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# JOKULHLAUPS ON SNOW RIVER IN SOUTHCENTRAL ALASKA

## A Compilation of Recorded and Inferred Hydrographs and a Forecast Procedure

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NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

National Weather
Service
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## A Compilation of Recorded and Inferred Hydrographs and a Forecast Procedure

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ABSTRACT

A complete history of jokulhlaups on Snow River from 1947 to 1981 was developed using flow records for the Kenai River at Cooper Landing and the available Snow River records.

For those events for which Snow River records are available, the recorded jokulhlaup hydrographs were used to reconstitute the observed Cooper Landing hydrographs as a test of validity of the routing methods. For events for which Snow River records are not available, the inferred jokulhlaup hydrographs were similarly used as a test of validity of the inference.

It is demonstrated in this report that the cross-sectional area of the glacier-dammed lake outlet is proportional to the amount of water that has passed through the outlet. This relationship is established early in a jokulhlaup event and reveals itself in the operational hydrograph of Snow River flows. It is then possible to forecast the entire jokulhlaup hydrograph by selecting successive flows which simultaneously satisfy that relationship and the head and remaining lake storage requirements. A computer program was developed for that purpose and is included. Verification runs made on recorded events produced exceptionally good results.

## INTRODUCTION

Jokulhlaup (pronounced "yokel-loup" with the last syllable rhyming with "out") is an Icelandic term for sudden outbursts of water from glaciers or glacier-dammed lakes. Jokulhlaups usually occur at periodic intervals and generally have no direct relation to concurrent meteorologic conditions. Most are small and go unnoticed; others have been catastrophic. For example, Grimsvotn (the lakes of Grimur) in Iceland periodically spills up to eight million acre-ft in a flood in which streamflow discharges have reached nearly two million cubic ft per second. In 1959, a jokulhlaup in Kashmir caused a flood rise of more than 100 ft at a distance of more than 25 mi from the point of outburst. Such sporadic outburst floods have taken a heavy toll in life and property and have destroyed whole villages.

The best known examples of large jokulhlaups in North America are those from Lake George (Knik Glacier) near Anchorage, Alaska. The lake dumped annually from 1918 until 1966, missing only 1963. However, Lake George has not refilled since 1966 and will not until the glacier advances and dams the lake again.

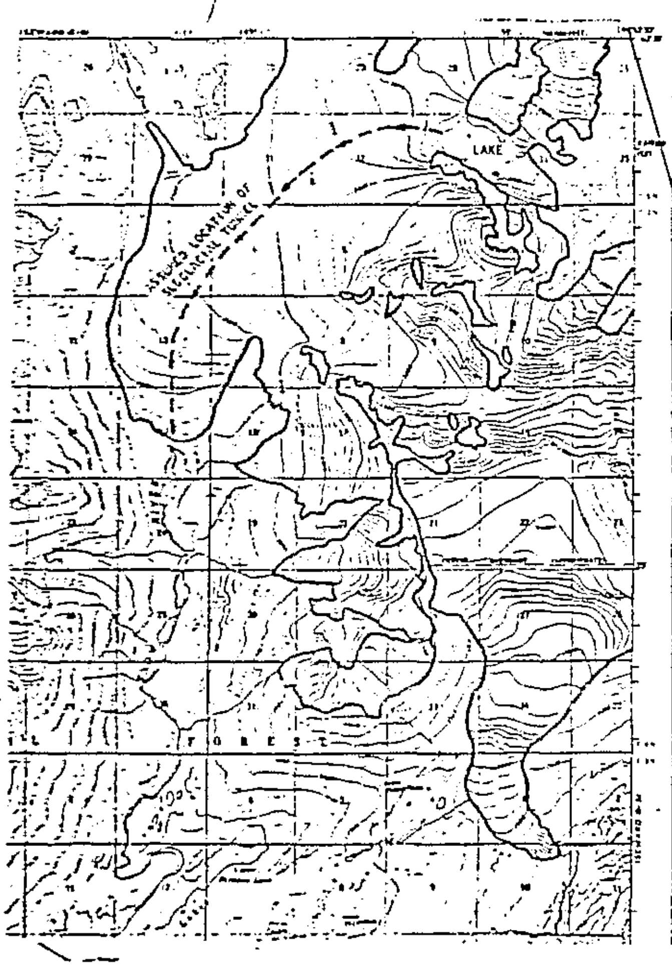
Large jokulhlaups presenting extreme flood hazards occur at more than twenty locations in Alaska. Presently, the glacier-dammed lake in the headwaters of Snow River is of the greatest economic interest in the state. In recent years it has dumped in late summer when flows on the downstream Kenai River were high. Residential, recreational, and commercial development along the Kenai River has been stimulated by paved highway access from Anchorage and by the economic boom of the Trans-Alaska Pipeline. When a jokulhlaup is imminent, or in progress in that area, river stage forecasts are in great demand. Figure 1 shows the location of the glacier-dammed lake, Snow River and Kenai River.

## PURPOSE

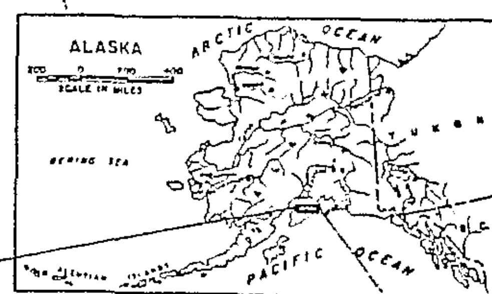
The purpose of this report is ultimately to present a forecast procedure for Snow River jokulhlaups. In the literature, whenever jokulhlaup forecasting is mentioned, it is consistently said to be impossible. The procedure presented herein will not predict when the event will begin but, once started, certain characteristics of the operational hydrograph, along with some known basin and hydraulic characteristics, make derivation of the entire event hydrograph possible several days before flooding begins. Before the method could be tested thoroughly, however, it was necessary to compile a history of Snow River jokulhlaups, many of which occurred before a Snow River gage was installed. The history itself is of value and is presented first.

## THE SELF-DUMPING LAKE

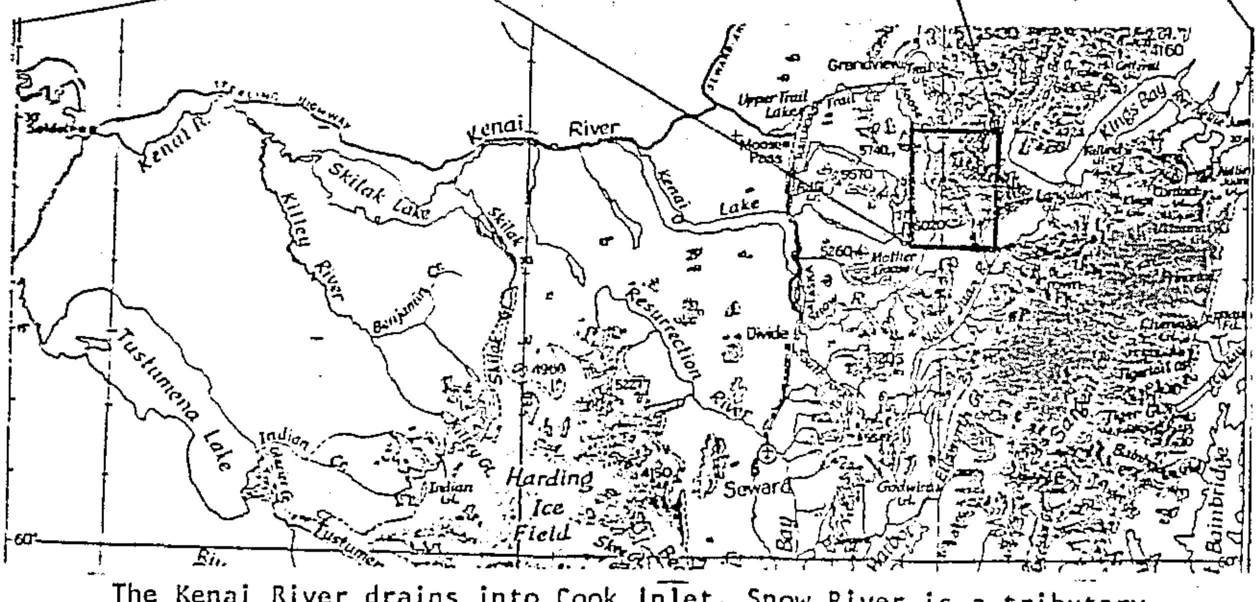
The lake that is the subject of this report is formed by the main valley glacier damming a tributary valley. During the summer, runoff from rainfall, snowmelt, and some glacier melt accumulate in the lake. In the winter, snowfall adds depth to




