Evaluation of Seepage From Chester Morse Lake and Masonry Pool King County, Washington

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1839-J

Prepared in cooperation with the city of Seattle Lighting Department

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By F. T. HIDAKA *and* A. A. GARRETT

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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Analysis of seepage losses from Chester Morse Lake and Masonry Pool and seepage gains to the Cedar and South Fork Snoqualmie Rivers

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EVALUATION OF SEEPAGE FROM CHESTER MORSE LAKE AND MASONRY POOL, KING COUNTY, WASHINGTON

By F. T. HIDAKA and A. A. GARRETT

ABSTRACT

Hydrologic data collected in the Cedar and Snoqualmie River basins on the west slope of the Cascade Range have been analyzed to determine the amount of water lost by seepage from Chester Morse Lake and Masonry Pool and the consequent gain by seepage to the Cedar and South Fork Snoqualmie Rivers. For water years 1957–64, average losses were about 220 cfs (cubic feet per second) while average gains were about 180 cfs in the Cedar River and 50 cfs in the South Fork Snoqualmie River.

Streamflow and precipitation data for water years 1908–26 and 1930–32 indicate that a change in runoff regimen occurred in Cedar and South Fork Snoqualmie Rivers after the Boxley Creek washout in December 1918. For water years 1919–26 and 1930–32, the flow of Cedar River near Landsburg averaged about 80 cfs less than it would have if the washout had not occurred. In contrast, the flow of South Fork Snoqualmie River at North Bend averaged about 60 cfs more than it would have.

INTRODUCTION

PURPOSE AND SCOPE

Under cooperative agreement with the city of Seattle Lighting Department, the U.S. Geological Survey analyzed hydrologic data for the water years 1957–64 to determine the approximate amount of seepage losses from Chester Morse Lake and Masonry Pool and the concurrent amounts of seepage to Cedar and South Fork Snoqualmie Rivers. The records for water years 1908–26 and 1930–32 were also used to investigate the effect that Boxley Creek washout of 1918 had on the runoff regimens of both the Cedar and South Fork Snoqualmie Rivers.

ACKNOWLEDGMENTS

Reports on previous investigations and data on reservoir altitudes were furnished by E. C. Brundage, power analyst with Seattle's Lighting Department. Valuable historical information was loaned by the division engineer of the Chicago, Milwaukee, St. Paul, and Pacific Railroad in Tacoma, Wash. I. S. Papadopulos, hydraulic engineer, U.S. Geological Survey, provided assistance in the analysis of the available ground-water data.

LOCATION AND GENERAL FEATURES

The study area includes Chester Morse Lake (formerly called Cedar Lake), other parts of the Cedar River basin, and parts of the Middle and South Fork Snoqualmie River basins. The area comprises about 250 square miles on the west slope of the Cascade Range in King County, Wash. The relation of the study area to the State as a whole and to the overall stream network is shown in figure 1; detailed features of the Cedar Falls-North Bend vicinity are shown in figure 2.

The part of the study area in the Cedar River valley includes the drainage system from Chester Morse Lake downstream to Landsburg. The Cedar River heads in the Cascade Mountains and flows westward 12 miles to Chester Morse Lake. The only other large tributary to the lake is the Rex River. Chester Morse Lake lies at an altitude of 1,550 feet and is 5 miles long and half a mile wide. The lake averages about 90 feet in depth and has a maximum depth of about 115 feet.

A timber crib dam is half a mile downstream from the natural outlet of Chester Morse Lake. Another dam spans the narrow valley 1.5 miles below the crib dam. Originally, this second dam was called Masonry Dam and the reservoir it formed was called Masonry Pool. These commonly used names have become the official designations of the dam and reservoir.

From Masonry Dam, Cedar River continues to flow westward on a fairly uniform gradient of about 40 feet per mile to Landsburg. Taylor Creek is the largest tributary to the Cedar River between the the dam and Landsburg.

The part of the study area in the Snoqualmie River valley is a 6-mile reach extending from Edgewick to North Bend. This reach lies north of Chester Morse Lake, and includes segments of both the Middle and South Forks Snoqualmie River. The Snoqualmie Valley is separated from the Cedar River basin by a divide at an altitude of about 920 feet. The Snoqualmie flood plain ranges in altitude from 440 feet at North Bend to about 700 feet near Edgewick.

The Cedar and South Fork Snoqualmie Rivers are about 3 miles apart at their closest point, in the vicinity of Cedar Falls. Rattlesnake Lake lies half a mile north of Cedar River in the area between the two rivers (fig. 2). The lake has no outlet, but any surface outflow would enter Boxley Creek, a tributary of South Fork Snoqualmie River, rather than Cedar River.

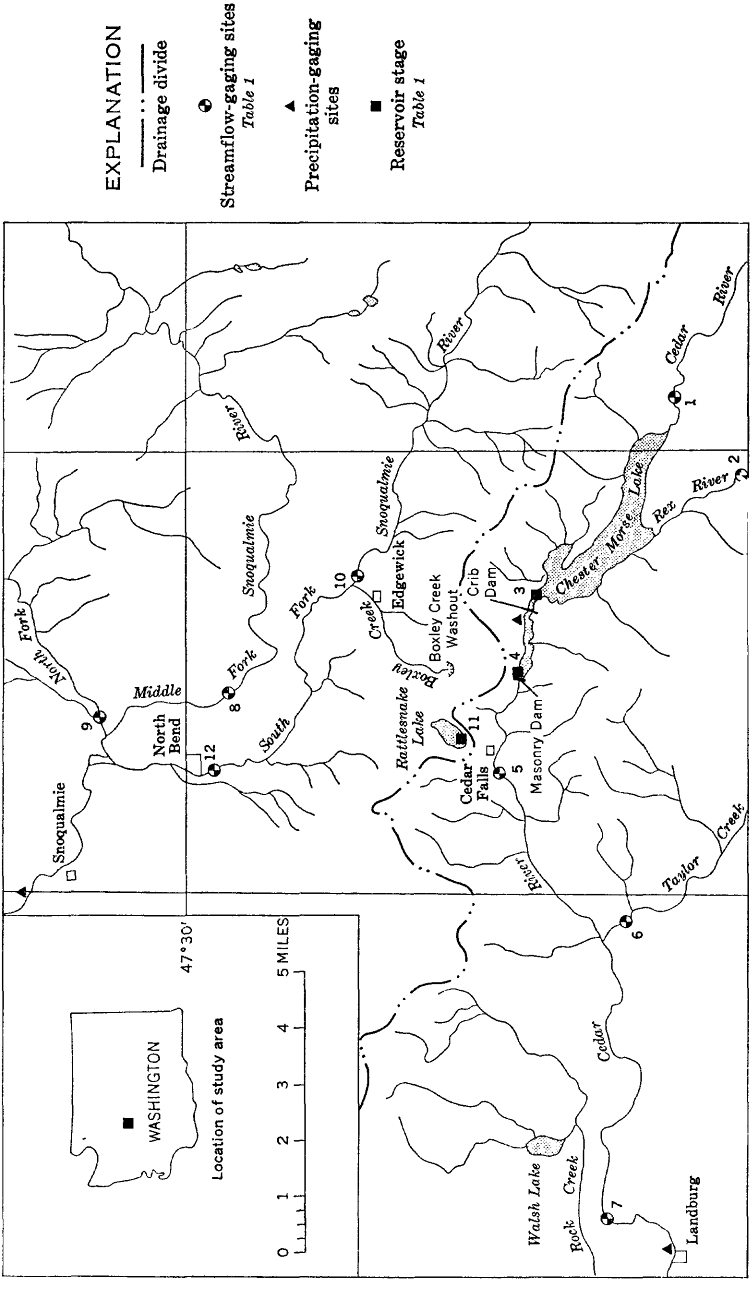

FIGURE 1.—Hydrologic data-collection sites in the vicinity of Chester Morse Lake.

