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THE RAFT RIVER BASIN, IDAHO–UTAH AS OF 1966: A REAPPRAISAL OF THE WATER RESOURCES AND EFFECTS OF GROUND–WATER DEVELOPMENT

by

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AND EFFECTS OF GROUND–WATER DEVELOPMENT

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ABSTRACT

The Raft River basin, mostly in south-central Idaho and partly in Utah, is a drainage basin of approximately 1,510 square miles. Much arable land in the basin lacks water for irrigation, and the potentially irrigable acreage far exceeds the amount that could be irrigated with the 140,000 acre-feet estimated annual water yield. Therefore, the amount of uncommitted water that could be intercepted and used within the basin is the limiting factor in further development of agriculture irrigated with water derived from within the basin. Water for additional irrigation might be obtained by pumping more ground water, but only if large additional ground-water storage depletion can be tolerated. Alternatively, supplemental water might be imported.

The Raft River basin is an area of rugged mountain ranges, aggraded alluvial plains, and intermontane valleys. Topography and geologic structure strongly influence the climate and hydrology. The Raft River rises in the Goose Creek Range of northwestern Utah and flows generally northeastward and northward, joining the Snake River in the backwater of Lake Walcott.

The climate ranges from cool subhumid in the mountains to semiarid on the floor of the Raft River valley. Precipitation ranges from less than 10 inches on the valley floor to more than 30 inches at some places in the mountains. Rainfall is light during the growing season of about 100 days, and irrigation is necessary for most cultivated crops.

About 87,000 acres of land was irrigated in the 1960's, on the average, and most of that is in the lower Raft River valley. Nearly all usable surface water in the basin is diverted for irrigation and as of 1966 less than 20,000 acres were irrigated exclusively with surface water. Most stock, farm, and domestic water is from wells. Irrigation with ground water is widely practiced and about 69,000 acres were irrigated partly or wholly with ground water in 1966. In 1963 the valley was closed to further issuance of permits to appropriate ground-water because of declining water levels.

Geologic structure, lithology, and physiographic history control the surface-drainage pattern as well as the occurrence and movement of ground water. The principal water-bearing formations are the Salt Lake Formation of Pliocene age, consisting mainly of

weakly consolidated sandy sediments and some layers of volcanic rock; the Raft Formation of Pleistocene age consisting of sand and gravel, lake sediments, and thin beds of silt and clay; and alluvial deposits of Holocene age that form aquifers beneath the bottom lands of the valleys. Good yields from wells, ranging upward to several thousand gallons a minute, are obtained from the water-bearing formations. Basalt lavas of the Snake River Group yield water where they occur below the water table of the valley. A few wells that penetrate limestone obtain substantial supplies from crevices.

Thickness of the composite aquifer ranges from 0 to more than 1,500 feet. Transmissivity of the composite aquifer is estimated to vary from about 10,000 gpd/ft (gallons per day per foot) along the basin margins to more than 450,000 gpd/ft. Permeability of the water-bearing deposits is highly variable, but is estimated to average about 300 gpd/ft^2 for the basin as a whole.

The ground-water storage capacity of the basin is large; in the lower Raft River subbasin alone, the upper 200 feet of saturated deposits contain an estimated 9,000,000 acre-feet of water. The average specific yield of the shallow deposits is estimated to be 20 percent.

The water yield of the Raft River basin is estimated to average about 140,000 acre-feet per year as compared to 183,600 acre-feet estimated by Nace and others (1961) and 320,000 acre-feet estimated by Mundorff and Sisco (1963). Surface outflow of the Raft River to the Snake River now amounts to only about 1,900 acre-feet per year, a decline of about 15,000 acre-feet a year from the estimated original average outflow prior to irrigation of about 17,000 acre-feet per year.

Ground-water outflow from the basin originally averaged approximately 83,000 acre-feet annually; it has declined only slightly as a result of pumping and was estimated to be about 80,000 acre-feet annually in 1966.

In general, the quality of surface and ground water is good; dissolved solids in a few exceptional wells range up to more than 2,000 mg/l (milligrams per liter) where the temperature is high or where a substantial percentage of water pumped was previously used for irrigation. Most of the surface and ground water is suitable for irrigation and has a dissolved solids content of less than 600 mg/l, mainly calcium bicarbonate. Dissolved-solids concentration in the surface-water outflow from the basin is increasing.

The pumping of ground water has caused a net water-level decline beneath about 235 square miles of the valley floor. Beneath and adjacent to the bottom lands, water levels recover a number of feet during years of above-average runoff, owing to recharge from the Raft River and Cassia Creek. However, a steady decline of as much as 5 feet per year is occurring beneath pumped areas that are some distance from sources of recharge.

Consumption of ground water for irrigation, under present-day practices, averages about 1.6 per acre annually. Total consumption of water by irrigated crops has risen from about 40,000 acre-feet to about 160,000 acre-feet annually.

Pumping of ground water increased from approximately 8,600 acre-feet in 1948 to 235,000 acre-feet in 1966, a year of deficient streamflow.

Assuming 20 percent for the specific yield of the water-bearing formations, the depletion of ground-water storage during the 14 years 1952 to 1965 inclusive was approximately 410,000 acre-feet. By the end of 1966 it was nearly 515,000 acre-feet.

Salvage of ground-water outflow from Raft River valley subbasin will require reduction or elimination of the present northward hydraulic gradient of about 15 feet per mile. Reducing the gradient by one half would salvage about one half the outflow, or about 40,000 acre-feet annually. However, with present pumping patterns and quantities, this reduction would require several hundred feet of water-level decline near the pumping wells, many decades of time, and several millions of acre-feet of additional depletion of stored ground water.

INTRODUCTION

The Raft River basin, mostly in south-central Idaho but partly in northern Utah, is a major drainage basin tributary to the Snake River. Prior to development and use of its water resources by man, the basin contributed an estimated average 100,000 acre-feet of surface and subsurface flow to the Snake River system annually. Of the remaining estimated 140,000 acre-feet total annual water yield, about 40,000 acre-feet was nonbeneficially consumed by riparian vegetation along stream channels. The area of the drainage basin used in this report is about 1,510 square miles, nearly all of which lies in Cassia County, Idaho. A few square miles lie in Oneida and Power Counties, Idaho, and about 270 square miles in Box Elder County, Utah (fig. 1).

Approximately 700 square miles of the area is in the broad, gently sloping Raft River valley that extends southward from the Snake River Plain. Beginning in the 1870's, large tracts of this acreage that could be served by diversion of surface flow from the Raft River and its principal tributaries were developed for agriculture. By the late 1880's nearly all available surface water was appropriated. Pumping ground water for irrigation in the valley started in the 1920's, but it was not until about 1950 that large-scale pumping began for supplemental irrigation and the irrigation of large tracts remote from surface supplies.

Between 1948 and 1952 the quantity of ground water pumped annually for irrigation, as computed from power-consumption records, increased from about 8,700 acre-feet to approximately 22,900 acre-feet. This increased pumping caused local concern that the water resources of the basin were being overdeveloped and detailed studies were begun by the U.S. Geological Survey in cooperation with the Idaho Department of Reclamation to define and describe the water resources of the basin. These studies resulted in a comprehensive report titled "Water Resources of the Raft River Basin, Idaho-Utah" (Nace and others, 1961).

Ground-water pumping continued to increase until by 1955 the computed pumpage was about 64,000 acre-feet annually. It reached an estimated 112,000 acre-feet in 1960, at which time it was evident that ground-water development had markedly affected the streamflow of the Raft River and was causing water-level declines in the more heavily pumped parts of the valley.

The Geological Survey prepared a report summarizing data collected during the period 1956-60, which documented the effects of pumping for irrigation in the Raft River valley subbasin. The report, "Ground Water in the Raft River Basin, Idaho, with Special Reference to Irrigation Use, 1956-60" (Mundorff and Sisco, 1963), described the magnitude and distribution of water-level declines within the basin and made new estimates of water yield and ground-water underflow from the basin as of 1960.

New and increased use of the ground-water resource continued in the early 1960's with attendant water-level declines. The potential effect of these declines on established water rights caused the State Reclamation Engineer to close the basin in July 1963 to further applications to appropriate ground water. This action was challenged by local interests and litigation followed which pointed up a need for more detailed information on the water resources of the basin.

Consequently, the study upon which this report is based was begun by the Geological Survey in cooperation with the Idaho Department of Reclamation in 1965 and continued through June 1967. The goals of the study were to:

1. Re-describe those aspects of the geologic framework of the basin that influence the occurrence, movement, and availability of the water resource. This re-description to be based on new surface mapping of geologic units, new data from well logs, and the results of regional geologic investigations that led to re-definition of geologic formations and their distribution within the basin.

2. Re-determine the water yield of the basin by independent assessment of precipitation occurrence and distribution, and of natural water loss through evaporation and transpiration.

3. Collect additional records of streamflow on which to base computation of the long-term average annual runoff as an indicator of minimum water yield and changes caused by diversion and use.

4. Update all data related to pumping of ground water, change in water level, distribution of water-bearing units, and use of water for irrigation.

5. Determine a new water budget for the basin which identifies the elements of inflow, outflow, and storage change in terms of current water use as compared with natural basin conditions.

6. Describe the location and magnitude of change in ground-water storage resulting from pumping, and relate the change to total storage available.

CONCLUSIONS

The study provided additional data over that available for earlier investigations and the data, when applied to the enumerated goals, allow interpretations and conclusions that fulfill most of the objectives and current management needs.

1. Ground water suitable for development for irrigation in the Raft River basin occurs in the valley fill – including Holocene alluvium and the Pleistocene Raft Formation – and in the upper part of the Pliocene Salt Lake Formation. Most of this water is in the Raft River valley subbasin, east of the Cotterell Range. There the ground water is generally unconfined, and the several geologic formations constitute a single aquifer with a thickness exceeding 700 feet under most of the lowlands, which is underlain by relatively impermeable rocks. Aquifer permeabilities and yields vary widely from place to place, and are likely to be less in the older formations whether they are deeply buried under the valley floor or near the surface along the margins of the subbasin. West of the Cotterell Range, the same geologic formations are waterbearing in the Yost-Almo and Elba subbasins, but data are inadequate to delineate aquifer characteristics or thickness. From these subbasins, there is outflow to the Raft River valley subbasin through the alluvial valleys occupied by Raft River and Cassia Creek as they traverse the Cotterell Range.

The Raft River valley subbasin is bordered on the north by basalt which on the grand scale of the Snake River Plain is highly permeable, but which includes massive impermeable rocks as well as very permeable zones. Outflow of ground water from the subbasin through this basalt and included sediments is indicated by a northward water-table gradient of about 15 feet per mile. This underflow occurs along a section about 10 miles wide, but data are still lacking as to the permeability and thickness of the section, so that the rate of underflow cannot be calculated directly.

2. The perennial water yield of the basin is the average natural annual discharge from the Raft River basin. In this, as in previous studies, the yield has been determined indirectly as the difference between the average annual precipitation and the average annual evapotranspiration throughout the Raft River basin under natural conditions. The calculated volume of annual precipitation – 1,280,000 acre-feet – is practically identical with the average volume estimated by Nace and others (1961), who also estimated that 86 percent of this volume was returned to the atmosphere by evapotranspiration within the basin, and the remainder of 184,000 acre-feet constituted the water yield. In the present study, the water yield at selected sites was determined by empirical procedures that provide estimates of average monthly precipitation and potential evapotranspiration and soil-moisture deficit at each site; these data were then plotted on a map that was used for computation of average water yield in each subbasin. By this method, the calculated water yield is 140,000 acre-feet and thus 89 percent of the precipitation is lost naturally from within the basin by evapotranspiration. Either calculation of the water yield should be viewed as only a rough approximation, in view of the assumptions and empiricial procedures that are involved in estimating evapotranspiration.

3. The natural surface outflow from the Raft River basin, based on measurements of the Raft River as early as 1910, is estimated to have averaged about 17,000 acre-feet a year.

The quantity available for man's development and use in the Raft River valley subbasin (east of the Cotterell Range) was considerably greater, for it included average annual inflow of about 18,000 acre-feet from Cassia Creek, 24,000 acre-feet from Raft River at The Narrows, 8,400 acre-feet from creeks draining the Raft River Mountains, and 5,400 acre-feet from creeks rising in the Sublett Range – an aggregate surface inflow of about 56,000 acre-feet. Most of this water contributed to recharge of the ground-water reservoir, or was consumed by riparian or phreatophytic vegetation.

Diversion and use for irrigation of the waters in the mountain creeks has caused progressive reduction in the surface-water inflow to the Raft River in the Raft River valley subbasin. In the 30 years 1931-60, the average inflow has been 12,500 acre-feet from Cassia Creek, 11,600 acre-feet in Raft River at The Narrows, and none from small creeks draining the Sublett and Raft River Mountains. Much of this inflow disappeared by diversion or seepage, so that the river was dry along several miles of its course each year, the outflow was probably between 9,000 and 7,000 acre-feet a year. By 1967 the inflow in Raft River at The Narrows had dwindled to 6,500 acre-feet, and the spring-fed outflow to less than 2,000 acre-feet. The consumptive use of surface water, estimated at about 40,000 acre-feet a year by riparian vegetation aboriginally, increased to nearly 50,000 acre-feet as the water was applied for irrigation and native vegetation was cleared. Since 1948 the consumptive use of surface water has dwindled with decreasing availability, to about 20,000 acre-feet in the dry year 1966.

4. Pumpage for irrigation from wells in the Raft River valley subbasin began after World War II, increased from 8,600 acre-feet in 1948 to 148,000 acre-feet in 1965, and to 225,000 acre-feet in the dry year 1966. Aggregate pumpage in this subbasin in two decades is estimated to have been about 1½ million acre-feet by the end of 1966. Pumping began in the Yost-Almo subbasin in 1956 and increased to about 8,400 acre-feet in 1966, and in the same year less than 1,000 acre-feet was pumped in the Elba subbasin; the aggregate pumpage in both these subbasins was only 46,000 acre-feet by the end of 1966. Assuming that 40 percent of the water pumped is used nonconsumptively and then returns to the ground-water reservoir, the net withdrawal of ground water for consumptive use throughout the Raft River basin increased from about 5,000 acre-feet in 1948 to 90,000 in 1965 and to 140,000 acre-feet in 1966.

In the Raft River valley subbasin, water levels in wells have been lowered substantially throughout the area irrigated from wells. From the spring of 1952 to 1966, the water table declined under an area of 235 square miles, and the decline exceeded 50 feet in several parts of the valley north of Malta. The volume of materials dewatered during the 14-year period is computed to be about 2 million acre-feet. On the basis of well logs and other data, the average specific yield of the dewatered materials is estimated to be 20 percent, and the water drained from them is thus about 400,000 acre-feet. The water pumped from wells during the period was more than 1,200,000 acre-feet, and assuming that 40 percent of this returned to the reservoir, the net withdrawal was about 740,000 acre-feet. From these data, it would appear that there was inflow to the pumping depression amounting to about 340,000 acre-feet, or an average of about 24,000 acre-feet a year; this may have included lateral inflow, seepage of surface water, and infiltration of precipitation. During the dry year 1966, the gross irrigation pumpage in the subbasin was 225,000 acre-feet. Assuming the same proportionate distribution, 90,000 acre-feet of this was used nonconsumptively and then seeped back to the aquifer; 75,000 acre-feet was removed from accumulated storage; and 60,000 acre-feet was replenished either by infiltration of precipitation or surface water or by lateral inflow to the pumping area.

The water that is pumped for irrigation and then seeps back to the aquifer is likely to carry dissolved salts from the soil and land surface. Several wells in the bottomlands yield water with more than 600 mg/l (milligrams per liter) of dissolved solids, and in some the dissolved solids are chiefly sodium and chloride. These dissolved salts accumulate during natural evapotranspiration of the river water, and available data do not show whether the concentration has been increased by irrigation return. The surface outflow from the valley, however, now has dissolved solids about 30 percent greater than those measured prior to irrigation development.

5. It has been calculated that the average water yield of the entire Raft River basin is about 140,000 acre-feet a year, of which under natural conditions 40,000 acre-feet was consumed by riparian vegetation, 17,000 was surface-water outflow and 83,000 acre-feet ground-water outflow. So far as the main valley – the Raft River valley subbasin – is concerned, most of the natural surface-water inflow of 56,000 acre-feet has been diverted for irrigation in the tributary subbasins, so that by 1967 the surface inflow to the valley subbasin had been reduced to less than 20,000 acre-feet. The total water diverted or pumped for irrigation in the tributary subbasins is greater than the amount of depletion of streamflow to the main valley. This is true because some irrigation consumptive use replaces natural riparian consumptive use, and the water used nonconsumptively for irrigation becomes ground water that may eventually return to the stream or continue by underflow to reach the valley subbasin.

Within the Raft River valley subbasin, the use of water for irrigation doubtless substitutes in part for consumptive use by native riparian vegetation. but the surface outflow has also been reduced from 17,000 to 2,000 acre-feet. The principal consumptive use of water in the valley subbasin, however, is by irrigation with water pumped from wells. In 1966 this consumptive use amounted to an estimated 135,000 acre-feet, approximately equivalent to the calculated water yield from the entire basin.

6. The water pumped from wells for irrigation has come partly from accumulated storage within the aquifer as shown by the progressive decline of water levels in the areas of pumping. Whatever the amount of ground-water outflow northward from the basin, pumping has caused no significant change in that outflow. This is shown by water levels in the northern outflow area which have changed very little during 14 years of progressively increasing pumping. Lowering the water level by 50 feet in an area of intensive pumping has lowered the water table less than 1 foot 4 miles to the north. Basalt in the outflow section has a thickness of several hundred feet – wells have been drilled in it to depths of nearly 500 feet – and a reduction of less than a foot in saturated thickness would cause a very small reduction in the outflow. Until the pumping in the valley has significant effect upon the outflow, accurate determination of the amount of outflow is of academic interest only.

The water pumped from storage comes from the valley aquifer where it is generally most permeable, most productive and thickest. In the area of most intensive pumping north of Malta, the aquifer extends to depths greater than 1,400 feet, and it is more than 700 feet thick under practically the entire area of irrigation pumping. In this pumping area, the aquifer has an estimated average specific yield of 20 percent – comparable to the materials already dewatered – down to depths generally more than a hundred feet below the water table as of 1967. The older sediments at greater depths and around the margins of the valley have lower permeability and lesser yields, estimated to average about 15 percent. In the Raft River valley subbasin, it is estimated that the permeable sediments down to depths 200 feet below the water table in 1967 contain 9,000,000 acre-feet of water in storage.

7. All studies, including this one, have noted the quantity of ground water leaving the Raft River valley subbasin as ground-water outflow. This water, once it moves northward into the Snake River Plain, is lost to use within the Raft River basin. Thus, many have been led to believe that pumping near the outflow area would intercept a major part of the water now moving from the basin as underflow. The pumping to date, however, has not reduced the outflow by any significant amount. Although pumping until 1966 was less than the calculated perennial yield of the basin, much of that "yield" continued to flow out of the basin; the pumping was in excess of local replenishment and, therefore, in part from accumulated storage in the aquifer. Continued pumping can be expected to broaden and deepen the existing cones of depression, and to cause further depletion of storage and increased pumping lifts before any significant decrease in subsurface outflow occurs.

This depletion of ground-water storage poses many problems to the development and use of the ground-water resource. Of particular importance is the realization that the ground-water resources have been and are being depleted, and that this depletion may continue for decades under present pumping practices. The depletion will continue during a transient state of imbalance that began when man first disturbed the natural equilibrium, and will end only when a new equilibrium is reached. This new equilibrium can occur only if the total quantity consumed by man is equal to or less than the perennial yield (140,000 acre-feet) of the basin. In the course of this depletion, it must be anticipated that so long as present pumping practices continue there will be a progressive increase in pumping lifts and decreases in well yields. The information on which to base an estimate of the point in time at which a new equilibrium would be established is not now available.

PREVIOUS WORK AND REPORTS

The general geology and water resources of the Raft River basin have been studied in part and in varying detail by several workers. Despite this work, the geology of the valley areas and the regional structural features are still imperfectly known, and more detailed investigations and further data collection are needed on which to base detailed hydrologic analysis of the basin. The results of all previous work in the basin have been used in the analyses, interpretations, and conclusions of this report.

The earliest known study of the hydrologic characteristics of the area was made by Stearns and others in 1928 during a reconnaissance of the Snake River Plain and tributary valleys. This work was published in two reports (Stearns and others, 1936, 1938). Kirkham (1931) compared the Tertiary stratigraphy of the Raft River basin with that of other areas in southern Idaho. The basic reference on the geology of the area was prepared by Anderson (1931), who described the general geology and mineral resources of eastern Cassia County with special emphasis on the upland areas. The report contributed little information about the geology of the valley lowlands.

Fader (1951) prepared a preliminary report which contained records of wells, ground-water levels, and pumpage for irrigation. The most comprehensive report of the water resources of the basin, however, including well data and estimates of all elements of the hydrologic budget, was prepared by Nace and others (1961) as the result of work done in 1948-55. That report discussed estimates of the total water yield of the basin, the amounts of that yield available as surface water and as ground water, the amount of ground water that might be recovered for beneficial use, and the effects of such use on downstream water supplies. However, the accuracy of the estimates was greatly limited by the sparse records then available.

A report by Crosthwaite and Scott (1956) contained data on wells at the extreme northern end of the basin, and Felix (1956) presented data on the geology of the eastern part of the Raft River Mountains. Mundorff and Sisco (1963) completed a brief study of the valley part of the area in 1960 and published a short report containing water levels, declines of water level since 1952, pumpage, and estimates of water yield and ground-water outflow. A principal conclusion of the report was that ground-water development during 1955-60 had materially reduced the unused and uncommitted underflow from the basin and that continued ground-water pumping could economically intercept perhaps one-fourth of the then estimated 140,000 to 200,000 acre-feet leaving the basin as underflow. An unpublished report by Haight (1965) contained data on pumpage of ground water through 1964, water levels as of the spring of 1965, and water-level change.

Additional information about the geology of the mountainous parts of the area was published by Armstrong (1966), Compton (1966), and Damon (1966). The Utah part of the basin was described on a reconnaissance geologic map (Butler and others, 1920, pl. 4), but the work was too general to be useful in this study.

Present use of water in the basin is considered in the report only in relation to the hydrologic system. The analysis is directed toward the storage and movement of water in the system. The merits, effectiveness, or relative efficiency of the various uses are considered to be beyond the scope of this report. The report is intended principally for use by persons who have the responsibility of managing the basin and for selecting alternative plans of developing or regulating the water resources of the valley.

PURPOSE AND SCOPE

Since conclusion of the principal studies in 1955 and 1960, new information has become available as a result of additional well drilling, additional mapping of irrigated acreage, and longer records of precipitation, streamflow, pumpage, and ground-water levels.

The availability of these data offers opportunity to reevaluate the elements of the hydrologic budget of the basin and refine quantitative estimates made during the earlier studies.

The purpose of the report is to present new data on which reevaluation and refinement of the budget elements are based, and to describe procedures used to develop a new and independent hydrologic budget for the basin.

The scope of the studies applicable to the purpose of the report was as follows:

1. The areal distribution of the geologic formations and units of importance to the water resources was re-described with the aid of aerial photographs and better maps than were available to previous workers. This re-description, along with additional well logs, enabled the authors to better determine the location of aquifers and geologic features that control ground-water occurrence and movement.

2. A new precipitation-distribution (isohyetal) map was prepared, including data gained from new measuring sites established as a part of the study.

3. The total water input to the basin was estimated with the aid of the isohyetal map. Measurements of streamflow in the principal tributary drainages made as a part of the study, and recomputation of natural water losses through evapotranspiration were used to estimate water yield of the basin.

4. All wells drilled since 1955 were inventoried. These data, plus earlier records, were used to determine and describe the occurrence of the ground-water resource in the basin.

5. Estimates of net ground-water withdrawal were derived from updated pumpage and consumptive-use data, and data on the quantity of surface and ground water applied to the irrigated acreage.

6. Systematic measurements of water levels were continued at existing observation sites, and initiated at others to define historic changes in ground-water levels.

7. Areas of net decline in water levels were determined and estimates made of net change in ground-water storage, as well as reduction of subsurface outflow from the basin.

8. A water budget was prepared to interrelate the estimated elements of water input to the basin, consumptive use, outflow, and storage change within the basin.

9. Streamflow and ground-water samples were analyzed for chemical content as a basis for estimating effects of development and use on the chemical quality of the water resource, and the distribution of these effects in space and time.

REFERENCE PERIOD USED IN THE REPORT

The U.S. Weather Bureau uses the 30-year period 1931-60 as a base period for the computation of normal precipitation and temperature. For ready comparison the same period is used in this report for the analysis of precipitation, temperature, evapotranspiration, streamflow, and water-yield data. Records that do not encompass this period are adjusted to the period by correlation with long-term records, and by extrapolation.

The period of rapid change in ground-water occurrence and use extends only from about 1948 to the present, and there is no value to extending this record to the 1931-60 base period. Consequently, changes in ground-water recharge, discharge, and storage are referenced only to the period for which data are available.

ACKNOWLEDGMENTS

Well drillers furnished logs and other information about wells. Residents and well owners supplied helpful data and permitted measurements of wells. The Raft River Rural Electric Cooperative furnished records of power consumption. The Idaho Department of Reclamation and the U.S. Bureau of Reclamation made available to the Geological Survey data from their files that aided materially in the preparation of sections on storage change and the water budget. The information made available by the many individuals and several agencies materially aided the study, and the assistance given is acknowledged with much appreciation.

The field investigations and preparation of data and interpretations for the report were under the project leadership of the senior author. Wells were canvassed and water-level data were collected by E.H. Walker and H.G. Sisco. S.O. Decker and C.A. Thomas supervised the installation and operation of miscellaneous streamflow measuring sites and precipitation stations, and Mr. Decker prepared the report data related to streamflow. The information for the sections on precipitation distribution and water yield were prepared by K.L. Dyer.

The senior author was transferred from the Idaho district prior to complete preparation of the report. L.C. Dutcher assumed responsibility for the final report assembly, and prepared the discussion of ground-water occurrence, ground-water movement and discharge, storage change, transient-state yield, and conclusions. All sections not credited otherwise are the work of the senior author.

The project was begun under the supervision of H.A. Waite, district geologist, Ground Water Branch,and completed under the supervision of W.L. Burnham, district chief, Water Resources Division. Because of the numerous changes in project and authorship responsibility and the number of investigators involved, Mr. Burnham assumed final responsibility for the report content and format and made extensive revisions. In addition to helping to shape the final version during review, H.E. Thomas added the notes on legal aspects of the Raft River basin problem that appear in "Conclusions".

THE ENVIRONMENT

GEOGRAPHIC FEATURES

The Raft River basin is characterized by rugged mountains rising above aggraded alluvial valleys. The topography in and around the basin strongly influences the climate, and local factors of geology and water use control runoff and ground-water recharge. Figure 1 shows the location and arrangement of the valley areas with respect to their enclosing mountain ranges, and to the various subbasins, stream systems, and geographic features referred to hereafter in this report. The basin includes all the surface area drained by the Raft River and its tributaries above the stream-gaging station Raft River at Yale, sec. 1, T. 10 S., R. 27 E. (fig. 1).

The Raft River basin has been divided into three subbasins, both because of hydrologic considerations, and for convenience in discussion. The subbasins have been designated as Raft River valley, Yost-Almo, and Elba (fig. 1). Throughout the discussion of water resources, those subbasins will be considered as entities whose sum makes up the whole surface-water discharge and water yield of the Raft River basin; the ground-water subbasins, similarly, conform to the three-fold division but are restricted in the sense that the area of each subbasin underlain by aquifers capable of yielding significant quantities of water to wells is distinguished from the drainage subbasin in which the ground-water subbasin lies.

Mountain Ranges

The mountains surrounding Raft River valley have a two-fold importance in relation to water resources. The crests of the ranges are taken as the hydrologic boundary of the basin, and the higher slopes within the basin are the areas of principal water catchment as precipitation generally increases with increasing altitude. Further, the rocks that form the mountains, and their extensions that underlie the valleys of the basin, are largely though not entirely – impermeable. Therefore, those rocks are considered to form the boundaries of the developed and developable aquifers of the Raft River hydrologic system.

The Albion Range forms most of the western margin of the basin, is bounded by steep slopes on the eastern side, and rises about 5,000 feet above the adjacent Yost-Almo and Elba subbasins.

