Hydrogeology of Middle Canyon Oquirrh Mountains Tooele County, Utah

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-K

Prepared in cooperation with the Utah Water and Power Board

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By JOSEPH S. GATES

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

HYDROGEOLOGY OF MIDDLE CANYON, OQUIRRH MOUNTAINS, TOOELE COUNTY, UTAH

By JOSEPH S. GATES

ABSTRACT

Geology and climate are the principal influences affecting the hydrology of Middle Canyon, Tooele County, Utah. Reconnaissance in the canyon indicated that the geologic influences on the hydrology may be localized; water may be leaking through fault and fracture zones or joints in sandstone and through solution openings in limestone of the Oquirrh formation of Pennsylvanian and Permian age. Surficial deposits of Quaternary age serve as the main storage material for ground water in the canyon and transmit water from the upper canyon to springs and drains at the canyon mouth. The upper canyon is a more important storage area than the lower canyon because the surficial deposits are thicker, and any zones of leakage in the underlying bedrock of the upper canyon probably would result in greater leakage than would similar outlets in the lower canyon.

The total annual discharge from Middle Canyon, per unit of precipitation, decreased between 1910 and 1939. Similar decreases occurred in Parleys Canyon in the nearby Wasatch Range and in other drainage basins in Utah, and it is likely that most of the decrease in discharge from Middle Canyon and other canyons in Utah is due to a change in climate.

Chemical analyses of water showed that the high content of sulfate and other constituents in the water from the Utah Metals tunnel, which drains into Middle Canyon, does not have a significant effect on water quality at the canyon mouth. This suggests that much of the tunnel water is lost from the channel by leakage, probably in the upper canyon, during the dry part of the year.

Comparison of the 150 acre-feet of water per square mile of drainage area discharged by Middle Canyon in 1947 with the 623 and 543 acre-feet per square mile discharged in 1948 by City Creek and Mill Creek Canyons, two comparable drainage basins in the nearby Wasatch Range, also suggests that there is leakage in Middle Canyon.

A hydrologic budget of the drainage basin results in an estimate that about 3,000 acre-feet of water was unaccounted for in the 1947 water year. This may represent a reasonable estimate of annual leakage from Middle Canyon.

The future development of Middle Canyon water can best be planned after additional information is obtained on movement of water through the channel fill. Much of this information could be supplied by test drilling in the channel fill.

INTRODUCTION

PURPOSE AND METHODS OF THE INVESTIGATION

The purpose of this investigation was to determine the geologic and climatic factors that affect the hydrology of Middle Canyon, Tooele County, Utah. Knowledge of these factors might help solve the problems that holders of water rights in the canyon have faced in recent years. These problems include determining if an apparent decrease in total annual discharge from the canyon over the past 50 years has actually occurred; what the possible causes for such a decrease are; and whether there is a significant amount of leakage from the canyon, where such leakage may be occurring, and where the water is going. The answers to these problems, and especially the location of possible leakage zones, will aid in determining the best method of future development of the water supply of Middle Canyon.

Much of the investigation consisted of a study of the geology of the Middle Canyon drainage basin. The months of August and September 1959 were spent on reconnaissance mapping on aerial photographs. Field data and data compiled from other investigations were combined to produce a map of the geologic structure of the canyon, showing attitude of the sedimentary rocks, faults, and the outcrop pattern of the two thick limestone beds in the sedimentary section. Profiles of the canyon were plotted to bring out geomorphic features that might be related to the hydrologic cycle.

The rest of the investigation centered on collection and analysis of all hydrologic data available for Middle Canyon. Data on the discharge of Big Spring and on surface runoff were used to calculate total discharge for 11 years. These data were compared with precipitation data for corresponding periods of time in an attempt to discover if discharge per unit of precipitation has changed since the early 1900's. Data on quality of water, a comparison of Middle Canyon discharge with discharge data for nearby drainage basins, and an estimated hydrologic budget were used to indicate whether significant leakage occurred in Middle Canyon.

This investigation was suggested by Professor Ray E. Marsell, consultant to the Utah Water and Power Board, and was made under a cooperative agreement between the U.S. Geological Survey and the Water and Power Board. The study was under the general supervision of H. A. Waite, district geologist of the Ground Water Branch of the Geological Survey in Utah; and under the direct supervision of H. D. Goode, geologist.

PREVIOUS AND CURRENT INVESTIGATIONS

The southern half of the drainage area of Middle Canyon was included in a study by James Gilluly (1932). A study was made in Tooele Valley, to which Middle Canyon is tributary, by H. E. Thomas (1946); no detailed work was done in Middle Canyon, however. Work in a nearby area was done by J. M. Boutwell (1905), whose report included sections by Emmons (1905) and Keith (1905). Hunt (1924, 1933) and Bissell (1959) also prepared reports on areas near Middle Canyon. During the present field investigation, Ralph J. Roberts and Edwin W. Tooker, of the U.S. Geological Survey, were mapping the Oquirrh Mountains north of the area studied by Gilluly. The cited publications and unpublished material by Roberts and Tooker were freely drawn upon in the study of the geology of the Middle Canyon drainage basin.

Many of the available hydrologic data for Middle Canyon are contained in an unpublished report of the U.S. Soil Conservation Service dated April 14, 1948, "Interim Progress Report of Middle Canyon Water-Studies," by D. F. Lawrence and G. M. England. Hydrologic data in a drainage basin in the Wasatch Range are published in a report by Croft and Monninger (1953).

ACKNOWLEDGMENTS

The writer is indebted to many people for advice and assistance during this investigation. Professor Ray E. Marsell, of the University of Utah, gave many helpful suggestions during the course of the study. Messrs. Ralph J. Roberts and Edwin W. Tooker, of the U.S. Geological Survey, who were mapping the Oquirrh Mountains, gave advice and information during the course of the fieldwork. Mr. Eugene L. Peck, of the U. S. Weather Bureau, gave valuable help on the estimation of the water budget. Mr. Daniel F. Lawrence, of the Utah Water and Power Board, reviewed the section on the history of water development in Middle Canyon. Mr. Mark R. Gardner, of the Water and Power Board, gave information on the occurrence of water in some of the Bingham district's mine workings. The city of Tooele, the Middle Canyon Irrigation Co., and the Utah Water and Power Board were generous in allowing the use of their records pertaining to Middle Canyon.

GEOGRAPHY

LOCATION, EXTENT, AND RELIEF OF THE DRAINAGE BASIN

Middle Canyon is on the west side of the Oquirrh Mountains near the center of the east edge of Tooele County, Utah, and within the Basin and Range province (fig. 1). The month of the canyon is about 2 miles southeast of the city of Tooele, and its basin, which trends northwestward, includes an area of about 11 square miles.

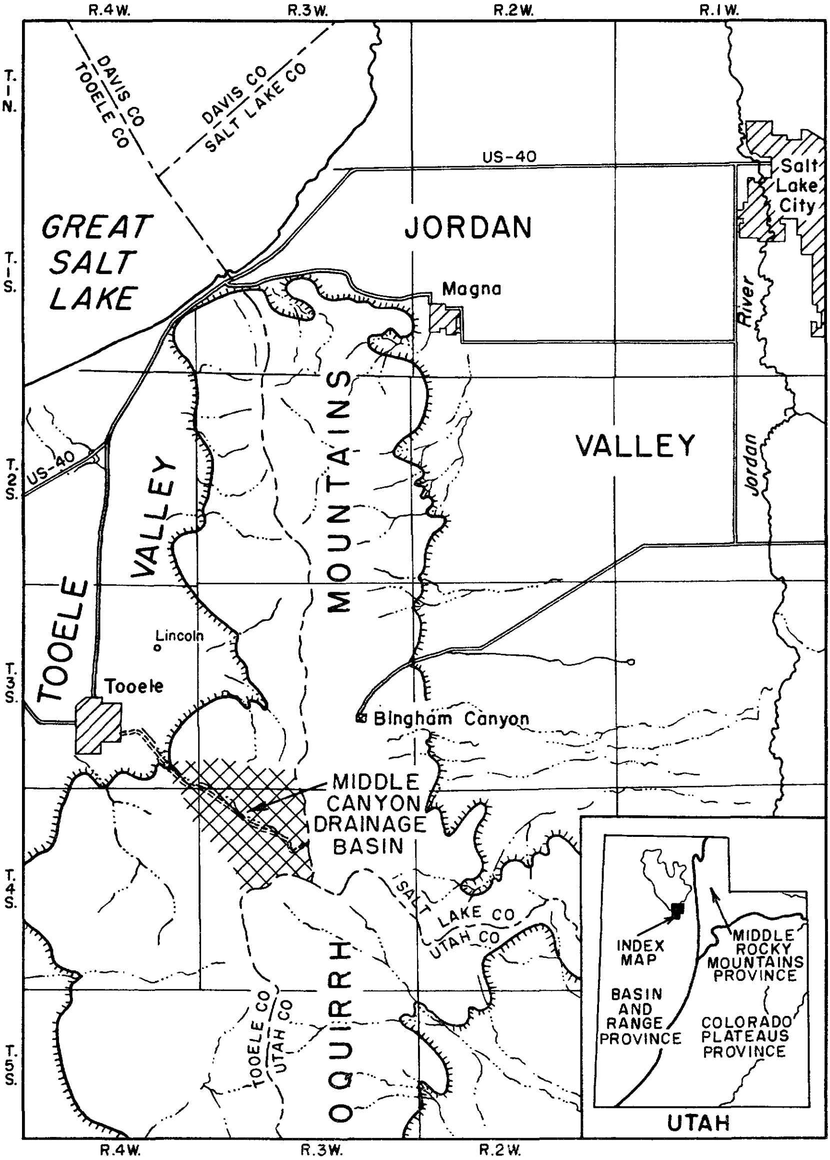

FIGURE 1.—Index map showing the location of the Middle Canyon drainage basin.

