okanogan Irrigation District. That is, the wells were only pumped when district water was not available. In addition, several applications for permit to appropriate ground water have been received since 1945, so there are now about 30 ground-water rights in the report area. As near as could be determined, about 460 acres of land not served by the district are included in the existing rights and are termed primary rights. A check of records for the Okanogan Irrigation District showed that about 2200 acres in the Duck Lake area are entitled to district water. Consequently, with extremely low water years, the lakes and the Duck Lake aquifer could conceivably have an annual demand for enough water to irrigate 2660 acres if all the persons entitled to water from either the district or individual rights had their land under full production. It is noted, however, that much of the land entitled to water is no longer under cultivation.

STORAGE DATA FOR SALMON LAKE AND CONCONULLY RESERVOIRS

Year	Run-Off (acre-feet)	Diversion	Maximum Storage	Carry-over at end of irrigation season
1929	3,496	6,433	4,847 May	0
30	2,246	2,246	1,170 "	0
31	1,423	1,383	1,306 May	40
32	9,488	8,878	5,920 July	650
33	17,675	14,953	10,500 "	2,850
34	14,082	15,708	10,225 June	893
35	17,215	16,276	10,525 "	1,895
36	9,733	11,164	8,810 "	1,072
37	16,674	12,185	11,785 July	4,705
38	30,570	24,146*	19,095 June	6,652
39	5,915	12,316	10,890 May	313
1940	10,685	10,123	7,610 June	260
41	32,842	12,430	22,023 July	17,901
42	46,125	17,481	23,600 June	15,995
43	14,407	16,476	23,500 "	13,875
44	10,511	13,011	18,777 "	10,155
45	20,334	17,744	23,500 "	12,376
46	19,471	17,857	23,265 "	13,862
47	8,660	14,627	16,262 "	7,365
48	71,019	13,878	21,777 July	17,617
49	14,098	19,942*	23,350 May	12,078
1950	24,033	21,290*	23,500 June	13,455
51	43,803	39,855*	23,500 May-June	17,698
52	36,365	39,069*	23,500 May-June-July	16,226
53	27,677	25,810*	23,500 "	17,337
54	13,696	16,262	20,980 June	13,290
55	19,889	15,961	23,500 "	16,056
56	36,638	36,346*	23,500 May-June	16,822
57	31,512	27,755*	23,500 "	15,577
58	33,269	32,794*	23,500 "	16,200
59	31,122 to 10/31	26,908*	23,500 June-July	16,336

* Includes all outflow May to September, a considerable portion of which was wasted into the Okanogan River.

POSSIBLE ADVERSE EFFECTS OF GRANTING FUTURE PERMITS TO APPROPRIATE GROUND WATER FROM THE DUCK LAKE AQUIFER

With the basic data presented, attention can now be directed toward the determination of possible adverse effects upon existing rights if additional ground-water permits are granted in the Duck Lake area. In accordance with Section 90.44.070 R.C.W., no permit shall be granted for the development or withdrawal of public ground waters beyond the capacity of the underground bed or formation in the given basin, district or locality to yield such water within a reasonable or feasible pumping lift in case of pumping developments, or within a reasonable or feasible reduction of pressure in the case of artesian developments. Additionally, all permits are granted subject to existing rights and the supervisor of Water Resources shall have the power to determine whether the granting of any such permit will injure or damage any vested or existing right or rights under prior permits and may in addition to the records of his office, require further evidence, proof, and testimony before granting or denying any such permits.

On the basis of available data, it is apparent that the Duck Lake aquifer is not overappropriated at present (under existing conditions) in periods of normal precipitation. This is substantiated by the hydrographs of record which indicate the aquifer is fully recharged each year. Additionally, ground-water deficiencies, with the exception of local interference problems, have not been reported for any of the established wells in the Duck Lake area. During the period of study, there was no evidence found to even suggest the Duck Lake aquifer was being utilized beyond its capacity. Consequently, under existing conditions, it does not appear that the granting of more permits in the Duck Lake area would be a serious detriment to existing ground-water rights.