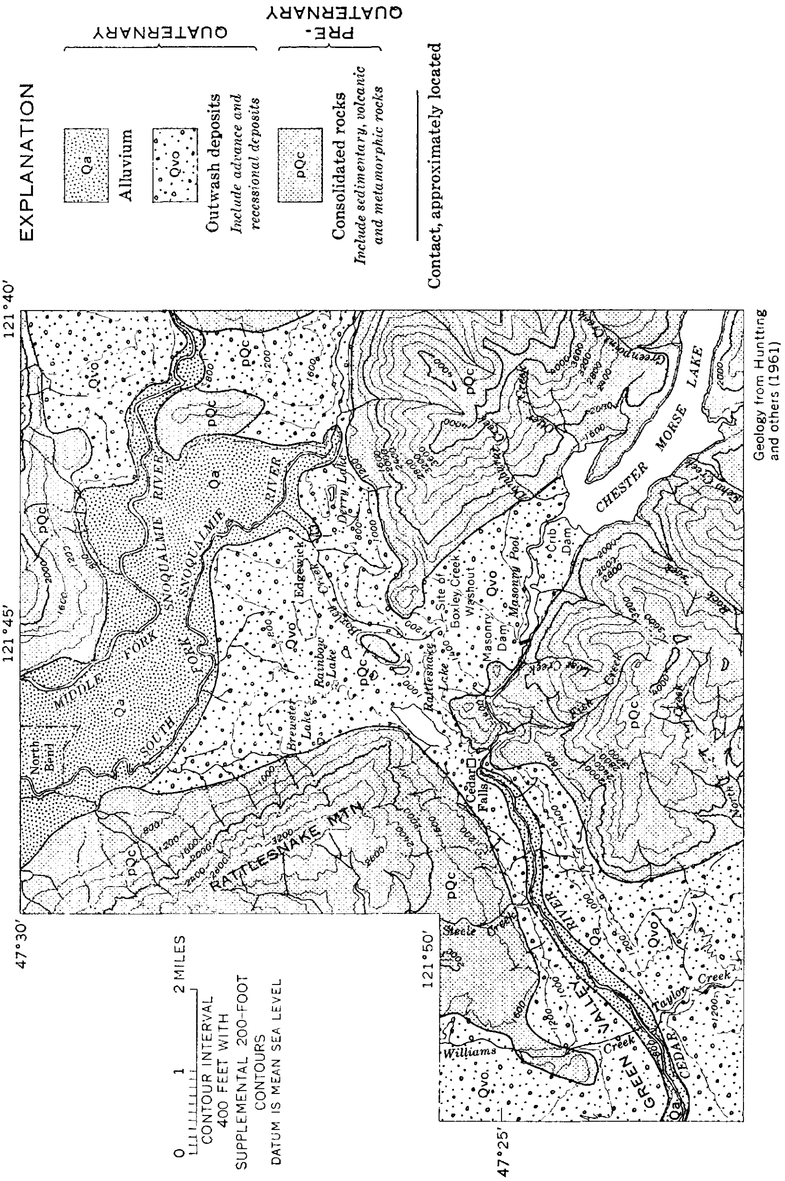

FIGURE 2.—Physiographic setting and generalized geology of the Cedar Falls-North Bend area.

HISTORY OF CEDAR RIVER DEVELOPMENT AND SEEPAGE FROM CHESTER MORSE LAKE AND MASONRY POOL

Cedar River is the source of municipal water supply for Seattle. In 1900, construction of a dam and diversion works was started at Landsburg, and in 1901, the first water was delivered to Seattle in gravity lines (McWilliams, 1955, p. 63).

The use of Cedar River in the vicinity of Chester Morse Lake for the development of hydroelectric power was investigated as early as 1895. The large amount of potential storage in the lake, together with about 600 feet of fall in the river below the lake, were responsible for the early interest in development of the river. Construction of a powerplant at Cedar Falls began in 1902, and the first electricity was delivered to Seattle in 1905. The headworks was the timber crib dam half a mile below the natural outlet of Chester Morse Lake. The dam raised the lake level 18 feet, to 1,548 feet altitude, and provided 25,000 acre-feet of storage in addition to the 33,500 acre-feet in the natural lake. The water was carried 3 miles from the dam to the powerplant, and in this distance a gross head of 600 feet was available.

In 1910, construction of a new dam (Masonry Dam) 1.5 miles below the crib dam in the narrow valley was proposed. The dam was designed to have a spillway crest at 1,605 feet and was meant to provide an increase in storage capacity of 125,000 acre-feet. Because of seepage problems during the dam's construction, the spillway crest was lowered to 1,590 feet, and an opening in the dam was provided at 1,555 feet. Water storage in the reservoir (Masonry Pool) created by the dam was started in December 1914. In the spring of 1915, a rapid rise in the water level of Rattlesnake Lake (fig. 2) flooded the town of Cedar Falls. The flooding was attributed to seepage that resulted from storage of water behind Masonry Dam. To stop the seepage, the banks of Masonry Pool were flattened and sluiced with clay and other fine materials. This work was continued until 1918 when it was believed that most of the larger leaks had been sealed. Water storage was started again, and the water-level rise in Masonry Pool caused increased flow from the south flank of South Fork Snoqualmie Valley to Rattlesnake Lake and Boxley Creek. Heavy rains helped to raise the level of Masonry Pool to 1,550 feet, and on December 23, 1918, a large slide and washout occurred above the source of Boxley Creek. The washout resulted in the release of a large amount of water and gravel outwash, which flooded a sawmill and half a mile of railroad grade near the Boxley Creek channel.

Following the washout, a continued effort was made to seal Masonry Pool by sluicing. This effort was discontinued in 1930. The dam has never been used to its capacity because of the excessive seepage and the possibility of additional washouts.

EARLIER INVESTIGATIONS

Many geologic and engineering investigations have been conducted in the vicinity of Chester Morse Lake since the washout of Boxley Creek. Some of the purposes of the studies were (1) to describe the geologic setting of the area and to analyze the Boxley Creek washout, (2) to determine the amount of seepage from Chester Morse Lake and Masonry Pool, (3) to determine the feasibility of sealing the reservoir banks to prevent the seepage, and (4) to evaluate the effect of replacing the timber crib dam with a higher and more solidly constructed dam at the outlet of Chester Morse Lake.

In 1919, an unpublished report regarding damage to the railroad right-of-way by the Boxley Creek washout of December 23, 1918, was prepared by J. C. Ralston for the Chicago, Milwaukee, St. Paul, and Pacific Railroad.

Reports were prepared in 1923 and 1952 by S. B. Hill for the city of Seattle. These unpublished reports evaluated the amount of seepage from Chester Morse Lake and Masonry Pool and considered the feasibility of sealing the banks of both reservoirs. In his earlier report, Hill stated that: "There was a large seepage loss from Cedar Lake [Chester Morse Lake] after construction of the crib dam. This averaged for the first six years 122,000 acre-feet per year or an average of 168 second-feet." However, he also mentioned that the amount decreased over the years: "The seepage loss from the lakes has decreased from year to year. * * * There is now but very slight seepage loss from Cedar Lake below 1,540 feet water level." Hill also concluded that seepage losses from Masonry Pool were large. According to his computations, the average loss per day during the period 1919–23 ranged from 200 acre-feet when the altitude of Masonry Pool was 1,520 feet to 983 acre-feet when the altitude was 1,550 feet.

Hill's later report supplemented and updated the earlier report. Benefits to the Lighting and Water Departments from additional storage in Chester Morse Lake were discussed.

New studies on the feasibility of reconstructing the crib dam at the outlet of Chester Morse Lake are currently (1964) being carried on by the consulting firm of Shannon and Wilson for the Seattle Lighting Department.

STUDY AREA

CLIMATE

Climate in the vicinity of Chester Morse Lake is mild and wet, owing to the prevailing air currents that move inland from the Pacific Ocean. The Cascade Mountains to the east protect the area from the cold continental air masses. The combination of these two features produces a marine-type climate that is cool in the summer and relatively mild in the winter (Phillips, 1965).