The topography of Middle Canyon is steep and rugged, the altitude ranging from 5,400 feet at the mouth of the canyon to more than 10,300 feet on the southern rim of the drainage basin (pl. 1). In the lower half of the canyon the main channel is narrow, and the tributaries are short and steep. The upper half of the drainage basin is more mature than the lower half, and the main channel is broader and the tributary canyons are larger and better developed. The upper half of the canyon has two systems, the main channel and Left Hand Fork. About halfway up Middle Canyon, Left Hand Fork branches off to the northeast and then turns to the east. It has no large tributary canyons. The main canyon continues to the southeast and shows strikingly different characteristics on its two sides. The north side is steep and has poorly developed drainage basins, whereas the south side has several well-developed tributary canyons reaching to the high southern rim.

A gravel road goes from the mouth of the canyon to the Oquirrh Mountain divide at the head of the canyon. In 1959 the Utah National Guard extended this road to the north along the Oquirrh divide to a point on the west side of West Mountain, giving access to the northern half of the upper canyon.

VEGETATION

The vegetation of Middle Canyon is typical of the upland regions of the Great Basin, varying widely in response to rainfall, temperature, and soil conditions. The northward-facing slopes of the drainage basin are covered with timber, principally Douglas-fir, spruce, and some yellow pine. Stands of aspen grow on White Pine Flat and several of the other high basin areas. On the southward-facing slopes of the canyon the vegetation is strikingly different and much thinner, consisting mainly of scrub oak, various kinds of brush, herbaceous plants, and grasses. Thick growths of trees are present in the lower parts of the main channel and on the alluvial fans at the mouths of tributary canyons in upper Middle Canyon.

Vegetation in the drainage basin gives valuable information on ground-water conditions in Quaternary deposits. The thick growths of trees on the alluvial-fan deposits and in the stream channels indicate the presence of ground water. The heavy growth of vegetation on the northward-facing slopes of the drainage basin is the result of an adequate supply of water stored in the thick alluvial, colluvial, and soil cover on these slopes.

CLIMATE

The climate of the Middle Canyon region is typical of the mountainous areas of the Great Basin. The Great Basin as a whole is semiarid, but the high parts of the Oquirrh Mountains, in common with many of the Great Basin mountain ranges, receive enough precipitation to be classified as humid.

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Records of precipitation at a storage gage installed by the Soil Conservation Service in 1956 in White Pine Canyon, a tributary of Middle Canyon, indicate that for the period August 1956 through April 1959 the station had about twice the precipitation recorded at the U.S. Weather Bureau substation at Tooele. Thus, the mean annual precipitation at the White Pine storage gage is about twice the 1931–52 mean annual precipitation of 15.81 inches at Tooele, or more than 30 inches. The pattern of precipitation is the same for the two stations, but each storm deposits about twice as much moisture at the White Pine storage gage as at Tooele. The pattern at both stations is similar to that of most stations in northern Utah; the maximum precipitation occurs in late winter and early spring, and the minimum in summer.

Figure 2 shows the cumulative departure from the 1897–1952 mean annual precipitation at Tooele for the period 1897–1959. This curve shows that precipitation in the vicinity of Tooele occurs in an irregular cyclic pattern made up of alternating sequences of wet and dry years.

FIGURE 2.—Cumulative departure from the 1897–1952 mean annual precipitation at Tooele, Utah, for the period 1897–1959.

The downward slope of the line from 1931 through 1935 represents the drought of the 1930's. The year 1959 is included in a dry period that began in 1948.

At Tooele the 1931–52 mean maximum and minimum temperatures for January are 36.8°F and 18.3°F, respectively; in July they are 90.2°F and 63.4°F.

GEOLOGY

The Oquirrh Mountains form a typical northward-trending range of the Basin and Range province. The range has been described as a block, faulted and uplifted on its west edge and tilted to the east (Gilluly, 1932, p. 91). The range is composed of Paleozoic sedimentary and Tertiary igneous rocks, and the greater part of it is made up of the Oquirrh formation of Pennsylvanian and Permian age, which has a thickness of more than 16,000 feet. The basins bordering the Oquirrh Mountains are filled with Tertiary and Quaternary alluvial and lacustrine deposits.

Structurally the Oquirrh Mountains near Tooele consist of a series of large folds which trend northwestward and which, on the west side of the range, plunge to the northwest. These folds probably were compressed during the Late Cretaceous and early Tertiary Laramide orogeny, and they have been truncated by late Tertiary normal faults.

STRATIGRAPHY

The bedrock of the Middle Canyon drainage basin is the Oquirrh formation of Pennsylvanian and Permian age, which has been intruded in places by Tertiary igneous rocks. Unconsolidated Quaternary deposits occur along the main and tributary channels and in some of the upper parts of the tributary canyons on the south rim of the drainage area.

The stratigraphy of the Oquirrh formation was studied by Gilluly (1932), and the stratigraphy of Middle Canyon was reexamined to determine its relation to the hydrology of the canyon.

PENNSYLVANIAN AND PERMIAN SYSTEMS

OQUIRRH FORMATION

The Oquirrh formation was named and defined by Gilluly in 1932. It is a great thickness of alternating limestone and quartzose sandstone, the sandstone predominating. The formation is exposed in much of the range, and makes up nearly the entire volume of its northern half. Gilluly (1932, p. 34–36) estimated a total thickness of 16,000 to 18,000 feet for the Oquirrh formation in the Oquirrh Mountains and stated that the top of the formation may not be present in the range.

The Oquirrh formation is of Pennsylvanian age at the type locality (Gilluly, 1932, p. 36), although Bissell (1959, p. 126) states that there may be a full Wolfcamp (Lower Permian) section in the northern part of the range. The Permian age of the upper part of the Oquirrh formation has been established in the Wasatch Range, about 30 miles to the east, by the work of Bissell and Thompson (Bissell, 1959, p. 127).

The Oquirrh formation is dominantly quartzose sandstone, cemented by either silica or calcium carbonate. The term "quartzite" is commonly applied to the sandstone and thus will be used in this report, although to be strictly correct this designation should be applied only to sicila-cemented sandstone. Both silica- and carbonate-cemented types have a detrital fraction composed almost entirely of quartz grains, which range in size from coarse silt to fine sand, and minor amounts of heavy minerals. Banding and crossbedding are common.

Nygreen (1958, p. 18) made the following statement on the effects of the cementing material:

> Cementing material is of carbonate or silica, and this is usually reflected in weathering characteristics. The quartzose sandstone and quartzose siltstone are carbonate cemented, commonly crossbedded, and are characterized by having a light to medium-gray or light brown color on fresh surfaces and light-brown weathered color. The carbonate-cemented sandstone is only moderately resistant to weathering, being less resistant than orthoquartzite and limestone * * *. The orthoquartzites are silica cemented, usually massive and characteristically brown on both weathered and fresh surfaces. They are resistant to weathering, characteristically forming ridges.

The limestones of the Oquirrh formation are typically light gray on a weathered surface and dark blue to black on a fresh surface. They are fine grained and commonly contain discontinuous zones of chert nodules.

Gilluly (1932, p. 35) reported that the quartzite beds were lenticular and would lens out in short distances, and he was unable to correlate beds between the southern Oquirrh and Bingham Canyon areas. He considered the limestone beds to be less lenticular than the quartzites and traceable for considerable distances. R. J. Roberts, U.S. Geological Survey, stated that both the limestone and the quartzite beds are not so lenticular as Gilluly had previously reported (oral communication, Sept. 22, 1959).

The Oquirrh formation is the only sedimentary outcrop in the Middle Canyon area. Two thick limestone beds crop out along the length of Middle Canyon with little change in thickness. Emmons (1905, p. 24) states that—

the nearly adjoining limestones, locally designated the "Commercial" and "Jordan" members, which are the most important ore carriers of the [Bingham mining] district [south of Bingham Canyon, shown on fig. 1] have been traced in practical continuity from near the mouth of Bingham Canyon southward and westward to the Commercial and Jordan Mines and again along the southern and western slopes of West Mountain beyond the limits of the map, and down Tooele [Left Hand Fork of Middle] Canyon.

Fieldwork confirms that the two thick limestone beds in Middle Canyon are the Jordan and Commercial limestone members of the Bingham quartzite. The Bingham quartzite was named and defined in the Bingham district by Keith (1905, p. 33). Gilluly (1932, p. 34) recognized that the Bingham quartzite was included in the upper part of the Oquirrh formation, but the Bingham quartzite has never been formally redefined. In this report, the terms "lower" and "upper limestone members" will be used, corresponding to the Jordan and Commercial members. A revision of the nomenclature of the Oquirrh formation will be published in the future by R. J. Roberts and E. W. Tooker (R. J. Roberts, U.S. Geological Survey, written communication, July 22, 1960).

On the geologic map (pl. 1), these two beds of limestone are the only members of the Oquirrh formation that are shown in detail. The offsetting of strata caused by the numerous faults on the ridge separating the main canyon from Left Hand Fork made individual beds difficult to trace and necessitated the use of inferred contacts for the lower and upper limestone members. Along this ridge, detailed mapping of these limestones was not considered essential to a hydrologic study of Middle Canyon.

LOWER LIMESTONE MEMBER

The lower limestone member is the lower and more conspicuous of the two beds of limestone that crop out in Middle Canyon. Similar to other limestones in the Oquirrh formation, the lower limestone member is a fine-grained blue to blue-black bedded limestone containing numerous zones of chert nodules. The limestone is resistant to weathering and forms ledges on all slopes, except those most heavily covered with surficial material. The limestone weathers to a light gray, and the included chert nodules weather to dark gray to black.

The upper and lower contacts of the lower member change in aspect locally, but in general the lower contact is sharp and the upper gradational. At the upper contact with the overlying quartzite, stringers and lenses of brown-weathering calcareous quartz sandstone interfinger with the upper part of the limestone. The lower limestone member is 300 feet thick at West Mountain at the northeast corner of the drainage basin, and averages 200 feet in the Bingham district (Keith, 1905, p. 40). The writer measured an approximate thickness of 340 feet for this member by pacing across an outcrop of vertical beds on a spur on the south side of lower Middle Canyon.

Above the lower limestone member, and separating it from the upper limestone member, is 200 to 300 feet of tan quartzite. This quartzite varies in thickness more than either of the two limestone beds.