However, in discussing the "possible" adverse effects of granting such permits, it must be re-emphasized that the existing ground-water conditions in the Duck Lake area are not entirely natural. The availability of ground water from the Duck Lake aquifer would be considerably diminished if there were no artificial recharge by the Okanogan Irrigation District and if all the ground-water rights as well as the district's surface water right from Duck Lake were being utilized. If these events occurred, it is possible that the aquifer would be fully appropriated and the withdrawals of some of the appropriators with lesser or inferior priorities would have to be regulated.

CONCLUSIONS AND RECOMMENDATIONS

The Duck Lake area is underlain by one aquifer (Duck Lake aquifer) which is in direct continuity with the surface waters of Duck Lake, Frye (Loon) Lake and Proctor Lake. The Duck Lake aquifer, composed of glacially derived sand and gravel of Pleistocene age, has an areal extent of over 4000 acres and is generally bounded by bedrock on all sides, but it is not thought to lie in a perfect basin; both subsurface recharge to and discharge from the aquifer are suspected.

The specific yield of the aquifer has been estimated to be between 9600 and 40,000 acre-feet assuming the aquifer is fully recharged. The ground-water conditions in the Duck Lake area are not natural in that the Duck Lake aquifer is artificially recharged by water from Salmon and Johnson Creeks as well as receiving water incidental to the irrigation of district lands by water from Salmon Lake and Conconully Reservoirs.

The Duck Lake aquifer, under existing conditions, is not fully appropriated each year, but if the artificial recharge program of the Okanogan Irrigation District were stopped and all water rights in the area were fully utilized, it is possible that an overdraft of the aquifer could occur. In that event, regulation of withdrawals would be necessitated in accordance with established priorities of the individual water rights. Assuming no project water from Salmon Lake or Conconully Reservoirs, the Duck Lake aquifer could conceivably be called on to yield enough water for the irrigation of 2660 acres.

Most of the wells in the Duck Lake area do not penetrate the entire thickness of the aquifer. There are definite indications that water would still be available from Duck Lake after most of the existing wells were pumped dry. Additionally, increased pumping and lowering of the water table would increase storage capacity such that more recharge water would be retained by the aquifer and more water that may be escaping from the aquifer would be utilized. Consequently, in periods of extreme drought, the rights of the Okanogan Irrigation District would probably be about the last to be critically affected.

The following recommendations for future development and utilization of all waters in the Duck Lake area are based on conditions as they were during the period of study. The Division of Water Resources should continue to issue permits for the appropriation of ground water from the Duck Lake aquifer, but future applicants should be fully cognizant of the fact that they are only establishing rights to the use of these waters when they are available without adversely affecting existing rights. The mere perfecting of a right for use of ground water which may in part result from artificial recharge to the aquifer will not in any manner assure the continuance of the artificial recharge program by the Okanogan Irrigation District.

Placement of future wells should be established to minimize the possibilities of local interference problems. New applicants should consider existing wells which enjoy supplementary rights. Although these wells may not be in use at the time of the new construction, they can be put into full operation when needed to supplement district water.

On new lands, not covered by district water or existing ground-water rights, it is recommended that the planting of annual crops rather than orchards be strongly considered. If this plan were followed, any losses resulting from extreme water shortage would be limited to a year's crop loss, whereas if orchards had been planted, many years of investment and time in developing the orchards could be lost in addition to the loss of crops for the year.

It is suggested that the Okanogan Irrigation District, because its members could be vitally affected by the future ground-water conditions in the Duck Lake area, keep complete and accurate records of the quantities of water diverted into Duck Lake as well as any withdrawals made from the lake. Additionally, it would be to their advantage to maintain a continuous record of the lake level and establish one or two observation wells near the lake. These data would all be significant if the Duck Lake area is ever designated as a ground-water area or sub-area in accordance with Section 90.44.130 R.C.W. because in that event, the district would probably desire to declare the water they are artificially storing.