Summer temperatures usually remain below 80°F and winter temperatures normally remain above freezing. The average monthly temperature ranges from 35°F in January to 61°F in July at Cedar Lake. (The U.S. Weather Bureau retains the old name, Cedar Lake, for its climatological station and records, although the lake's name was officially changed to Chester Morse.)

Precipitation over the area comes from warm, moisture-laden winds that move inland from the Pacific Ocean and are forced upward by the west slope of the Cascade Mountains. The rising air is cooled, and the moisture is condensed to produce rain or snow. Orographic influences cause a wide difference in precipitation within a relatively short distance, as illustrated by the records at Landsburg and Cedar Lake. Within a distance of only 12 miles between the two gages, average annual precipitation increases from 55 inches at Landsburg (altitude 535 ft) to 102 inches at Cedar Lake (altitude 1,560 ft).

GEOLOGIC SETTING

The study area, in the western foothills of the Cascade Range, includes a segment of the Puget lowland. The topography of the study area as a whole is that of a youthful upland, incised by steep-sided stream valleys. The area has been modified greatly by glacial action. The crests of ridges show results of the characteristic eroding action of alpine glaciers, and the valleys have become filled with large quantities of morainal debris and outwash associated with the several Pleistocene continental glaciations.

The following topographic features are important parts of the study area: (1) The segment of the Puget lowland that has been called the Snoqualmie embayment by Mackin (1941b, p. 451), that extends into the mountains, and that is occupied by the South and Middle Forks of the Snoqualmie River, (2) the northwestward-trending valley occupied by Chester Morse Lake, (3) the southwestward-trending valley occupied by the Cedar River downstream from the lake, and (4) the extensive moraine that separates the Cedar River drainage from the Snoqualmie drainage to the north.

Both the Snoqualmie embayment and the Cedar embankment are shown in figure 2, which presents a segment of the study area in detail. The Snoqualmie embayment includes virtually all the area presently underlain by alluvium or outwash in the northeast part of the segment as shown in figure 2. The Cedar embankment includes the east-central part underlain by outwash.

Prior to the onset of glaciation, the valley now occupied by Chester Morse Lake drained northwestward, converging with the valleys of the South and Middle Fork of Snoqualmie River. The depths of these valleys are not known. In Pleistocene time—a period of extensive glaciation—a glacier entered the Snoqualmie embayment from the northwest. It built a composite till-outwash moraine, the Cedar embankment of Mackin (1941b), opposite the Cedar Valley, to form Chester Morse Lake. The lake became a sizable water body shortly after glacial blockage of the valley mouth. According to Mackin (1941a, p. 457), the outwash gravel deposited during the advance of the glacier overlaps and grades into lacustrine deposits. These deposits represent successive positions occupied by the lake at later and later stages of ice advance. In other words, the lake was reduced in area by encroachment of the moraine, which covered the lacustrine deposits to a greater and greater depth as it advanced.

As a result of the blockage which dammed the Middle and South Forks of the Snoqualmie as well as the Cedar River the drainage pattern changed markedly. Most of the drainage from the Snoqualmie-Cedar area presumably escaped to the southwest (fig. 2) through the valley now occupied by the Cedar River. The drainage escaped in this direction by breaching the southwest divide at its lowest point. According to Mackin (1941a, p. 466), "Incision of part or all of the Snoqualmie-Cedar drainage in the course so determined, during one or more interglacial interstages, could then have produced the deep rock valley utilized as a spillway during the last glacial invasion." When the glacier withdrew, "the Middle and South Forks happened to begin downcutting in weak glacial detritus; these streams have subsequently trenched the valley mouth embankments, drained the glacial lakes, and cut deeply into the former lake floors." (Mackin, 1941b, p. 20). In contrast, outflow from Chester Morse Lake by way of Cedar River had already become established across the southwest divide, just southwest of Rattlesnake Lake (fig. 2), so the retreat of the glacier had no effect on the Cedar River regimen. Furthermore, because the point where the Cedar River crosses the southwest divide is underlain by bedrock, "the river has been able only to cut a narrow gorge part way through * * * [bedrock] spurs [and] the Cedar morainal embankment is practically uneroded * * *" (Mackin, 1941b,

p. 20). The near absence of headward erosion has, of course, allowed Chester Morse Lake to remain intact, "only slightly lowered from its Pleistocene elevation."

HYDROLOGIC SETTING

The Cedar River basin and the Snoqualmie River basin are separate physiographic entities. However, because of the permeable nature of the Cedar embankment, transfer of water takes place between the two drainage systems by means of subsurface leakage. In general, water is lost from Masonry Pool and, to a lesser extent, from Chester Morse Lake and moves downgradient through the embankment. Part of this water enters the Snoqualmie drainage system and is intercepted by the South Fork of the Snoqualmie River, within the reach between Edgewick and North Bend. Almost all of the remainder returns to the Cedar River system.

Rattlesnake Lake, which lies in the area between the two rivers, accepts some seepage from Chester Morse Lake and Masonry Pool. The area covered by Rattlesnake Lake has increased in size in the last century (many large tree stumps are now under water), and much of the increase doubtless has occurred since the construction of Masonry Dam. In general, the lake stage responds to changes in the stage of both Chester Morse Lake and Masonry Pool. Figure 3 shows the comparison of stages of Chester Morse Lake, Masonry Pool, and Rattlesnake Lake for water years 1961–64.

Water-level measurements in test wells constructed near the north end of Chester Morse Lake suggest that seepage occurs mainly from Masonry Pool. Water levels in the Cedar embankment are controlled in large part by the level in the Pool and to a significant extent also by precipitation that falls on the embankment.

As stated earlier (p. J2), Rattlesnake Lake is in the Snoqualmie River drainage system. Nevertheless, fragmentary data suggest that the ground-water divide may be north of the lake, so that seepage from the lake may return to the Cedar River drainage system.

In the Snoqualmie River valley southeast of North Bend, ground water moves generally downgradient and parallel to the course of the South and Middle Forks. The available data suggest that no large transfer of water by ground-water movement occurs from the Middle to the South Fork. Doubtless, during times of changing stage in both forks, some water is taken into or out of ground-water storage. However, the amount of water in temporary storage is not critical compared to the amount transferred to the South Fork as underflow through the Cedar embankment.