UPPER LIMESTONE MEMBER

The upper limestone member, lying conformably on the tan quartzite, is not exposed as conspicuously as the lower member because it is commonly covered with talus deposits derived from overlying quartzite. Keith (1905, p. 40) states that this, the Commercial member, is the most extensive of the limestone bodies of the region.

The upper member is similar lithologically to the lower member—a fine-grained blue to blue-black limestone that is gray on the weathered surface. There are more chert nodules, and in many places the nodules join one another to form continuous beds of chert.

The lower contact of the upper member is fairly sharp and resembles the lower contact of the lower member. The upper contact varies from place to place, but in general the gradational zone between the limestone and the overlying quartzite is absent or much thinner than the zone that forms the upper contact of the lower member.

Keith (1905, p. 40) reported an average thickness of 200 feet for the Commercial member, and the writer paced an approximate thickness of 175 feet across the outcrop mentioned above.

TERTIARY SYSTEM

INTRUSIVE ROCKS

Intrusive quartz monzonite porphyry crops out in the upper part of Middle Canyon in a northeastward-trending zone that extends toward the Bingham district. Large outcrops of the porphyry are present on the Middle Canyon drainage divide above and west of White Pine Flat and on the north wall of Middle Canyon proper about 2,000 feet below the mouth of White Pine Canyon. There are small outcrops on the west wall of lower White Pine Canyon, in the drainage basin west of White Pine Canyon, and in the upper basin of Left Hand Fork.

Gilluly (1932, p. 54) cited bending of a limestone at its contact with the monzonite as evidence for forcible intrusion of the monzonite bodies. He stated that the quartz monzonite represents the last stage of local igneous activity and assigned it an early Tertiary age.

The intrusive bodies may be controlled by the northeastward trend of the faults in the upper part of Middle Canyon, and certainly they are related genetically to the intrusions of the Bingham district.

SALT LAKE FORMATION

The Salt Lake formation forms the foothill slopes above the highest shorelines of Lake Bonneville in discontinuous areas around the margin of Tooele Valley (Thomas, 1946, p. 116–117). Thomas described this formation as a typical fanglomerate composed of poorly sorted subangular to subrounded boulders, gravel, and sand in irregular beds loosely to firmly cemented by a calcareous cement.

The Salt Lake formation is shown northwest of the mouth of Middle Canyon (pl. 1), where what are probably poorly cemented exposures of the formation occur along the west side of the road leading to the canyon mouth. The Salt Lake formation is of Pliocene age.

QUATERNARY SYSTEM

Surficial deposits of Quaternary age in the Middle Canyon drainage basin include alluvial deposits in the stream channels, colluvial deposits, glacial deposits in the upper parts of the basin, and the surficial cover of weathered rock.

Alluvial deposits fill the stream channels of the drainage basin to various depths. The exact thickness of alluvium in the main channel is unknown, although it is probably about 100 feet in the upper canyon and 50 feet in the lower canyon. The upper-canyon fill seems to include a large amount of fine-grained material; the lower-canyon fill is largely coarse angular pieces of quartzite.

This contrast in texture of fill material is a result of differences in material available and gradients of the side slopes in the upper and lower canyon. More fine-grained material is available as weathered surficial deposits in the upper canyon because there is more moisture and vegetation than in the lower canyon. The steeper side slopes in the lower canyon enable coarse material to move directly into the main channel by mass wastage.

Exposures of bedrock at several locations in the tributary canyons indicate that their depth of alluvial fill rarely exceeds 10 feet.

Colluvial material is present over the drainage basin as talus and landslide deposits. The outcrops of fractured quartzite weather to different-sized fragments to produce material for the talus deposits. There are a few small landslide deposits in the tributary canyons on the south side of the main canyon in the upper part of the drainage basin.

Glacial deposits are present in the upper parts of the tributary canyons on the south side of Middle Canyon. They are best developed in White Pine Flat, which is the floor of a cirque. The deposit there is the only one of sufficient thickness and extent to be shown on plate 1. A lateral moraine about 30 feet high lies on the east side of White Pine Flat, and the glacial and associated colluvial debris is at least 200 feet thick in the lower part of the flat. Small glaciers probably occupied the upper reaches of the highest northward-facing drainage basins in the Oquirrh Mountains during Wisconsin time (Gilluly, 1932, p. 40).

The thickness of weathered surficial material varies over the drainage basin, chiefly as a result of processes that depend on the amount of solar radiation received locally. Precipitation is fairly uniform over the basin at a given altitude, although northward- and westward-facing slopes may receive slightly more precipitation because passing storms generally approach from the northwest. Precipitation is concentrated in the winter, and rising temperatures in the spring initiate snowmelt. Southward-facing slopes receive the most solar radiation and their runoff is rapid. Because the northward-facing slopes are protected from the direct rays of the sun and melting of the snow is slower, surficial material on these slopes remains moist for a longer time. This condition results in intensification of the weathering process and the production of greater amounts of weathered material on the northward-facing slopes, and, in turn, produces more storage capacity for moisture and further intensification of the weathering process. The increased amount of water in storage on the northward-facing slopes results in more vegetative cover, which, in turn, furnishes some protection to the snow cover and further delays runoff. In addition, vegetation increases the weathering process, adding to the soil cover and increasing the water-storage potential.

STRUCTURE

FOLDS

The Oquirrh Mountains form an uplifted block that has been deformed into a series of broad folds that, in the central and southern parts of the range, trend northwest-southeast. Gilluly (1932, p. 69) state that the axis of a transverse uplift crosses the range almost at right angles to the trend of the folds, and that from this axis the folds plunge north and south. The major folds are of large dimensions, and the southern half of the range is composed of only four folds. They are asymmetrical and generally open, although locally they may be overturned. Minor folds or local warpings, called "small rolls" by Keith (1905, p. 56), occur on the limbs of the major folds and have dimensions of a few hundred feet.

In the Oquirrh Mountains, the age of the folding can only be dated as post-Pennsylvanian and pre-Pleistocene. Geologic studies of nearby regions indicate a Late Cretaceous to early Eocene, or Laramide, age for the folding in northern Utah (Gilluly, 1932, p. 73).

In Middle Canyon, the axis of the Long Ridge anticline lies across the southern part of the drainage basin in a northwest-southeast direction, roughly parallel to the main canyon. The axis of the Bingham syncline lies to the north of the Middle Canyon drainage and is parallel to the axis of the Long Ridge anticline. Both of these structures plunge to the northwest.

The northeast half of the upper canyon is a broad structural terrace, between and plunging with the more steeply dipping limbs of the Long Ridge anticline and Bingham syncline. This structural terrace is shown on section *C–C′* (pl. 1).

The folds tighten as they plunge to the northwest, as shown by a comparison of sections *C–C′* and *A–A′* (pl. 1). At the canyon mouth, the fold between the steeply dipping northeast limb of the Long Ridge anticline and the structural terrace of the upper canyon has been compressed into an overturned syncline.

FAULTS

Faults in different parts of the Oquirrh Mountains have been classified by Gilluly (1932) and Hunt (1933). The faults in Middle Canyon were not investigated in detail, but all the faults observed probably could be included in Hunt's classification.

Gilluly (1932, p. 74–90) classified the faults in the southern Oquirrh Mountains into four principal groups on the basis of location and relative age. Three of the fault groups, classified mainly on location, are within the range and are probably early Tertiary faults that developed after the time of major folding. The fourth group includes the late Tertiary to Recent basin-and-range faults along the west front of, and possibly within, the range.

Hunt (1933, p. 52–53) classified the faults in the Bingham district in the northern Oquirrh Mountains into four groups on the basis of attitude and relative age. The oldest faults strike northwest and dip gently to the west. They antedate the monzonite intrusions and all other faults, and may be older than the folding in the range. The second group includes bedding-plane faults. Most of these faults are older than the intrusions and mineralization in the Bingham district. Gilluly (1932, p. 88) discussed bedding faults in an area in the southern Oquirrhs and considered them to be contemporaneous with the folding in the area. The third, and probably largest, group of faults includes high-angle normal faults that strike northeast and have small or moderate displacements. These faults are believed to be equivalent in age to the late stages of intrusive activity, but antedate mineralization. The youngest faults strike northwest and dip to the west. They postdate intrusion and mineralization and may be related to the basin-and-range faults along the west side of the range.

In Middle Canyon the faults are most numerous in the upper canyon, and especially on the ridge separating the main canyon from Left Hand Fork. This faulting appears to be associated with the zone of monzonite intrusions that cuts northeast across Middle Canyon, because the strike of the faults parallels the trend of the intrusions. These faults are high-angle normal faults having displacements of about 100 feet, and probably correlate with Hunt's group of northeast-striking faults. There are fewer faults in the lower part of the canyon, and although a northeast strike is most common, north- and northwest-striking faults are present.

Keith (1905, p. 57–61) noted the large range in magnitude of the faults in the Bingham district and the range in width of breccia zones, from a few inches to several yards, that characterizes many of the faults. The wide range in displacements along faults is probably related to the brittleness of the quartzite. Major faults in the quartzite resulted in minor faulting and jointing in the surrounding rock. The width of a breccia zone along a fault is probably related to the magnitude of the fault, the wider breccia zones occurring with the faults of largest displacement. The range in displacements along faults and width of breccia zones also occurs in Middle Canyon. Breccia zones along faults in Middle Canyon are composed of small angular pieces of quartzite and a yellowish matrix of finely ground material. They grade outward to intensely fractured quartzite.

Many faults may have been overlooked in mapping the Middle Canyon drainage basin because the uniform lithology of the quartzites makes faults difficult to recognize. Only where faults cut limestone beds can they be mapped with certainty.

The mountain-front scarp, at the mouth of Middle Canyon, is at or just southeast of a late Tertiary basin-and-range normal fault along which the mountain, or southeast side, was upthrown. The 200-foot-wide zone of brecciated quartzite at the canyon mouth suggests a fault of large displacement, when compared with the narrow zones of brecciated quartzite along faults of small displacement in the interior of the range. Quartzite beds as much as a mile up the canyon from the mountain-front fault are intensely jointed. This fracturing probably is related to movement along the fault.