View of glacier-dammed lake looking southeast from above the ice dam. July 1974




Upper Snow River Area
Glacier-dammed lake is shown near upper right corner. Bold outline shows glacier limits.




The Kenai River drains into Cook Inlet. Snow River is a tributary draining into the upper end of Kenai Lake. Glaciers and ice fields are shaded.

Figure 1. Location of glacier-dammed lake on Snow River.

the lake as does continued drainage from the glacier of melt water from an earlier season. In the course of two to four years, the lake fills to a depth of 300 to 500 ft and creates a hydrostatic head sufficient to initiate the self-dumping process. This is often when the height of the lake surface is about 0.9 of the height of the ice dam, which suggests that lifting of the dam may take place. Once begun, the flowing water enlarges its escape route and the discharge accelerates until the head is insufficient to support acceleration. Then the lake is nearly empty and the discharge drops abruptly. The typical jokulhlaup hydrograph has the appearance of a breached dam hydrograph in reverse.

## FLOOD POTENTIAL

This glacier-dammed lake drains under the glacier for a distance of 5 mi. It drains completely; the water emerges at the terminus of the glacier. From that point, it flows down Snow River, a distance of 29 mi to Kenai Lake. During some of the jokulhlaup events, the U.S. Geological Survey operated a recording stream gage at the railroad bridge near the mouth of Snow River. The flood wave at that location is necessarily very similar to the hydrograph at the glacier terminus because much of the flow in Snow River is supercritical, slowing down only for a few miles through Paradise Valley and arriving at the gage about 3 hr after leaving the glacier. Very little attenuation is possible, and very little flooding occurs on Snow River except near the mouth.

As the flood wave passes through Kenai Lake, it is greatly attenuated, however. Kenai Lake is about 23 mi long; its width is a nearly uniform 1 mi throughout its length and the normal surface area is 21.6 $mi^2$. In some places the lake is over 560 ft deep, but the normal pool elevation ranges between 430 and 440 ft, msl, which means that the bottom of the lake is more than 100 ft below sea level. Floods frequently inundate parts of Primrose and Quartz Creek campgrounds and several fixed boat docks around the lake. Less frequently, floods damage cabins and summer homes.

At the outlet of Kenai Lake the Sterling Highway crosses the river near Cooper Landing. The USGS has maintained a gage at that location since 1947. Cooper Landing is a small community built along the Kenai River where large floods can reach a few homes, but the occurrences have been so infrequent that the residents seldom show concern. Below Cooper Landing to Skilak Lake, there is little development in the flood plain, although two lodges are sometimes threatened by high water.

Skilak Lake is larger than Kenai Lake, having a surface area of 38 $mi^2$. Snow River jokulhlaups are usually so thoroughly attenuated on leaving Skilak Lake that only a long slow rise and fall are seen downstream. There is, however, another glacier-dammed lake that dumps into Skilak Lake. It is dammed by Skilak Glacier, a tongue of ice extending from the Harding Ice Field. In 1977, that glacier-dammed lake dumped at a most inopportune time: its peak flow coincided with the peak of a Snow River jokulhlaup that had occurred a few days earlier, both of which were in addition to high flow from the melting of a record snow-pack in the Kenai Mountains. This resulted in the highest flows of record on the lower Kenai River.

Below Skilak Lake, near Sterling, a recreational and residential development known as Kenai Keys has been built on the Kenai River, much of which is susceptible to flooding. Floods cut off access to the area first, making it impossible for the Anchorage weekenders to move their trailers out if they wait too long, after which the trailers and some cabins may be flooded. This is the location for which more individuals request river forecasts than any other location in the State.

Between Kenai Keys and Soldotna, there is little development in the flood plain as the river flows through the Kenai National Moose Range. At Soldotna, it is unusual for a Snow River jokulhlaup to contribute to flooding although it happened in 1977 during the highest flow of record mentioned above. That was not the highest stage of record, however. In mid-January 1969, a jokulhlaup from Skilak Glacier caused the river ice to break up from Skilak Lake to the mouth of the Kenai River. An ice jam formed near Soldotna and caused the highest stage by several feet. Many families were evacuated in the sub-zero (F) weather.

## COMPUTATION OF SNOW RIVER JOKULHLAUP HYDROGRAPHS

Two stream gages are used in these computations. "Kenai River at Cooper Landing" is located on the Sterling Highway bridge at the outlet of Kenai Lake. "Trail River near Lawing" is near the mouth of Trail River which empties into Kenai Lake. Both gages began operation in 1947 and, although the USGS discontinued operation of the Trail River gage, the NWS has maintained records during the open-water season. A third gage, "Snow River near Seward" is located on the railroad bridge near the mouth of Snow River. The Snow River record is incomplete. The USGS has operated a recording gage at that location through a few jokulhlaups and for those events these computations would not have been necessary but are included for verification of the methods.

For those events when no Snow River record is available, the storage-indication method of reservoir routing was used to determine inflow to Kenai Lake. This method is appropriate because Kenai Lake is a large reservoir with a constricted outlet that functions like an uncontrolled spillway. The lake is very deep, so virtually no wedge storage exists at any time. For the first

Table 1
Snow River Jokulhlaups - Volumes and Peak Flows

| | Glacier Dammed Lake | | | Snow River Gage | | Cooper Landing | | |
|---|---|---|---|---|---|---|---|---|
| Year | Jokulhlaup Incl. Dates | Est. Volume (ac. ft.) | Est. Peak Outflow (cfs) | Peak Flow (cfs) | Date | Peak Flow (cfs) | Stage (ft.) | Date |
| 1949 | 10/18-10/29 | 116,400 | 14,900 | 16,400 (1) | 10/27 | 11,600 | 13.55 | 10/28 (2) |
| 1951 | 11/6 -11/21 | 78,700 | 11,000 | 11,500 (1) | 11/17 | 6,250 | (5) | 11/18 |
| 1953 | 12/6 -12/18 | 80,100 | 7,000 | 7,300 (1) | 12/15 | 4,420 | (5) | 12/17 |
| 1956 | 10/19-10/31 | 105,200 | 12,500 | 12,900 (1) | 10/29 | 7,310 | (5) | 10/30 |
| 1958 | 10/8 -10/20 | 104,500 | 13,900 | 14,200 (1) | 10/17 | 8,350 | (5) | 10/17 |
| 1961 | 9/29-10/8 | 142,000 | 19,200 | 20,000 (3) | 10/7 (3) | 14,000 | 10.5 | 10/8 |
| 1964 | 9/17-9/26 | 125,600 | 15,900 | 17,900 (2) | 9/23 | 14,200 | 14.30 | 9/24 |
| 1967 | 8/26-9/3 | 122,000 | 27,500 | 27,000 (4) | 8/31 | 21,500 | 16.25 | 9/1 |
| 1970 | 9/10-9/24 | 153,000 | 17,000 | 17,800 (2) | 9/22 | 12,100 | (5) | 9/23 |
| 1974 | 9/10-9/22 | 195,000 | 25,000 | 26,400 (2) | 9/20 | 23,100 | 17.18 | 9/21 |
| 1977 | 8/30-9/8 | 122,500 | 13,900 | 16,700 (2) | 9/5 | 14,900 | (5) | 9/6 |
| 1979 | 10/19-10/24 | 103,000 | 14,800 | 15,700 (1) | 10/24 | 12,800 (6) | 13.62 (6) | 10/24 |