The Goose Creek Range sheds runoff to Junction Valley at the head of the Raft River drainage, and rises about 2,900 feet above the adjacent Junction Valley floor.

The Raft River Mountains lie along and just south of the Idaho-Utah boundary and rise about 4,800 feet above the floor of Raft River valley. This range trends eastward from the valley of South Junction Creek to southeast of Strevell where a low pass separates the range from the southern end of the Black Pine Range.

The Black Pine Range rises steeply from broad piedmont alluvial slopes, trends northward, and forms the southeastern margin of the Raft River valley. The range rises about 4,600 feet above the valley floor and is characterized by narrow ridges and deep, narrow valleys.

The Sublett Range also contains narrow ridges and steep, narrow valleys that trend northwest along the northeastern valley margin. This range is separated from the Black Pine Range by the valley of Meadow Creek and rises steeply above the floor of Raft River valley to an altitude of about 7,400 feet. The northern end slopes gently downward, reaching the level of the Snake River Plain about 4 miles south of the Snake River.

The Cotterell Range is a westward-tilted fault block lying mainly within the valley part of the Raft River basin. It separates the main Raft River valley from the Yost-Almo and Elba subbasins. This range is identified as the Malta Range in most earlier reports, but modern maps and most local references now use the name Cotterell Range. The range rises to an altitude of about 8,050 feet, with the central part of its southern segment rising about 3,400 feet above the Raft River valley. A broad pass separates the range from the Raft River Mountains on the south, and the northern end slopes downward to the Snake River Plain. Raft River crosses the extreme southern end of the Cotterell Range at The Narrows, and Cassia Creek divides the range near its midpoint. The western flank slopes gently westward toward the Albion Range, but the eastern flank is steep and rugged with massive slide and slump blocks marking the transition from the sharp crest to the alluvial slopes of the valley floor. In this report, the northwestern margin of the Raft River drainage basin is considered to lie at the crest of the northern segment of the range (fig. 1).

Principal Valleys and Subbasins

The Raft River valley is the largest of the several valleys in the Raft River basin. Its floor is an alluvial plain, 10 to 15 miles wide. The valley floor rises gently from the Raft River in the central part of the valley with steepening slopes near the mountains. The altitude of the valley floor is about 4,200 feet near the mouth of the Raft River, about 4,500 feet near Malta, 5,000 feet at The Narrows, and about 5,200 feet at places on the piedmont slopes.

The section of the valley from about 4 miles north of Idahome to the Snake River was referred to by Nace and others (1961, p. 11) as the Northern Plains section. This part of the valley is physiographically a part of the Snake River Plain, but is included in the Raft River valley because of its close hydrologic relation with the remainder of the Raft River basin. It has been only slightly modified by erosion since emplacement of the volcanic rocks, and volcanic cones locally rise several hundred feet above the general level of the valley. The entire valley, from near the Snake River southward to The Narrows and the vicinity of Strevell, is designated the Raft River valley subbasin. The entire subbasin is approximately 1,000 square miles in extent and includes several subareas with distinctive hydrologic characteristics.

The Elba subbasin lies between the Albion and Cotterell Ranges, and is about 100 square miles in extent. The valley-floor area of the subbasin, however, is much smaller, averaging about 3 miles in width and 12 miles in length. Talus slopes along the flanks of the surrounding mountains grade into the alluvial fill of the valley floor, which has a very steep slope except along the bottom lands in the lower reaches. The outlet of the subbasin is a steep-sided gorge cut transversely through the Cotterell Range by Cassia Creek.

The Yost-Almo subbasin opens westward from the southern end of the Raft River valley upstream of The Narrows to form what has been called the upper Raft River valley. This subbasin, an alluvial valley of irregular form which slopes from the north and south toward The Narrows, is bounded by the Albion Range on the west, the Raft River Mountains on the south, and the Cotterell Range on the east. Junction Valley is separated from the subbasin by a steep gorge at the Upper Narrows. It is a small, mountain-enclosed alluvial lowland lying mainly in Utah at the headwaters of the Raft River. The Yost-Almo subbasin contains approximately 410 square miles. The valley-floor part of the subbasin makes up more than half the total area.

Most of the lowlands within the Raft River basin are floored by alluvial fans that extend, with gradually decreasing slope, from the mountains and foothills toward the Raft River or its principal tributaries. Strips of fairly level bottom land occur along the Raft River, Cassia Creek, and the larger tributary streams. The tributaries have moderately trenched the alluvial fans to form small local relief, and a few hills such as Round Mountain stand above the generally smooth alluvial slopes.

CLIMATE

The climate of the Raft River basin ranges from humid to subhumid in the higher mountains, and to semiarid on the floor of the Raft River valley. Records of the various elements of the climate are sparse within the basin, however, and previous estimates of precipitation distribution throughout the basin (Nace and others, 1961) were necessarily based on extrapolations or correlation with records for stations outside the basin. Also, the isohyetal map developed for the 1961 report showing distribution of precipitation within the basin, and the one prepared by the U.S. Weather Bureau (1959) at small scale, are both based mainly on records for stations either outside the basin or at the lower elevations. Therefore, as a part of this study, eight additional precipitation-storage gages were installed and operated during the period 1965-67 to provide data for adjusting estimates of precipitation distribution. Using the adjusted data, a new isohyetal map was prepared on which to base estimates of water yield from the various drainages and subbasins of the study area.

Records of other elements of climate, such as temperature, humidity, wind direction and velocity, evaporation, and solar radiation are virtually lacking within the study area. Of them, only temperature is recorded within the basin, and that at Strevell.

Precipitation

Precipitation on the Raft River basin is derived mainly from winter storms moving eastward across the basin and to lesser degree from summer thunderstorms that generally move north or northeastward from Utah and Nevada. Most of the precipitation in the higher mountains falls as snow. Winter precipitation at a given altitude tends to decrease from northwest to southeast. Summer precipitation tends to increase toward the southeast. On the higher mountains, only about 10 percent of the annual precipitation falls during the growing season, but as much as 45 percent falls during the growing season in the valleys at the base of the mountains. Table 1 gives average monthly and annual precipitation for 12 long-term stations in and adjacent to the basin, and table 2 gives data for the eight short-term gages operated during this study.

The distribution of precipitation over the basin, adjusted for exposure, local terrain, and rain-shadow effects is given by isohyetal lines in figure 2. The adjustments were made by the following procedure: (1) The altitude of each gage site was adjusted to an effective altitude to account for local terrain effects by averaging the altitude at the gage site with the altitude at eight points of the compass 1.5 miles from the gage site; (2) the effective altitudes were then plotted against the precipitation at each site adjusted to the 1931-60 normal, and average altitude-precipitation curves were drawn (fig. 3); (3) curves were drawn parallel to the average and through geographically similar groups of stations to determine change of precipitation at equal altitude, generally from north to south; (4) lines of equal precipitation (isohyetal lines) were drawn; and finally (5) the isohyetal lines were adjusted either up or down slope in accordance with the curves of figure 3 in localities having obvious rain-shadow effects or direct exposure to prevailing winter storms. The western and northern flanks of the Albion and Sublett Ranges have such direct exposure; consequently, isohyetal lines in these areas were adjusted downslope slightly. Similarly, minor rain-shadow effects were considered probable on the eastern side of the higher mountains and the isohyetal lines were adjusted upslope slightly. The decrease in precipitation from north to south in the basin is probably the result of rain-shadow effects caused by high mountain ranges west of the southern part of the basin.

The adjusted precipitation distribution shown in figure 2 differs considerably from the U.S. Weather Bureau isohyetal map for the area, and at specific locations it differs markedly from precipitation values given by Nace and others (1961). The differences are largely the result of the more detailed data now available and, to some degree, to differences in subjective judgment applied to adjustments. In general, the quantities of precipitation shown are considered to be conservative. However, it should be noted that data from this study show an average annual precipitation at Sublett more than 5 inches greater than was estimated by Nace and others (1961). Also, a correlation of monthly data for the short record at the old Almo station gives an adjusted annual precipitation at 12.9 inches for the base period 1931-60 as compared to the adjusted 15.6 inches obtained by Nace and others (1961).

As shown in figure 2, the average annual precipitation ranges from less than 10 inches on the central part of the valley floor to more than 30 inches near the summits of the Albion Range and Raft River Mountains. Average annual precipitation over the entire basin is 15.0 inches or 1,280,000 acre-feet of water, practically identical with the estimate of 1,290,000 acre-feet by Nace and others (1961, p. 32).

Table 1. Average monthly and annual precipitation in Raft River basin and adjacent areas. (Based on published records of U.S. Weather Bureau)

Station	Period of record (years)	Altitude (feet above msl)	Average monthly precipitation (inches)												Average annual precipi- tation (inches)	Normal precipi- tation 1931-60 (inches)
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		
Idaho																
Albion	24	4,650	1.47	1.31	1.10	1.47	1.62	1.03	0.56	0.43	0.82	1.23	1.48	1.40	13.92	a14.00
Almo	6	5,530	1.58	1.43	.37	.92	1.95	2.88	1.63	1.01	1.25	2.09	1.42	.80	17.33	a12.93
American Falls	64	4,318	1.29	1.00	1.20	1.18	1.46	.99	.55	.52	.65	1.09	1.08	.99	12.00	10.12
Burley	44	4,180	1.04	.87	.78	.99	.92	.76	.30	.42	.47	.76	.86	.92	9.09	8.61
Malta	12	4,540	.75	.66	.59	.66	1.45	1.15	.45	.87	.55	.54	.58	1.43	9.68	a9.15
Oakley	68	4,600	.80	.73	.85	1.13	1.35	1.07	.63	.62	.71	.89	.78	.69	10.25	10.08
Minidoka Dam	20	4,280	.97	.61	.61	.84	1.15	.75	.33	.41	.48	.59	.83	.91	8.48	a8.88
Rupert	55	4,204	1.08	.90	.82	.89	.98	.82	.35	.36	.56	.87	.94	.95	9.52	8.27
Standrod	22	5,750	1.01	.84	1.15	1.44	1.63	1.40	1.43	1.04	1.15	1.32	.94	.66	14.01	a11.00
Strevell	26	5,280	.62	.62	.78	1.20	1.62	1.40	.71	.97	.75	.88	.77	.71	11.03	10.13
Utah																
Park Valley	50	5,540	.95	.85	.75	.94	1.11	.85	.91	.82	.63	.62	.82	.99	10.24	10.35
Snowville	53	4,530	1.18	.88	1.23	1.24	1.60	.88	.48	.55	.71	.99	.93	1.07	11.74	a11.02

[a] Short term or incomplete records were adjusted to estimate precipitation for the normal period.

Table 2. Precipitation records from storage gages in Raft River basin. (Records collected by U.S. Geological Survey, except as noted)

Station	Location	Period of record	Altitude (feet above msl)	Mean altitude of area (feet)	Total precipitation for period of record (inches)	Approximate annual precipitation for period (inches)	Calculated normal precipitation (1931-60) (inches)
Idaho							
Almo 2 SE	Sec.35, T.15 S., R.24 E.	9- 4-65 to 8-24-67	5,200	5,200	17.75	8.9	9
Black Pine Canyon	Sec.29, T.15 S., R.29 E.	8- 2-65 to 7-25-67	7,100	7,100	43.15	21.6	22
Boy Scout Camp	Sec. 8, T.14 S., R.24 E.	8- 2-65 to 7-27-67	7,600	7,450	60.19	30.2	29
Gunnell Guard Station[a]	Sec.16, T.15 S., R.28 E.	11-18-58 to 4-20-60 2-21-61 to 7-14-67	5,880	5,980	120.10	14.2	13.6
Howell Canyon	Sec. 2, T.13 S., R.24 E.	8- 2-65 to 7-27-67	8,200	7,970	56.12	28.2	28
Sublett Guard Station[a]	Sec. 9, T.12 S., R.30 E.	11-18-58 to 4-20-60 8- 3-60 to 7-14-67	5,800	6,070	171.24	21.1	20.3
Utah							
Onemile Summit	Sec.14, T.14 N., R.14 W.	8- 2-65 to 3-29-66 9-27-66 to 8-24-67	7,300	7,520	40.08	23.0	23
Vipont	Sec. 7, T.14 N., R.17 W.	7-31-66 to 6-21-67	7,700	7,360	41.52	21.3	21

a Record collected and published by U.S. Weather Bureau.

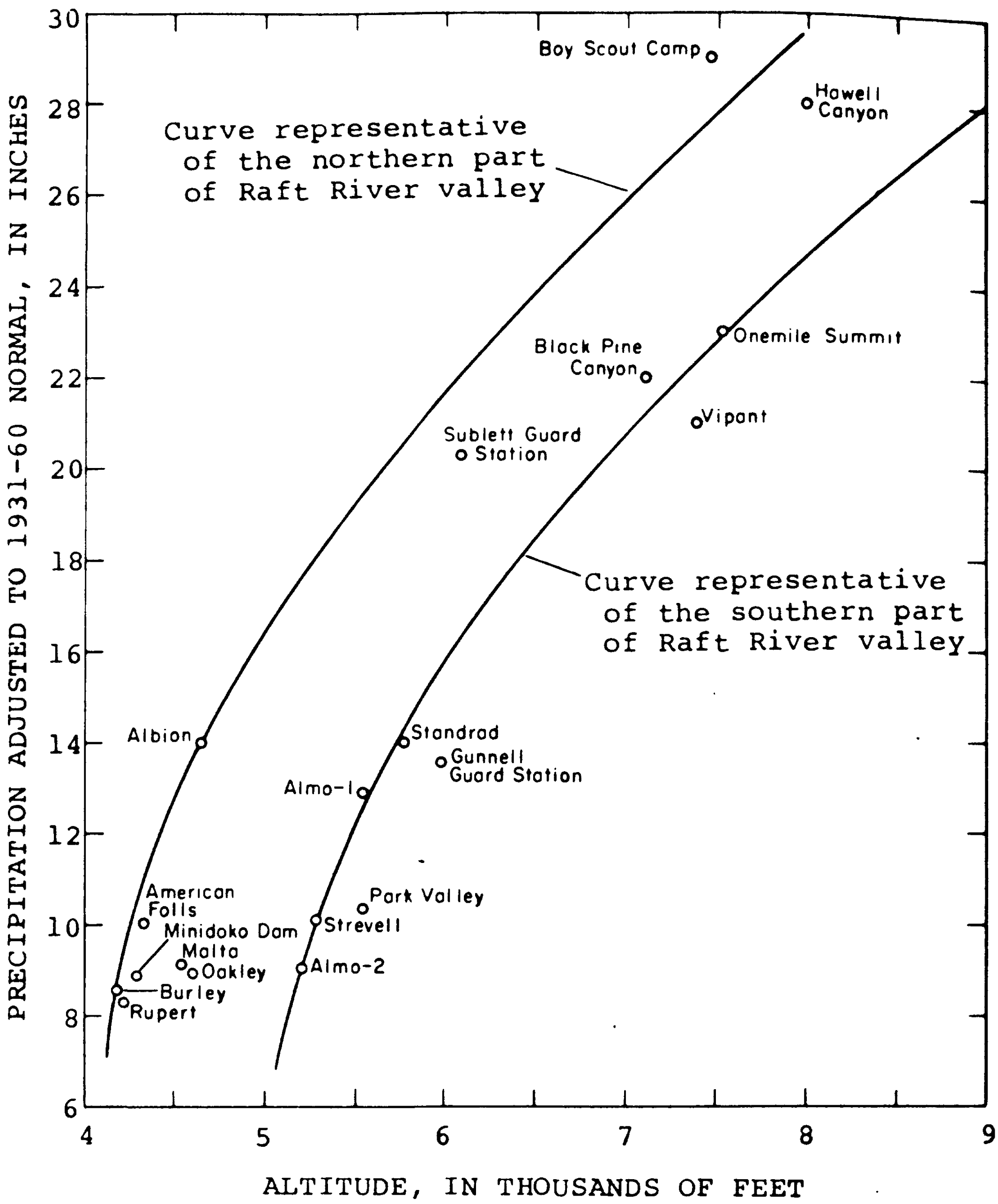


FIGURE 3.– Approximate relation between altitude and precipitation.

The average distribution of the precipitation during the year is shown by curves in figure 4.

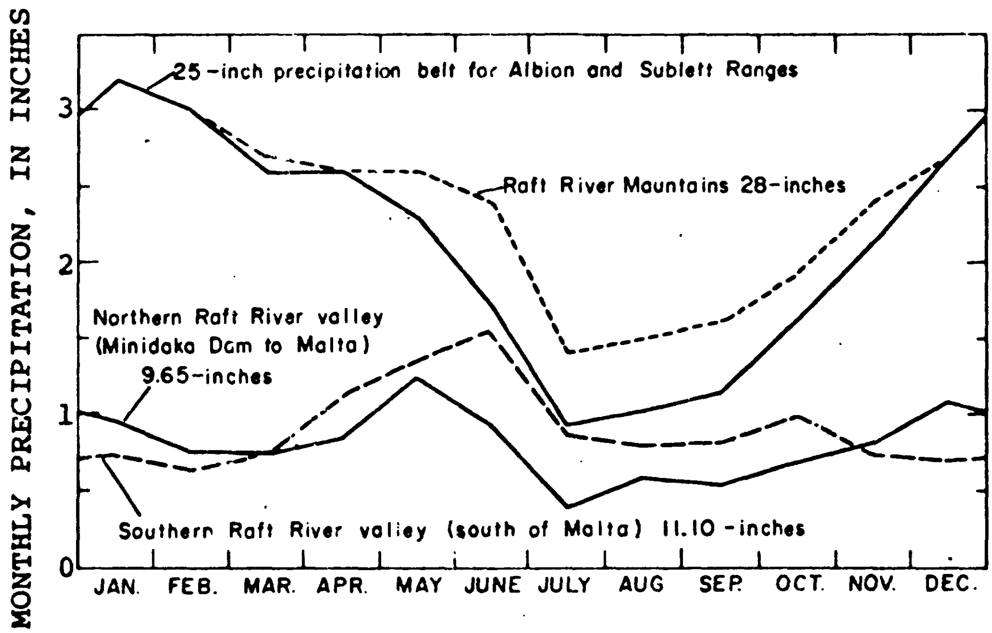


FIGURE 4.– Generalized seasonal precipitation distribution for different parts of the Raft River basin.

Temperature and Evaporation

Strevell is the only location in the Raft River basin where long-term temperature records have been collected. That record and records at Oakley in the Goose Creek basin to the west, at Albion in the Marsh Creek basin, and at Burley and Rupert on the Snake River Plain, all at the northwestern margin of the Raft River basin, were used to develop estimates of average temperatures within the basin. The altitudes of these weather stations range from 4,180 feet at Burley to 5,280 feet at Strevell.

The mean annual temperature for the 1931-60 normal period ranged from 45.4° F (7.4° C) at Strevell to 49.6° F (9.8° C) at Burley. Recorded minimum temperatures have ranged from about −35° F (−37° C) at Burley to about −17° F (−27° C) at Strevell, and recorded maximum temperatures have ranged from about 100° F (38° C) at Albion to about 106° F (42° C) at Oakley. The average frost-free period in the Raft River valley is about 100 days. A summary of the mean temperatures by months and years, all based on the 30-year normal period 1931–60, is given in table 3. Also shown in table 3 is the average of the mean monthly temperature and the altitude of the five stations.

Table 3. Mean monthly and annual temperature in Raft River basin and adjacent areas for period 1931-60. (From records published by U.S. Weather Bureau)

Station	Period of record (years)	Altitude (feet above msl)	Mean monthly temperature (° F)												Mean annual temperature (°F)
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Albion[a]	23	4,750	28.1	30.5	37.9	45.2	52.4	58.8	66.6	66.7	56.5	47.3	37.0	29.8	46.4
Burley	48	4,180	26.6	31.5	39.1	48.6	56.9	64.2	73.8	71.4	62.1	51.3	38.0	31.3	49.6
Oakley	64	4,600	27.5	31.9	38.4	47.2	55.0	62.0	71.3	69.2	60.7	51.0	38.4	31.7	48.7
Rupert	54	4,204	24.4	29.2	37.0	47.3	55.7	62.8	72.5	69.6	60.2	49.8	36.7	29.4	47.9
Strevell[a]	21	5,280	22.2	25.8	34.0	44.1	52.0	62.6	70.0	67.7	60.1	47.3	33.7	25.6	45.4
Average			25.8	29.8	37.3	46.5	54.4	62.1	70.8	68.9	59.9	49.3	36.8	29.6	47.6

a Adjusted to 30-year normal period, 1931-60.

Evaporation from a U.S. Weather Bureau class A land pan at Minidoka Dam (Lake Walcott) near the northern end of the Raft River valley averaged about 63.6 inches during the April through October period for the years 1949-61 (table 4). Application of an

Table 4. Evaporation from class A land pan at Minidoka Dam. (Inches of water. Based on records of the U.S. Weather Bureau)

Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
1949	-	8.61	12.17	13.56	11.69	9.14	3.68	2.94	61.79
1950	-	9.67	9.73	13.51	11.21	7.64	5.15	-	56.91
1951	7.71	9.21	11.25	13.77	10.24	9.24	4.20	-	65.62
1952	-	8.91	10.30	12.40	12.52	8.68	5.97	-	58.78
1953	-	6.80	9.16	13.84	12.29	9.20	4.77	-	56.06
1954	-	9.73	9.65	12.80	12.20	9.00	4.76	2.37	60.51
1955	-	7.80	10.27	11.37	11.39	8.21	5.42	-	54.46
1956	-	7.27	11.26	12.69	10.88	8.27	4.25	-	54.62
1957	-	6.31	10.20	12.22	11.78	8.75	4.19	-	53.45
1958	-	9.33	10.16	12.27	11.55	8.09	5.77	-	57.17
1959	6.93	7.15	11.64	13.49	10.89	6.70	4.69	-	61.49
1960	6.66	7.91	12.26	13.51	11.59	8.31	4.49	-	64.73
1961	6.85	9.37	12.65	13.74	10.96	6.69	3.75	-	64.01
1962	6.96	6.29	-	-	-	-	-	-	-
Average	7.02	8.17	10.82	13.01	11.47	8.38	4.70	2.66	[a]63.57

[a] Total of April through October averages.

equation given by Kohler, Nordenson, and Baker (1959) to compute natural open-water evaporation from meteorological data at Lake Walcott suggests a probable average annual evaporation at the lake of about 48.6 inches. A U.S. Weather Bureau map presented in their report shows an average annual evaporation in the vicinity of Lake Walcott of about 38 inches, but this very generalized map value was based on data from an old record at Milner Dam where recorded wind velocities differed greatly from those at Minidoka Dam.

A procedure given by Rohwer (1931) also allows computation of evaporation from a free water surface. That procedure provides a value of 47.8 inches for annual evaporation at Lake Walcott from the reservoir surface.

IRRIGATED AREA AND REMAINING UNIRRIGATED LAND

In 1966 the area of irrigated land in the Idaho part of the Raft River basin was about 130 square miles or 83,000 acres (fig. 5). This included some narrow strips of bottom land that are occupied by willows and tall grass and are too narrow or irregular in shape to be economically cultivated. In addition, about 6.5 square miles or 4,200 acres were irrigated in the Utah part of the basin downstream from the Upper Narrows and in the valleys draining the north side of the Raft River Mountains near Naf, Standrod, and Yost. The sum, about 87,000 acres, represents the maximum acreage irrigated in those years when a full surface-water supply is available. Much acreage in the southern parts of the basin, near Almo, Yost, Standrod, and Naf, is supplied by surface water only, and receives inadequate water in years of average runoff. These areas receive little or no water in dry years. Also, not all acreage supplied by ground water is irrigated every year. For these reasons, the average area irrigated annually in recent years is less than the maximum, and is estimated to have been about 84,000 acres.

Irrigation with surface water in the Raft River basin has reached the practical limit of development without surface storage. Although the remaining surface flow is small, there has been a strong demand for additional water in recent years, and the water supply available for irrigation is a critical factor in the economic future of the area.

Nace and others (1961, t. 19, p. 81) estimated there were about 386,000 acres of undeveloped land in the lowland area of Raft River valley in 1956. At that time, about 43,000 acres were estimated to be under irrigation. Irrigated acreage increased to about 84,000 acres by 1966. Thus, the remaining undeveloped lowland area of Raft River valley, much of which probably could be irrigated if water were available, includes about 345,000 acres.

THE GEOLOGIC FRAMEWORK

GENERAL DISTRIBUTION AND STRATIGRAPHY OF THE ROCKS

The geologic framework of the Raft River basin is made up of complexly folded, faulted, and eroded mountain masses of crystalline, metamorphic, volcanic, and consolidated sedimentary rocks ranging in age from Precambrian to middle Tertiary; with structurally depressed valley areas containing large thicknesses of volcanic rocks, lake sediments, alluvial and fluvioglacial deposits, and windblown silt (loess). The valley-filling rocks and deposits accumulated from early or middle Tertiary time to the present.

Anderson (1931) prepared one of the earliest and most detailed descriptions of the rocks and deposits of the Raft River basin with primary emphasis on the consolidated rocks of the mountains. He described the occurrence of the principal geologic formations of the mountain areas as well as the highly complex geologic structures that control the present-day topography and drainage. He also described the simpler structures that control the distribution of the younger deposits that are of importance to the water resources of the area. Lack of adequate base maps, however, hampered precise mapping of geologic contacts and structural features by earlier workers, and they gave little attention to description of the unconsolidated valley-filling deposits. More recently, Nace and others (1961), Armstrong (1966), Compton (1966), and Damon (1966) have described parts of the area in greater detail.

As a part of the study for this report, the geologic contact between the post-Cretaceous and the Cretaceous and older rocks, as well as the contacts between the several post-Cretaceous formations, were remapped with the aid of aerial photographs and some additional field studies. This remapping (fig. 1) differs considerably in some parts of the valley from that shown by Anderson, and also from that shown by Nace and others which was compiled from several sources.

Nace and others (1961, p. 18-28) discussed the general geology of the Raft River basin, including a description of the rock units of importance to the water resources, the geologic structure, and the physiographic development of the basin. In general, the present study confirms the earlier interpretations and adds further detail to discussion of the character and distribution of the units that are important to occurrence and distribution of the water resources of the basin. The principal differences are in the subdivision of the Salt Lake Formation, the modern designation of a Raft Formation including the Raft lakebeds as a facies, and a reinterpretation of the thickness and distribution of the Quaternary alluvium.

The rock units shown in figure 1 are the ones related most directly to water supply in the Raft River basin. Rocks older than and including the granitoid Cassia batholith of Late Cretaceous or early Tertiary age are grouped as a single unit because in the basin as a whole they affect the hydrology approximately uniformly.

The diagram of figure 6 shows the stratigraphic relations and description of the lithologic units, based largely on the work by Anderson (1931), but the indicated thicknesses of the rocks of late Tertiary and Quaternary age are estimates by the authors.

Rocks of Pre-Tertiary Age

The rocks of pre-Tertiary age are extremely diverse; they include metamorphic materials such as quartzite, marble, and schist, and a wide variety of consolidated sedimentary rocks such as limestone, sandstone, shale, and chert. Identification and differentiation of these is essential only in order to recognize geologic structures and relations and to decipher the geologic history. Most of the pre-Tertiary rocks are relatively impermeable and ground water occurs in them chiefly in open joints. Where solution cavities exist in limestone, however, wells that intercept these cavities yield large quantities of water.