There are probably additional faults northwest of, and parallel to, the fault at the mountain front. Gilluly (1932, p. 84) states that one characteristic of the basin-and-range faults along the west front of the Oquirrhs is their occurrence en echelon with steplike displacements.

JOINTS

Jointing is common in the Oquirrh formation, although definite joint systems were not apparent in the Middle Canyon area. Joints intersect the beds at all angles, but the most common combination is a plane of jointing parallel to the plane of bedding and two or more planes normal to the bedding. Keith (1905, p. 61) states that the joints in the Bingham district were younger than, and developed without regard to, folds and faults; he evidently did not consider the fractures adjacent to faults as joints.

Jointing has a marked effect on the weathering of the Oquirrh formation, particularly the quartzite. The numerous joints facilitate the breaking off of the angular fragments of quartzite that form the talus slopes in Middle Canyon.

GEOMORPHOLOGY

The drainage of Middle Canyon is controlled by structure. The main channel roughly coincides with the sharp decrease in angle of dip where the steeply dipping northeast limb of the Long Ridge anticline passes into the structural terrace between the Long Ridge anticline and the Bingham syncline. The main stream followed this fold in cutting its channel.

Faulting also may have occurred along this sharp decrease in angle of dip, and broken easily eroded rock along the fault may have influenced the stream course. Such a fault cuts the lower limestone member in the west-central part of sec. 6, T. 4 S., R. 3 W., and R. J. Roberts, U.S. Geological Survey, suggested that this fault may continue northwestward along the main channel to the mouth of the canyon (oral communication, Sept. 22, 1959). However, there is no definite evidence for faulting parallel to the channel along most of its length.

The uniform lithology of the Oquirrh formation in the Middle Canyon drainage basin suggests that erosion along weak strata did not control the course of the main canyon.

The longitudinal profile of Middle Canyon (fig. 3) and the profiles across the channel (fig. 4) indicate that the canyon has been rejuvenated. The longitudinal profile shows several knickpoints, the most prominent of which is at the boundary between the upper and lower parts of the canyon. The cross profiles (fig. 4) show that the upper canyon has a wider valley, a broader channel, and more gentle side

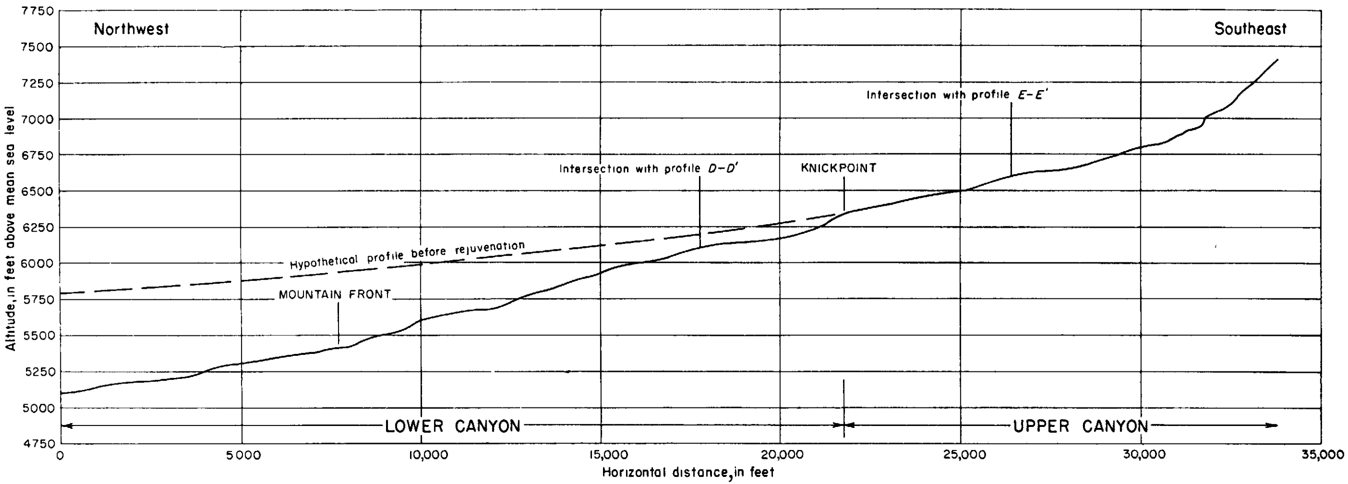

FIGURE 3.—Longitudinal profile of Middle Canyon showing location of the profiles across the canyon, the knickpoint, and the hypothetical profile before rejuvenation, Oquirrh Mountains, Utah.

slopes than the lower canyon. Because the upper part of a canyon is commonly narrower and has steeper side slopes than its lower part, a reversal of normal conditions must have occurred. This reversal, and the sharp knickpoint at the place where the reversal occurs, suggests that uplift of the range along the mountain-front fault to the west has rejuvenated the lower canyon. The hypothetical profile before rejuvenation is shown on figure 3.

Uplift at the west edge of the range began in the late Miocene or Pliocene and has continued to the present, and erosion following these uplifts has destroyed the pre-Pliocene mature erosion surface and produced the present rugged topography (Gilluly, 1932, p. 91). The differences in gradient and steepness between the upper and lower canyon are probably the result of Pleistocene and Recent uplift.

The steeper side slopes in the lower canyon resulting from continued rejuvenation have been a large factor in producing the contrast in texture between the coarse alluvial deposits in the lower canyon and the finer deposits in the upper canyon.

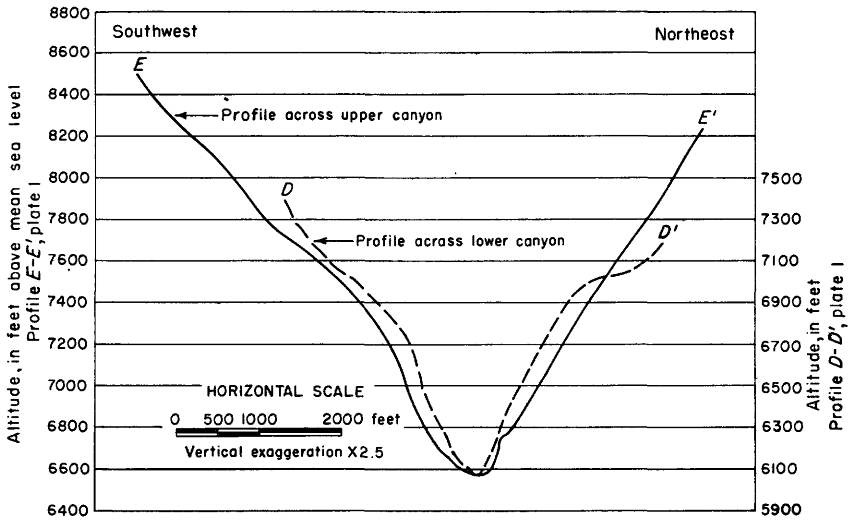

FIGURE 4.—Comparison of profiles across lower and upper Middle Canyon, Oquirrh Mountains, Utah.

HYDROLOGY

GENERAL HYDROLOGIC CHARACTERISTICS

The precipitation over the Middle Canyon drainage basin that is most effective in producing stream and spring flow occurs as snow from October through April. When daily maximum temperatures are sufficiently high, melting snow produces runoff in the upper canyon.

The peak flow of the major tributaries, White Pine and Hansen Forks, occurs from April to late May.

The main flow at the mouth of the canyon comes from Big Spring, which is at the mountain-front fault zone. The annual peak flow of this spring occurs in June or early July, and the maximum peak flow recorded is 8,000 gpm (gallons per minute). Frequently the spring has gone dry in the late fall.

Local residents report that Middle Canyon Creek was once a permanent stream, but in the past 25 years only occasional surface flow has reached the canyon mouth.

A few small developed springs below Big Spring contribute lesser amounts of water to the total water supply available from the canyon. These springs are close to Big Spring and are not shown separately on plate 1.

HISTORY OF WATER DEVELOPMENT

The water from Middle Canyon has been used for irrigation east of Tooele since the area was settled in 1849. In 1906 the Middle Canyon Irrigation Co. was incorporated to organize distribution of the water and to make improvements in the irrigation system. The drought of the 1930's necessitated additional development; no major improvements have been made in the irrigation system since that time.

The city of Tooele has used water from underground drains and developed springs at the canyon mouth for domestic supplies since the early 1900's. The small community of Lincoln, northeast of Tooele (fig. 1), obtains its domestic water supply from a developed spring in the same area. Tooele also has the right to 190 gpm from Big Spring. In addition, Tooele has drilled several wells below the spring area (pl. 1), three of which were in use in 1959.

A few of the local mining companies also have had an interest in Middle Canyon water. In 1910 the Utah Metal Mining Co., which has since been absorbed by the Anaconda Co., sued the Middle Canyon Irrigation Co. to obtain the right to use some of the upper-canyon water for power generation during the driving of a tunnel, hereafter referred to as the Utah Metals tunnel (pl. 1), from upper Middle Canyon to Carr Fork of Bingham Canyon. The Third District Court in Tooele granted the Utah Metal Mining Co. the right to use the water, provided they returned the water to the Middle Canyon drainage after using it.

In 1914 the Third District Court decreed the division of Middle Canyon water among those holding water rights in the canyon, and stated that the Utah Metal Mining Co. owned the water developed by its tunnel. The Kennecott Copper Corp. later bought the rights to the tunnel water from the Utah Metal Mining Co. and traded these water rights to the Middle Canyon Irrigation Co. for the right to take an equivalent amount of water from the White Pine and Hansen drainage basins of upper Middle Canyon and pipe it through the tunnel to Bingham Canyon. Kennecott has since made weekly water measurements which show that the amount of water contributed by the tunnel has generally exceeded the amount taken from the upper canyon.

The city of Tooele and the Middle Canyon Irrigation Co., the major holders of water rights in the canyon, have been in disagreement over development of Middle Canyon water for almost 30 years. The irrigation company has advocated the construction of a pipeline to transport the water flowing in the upper canyon to the canyon mouth, claiming that this would prevent water from entering bedding planes in the bedrock and migrating out of the drainage basin. Tooele has opposed the construction of a pipeline, claiming that it would cut off the supply of water to the city's springs and drains at the canyon mouth.