(1) Inferred by downstream gages.

(2) Published by U.S.G.S.

(3) Peak flow and date shown are inferred by downstream gages. The 1964 surface water records of Alaska show peak flow of 25,000 cfs on September 30, 1961. That date cannot be supported by Cooper Landing flow records.

(4) Peak flow and date shown are inferred by downstream gages. The 1970 Water Resources Data for Alaska show 55,000 cfs on August 31, 1967.

(5) Stages not published. Corresponding flows are daily flows, not necessarily peak flows.

(6) From unpublished NWS records.

trial computation, the recorded Cooper Landing flows were routed backward to obtain lake inflows. This is a very sensitive procedure that greatly overreacts to small input errors, so the result was smoothed and used as a trial inflow. That inflow was routed through the lake and compared with the recorded Cooper Landing flows. The inflow hydrograph was then adjusted and rerouted until the reproduction of the Cooper Landing flows was satisfactory or excellent, if possible. The next step was to separate the inflow into components of Snow River flow and non-Snow River flow. In most cases this was not difficult as most of the jokulhlaups occurred when there was no significant rainfall. One outstanding exception was in 1974 but the Snow River gage was in operation then, obviating the separation of flows with an abominable lack of precipitation data. For the usual case, i.e., no significant rainfall and no flow data for Snow River, the ungaged area flow was proportioned to Trail River flow by drainage area ratio. Then, having the Snow River flow so determined, that part attributed to lake drainage was separated and the volume of the jokulhlaup was determined.

Table 1 lists all Snow River jokulhlaups since 1947 along with the estimated volume of each and the peak flows at the Snow River gage and at Cooper Landing.

Some notes are appropriate on three events:

1961: The Snow River flow records are not supported by the Cooper Landing flow records. The Snow River flows used in the 1961 computations are estimated on the basis of the reconstitution of the Cooper Landing hydrograph.

1974: The reconstitution of the Cooper Landing hydrograph is less than good because the spatial and temporal distribution of the scattered heavy rainfall cannot be determined on the basis of available records. In the reconstitution shown, the ungaged area flow was determined the same way as in all the other reconstitutions, viz., 1.8 times the Trail River flow. This, however, is not appropriate when scattered heavy rainfall is involved. The Snow River flows are recorded and therefore, not dependent upon a good reconstitution. In the determination of the glacier-dammed lake outflow, the Snow River intervening area/base flow values were deliberately selected to result in a typically-shaped jokulhlaup hydrograph. While those selections cannot be strongly defended, the timing and relative magnitude of the rises are supported by rainfall records of Cooper Lake Project and Lawing.

1979: The flow data shown were taken from NWS files as the official USGS flows had not been published at the time of this writing. The Snow River flows were estimated on the basis of the Cooper Landing hydrograph reconstitution as the Snow River observer was unable to make observations at that time.

Figures 2 through 13 show the estimated or observed Snow River jokulhlaup hydrographs and the resulting reconstitutions of the Cooper Landing hydrographs.

## GLACIER-DAMMED LAKE CAPACITY

Unlike common lakes and reservoirs for which fairly accurate storage versus pool elevation relationships can be determined from surveys, such relationships can change in glacier-dammed lakes. The lake may change size due to changes in the damming glacier. Varying amounts of ice in the lake are equivalent to a change in storage since large ice blocks remain after the lake has dumped. More important is intra- and/or sub-glacial storage. Evidence that it exists with the Snow River lake can be seen as the lake approaches its dumping level. The glacier begins to dome up and arcuate cracks appear in the surface near the lake. A large volume of water could be stored under the dome. Therefore, even though the lake might have been surveyed at some time when it was empty, no firm storage versus pool elevation relationship can be developed.

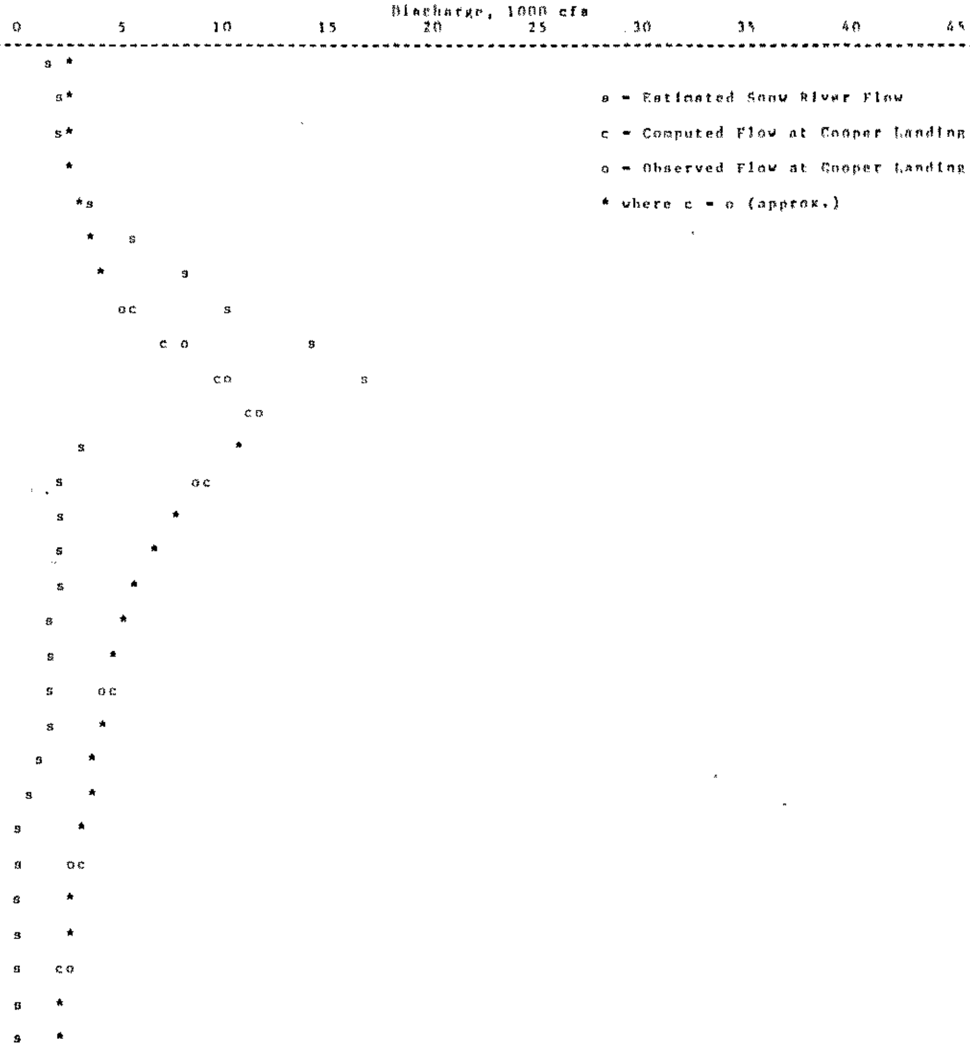
Instead, a gross estimate was made on the basis of aerial observations before and after the 1970 jokulhlaup. Before the event, the surface area of the lake was guessed at 500 acres. After the event, the lake was estimated to have been 450 ft deep, and the hydrograph showed that the volume of the 1970 dump was about 150,000 acre-ft. The lake geometry was simplified to a truncated triangular pyramid having 500 acres on the top, a height of 450 ft, and a bottom area of 195 acres. The resulting volume is 150,000 acre-ft. The storage versus head relationship could then be reduced to:

$$S = (h + 748)^3/8620 - 48600 \text{ or}$$
$$h = (8620S + 4.19 \times 10^8)^{1/3} - 748$$

where S = storage in acre-ft, and
h = head in ft.

Three significant figures make the two equations mutually compatible; accuracy to three significant figures is not implied. Very little accuracy is claimed but the equations are necessary tools in the procedures that follow. Fortunately, storage and head are not sensitive parameters in those procedures.

| Date | Snow River (est) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) |
|---|---|---|---|---|
| 101849 | 1650 | 367 | 2540 | 2440 |
| 101949 | 1830 | 348 | 2571 | 2550 |
| 102049 | 1990 | 340 | 2620 | 2530 |
| 102149 | 2580 | 333 | 2720 | 2690 |
| 102249 | 3330 | 330 | 2911 | 2810 |
| 102349 | 5400 | 320 | 3314 | 3390 |
| 102449 | 7910 | 318 | 4111 | 4160 |
| 102549 | 10200 | 348 | 5374 | 5190 |
| 102649 | 13900 | 540 | 7247 | 7810 |
| 102749 | 16400 | 540 | 9524 | 9800 |
| 102849 | 11600 | 495 | 11001 | 11300 |
| 102949 | 3180 | 470 | 10454 | 10700 |
| 103049 | 2190 | 450 | 8843 | 8680 |
| 103149 | 2110 | 455 | 7531 | 7420 |
| 110149 | 2000 | 435 | 6508 | 6450 |
| 110249 | 1860 | 435 | 5696 | 5630 |
| 110349 | 1740 | 435 | 5070 | 5030 |
| 110449 | 1700 | 408 | 4611 | 4500 |
| 110549 | 1630 | 410 | 4255 | 4230 |
| 110649 | 1440 | 430 | 3950 | 3950 |
| 110749 | 1090 | 455 | 3665 | 3730 |
| 110849 | 580 | 455 | 3377 | 3390 |
| 110949 | 230 | 455 | 3089 | 3090 |
| 111049 | 140 | 415 | 2812 | 2740 |
| 111149 | 140 | 380 | 2567 | 2470 |
| 111249 | 120 | 350 | 2365 | 2330 |
| 111349 | 56 | 330 | 2194 | 2300 |
| 111449 | 50 | 348 | 2049 | 2100 |
| 111549 | 50 | 330 | 1922 | 1890 |




***End***

Figure 2. The 1949 estimated Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

| Date | Snow River (est) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) | Discharge, 1000 cfs: 0 5 10 15 20 25 30 35 40 45 |
|---|---|---|---|---|---|
| 110251 | 800 | 260 | 1280 | 1310 | s* |
| 110351 | 2000 | 260 | 1358 | 1460 | *s |
| 110451 | 2000 | 260 | 1505 | 1640 | *s |
| 110551 | 1500 | 260 | 1622 | 1730 | * |
| 110651 | 1300 | 260 | 1683 | 1840 | s* |
| 110751 | 1300 | 260 | 1724 | 1880 | s* |
| 110851 | 1400 | 260 | 1767 | 2000 | s* |
| 110951 | 1500 | 260 | 1816 | 2030 | s* |
| 111051 | 1600 | 260 | 1872 | 2050 | s* |
| 111151 | 2050 | 260 | 1954 | 2180 | * |
| 111251 | 2800 | 260 | 2098 | 2320 | *s |
| 111351 | 4400 | 260 | 2388 | 2710 | * s |
| 111451 | 4100 | 260 | 2770 | 3120 | * s |
| 111551 | 5300 | 260 | 3210 | 3360 | .* s |
| 111651 | 7500 | 180 | 3914 | 3700 | * s |
| 111751 | 11000 | 180 | 5154 | 5220 | * s |
| 111851 | 5400 | 180 | 5941 | 6250 | sco |
| 111951 | 800 | 180 | 5393 | 5160 | s * |
| 112051 | 300 | 180 | 4450 | 4430 | s * |
| 112151 | 300 | 180 | 3731 | 3390 | s * |
| 112251 | 300 | 180 | 3197 | 3130 | s * |
| 112351 | 300 | 180 | 2804 | 2770 | s * |
| 112451 | 300 | 180 | 2496 | 2520 | s * |
| 112551 | 300 | 180 | 2266 | 2230 | s * |
| 112651 | 300 | 180 | 2083 | 2070 | s * |
| 112751 | 300 | 180 | 1929 | 1890 | s * |
| 112851 | 300 | 180 | 1794 | 1780 | s * |
| 112951 | 300 | 180 | 1675 | 1670 | s * |
| 113051 | 300 | 180 | 1570 | 1570 | s * |

s = Estimated Snow River Flow
c = Computed Flow at Cooper Landing
o = Observed Flow at Cooper Landing
* where c = o (approx.)

***End***

Figure 3. The 1951 estimated Snow River jokulhlaup hydrograph and the resulting reconstitution of th[illegible]per Landing hydrograph.

| Date | Snow River (est) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) |
|---|---|---|---|---|
| 120653 | 700 | 160 | 909 | 940 |
| 120753 | 950 | 150 | 916 | 980 |
| 120853 | 1450 | 150 | 987 | 1020 |
| 120953 | 2250 | 150 | 1084 | 1090 |
| 121053 | 3000 | 160 | 1211 | 1170 |
| 121153 | 3950 | 160 | 1495 | 1580 |
| 121253 | 4850 | 160 | 1890 | 2110 |
| 121353 | 5700 | 150 | 2379 | 2260 |
| 121453 | 6600 | 150 | 3009 | 3050 |
| 121553 | 6700 | 150 | 3733 | 3780 |
| 121653 | 5200 | 160 | 4251 | 4180 |
| 121753 | 2700 | 160 | 4280 | 4420 |
| 121853 | 900 | 160 | 3879 | 3730 |
| 121953 | 400 | 160 | 3360 | 3330 |
| 122053 | 300 | 160 | 2924 | 2890 |
| 122153 | 300 | 160 | 2580 | 2560 |
| 122253 | 300 | 160 | 2319 | 2330 |
| 122353 | 200 | 160 | 2114 | 2180 |
| 122453 | 200 | 160 | 1938 | 2000 |
| 122553 | 200 | 160 | 1782 | 1780 |
| 122653 | 100 | 150 | 1638 | 1670 |
| 122753 | 100 | 150 | 1504 | 1430 |
| 122853 | 100 | 140 | 1388 | 1350 |
| 122953 | 100 | 140 | 1304 | 1310 |
| 123053 | 100 | 140 | 1242 | 1240 |
| 123153 | 100 | 140 | 1186 | 1200 |
| 010154 | 100 | 130 | 1133 | 1120 |
| 010254 | 100 | 130 | 1082 | 1100 |