Because of their relation to the structural history of the area and their resistance to erosion, the pre-Tertiary rocks form the mountains and highlands of the area. They receive

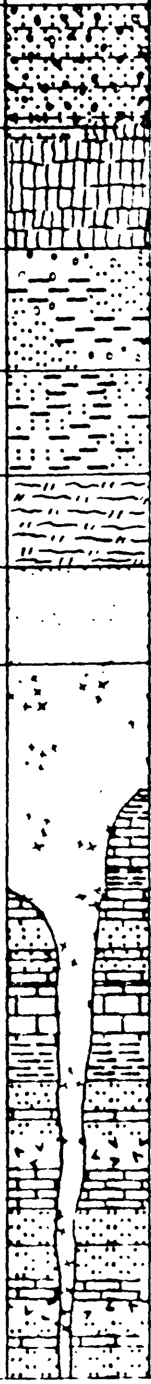
Era	MAP SYMBOL		FORMATION OR DEPOSIT	MAXIMUM THICKNESS, IN FEET	PART OF FORMATION OR DEPOSIT SERVING AS AQUIFER
Cenozoic	Qal		Alluvium, fan deposits, landslides, and glacial outwash	250	Surficial sheets of alluvium and fan materials
Cenozoic	Qb		Basalt of the Snake River Group	>400	Joints and cracks, and interflow brecciated zones
Cenozoic	Qr		Raft Formation	1,000	Sand and gravel in alluvium and lake beds
Cenozoic	Tslu		Salt Lake Formation (upper unit)	500	Silty sand and tuff
Cenozoic	Tslv		Salt Lake Formation (middle unit)	500	Fractures
Cenozoic	Tsll		Salt Lake Formation (lower unit)	1,700	Sand, tuff, and sandstone
Paleozoic and Mesozoic	pTc		Granitoid rocks of the Cassia batholith of Cretaceous(?) age		Fractures
Paleozoic and Mesozoic	pTc		Phosphoria Formation of Permian age	700	Not determined
Paleozoic and Mesozoic	pTc		Wells Formation of Pennsylvanian age	2,900	Not determined
Paleozoic and Mesozoic	pTc		Limestone of Mississippian age	>1,400	Not determined
Paleozoic and Mesozoic	pTc		Undifferentiated sedimentary and metamorphic rocks of Cambrian age	10,000	Fractures
	pTc		Undifferentiated rocks of Precambrian age	10,000	Fractures

FIGURE 6.-- Correlation of chronologic, stratigraphic, and hydrologic units in Raft River basin.

the major part of the precipitation and deliver it to the valleys and lowlands as runoff or by the way of the fractures and solution cavities directly to the aquifer units of the valley fill.

Salt Lake Formation

The Salt Lake Formation consists of sedimentary and volcanic rocks having an aggregate exposed thickness of at least 2,500 feet. The general relations (fig. 7) suggest that the formation is composed of three units having maximum thicknesses of about 1,700 feet for a lower sedimentary unit, 500 feet for a central zone of welded tuffs, and as much as 500 feet for an upper sedimentary unit. Earlier workers, particularly Nace and others (1961), considered the Salt Lake Formation to consist of two units, the upper capped by massive dark volcanic flow rocks that are exposed primarily in the Cotterell Range. The age of these rocks was not identified by earlier authors, except that they were considered to occur between the Salt Lake Formation and the next-younger Raft lakebeds.

In this report, the Salt Lake Formation is considered to be composed of three major units, with the massive volcanic rocks of the Cotterell Range occupying the central unit, the same relative position as the welded tuffs reported by Mapel and Hail (1959) west of Raft River valley in the Goose Creek basin. Present usage restricts the name Salt Lake Formation to deposits of Pliocene age.

Most of the wells that produce water from the Salt Lake Formation penetrate only beds of sandstone, thin conglomerate, and occasional layers of clayey silt. A few wells penetrate volcanic flow rocks that are interbedded with the sediments.

Data from 18 wells that derive water from the upper unit of the Salt Lake Formation only show yields that range from 270 to 3,240 gpm, and average about 1,500 gpm. The median yield of these 18 wells is about 1,600 gpm.

The Salt Lake Formation yields important quantities of water to many wells in addition to the 18 cited above. Many wells are drilled through the Raft Formation and into the underlying Salt Lake Formation, and are constructed so as to obtain water from both formations.

Raft Formation

The Raft Formation consists of lake and stream deposits that accumulated on the eroded surface of the Salt Lake Formation, as drainage to the north was progressively blocked by basalt of the Snake River Plain. The deposits were first named the Raft Lake Beds (Stearns and others, 1938, p. 48) and were considered to be probably late Pliocene in age. Work by Trimble and Carr (1961), however, has yielded fossil evidence to show that the deposits are of middle or late Pleistocene age. Also, the deposits were renamed the Raft Formation in recognition of associated, widely distributed material that is alluvial and possibly fluvioglacial as well as lacustrine.

The Raft Formation is well exposed only in the northeastern part of the valley, yet it probably underlies most of the valley to the south, beneath a cover of younger alluvial materials.

Well drilling has disclosed sediments of probable lacustrine origin at many places beneath the floor of the valley, and these are presumed to be in the Raft Formation. In general, subsurface lakebeds at shallow depth beneath the north-central part of the valley floor probably are Raft Formation or younger, whereas those at greater depth and along the east and south flanks of the valley are indeterminate as to whether they are Raft Formation or a part of the Salt Lake Formation.

The percentage of coarse-grained material in the Raft Formation in the main valley increases markedly toward the south. Gravel is much more common toward the south than it is at the north, and the sand is coarser grained. Beds of clay are mostly thin but are abundant. Individual beds thicken or thin within short distances and can only rarely be correlated between wells a short distance apart.

The lacustrine deposits of the Raft Formation aggregate probably little more than 200 feet in thickness, and are poor aquifers. Many wells drilled recently in parts of the valley show, however, that the Raft Formation is thicker, and that generally the materials are coarser nearly everywhere in the valley than was previously thought. Some coarser beds previously assigned to the Salt Lake Formation are now interpreted as part of the Raft Formation, although identification of both formations in drillers' logs of wells is uncertain at best. The proportion of glass shards and other volcanic debris is generally greater in the Salt Lake Formation. In general, and contrary to earlier reports, the Raft Formation as a whole is a good aquifer from which the majority of the irrigation wells in the valley obtain their supply.

Basalt of the Snake River Group

In Tps. 10 and 11 S., Rs. 26 and 27 E. (fig. 1), basaltic lavas of the Snake River Group crop out at land surface. There, and for some distance southward in the subsurface, the basalt interfingers with stringers of the Raft Formation, suggesting that a thickening section of basalt progressively dammed the outlet of the ancestral Raft River, leading to formation of lacustrine conditions in the northern part of the valley, and deposition of thick sections of Raft Formation alluvial deposits southward in the valley.

The basalt flows, in exposure and as reported in logs of wells, have characteristics similar to those of basalt underlying the main Snake River Plain. Individual flow units tend to be massive and effectively impermeable. However, rubbly zones between flows have high permeability and transmissivity and may be major aquifers. Each basaltic aquifer zone tends to be virtually separate from that above and below because of the impermeable character of the massive, intervening lava. Locally, columnar jointing commonly found in basalt may provide weak inter-aquifer connections. In the Raft River area, however, columnar jointing is not exposed, and can only be inferred to occur in the subsurface.

Alluvium, Fan Deposits, Landslides and Glacial Deposits

Deposits of mud, silt, sand, and gravel are widespread on valley floors and scattered on the mountain slopes. Much of the material has been transported for long distances by running water and is moderately to well sorted and distinctly stratified. Where the alluvium has not been moved far, as in alluvial fans along the bases and lower slopes of mountains, it is less well sorted and is poorly stratified. Very poorly sorted material along the mountain slopes commonly lacks stratification and is called "hill wash" herein.

Morainal and outwash deposits described by Anderson (1931) are grouped on the map with the alluvium and "hill wash" materials.

Windblown deposits are not distinguished on the geologic map but are widespread; they overlie much of the basalt of the Snake River Group and other formations in the vicinity of Sublett, Heglar, and the northwestern part of the valley. The deposits reach a thickness of at least 100 feet in depressions on the basalt of the Snake River Group, on leeward slopes of hills and in sheltered basins. Most of the material is silt size; it is buff to brown, highly porous, unstratified, and has crude columnar structure. The age probably is late Pleistocene and Holocene.

The windblown material is not an aquifer because it is above the zone of saturation. It forms rich soil and has a high moisture-holding capacity.

STRUCTURE

The principal geologic structural features (fig. 1) in the Raft River basin control the hydrology of the area. Considerably more structural detail was mapped by Anderson (1931) than is shown in figure 1; only the structures that are known to influence ground- or surface-water occurrence or flow in the basin are discussed herein.

The geologic structures most clearly related to hydrology of the basin are high-angle normal faults of large displacement. Those faults, trending generally north, bound the fault-block mountains on either side of the valley and delimit the eastern and western margins of the Cotterell Range. The present study did not materially modify Anderson's (1931) interpretations, nor did this study include detailed mapping within the mountain blocks.

However, on the basis of distribution of some formational units in exposure, nearly linear occurrence of springs and wells that discharge thermal water, and alinement of volcanic vents and topographic features, the positions of major faults (fig. 1) have been shifted from positions shown on earlier maps. Because fault traces are concealed beneath younger rocks throughout much of the area, delineation of faults on maps must be highly interpretive. The faults that bound the Cotterell Range and their extensions from the flanks of the Raft River Mountains to the Snake River Plain are particularly important in interpretation of the hydrology of the basin. More detailed study of the subsurface may disclose other large faults, also of hydrologic significance.

The floor of the main Raft River valley overlies a westward-tilted block of consolidated rocks whose depressed western part is blanketed by westward-thickening wedges of the Salt Lake and Raft Formations. Along the major fault that terminates the western edge of this block, another block is greatly uplifted and tilted westward. That block forms the Cotterell Range, whose eastern face is scarred by great slide and slump masses that have collapsed off the steep face of the uplifted block. Because of this the actual fault trace is obscured and its exact position is unknown. The fault is interpreted herein as a broad zone of fractures perhaps as much as 2 miles wide along which eruptive basalt has issued at the northern end of the basin, and hot, saline waters occur southwest of Bridge. This fault is shown in figure 1 at the location given by Anderson. The detail of its southern terminus is unknown, but it has not been identified as extending into the Raft River Mountains. Nace and others (1961) suggested that it may be terminated by a cross-fault through The Narrows and this may be the case, but the position or orientation of such a cross-fault cannot be documented with existing data. The authors believe that a zone of older faulting probably does trend west in the vicinity of The Narrows, that this zone so weakened the basement rocks that a broad erosional trough developed between the Raft River Mountains and the end of the Cotterell Range, and that the fault along the east side of the Cotterell Range probably terminates at the zone. The trough has subsequently filled with Salt Lake Formation, Raft Formation, and alluvium.

The tilted block of the Cotterell Range dips westward into much older rocks of the Albion Range which rise many thousands of feet above the block. Anderson placed the fault separating these rock masses very close to the exposed western edge of the welded tuff of the Cotterell Range, and extended it southward nearly to Yost through the small hill southeast of Reed Spring. Further data collected during this study indicate that although there is a fault on the east flank of the hill near Reed Spring as Anderson noted, the main fault is located farther west nearer the margin of the Albion Range outcrops as shown in figure 1. Hot water in wells near Almo, and an outcrop of the upper unit of the Salt Lake Formation at the northwest corner of T. 15 S., R. 25 E., support this conclusion.

Nace and others (1961) also postulated transverse faulting across the Cotterell Range at Cassia Creek, but there remains no direct evidence for such faulting.

In summary, the general structure of the Raft River basin that affects the hydrology is quite simple, despite its complexity in detail in the older rocks. The basin consists of a block of the earth's surface that has been tilted toward the west and is broken along two or more major normal faults whose direction of displacement is upward on the west. The surrounding mountains form the basin boundaries, and the depressed area has, over the course of geologic time, accumulated thick deposits of permeable materials that now contain ground water.

THE AQUIFER SYSTEM

Lateral Boundaries

The extent of each ground-water subbasin corresponds, in general, to one of the three surface-water subbasins, but there are important differences. The ground-water subbasin boundaries, in restricted sense, lie at the limit of the permeable water-bearing terrain within the boundary of the surface-water drainage basin. The term "ground-water subbasin" is used in the restricted sense in the following discussion.

Any ground water contained in the older rocks surrounding the ground-water subbasins discharges as subsurface or surface flow across the ground-water subbasin boundary. On the other hand, pumping of wells penetrating the older rocks outside the ground-water subbasin boundaries but within the Raft River drainage basin would eventually cause reduced inflow across the boundaries and change the flow regimen. In that sense, the entire area within the Raft River basin drainage divide is within one ground-water basin.

The external boundaries of the three ground-water subbasins are, except locally, at the contact between the saturated younger formations and either the middle or lower unit of the Salt Lake Formation or the consolidated rocks of pre-Tertiary age. At the northern end of the Raft River valley, the ground-water basin boundary corresponds to the surface-water divide.

The lower and middle units of the Salt Lake Formation are probably poorly permeable; wells that penetrate these two units have yields which are very low to moderate and are generally too small for economic use in irrigation. Therefore, where only these two units contain ground water beneath a very thin layer of saturated alluvium, the position of the ground-water subbasin boundary is at the base of the saturated younger rocks.

Of the older consolidated rocks in the area surrounding the ground-water subbasins, only the limestone and dolomite may yield sufficient water to wells for use in irrigation.

Where solution by ground water has enlarged cracks and crevices, limestone and dolomite outside the ground-water subbasins can absorb much water, as shown by the lack of streams in the Sublett and Black Pine Ranges where limestone is abundant.

At some localities, limestone underlies the Salt Lake and the Raft Formations, and a few wells in the northeastern part of the Raft River valley probably yield water from limestone. When tested, well 9S-28E-33bb1 produced 1,170 gpm (gallons per minute) from limestone with a drawdown of 100 feet. Well 10S-28E-15ad1 yielded 1,800 gpm, part of which at least came from limestone. The drawdown was 54 feet.

Although limestone aquifers may provide good yields, the storage capacity is normally low compared to that of sand, or sand and gravel aquifers.

Raft River Valley Subbasin

The Raft River valley ground-water subbasin (fig. 1) is, in general, separated from the Yost-Almo and Elba ground-water subbasins on the west by the Cotterell Range. It is bordered on the north by the Snake River Plain, and on the west by the eastern fault bounding the Cotterell Range. At The Narrows and where the Cotterell Range is crossed by Cassia Creek, the boundary between the ground-water and surface-water subbasins is at the narrowest part of the canyon through which the streams flow.

On the south the Raft River valley ground-water subbasin is bordered by an east-west line along which alluvium, Raft Formation, or the upper unit of the Salt Lake Formation abut the northern extent of the middle or lower unit of the Salt Lake Formation. South of that line only the middle or lower unit of the Salt Lake Formation, or older rocks, contain ground water beneath a thin covering of saturated alluvium.

On the east, also, the Raft River valley ground-water subbasin is bordered by the subsurface western extent of the middle unit of the Salt Lake Formation, where only that unit or older rocks contain ground-water beneath a thin covering of saturated alluvium. Locally along the eastern margin of the subbasin the middle or lower unit of the Salt Lake Formation is overlain by a moderate thickness of saturated alluvium or water-bearing materials in the Raft Formation. In these places the basin margin is at the contact of the ground-water table with the consolidated rocks of the pre-Tertiary age or the lower member of the Salt Lake Formation.

Yost-Almo Subbasin

The Yost-Almo ground-water subbasin is bordered on the north by the surface-water divide between Elba and Yost-Almo subbasins; on the west by the normal faults along the base of the Albion Range; on the south by the contact with pre-Tertiary rocks or the middle and lower units of the Salt Lake Formation; and on the east by the western extent of the middle and upper units of the Salt Lake Formation. At the southern end of the Cotterell Range, the Yost-Almo and Raft River valley subbasins have a common boundary.

Elba Subbasin

The Elba ground-water subbasin is bordered on the north and west by the consolidated rocks of the Albion Range, on the south by the Yost-Almo ground-water subbasin, and on the east by the western extent of the lower and middle units of the Salt Lake Formation. Within the alluvium-filled gap where Cassia Creek crosses the Cotterell Range, the subbasin boundary is common with the boundary of the Raft River valley subbasin.

Thickness and Extent of the Water–Bearing Rocks

The upper unit of the Salt Lake Formation and the combined alluvium and Raft Formation, with the interbedded basalt, constitute the main water-bearing units in the Raft River basin. The exact thickness of these units cannot be determined from existing data and well logs, but the thickness can be approximated in most areas. Few wells penetrate the full thickness of the units, and well distribution is insufficient to provide areal coverage. Also, the lithology of the units is so similar that, except for the basalt, drillers are not able to recognize the depth at which each is encountered.

Certain features allow, however, general interpretations of the regional distribution and thickness of the units. The upper unit of the Salt Lake Formation contains white sand that is distinctive when drilled. Also, this unit contains a much greater proportion of glassy volcanic material than occurs in the younger deposits. This unit was deposited before the regional mountain and valley system was well developed, and the sediments were derived from different rocks than were those of the younger deposits.

The Raft Formation and the alluvium are virtually indistinguishable in the subsurface because the alluvium is only the continuation in time of the basin-filling alluviation that began at the beginning of Raft Formation time. It is obvious that there is modern alluvium along the stream channels, on the flood plains, and forming alluvial fans and aprons along the mountain fronts, and that this is younger than the age assigned to the Raft Formation. However, there is no distinguishable break in lithology, stratigraphy, or mode of deposition. For purposes of this report, the combined alluvium, Raft Formation, and interbedded basalt are differentiated areally only on the basis of apparent differences in permeability. The thickness of the total unit is estimated, and the thickness and distribution of the most permeable part of the unit is identified.

Figure 8 shows maps of the estimated thickness and distribution of the units based on the above concepts, and on regional structural conditions and the history of deposition of the units. Only the area of the Raft River valley ground-water subbasin is shown because there are even fewer data for the other subbasins. The Elba subbasin apparently contains moderately thick alluvium. The outflow channel of Cassia Creek across the Cotterell Range is believed to be floored only with alluvium.

The Yost-Almo subbasin probably contains major thicknesses of all the water-bearing units except basalt. In the northern part of the subbasin, north of Reed Spring and east of Almo, the water-bearing deposits are mainly alluvium. Between Reed Spring and The Narrows, however, all the units are believed present and the aggregate thickness may be several hundred feet, as indicated by a few wells.

There are no deep wells in the vicinity of The Narrows and the extent of water-bearing units there is unknown. However, the topographic gap through which the Raft River flows is very narrow, and it is not reasonable to assume that the alluvial fill in the gap is sufficiently thick or permeable to transmit the total estimated underflow from the Yost-Almo ground-water subbasin. A cross-sectional area at least 1 mile wide and several hundred feet thick would be required to transmit the estimated underflow under the indicated existing gradient through materials of reasonable permeability. Such a large cross section does not exist in the area of The Narrows unless one considers the following:

1. The southern end of the Cotterell Range is either terminated by a large normal fault that displaces the middle unit of the Salt Lake Formation downward on the south, or it is terminated by a deep erosional trough.

2. The northern extent of the lower unit of the Salt Lake Formation south of The Narrows (fig. 1) is either terminated by a large normal fault that displaces the unit downward on the north, or it is deeply eroded.

3. The large exposed mass of the middle unit of Salt Lake Formation south of The Narrows is a landslide mass resting on deep, permeable fill in the down-faulted or deeply eroded gap.

Alternatives to these possibilities would be difficult to accept. One would be that the middle and lower units of the Salt Lake Formation are much more permeable at depth there than anywhere known, thus allowing the estimated underflow to occur through those units. Another would be that the quantity of underflow from the Yost-Almo subbasin estimated in this report is far too large.

Whatever the actual extent and distribution of water-bearing units in the area of The Narrows, the interpretation used throughout the remainder of this report is that of a deep, permeable cross section in a wide, erosional trough sufficient in area to transmit the estimated quantity of underflow at the prevailing gradient.

In general, the combined thickness of basalt, alluvium, and Raft Formation ranges from zero along the southern and eastern margins of the Raft River valley subbasin, to a maximum thickness of about 1,000 feet in the northwestern part of the subbasin. The upper unit of the Salt Lake Formation also thickens westward from zero along the southern and eastern margins of the subbasin, but the maximum thickness along the western margin of the basin is probably about 500 feet (fig. 8). Within the underflow section of The Narrows, the combined thickness of alluvial deposits and Raft Formation probably ranges from about 300 to about 600 feet; the upper unit of the Salt Lake Formation possibly from about 300 to 500 feet.

WATER YIELD OF THE BASIN

One of the primary objectives of the study is to refine the estimate of water yield in view of new development in the basin, longer periods of record available for computations, and additional data collected specifically for the purpose. Water yield, as used throughout this report, is the total quantity of the average annual water input to the basin that is available for use by man, either flowing in surface channels or moving through the formations underground. Water yield, therefore, is the total long-term input (precipitation) minus the total long-term average annual quantity evaporated at the surface and transpired by native vegetation (natural evapotranspiration) prior to the water becoming streamflow or a part of the ground-water body. In this sense, water transpired by native riparian vegetation after it has become a part of streamflow or the ground-water body is not considered in calculating water yield.

Several methods are commonly used to estimate water yield, but not all are applicable to a given area. Where the basin under study is such that all input to the basin is discharged over an impervious bedrock lip as surface-water flow after all natural evapotranspiration demands have been met, then water yield may be measured directly as streamflow. Nowhere in the Raft River basin does such a condition exist. At all sites, and especially at the outflow area from the basin as a whole, a large amount of water moves past the measuring site as underflow.

For small basins, and basins wherein the factors that influence natural evapotranspiration and infiltration are fairly constant, a direct relation between precipitation and measured runoff often provides a close estimate of water yield. However, because of the large size of the Raft River basin, the great variation in factors controlling evapotranspiration and infiltration, and the scarcity of direct-runoff data, this method is not applicable. The difficulty in developing a useful index of water yield from precipitation-runoff data is illustrated in figure 9.

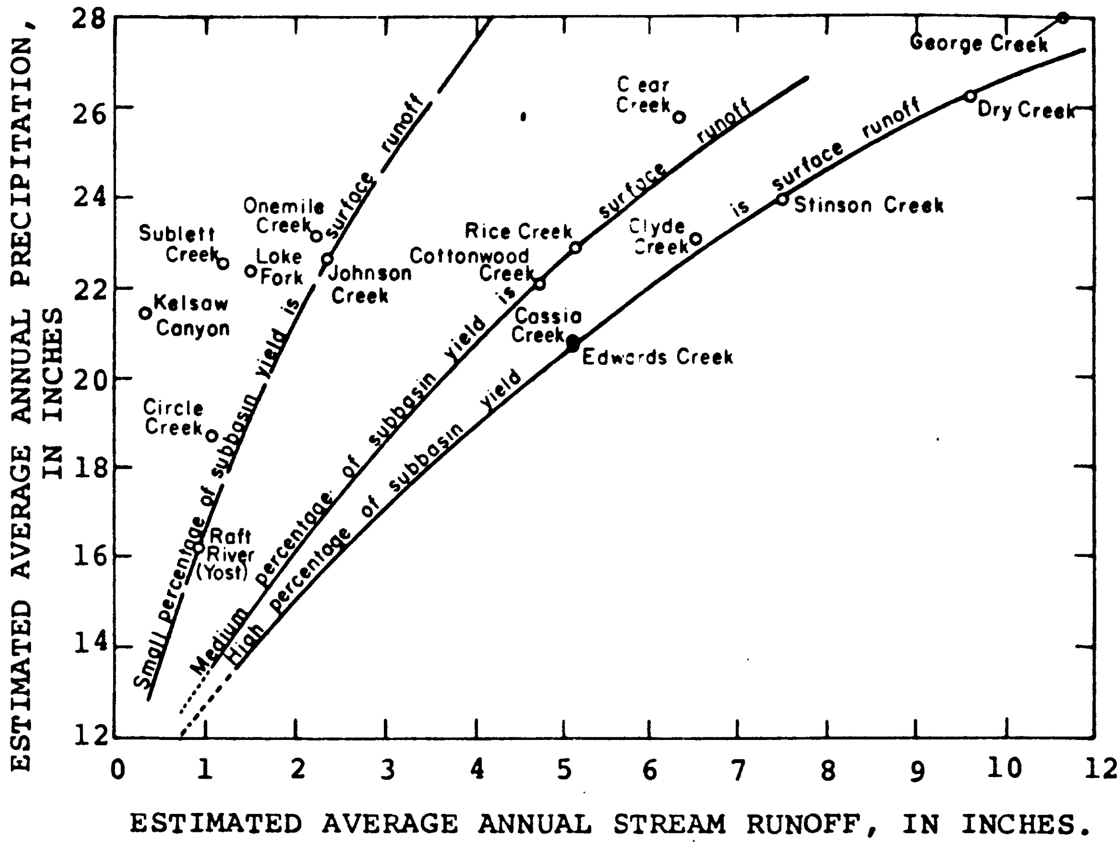


FIGURE 9.– Comparison between streamflow and precipitation.

The data indicate that a family of precipitation-runoff curves is needed to represent the actual situations in the different subbasins. The difference between precipitation and runoff in each subbasin, consisting of natural water losses by evapotranspiration and deep percolation which goes to recharge the ground-water bodies, is highly variable. For example, in the Sublett Creek drainage area, the average precipitation is fairly high, about 22.5 inches annually, and the runoff is only about 1.2 inches annually, whereas on the Rice Creek drainage basin, tributary to Clear Creek near Naf, the average precipitation is about 22.8 inches and the runoff is about 5.1 inches annually.

A third method, and the one most applicable to the Raft River basin, permits estimation of water yield as the difference between precipitation and the sum of all factors that make up actual evapotranspiration. The basic method is similar to that applied by all previous workers, particularly Nace and others (1961). As defined in this study, the method is quite different in application and results. Additional data and longer periods of record have become available since 1961, and these are applied to an entirely independent computation procedure, from which a new figure for water yield is derived.

PREVIOUS ESTIMATES

The first estimate of average annual water yield of the Raft River basin was 183,600 acre-feet, made by Nace and others (1961, p. 31) in 1955. In deriving this estimate, total precipitation was computed from an isohyetal map based on an altitude-precipitation relation developed by W. B. Langbein and R. L. Nace, and natural water losses were computed by a procedure developed by W. B. Langbein. From these relations, an altitude-annual water yield graph for each of three major divisions of the basin was developed, and from these a map was prepared showing estimated water yield over the basin. By summation of the water yield of selected altitude ranges, the total water yield was calculated.

The authors of the 1961 report clearly recognized a scarcity of data on which to base calculations and estimates, yet showed that the water-yield estimate was credible but probably not accurate everywhere.

A second estimate was made in 1960 by Mundorff and Sisco (1963, p. 14). By use of a precipitation-water yield relation developed for areas surrounding the Snake River Plain (Mundorff, Crosthwaite, and Kilburn, 1964, p. 43-46), Mundorff and Sisco estimated an average annual water yield of 320,000 acre-feet, nearly double that of Nace and others. There is some uncertainty about the equivalence of the definition of the term "water-yield" as used in these two reports; nevertheless, there remains a wide divergence between estimates. This divergence is reflected also in all other estimates relating to the distribution of the yield and quantities of water throughout the basin.

PRESENT ESTIMATE

The difference between the present estimate of water yield and previous estimates results largely from more and longer records of precipitation, a new estimate of precipitation distribution (fig. 2), and further refinement of estimates of yield from areas of low precipitation. Because the earlier estimates were so greatly different – 184,000 acre-feet versus 320,000 acre-feet – a third, completely independent estimate was made in an attempt to resolve the difference and gain a figure for use in later computations of water availability and distribution.