In the drought years of the 1930's the irrigation company, with Works Progress Administration aid, constructed short pipelines and rock- and concrete-lined ditches in parts of the upper canyon to reduce seepage losses.

In 1946 the irrigation company applied to the Soil Conservation Service for assistance in determining the best method of developing Middle Canyon water. The results of the 1947 water-measurement study by D. F. Lawrence and G. M. England, U.S. Soil Conservation Service (written communication, Apr. 14, 1948) did not clearly indicate any water losses, but a few years later the Soil Conservation Service recommended the pipeline project. In 1953 the irrigation company applied to the Utah Water and Power Board for a loan to construct the pipeline.

The city of Tooele filed a protest against the pipeline with the State Engineer on the basis that it would reduce the flow of the city's springs and drains. On the advice of consulting geologists, the city rejected the theory that there were water losses in the upper canyon and claimed that virtually all the upper-canyon water percolates through the alluvial fill in the main channel to the mouth of the canyon.

As this protest has halted the pipeline project, subsequent efforts have been directed toward finding some compromise solution agreeable to the city and the irrigation company. Because the difference of opinion was about the amount of upper-canyon water reaching the mouth of the canyon, a test-drilling project was proposed by the city of Tooele in 1954 to determine the amount of water moving through the alluvium in the lower canyon. A drilling site was located below

Left Hand Fork, where the lower limestone member crops out across the main canyon. Because the city and the irrigation company have not been able to agree on the division of any unappropriated water discovered by test drilling, the project was not begun. No progress has been made in the past few years toward a compromise solution.

DECREASE IN DISCHARGE SINCE 1910

Local residents claim that Middle Canyon Creek was formerly a perennial stream, and that the total discharge from the canyon has decreased since the early 1900's. Records of the combined surface runoff and Big Spring discharge for 1906, 1909, and 1910 were obtained from the files of the city of Tooele and hydrographs for these years were plotted. These hydrographs, along with hydrographs for 1939, 1940, 1941, 1942, 1947, 1953, 1954, and 1955, were used to calculate the total amount of discharge per water year, in acre-feet. The discharges were plotted against precipitation at Tooele for the period October through April of the corresponding and preceding years in an attempt to obtain a relation between amount of flow and amount of precipitation (fig. 5). The years in the early 1900's show a greater discharge for a given amount of precipitation than do more recent years.

Possible reasons for this decrease include man's activities and natural causes. There have been no activities of man such as lumbering, agriculture, or other development in Middle Canyon that could account for the decrease in discharge in the past 50 years. Many of the local residents believe that mining activity in the nearby Bingham district has been responsible for the decrease. Tolman (1937, p. 299) states that a tunnel may drain the entire fracture system tributary to the fractures intercepted by the tunnel. Such a dewatering of areas around mine workings in the Bingham district could increase the local hydraulic gradient in the bedrock and thus increase water losses through fault and fracture systems in nearby drainage basins. There is no evidence to show how much effect, if any, mining activity has on Middle Canyon hydrology.

The most likely natural change that could have occurred in such a short time is a change in climate. According to M. T. Wilson, U.S. Geological Survey (oral communication, May 26, 1960), such a change in climate is indicated by the records of many other streams in Utah which show that a decrease in discharge for a given amount of precipitation is not peculiar to Middle Canyon. For example, Parleys Canyon, in the Wasatch Range near Salt Lake City, is a drainage basin similar to Middle Canyon in orientation and altitude and has had a decrease in relative discharge during the same period. Figure 6 shows a comparison of the discharge per water year of Parleys Creek with the

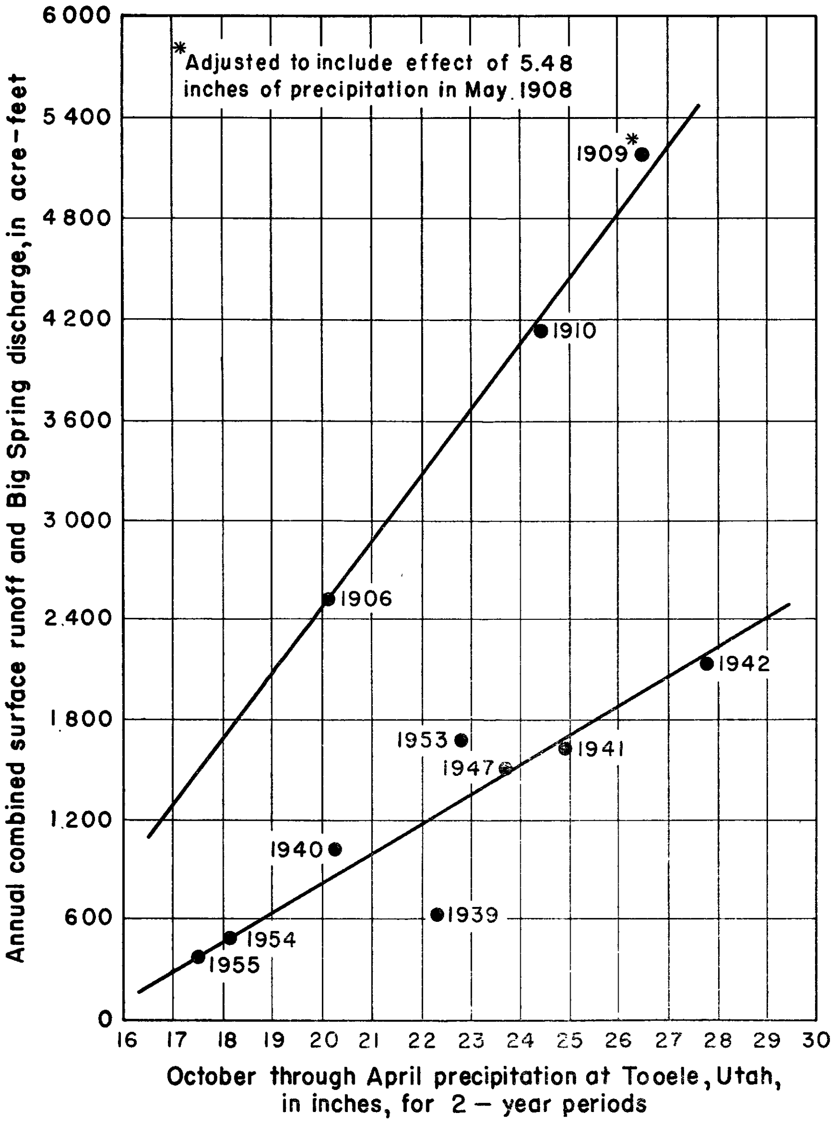

FIGURE 5.—Comparison of discharge from Middle Canyon with the October through April precipitation at Tooele, Utah. The precipitation shown is for 2-year periods, the year of indicated discharge and the preceding year. Points are plotted for all years for which comparative data are available.

October through April precipitation of the corresponding and preceding years at Salt Lake City. Because virtually the same years were used for both figures 5 and 6, the two figures can be compared directly. It is apparent that since the early 1900's the same type of decrease in discharge has occurred in both Parleys and Middle Canyons.

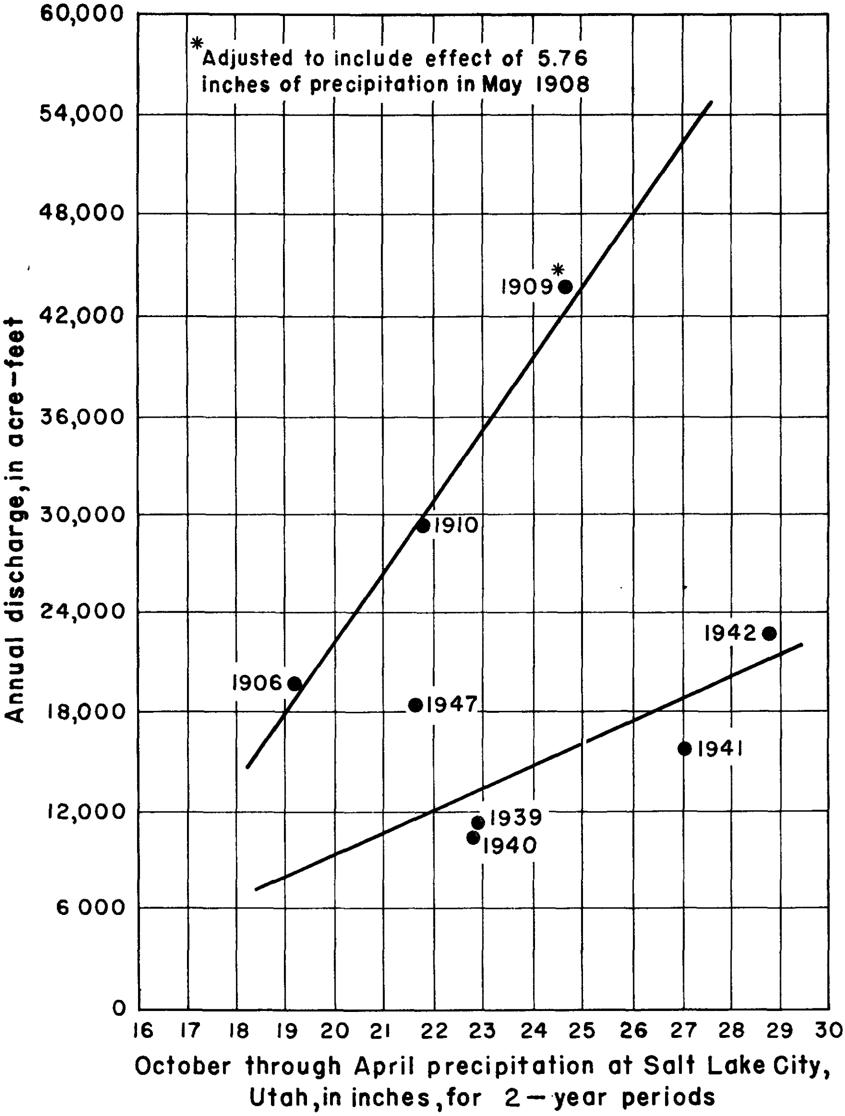

FIGURE 6.—Comparison of discharge from Parleys Canyon, Wasatch Range, with the October through April precipitation at Salt Lake City, Utah. The precipitation shown is for 2-year periods, the year of indicated discharge and the preceding year. Points are plotted for all years for which comparative data are available.