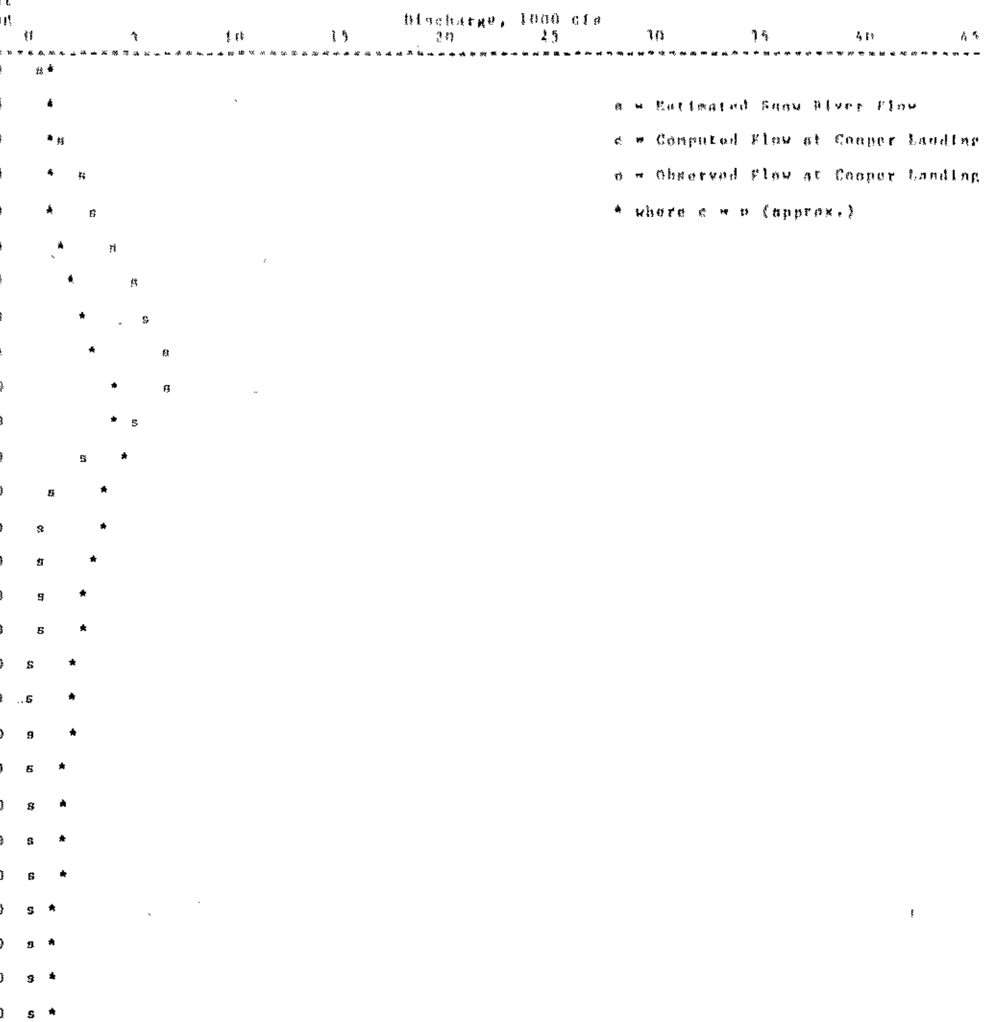



Figure 4. The 1953 estimated Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

| Date | Snow River (est) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) |
|---|---|---|---|---|
| 101856 | 840 | 244 | 1337 | 1350 |
| 101956 | 850 | 215 | 1353 | 1360 |
| 102056 | 1030 | 229 | 1379 | 1370 |
| 102156 | 1300 | 229 | 1430 | 1430 |
| 102256 | 1800 | 212 | 1519 | 1520 |
| 102356 | 2700 | 200 | 1676 | 1670 |
| 102456 | 3650 | 198 | 1923 | 1930 |
| 102556 | 5300 | 191 | 2313 | 2260 |
| 102656 | 6850 | 180 | 2951 | 2970 |
| 102756 | 8400 | 202 | 3892 | 3880 |
| 102856 | 10100 | 208 | 5131 | 5170 |
| 102956 | 11800 | 202 | 6614 | 6680 |
| 103056 | 4540 | 193 | 7124 | 7310 |
| 103156 | 1000 | 184 | 6199 | 6200 |
| 110156 | 250 | 174 | 5028 | 4970 |
| 110256 | 100 | 176 | 4116 | 4050 |
| 110356 | 100 | 174 | 3446 | 3350 |
| 110456 | 100 | 172 | 2950 | 2940 |
| 110556 | 100 | 170 | 2576 | 2540 |
| 110656 | 100 | 167 | 2293 | 2160 |
| 110756 | 100 | 161 | 2075 | 1930 |
| 110856 | 100 | 158 | 1891 | 1700 |
| 110956 | 100 | 160 | 1729 | 1460 |
| 111056 | 100 | 161 | 1587 | 1390 |
| 111156 | 100 | 161 | 1463 | 1380 |
| 111256 | 100 | 160 | 1362 | 1380 |
| 111356 | 1[illegible]0 | 156 | 1290 | 1340 |
| 111456 | 100 | 153 | 1233 | 1260 |