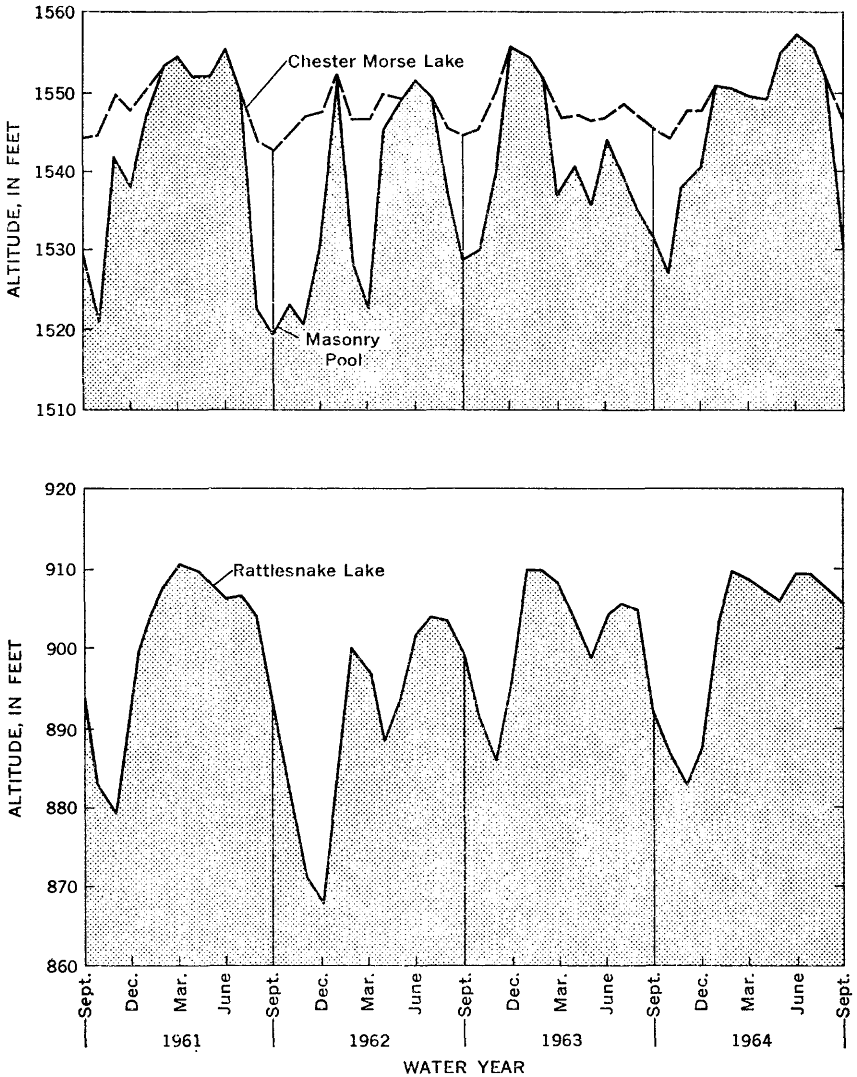

FIGURE 3.—Comparison of stages of Chester Morse Lake, Masonry Pool, and Rattlesnake Lake, 1961–64.

RECORDS USED IN THE STUDY

STREAMFLOW AND STAGE RECORDS

Many streamflow and stage records have been collected in and adjacent to the study area. Flow in the Cedar River near Landsburg has been gaged continuously since 1895. Other gaging stations in the Cedar River basin have been in operation for shorter periods.

Streamflow records on the three forks of the Snoqualmie River were started in 1908 but were collected only intermittently through 1964. Records were collected on the South Fork Snoqualmie River at Edgewick from 1962, after the start of this study, to 1964.

Stage records for Masonry Pool have been gathered by the Seattle Lighting Department since 1914. Stage records on Chester Morse and Rattlesnake Lakes are also available.

Sites at which streamflow and stage records were collected for use in this study are shown in figure 1. Lengths of records at these sites are listed in table 1.

TABLE 1.—*Length and type of available records for selected stage- and streamflow-gaging stations in Cedar and Snoqualmie River basins*

No. on fig. 1	Station name	Drainage area (sq mi)	Period of record (water years)	Type of record
	Cedar River basin			
1	Cedar River near Cedar Falls (above Chester Morse Lake).	40.7	1946–64	Discharge.
2	Rex River near Cedar Falls (tributary to lake).	13.4	1946–64	Discharge.
3	Chester Morse Lake	78.4	1905–64	Stage.
4	Masonry Pool	81.3	1918–64	Stage.
5	Cedar River at Cedar Falls	84.2	1914–64	Discharge.
6	Taylor Creek near Selleck	17.2	1957–64	Discharge.
7	Cedar River near Landsburg	117	1895–1964	Discharge.
	Snoqualmie River basin			
8	Middle Fork Snoqualmie River near North Bend.	169	1908–26 1930–32	Discharge.
9	North Fork Snoqualmie River near North Bend.	95.7	1908–26 1930–38 1960–64	Discharge.
10	South Fork Snoqualmie River at Edgewick.	65.9	1962–64	Discharge.
11	Rattlesnake Lake	1.86	1953–64	Stage.
12	South Fork Snoqualmie River at North Bend.	81.7	1908–26 1930–38 1945–50 1960–64	Discharge.
	Griffin Creek near Carnation[1]	17.1	1946–64	Discharge.

[1] Not shown on map.

WELL RECORDS

From August 1962 to November 1964, a series of water-level measurements was obtained from each of about 50 domestic wells in the flood plain of the Middle and South Forks of Snoqualmie River and from several wells in the Cedar embankment. The measurements on the flood plain were made to determine the general features of ground-water occurrence in the interstream area, while those in wells on the embankment were made to determine whether the ground-water levels there fluctuate in response to changes in stage of Masonry Pool.

Virtually all the wells on the flood plain are near North Bend. No wells are known to exist in the area between the Middle and South Forks near Edgewick. This situation makes any evaluation of the ground-water features between the two streams difficult throughout much of the flood plain. Likewise, all wells in the embankment are concentrated on the steep northward-facing slope, whereas none are in the vicinity of Rattlesnake Lake or Masonry Pool. For that reason, the water-level gradient cannot be determined throughout much of the embankment.

PRECIPITATION RECORDS

Precipitation records used in the study were collected by the U.S. Weather Bureau at Cedar Lake (p. J7), Landsburg, and Snoqualmie Falls. The Landsburg precipitation gage has continuous records from 1904, whereas the Cedar Lake gage was started in 1903 and the Snoqualmie Falls gage, in 1899. The Landsburg and Snoqualmie Falls gage are at altitudes of 535 feet and 435 feet respectively, and the Cedar Lake gage is at the altitude of 1,560 feet. The gage sites are shown in figure 1.

SEEPAGE ESTIMATES FOR WATER YEARS 1957–64

Streamflow data collected in water years 1957–64 were used to estimate the seepage from Chester Morse Lake and Masonry Pool and the seepage to Cedar and South Fork Snoqualmie Rivers. Analysis was limited to the 8-year period by the length of records collected for Taylor Creek near Selleck. Any extension of the analysis to a longer period would require an estimation of discharge for Taylor Creek. This estimate is not considered necessary for the purposes of this study.

Annual values were used throughout this analysis except in the estimation of incremental flow to the South Fork Snoqualmie River between Edgewick and North Bend, where monthly estimates were computed and combined to obtain annual figures.

SEEPAGE FROM CHESTER MORSE LAKE AND MASONRY POOL

The seepage from Chester Morse Lake and Masonry Pool is assumed to be the difference between the estimated net discharge from the basin above the Cedar River gaging station at Cedar Falls and the measured discharge at that station, corrected for changes in storage in the lake and pool.

The estimated discharge from the basin above Cedar Falls was computed by summing the measured discharges of Cedar and Rex Rivers upstream from Chester Morse Lake (fig. 1, sites 1 and 2) and the estimated discharge for the remaining ungaged drainage area and subtracting the losses due to lake-surface evaporation. The basin above the Cedar Falls station has a drainage area of 84.2 square miles, and the two major tributaries to Chester Morse Lake drain 54.1 square miles. This difference leaves an ungaged area of 30.1 square miles. The discharge per square mile from the gaged area of 54.1 square miles was used to estimate discharge from the ungaged 30.1 square miles. Evaporation from Chester Morse Lake and Masonry Pool was estimated by assuming an annual loss of 24 inches from a water-surface area of 3 square miles. This evaporation rate is considered equal to the potential evapotranspiration value reported for Landsburg (U.S. Weather Bureau and U.S. Soil Conservation Service, 1961, p. 6). From these values, annual evaporation losses were computed to average 5 cfs (cubic feet per second). For the present study, the 5-cfs value is assumed to be constant from year to year.

Values of annual mean discharge obtained at the Cedar Falls station were adjusted for changes in storage in Chester Morse Lake and Masonry Pool. The adjusted values represent the natural flow at the Cedar Falls station.

As mentioned previously (p. J12), the difference between the estimated discharge from tributary areas above the station at Cedar Falls and the adjusted discharge at the station itself was considered equivalent to the seepage from Chester Morse Lake and Masonry Pool. Table 2 summarizes the computations of seepage for water years 1957–64.