The major cause of the decrease in discharge of Middle Canyon, Parleys Canyon, and other drainage basins in Utah probably has been changes in climate. Figure 7 shows a comparison between the cumulative departure from the mean annual precipitation at Salt Lake City and the cumulative departure from the mean annual discharge from Parleys Canyon. The general similarity of the two curves indicates that climatic change, and specifically factors related to long-term variations in precipitation, has been the major factor in the variation in discharge from Parleys Canyon. The cumulative departure from the mean annual precipitation at Tooele (fig. 2) is similar to the precipitation departure of figure 7. If complete data were available on the discharge of Middle Canyon from 1899 through 1950, the departure curve of the discharge probably would be similar to that of Parleys Canyon.

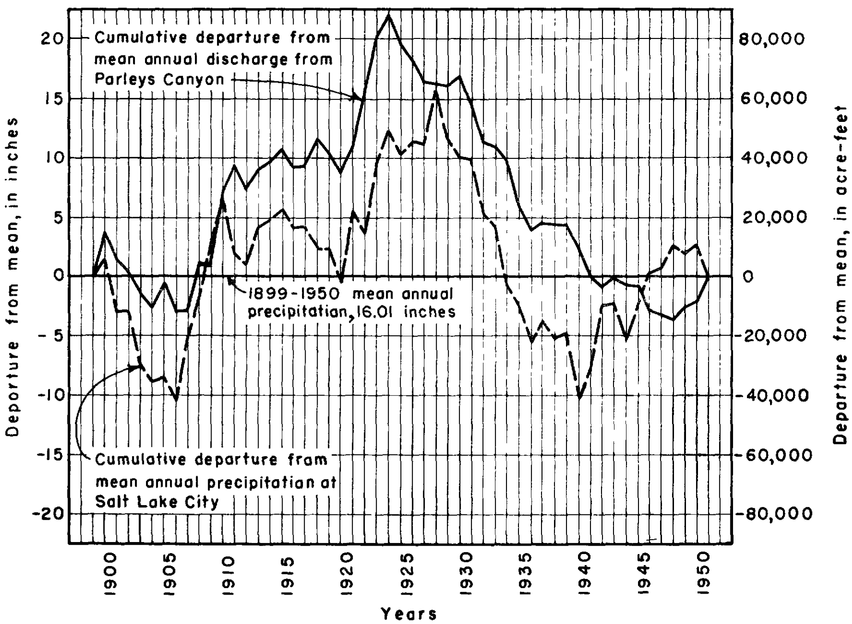

FIGURE 7.—Comparison of cumulative departure from 1899–1950 mean annual precipitation at Salt Lake City, Utah, with cumulative departure from 1899–1950 mean annual discharge from Parleys Canyon, Wasatch Range, Utah.

INFLUENCE OF GEOLOGIC FACTORS ON HYDROLOGY

STRATIGRAPHIC FACTORS

OQUIRRH FORMATION

The quartzites of the Oquirrh formation have little primary porosity and are relatively impermeable except where fractured. It has been believed by local residents that water could be entering the bedrock and migrating out of the drainage basin along bedding planes. This could occur if the bedding planes coincide with joint planes which are capable of transmitting water out of the Middle Canyon area.

The limestones of the Oquirrh formation could have an important effect on the canyon's hydrology. Limestone is a soluble rock, and solution openings may be formed in limestone by the action of percolating water.

Inspection of the Utah Metals tunnel in the spring of 1960 indicated that limestone solution may be a significant factor in the hydrology of Middle Canyon. Two drifts about 7,400 feet in from the Middle Canyon portal were contributing most of the flow in the tunnel. The east drift was dammed and its source of water could not be determined; but the west drift was open to a caved portion about 600 feet in from its junction with the tunnel. The last 200 feet of the west drift was through limestone, and most of the total flow of the drift was coming from this zone.

Extensive limestone solution was not mentioned in any of the reports on the Oquirrh Mountain mining districts. However, in his discussion of the Bingham quartzite, Keith (1905, p. 36) states that at great depths the rock is acted upon by underground waters and its materials removed by solution. Gilluly (1932, p. 162) observed that in the Honerine mine just west of Stockton, the "Galena King" limestone unit of the Oquirrh formation was more permeable to ground water than the other limestones in the mine. These observations suggest that there has been some solution of the limestones of the of the Oquirrh formation.

Limestone solution would most affect the hydrology of Middle Canyon at the outcrop of the lower and upper limestone members in the north-central part of sec. 6, T. 4 S., R. 3 W. At this location, the main canyon is cut through more than 500 feet of limestone that dips downstream at an angle of 25°to 30°. There is no surface evidence of limestone solution at this location, but long-continued percolation of underflow across the buried outcrops in the channel may have formed solution openings in the two limestone beds.

The faults that cut the two limestone members on the north side of the upper canyon could have provided permeable zones in the limestone along which solution openings may be localized. If they exist, water could be moving toward the Bingham syncline through such solution openings in the limestone beds.

SURFICIAL DEPOSITS

The surficial deposits of Quaternary age in Middle Canyon serve as the main storage and transmission material for the ground water of the drainage basin. Glacial deposits and weathered surficial material, especially on the south side of the upper canyon, absorb large quantities of water from spring snowmelt and prevent rapid runoff. White Pine Flat, with its great thickness of glacial and weathered debris, makes White Pine Canyon the best source of water among the tributaries to the main canyon. In contrast, the lesser thickness of surficial material in the Left Hand Fork drainage basin is a factor in the small amount of sustained flow that this tributary contributes to Middle Canyon.

The alluvial material in the main channel consists of gravel, sand, and silt and is permeable to ground-water movement. Spring runoff in the upper canyon percolates into the channel fill and is transmitted as underflow to the mouth of the canyon, where it furnishes most of the discharge of the springs and drains.

STRUCTURAL FACTORS

The folding in the Oquirrh Mountains may affect the hydrology of the Middle Canyon drainage basin; water may be moving downdip through the bedrock on the flanks of the folds along bedding-plane joints or through solution openings in limestone beds.

Faulting and associated jointing may have an important effect on the hydrology of the canyon. The numerous fault zones and joint sets in the Oquirrh formation may form interconnected systems through which water could migrate out of the drainage basin. In Middle Canyon, most of any water losses to fault and fracture systems probably occur in the numerous fault zones in the upper canyon.

Joints often control and facilitate the formation of solution openings in limestone. The numerous planes of jointing in the limestone of the Oquirrh formation indicate that, other conditions being favorable, the limestone would be readily accessible to solution.

Structure probably controls the location of Big Spring. The spring is at the intersection of the main channel with the mountain-front fault zone and possibly some water rises along the fault zone and is discharged from the spring. However, it is presumed that underflow is the main source of water for Big Spring because hydrographs of the spring are very similar to hydrographs of surface streams in the area.

After each movement along the fault, the stream restored the gradient of its channel across the fault zone, thinning the alluvium in the channel immediately upstream from the fault. The thinner alluvium just above the fault zone cannot transmit as much water as alluvium farther upstream, and when there is sufficient underflow to exceed the water-transmitting capacity of the alluvium at the fault, Big Spring flows.

GEOMORPHIC FACTORS

The observation that the topography of the upper half of Middle Canyon is more mature than the lower half was discussed on pages K15–K17. The broader channel of the upper main canyon has a greater thickness of alluvial fill and a higher proportion of fine material in the fill than does the channel of the lower canyon. The surficial material is thicker and more extensive over the upper canyon drainage area, and glacial and colluvial debris on White Pine Flat adds to the total amount of unconsolidated deposits in the upper canyon.

The greater thickness and lesser permeability of the unconsolidated material in the upper canyon tend to make the upper canyon a better water storage area than the lower canyon. Because there is more ground water in storage in the upper canyon than in the lower canyon, any structural or stratigraphic condition that would result in migration of water through bedrock and out of the drainage basin would have a much greater effect on Middle Canyon hydrology if located in the upper canyon. Such a condition is probably afforded by the fault zones in the upper canyon.

QUALITY OF WATER

Four water samples were taken at different locations in Middle Canyon, and their analyses were compared with analyses of older samples (table 1). Except for water from the Utah Metals tunnel, all the water samples have similar chemical characteristics. Typical Middle Canyon water is a hard calcium bicarbonate water containing 250 to 350 ppm (parts per million) of dissolved solids. If softened, this water is excellent for domestic uses.

Water from the Utah Metals tunnel is more mineralized than the other water samples. The high sulfate content results from leaching of oxidized sulfides associated with the intrusive bodies in the vicinity of the tunnel. The high calcium and magnesium content indicates that the water has dissolved calcium carbonate, which supports the previous observation that limestone beds in the west drift are contributing most of the water to the flow in the drift.

The analyses of samples from the city's wells and developed springs at the mouth of the canyon do not suggest that this water has any

TABLE 1.—*Chemical analyses of water from Middle Canyon, Oquirrh Mountains, Utah*

[PH, Analysis by Utah State Department of Public Health; GS, Analysis by U.S. Geological Survey]

Source	Date collected	Field No.	pH	Temperature (° F)	Specific conductance at 25° C (micromhos)	Constituents, in parts per million: Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Na+K: Sodium (Na)	Na+K: Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$: Calcium and magnesium	Hardness as $CaCO_3$: Non-carbonate	Percent sodium	Sodium-adsorption-ratio	Analysis by
Lincoln Spring	Dec. 15, 1950					9.5	0	62	27	16		277	40	17	0.2	2.0	312	264				PH
Lincoln Spring	Mar. 1, 1951				558	12	.02	76	22	14	2.7	298	39	15	.1	2.4	320	280		10		GS
Tooele city supply [1]	[2] Sept. 19, 1952		7.9			3.2	.08	80	6.9	45		283	67	16	.3	0	358	228				PH
White Pine Fork [3]	Aug. 5, 1959	MC-1	8.0	52	435	12	0	54	20	10		246	20	10		2.1	249	216	14	9	0.3	GS
Utah Metals tunnel	do	MC-2	7.9	48	1,070	11		124	72	13		280	369	16		1.2	744	608	378	5	.2	GS
Tooele city supply [4]	Aug. 7, 1959	MC-3	7.8	49	566	9		67	26		9.2	290	33	16		1.9	305	276	38	7	.2	GS
Hansen Fork [3]	Aug. 11, 1959	MC-4	7.8	49	427	7.6		51	21		9.0	250	13	9		3.1	237	214	9	8	.3	GS

[1] Big Spring and developed springs at the mouth of Middle Canyon.
[2] Date of report of analysis.
[3] At Kennecott Copper Corp. diversion.
[4] Developed springs and 3 wells at the mouth of Middle Canyon.

source other than the upper canyon. The city water is slightly more mineralized than the water from the upper canyon (White Pine and Hansen Forks), and its composition probably reflects the greater distance it has traveled.