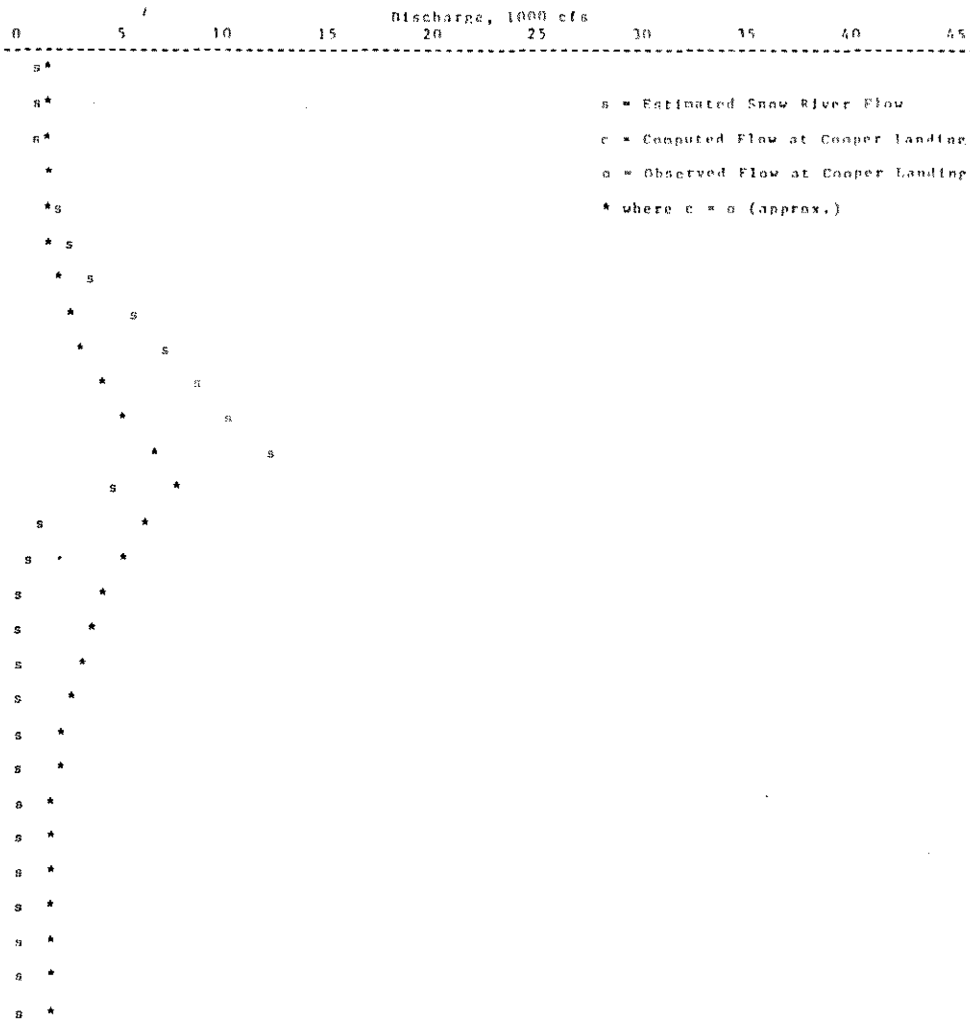



Figure 5. The 1956 estimated Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

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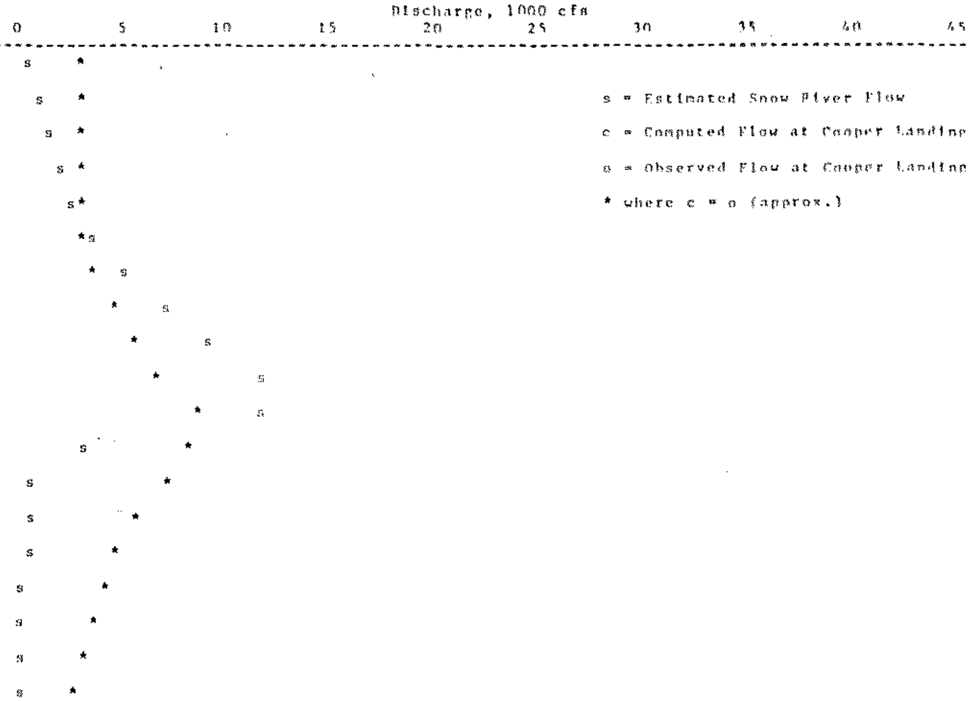
| Date | Snow River (est) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) |
|---|---|---|---|---|
| 100758 | 580 | 664 | 2862 | 2900 |
| 100858 | 860 | 588 | 2798 | 2880 |
| 100958 | 1270 | 533 | 2771 | 2880 |
| 101058 | 1840 | 490 | 2807 | 2920 |
| 101158 | 2530 | 453 | 2921 | 3060 |
| 101258 | 3420 | 417 | 3130 | 3100 |
| 101358 | 5150 | 381 | 3536 | 3480 |
| 101458 | 7200 | 369 | 4249 | 4400 |
| 101558 | 9100 | 381 | 5313 | 5390 |
| 101658 | 11400 | 377 | 6728 | 6600 |
| 101758 | 11400 | 369 | 8110 | 8350 |
| 101858 | 2930 | 361 | 8129 | 8040 |
| 101958 | 410 | 342 | 6805 | 7010 |
| 102058 | 270 | 324 | 5478 | 5340 |
| 102158 | 250 | 307 | 4525 | 4690 |
| 102258 | 240 | 278 | 3842 | 4040 |
| 102358 | 230 | 262 | 3312 | 3450 |
| 102458 | 220 | 253 | 2914 | 3080 |
| 102558 | 210 | 242 | 2595 | 2640 |




***End***

Figure 6. The 1958 estimated Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

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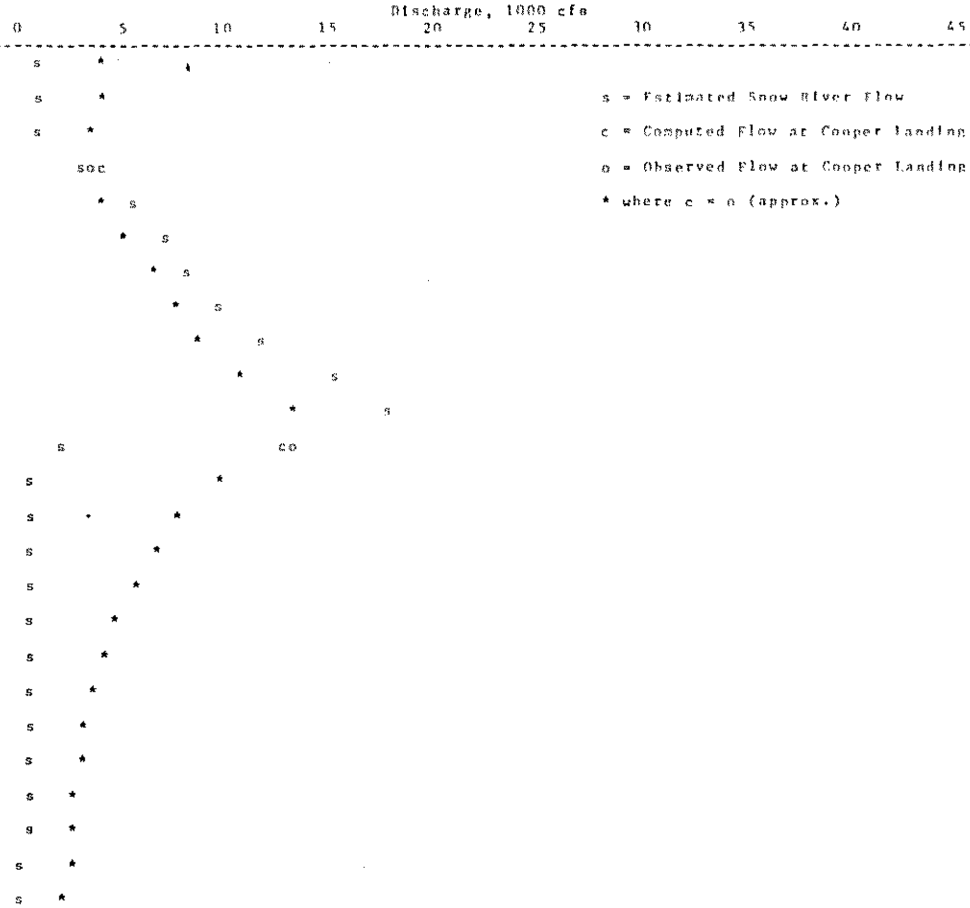
| Date | Snow River (est) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) |
|---|---|---|---|---|
| 092761 | 950 | 838 | 4183 | 4100 |
| 092861 | 760 | 772 | 3971 | 3940 |
| 092961 | 930 | 705 | 3762 | 3580 |
| 093061 | 2840 | 665 | 3770 | 3380 |
| 100161 | 5300 | 640 | 4190 | 4110 |
| 100261 | 7050 | 715 | 5002 | 5040 |
| 100361 | 7800 | 1010 | 6117 | 6260 |
| 100461 | 9300 | 1040 | 7399 | 7340 |
| 100561 | 11400 | 936 | 8782 | 8680 |
| 100661 | 15000 | 821 | 10509 | 10400 |
| 100761 | 17700 | 730 | 12840 | 12900 |
| 100861 | 2000 | 680 | 12530 | 13000 |
| 100961 | 380 | 615 | 9833 | 9690 |
| 101061 | 480 | 542 | 7951 | 7740 |
| 101161 | 530 | 488 | 6499 | 6380 |
| 101261 | 610 | 461 | 5395 | 5330 |
| 101361 | 660 | 444 | 4626 | 4490 |
| 101461 | 570 | 440 | 4078 | 3980 |
| 101561 | 520 | 420 | 3619 | 3540 |
| 101661 | 470 | 404 | 3261 | 3220 |
| 101761 | 400 | 392 | 2980 | 2930 |
| 101861 | 360 | 373 | 2729 | 2690 |
| 101961 | 310 | 354 | 2517 | 2560 |
| 102061 | 220 | 351 | 2341 | 2340 |
| 102161 | 110 | 354 | 2188 | 2130 |