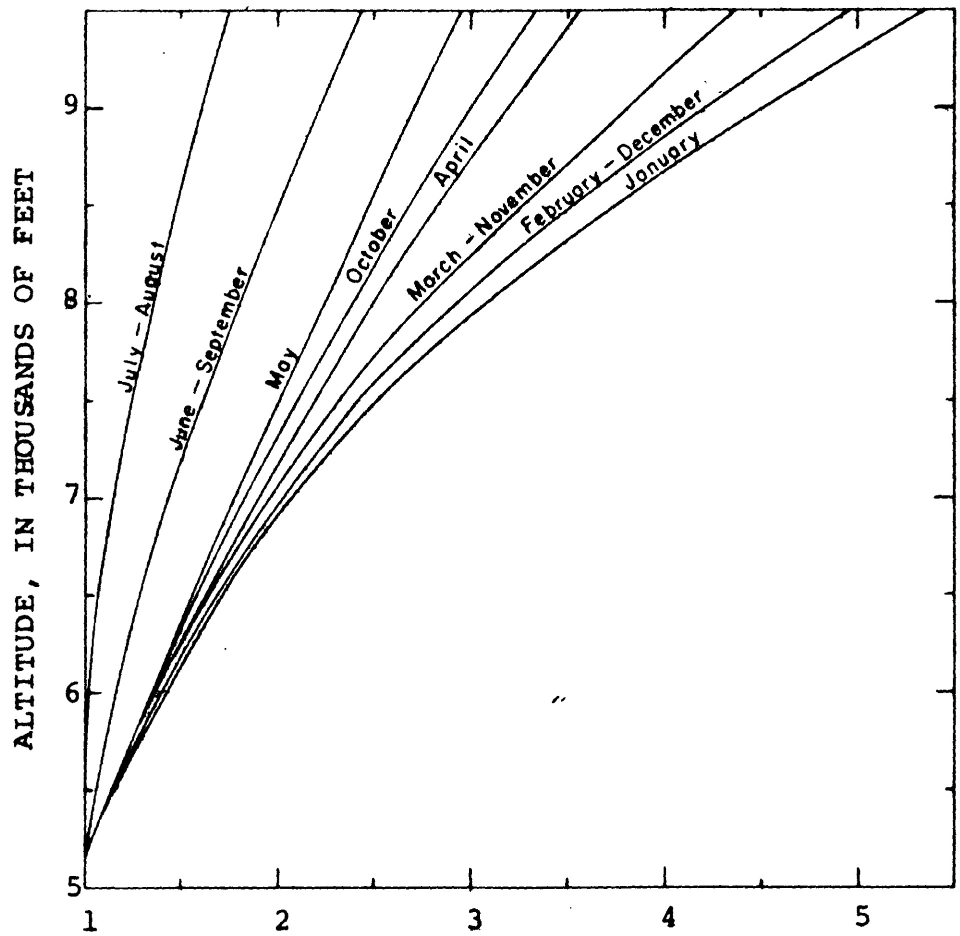
All methods of estimating water yield are subject to large errors in the estimation of the numerous variables that influence precipitation distribution, potential evapotranspiration, soil-moisture retention, deep precolation, and runoff. None of the methods provide more than gross approximations, at best, but a method based on evaporation from a free water surface, on soil-moisture content, and on precipitation distribution appears to lend itself to conditions in the basin. The following procedures were used in developing values for application of this method:

Average monthly values of precipitation, potential evapotranspiration, and available soil-moisture accumulation or depletion are needed to compute annual water yield. These values are needed throughout the basin, at representative locations relative to altitude, exposure, wind conditions, soil characteristics, and regional storm patterns so that the computed water-yield-distribution map will be representative of the basin as a whole.

Monthly precipitation data are available at only a few localities within or near the basin, all at low altitudes. Consequently, monthly values for other locations in the basin must be extrapolated from these data, from the isohyetal map (fig. 2), and from empirical factors developed as best-fit values from trial and error procedures that yield known total annual precipitation at selected altitudes. The factors must also meet the test of reasonable fit with data from stations elsewhere in southern Idaho that show that the relative proportion of precipitation in winter months increases rapidly with increased altitude. Figure 10 contains curves for computational factors by months. To apply the procedure, the desired site for determining average monthly precipitation is chosen, and the average annual precipitation and altitude for that site are read from figure 2. If the site is in the southern part of the basin, the average monthly precipitation base data for the recording stations at Strevell and Oakley, Idaho, and Park City, Utah, are computed, adjusted for snow, and tabulated by months, as follows:

Precipitation in south end of basin

	Strevell-Park Valley (inches)	Factor	Selected site (7,000 ft) (inches)
January	0.96	2.06	1.98
February	.86	2.03	1.74
March	.83	1.96	1.63
April	1.04	1.90	1.98
May	1.31	1.77	2.32
June	1.06	1.44	1.53
July	.73	1.15	.84
August	.77	1.15	.89
September	.67	1.44	.96
October	.77	1.84	1.42
November	.84	1.96	1.65
December	.92	2.03	1.87
Average annual precipitation (inches)	10.76		18.81



FACTOR
(To be multiplied by base data to obtain
monthly values at selected sites)

FIGURE 10.– Empirical curves for computation of average monthly precipitation at ungaged sites.

In the example used, the selected site at 7,000 feet altitude received about 19 inches of precipitation. The factor by which each monthly base value is multiplied is read from figure 10 by entering at or near the 7,000-foot level, reading across to the appropriate month, then down to the factor required. The computed monthly values are then tabulated and totaled. The altitude shown in figure 10 is approximate since precipitation has been adjusted to show effects of exposure, location, interpreted snow conditions or any known factor that might influence total precipitation, and consequently will not correlate exactly with altitude in any given portion of the study area.

For the northern and extreme western parts of the basin (and the area of the Sublett Range), the base value for average monthly precipitation was computed from stations at Malta, Albion, Oakley, and Minidoka Dam. The data are as follows, and the computation of monthly values for selected sites is the same as described above.

Precipitation in north end of basin and Sublett Range

	Malta-Minidoka (inches)	Factor	Selected site (6,500 ft) (inches)
January	1.22	1.71	2.09
February	.94	1.70	1.60
March	.79	1.65	1.30
April	.95	1.63	1.55
May	1.30	1.56	2.03
June	.94	1.29	1.24
July	.50	1.07	.54
August	.55	1.05	.59
September	.59	1.29	.76
October	.73	1.59	1.16
November	.87	1.65	1.43
December	1.18	1.70	2.00
Average annual precipitation (inches)	10.56		16.29

From this procedure, the average monthly precipitation was estimated for a large number of sites throughout the basin, then average monthly potential evapotranspiration was estimated for those sites.

Average monthly potential evapotranspiration was estimated by use of evaporation data from Minidoka Dam, a computation procedure modified from Rohwer (1931), and a series of assumptions, extrapolations, and adjustments. The Rohwer procedure is based on an equation for evaporation from a reservoir, and it was assumed the equation would apply to any site within the Raft River basin. The equation follows:

$$E = 0.771\,(1.465 - 0.0186B)\,(0.44 + 0.118W)\,(e_s - e_d)$$

where

E = Evaporation in inches per 24 hours

B = Mean barometer, in inches of mercury at 32° F

W = Mean velocity of ground wind or water-surface wind in miles per hour (measured at 6 inches above ground or water surface)

e_s = Mean vapor pressure of saturated vapor at the temperature of the water surface

e_d = Mean vapor pressure of saturated air at the temperature of the dew point

The constant 0.771 is a coefficient relating pan evaporation to reservoir evaporation.

It is assumed that potential evapotranspiration at any site is the amount that would evaporate from a free-water surface, or that would evaporate and transpire from completely saturated ground. Therefore, evaporation from Lake Walcott above Minidoka Dam is assumed to be directly comparable to potential evapotranspiration within the basin. Data are available for pan evaporation, wind velocities, barometric pressure, and relative humidity at or near Minidoka Dam. From these data, the average monthly potential evapotranspiration at the vicinity of Lake Walcott may be computed. Using the Minidoka data and computations as an example, the procedure used to derive values at other localities may be explained as follows:

1. Barometric pressure is a function of altitude and, except for diurnal and storm-related variations, is relatively constant for any given altitude. Average daily values may be obtained from published tables. The average barometric pressure at 32°F (0°C) at altitudes ranging from 4,000 feet (Minidoka) to 10,000 feet (Albion Range) varies from about 25.84 to 20.58 inches of mercury. Thus, the factor (1.465 - 0.0186B) in the equation is nearly 1, and ranges from 0.985 at 4,000 feet to 1.082 at 10,000 feet.

2. Recorded wind velocities at Minidoka were converted to velocities at 6 inches above ground as required by the equation, and average monthly values tabulated. The basin was then subdivided into subareas based on average wind conditions estimated from reports of wind persistence and intensity by local residents, field observers, and highway officials. Some wind data were obtained from local and state aviation organizations, and from sparse

local measurements. The exposed northern end of the basin around and south of Lake Walcott, and the windward side of the Sublett Range, and exposed ridge crests at high altitudes were assumed to have wind conditions virtually the same as those at Minidoka. For these areas, the factor (0.44 + 0.0118W) ranges from about 0.8 to 0.9 during the year. Subareas in the southern end of the basin in the lee of ridges and mountain ranges, and in interior valleys are less windy than at Minidoka. For these subareas, the average monthly wind velocity at Minidoka was reduced arbitrarily by one-third, and the factor (0.44 + 0.0118W) in these subareas ranges from about 0.68 to 0.76 during the year.

3. The final factor of the equation (e_s-e_d) is a moisture-deficit factor related to relative humidity and temperature. The mean vapor pressure of air (e_d) may be expressed as the mean vapor pressure of saturated vapor (e_s) times percent relative humidity, and the factor may be rewritten as e_s - (e_s RH/100), or e_s (1 - RH/100). The relative humidity is measured at several places in southern Idaho and is assumed to be the same at all localities within the basin at a given time. This is not strictly correct, but the effect on the final estimate of evapotranspiration is probably negligible.

The vapor pressure of air saturated with water vapor is a function of temperature. Average monthly temperature is recorded at stations such as Strevell and Minidoka, and a lapse rate of 3.2°F per 1,000 feet of altitude change can be shown to exist throughout the basin. This rate is the same as reported by Nace and others (1961), and was verified in this study. The saturation vapor pressure at any given altitude may thus be determined from the temperature and by reference to published tables.

All factors of the equation can thus be computed for any selected site and time. Since the equation gives evapotranspiration per day, the results must be multiplied by days per month to obtain average monthly potential evapotranspiration. For a site at 7,000 feet in the southern part of the basin, the average potential evapotranspiration for the month of June may be estimated as follows:

$$E_m = 30E = (30 \times 0.771) [1.465 - (0.0186 \times 23.09)] [0.44 + (0.118 \times 2.41)] [0.425 (1 - 47/100)]$$

$$= 23.1 \times 1.035 \times .724 \times .226$$

$$= 3.91 \text{ inches}$$

Table 5 shows average monthly and yearly potential evapotranspiration for selected locations and altitudes in the basin. Similar computations were made to obtain values at all sites where average monthly precipitation had been estimated.

Water yield is the difference between precipitation and actual natural evapotranspiration. To obtain actual natural evapotranspiration, it is necessary to estimate

Table 5. Average monthly and yearly potential evapotranspiration, in inches, at selected altitudes in Raft River basin.

Month	Altitude (feet above msl)								
	4,280	4,600	5,000	6,000	7,000	8,000	9,000		10,000
	High wind	Moderate or low wind					High wind	Low wind	High wind
	Minidoka	Malta							
Jan.	0.59	0.51	0.48	0.42	0.37	0.32	0.33	0.28	0.29
Feb.	.81	.65	.62	.54	.47	.41	.40	.34	.37
Mar.	1.50	1.40	1.34	1.20	1.06	.93	.99	.81	.86
Apr.	2.97	2.49	2.39	2.15	1.93	1.73	1.85	1.54	1.62
May	4.49	3.64	3.49	3.16	2.85	2.56	2.74	2.30	2.45
June	6.12	4.96	4.77	4.33	3.92	3.54	3.81	3.19	3.42
July	10.30	8.09	7.80	7.09	6.45	5.85	6.29	5.29	5.67
Aug.	9.55	7.59	7.31	6.65	6.03	5.47	5.88	4.95	5.29
Sept.	6.01	4.70	4.51	4.09	3.70	3.34	3.52	3.00	3.16
Oct.	3.26	2.65	2.54	2.29	2.05	1.85	1.96	1.65	1.75
Nov.	1.25	1.05	1.00	.89	.78	.69	.71	.60	.51
Dec.	.78	.65	.61	.54	.47	.41	.43	.35	.36
	47.75	38.37	36.87	33.36	30.07	27.09	28.91	24.30	25.75

the soil-moisture requirement (defined herein as the available waterholding capacity of the soil within the root zone) and relate this to average precipitation and average potential evapotranspiration. The soil-moisture requirement throughout the basin was estimated by the following procedure:

By use of soil maps (Chugg and others, 1967) and field inspection, the entire basin was subdivided into units of equivalent soil-moisture requirement. A maximum requirement of 6 inches was assigned to deep, well-developed soil, and a minimum of 2 inches was assigned to shallow, rocky areas. The main valley bottom lands and most of the Sublett Range area were assigned a 6-inch requirement; the northern part of the Black Pine Range, much of Raft River Mountains, Junction Valley, and small areas elsewhere were assigned a 5-inch requirement; the southern, granitic part of the Albion Range was assigned 4 inches; a few mountain slopes were assigned a 3-inch requirement; and a 2-inch requirement was assigned to the Cotterell Range and its eastern flank as well as the area of basalt at the northern end of the basin.

From the foregoing estimates of average monthly precipitation, average monthly potential evapotranspiration, and soil-moisture requirement, it is possible to calculate a preliminary average annual water yield at any selected location. To illustrate the procedure, the determination of water yield for three sites in the basin is shown in the following table. All values are in inches.

	7,300 ft. Raft River Mtns. Soil-moisture requirement = 5 inches				6,000 ft. Albion Range Soil-moisture requirement = 6 inches				5,500 ft. Sublett Range Soil-moisture requirement = 6 inches			
	Pot. E.T.	Pre- cipita- tion (inches)	Avail- able soil water, end of month	Yield	Pot. E.T.	Pre- cipita- tion (inches)	Avail- able soil water end of month	Yield	Pot. E.T.	Pre- cipita- tion (inches)	Avail- able soil water end of month	Yield
Jan.	0.35	2.40	4.97		0.42	2.51	4.76		0.45	1.91	3.06	
Feb.	.45	2.06	5.0	1.58	.54	1.91	6.0	0.13	.58	1.46	3.94	
Mar.	1.02	1.91	5.0	.89	1.20	1.55	6.0	.35	1.27	1.19	3.86	
Apr.	1.90	2.29	5.0	.39	2.15	1.81	5.66		2.27	1.42	3.01	
May	2.74	2.62	4.88		3.16	2.30	4.80		3.32	1.88	1.57	
June	3.81	1.70	2.77		4.33	1.35	1.82		4.55	1.16	0	
July	6.27	.88	0		7.09	.57	0		7.45	.52	0	
Aug.	5.84	.92	0		6.65	.63	0		6.98	.58	0	
Sept.	3.59	1.07	0		4.09	.85	0		4.30	.73	0	
Oct.	1.99	1.62	0		2.29	1.34	0		2.41	1.07	0	
Nov.	.75	1.91	1.16		.89	1.70	.81		.95	1.31	.36	
Dec.	.45	2.21	2.92		.54	2.40	2.67		.58	1.82	1.60	
	29.16	21.59		2.86	33.36	18.92		0.48	35.11	15.65		-2.04

Determination of water yield for all sites in the basin could be similarly given, but those shown serve to illustrate that beginning in about July of each year the monthly potential evapotranspiration is much greater than monthly precipitation, and soil moisture is depleted. By November precipitation exceeds potential evapotranspiration and the excess begins to accrue to the soil moisture requirement. This accumulation continues through the winter until by about February the soil-moisture requirement is satisfied and an excess is available as water yield. By about April or May the potential evapotranspiration again exceeds precipitation and soil moisture begins to be depleted. Water yield ends as soon as there is a soil-moisture requirement to be satisfied. In some locations, the soil-moisture requirement is not satisfied during the year, and there is no yield, or a negative yield is indicated.

Obviously, the values obtained by the above procedure are based on the assumption of uniform average annual precipitation distribution, and this does not happen in nature. There are times when precipitation is greatly different from the computed monthly average, and this greatly affects the water yield. To correct the preliminary water-yield values obtained by the above procedure, a statistical evaluation of the magnitude and frequency of yearly precipitation events that differ from the computed yearly average was made for all sites. The final estimate of average annual water yield was made after this adjustment.

The statistical evaluation for the site at 6,000 feet altitude in the Albion Range is presented as an example of the procedure used to adjust the preliminary water-yield determination at all selected sites to a final estimated value. At this site, the average annual precipitation is 18.92 inches, and the precipitation during the months of excess precipitation over potential evapotranspiration, when yield could occur, is 10.07 inches (November through March). During this period, only 9.59 inches were required to satisfy evapotranspiration and soil-moisture requirements, and 0.48 inch of yield occurred. Consequently, the ratio 18.92/10.07 is equal to the ratio x/9.59 and x = 18 inches, the annual amount of precipitation needed at this site before water yield can occur.

From a log-probability plot of the precipitation records at Idaho City and Oakley (fig. 11), it is determined that in 54 years out of each 100 years, precipitation will exceed 18 inches at a site where the average annual precipitation is 18.92 inches. The records at Idaho City and Oakley were chosen as being representative of conditions in the Raft River basin, and the adjustment of all yield determinations was made from this probability relationship. From this probability plot, a table was made and a curve drawn (fig. 12) to define the years per 100 years when precipitation will equal or exceed a given annual precipitation. The quantity of water represented by the area under the curve in figure 12 has been designated "potential yield" and is a measure of the cumulative precipitation in excess of 18 inches per year which can be expected each 100 years. The computations for estimating potential yield from the curve are given in figure 12 and for this example show a potential yield of 231 inches per 100 years of 2.31 inches per year.

At the Albion Mountains site, water yield during average years can only occur during the period November through March when precipitation averages 10.07 inches and both potential evapotranspiration and soil-moisture requirements are satisfied. Therefore, even though sufficient precipitation may occur during any year to provide a potential water yield of 2.31 inches, actual water yield can occur only during a part of the year. The ratio of precipitation (10.07 inches) during the November-March period to average annual precipitation (18.92 inches) times potential yield gives the estimated long-term annual yield for the site -- 1.23 inches.

The foregoing computations to obtain estimated water yield were made for selected sites throughout the basin, the values were plotted on a map of the basin, and lines of equal water yield were drawn. From the resulting map (fig. 13) the long-term average annual water yield of the subareas, subbasins and the total basin was computed by summing the products of mean water yield and area between successive lines of equal water yield within each area. Table 6 shows the estimates for individual subbasins and subareas, and a total average annual water yield for the basin of 140,000 acre-feet.

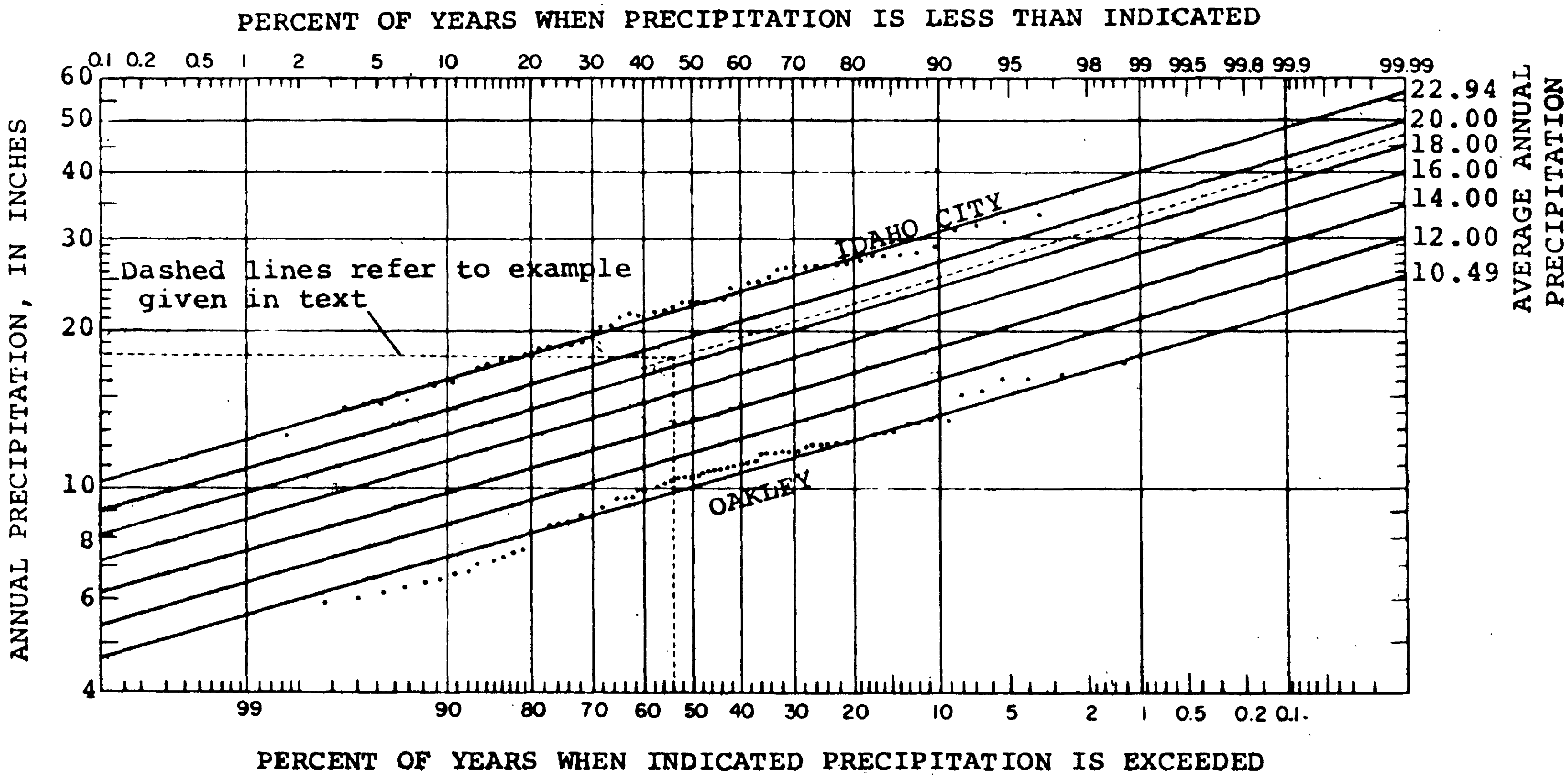
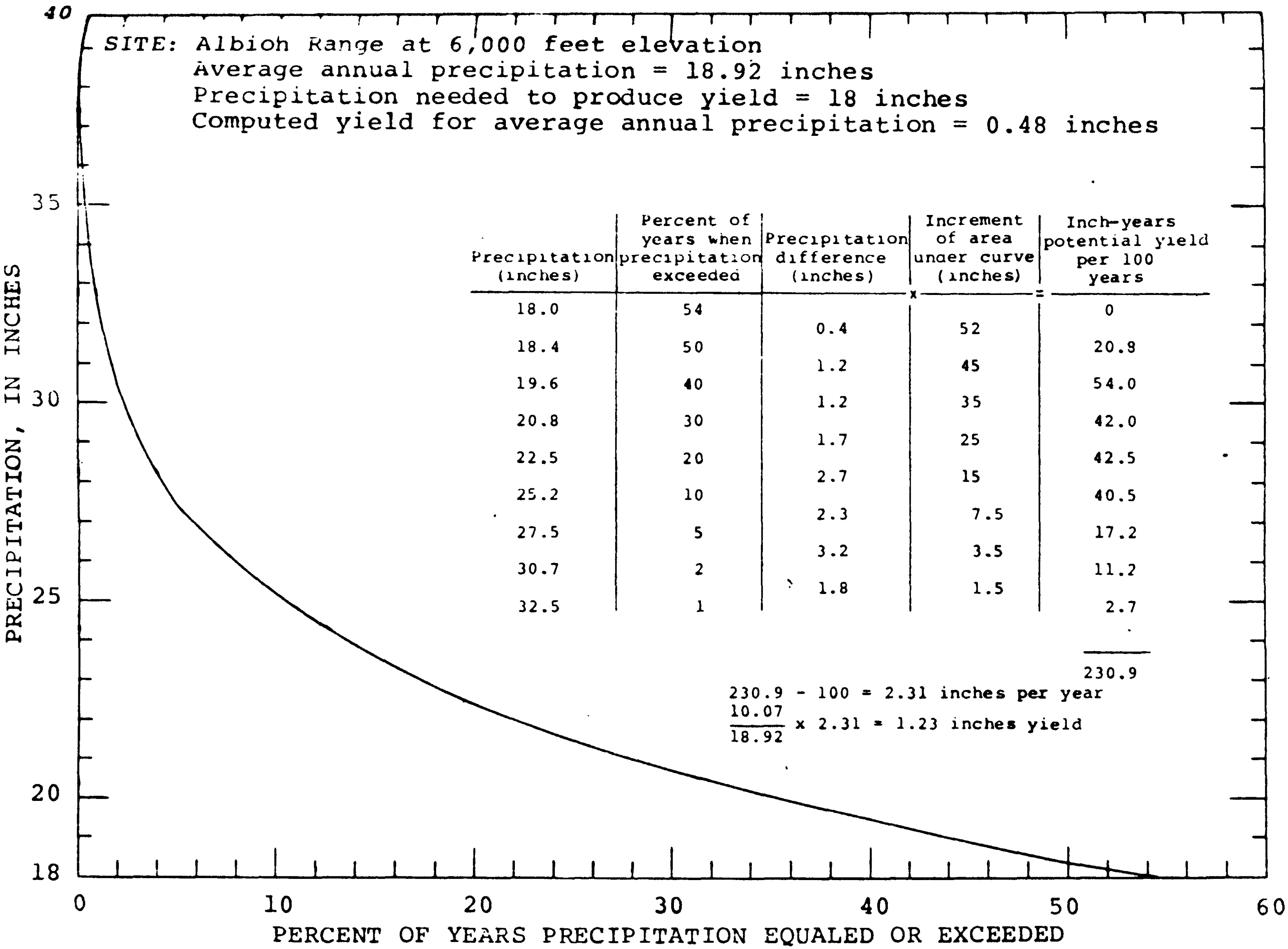


FIGURE 11.– Log probability of annual precipitation at Oakley and Idaho City, Idaho.



Precipitation (inches)	Percent of years when precipitation exceeded	Precipitation difference (inches)	Increment of area under curve (inches)	Inch-years potential yield per 100 years
18.0	54			0
		0.4	52	
18.4	50			20.8
		1.2	45	
19.6	40			54.0
		1.2	35	
20.8	30			42.0
		1.7	25	
22.5	20			42.5
		2.7	15	
25.2	10			40.5
		2.3	7.5	
27.5	5			17.2
		3.2	3.5	
30.7	2			11.2
		1.8	1.5	
32.5	1			2.7
				230.9

FIGURE 12.-- Annual precipitation in excess of average at a selected site, and computed long-term annual water yield.

Table 6. Estimated average annual water yield in Raft River basin.

Subarea	This report			Nace and others (1961, table 5)		
	Area		Water yield (acre-feet)	Area		Water yield (acre-feet)
	Square miles	Acres		Square miles	Acres	
Yost-Almo subbasin	411	263,040	46,000	411	263,000	77,000
Elba subbasin	99	63,360	22,600	105	67,200	27,400
Raft River Mountains subarea	110	70,400	17,400	(a)	(a)	(a)
Meadow Creek subarea	79	50,560	7,700	81	51,800	8,200
Sublett Creek subarea	59	37,760	9,700	62	39,600	7,300
Heglar Creek subarea	52	33,280	8,900	80	51,200	9,000
Raft River valley subarea	[b]700	448,000	27,700	823	526,500	[c]54,700
Total	1,510	966,400	140,000	1,562	999,500	183,600

a Included in Raft River valley by Nace and others (1961).

b Includes only a part of Northern Plains section reported in Nace and others (1961).

c Includes about 600 acre-feet from outside of area used in this report. Value of 54,700 - 600 = 54,100 compares with 27,700 + 17,400 = 45,100 acre-feet in this report.

The calculated total precipitation on which this water yield is based is only 10,000 acre-feet per year less than that calculated by Nace and others (1961). The lower figure for water yield results, therefore, mainly from a difference in the definitions of the terms "water yield" and "total evapotranspiration," as well as the manner in which evapotranspiration is calculated. The numerical values for water yield derived in each of the three reports – Nace and others (WSP 1587), Mundorff and Sisco (WSP 1619-CC), and the present report – can best be compared if each value is related to the following restricted definitions of water yield:

Water yield of the Raft River basin is the long-term average unconsumed part of total precipitation that annually flowed out of the basin when the basin was in its native state, the outflow being either as surface runoff or as subsurface outflow.

Nace and others (1961, table 5) calculated the total outflow from the basin under natural conditions as the sum of the water yields from each of seven subareas. The total, 183,600 (rounded to 184,000) acre-feet per year, includes both surface and subsurface outflow.

Mundorff and Sisco (1963, p. 13-14) applied a runoff-precipitation relationship developed for drainage basins tributary to the Snake River Plain, principally the northern part. From this relationship, published by Mundorff, Crosthwaite, and Kilburn (WSP 1654, 1964, p. 43 and fig. 7), they estimated a combined surface and subsurface outflow from the basin of 320,000 acre-feet per year which they defined as water yield. Thus, on a comparable basis, the estimate by Nace and others is only 59 percent of the estimate by Mundorff and Sisco.

In the present report, the surface outflow under natural conditions is estimated to have been about 17,000 acre-feet per year. The subsurface outflow, similarly, is estimated to have been about 83,000 acre-feet per year. Thus, the total outflow, or water yield according to the comparative restricted definition, was about 100,000 acre-feet per year. This estimate does not include the Northern Plains subarea that was included in the earlier reports. Nace and others (table 5) show this subarea to yield about 1,200 acre-feet annually. Therefore, for comparison purposes, the estimate in the present report should be about 101,000 acre-feet per year.