Apparently the addition of the tunnel water does not have much effect on the chemical quality of the water at the canyon mouth. Possibly the tunnel water is being diluted by channel underflow, but more than 6,000 gpm of water of the composition of White Pine and Hansen Forks would be required to dilute the sulfate content of the 200 to 300 gpm of tunnel discharge to the sulfate content of the water at the mouth of the canyon. Because underflow in the dry part of the year is considered to be much smaller than 6,000 gpm, a better explanation might be that in times of low flow during the late summer and fall, most of the upper canyon and tunnel water is lost from the channel by leakage. At this time, water from the city's springs and wells would be largely derived from underflow of lower canyon tributaries. During the spring runoff, the excess of upper-canyon water over leakage moves down the canyon and furnishes the Big Spring discharge. At this time of year, there is sufficient underflow to dilute the tunnel water so that its chemical characteristics are not noted in the water at the canyon mouth.

LEAKAGE

Data on quality of water suggest that leakage is occurring in upper Middle Canyon. Leakage from the basin is suggested also by comparison of discharge data from Middle Canyon and other drainage basins in the area. Records furnished by Professor Ray E. Marsell show the 1948 surface runoff, in acre-feet per square mile of drainage area, for several creeks in the Wasatch Range near Salt Lake City.

Surface runoff of selected streams in the Wasatch Range in 1948 and discharge of Middle Canyon in 1947

	Acre-feet per square mile
1948 [1]	
City Creek	623
Parleys Creek	466
Mill Creek	543
Big Cottonwood Creek	1, 110
Little Cottonwood Creek	1, 665
Neff Canyon Creek	332
1947 [2]	
Middle Canyon	150

[1] 1948 figures furnished by Professor Ray E. Marsell.

[2] 1947 figure calculated from data of D. F. Lawrence and G. M. England, U.S. Soil Conservation Service (written communication, Apr. 14, 1948).

City Creek Canyon and Mill Creek Canyon are those most comparable to Middle Canyon in drainage area, altitude, and types of rock. The runoff totals for City Creek and Mill Creek, 623 and 543 acre-feet per square mile, respectively, are much greater than the 150 acre-feet per square mile that Middle Canyon discharged in 1947. The 1948 discharge of Middle Canyon probably was even less than 150 acre-feet per square mile, because at Tooele the precipitation from October through April was less in 1948 than in 1947.

Data released subsequent to this study (U.S. Geol. Survey, 1960, p. 184–203) show that the 1948 water-year discharges of the first five of the selected streams above and the 1947 water-year discharge of Middle Canyon are in close agreement with the comparison presented in this report.

SOLUTION CHANNELS

The possible effect of limestone solution on Middle Canyon hydrology was discussed on pages K24–K25. Water could be moving as underflow down the main channel and entering solution openings in the lower and upper limestone members at places where these beds crop out across the main channel. The outlet for this leakage could be the mountain-front fault, which certainly truncates the limestone beds at depth. Water possibly moves downdip through the limestone beds to the brecciated fault zone, and then migrates upward along the fault zone until it escapes into the valley fill.

FAULT ZONES AND JOINTS

Leakage may be taking place along fault and associated fracture zones in the upper canyon. Water could be entering fault and fracture systems and eventually moving into the unconsolidated deposits in the intermontane basins bordering the range. There is some evidence that leakage is taking place along fault and fracture systems in the Oquirrh Mountains. Keith (1905, p. 30) reported that in the Bingham district "The quantity of underground water is very great at any time of year and its disposal is a serious question in the deeper mines." Mark R. Gardner, of the Utah Water and Power Board, a former mining engineer at Bingham, stated that mine workings commonly intersected fracture zones in the quartzites that yielded considerable amounts of water (oral communication, Feb. 8, 1960). Most of these zones were eventually drained, indicating a dewatering of the area around the tunnel or drift.

Jointing, although a possible cause of leakage of water from Middle Canyon, probably is not of major importance. Joints in the walls of the Utah Metals tunnel were observed to be contributing minor amounts of water. In the mine workings of the Bingham district, joints are not a major source of water (M. R. Gardner, oral communication, Feb. 8, 1960). Some water could be leaking into the zone of intense jointing near the mouth of the canyon, but most of the leakage probably occurs upstream from this point.

The greatest effect of jointing is probably that water moves into fault zones largely through nearby joint systems close to the land surface, and a fault zone probably obtains water from a much larger area than is represented by its surface exposure.

There are not enough data to locate definitely areas of leakage. Leakage may occur along the whole length of the canyon, and not be limited to localities such as the zone of faulting in the upper canyon or the outcrop of the limestone beds across the main channel. However, most of the water in the mine workings in the Bingham district occurs in fault and fracture zones, and leakage from the Middle Canyon drainage basin probably occurs mainly through similar zones in the upper canyon.

HYDROLOGIC BUDGET

A hydrologic budget is a statement in which water gains and losses in a drainage basin are balanced over a given period of time. The 1947 water year, from October 1, 1946, to September 30, 1947, was selected as the period over which a hydrologic budget was to be estimated for the Middle Canyon drainage basin, because the 1947 study of D. F. Lawrence and G. M. England, U.S. Soil Conservation Service (written communication, Apr. 14, 1948), has been the only water-measurement project in Middle Canyon.

The hydrologic budget is at best a rough estimate because a lack of data permitted little more than estimates of many factors of the budget. However, it is believed that the figures for the various water gains and losses in the canyon represent reasonable estimates of the amounts of water involved. The budget is presented below; the various items are discussed in following pages.

Hydrologic budget of Middle Canyon for the 1947 water year

	Volume of water (acre-feet)
Water gains:	
Precipitation	18,500
Utah Metals tunnel water	Canceled by water piped to Bingham Canyon.
Total	18,500

Hydrologic budget of Middle Canyon for the 1947 water year—Continued

	Volume of water (acre-feet)
Drainage-basin storage	No gain or loss.
Water losses:	
Evapotranspiration	12,500
Big Spring flow and surface runoff	1,400
Tooele and Lincoln springs, drains, and wells	1,100
Channel underflow	500
Water piped to Bingham Canyon	Canceled by Utah Metals tunnel water.
Total accounted for	15,500
Presumed leakage	3,000
Total	18.500

WATER GAINS

PRECIPITATION

The principal, and perhaps the sole, source of Middle Canyon water supply is precipitation over the drainage basin. The Weather Bureau considers the October through April precipitation as most significant in the hydrologic budget of an area in northern Utah. Precipitation during the remainder of the year is largely lost by evapotranspiration and is not effective in producing streamflow and spring discharge.

The average October through April precipitation for different altitude zones in the Wasatch Range, Utah, is used in this water budget to calculate the average amount of water added annually to the Middle Canyon drainage basin because there are few data on precipitation in the Oquirrh Mountains. Although the Wasatch Range probably receives more precipitation than the Oquirrh Mountains, there is no major difference in the amounts of precipitation over the two mountain ranges. The calculated mean annual precipitation at the White Pine Canyon storage gage at an altitude of 7,000 feet in the Oquirrh Mountains is about 31.6 inches, and the annual average at the 7,000-foot level in the Wasatch Range is 32 inches.

The areas in the Middle Canyon drainage basin included between successive 1,000-foot contours were measured on the topographic base map by planimeter. The average annual October through April precipitation in the Middle Canyon drainage basin was calculated to be 16,200 acre-feet by multiplying the average October through April precipitation over 1,000-foot intervals in the Wasatch Range by the area within the 1,000-foot intervals in the Oquirrh Mountains (table 2).

TABLE 2.—*Calculated average annual water gain from precipitation in Middle Canyon*

Altitude (feet)	Area, in acres (rounded)	Average October through April precipitation [1] (inches)	Average annual amount of precipitation added (acre-feet)
<6,000	190	15.8	250
6,000–7,000	1,470	19.8	2,430
7,000–8,000	2,820	25.6	6,000
8,000–9,000	2,300	31.7	6,080
>9,000	450	38.5	1,440
Total	7,230		16,200

[1] Data supplied by Eugene L. Peck, of the U.S. Weather Bureau.

The October 1, 1946, to April 30, 1947, precipitation at Tooele was 124 percent of the 1931–52 mean. However, the precipitation at Tooele was not used to adjust the 1947 water-year precipitation in Middle Canyon because a station at a low altitude will receive a larger percentage increase in precipitation in a wet year than a station at higher altitude. The 114 percent of normal precipitation for October 1946 through April 1947 recorded at the Farmington Rice storage gage, a station 15 miles north of Salt Lake City at an altitude of 6,800 feet in the Wasatch Range, was used to adjust the Middle Canyon precipitation. The adjusted total amount of precipitation effective in producing stream and spring flow in the Middle Canyon drainage basin during the 1947 water year was calculated to be 18,500 acre-feet.

WATER FROM UTAH METALS TUNNEL

The Utah Metals tunnel discharges 100 to 400 gpm to the upper-canyon channel. Records kept by the Kennecott Copper Corp. show that this gain in water is approximately balanced by the water piped from Middle Canyon through the tunnel to Bingham Canyon. If the tunnel contributes water that originally was precipitation over the drainage basin, this water could not be considered as a gain additional to the water derived from precipitation. However, it is not known whether the tunnel water represents water leaking out of the drainage basin or water from outside the basin. Because most of the water flows into the tunnel a a point 7,400 feet from the Middle Canyon portal and north of the overlying surface drainage divide, it is assumed here that the tunnel is a source additional to precipitation. The gain, however, was balanced in 1947 by the loss of water piped to Bingham Canyon.