TABLE 2.—*Estimated seepage from Chester Morse Lake and Masonry Pool, 1957–64*

[Quantities in cubic feet per second]

Water year	Rex River	Cedar River above Morse Lake	Ungaged area	Evaporation from lake and pool	Net discharge at Cedar Falls [1]	Cedar River at Cedar Falls	Change in storage	Adjusted discharge [2]	Estimated seepage [3] (rounded)
	1	2	3	4	5	6	7	8	9
1957	102	260	201	5	558	336	+1	337	220
1958	74.6	202	154	5	426	230	+2	232	190
1959	142	373	287	5	797	456	+36	492	300
1960	111	286	221	5	613	442	−33	409	200
1961	112	288	223	5	618	395	−3	392	230
1962	90.8	232	180	5	498	290	+6	296	200
1963	84.6	218	169	5	467	278	−1	277	190
1964	125	309	241	5	670	433	+6	439	230
Average	105	271	210	5	581	357	+2	359	220

[1] Net discharge at Cedar Falls (col. 5) for given water year is total of cols. 1, 2, and 3 minus evaporation from lake and pool (col. 4).
[2] Adjusted discharge (col. 8) is total of cols. 6 and 7.
[3] Estimated seepage (col. 9) is cols. 5 minus 8.

SEEPAGE TO CEDAR RIVER

Seepage to Cedar River downstream from Masonry Pool is assumed to occur in the reach between the gaging stations at Cedar Falls and Landsburg. Total discharge in this reach of river is the sum of the discharges of Cedar River at Cedar Falls and Taylor Creek near Selleck plus an estimated discharge from the remaining ungaged area of 15.6 square miles. The difference between this sum and the discharge at the Landsburg station was considered to be the seepage to Cedar River. The estimated discharge from the ungaged area was computed using the same discharge per square mile as that at the Taylor Creek station. The computations are summarized for the water years 1957–64 in table 3.

TABLE 3.—*Estimated seepage to Cedar River between Cedar Falls and Landsburg, 1957–64*

[Quantities in cubic feet per second]

Water year	Cedar River at Cedar Falls	Taylor Creek near Selleck	Ungaged area	Total estimated discharge at Landsburg [1]	Cedar River near Landsburg	Estimated seepage [2] (rounded)
	1	2	3	4	5	6
1957	336	97.5	88.4	522	716	190
1958	230	71.8	65.5	367	535	170
1959	456	131	119	706	906	200
1960	442	122	111	675	865	190
1961	395	116	105	616	801	180
1962	290	86.1	78.1	454	591	140
1963	278	94.1	85.3	457	637	180
1964	433	122	111	666	818	150
Average	357	105	95	557	734	180

[1] Total estimated discharge at Landsburg (col. 4) for given water year is total of cols. 1, 2, and 3.
[2] Estimated seepage (col. 6) is cols. 5 minus 4.

SEEPAGE TO SOUTH FORK SNOQUALMIE RIVER

All seepage to South Fork Snoqualmie River is assumed to enter from the south: that is, from the general direction of the Cedar embankment and the flank of Rattlesnake Mountain (fig. 2). This assumption seems valid because seepage from the Middle to the South Fork has been proven insignificant.

In the method used to compute seepage to South Fork Snoqualmie River, a quantity of water was assumed to be contributed by surface runoff from the drainage area between the Edgewick and North Bend gaging stations. That quantity was subtracted from the difference between discharges at the two stations, and the resulting value was considered to be incoming seepage.

The computation of seepage to the South Fork for water years 1957–64 required an estimation of the difference between discharges at Edgewick and North Bend for about 6 years of no record. Estimates were needed for water years 1957–61 and parts of water years 1962 and 1963. Because the available record is short, regression analyses were possible only on a monthly basis. The monthly data admittedly are not random because adjacent monthly values are usually related.

Two separate regressions were computed to estimate the increment of discharge between Edgewick and North Bend for the period of no record. Differences in monthly mean discharge for the 22 months of concurrent record at the two gaging stations were computed; these differences presumably consist not only of runoff accretions from precipitation over the intervening draining area but also of seepage from Cedar River basin.

In the first analysis, a multiple regression was computed, relating the increments of monthly mean discharge from the reach of the South Fork Snoqualmie River between Edgewick and North Bend to the stage in Masonry Pool and to precipitation. The amount of seepage and runoff accretions was assumed to be directly related to the stage and precipitation. A 2-month average value for stage of Masonry Pool, based on the current month and previous month, was used as an index of stage. An average of the monthly precipitation values recorded at Cedar Lake, Landsburg, and Snoqualmie Falls was computed for each month and then combined with half of the previous month's average to give an index of precipitation. The multiple regression using these variables is:

$$I = -130 + 4.0(S - 1{,}500) + 7.1P \qquad (1)$$

where

I=discharge increment between Edgewick and North Bend,
S=stage index for Masonry Pool, and
P=precipitation index.

The relation is shown graphically in figure 4.

In the second analysis, the increment of discharge between Edgewick and North Bend was related to a similar increment in the Cedar River between the Cedar Falls and Landsburg gaging stations. The increments of discharge in both streams are assumed to be related because both presumably include seepage from Chester Morse Lake and

Masonry Pool plus runoff accretion. The regression was computed from 22 months of record as:

$$I=-69+0.49C \tag{2}$$

where

I=discharge increment between Edgewick and North Bend and
C=comparable value for Cedar River between Cedar Falls and Landsburg.

The relation is shown graphically in figure 5.

These two regressions were used to estimate discharge increments for South Fork Snoqualmie River between Edgewick and North Bend for all months of no record at Edgewick during the 1957–64 water years. The monthly estimates were then combined to obtain annual figures. The average of the two annual figures was used as the estimated difference in discharge between Edgewick and North Bend.

Since the discharge increment includes both seepage and runoff accretion, the runoff part must be subtracted to determine the seepage. The drainage area between Edgewick and North Bend gaging stations is 15.8 square miles. The runoff accretion from this area was estimated to be the same as the average of Taylor Creek, a tributary to Cedar River, and Griffin Creek, a tributary to Snoqualmie River.

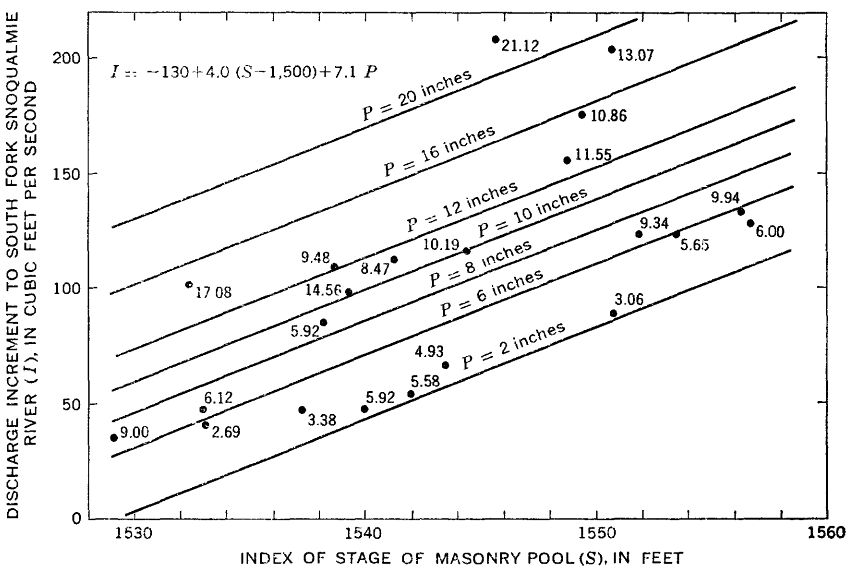

FIGURE 4.—Relation of monthly mean discharge increment to South Fork Snoqualmie River between Edgewick and North Bend (I) to index of stage of Masonry Pool (S) for a range of precipitation indices (P), 1962–64. Numbers are precipitation indices, in inches.