The estimates of average annual water yield of the Raft River basin, based on the restricted definition common to all three procedures for estimating, varies from about 101,000 acre-feet to about 320,000 acre-feet. The estimation procedure used in the present report allows for a much more precise accounting of evapotranspiration demand in the lowlands than either of the other procedures. Also, the modern data allows for a more precise determination of the distribution of precipitation, both in space and time. Consequently, the more conservative value for water yield is considered appropriate and applicable.

THE HYDROLOGIC SYSTEM

All water that occurs in the Raft River basin comes from rain and snow that falls within the basin. Prior to man's development and use of the water, part of the annual precipitation input to the basin was returned directly to the atmosphere as evaporation and as transpiration by native vegetation; a part replaced depleted soil moisture from which it was eventually either evaporated or transpired; a part went into ground-water storage to replace that which continually flowed northward out of the valley as ground-water underflow; and the remainder left the basin as streamflow in the Raft River. In the valley areas, pumping of ground water and diversion of streamflow for irrigation have changed the relative magnitude of each of these elements of distribution of the annual input, but the long-term average input remains unchanged. Thus, although it is important to know the amount of input, it now is equally important to determine the magnitude and variation in both time and location of the various elements of distribution of the input under existing or planned conditions of development and use.

The areas of use are virtually all within the valley lowlands, so that the principal changes in elements of distribution of input are those of ground-water storage, and of surface and subsurface outflow. Surface outflow can be measured or estimated directly, but there are no means by which quantity or subsurface outflow and storage change can be measured directly and estimates must be derived by indirect methods.

Most of the water resource available for development and use within the lowlands of the Raft River basin originates in the mountain and foothill areas. The following sections discuss the distribution and character of the surface-water runoff to, within, and from the central valley area, the occurrence, movement, storage changes, and discharge of the ground-water, and the chemical quality of the water.

SURFACE–WATER INFLOW AND OUTFLOW

The largest part of the runoff in the Raft River basin is derived from the Albion and Goose Creek Ranges and the Raft River Mountains (fig. 1). When in its natural condition, the Raft River maintained flow throughout its entire reach. At present, and for decades past, the flow disappears in summer between Bridge and Malta. Most years the channel remains dry nearly to Yale where ground water enters and irrigation water pumped from wells drains from the nearby farms.

Cassia Creek is the principal tributary to the Raft River. It rises in the high country west of Elba, and at times flows some distance beyond Malta before flow disappears as a result of diversions for irrigation, percolation to ground water, and evapotranspiration.

Almo Creek and its tributaries, which collect the drainage from the high country west and north of Almo, generally flow to join the Raft River except near the end of summer.

The drainage from the Raft River Mountains – principally George, Johnson, Onemile, and Clear Creeks – formerly joined the Raft River during nearly every spring season of high runoff (Bartlett, 1906). Currently, because of diversions for irrigation, flow in Johnson and George Creeks reaches the Raft River only during part of the year, and the flow of Clear and Onemile Creeks reaches the river only during flood or occasional severe thunderstorm runoff periods.

Surface runoff does not reach the Raft River from the Black Pine and Sublett Ranges except locally after heavy storms, nor has it since settlement of the valley in the 1870's. Meadow Creek is a minor intermittent stream that drains a small basin between the Black Pine and Sublett Ranges. Sublett Creek drains the central western part of the Sublett Range, and Heglar Creek drains the northwestern part.

Because streamflow in some tributaries reaches the river only infrequently, if ever, the large Raft River valley subbasin is further subdivided into the Raft River Mountains, Meadow Creek, Sublett, and Heglar Creek subareas.

Runoff

Only a part of the water yield of the Raft River basin appears in streams as measured surface-water runoff, and the quantity has become less with time as increased use was made of water in the basin. Lowering of ground-water levels has provided greater opportunity for recharge through precolation of streamflow, and direct diversion for irrigation has diminished runoff in many parts of the basin. Measurements of runoff from the various subdivisions of the basin under natural conditions do not exist, and the long-term average streamflow must be estimated and adjusted by correlation with long-term records outside the basin, or with precipitation records.

The few records of streamflow that have been made are widely scattered and discontinuous. None is complete for the 30-year normal period 1931-60. Also, all gaging stations were unavoidably placed where a large component of the water yield of the area above the gage moved past the site as underflow. Consequently, measured runoff from the various subbasins and subareas can be considered only as an indicator of the minimum yield from the gaged area.

Gaging stations were in operation at the start of the study at Peterson Ranch near Bridge on the Raft River, Clear Creek near Naf, and George Creek near Yost. These stations were continued and additional continuous-record stations were installed on Cassia Creek above Stinson Creek, near Elba, and on Sublett Creek at Sublett Campground, near Sublett. To supplement data from those stations and to provide a basis for estimating runoff from peripheral tributary drainages, 18 partial-record stations were established covering most of the smaller drainages. The location of all measurement sites is shown in figure 13.

Short-term records of runoff reflect wide variations in both annual and short-term climatic elements – principally precipitation. It is therefore necessary to adjust the short-term records to a common average, or normal period, before they can be meaningfully related to similarly adjusted precipitation and water-yield computations.

Adjustment of the short-term and fragmentary records to the 30-year normal period 1931-60 was made by correlation, much of which is sufficiently tenuous that large probable error in the estimated long-term average runoff at some sites must be recognized. The record for the station at Peterson Ranch, near Bridge, being the longest and best record in the basin, was extended to the 30-year average by correlation with a continuous record for Trapper Creek near Oakley west of the Raft River basin. Records for Edwards Creek near Almo, Cassia Creek above Stinson Creek, near Elba, and Stinson Creek near Elba were also correlated with the record of Trapper Creek near Oakley. Records for Clyde Creek and Cottonwood Creek were then correlated with the computed record for Cassia Creek.

The record for the station Raft River near Yost (Upper Narrows) was correlated with Raft River at Peterson Ranch, near Bridge, then the record for Circle Creek near Almo was correlated with that for Raft River near Yost. Precipitation records at Strevell and at Park Valley, Utah, south of the Raft River Mountains, were used to extend the Clear Creek record, then the records for George Creek near Yost, Onemile Creek near Naf, Rice Creek near Naf, and Kelsaw Canyon were correlated with that for Clear Creek. The records of Johnson Creek near Yost and Dry Creek near Elba correlated well with the George Creek record.

The runoff records of tributaries draining the Sublett and Black Pine ranges do not correlate with any long-term records. Except for Warm Creek, which is spring-fed and for which a 30-year average was not computed, all the measured tributaries from these ranges had very fragmentary records of flow during the study period. These records were extended to the 30-year average on the basis of precipitation records.

The measured and estimated streamflow and related data at gaged sites in the Raft River basin are given in table 7. Table 8 gives data obtained from crest-stage gages and miscellaneous measuring sites where only short-term records were collected.

Mean Annual Inflow

Nearly all surface-water runoff occurs in the principal streams of the subdivisions outside the Raft River valley subbasin. Some runoff occurs at times from the mountain fronts on the eastern and western sides of the central valley, but the amounts are small and flow occurs only for short periods. The measured and computed surface-water runoff within each of the principal subdivisions of the valley, adjusted to the 30-year period, is given in table 9 and is described in the following sections.

Elba subbasin. – The estimated annual long-term average surface-water inflow from the principal streams tributary to Elba subbasin is about 12,500 acre-feet. There is no evidence that this inflow has been either measurably increased or decreased due to development by man in the subbasin.

Five tributary creeks – Cassia, Stinson, Dry, Clyde, and Cottonwood – provide the principal input to the subbasin, but short-term records near the mouth of the subbasin

Table 7. Yearly runoff, in acre-feet, at gaging stations in the Raft River basin.[a]
(Area of drainage basin above station, in square miles, is given in parentheses.)

Water year	George Creek near Yost (7.84)	Raft River at Peterson Ranch, near Bridge (412)	Raft River near Bridge (505)	Clear Creek near Naf (20.2)	Cassia Creek above Stinson Creek, near Elba (7.2)	Cassia Creek near Elba (84)	Cassia Creek near Conant (104)	Sublett Creek at Sublett campground, near Sublett (24)
1910	-	-	b26,700	b9,600	-	-	23,000	-
1911	-	-	b15,200	-	-	-	18,900	-
1912	-	-	32,500	-	-	-	b33,500	-
1913	-	-	29,200	-	-	-	-	-
1914	-	-	38,900	-	-	-	-	-
1945	-	-	-	11,630	-	-	-	-
1946	-	-	-	6,460	-	-	-	-
1947	-	10,410	-	6,550	-	-	-	-
1948	-	10,250	-	7,200	-	-	-	-
1949	-	20,690	-	7,620	-	-	-	-
1950	-	13,400	-	7,980	-	-	-	-
1951	-	24,000	-	7,150	-	-	-	-
1952	-	24,950	-	7,520	-	-	-	-
1953	-	14,750	-	5,920	-	-	-	-
1954	-	-	-	2,810	-	-	-	-
1955	-	-	-	4,310	-	-	-	-
1956	-	10,250	-	6,500	-	-	-	-
1957	-	10,400	-	7,140	-	b21,350	-	-
1958	-	13,440	-	8,810	-	22,250	-	-
1959	-	7,040	-	4,330	-	10,240	-	-
1960	3,090	6,260	-	4,180	-	8,920	-	-
1961	2,030	4,720	-	2,860	-	7,670	-	-
1962	5,570	10,780	-	9,760	-	15,060	-	-
1963	5,210	7,290	-	7,890	-	-	-	-
1964	5,470	12,360	-	9,890	-	-	-	-
1965	7,800	18,320	-	14,340	-	-	-	-
1966	4,140	8,380	-	5,960	1,250	-	-	1,470
1967	5,950	6,520	-	11,080	1,750	-	-	1,480

a Compiled from published data.
b Record estimated for part of year.

Table 8. Monthly and yearly streamflow at partial-record sites in the Raft River basin.[a]
(Monthly values and annual totals are in acre-feet; runoff is annual inches per square miles. Area of drainage basin above station, in square miles, is given in parentheses.)

Year	Month	Raft River near Yost (146)	Edwards Creek near Almo (3.9)	Johnson Creek near Yost (14.4)	Onemile Creek near Standrod (7.84)	Rice Creek near Naf (2.31)	Kelsaw Canyon near Strevell (6.52)	Stinson Creek near Elba (4.5)	Clyde Creek near Elba (6.4)	Cottonwood Creek near Elba (7.2)	Lake Fork above Sublett Reservoir, near Sublett (14.9)	Raft River near Yale (1,510)
1964	October	b198	d38	e65	f46	f16	-	-	-	-	-	-
	November	227	54	63	45	15	-	-	-	-	-	-
	December	529	123	90	60	17	-	-	-	-	-	-
1965	January	879	135	111	59	16	-	-	-	-	-	-
	February	1,010	141	87	56	16	-	-	-	-	-	-
	March	784	133	107	55	17	-	-	-	-	-	-
	April	1,200	310	343	95	55	30	-	-	-	-	-
	May	b2,010	d579	e588	f306	f237	61	-	-	-	-	-
	June	1,960	307	1,020	778	601	72	-	595	655	134	149
	July	754	173	418	320	123	28	-	246	289	138	126
	August	467	86	180	121	40	7	-	141	172	135	111
	September	386	71	119	66	24	2	-	125	83	120	83
	Total	b10,470	d2,150	e3,190	f2,010	f1,170	-	-	-	-	-	-
	Runoff, in.	b1.34	d10.34	e4.15	f4.81	f9.50	-	-	-	-	-	-
1965	October	416	68	106	61	20	0	33	123	74	107	123
	November	458	64	76	65	18	0	38	107	101	106	146
	December	415	52	96	58	15	0	37	129	117	100	231
1966	January	481	40	112	47	14	0	33	129	117	97	332
	February	460	46	90	39	13	0	26	106	89	100	339
	March	883	52	133	52	17	0	98	175	215	127	366
	April	964	102	289	70	35	2	214	405	393	119	333
	May	456	101	500	238	215	4	203	338	246	103	234
	June	209	67	172	167	149	0	101	143	143	90	98
	July	94	31	75	67	49	0	33	74	108	81	76
	August	122	18	45	27	12	0	27	61	43	74	73
	September	147	20	37	24	10	0	30	36	39	83	52
	Total	5,100	661	1,730	915	567	6	873	1,827	1,685	1,187	2,400
	Runoff, in.	0.65	3.18	2.25	2.19	4.60	0.02	3.64	5.35	4.39	1.49	0.030
1966	October	190	22	44	33	11	0	44	37	34	89	61
	November	305	21	52	31	12	0	55	60	27	86	110
	December	443	18	59	21	13	0	61	74	31	98	181
1967	January	389	30	71	32	12	0	61	111	34	85	215
	February	369	25	54	28	12	0	51	150	67	86	169
	March	501	40	71	35	13	0	89	258	221	99	132
	April	622	59	105	34	15	0	101	363	238	101	134
	May	670	130	707	200	175	86	595	547	369	117	148
	June	738	130	745	668	503	149	684	619	601	118	68
	July	252	77	281	152	92	52	215	246	252	95	43
	August	122	49	144	88	37	3	49	55	37	74	68
	September	149	45	120	78	29	0	39	42	24	66	65
	Total	c4,750	c646	c2,450	c1,400	c1,020	c290	c2,014	c2,562	c1,935	c1,114	c1,390
	Runoff, in.	c0.61	c3.11	c3.19	c3.35	c8.28	c0.83	c8.39	c7.51	c5.04	c1.40	c0.017

Circle Creek near Almo, drainage area 7.5 square miles, had a total streamflow for water years 1965-67 of 630, 282, and 260 acre-feet, respectively, and a runoff of 1.57, 0.71, and 0.60 annual inches per square mile for each year.

Zero flow was observed each month beginning with August 1965 at the station on Meadow Creek near Sublett, drainage area 36.8 square miles.

Dry Creek near Elba, drainage area 9.2 square miles, had an average streamflow and runoff for the 1965-67 water years of 6,520 acre-feet and 13.28 annual inches, respectively.

Warm Creek near Sublett (spring-fed) had a total streamflow of 2,570 acre-feet for water year 1966 and 2,390 acre-feet for water year 1967.

a Values not previously published; based on correlation with precipitation records and continuous-record streamflow stations.

b Runoff for October 1964 to May 1965 estimated; based on comparison with record of Raft River at Peterson Ranch, near Bridge.

c Runoff for September 1967 estimated.

d Estimated runoff for October 1964 to May 1965, based on comparison with record at Trapper Creek near Oakley, west of Raft River basin.

e Estimated runoff for October 1964 to May 1965, based on comparison with record at George Creek near Yost.

f Estimated runoff for October 1964 to May 1965, based on comparison with record at Clear Creek near Naf.

Table 9. Surface runoff and related data at gaged sites, adjusted to 1931-60 average, in the Raft River basin.

Station	Drainage area (sq. mi.)	Mean altitude (feet)	Surface runoff Acre-feet	CFS	Inches	Average precipitation (inches)
Elba subbasin (Inflow)						
Cassia Creek above Stinson Creek, near Elba	7.2	6,600	2,000	2.8	5.2	21
Stinson Creek near Elba	4.5	7,300	1,800	2.5	7.5	24
Dry Creek near Elba	9.2	7,900	4,700	6.5	9.6	26
Clyde Creek near Elba	6.4	7,100	2,200	3.1	6.5	23
Cottonwood Creek near Elba	7.2	7,400	1,800	2.5	4.7	22
Subtotals	34.5	-	12,500	17.3	-	-
Yost-Almo subbasin (Inflow)						
Raft River near Yost	146.	6,600	7,400	10.2	1.0	16
Circle Creek near Almo	7.5	6,500	400	.6	1.0	19
Edwards Creek near Almo	3.9	6,900	1,100	1.5	5.3	21
Johnson Creek near Yost	14.4	7,400	1,800	2.5	2.4	23
George Creek near Yost	7.8	8,400	4,500	6.1	10.7	28
Subtotals	179.6	-	15,200	20.9	-	-
Raft River valley subbasin (Inflow)						
Raft River at Peterson Ranch, near Bridge	412.	6,300	11,600	16.0	.5	-
Kelsaw Canyon near Strevell	6.5	7,000	120	.2	.3	21
East part Raft River Mountains subarea						
Onemile Creek near Standrod	7.8	7,400	940	1.3	2.2	23
Clear Creek near Naf	20.2	8,000	6,800	9.4	6.3	26
Rice Creek near Naf	2.3	8,100	630	.9	5.1	23
Meadow Creek subarea						
Meadow Creek near Sublett	36.8	6,000	No evidence of flow 8-65 to 8-67			
Sublett Creek subarea						
Sublett Creek at Sublett campground, near Sublett	24.	6,200	1,500	2.1	1.2	22
Lake Fork above Sublett Reservoir, near Sublett	14.9	6,200	1,200	1.7	1.5	22
Warm Creek near Sublett	-	-	ab2,500	ab3.4	-	-
Heglar Creek subarea						
South Heglar Creek above Indian Fork, near Heglar	6.9	6,200	c10	-	c.03	-
Indian Fork near Heglar	1.6	6,300	c40	-	c.4	
Heglar Creek tributary near Rockland	7.7	5,300	d150	-	d.4	
Subtotals	540.7	-	25,490	35.00	-	-
Raft River valley subbasin (Outflow)						
	1,510.	-	a1,900	a2.62	a.024	-

a Spring fed.
b Average of 1966 and 1967 water years.
c Estimated on the basis of observations of flow or no flow.
d Estimated on the basis of records of crest-stage gage and measurements or observation of no flow.

indicate a large input from other than these drainages. A 6-year record from a station at Cassia Creek near Elba in the lower part of the basin correlates well with the long-term record for Trapper Creek near Oakley. This correlation indicates an average annual discharge for the 30-year period 1931-60 of about 17,800 acre-feet, which is about 5,300 acre-feet more than the calculated long-term average inflow of the measured tributary creeks. Additionally, a 3-year record, 1910-12, for Cassia Creek near Conant suggests that average annual surface-water discharge from the Elba subbasin is at least 18,000 acre-feet. This outflow from the subbasin to the Raft River valley subbasin is probably little, if any, different than before irrigation began in the subbasin.

Yost-Almo subbasin. – The average long-term surface-water inflow to the Yost-Almo subbasin from the principal streams is estimated to be at least 15,200 acre-feet. The average annual flow in Almo Creek is unknown, but is estimated to be about 1,000 acre-feet. If it is included, the total Yost-Almo subbasin surface-water inflow is about 16,200 acre-feet annually.

The Yost-Almo subbasin is composed of two principal parts: Junction Valley above the Upper Narrows, and the broad valley extending from near Almo southeastward to the western end of the Raft River Mountains near Yost. Only about 70 percent of the estimated yield of the drainage area above the Upper Narrows appears as streamflow in the narrow bedrock canyon, even though at this point the streamflow appears to be occurring virtually in a bedrock channel.

The water yield of Junction Valley determined by computation from the water-yield map is about 10,900 acre-feet, or 3,500 acre-feet more than the 7,400 acre-feet derived from extension of the measured-flow record. If the computed water-yield figure is accepted, then it must be assumed either that there is a large underflow from Junction Valley, or the short, poor record of flow near the Upper Narrows cannot be extended to a long-term average with useful accuracy. For purposes of this report, a total average annual surface-water inflow to the Yost-Almo subbasin is estimated to be about 15,200 acre-feet.

Surface flow is diverted for irrigation within the subbasin, and ground water is pumped during the irrigation season of most years. Consequently, surface runoff from the Yost-Almo subbasin to the Raft River valley subbasin is variable and somewhat less than average annual inflow. The record for Raft River at Peterson Ranch, near Bridge is indicative of the surface-water runoff from the subbasin, and shows a long-term average annual discharge of about 11,600 acre-feet.

Before irrigation began in the Yost-Almo subbasin, the average surface outflow from the subbasin at The Narrows into the Raft River valley subbasin is estimated to have been about 24,100 acre-feet per year. This estimate is derived by comparing average annual values as shown in the table below.

Estimated average surface-water outflow from Yost-Almo subbasin[a]

	Surface-water outflow (A)	Consumptive use (B)	Ground-water outflow (C)	Long-term average water yield (D)
1931-60	11,600	b17,500	c16,900	d46,000
Natural conditions	e24,100	f5,000	16,900	46,000

a All values are in acre-feet per year and are rounded to nearest 100 acre-feet.

b Estimated on basis of irrigated acreage and crops grown in the subbasin.

c Computed by difference: C = D - (A + B).

d Computed from water-yield map.

e Computed by difference: A = D - (B + C).

f Estimated on basis of probable water use by riparian vegetation along stream channels.

The 5-year average surface-water outflow (1910-14), based on records for Raft River near Bridge, was about 28,500 acre-feet. However, the years 1912, 1913, and 1914 were wetter than normal and the long-term average of 24,100 acre-feet is considered to reasonably represent flow under natural conditions.

Raft River valley subbasin. – The Raft River valley subbasin is divided into five parts for convenience of discussion: The eastern part of the Raft River Mountains; Meadow Creek, Sublett Creek, and Heglar Creek subareas; and the large lower, main part of the Raft River valley subbasin. Long-term average annual inflow (1931-60) to the subbasin from the principal tributary streams is probably about 18,000 acre-feet from Elba subbasin; 11,600 acre-feet from Yost-Almo subbasin; 8,400 acre-feet from the Raft River Mountains subarea; 120 acre-feet from Kelsaw Canyon; 5,200 acre-feet from the Sublett Creek subarea; and 200 acre-feet from the Heglar Creek subarea. Thus, the total long-term average annual surface-water inflow to the Raft River valley subbasin is probably about 43,500 acre-feet. The inflow under present-day conditions has been reduced by diversions and pumping from wells in Yost-Almo subbasin. This reduction may average about 12,500 acre-feet annually. Thus, the surface-water inflow probably was about 56,000 acre-feet annually prior to man's development in the basin.

Surface Water Diversion and Use

There are no systematic records of diversion and use of water from streams in the Raft River basin, so consumptive use of diverted streamflow must be estimated by indirect means.

Over the years, virtually all divertable surface flow during the growing season has been fully exploited. By 1928, irrigation with streamflow throughout most of the valley occurred near and along the bottomlands where crops replaced native riparian vegetation. In addition, several thousand acres outside the bottomlands was being irrigated near Yost, and consumptive use is estimated to have been about 47,000 to 48,000 acre-feet.

The streamflow available varied from year to year, but the average amount diverted and used probably changed but little until heavy pumping began about 1948. Pumping was heaviest near and within the bottom lands, and streamflow was progressively diverted by percolation to replenish the lowered ground-water levels. As pumping increased, less and less streamflow was available for diversion to irrigated lands and native riparian vegetation until by 1955 only an estimated 34,000 acre-feet of surface water was being consumed. By 1960, this quantity had declined to an estimated 27,000 acre-feet, and by 1966 there were only a few tracts irrigated by surface water. The consumptive use of surface water in 1966 is estimated to have been only about 20,000 acre-feet, or about a half that consumed by native riparian vegetation prior to development within the basin.

The reduction in consumptive use of surface water reflects a large increase in recharge to ground water through percolation of streamflow prior to diversion and use, and a major adjustment in the location of applied irrigation water and types of crops grown. During the early days of agriculture, much of the reclaimed bottom land was used for growing hay and other forage crops, and large volumes of water were applied whenever it was available. In general, consumptive use was less than 50 percent of the water applied. As irrigated plots spread farther from the bottom lands and demands grew for the available supply, crops changed as well as irrigation practices, and consumptive use probably was at least 50 percent of applied surface water.

Outflow from Raft River Valley Subbasin

Before irrigation development began, the Raft River flowed perennially from The Narrows all the way to the Snake River. At present, and for decades in the past, the flow of the river disappears in some reaches; some years as far upstream as Bridge, in other years as far downstream as Malta. Flow begins again in the vicinity of Yale at the northern end of the valley, owing to ground-water discharge and waste irrigation water.

Flow out of the basin has been measured only sporadically at a gage on the Raft River half a mile south (upstream) from Yale and just above backwater from Lake Walcott. No measurements of the flow exist prior to when irrigation began in the valley, but to judge from trends based on a few measurements, the earliest in 1910, the original surface outflow of Raft River near Yale may have been in the range of 16,000 to 18,000 acre-feet per year. For purposes of preparation of a water budget, an average discharge of 17,000 acre-feet a year is used. By 1928 the flow of the river at its mouth had been reduced to about 9,000 acre-feet per year, according to Stearns (1938, p. 213). In the late 1940's and early 1950's, the flow near the mouth, though irregular from year to year, had been further reduced to an estimated 7,000 acre-feet a year. The flow has continued to decline gradually and in 1968 was only about 1,900 acre-feet a year. On the basis of the above estimates, it appears likely that diversion and ground-water pumping have reduced the surface-water outflow by about 15,000 acre-feet annually, or by about 90 percent.

GROUND WATER

It has been calculated (table 6) that the average annual water yield of the entire Raft River basin is about 140,000 acre-feet, yet the part that moved into the central valley area under native conditions as surface flow may have been only about one-third the water yield. Most of the remainder moved into and through the central valley as ground water. There was a minor contribution to the ground-water body each year, on the average, from precipitation on the central valley area, and under natural conditions there were large demands on the ground-water body from evaporation and transpiration by native vegetation. Under present conditions, too, most of the ground water moves into the central valley from the peripheral highlands, subareas, and subbasins; moves through the permeable valley fill; and moves out of the northern end of the valley – all as ground-water underflow. This water body is replenished each year, largely during the snowmelt period, from precipitation within the basin. It is depleted by continuous surface and subsurface drain-out plus an increasing amount of pumping for consumptive agricultural use during the growing season. Under native conditions, the replenishment, quantity in storage, and natural discharge were in balance and the hydrologic system was in long-term equilibrium. The present-day diversions and pumping for the uses of man have upset the original equilibrium so that the hydrologic system is in a transient state of adjusting toward a new balance. The quantity of water demanded for consumptive uses is continuously increasing, and a new balance will not be reached until economic and physical factors act to curtail use of the water. At that time, the water body will begin to stabilize at a new equilibrium wherein replenishment will be in balance with three discharge factors; natural evapotranspiration, consumptive demand by man, and subsurface outflow. The magnitude of man's consumptive demand on the water supply during the development of the new equilibrium will be represented largely by a net reduction in ground water in storage. Some will be reflected in reduced streamflow and some in reduced subsurface outflow.

Occurrence of Ground Water

Most of the ground water in the Raft River basin occurs in the upper unit of the Salt Lake Formation, in the Raft Formation, and in the alluvial deposits. These are the principal water-bearing formations or aquifers of the valley. In the consolidated rocks, penetrated by a few wells, a relatively minor quantity of water occurs in cracks and fractures.

Evidence from many hundreds of wells shows that the main body of ground water in the Raft River basin is unconfined. Even in the formations penetrated by the deepest wells, the water is only semiconfined and stands in deep wells at about the same level as water in nearby shallow wells.

Water under artesian pressure occurs at a few places along the margins of the lowlands.

Several wells in the Raft River basin yield hot water under artesian pressure. Examples are an unnumbered well, now capped, just north of the church in Almo; well 15S-26E-23bb1 a short distance northwest of the road from Bridge to The Narrows; and well 15S-26E-23dd1 immediately south of the Raft River.

Bodies of ground water of small areal extent occur locally above the true water table beneath parts of the lowlands during the irrigation season, and some persist for several months afterward. These perched water bodies develop where water percolates downward from irrigated land and other areas of recharge, and accumulates above the water table on some semi-permeable layer of silty or clayey material. Cascading water in wells is indicative of perched water and is most common in wells in or near the bottom lands.

Depth to Ground Water

The depth to ground water in the lower Raft River subbasin ranges from virtually land surface locally near the river to more than 400 feet below land surface. The depth to water along the Raft River channel in most places is only a few feet.

Three areas of deep ground water occur in the Raft River valley subbasin: (1) An area beneath the large alluvial fan bordering the Cotterell Range on the east between The Narrows and Cassia Creek where the depth to water probably increases toward the west from about 150 to more than 400 feet; (2) a long narrow strip beneath the alluvial fans along the eastern margin of the subbasin where the depth to water probably ranges from about 150 to more than 300 feet; and (3) an area in the northwestern corner of the subbasin where the basaltic terrain rises and the depth to ground water probably increases from about 150 to more than 250 feet. Throughout the rest of the subbasin, and in the Elba and Yost-Almo subbasins, the depth to water may be equally great in small local areas, but in general the depth to ground water is less than 150 feet. Throughout the basin, the slope of the underlying water table is, as is normal, much flatter than the slope of the land surface. The varying depths to water, therefore, reflect the differential slopes and do not imply occurrence of different ground-water bodies in different parts of the valleys.