***End***

Figure 7. The 1961 estimated Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

>>

| Date | Snow River (obs) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) | Discharge, 1000 cfs (0 5 10 15 20 25 30 35 40 45) |
|---|---|---|---|---|---|
| 091664 | 720 | 845 | 4514 | 4690 | s * |
| 091764 | 860 | 815 | 4237 | 4710 | s co |
| 091864 | 3000 | 955 | 4271 | 4960 | s co |
| 091964 | 6000 | 1640 | 5106 | 5720 | cos |
| 092064 | 9200 | 1660 | 6761 | 7760 | c o s |
| 092164 | 13500 | 1570 | 8964 | 9200 | * s |
| 092264 | 15400 | 1520 | 11546 | 11600 | * s |
| 092364 | 16700 | 1370 | 14279 | 13100 | o c s |
| 092464 | 11500 | 1180 | 15496 | 12200 | so c |
| 092564 | 3430 | 1010 | 13766 | 12200 | s o c |
| 092664 | 2080 | 900 | 11144 | 9790 | s o c |
| 092764 | 1610 | 820 | 9341 | 9220 | s * |
| 092864 | 1620 | 755 | 8006 | 8030 | s * |
| 092964 | 2220 | 725 | 7036 | 7690 | s co |
| 093064 | 1790 | 760 | 6322 | 6000 | s oc |
| 100164 | 1450 | 755 | 5698 | 5140 | s oc |
| 100264 | 1270 | 735 | 5162 | 4740 | s oc |
| 100364 | 1140 | 675 | 4734 | 4440 | s * |
| 100464 | 1270 | 626 | 4396 | 4240 | s * |
| 100564 | 1730 | 594 | 4162 | 4100 | s * |

s = Observed Snow River Flow
c = Computed Flow at Cooper Landing
o = Observed Flow at Cooper Landing
* where c = o (approx.)

***End***

Figure 8. The 1964 observed Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

```
>>DIR
          Snow    Trail    Kenai River at
  Date    River   River    Cooper Landing                                 Discharge, 1000 cfs
          (est)   (obs)    (comp)   (obs) 0         5         10        15        20        25        30        35        40        45
-------------------------------------------------------------------------------------------------------------------------------------------------
082367    1800    1900     9212     9000     s             *
082467    3500    1800     8878     9000        s          *                                     s = Estimated Snow River Flow
082567    4300    1700     8859     9000          s        *                                     c = Computed Flow at Cooper Landing
082667    4300    1600     8874     9000          s        *                                     o = Observed Flow at Cooper Landing
082767    3300    1500     8696     8500        s         *                                      * where c = o (approx.)
082867    5400    1600     8695     8580            s     *
082967   11700    1700     9777    10200                     *  s
083067   18200    1800    12707    12700                          *          s
083167   27500    2000    18299    18200                                     *                  s
090167    7500    2010    20156    20700                s                        co
090267    1000    1990    16150    15600   s                            oc
090367    1000    1820    12644    12400   s                      *
090467    1000    1630    10657    10900   s                   *
090567    1000    1520     9334     9700   s                *
090667    1000    1560     8361     8860   s               co
-------------------------------------------------------------------------------------------------------------------------------------------------

***End***
```

Figure 9. The 1967 estimated Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

| Date | Snow River (obs) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) | Plot (Discharge, 1000 cfs: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45) |
|---|---|---|---|---|---|
| 090770 | 1520 | 1220 | 5493 | 5460 | s * |
| 090870 | 1300 | 1090 | 5288 | 5310 | s * |
| 090970 | 1290 | 961 | 5028 | 5090 | s * |
| 091070 | 1380 | 861 | 4780 | 4820 | s * |
| 091170 | 1330 | 785 | 4556 | 4630 | s * |
| 091270 | 1500 | 735 | 4361 | 4480 | s * |
| 091370 | 1750 | 716 | 4222 | 4430 | s * |
| 091470 | 2300 | 734 | 4189 | 4480 | s co |
| 091570 | 3060 | 781 | 4310 | 4670 | s * |
| 091670 | 4020 | 812 | 4598 | 4910 | sco |
| 091770 | 5440 | 789 | 5106 | 5270 | * |
| 091870 | 7540 | 773 | 5945 | 5890 | * s |
| 091970 | 10400 | 754 | 7194 | 6760 | * s |
| 092070 | 13500 | 712 | 8840 | 7920 | o c s |
| 092170 | 15400 | 658 | 10748 | 9540 | o c s |
| 092270 | 16500 | 597 | 12751 | 11400 | o c s |
| 092370 | 6070 | 538 | 12788 | 12100 | s o c |
| 092470 | 1290 | 503 | 10619 | 10300 | s * |
| 092570 | 704 | 467 | 8524 | 8680 | s * |
| 092670 | 960 | 451 | 6975 | 7260 | s co |
| 092770 | 930 | 449 | 5823 | 6140 | s * |
| 092870 | 841 | 460 | 4977 | 5270 | s co |
| 092970 | 704 | 473 | 4375 | 4650 | s * |
| 093070 | 664 | 471 | 3907 | 4110 | s * |

s = Observed Snow River Flow

c = Computed Flow at Cooper Landing

o = Observed Flow at Cooper Landing

* where c = o (approx.)