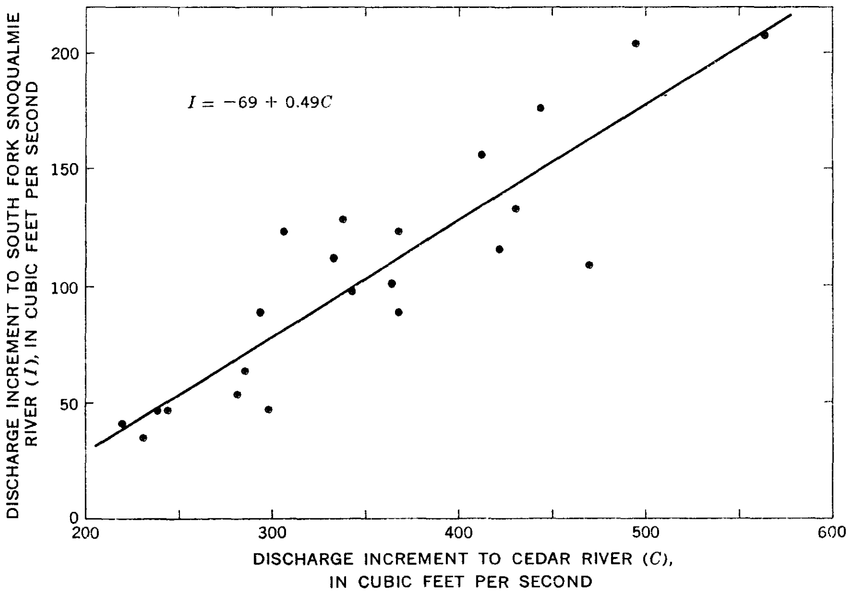

FIGURE 5.—Relation of monthly mean discharge increment to South Fork Snoqualmie River between Edgewick and North Bend (I) to a comparable value for Cedar River between Cedar Falls and Landsburg (C), 1962–64.

The estimated runoff accretion from the intervening drainage area was subtracted from the difference in discharge between Edgewick and North Bend, and the remainder was assumed to be seepage to South Fork Snoqualmie River. Table 4 presents a summary of the computations for the 1957–64 water years.

COMPARISON OF SEEPAGE ESTIMATES

Total seepage to the Cedar and South Fork Snoqualmie Rivers for the 1957–64 water years compares favorably with the estimated seepage from Chester Morse Lake and Masonry Pool. During this time span, the average seepage was computed to be about 180 cfs to the Cedar River and about 50 cfs to the South Fork Snoqualmie River, or a total of 230 cfs. Average seepage from Chester Morse Lake and Masonry Pool for the same period was computed to be about 220 cfs.

Although the two estimated seepage totals agree closely, within less that 5 percent, the amounts for some years do not agree as well. The greatest difference—about 25 percent—occurred in 1962. Table 5 summarizes the data used in making the comparisons.

TABLE 4.—*Estimated seepage to South Fork Snoqualmie River between Edgewick and North Bend, 1957–64*

[Quantities in cubic feet per second]

Water year	Discharge increment between Edgewick and North Bend			Surface runoff	Estimated seepage [1] (rounded)
	From equation 1	From equation 2	Average		
	1	2	3	4	5
1957	103	117	110	63	50
1958	79	81	80	48	30
1959	154	152	153	83	70
1960	125	139	132	76	60
1961	117	131	124	76	50
1962	70	79	74	55	20
1963	93	95	94	58	40
1964			[2] 133	77	60
Average			112	67	50

[1] Estimated seepage (col. 5) for given water year is cols. 3 minus 4.
[2] Measured discharge increment.

TABLE 5.—*Comparison of estimated seepage from Chester Morse Lake and Masonry Pool with that to Cedar and South Fork Snoqualmie Rivers, 1957–64*

[Quantities in cubic feet per second]

Water year	Estimated seepage			Estimated seepage from Chester Morse Lake and Masonry Pool
	To Cedar River	To South Fork Snoqualmie River	Total	
1957	190	50	240	220
1958	170	30	200	190
1959	200	70	270	300
1960	190	60	250	200
1961	180	50	230	230
1962	140	20	160	200
1963	180	40	220	190
1964	150	60	210	230
Average	180	50	230	220

The computed discharges listed in some of the columns of tables 2–4 may imply a greater accuracy than is warranted. The final seepage rates—those in the last column of each table and in table 5—have been rounded to two significant figures, or to the nearest 10 cfs.

In general, errors in the computed seepage from Chester Morse Lake and Masonry Pool probably are less than ±40 cfs and are based on the assumption that the errors in gaging-station records and in estimated discharges for ungaged areas are no greater than ±2 percent and ±10 percent, respectively. Errors in the computed seepage to

Cedar and South Fork Snoqualmie Rivers probably are less than ±40 cfs and ±20 cfs, respectively.

CHANGES IN RUNOFF REGIMEN FOLLOWING THE BOXLEY CREEK WASHOUT IN 1918

Streamflow records for Cedar River near Landsburg, South Fork Snoqualmie River at North Bend, and North and Middle Forks Snoqualmie River near North Bend in water years 1908–26 and 1930–32 along with precipitation records collected at Cedar Lake, Landsburg, and Snoqualmie Falls during the same period were used to determine changes in runoff regimen following the Boxley Creek washout in 1918.

Double-mass curves have been used to check the consistency of annual mean discharges of both Cedar River near Landsburg and South Fork Snoqualmie River at North Bend with records of precipitation and runoff. Cumulative discharge for Cedar River was plotted against cumulative precipitation values obtained by averaging the records at Cedar Lake and Landsburg. Likewise, cumulative discharge for South Fork Snoqualmie River was plotted against cumulative precipitation values obtained by averaging the catches at Cedar Lake and Snoqualmie Falls. The double-mass curves for water years 1908–26 and 1930–32 are shown in figure 6.

If a change in runoff regimen occurred in 1918, after the Boxley Creek washout, the double-mass curve should show a break in slope at that time. The curves for both streams do show a definite break in the relation between cumulative precipitation and discharge after 1918. The Cedar River curve shows a flattening of slope, indicating less runoff per unit of precipitation, whereas the South Fork Snoqualmie River curve shows a steepening of slope, indicating the opposite effect. The two trends suggest that changes in seepage occurred relative to the pre-1918 conditions.

As a check, double-mass curves were drawn comparing cumulative discharges of the Cedar River and the South Fork Snoqualmie River with similar values obtained by averaging the annual mean discharges of North and Middle Forks Snoqualmie River near North Bend. These two curves (fig. 7) show post-1918 changes similar to those shown by discharge and precipitation in figure 6.

Statistical tests of the significance of the breaks in slope on the double-mass curves were computed in a manner described by Searcy and Hardison (1960, p. 51). An analysis of variance indicates that all breaks are significant at the 5-percent level. Thus, from a statistical evaluation, changes in the regimen of Cedar and South Fork Snoqualmie Rivers did occur between 1918 and 1919.