Ground–Water Recharge

The principal areas where water enters the ground to recharge the aquifers are near the mountains where streams spread out onto gravelly and pervious alluvial fans.

Only two streams, Edwards Creek and Cassia Creek, reach the Raft River during most of the year. Even Clear, Onemile, George, and Johnson Creeks, which drain high basins in the Raft River Mountains, join the Raft River only in the spring of those years when a thick snowpack yields above-average runoff. Their flows are now largely diverted for irrigation on the gravelly and pervious soils near the mountains.

A considerable amount of water enters the ground along the bottomlands of the Raft River and Cassia Creek wherever the ground-water level is below stream level. Some water diverted for irrigation also percolates to the water table from unlined irrigation ditches and from fields.

The average annual recharge to the total Raft River basin prior to irrigation cannot be determined directly. The minimum amount, however, must have been equal to the sum of subsurface outflow plus a part of the water consumed by native vegetation and by evaporation along the bottom lands. Stearns (1938, p. 218) estimated evapotranspiration from marshy areas within the main valley downstream from Bridge in 1928 to be about 30,000 acre-feet. In addition to these bottom land areas, there were approximately 10 square miles, or 6,400 acres of similar areas of evapotranspiration in Elba and Yost-Almo subbasins and elsewhere in the peripheral drainages. It is estimated that the total loss from both ground and surface water under natural conditions was about 40,000 acre-feet.

It has been estimated that annual surface outflow from the basin prior to irrigation average 16,000 to 18,000 acre-feet and that total evapotranspiration averaged about 40,000 acre-feet annually. Consequently, because long-term annual average water yield was about 140,000 acre-feet (table 6), and was in balance with total discharge, the long-term average recharge must have been at least 82,000 to 84,000 acre-feet. Much of the water evaporated and transpired along the bottom lands was from areas where the ground-water level was less than 10 feet below land surface. Therefore, a large part of this water came from ground water, and it may be assumed that total recharge averaged more than 100,000 acre-feet annually.

Average annual ground-water recharge to the Raft River basin from all sources, under 1966 conditions of development, has increased since irrigation began and now may be about

130,000 acre-feet. The increase is caused principally by diverting surface water for irrigation, about half of which percolates beneath the root zone to recharge ground water, and partly by pumping which locally has lowered water levels beneath the stream channels and caused increased percolation from the streams to the underlying water table.

Ground–Water Movement

Viewed broadly, ground water in the Raft River basin moves from the mountains toward the central part of the peripheral subbasins and subareas, then into the Raft River valley subbasin and finally northward. At the northern end of the valley, the ground water moves northwestward beneath the lava plains south of the Snake River, and there joins the immense body of ground water in the Snake Plain aquifer. The water moves downgradient, and the paths of flow are essentially at right angles to the water-level contours (fig. 14).

As the water-level contours show, the slope of the water table is steepest near the mountains and gradually becomes flatter toward the north. The slope of the water table is about 200 feet per mile near Standrod, then diminishes in the Raft River valley subbasin to about 25 feet per mile near Bridge, and to about 17 feet per mile between Malta and Horse Butte. The slope of the water table beneath most of the lava plains south of the Snake River is low, at most only a few feet per mile.

The rate of movement of ground water throughout the basin is slow, especially in the areas of flatter slope of the water table. Even at much steeper water-table gradients such as exist in and near the heavily pumped areas, the rate of movement of the ground-water body is only a few inches or feet per day. As a result, the hydrologic system is slow to adjust to the large pumping stresses and other consumptive demands now imposed upon it. The permeability of the material making up the water-bearing units largely determines the rate at which the water will move under existing conditions and, therefore, the rate at which the system adjusts to new discharge demands or to recharge.

Yost-Almo Subbasin

Ground water moves from recharge areas that are along and within the Albion Range and Junction Valley toward the central part of Yost-Almo subbasin. Faulting and the occurrence at shallow depth of the poorly-permeable middle and lower units of the Salt Lake Formation restrict movement in the southwestern part of the subbasin, and some of the ground water emerges at Reed Spring. Underflow from the areas of George and Johnson Creeks and the creeks west of Almo moves generally toward the center of the subbasin, then eastward toward Raft River valley subbasin.

The details of where and how ground water moves through the vicinity of The Narrows are not known. Nace and others (1961, p. 47), the only investigators to publish analysis of this underflow, interpreted existing data to indicate a "throat" discharge from the subbasin at The Narrows and that nearly all discharge moved through it. Their analysis, even allowing for consumptive use within the subbasin and for some underflow through the Salt Lake Formation other than at The Narrows, was based on a gradient of 40 feet per mile and an alluvial channel-fill cross section of 500,000 square feet. This required a permeability of about 7,000 to 10,000 gpd per square foot to account for the computed amount of underflow.

At no other location in the Raft River basin is there evidence presented in previous reports or developed by the current study to indicate permeability values as great as 7,000 to 10,000 gpd per square foot in the valley-filling sediments. Nace and others (1961, p. 96) suggested an average permeability of about 1,000 gpd per square foot for the upper 200 feet of sand and gravel in the alluvial aquifer elsewhere in the basin, and this is substantiated by more modern data. When one takes note of the fact that the alluvium in the filled channel at The Narrows had to be, for the most part, transported across the aggrading, broad Yost-Almo subbasin floor to reach The Narrows, it seems unreasonable to expect the entire cross section to be uniform, coarse, well-sorted sand or gravel. Consequently, in this report, the average permeability of the alluvium at The Narrows is estimated not to exceed 2,000 gpd per square foot, or about twice that of the coarser alluvial deposits elsewhere in the basin. It probably is much less.

The long-term, average annual water yield of the Yost-Almo subbasin has been estimated to be about 46,000 acre-feet. Consumptive use by native riparian vegetation has not changed significantly and is estimated to be 5,000 acre-feet per year. Present-day agriculture in the subbasin consumes additionally about 12,500 acre-feet annually. Surface-water outflow averages 11,600 acre-feet annually under present-day conditions. Consequently, about 16,900 acre-feet annually cannot be accounted for and must be considered as ground water moving through the vicinity of The Narrows toward the Raft River valley subbasin. Using the same gradient and cross section as proposed by Nace and others (1961) and a permeability of 2,000 gpd per square foot, only about 8,500 acre-feet, or one half the total ground-water underflow, can move annually through the alluvium of The Narrows.

Elba Subbasin

Movement of ground water in the Elba subbasin is largely as shallow underflow along and beneath the principal stream channels. There are no extensive permeable valley-filling deposits to form large aquifers, and most of the yield of the subbasin discharges across the Cotterell Range as surface flow in Cassia Creek. The direction of ground-water movement is toward the valley center near Elba, then northeastward down the valley of Cassia Creek where the gradient is approximately 100 feet per mile. Probably no more than 600 to 800 acre-feet of ground water moves through the alluvium of Cassia Creek valley each year from

Elba subbasin to the Raft River valley subbasin.

Raft River Valley Subbasin

In addition to the approximately 18,000 acre-feet of underflow from the Yost Almo and Elba subbasins, the ground-water body of the Raft River valley subbasin receives large amounts from the Raft River Mountains, the area around Strevell, and the Black Pine Range. As the ground water moves toward the center of the valley and northward, it continues to increase in volume through underflow from the Black Pine and Sublett Ranges, and through percolation of streamflow and of water applied to lands overlying the subbasin. The gradient is steepest near the mountain flanks, decreasing uniformly toward the valley center and northward. This increasing volume and decreasing gradient reflects a greatly increased volume of water-bearing materials toward the north, and to some extent may reflect an increase in average permeability, particularly in the basalt.

As has been stated, the long-term average annual water yield of the entire basin is estimated to be 140,000 acre-feet, of which about 82,000 to 84,000 acre-feet annually was ground-water outflow under native conditions. It is of interest to assess the ability of the aquifers to transmit this volume of ground water.

Nace and others (1961, p. 95-96) showed by use of the equation

$$Q = TIW$$

Q = quantity of water, in gallons per day

T = transmissibility, in gallons per day per foot

I = gradient of the water table, in feet per mile

W = cross-sectional width of the valley, in miles

that an east-west cross section about 3 miles north of Idahome would transmit about 54,000 acre-feet per year through the upper 200 feet of alluvial aquifer if it had an average permeability of 1,000 gpd per square foot, a gradient of 20 feet per mile and a width of 12 miles. The more than 1,200 feet of less-permeable deeper materials were judged to be adequate to transmit the remainder of the full estimated underflow.

Modern well logs and new mapping show that the outflow section chosen by Nace and others (1961) probably averages only about 10 miles in width (fig. 1 and geologic cross section A–A'), but that it is fully as thick as suggested. Using the equation and values of 84,000 acre-feet per year (75,000,000 gpd), a gradient of 20 feet per mile, and a width of

10 miles and solving for T:

$$T = \frac{75,000,000}{20 \times 10} = 375,000 \text{ gpd per foot}$$

The average thickness of the combined aquifers at this location (fig. 8) is about 1,300 feet, consequently the average permeability needed to transmit 84,000 acre-feet per year through the cross section is somewhat less than 300 gpd per square foot. This value is nearly the same as the average permeability that may be estimated by applying known permeability values to the various units described in drillers' logs. It is of the same order of magnitude but somewhat higher than the permeability that may be derived from specific-capacity data by application of a procedure proposed by Theis and others (1963). Although direct measurements have not been made to determine average permeability throughout the basin, the indirect data show that the water-bearing units of the valley fill are capable of transmitting the estimated quantity of ground water available for movement through the various parts of the basin.

Ground–Water Discharge

Ground water is discharged from the saturated rocks of the Raft River basin in several ways, by far the most important of which are pumping and subsurface outflow. Springs and evapotranspiration draw upon the ground-water body, but their aggregate demand is small by comparison.

Wells and Well Yields

When the Raft River basin was closed to further drilling of irrigation wells in 1963, about 290 irrigation wells were in use in the valley. By 1966, holders of valid permits at the time of closing had constructed additional wells, and about 320 wells were in use. The majority of these wells is grouped in the northern end of the Raft River valley subbasin in T. 11 S., with most of the remainder spread southward along the river bottom lands in Tps. 12-15 S., Rs. 26-27 E. (fig. 15).

The aggregate pumpage is large, but the yield of individual wells varies greatly. Many factors cause the variability of yield, but possibly the most important are well depth, method and adequacy of construction, and development after construction. The aquifer units also vary as to yield characteristics from one locality to another.

Yield alone is not a useful measure by which wells or the water-bearing properties of formations can be compared. For example, two wells that each yield 100 gpm, but have drawdowns of 5 and 50 feet, respectively, either tap formations of different water-yielding character and thickness or one of them was not constructed to take full advantage of the water-yielding properties of the available aquifer.

The specific capacity, yield in gallons per minute per foot of drawdown, is a much better index of the water-yielding character of the well and penetrated formation than is the yield alone. The specific capacity is generally determined during completion tests by well drillers but was determined for a large number of the wells in the valley by the authors specifically for use in this study. A summary of average yield and specific capacity of wells in the several water-bearing formations is given in the following table.

Yields and specific capacities of wells in the water-bearing formations of the Raft River basin.

Formation	Yield (gpm)			Specific capacity		
	No. of tests	Average	Median	No. of tests	Average	Median
Limestone of pre-Tertiary age	2	1,485	-	2	22.5	-
Upper unit of the Salt Lake Formation	18	1,520	1,600	9	27	19
Raft Formation	96	1,350	1,200	64	32	25
Basalt of Snake River Group	6	2,700	-	4	250	-
Alluvium	21	984	900	13	72	68

The aquifer thickness penetrated by wells is a major influence on the specific capacity. For example, deep wells which fully penetrate a thick aquifer of uniformly permeable materials have higher specific capacities than shallower wells which penetrate a smaller thickness of the aquifer, if wells are compared whose construction is equal and adequate.

Water–Level Changes

The natural fluctuations of water level in the Raft River valley are shown by hydrographs (fig. 15) based on measurements in two unused wells distant from irrigation. Well 15S-25E-6ab1 is a short distance north of Almo, and well 16S-27E-26ba1 about 7.5 miles north of the foot of the Raft River Mountains and a mile east of Naf. The water level in both begins to rise in late winter or early spring, crests in summer, and declines to a

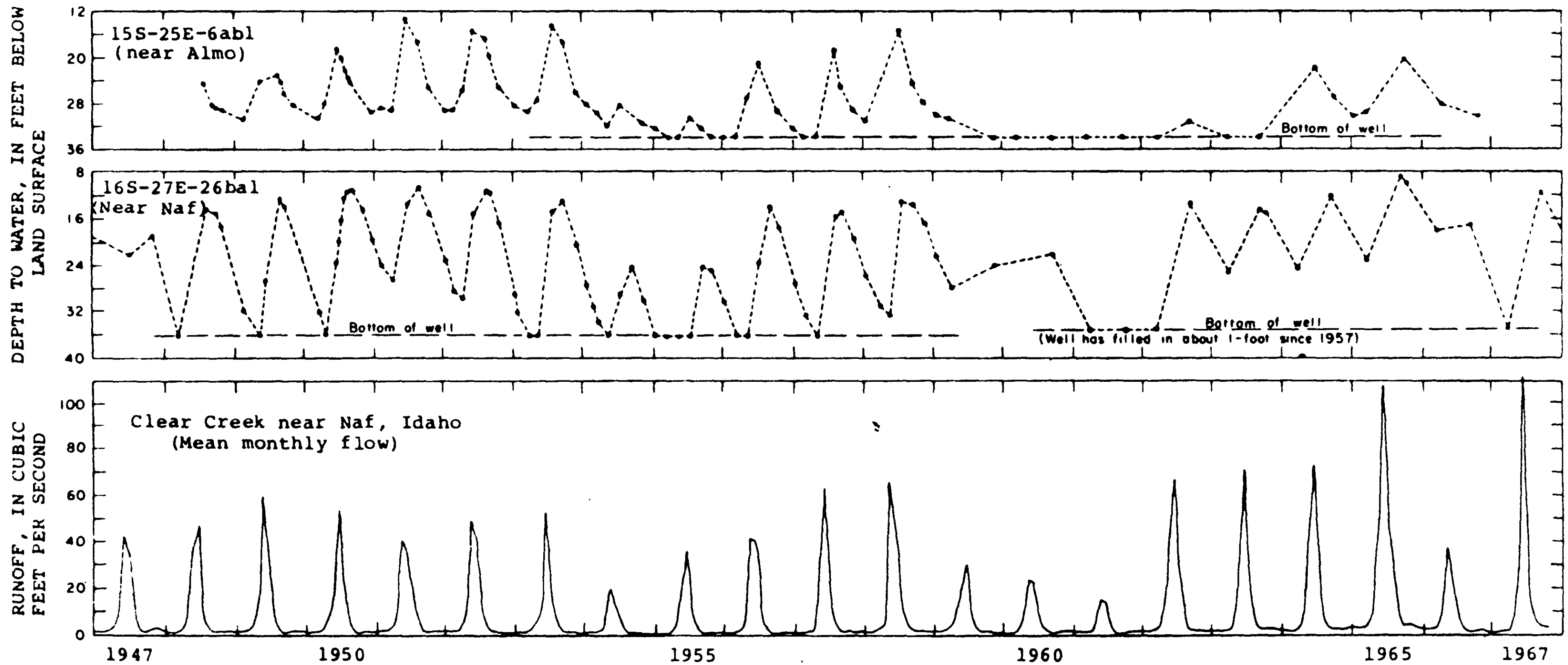


FIGURE 15.– Hydrographs of selected wells in southern part of Raft River basin, and runoff of Clear Creek near Naf.

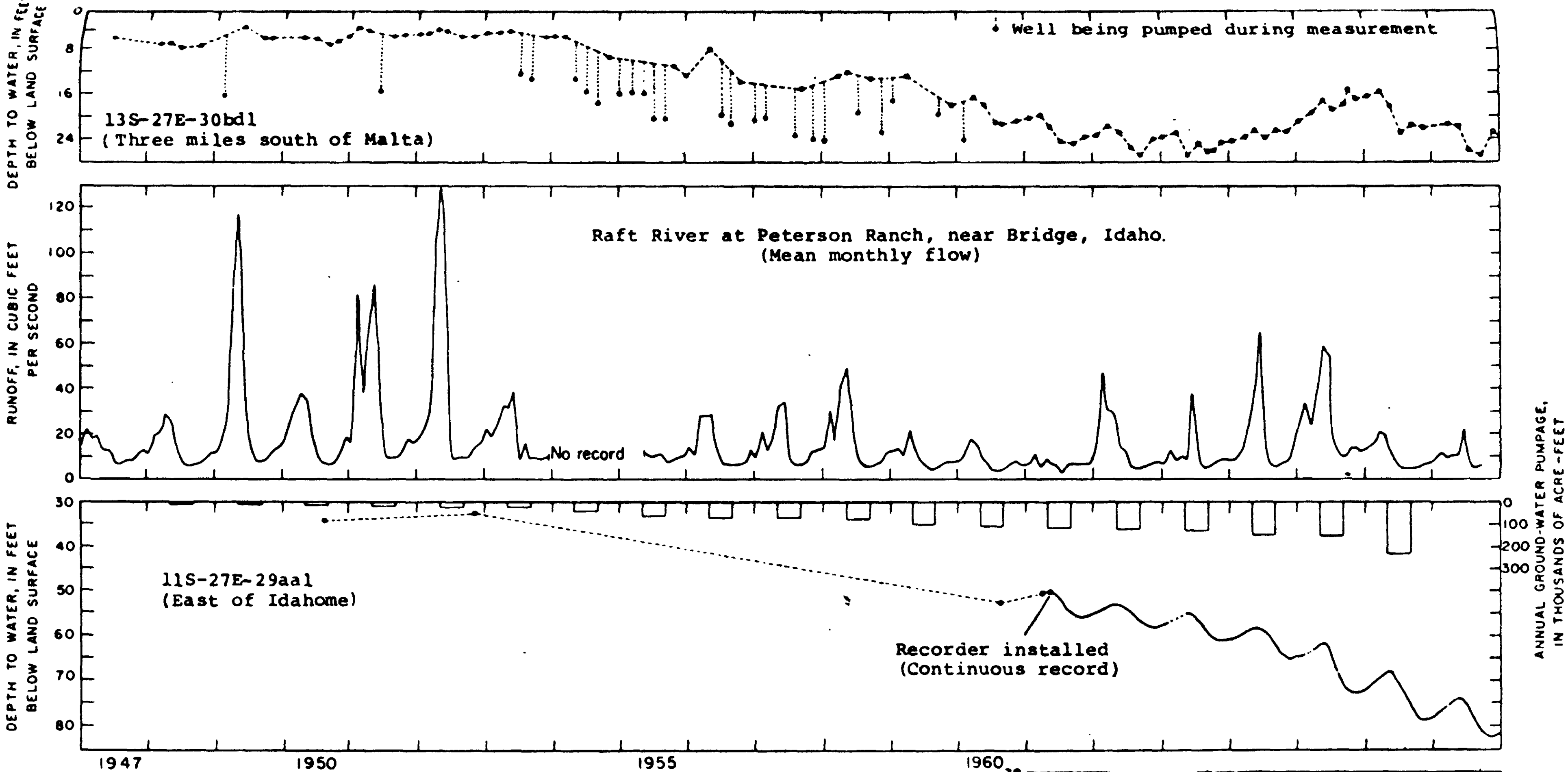
seasonal low in late winter. The water level begins rising earlier (in March or April) in well 15S-25E-6ab1 north of Almo, than it does in well 16S-27E-26ba1 (in April-May) near Naf because snowmelt occurs earlier near Almo than on the northern side of the Raft River Mountains. Natural fluctuations of water level in other parts of the Raft River basin, if they were not masked by the effects of irrigation or pumping, probably would show about the same pattern. However, the rise in water level would begin later in spring along the bottom lands of the Raft River and Cassia Creek than at sites near the mountains.

Beneath the wide alluvial fans east of the Raft River, where the distance from streams which provide recharge is large, water level begins to rise much later in spring than in localities nearer to sources of recharge.

Natural water-level fluctuations closely reflect the changing amounts of recharge that result from differences in precipitation and runoff from year to year. The hydrograph (fig. 15) of well 16S-27E-26ba1 a mile east of Naf shows close correlation with the runoff of Clear Creek (Nace and others, 1961, p. 67). The water level in the well, as indicated by the yearly crests, rose gradually from 1947 until the early 1950's, and the runoff increased yearly during this time. The water level declined markedly in 1954, a year of below-average runoff. The water level then rose until 1958, responding to years of above-average runoff, and declined in 1959 and 1960, when runoff decreased. Thereafter, the water level rose to a record high in 1965 after the 3 wet years 1963-65, and declined sharply in 1966, an unusually dry year.

Most observation wells in the Raft River basin are located where irrigation has affected water levels, and the hydrographs of these wells reveal several important results of irrigation. The water levels in areas where large amounts of water are pumped for irrigation show a generally similar pattern of seasonal fluctuations, as is shown in the hydrograph of well 11S-27E-29aa1 (fig. 16). The water level in the well rises through winter and spring and reaches a peak sometime near the end of May when it begins to decline because pumping begins from nearby wells. The decline continues until pumps are turned off in October or November, depending on the water needs of the particular year. Water level then begins a rise that continues through winter and spring, until pumping begins again. This rise is due chiefly to water moving from surrounding areas into the cones of drawdown that summer-long pumping has created. This rise in water level through autumn and winter is the distinguishing feature of hydrographs of wells in areas of pumpage, as contrasted with natural water levels which normally decline through autumn and winter.

The long-term changes of water level beneath irrigated areas in the Raft River basin depend on location. The water-level changes near streams capable of supplying recharge differ significantly from those in areas farther from sources of recharge. The hydrograph for well 13S-27E-30bd1 (fig. 16) shows the water-level changes since 1948 in the bottom lands along the Raft River. This record reflects fairly closely the total pumping in this area, because the annual pumpage from the whole basin in 1948 was only about 10,000 acre-feet



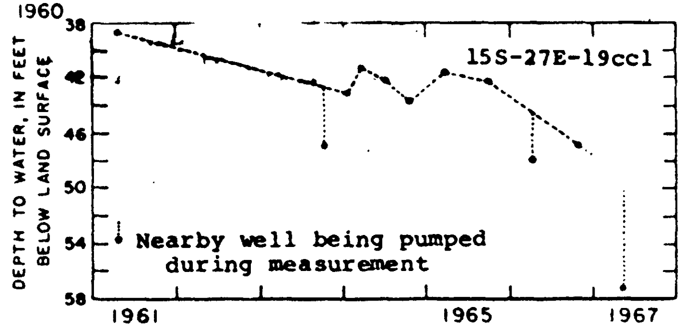


FIGURE 16.– Hydrographs of selected wells in central part of Raft River basin, annual ground-water pumpage, and runoff of Raft River at Peterson Ranch.

and ground-water levels apparently had not been affected appreciably. Prior to 1948 the water level was still within a few feet of land surface beneath the bottom lands. The water-bearing formation was, therefore, nearly full beneath the bottom lands and capable of accepting only a small amount of recharge from the Raft River.

The overall record from this well shows that net pumpage in this part of the valley exceeds local recharge during years of normal precipitation but that the water level recovers in wet years, due mainly to local recharge from the river and seepage of water diverted from the river. Hydrographs of other wells along the Raft River bottom lands, from well 15S-27E-19cc1 northward, show the same pattern of fluctuations from the early 1950's to the early 1960's, a rise during the wet years 1963-65, and then a decline.

The hydrographs also show that recovery of the water level, in the wet years 1963-65, decreased north of Malta, until in well 10S-27E-35ac1 (fig. 17) there is no evidence of recovery. Recovery of water level is less toward the north because the source of recharge, flow in Raft River and Cassia Creek, is now nearly fully utilized to the south.

Beneath heavily pumped areas that are located away from principal sources of recharge, the ground-water level generally shows a progressive decline. The hydrographs of many wells show this trend, but it is illustrated especially well by the hydrograph of well 11S-27E-29aa1 (fig. 16). The peaks and troughs of this hydrograph are lower each successive year, signifying that part of the pumped water is derived from storage. The water level declined 46 feet in this well from the first measurement in August 1950 to August 1967, or at an average rate of 2.7 feet per year. The water level showed neither a recovery nor a decrease in the rate of decline during the wet years 1963-65. The average rate of decline has increased to about 6 feet per year in the period 1965-67, reflecting the increasing amount of nearby pumping and pumping elsewhere in the valley.

Ground–Water Pumping

Pumping of ground water in the early years was to supplement the inadequate supplies of surface water. The success of wells and the coming of electrical power stimulated development, and irrigation with ground water spread from the bottom lands onto the higher alluvial fans. The discovery that ground water could be obtained almost anywhere in the valley led to the present (1966) distribution of irrigated land (fig. 5).

Ground-water pumpage in the Raft River valley is shown in figure 18 and is listed by township in table 10. Pumpage increased from about 8,600 acre-feet a year in 1948, the first year pumpage was estimated, to about 235,000 acre-feet in 1966. Total pumpage prior to 1948 is estimated at about 30,000 acre-feet. Total pumpage through the 1966 irrigation season is computed to be about 1,600,000 acre-feet.

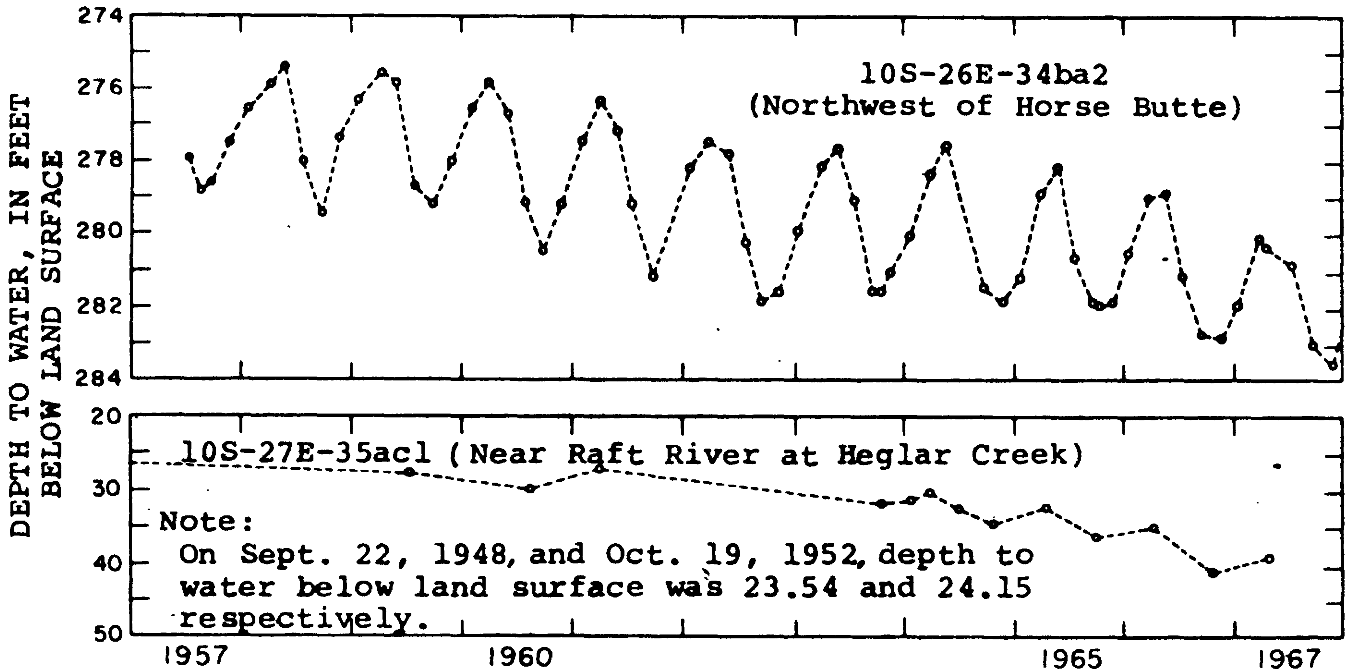


FIGURE 17.– Hydrographs of selected wells in the outflow area at the north end of the Raft River basin.