It is difficult to determine whether water developed by the Utah Metals tunnel originates in the Middle Canyon drainage basin. Water moving into the tunnel along solution channels or bedding-plane joints may be moving to the north out of the drainage basin, following the dip of the sedimentary strata. Water moving along fault zones or joints not parallel to bedding may be moving into the tunnel from various directions according to the local hydraulic gradient.

DRAINAGE-BASIN STORAGE

Drainage-basin storage can be a significant factor in the calculation of a hydrologic budget. In a wet year following several dry years, a considerable amount of the precipitation is used in making up the moisture deficit in the surficial material, and to some extent in the bedrock, of a drainage basin.

Although the Middle Canyon drainage basin does not have an extensive and thick cover of surficial material, the precipitation of the previous year has an effect on the annual discharge of Big Spring. A curve obtained by plotting Big Spring flow plus surface runoff against October through April precipitation of the corresponding year plus that of the preceding year (fig. 5) gives a better representation of the increase in flow that results from increase in precipitation than does the curve representing Big Spring and surface flow versus only the corresponding year's October through April precipitation.

Because the 3 years previous to 1947 had above-average annual precipitation as measured at Tooele (1944, 124 percent; 1945, 127 percent; and 1946, 112 percent), there probably was little soil-moisture deficit in 1947. For this reason it is estimated that drainage-basin storage had no effect on the 1947 water budget.

WATER LOSSES

EVAPOTRANSPIRATION

Evapotranspiration losses include transpiration by plants and evaporation from the ground or from a snow surface. The amount of water lost in a drainage basin by evapotranspiration is obviously difficult to calculate. Methods have been devised to calculate, from climatological data, the amount of evapotranspiration over large areas of uniform topography; but the application of these methods to small drainage basins in the Basin and Range province is not believed in general to be practical.

However, a study of evapotranspiration losses in Parrish Canyon a drainage basin in the Wasatch Range east of Farmington, Utah, 15 miles north of Salt Lake City, provides some pertinent data on which to base an estimate (Croft and Monninger, 1953). Altitudes in this drainage basin range from 4,600 to 8,900 feet, and the Parrish Creek Research Center is at an altitude of 8,400 feet. From 1946 to 1949, records were kept in Parrish Canyon of precipitation, rainfall interception, storm runoff, and yearly soil-moisture deficits. Evapotranspiration losses for areas having various types of vegetation were calculated in inches, and the differences between the total precipitation and the evapotranspiration were assumed to be water available for runoff and channel underflow. From table 9 of Croft and Monninger (1953, p. 571), evapotranspiration losses for the 1947 water year can be calculated. The greatest loss occurred in an area covered by aspen and herbaceous vegetation, and was 44 percent of the total precipitation of the water year. Croft and Monninger (1953, p. 573) state that these data on water available for streamflow should apply satisfactorily to steep mountain watersheds between 7,000 and 10,000 feet in altitude.

Precipitation in the Oquirrh Mountains probably is slightly less than in the Wasatch Range, and the percentage of precipitation that represents evapotranspiration increases as the total precipitation decreases. Therefore, there probably is a greater relative amount of evapotranspiration in Middle Canyon than in Parrish Canyon. In addition, the lesser mass of the Oquirrh Mountains as compared to the Wasatch Range would result in higher temperatures and greater evaporation losses in the Oquirrhs.

Two-thirds, or 67 percent, was used as the proportion of precipitation lost by evapotranspiration in Middle Canyon. This proportion should allow for any greater relative evapotranspiration in the Oquirrh Mountains and should help compensate for any underestimation of water losses or overestimation of water gains in the hydrologic budget.

Multiplying the total water gain of 18,500 acre-feet by 67 percent gives about 12,500 acre-feet as the total amount of water lost by evapotranspiration in Middle Canyon during the 1947 water year. This figure has the largest possible error of those used in the budget.

BIG SPRING FLOW AND SURFACE RUNOFF

The most obvious loss of water from the drainage basin is the discharge of Big Spring at the mouth of the Canyon. The flow of Big Spring, combined with any surface runoff that reaches the canyon mouth, is measured by a 12-inch Parshall flume owned by the Middle Canyon Irrigation Co.

During the 1947 water year, the total flow in the irrigation company's flume was calculated from measurements made by D. F. Lawrence and G. M. England, U.S. Soil Conservation Service (written communication, Apr. 14, 1948). From May 1, 1947, when Big Spring started flowing, to October 15, the total flow was 1,400 acre-feet.

TOOELE AND LINCOLN SPRINGS, DRAINS, AND WELLS

Tooele obtains water from Middle Canyon from Big Spring, from developed springs and drains, and from wells near the canyon mouth; and Lincoln obtains water from a developed spring at the canyon mouth. The 190 gpm that Tooele can take from Big Spring is diverted to the city system above the 12-inch Parshall flume, and is not included in the measured flow at Big Spring.

In their report, Lawrence and England (written communication, Apr. 14, 1948) stated that the amount of Middle Canyon water used by Tooele and Lincoln, respectively, from May 1 to October 1, 1947, was 277 and 37 acre-feet. Mr. Dale James, former Tooele city manager, said that the figure for city water use was too low and suggested using city water records to obtain a better estimate (oral communication, Nov. 28, 1959). Records were available for 1953, a year in which the total Big Spring flow of 1,650 acre-feet was reasonably close to the 1947 water-year flow of 1,400 acre-feet.

The total amount of water used by Tooele in 1953 was 978 acre-feet. Rounding off this figure to 1,000 acre-feet and adding an estimated 1947 water-year use of 100 acre-feet for Lincoln gives a total of 1,100 acre-feet for the water use by the two communities.

CHANNEL UNDERFLOW

Certainly some water is being lost to the valley fill by channel underflow out of Middle Canyon. The water tapped by the Tooele city wells at the canyon mouth is part of this underflow, and additional water must be escaping from the canyon in this way. The amount of water obtained by the city wells is included in the 1953 city water records used to adjust the 1947 city water use, but the amount of additional water lost by channel underflow is difficult to estimate.

The city wells cannot pump more than a few hundred gallons per minute, and pumps on 2 of the 3 wells will break suction if they are in continuous use. This indicates that the channel fill just northwest of the canyon mouth has a low permeability. The amount of additional water lost by channel underflow is estimated here to be about 500 acre-feet per year.

WATER PIPED TO BINGHAM CANYON

The water loss represented by the water piped to Bingham Canyon through the Utah Metals tunnel is assumed to be balanced by the contribution of the water developed by the tunnel.

CONCLUSIONS

The hydrologic budget for Middle Canyon for the 1947 water year is based on rough estimates, at best, of the amounts of water involved. A significant amount of water, about 3,000 acre-feet, is represented by the difference between water gains and losses. The actual value of the difference may be substantially greater or less, because of the large possible error in the estimate of evapotranspiration and the somewhat smaller possible errors in the other items. However, what ever its actual value, the difference is probably best accounted for by leakage from the basin through fault zones and solution channels.

FUTURE DEVELOPMENT

A detailed discussion of possible methods for the future development of Middle Canyon water is not within the scope of this report, and the following comments stress the need for additional information.

Completion of the drilling project proposed in 1954 would add valuable information on the movement of water in the drainage basin. The site originally chosen for the test holes, just above the outcrops of the two limestone members across the channel, is satisfactory to test for leakage in the upper canyon. Additional test holes below the limestone outcrops would help determine if there is any leakage through solution openings. Test holes just above Big Spring would aid in the estimation of leakage in the lower canyon.

If testing indicates the leakage of large amounts of water through solution openings in the limestone, a cut-off dam above the limestone outcrops might prevent the loss of water by leakage, or several wells could be drilled to intercept the water to prevent its loss from the basin.

If testing indicates leakage in the upper canyon, probably through faults and other fractures, the possibility of constructing a pipeline down the canyon would merit further consideration. Much of the spring runoff in the upper canyon seeps into the channel fill and is eventually discharged from Big Spring and other springs along the frontal fault, or is lost by leakage. If the proposed pipeline were constructed to bring most of this runoff to the canyon mouth, the discharge of Big Spring and the city's developed springs probably would diminish. The pipeline would save any surface runoff that seeps into the channel to replenish ground water lost by leakage. If the pipeline were used only to bring the water discharged from the Utah Metals tunnel down the canyon, there probably would be little effect on the springs at the canyon mouth. In the late summer, most of the tunnel water probably is lost by leakage after seeping into the channel fill in the upper canyon; and this water would be saved by piping it down the canyon.

Removal of the trees in the main channel and on the alluvial fans of tributary canyons could decrease evapotranspiration losses, but whether this would make available significant amounts of water is debatable.

SUMMARY

A geologic and hydrologic study was made of Middle Canyon to investigate a reported decrease in discharge over the past 50 years and possible leakage from the canyon.

A comparison of records of total annual combined Big Spring and surface discharge with precipitation at Tooele indicates that the annual discharge for a given amount of precipitation has decreased over the past 50 years. This trend has been observed in other drainage basins in Utah, and probably is largely related to climatic changes.

Data on quality of water and comparison of the discharge of Middle Canyon with that of nearby drainage basins indicate that water may be leaking from Middle Canyon. The estimated hydrologic budget for 1947 suggests that as much as half the water potentially available for spring discharge and surface flow was missing and may be leaking from the drainage basin.

The reconnaissance of the geology indicates that leakage, if it occurs, probably takes place along northeastward-trending fault zones in the upper canyon and through solution openings in the limestone members of the Oquirrh formation. However, there is no conclusive evidence of the exact location of the area or areas where the chief leakage from Middle Canyon is occurring.

Additional information is needed on the amount of underflow in various reaches of the canyon to definitely locate zones of leakage. The proposed test-drilling project would provide much of this information and aid in the planning of future development for Middle Canyon water.

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INDEX