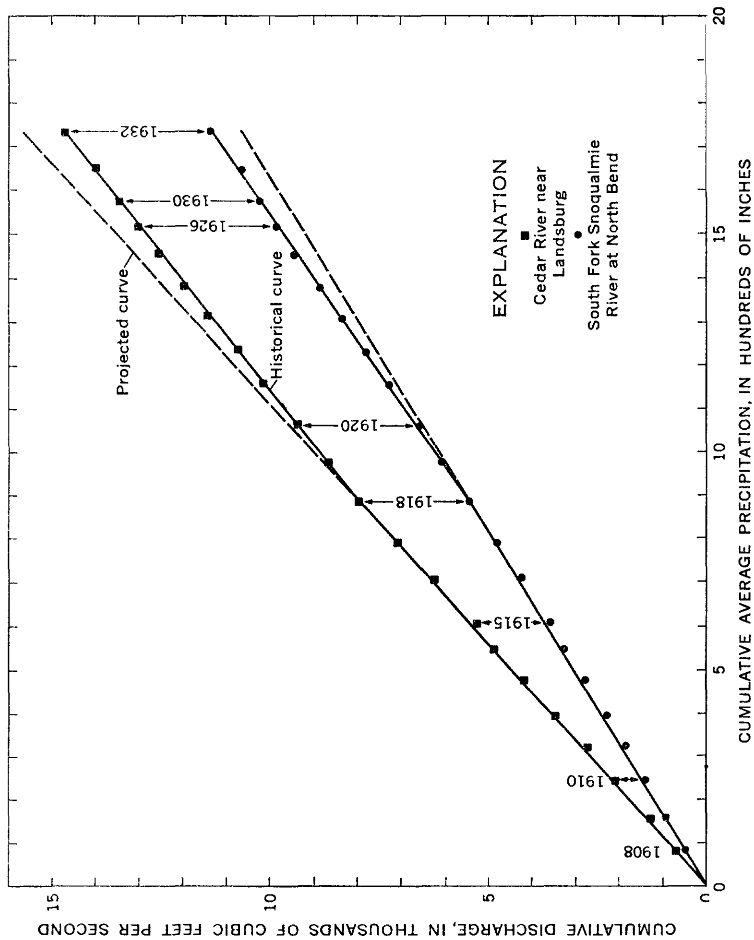

FIGURE 6.—Relation of cumulative discharge for Cedar River near Landsburg to cumulative average precipitation for Landsburg and Cedar Lake, and of cumulative discharge for South Fork Snoqualmie River at North Bend to cumulative average precipitation for Snoqualmie Falls and Cedar Lake, 1908–26 and 1930–32.

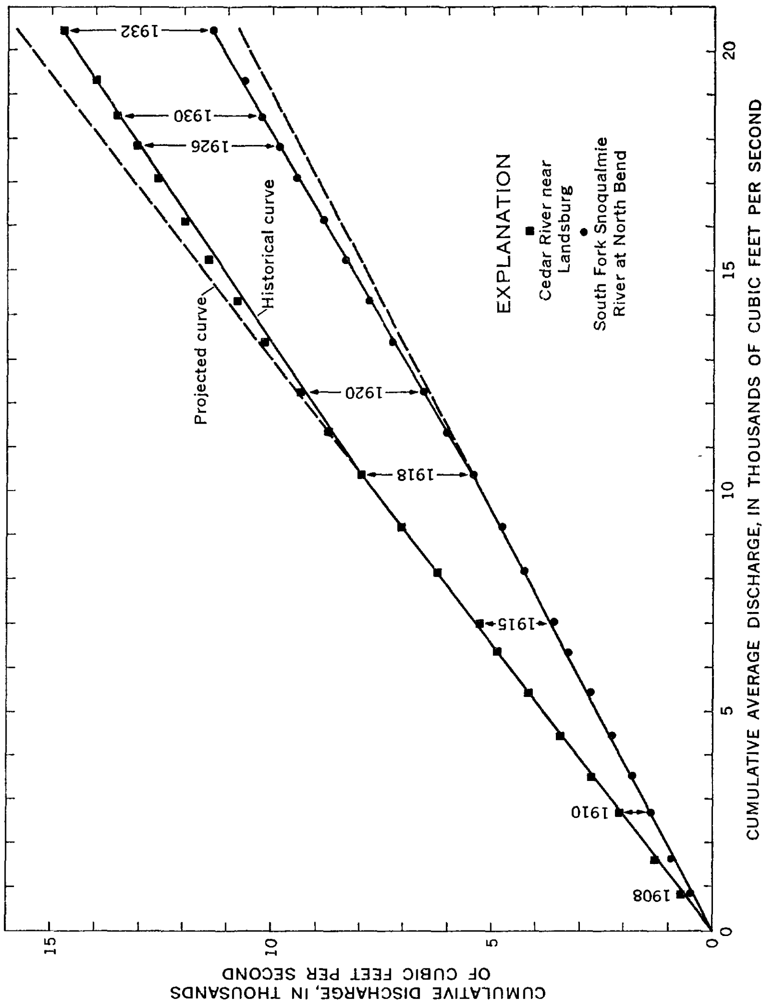

FIGURE 7.—Relation of cumulative discharge for Cedar River near Landsburg and South Fork Snoqualmie River at North Bend to cumulative average discharge for Middle and North Forks Snoqualmie River, 1908–26 and 1930–32.

Quantitative values for seepage from Cedar River basin to South Fork Snoqualmie River have been obtained from records collected during water years 1908–26 and 1930–32. Annual mean discharges for Cedar River near Landsburg and South Fork Snoqualmie River at North Bend prior to the Boxley Creek washout in 1918 were each related to the average precipitation and average discharges used in the double-mass curve analysis. Simple regressions computed by the least-squares method express the relation between variables that would have existed if no change had occurred in 1918.

The following model was used in computing the regression between discharge and precipitation.

$$Y=a+bP$$

where

Y=annual mean discharge of Cedar River near Landsburg or South Fork Snoqualmie River at North Bend,

P=the respective average annual precipitation used in the double-mass curves, and

a, b=constants.

The regressions for water years 1908–18 were computed as:

$$Y=-230+11.8P \qquad (3)$$

for the Cedar River near Landsburg, and

$$Y=-100+7.4P \qquad (4)$$

for the South Fork Snoqualmie River at North Bend. The two curves and the points upon which they are based are shown in figure 8.

For the discharge-versus-discharge relations, the following model was used:

$$\log Y=a+b \log X$$

where

Y=annual mean discharge of Cedar River or South Fork Snoqualmie,

X=average of the annual mean discharges of North and Middle Forks Snoqualmie River, and

a, b=constants.

The regressions for water years 1908–18 were computed as:

$$\log Y=-0.64+1.18 \log X \qquad (5)$$

for Cedar River and

$$\log Y=-0.15+0.96 \log X \qquad (6)$$

for South Fork Snoqualmie River. The curves in figure 9 express these two relations.

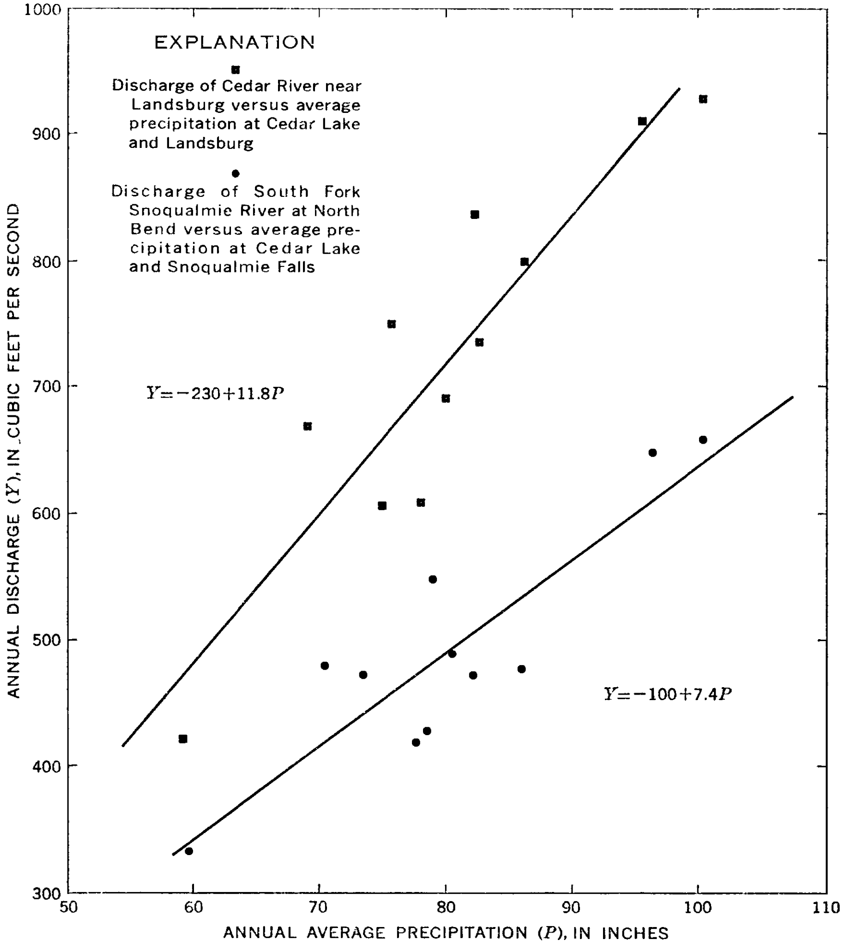

FIGURE 8.—Relation of annual mean discharge for Cedar River near Landsburg (Y) to average of annual precipitation at Cedar Lake and Landsburg (P), and of annual mean discharge for South Fork Snoqualmie River at North Bend (Y) to average of annual precipitation at Cedar Lake and Snoqualmie Falls (P), 1908–18.