Table 10. Ground water pumped, in acre-feet, in the Raft River basin, 1948-66. (Data from Nace and others, 1961; Mundorff and Sisco, 1963; and data compiled by H. G. Haight and E. H. Walker. Values computed from power-use data.)

Town-ship	Range	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	Total
10	25	-	-	-	-	-	-	-	-	-	-	400	490	700	590	-	790	560	750	1,630	5,910
	26	0	0	0	0	260	360	700	1,800	2,000	2,000	2,200	2,700	2,820	3,130	5,410	4,540	4,920	4,910	6,700	44,450
	27	0	0	40	300	950	1,600	1,000	1,000	1,000	1,000	1,150	1,410	2,730	4,040	3,770	3,590	5,230	6,870	8,940	44,620
	28	0	510	700	640	620	1,040	900	900	2,700	3,000	5,000	6,130	4,490	2,250	2,620	4,200	5,280	5,420	6,090	52,490
11	26	870	1,100	2,400	2,900	5,400	4,950	6,700	9,800	9,500	9,000	9,700	11,890	13,640	12,670	16,320	13,170	17,370	17,130	26,330	190,840
	27	470	1,400	-	1,300	2,800	2,900	5,000	8,800	10,500	11,000	13,400	16,430	17,960	22,850	21,060	27,030	35,940	43,240	53,940	296,020
	28	0	0	0	0	0	0	1,000	1,300	1,500	1,500	2,000	2,450	1,760	1,430	2,210	2,180	3,930	5,140	7,490	33,890
12	26	40	40	190	1,800	2,200	2,850	5,900	6,700	7,000	7,000	7,800	9,560	7,750	6,850	8,520	9,080	8,820	7,510	11,110	110,720
	27	0	0	70	210	500	520	1,700	2,100	2,100	2,000	2,700	3,310	3,700	4,570	5,040	4,850	6,030	4,820	7,910	52,130
	28	-	-	-	-	-	-	-	-	300	400	650	800	1,140	1,650	1,820	680	1,850	690	2,750	12,730
13	25(Elba)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70	180	220	740	1,210
	26	380	440	250	340	490	520	750	2,300	2,300	1,800	1,800	2,210	5,460	3,520	3,480	3,940	3,080	1,400	9,900	44,360
	27	3,600	3,900	4,800	3,300	4,200	4,700	8,200	9,300	9,500	9,600	10,400	12,750	14,520	16,330	18,070	17,290	19,990	19,000	32,090	221,540
	28	-	-	-				-	-	80	80	80	100	570	1,970	2,360	2,330	2,360	2,280	3,050	15,260
14	25(Elba)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	260	260	250	770
	27	900	1,600	2,500	2,200	3,000	3,100	8,200	11,500	13,500	14,000	16,300	19,990	21,120	24,600	21,060	20,370	18,030	16,260	26,410	244,640
15	24(Almo)	-	-	-	-	-	-	-	-	650	800	1,000	1,230	1,890	1,360	840	980	750	260	1,370	11,130
	25(Almo)	-	-	-	-	-	-	-	-	0	0	0	0	620	830	630	630	490	230	950	4,380
	26	1,300	1,400	1,500	1,200	1,100	910	2,200	2,100	2,300	2,400	2,500	3,060	3,520	2,460	2,480	3,030	3,230	4,540	5,710	46,940
	27	840	800	1,000	790	1,100	1,800	4,200	6,400	5,500	5,100	5,100	6,250	5,630	5,080	4,810	6,440	5,980	7,630	14,640	89,090
16	24(Almo)	180	200	220	200	200	220	-	-	300	350	400	490	1,230	1,030	720	1,330	1,940	1,820	3,470	14,300
	25(Almo)	70	70	70	70	70	70	70	70	400	600	650	800	480	1,560	1,410	1,660	1,880	1,610	2,660	14,270
	26	-	-	-	-	-	-	-	-	370	370	370	450	40	-	-	-	-	-	-	1,600
	27	-	-	-	-	-	-	-	-	-	-	160	200	,210	360	60	80	-	-	860	1,930
Total (rounded)		8,600	11,500	13,700	15,200	22,900	25,500	46,500	64,100	71,500	72,000	83,800	102,700	112,000	119,100	122,700	128,300	148,100	152,000	235,000	1,555,200

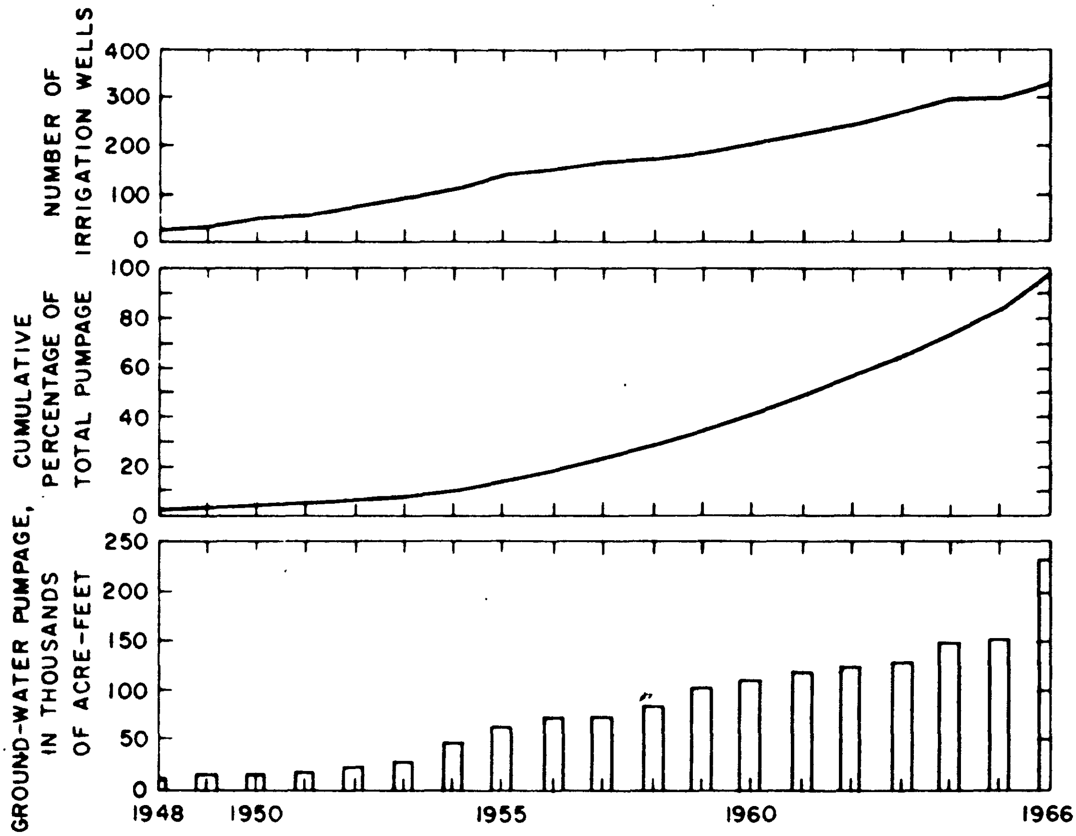


FIGURE 18.– Graphs showing pumpage in the Raft River basin and number of irrigation wells.

The prime data used for computing ground-water pumpage are the kilowatts of electric power and therms of natural gas used by irrigation-well pumps. These data have been made available through the courtesy of the Raft River Electric Cooperative and the Intermountain Gas Company. The relation between energy consumed and acre-feet of water pumped has been determined by measurements at more than half the irrigation wells in the valley. The pumpage from other wells has been computed by applying factors developed from the measurements to the amount of energy consumed by individual pumps.

Pumpage was estimated for the years 1948-55 by Nace and others (1961), for the years 1956-60 by Mundorff and Sisco (1963), and for the years 1961-64 by H. G. Haight (1965) of the Idaho Department of Reclamation. Pumpage in 1965 and 1966 was computed by the authors.

The methods used by Mundorff and Sisco (1963) to estimate the pumpage for 1956-60 give more acre-feet of water pumped per unit of energy than does the method used during the more detailed studies by H. G. Haight and during this study. The pumpage estimated by Mundorff and Sisco for 1960 has been revised downward slightly in the present report to avoid showing an apparent slight decline in pumpage from 1960-61, when an increase in energy consumption occurred, and therefore, presumably in pumpage.

Pumpage increased markedly in 1954, a dry year, and kept climbing thereafter. As shown by the curve of cumulative percentage of total pumpage (fig. 18), about half the total occurred during the years 1962-66 and a quarter in 1965-66. Pumpage climbed to 235,000 acre-feet in 1966, an increase of 83,000 acre-feet over the previous year. This unusually large increase occurred because precipitation at lowland stations was only about 6 inches or about half of normal; upland precipitation and runoff were correspondingly low.

Consumptive Use of Ground Water

The relative proportions of pumped ground water that are evaporated or consumed by crops, or that percolate downward to the water table, vary with time and place depending on the amounts applied, method of application, and character of the soil. Direct measurement of the consumptive use by crops in the Raft River basin was not made, nor have such measurements been reported. To estimate the quantity of ground water consumed by irrigation, a consumptive-use factor based on the types of crops grown is applied to total acres irrigated by ground water.

The total water estimated to be needed for maturing the types of crops grown in the Raft River basin (see Jensen and Criddle, 1952) is given below. The values for water requirements include average unavoidable evaporation.

Consumptive water requirement, in inches, for crops in Raft River basin

Crop	Total consumptive water use	Average precipitation during growing season	Consumptive irrigation water use
Alfalfa	22.1	3.5	18.6
Grass, pasture	20.8	3.5	17.3
Sugar beets	19.5	3.5	16.0
Potatoes	18.9	3.5	15.4
Small grains	15.66	2.5	13.1
Average	19.4		16.1 (1.34 feet)

Precipitation during the growing season provides some moisture, and this precipitation is subtracted from the total consumptive water use to give the consumptive irrigation water use requirement. The precipitation during the growing season was calculated from the records at Malta, where the length of growing season, about 120 days, and the precipitation values are believed to be representative of the areas where most of the irrigation agriculture is concentrated.

The procedure for determining consumptive irrigation water use does not take into account water that may be stored as soil moisture from precipitation before the growing season. Under favorable conditions a few inches of water may be stored in the soil, thereby reducing the requirement for irrigation water. On the other hand, summer precipitation is less than 100 percent effective in supplying the needs of plants, because much summer precipitation only wets the uppermost part of the soil and evaporates before being used by crops. Moisture carried over in the soil from before the growing season is, therefore, assumed to balance out the portion of summer precipitation which is ineffective.

It is assumed that the consumptive irrigation water use of crops irrigated with surface water has remained relatively constant over the years at about 1.35 feet per acre annually, but the data on pumpage and acreage irrigated indicate that the average consumptive irrigation water use of crops irrigated with ground water has increased over the years. In the early years, consumptive use of ground water is assumed to have also averaged about 1.35 feet per acre annually but gradually increased due to crop changes or changing irrigation practices.

For example, during the period 1948-55, the records of acres irrigated and total water pumped each year show that an average of about 2.25 acre-feet of water was pumped per acre irrigated. If the consumptive irrigation water use was 1.35 feet per acre, then 60 percent of the applied water was consumed. Since 1955, the amount of ground water pumped per acre irrigated has increased, until in 1964 and 1965 the average was about 2.8 acre-feet per acre. If consumptive use is still considered to be 60 percent, then the indicated average consumptive irrigation water use is increased to 1.68 feet per acre.

It may be that prior to 1955 a part of the consumptive use requirement was met on some acreage by surface water, so the net consumptive irrigation water use was greater than 1.35 feet per acre. Alternatively, it may be that current practices apply more water than necessary and that consumptive use is less than 60 percent. For purposes of this report, consumptive use of ground water is assumed to be 60 percent of total pumpage, and this value is used to compute total consumptive use in table 11.

Table 11. Estimated irrigated acreage, pumpage, consumptive use, and outflow of both ground water and surface water, 1928-66.

Year	Ground water				Surface water	
	Irrigated acreage	Pumpage (acre-feet)	Consumptive use (acre-feet)	Subsurface outflow (acre-feet)	Consumptive use (acre-feet)	Surface outflow (acre-feet)
1928	0	0		83,000	a47,500	9,500
1948	3,800	8,600	5,200	83,000	46,300	7,000
1949	5,100	11,400	6,900	83,000	44,100	7,000
1950	6,100	13,700	8,200	83,000	41,900	6,500
1951	6,800	15,200	9,100	83,000	39,700	6,500
1952	10,100	22,900	13,700	83,000	37,500	6,000
1953	11,300	25,500	15,300	83,000	35,300	5,500
1954	20,700	46,500	28,000	83,000	34,100	5,500
1955	26,000	64,000	38,400	82,800	33,800	5,000
1956	30,000	71,500	43,000	82,600	32,000	4,500
1957	30,000	72,000	43,200	82,300	31,000	4,000
1958	34,000	83,700	50,200	82,000	30,000	3,500
1959	39,000	102,700	61,500	81,800	28,000	3,000
1960	42,000	112,000	67,000	81,600	27,000	2,700
1961	44,000	119,000	71,500	81,300	26,000	2,400
1962	46,000	122,700	73,600	81,000	25,000	2,000
1963	49,000	128,200	77,000	80,800	24,000	2,000
1964	54,000	148,000	89,000	80,500	22,000	2,000
1965	54,000	152,000	91,200	80,200	21,000	1,900
1966	69,200	235,000	141,000	80,000	20,000	1,900

a 40,000 acre-feet consumed by riparian vegetation plus 7,500 from diversion for irrigation.

THE WATER BUDGET

The data from this study show that average annual precipitation input to the Raft River is about 1,280,000 acre-feet, and that water yield averages 140,000 acre-feet annually. From the definition of water yield, it is apparent that natural evapotranspiration averages about 1,140,000 acre-feet annually, or 89 percent of total average precipitation. Stated differently, only 11 percent of the average annual precipitation input to the basin is available as water yield; and that small amount has large natural demands against it. When the basin was in a natural condition, the increments of the water budget, in acre-feet, for the basin and its subbasins are estimated to have been as follows:

Yost–Almo subbasin		
Water yield from Junction Valley area		10,900
Water yield of main part of Yost-Almo subbasin		35,100
Consumptive use by riparian vegetation	5,000	
Subtotal	5,000	46,000
Elba subbasin		
Water yield of subbasin		22,600
Consumptive use by riparian vegetation	5,000	
Subtotal	10,000	68,600
Raft River Valley subbasin		
Water yield of subbasin		71,400
Consumptive use by riparian vegetation	30,000	
Surface-water outflow	17,000	
Subsurface outflow	83,000	
Total	140,000	140,000

As the water resources of the basin were developed and used, the elements of the budget in the subbasins were greatly modified until, by 1966, there existed a large imbalance between water yield and total discharge from the system. In the Elba subbasin, a small growth of consumptive use for irrigation was virtually offset by a reduction in use by riparian vegetation as land was cleared. Irrigated agriculture in the Yost-Almo subbasin, however, increased consumptive use in that subbasin to about 17,500 acre-feet so that outflow from the subbasin was reduced. Heavy pumping near the northern end of Raft River valley subbasin caused a small net reduction in water-level gradient within the ground-water outflow section, but the pumping depression had not been maintained long enough by 1966 to allow the gradient to adjust to a new equilibrium. Consequently, the quantity of outflow has been reduced only slightly and is estimated to have been about 80,000 acre-feet in 1966.

The amount and character of the imbalance under existing conditions in the basin are shown by a water budget for 1966. All values are in acre-feet.

Water budget, 1966 – Raft River basin

Water yield		140,000
Consumptive use:		
Riparian vegetation in Yost-Almo and Elba subbasins plus surface water diversion for irrigation in all subbasins	20,000	
Pumped ground water (table 11)	141,000	
Surface-water outflow	1,900	
Subsurface ground-water outflow	80,000	
Total	242,900	140,000
Imbalance (storage draft), rounded	103,000	

The approximately 103,000 acre-feet of net withdrawal from the basin in 1966 in excess of water yield must have come from ground water in storage. The effects of this depletion can be assessed by consideration of the amount of water in storage and the manner in which it is distributed.

GROUND WATER IN STORAGE

The total volume of ground water in storage in the basin is unknown and cannot be determined practically. Estimates can be made, however, of the amount of stored ground water that would be yielded by gravity drainage from the various water-bearing units as the static water level is lowered a specified distance. For purposes of this report, it is assumed that the ground water of economic interest is that which is stored within the 200-foot interval beneath the 1966 static water level. The specific yield of the deposits in this depth interval is the ratio of the volume of water which the deposits will yield by gravity, after being saturated, to the volume of the deposits drained. Thus, if the area of the deposits, the thickness drained, and their average specific yield is known, the volume of water in storage may be approximated.

Figure 19 shows the estimated average specific yield of deposits within the various storage units of the Raft River valley subbasin, based on estimates of specific yield as developed in the following sections. Similar estimates have not been made for the other subbasins. Using the areas shown in figure 19, the indicated average specific yield, and a depth interval of 200 feet below the 1966 water level, or to the top of underlying low-permeability deposits, whichever is less, it is estimated that about 9,000,000 acre-feet of ground water was stored in the 200-foot interval of the Raft River valley subbasin storage units in 1966.

Specific Yield

The average specific yield of the basic lithologic types of basin-filling sedimentary deposits has been determined by many investigators in numerous localities. Also, laboratory determination of specific yield on a large number and a broad range of samples is summarized in a report by Morris and Johnson (1967). Johnson (1967) has compiled average values for basin-filling sediments in numerous localities, and these values are herein accepted as representative of the water-bearing sediments of the Raft River basin.

Estimated specific yield of water-bearing sediments in Raft River basin

Material	Range	Average
Clay	1- 5	2
Silt	3-12	8
Sandy clay	3-12	7
Fine sand	10-32	21
Medium sand	15-32	26
Coarse sand	20-35	27
Gravelly sand	20-35	25
Fine gravel	17-35	25
Medium gravel	13-26	23
Coarse Gravel	12-26	22

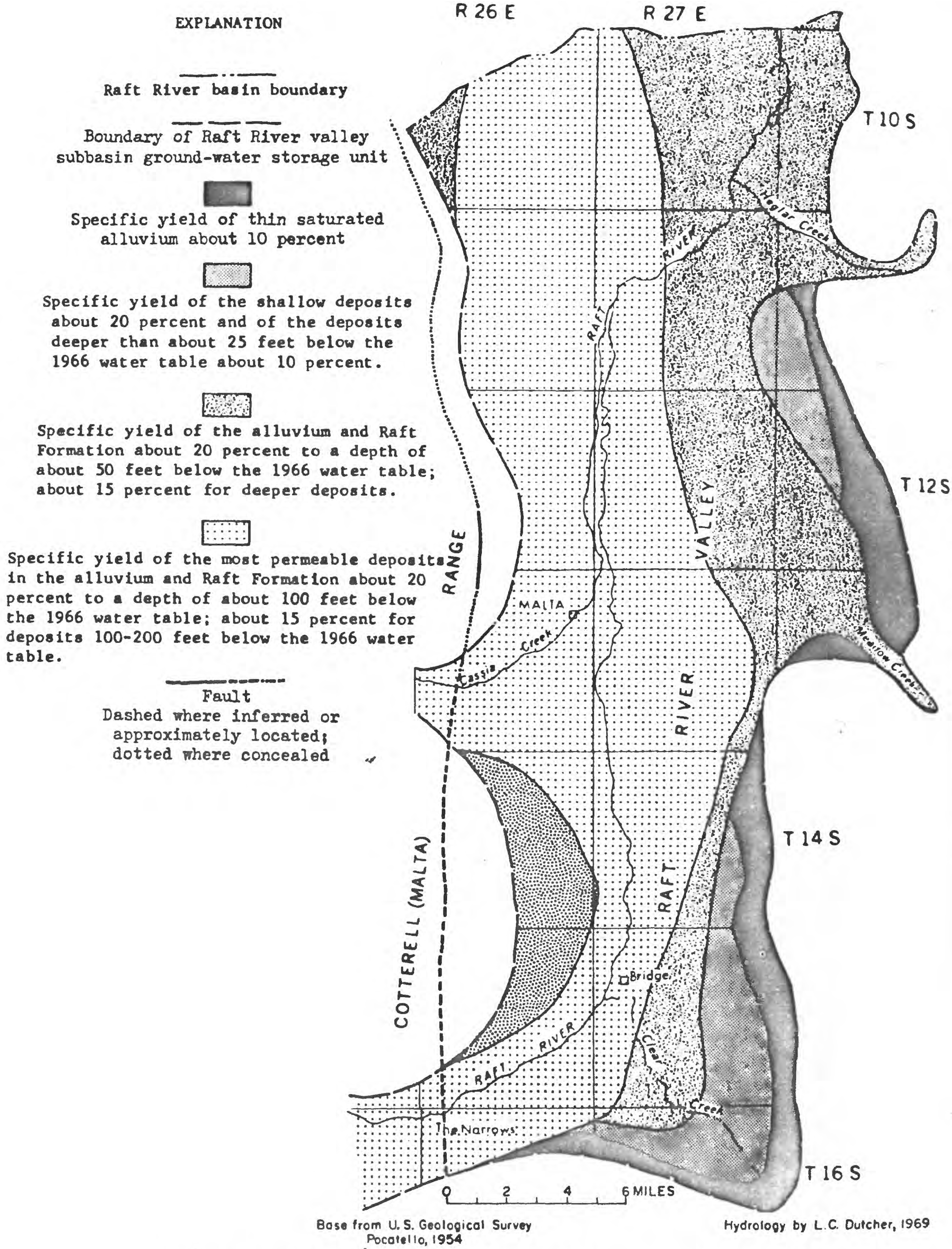


FIGURE 19.– Estimated average specific yield of water-bearing deposits in Raft River valley subbasin.

To apply these values to lithologic units of the Raft River basin, it is necessary to relate terms used in drillers' logs to the general lithologic classes listed and estimate where the term falls within each range.

All terms used to describe the sediments reported on drillers' logs of wells in the basin were listed and classified according to the basic lithologic types listed above. Within this listing, a value for specific yield within the range for that type was assigned to each term according to such descriptors as uniform, dirty, mixed, clean, etc. These values were then averaged to obtain the estimated average specific yield for the lithologic type. Next, the products of estimated specific yield times the thickness for each lithologic type were summed, then divided by total thickness to obtain the average specific yield at that location. By this procedure, and by considering only the first 200 feet or less beneath the 1952 water level, an average specific yield of approximately 20 percent is estimated for the zone within which storage change had occurred as of 1966. This procedure is highly subjective and depends entirely on the opinion of the investigator as to what value is assigned to each descriptive lithologic term. Nevertheless, it provides an estimate that is comparable throughout the parts of the basin for which there are drillers' logs, and one that can be used to estimate the order of magnitude of storage change to be expected as further ground-water development proceeds. The estimate may be checked by computing specific yield from measurements of change in ground-water storage that has already occurred.

Change in Storage

Hydrographs of wells in the basin show that there was virtually no net change in stored ground water prior to about 1953 or 1954. By the beginning of 1966, however, water levels in the Raft River valley subbasin showed a marked net change in several localities, reflecting net ground-water withdrawal in excess of average recharge. This change in water levels is shown in figure 20 for the period between measurements made in the spring of 1952 and again in the spring of 1966. The figure shows that net changes of more than 50 feet occurred in some places and that some net change occurred over an area of approximately 235 square miles. By measuring the areas over which the various increments of change occurred, the volume of materials dewatered during the 14-year period is computed to be slightly more than 2 million acre-feet.

During the 14-year period, ground-water underflow out of the basin declined only about 4 percent as water levels were lowered and the outflow gradient was reduced slightly. The total ground-water outflow during the period is estimated to have been about 1,150,000 acre-feet (table 11). Surface-water outflow was also decreasing progressively throughout the period as diversions and ground-water recharge capability increased and is estimated to total 50,000 acre-feet. Consumptive use of surface water within the subbasin declined as water levels fell beneath the areas of riparian vegetation, and opportunity increased for surface flows to percolate into stream channels. For the period, consumptive

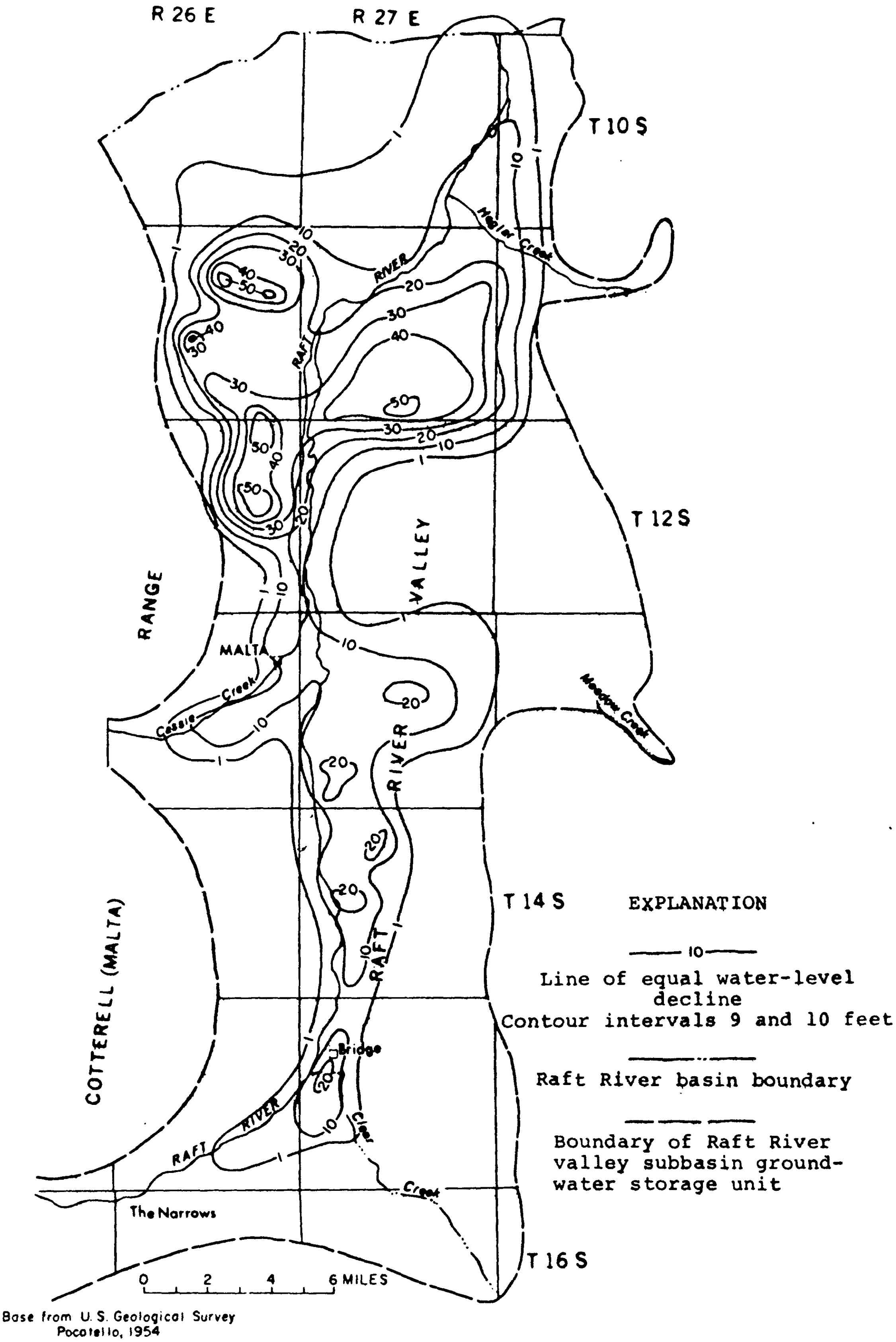


FIGURE 20.– Net water-level change in Raft River valley subbasin, spring of 1952 to spring of 1966.

use of surface water is estimated to have been about 410,000 acre-feet. About 1,270,000 acre-feet of water was pumped during the period, and slightly more than 760,000 acre-feet of this ground water was consumptively used. Thus, total cumulative demand on the water resource of the basin exceeded cumulative water yield by about 410,000 acre-feet; all of which was derived from stored ground water. The volume removed from storage, divided by the volume of water-bearing materials drained, is the specific yield:

$$\frac{4.1 \times 10^5 \text{ acre-feet removed from storage}}{2.01 \times 10^6 \text{ acre-feet of material drained}} = \text{approx. 20 percent}$$

Each of the independent procedures for estimating specific yield indicates an average value of about 20 percent for the water-bearing materials within the upper few tens of feet of the basin deposits. As water levels decline into deeper and older formations, and as water-level decline spreads laterally away from the more permeable units of the valley center, the average specific yield will become somewhat less. The analysis of the drillers' logs suggests that the average in the Raft Formation may be 15 percent or less, and much of the upper part of the Salt Lake Formation probably has an average specific yield of 10 percent or less. For the materials now being drained by water-level decline, and those that will be influenced for many years in the future, the average specific yield is estimated to be 20 percent.