The above regressions represent the relation between the variables prior to the Boxley Creek washout. If these relations were assumed to continue after the washout, estimates of annual discharge based on them would represent the hypothetical values under unchanged conditions. Differences between the estimated and measured discharges could then be considered to represent changes in the amount of seepage from the Cedar River drainage to the South Fork Snoqualmie River.

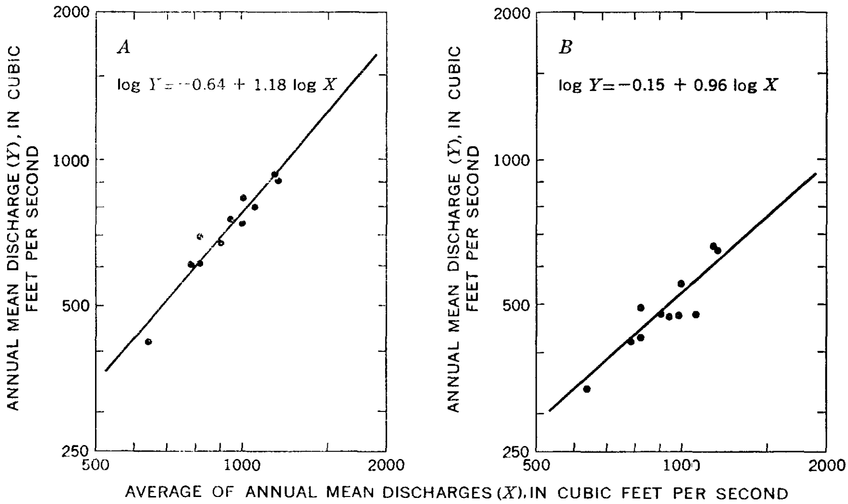

FIGURE 9.—Relation of annual mean discharge, 1908–18. *A*, Cedar River near Landsburg (*Y*) to average of Middle and North Forks Snoqualmie River (*X*). *B*, South Fork Snoqualmie River at North Bend (*Y*) to average of Middle and North Forks Snoqualmie River (*X*).

Annual mean discharges for Cedar River were estimated for water years 1919–26 and 1930–32 using the two appropriate equations. The two estimates for each year were averaged, and the resulting values were considered to represent the hypothetical annual mean discharges for Cedar River in the absence of a change in runoff regimen. Table 6 shows a comparison of the measured and estimated discharges for the 11-year period. For all years of record, the estimated discharge was greater than the actual discharge.

The same procedure was followed for South Fork Snoqualmie River, but the computations show that estimated discharges were less than actual discharges (table 7).

For the 11-year period, 1919–26 plus 1930–32, the average annual seepage from Cedar River basin was computed as about 80 cfs, and the average annual seepage to South Fork Snoqualmie River was computed as about 60 cfs. Although the two average values agree closely, the comparison for individual years is not very close. Estimates for the 1920 and 1931 water years show the largest differences.

The computed discharges listed in some of the columns of tables 6 and 7 may imply—as did some of those in tables 2 to 4—a greater accuracy than is warranted. The final seepage values have been rounded to two significant figures, or to the nearest 10 cfs. The errors

TABLE 6.—*Decreases in seepage from Cedar River above Landsburg, 1919–26 and 1930–32*

[Quantities in cubic feet per second]

Water year	Estimated discharge, based on relationships for 1908-18			Measured discharge	Decrease in seepage (rounded) [1]
	From equation 5	From equation 3	Average		
1919	791	868	830	742	90
1920	715	797	756	654	100
1921	928	896	912	784	130
1922	727	668	698	626	70
1923	724	678	701	650	50
1924	669	561	615	556	60
1925	784	643	714	619	100
1926	562	563	562	470	90
1930	494	457	476	449	30
1931	598	611	604	483	120
1932	934	775	854	771	80
Average	721	683	702	619	80

[1] Decrease in seepage equals estimated discharge minus measured discharge.

in the computed seepages determined separately by the two independent methods are considered to be small because the final seepage values are in disagreement by only 20 cfs.

TABLE 7.—*Increases in seepage to South Fork Snoqualmie River above North Bend, 1919–26 and 1930–32*

[Quantities in cubic feet per second]

Water year	Estimated discharge, based on relationship for 1908-18			Measured discharge	Increase in seepage (rounded) [1]
	From equation 6	From equation 4	Average		
1919	535	578	556	627	70
1920	493	518	506	502	0
1921	610	596	603	719	120
1922	500	464	482	518	40
1923	498	474	486	551	60
1924	467	413	440	476	40
1925	531	449	490	626	140
1926	405	382	394	433	40
1930	365	336	350	363	10
1931	426	434	430	431	0
1932	613	547	580	698	120
Average	495	472	485	540	60

[1] Increase in seepage equals measured discharge minus estimated discharge.

SUMMARY

Interchange of water between the Cedar and South Fork Snoqualmie Rivers was computed for two periods, water years 1908–26 plus 1930–32 and water years 1957–64. For the 1957–64 period, seepage from Chester Morse Lake and Masonry Pool was determined and compared with seepage to Cedar and South Fork Snoqualmie Rivers. For the 1908–26 and 1930–32 period, the changes in regimens of the two rivers were compared before and after the Boxley Creek washout.

Average seepage from Chester Morse Lake and Masonry Pool was about 220 cfs for water years 1957–64. For the same period, average seepage to Cedar River between Cedar Falls and Landsburg and to South Fork Snoqualmie River between Edgewick and North Bend was about 180 and 50 cfs respectively, giving a total of 230 cfs.

A definite change in runoff regimen occurred in both the Cedar River above Landsburg and South Fork Snoqualmie River above North Bend after the Boxley Creek washout in 1918. For the combined 11-year period 1919–26 plus 1930–32, the changes in seepage from Cedar River basin and to South Fork Snoqualmie River averaged about 80 and 60 cfs respectively.

REFERENCES CITED

Huntting, M. T., and others, compilers, 1961, Geologic map of Washington: Washington Div. Mines and Geology.

Mackin, J. H., 1941a, A geologic interpretation of the failure of the Cedar Reservoir, Washington: Washington Univ. [Seattle] Eng. Expt. Sta. Series Bull. 107, 30 p.

——— 1941b, Glacial geology of the Snoqualmie-Cedar area, Washington: Jour. Geology, v. 49, no. 5, p. 449–481.

McWilliams, Mary, 1955, Seattle Water Department History, 1854–1954: Seattle, Wash., Dogwood Press, 262 p.

Phillips, E. L., 1965, Climate of Washington: U.S. Weather Bur., Climatography of the United States, no. 60–45, 27 p.

Searcy, J. K., and Hardison, C. H., 1960, Double-mass curves: U.S. Geol. Survey Water-Supply Paper 1541–B, 66 p.

U.S. Weather Bureau and U.S. Soil Conservation Service, 1961, Normals of precipitation and evapotranspiration, State of Washington: Seattle, Wash., U.S. Weather Bur. and U.S. Soil Conserv. Service, 15 p.

U.S. GOVERNMENT PRINTING OFFICE: 1967