The data indicate that ground-water storage in the Raft River valley subbasin was depleted by about 410,000 acre-feet as of the spring of 1966. The 1966 irrigation season was one of exceptionally low precipitation, and an average of nearly 3.4 acre-feet of water was pumped and applied to each acre irrigated with ground water. In addition, more than 15,000 acres were added to the area irrigated with ground water over that of the previous year, and there was only a slight reduction in other demands on the water resource. Consequently, by the end of the 1966 irrigation year, an additional 103,000 acre-feet of ground water is estimated to have been removed from storage, for a total of about 513,000 acre-feet. Figure 21 is a diagram that shows the distribution of water yield through the basin as of 1966. The upper part of the diagram shows the quantities of water derived from storage. The right side of the diagram shows projected water use, assuming that future total demand on the water-resource system will ultimately be controlled at 140,000 acre-feet and sufficient time elapses to allow ground-water outflow and other elements of the system to approach a new equilibrium. It should be noted that such a new equilibrium condition would require the removal from storage of a volume equivalent to the areas (A) + (B) under the curves of the upper parts of the diagram.

CHEMICAL QUALITY OF WATER

The chemical quality of the ground water in the Raft River basin and its suitability for irrigation use on the soils of the basin was discussed briefly by Nace and others (1961, p.

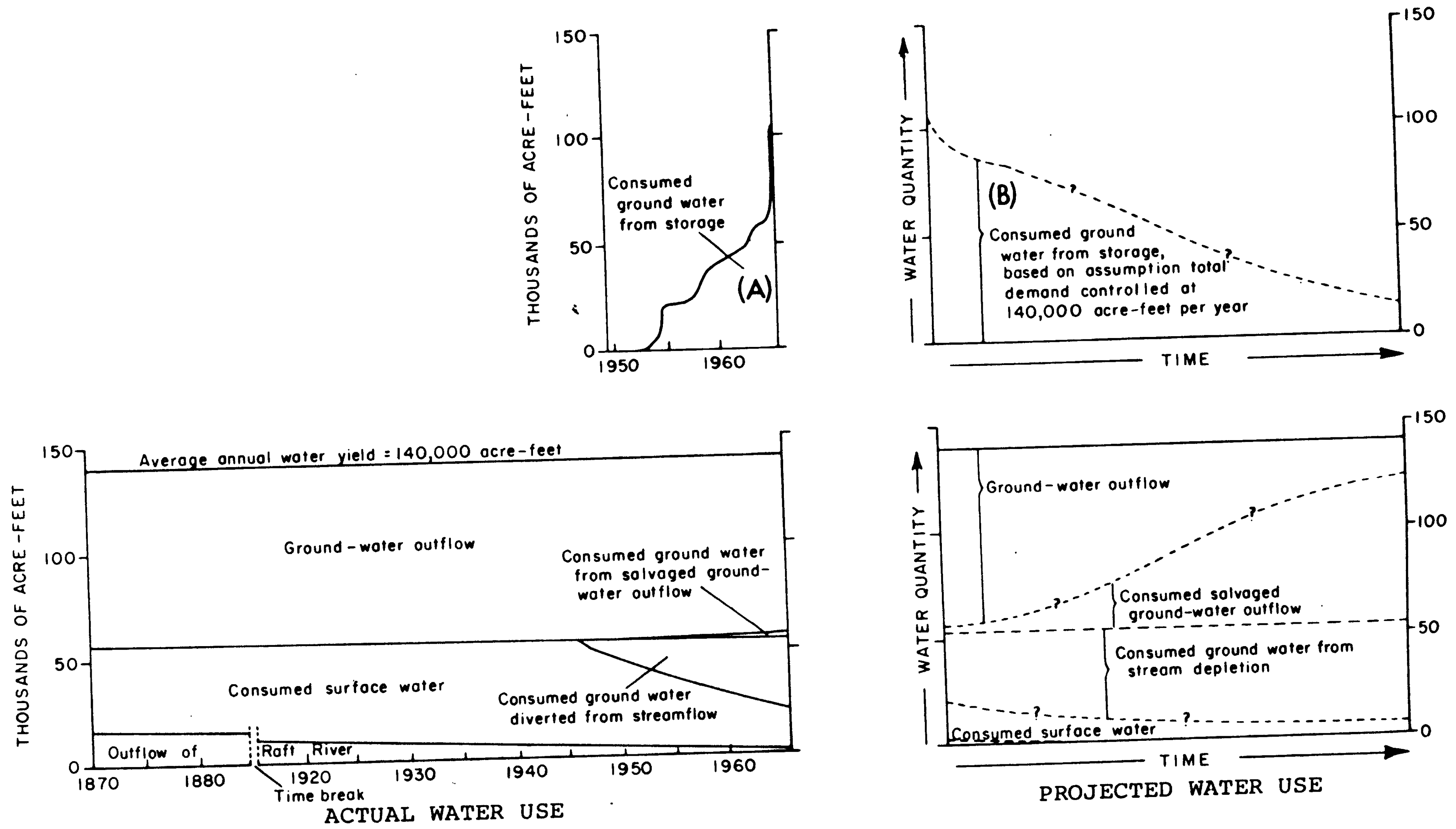


FIGURE 21.– Diagram showing distribution of water yield, water use, change in storage, and projected water-resource distribution.

76). The report noted that analyses from five wells indicated that most ground water of the basin is generally suitable for irrigation, but that the warm water from the artesian zones has a high sodium hazard and is not suitable for irrigation. Mundorff and Sisco (1963, p. 13) noted the earlier work and reported that analyses of 19 additional samples of ground water showed the water to be generally satisfactory for irrigation of most crops where applied on well-drained soils.

As a part of the present investigation, water samples were collected for chemical analysis from 23 stations on streams, from seven springs, and from 44 wells. Conductivity and temperature measurements were made in the field on water from an additional 30 wells. Most surface-water stations were sampled more than once to provide information on changes in water quality with time. The general character of the water is shown in figures 22 and 23, and the analytical data are on file in the Idaho District Office, Boise, Idaho.

Surface Water

Surface-water samples were collected periodically at 23 sampling stations shown in figure 22. The figure also shows graphically the chemical characteristics of selected surface waters. Electrical-conductivity measurements and the May 9, 1966 analyses of waters from Cottonwood Creek and Clyde Creek above Cottonwood Creek were obtained in the field. All other analyses were made in the laboratories of the U.S. Geological Survey.

The streamflow in the Raft River basin may be divided into two categories, spring-fed base flow and direct runoff, including an unknown amount of flow which has rapidly passed through soil or coarse alluvium without having been significantly delayed in transit. The peak flow on the smaller streams is largely direct runoff but the base flow of the perennial streams represents ground water which has entered surface channels through springs and seeps. The chemical characteristics of these two types of flow differ significantly.

Direct Runoff

Direct runoff in the Raft River basin contains generally less than 150 mg/l (milligrams per liter) dissolved solids with calcium and bicarbonate predominating. Direct runoff normally flows but a few miles before it enters the ground or before it becomes mixed with a more mineralized ground-water inflow.

The chemical character of direct runoff from snowmelt is illustrated by samples collected in May and June from Dry Creek, Almo Creek, and Stinson Creek. These waters contained less than 50 mg/l dissolved solids and were largely calcium or magnesium bicarbonate in type; they are very soft.

Base Flow

The base flow of all perennial streams in the Raft River basin is fed by springs and seepage. Because the Raft River alternately gains and loses water, its quality resembles that of the upper stratum of ground water throughout its course. In general, the base flow of all the perennial streams is similar in quality to the ground water which supplies the flow.

The Raft River was originally perennial from near the Upper Narrows to its mouth, but now is intermittent from the vicinity of Bridge to Yale. Two stations on the Raft River, one at Peterson Ranch and one near Yale, were sampled at approximately 5-week intervals for 2 years. There was remarkably little variation in quality among samplings at either station, indicating little admixture of direct surface runoff with the base flow at any time of the year. Likewise, there was little increase in dissolved-solids concentration along the more than 40 miles of channel between the stations. The base flow in the Raft River at Peterson Ranch is derived from ground water which comes to the surface above The Narrows; but the mineralization increases between The Narrows and Peterson Ranch. The water is predominantly of the calcium and sodium chloride type (based on chemical equivalents). Magnesium, bicarbonate, and sulfate ions also contribute significantly to the total mineral load at this station.

Water in the Raft River near Yale is representative of shallow ground water in the lower end of the Raft River basin. Some of the streamflow is water returned from irrigated land during the summer. The water is predominantly of the sodium bicarbonate type. The calcium, sulfate, chloride, and fluoride concentrations are all less at Yale than at Peterson Ranch, but the magnesium, sodium, bicarbonate, and nitrate concentrations are greater.

The sodium percentage and the sodium adsorption ratio are both higher in the Raft River water near Yale than they are at Peterson Ranch. Increases in both usually occur as water flows downstream and is subjected to the effects of evapotranspiration.

The silica concentration is significantly higher near Yale than at Peterson Ranch. Total water hardness is about the same at both stations, but the noncarbonate hardness found at Peterson Ranch is almost nonexistent at Yale. All water from the Raft River proper is very hard.

Sublett Creek is spring fed and almost uniform in flow throughout the year. Water in this creek and Sublett Reservoir contains a nearly constant concentration of about 380 mg/l dissolved solids, largely calcium, magnesium, and bicarbonate. The water is very hard.

Three streams at the base of the Black Pine Range are ephemeral and contain water only during the spring snowmelt season or immediately following heavy rains. The moderately high mineral content of water in these streams suggests that some of the snowmelt probably circulates underground before arriving at the main stream channel. The average dissolved-solids concentration of the water in Kelsaw Canyon was about 280 mg/l, that in Sixmile Canyon was about 210 mg/l, and that in Eightmile Canyon averaged about 180 mg/l. All are strongly calcium or magnesium bicarbonate in type and are hard.

Water in all streams on the north slope of the Raft River Mountains is similar in quality. Included in this group are George Creek, Onemile Creek, and Clear Creek. During periods of heavy snowmelt, George Creek and Clear Creek contain about 65 mg/l dissolved solids. During the remainder of the year, the content ranges upward to slightly more than 200 mg/l. Onemile Creek dissolved solids do not drop below about 120 mg/l, even during the spring runoff period. All these waters are predominantly calcium bicarbonate type with appreciable magnesium, sodium, and chloride. The water ranges from soft to moderately hard, depending upon the season.

Johnson Creek flow is largely derived from springs and seeps. Dissolved solids average more than 200 mg/l and probably are near this level throughout the year. The water is hard to moderately hard.

In the Albion Range, Cassia Creek water is relatively low in dissolved solids, increasing from about 120 mg/l near the headwaters to about 180 mg/l at Malta. There is little seasonal variation. The water is hard to moderately hard, and is predominantly bicarbonate in type with calcium accounting for 50 percent of the dissolved cations (on a chemical equivalent basis) and magnesium and sodium equally accounting for the remaining 50 percent.

Clyde and Cottonwood Creeks are similar in quality to the water of upper Cassia Creek. Water from Dry Creek and Stinson Creek rarely contains more than 35 mg/l dissolved solids. This would make these two streams unique in the Raft River basin, because all other streams seem to have a base flow containing at least 120 mg/l dissolved solids. Both Dry Creek and Stinson Creek have very soft water.

Edwards Creek has about 120 mg/l dissolved solids, and the water varies from soft to moderately hard.

Almo Creek is largely fed by spring snowmelt with an average mineral content of less than 50 mg/l. The base flow is undoubtedly somewhat more mineralized.

Most of the water in Circle Creek originates in springs; consequently, both flow and water quality remain relatively constant throughout the year. Total dissolved-solids concentration averages about 300 mg/l and is predominantly bicarbonate. The water is hard to very hard.

Ground Water

Chemical analyses of water from wells in the Raft River basin have been made since 1945. The bulk of the analyses represent samples collected for the current study between June 1965 and September 1967. Analyses prior to 1950 were published in Water-Supply Paper 1587 (Nace and others, 1961). Analyses of samples collected between 1956 and 1960 were published in Water-Supply Paper 1619CC (Mundorff and Sisco, 1963). In figure 23 ground-water quality is mapped according to the approximate dissolved-solids concentration of water currently yielded from wells. Also shown are the dissolved chemical constituents in waters from selected shallow and deep wells.

The average dissolved-solids concentration of well and spring water in the basin is about 750 mg/l. Most of the ground water is very hard, and the sodium adsorption ratio is generally low. There are, however, several notable places where ground-water quality differs greatly from the average. The observed dissolved solids range from 120 mg/l to 3,200 mg/l within short distances, depending upon the depth of the wells and location with respect to the lowland areas along streams or irrigated land. For these reasons, in the Raft River valley subbasin, most of the area is shown in figure 23 as underlain by ground water having dissolved solids ranging from as low as 320 mg/l to more than 1,280 mg/l.

A small zone of hot, sodium chloride type water is found southwest of Bridge. Dissolved solids there range up to 3,200 mg/l and the water in one deep well is at the boiling point.

Water of poor quality, but non-thermal, is also found locally north of Idahome. The high dissolved-solids content of this water is believed to have resulted from evaporation and from leaching of soils during the recycling of ground water used at least once previously for irrigation.

Many of the wells in the basin yield water more than 5° C warmer than the mean annual air temperature of the area. Except for the area near Bridge, where deep wells tap hot water in the upper part of the Salt Lake Formation, hot ground waters do not seem to have higher than average dissolved-solids concentration, however. Most of the springs that yield warm water are near the base of the Sublett Range, although warm water is also found locally in Yost-Almo subbasin and in Elba subbasin.

Most of the ground water now leaving the basin is believed to contain between 500 and 1,000 mg/l dissolved solids, but some shallow ground water, returned after use for irrigation, may contain 3,000 mg/l or more dissolved solids.

Calcium carbonate ($CaCO_3$) in the form of carbonate cement or limestone is the largest single source of dissolved solids in the ground water. Virtually all the alluvial fill of the valley is believed to contain undissolved $CaCO_3$. Thus, ground water quickly becomes saturated with respect to $CaCO_3$. Because different ion-exchange characteristics prevail in the aquifers, $CaCO_3$ may alternately be precipitated and dissolved many times as ground water flows downgradient.

Commercial fertilizers and other soil conditioners are a major source of sulfate and nitrate in the ground water of the basin, but some nitrate may be derived directly from the atmosphere. Chloride is derived mainly from the sedimentary deposits and weathering of the rocks of the basin, along with silica, potassium, iron, aluminum, manganese, boron, and fluoride.

Quality Conditions Within Subbasins

Yost-Almo subbasin. – The ground water in the Yost-Almo subbasin is virtually identical to that in the southern part of the Raft River valley subbasin. The water is very hard, pH values range from 7 to 8, and the water has a medium salinity hazard according to the classification system of the U.S. Salinity Laboratory (1954). Water entering from Junction Valley is also very hard with a medium salinity hazard.

Elba subbasin. – Ground water in the Elba subbasin is the best quality of any in the Raft River basin. The water is moderately hard and above Conner has a low salinity hazard. Downgradient of Conner, the water has a medium salinity hazard. Iron and boron are negligible and pH ranges from 7 to 8. Dissolved silica increases downgradient from about 15 mg/l to nearly 50 mg/l near Malta.

Raft River valley subbasin. – The bulk of the ground water in the Raft River valley subbasin is very hard. Iron, manganese, and boron concentrations are typically very low. Observed pH values are between 6.9 and 8.3. Salinity levels vary greatly and several chemically distinct types of ground water are pumped from wells in the subbasin. Some of the local variations are undoubtedly due to the return to the water table of water used in irrigation.

An extensive body of ground water in the central part of the basin along the river and Clear Creek extends from near Standrod and Strevell almost to the Snake River. The distinguishing characteristic of the ground water pumped in this area is that its dissolved-solids concentration ranges from 600 to 1,000 mg/l. It appears to be closely related chemically to surface water in the Raft River between The Narrows and the mouth of the river. The salinity hazard of this water is high; it has been increased by flowing through an area subjected to extensive evapotranspiration by native riparian vegetation before development by farming. The silica (SiO_2) content ranges from 30 to 70 mg/l.

The most extensive body of ground water of fairly uniform quality is beneath and within the alluvial fans extending westward from the Sublett and Black Pine Mountain ranges to the central valley area near the river. The distinguishing characteristic of this water is that it has a total dissolved-solids concentration ranging from about 320 to 500 mg/l (medium salinity hazard). The quality of the water found in the various springs of the area and in spring-fed Sublett Creek is almost identical to the underlying ground water. Similar ground water occurs along the base of the Raft River Mountains extending toward the river and Clear Creek from Naf to Standrod and along the east flank of the Cotterell Range extending from the valley margin to near the Raft River. Two wells near Heglar Canyon and one near Naf contained only moderately hard water, but most of the water is very hard. Silica content ranges from about 15 to 80 mg/l.

The ground water pumped from that part of the Raft River valley subbasin beneath the Cassia Creek fan is similar to the water of Cassia Creek. The shallow water generally has a dissolved-solids concentration of about 320 mg/l, or less, and so has only a medium salinity hazard.

Thermal water flows under artesian pressure from two or three wells about 3 miles southwest of bridge. This sodium chloride water is moderately mineralized (1,500 to 3,200 mg/l); consequently, its use for irrigation would involve a very high salinity hazard and a very high sodium hazard.

Another local body of moderately mineralized ground water occurs in the northern part of the Raft River valley. Calcium is the predominant cation in this water, pumped from a few wells north of Idahome, so the sodium hazard for irrigation is low and the hardness is exceedingly high. The dissolved-solids concentration ranges from 1,500 to 3,400 mg/l so the salinity hazard is very high. The source of the mineralization in this area is unknown, but it probably is from recirculated irrigation water. Water temperature is normal for the ground water of the area. The dissolved-solids concentration is about the same as that in the thermal flowing wells previously described; however, the sodium percentage is much lower.

There have been suggestions that some water in the Raft River valley subbasin has a volcanic source, or that the minerals dissolved in water from certain wells have a direct volcanic origin. No available data could be found to support such a belief, and the weight of scientific evidence in the valley makes it seem unlikely that either water or salt in significant and recognizable quantities is originating from such a source.

The northernmost segment of the Raft River valley is covered by basalt flows which contain some ground water that supplies a number of irrigation wells. The meager data available indicate that the dissolved-solids concentration in most of the ground water in the basalt ranges from 350 to 700 mg/l. These waters are classed as having a medium to high salinity hazard.

Change in Salt Balance

Firm data are not available by which to estimate the average change in quality of the surface outflow from the Raft River basin. Meager information indicates, however, that the surface-water outflow in 1967 contained, on the average, about 800 mg/l dissolved solids. This is an apparent increase in average dissolved solids, when compared to the estimated quality of the outflow prior to irrigation, of as much as 200 mg/l. This apparent increase in recent years is almost certainly due to recirculating water used for irrigation. Water from the fields is finding its way to the river from shallow ground-water flow or by direct runoff.

It is virtually certain that surface outflow will decline to nearly zero at Yale within a few years; that the mineralization of the water due to irrigation will increase; and that any salt removed from the system must then be by ground-water outflow. If ground-water outflow, in turn, is reduced, an adverse salt-balance will develop. In any case, the shallowest ground water will increase in dissolved solids, and locally may become too mineralized for reuse in irrigation.

PERENNIAL YIELD OF THE BASIN

BASIC CONCEPTS

The perennial yield of a ground-water reservoir is commonly defined as the maximum amount of water of usable chemical quality that can be withdrawn and consumed economically each year for an indefinite period of time. If the perennial yield is continually exceeded, water levels will decline until the ground-water reservoir is depleted of water of usable quality or until the pumping lifts become too great to be economical. Perennial yield cannot exceed the natural recharge to an area. More importantly, the perennial yield ultimately is limited to the maximum amount of natural discharge that can be economically salvaged for beneficial use.

Because the responses of the hydrologic system of a ground-water basin to stresses imposed by pumping or other developmental procedures of man are slow, a long period of time is required for the basin to adjust from one steady-state condition to another under different conditions. Consequently, the concept of perennial yield during the period of adjustment should take into account the transient-state condition. In the natural state, a ground-water basin is in a long-term steady-state condition, with recharge equal to discharge and no net change in amount of water in storage. When man enters the basin and begins consuming an annual water crop, through pumping for example, the steady-state condition is upset and the basin begins a slow adjustment toward a new steady state under different conditions of storage and discharge. During this transient-state period of adjustment, natural discharge plus man's consumptive demand exceed natural recharge, and the deficit is made up by a progressive depletion of stored water. The transient-state net draft on the basin is a changing quantity as all elements of the system progressively adjust toward a new steady state.

If the net pumping draft is held to a rate about equal to the salvageable natural discharge, and if the distribution and amount of the draft are strategically situated so as eventually to reduce natural discharge to a selected lesser amount, then the system eventually attains a new equilibrium or steady-state condition. The basin is operating under a transient-state concept until it reaches the new steady-state condition.

The amount of time required to make the full transition from steady state under natural conditions to the new steady state under pumping conditions is largely a function of the annual pumping rate, location of wells, and the amount of stored water that must be removed to salvage the selected quantity of natural discharge. Ordinarily, the time involved is measured in decades, provided that the annual net pumping draft is at a rate not greatly exceeding the perennial yield.

What has happened in the Raft River basin is typical of many ground-water basins in the west in that salvageable natural water losses in the form of evapotranspiration occur in all the subareas, yet the largest pumpage is in the north end of the Raft River valley subbasin where it cannot affect materially, for a very long time, the natural discharge in the other parts of the basin. This type of concentrated development commonly leads to a paradox where local overdraft occurs in one part of the basin while at the same time what appears to be an excess, or water available for development by pumping, goes unused in another part of the same basin.

Based on the concepts outlined above, the perennial yield of the Raft River basin equals the water yield, minus unsalvageable natural discharge, but the transient-state net pumping draft to date is greater than the perennial yield, and has increased annually since pumping first began.

SALVAGING GROUND-WATER OUTFLOW

As outlined in the previous section, long-term use of water from the ground-water subbasins cannot exactly equal the perennial yield until use has reduced natural water losses, principally ground-water outflow, and there are no further long-term ground-water storage depletions. To arrive at this condition, it is necessary first to solve the problem of how to locate wells and regulate pumping in an optimum manner to reduce the natural water losses.

In the following pages, the problem of salvaging ground-water outflow from the lower Raft River valley subbasin is discussed. The right side of the graph in figure 21 illustrates the inflow, outflow, change in storage, and salvage of ground-water outflow in future years. The graph shows, by projection without regard to scale, that if pumping from strategically placed wells at about the 1966 rate continues, the surface-water outflow from the basin will decline toward virtually zero, surface-water available for use directly will probably decline, and ground-water outflow will decline gradually toward virtually zero, probably after many decades.

The report by Nace and others (1961, p. 99) stated that a sufficient number of properly placed wells might intercept efficiently about 50,000 to 75,000 acre-feet of ground-water outflow from the lower Raft River valley subbasin each year. The report by Mundorff and Sisco (1963) states: "Reduction of underflow requires reducing one of the following three factors: (1) Hydraulic gradient, (2) transmissibility, or (3) the product of transmissibility multiplied by the hydraulic gradient. To effect a reduction in underflow of one-fourth, for example, would require reducing one of the three factors by one-fourth, and this would result in considerable dewatering of the aquifer and lowering of the water table – perhaps by one-fourth of the saturated thickness of the aquifer, which may be several hundred feet."

Although the estimates of ground-water outflow from the lower Raft River subbasin given in each of the two previous reports were considerably larger than the 80,000 acre-feet a year under 1966 conditions estimated herein–140,000 acre-feet a year by Nace and others (1961, p. 82) and "perhaps 200,000 acre-feet" a year by Mundorff and Sisco (1963, p. 14)–the problem of salvaging the outflow is clearly recognized. In both this report and that by Mundorff and Sisco, it is noted that water levels must be lowered signicantly, perhaps by several hundred feet, to effect major salvage.

Reduction of the ground-water outflow by about half, or about 40,000 acre-feet annually, would require lowering the water level several tens of feet in the area immediately north of the present areas of greatest water-level decline. The time required to effect the reduction would be very great, and very large additional quantities of ground water would be removed from storage. None of these values can be calculated precisely from existing data, but because the idea of salvaging ground-water outflow was a major part of both previous Geological Survey reports and has become a water-management concept within the basin, it needs further discussion – if only in general terms.

The ground-water hydraulic gradient toward the north in the spring of 1966 in the outflow area north of the areas of pumping averaged approximately 15 feet per mile. Because the coefficient of transmissibility is large and the aquifer thickness is great in the outflow area, the reduction in outflow would result mainly from reduced hydraulic gradient. Consequently, to effect a one-half reduction in outflow would require about a one-half reduction in hydraulic gradient. It is estimated that an average lowering of water level of 100 feet would be needed at about the north line of T. 11 S. to decrease the 1966 gradient by one-half.

The quantity of net pumping required, and the time needed to cause 100 feet of lowering at the chosen location may be approximated by use of equations and methods given by Ferris and others (1962) and a set of generalizing assumptions in addition or supplemental to those required by the equation, as follows:

1. The aquifer is homogeneous, isotropic, and infinite in extent.

2. The average coefficients of transmissibility and storage are constant at about 350,000 gallons per day per foot and 0.15, respectively.

3. The locus of pumping is about 4 miles south of the chosen location where the 100-foot water-level decline is measured, and average net pumpage is 120,000 acre-feet per year (average for 1965-66 seasons).

4. Ground water occurs throughout the aquifer under water-table conditions, and the aquifer is virtually horizontal.

5. Ground-water outflow will decrease uniformly over the period from 80,000 to 40,000 acre-feet per year and will average 60,000 acre-feet per year.

6. Consumptive use of surface water will decrease from 20,000 acre-feet per year to zero over the period and will average 10,000 acre-feet per year.

7. There is no surface-water discharge as streamflow from the basin, and all other consumptive-use demands within the basin average 10,000 acre-feet per year.

8. Water yield of the basin equals total recharge and averages 140,000 acre-feet per year.

With these assumptions, approximately 100 years would be required to effect a one-half reduction in hydraulic gradient and ground-water outflow. Water removed from storage during this period would be at least 6 million acre-feet, or 15 times the cumulative total storage depletion as of the spring of 1966. Pumping levels would be greatly lowered, the average being at least 400 feet deeper than in the spring of 1966.

These generalities serve only to indicate the order of magnitude of time and changes in the hydrologic system that might be expected if the pumping pattern and quantities that existed in 1966 are continued. It is obvious that the aquifers are not homogeneous, isotropic, and infinite in extent. Therefore, there will be lateral boundary effects that will increase the rate of water-level decline somewhat. Also, the water table has a gradient toward the area of outflow, and this also will cause greater water-level decline at the chosen site than the calculations indicate. Many other of the natural conditions differ somewhat from the assumed conditions, but in general it is clear that 40,000 acre-feet per year of natural ground-water outflow will not be salvaged by continuation of 1966 pumping patterns and quantities until many decades have elapsed, water levels are lowered several hundred feet in the pumping areas, and a vast amount of water has been removed from storage.

Effective increase in net pumping draft will not, therefore, be practically or economically accomplished within a reasonable period by continuation of the 1966 pumping pattern and quantities. To attain such increase through salvage of ground-water outflow with minimum storage depletion and a minimum lowering of pumping levels, well locations and pumping quantities must be adjusted so as to most effectively reduce the hydraulic gradient in the outflow cross section. The net pumping draft may also be increased by adjusting the pumping pattern and quantities so as to gradually reduce natural water losses by depletion of storage and lowering of water levels over a broad area of the basin. Such deliberate reduction of ground-water storage by spreading the pumping pattern widely throughout the basin would salvage some natural water loss within the basin, and eventually reduce ground-water outflow slightly through slowly declining regional water levels. It must be again emphasized, however, that the perennial yield of the basin is the water yield minus the unsalvageable natural water losses. Any increase in net pumping draft that does not come from salvaged natural water losses can come only from further depletion of stored ground water, with attendant lowering of water levels.

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