***End***

Figure 10. The 1970 observed Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

| Date | Snow River (obs) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) | Discharge, 1000 cfs (0 5 10 15 20 25 30 35 40 45) |
|---|---|---|---|---|---|
| 090774 | 1560 | 1180 | 5054 | 4920 | s * |
| 090874 | 1460 | 1040 | 4960 | 4620 | s oc |
| 090974 | 1340 | 917 | 4796 | 4320 | s oc |
| 091074 | 1900 | 843 | 4655 | 4120 | s oc |
| 091174 | 4030 | 904 | 4804 | 4400 | soc |
| 091274 | 6950 | 1470 | 5730 | 4970 | oc s |
| 091374 | 6550 | 1790 | 7080 | 5750 | osc |
| 091474 | 6690 | 1710 | 8154 | 6430 | o c |
| 091574 | 12100 | 2120 | 9750 | 7640 | o c s |
| 091674 | 10800 | 3100 | 12204 | 9510 | o s c |
| 091774 | 11100 | 2950 | 14630 | 11100 | o c |
| 091874 | 14400 | 2580 | 16878 | 13000 | o s c |
| 091974 | 20000 | 2100 | 19564 | 15600 | o cs |
| 092074 | 23800 | 1910 | 22759 | 19000 | o c s |
| 092174 | 19700 | 2090 | 24645 | 22500 | s o c |
| 092274 | 7700 | 1850 | 22444 | 21100 | s o c |
| 092374 | 5150 | 1580 | 17966 | 17300 | s oc |
| 092474 | 5930 | 1530 | 14843 | 14200 | s o c |
| 092574 | 5730 | 1480 | 13137 | 12500 | s oc |
| 092674 | 2880 | 1500 | 11691 | 10900 | s oc |
| 092774 | 1800 | 1700 | 10344 | 9180 | s o c |
| 092874 | 1300 | 1600 | 9335 | 7860 | s o c |
| 092974 | 1000 | 1500 | 8405 | 6710 | s o c |
| 093074 | 800 | 1400 | 7572 | 5750 | s o c |

s = Observed Snow River Flow
c = Computed Flow at Cooper Landing
o = Observed Flow at Cooper Landing
* where c = o (approx.)

***End***

Figure 11. The 1974 observed Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

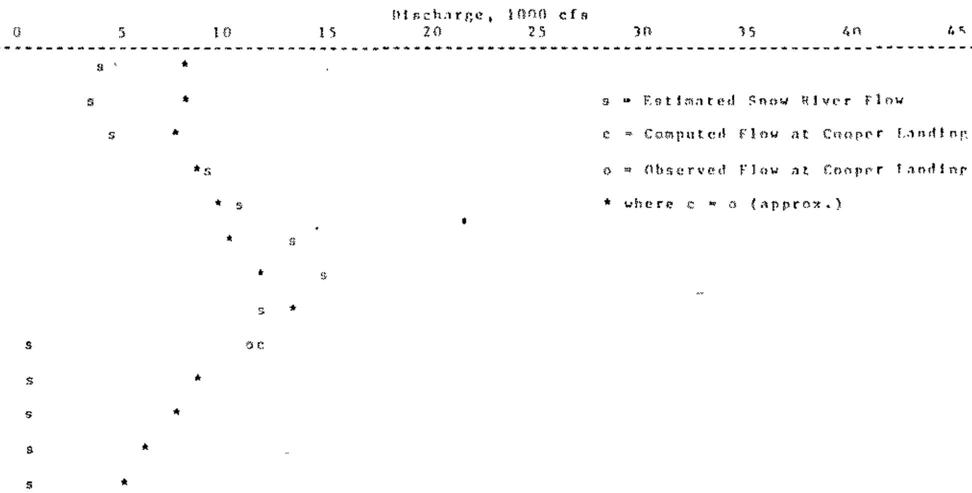
```
>>
         Snow    Trail   Kenai River at
 Date    River   River   Cooper Landing                                      Discharge, 1000 cfs
         (obs)   (obs)   (comp)  (obs)  0         5         10        15        20        25        30        35        40        45
-------------------------------------------------------------------------------------------------------------------------------------
082677     3960    2000    9208    9070          s          *
082777     4000    1850    8718    8690           s        *                                      s = Observed  Snow River Flow
082877     4220    1670    8377    8430           s        *                                      c = Computed Flow at Cooper Landing
082977     4540    1560    8185    8210            s      *                                       o = Observed Flow at Cooper Landing
083077     5000    1490    8133    8100            s      *                                       * where c = o (approx.)
083177     5800    1350    8246    8100               s   *
090177     7240    1290    8602    8340                 s  *
090277     9100    1230    9271    8780                    oc
090377    12000    1150   10370    9820                      oc   s
090477    14500    1090   12069   11200                         o c    s
090577    15900    1040   14180   13100                             o c   s
090677    13300     979   15506   14900                              s  oc
090777     6810    1110   14650   14600                 s              *
090877     3510    1320   12506   12700         -s               *
090977     2110    1350   10652   10900       s                 *
091077     2250    1270    9320    9540        s             *
091177     3020    1320    8477    8740         s          *
091277     1900    1390    7796    8120       s           *
-------------------------------------------------------------------------------------------------------------------------------------

***End***
```

Figure 12. The 1977 observed Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

>>

| Date | Snow River (est) | Trail River (obs) | Kenai River at Cooper Landing (comp) | Kenai River at Cooper Landing (obs) |
|---|---|---|---|---|
| 101779 | 4000 | 1320 | 7779 | 7970 |
| 101879 | 3600 | 1350 | 7720 | 7830 |
| 101979 | 4400 | 1080 | 7643 | 7530 |
| 102079 | 9200 | 895 | 8108 | 8270 |
| 102179 | 10500 | 754 | 9088 | 9330 |
| 102279 | 13000 | 700 | 10224 | 10240 |
| 102379 | 14500 | 656 | 11707 | 11680 |
| 102479 | 11500 | 620 | 12646 | 12750 |
| 102579 | 400 | 600 | 11268 | 10750 |
| 102679 | 300 | 573 | 8831 | 8710 |
| 102779 | 300 | 563 | 7153 | 7360 |
| 102879 | 300 | 552 | 5873 | 6240 |
| 102979 | 300 | 562 | 4950 | 5070 |




***End***

Figure 13. The 1979 estimated Snow River jokulhlaup hydrograph and the resulting reconstitution of the Cooper Landing hydrograph.

## THE SUBGLACIAL OUTLET

The glacier-dammed lake drains from the bottom of the lake and the water issues from under the glacier terminus some five miles down the valley. Little else is known about the lake outlet. It is convenient to think of it as a tunnel which may or may not remain partially open between events. In any case, some mechanism plugs the outlet and causes the lake to fill. Some other mechanism triggers the jokulhlaup, be it lifting, fracturing, or something else, that allows the lake water to begin flowing out. Once begun, the tunnel or, more specifically, the hydraulic control, is enlarged by melting, with most of the heat being derived from the potential energy of the very high head. The water contains very little transferable heat energy by virtue of its temperature which must be near the freezing point. Some erosion must also occur by physical scouring due to high velocity flow. Post and Mayo (1971) state that the cross-sectional area of the tunnel, i.e., the control, is proportional to the volume of water that has already passed through it.

A five-mile long tunnel is hardly an orifice; nevertheless, the orifice flow formula is convenient to apply in this work. In view of the very high head and the very small outlet, i.e., relative to the head, the orifice formula might be appropriate, as well. Considering all the uncertainties and assumptions, it is a reasonable choice. The formula states:

$$Q = CA\sqrt{2gh}$$

where Q = discharge in cfs
C = coefficient of discharge
A = cross-sectional area of the orifice in $ft^2$
g = 32.2 $ft/sec^2$
h = head, in ft, the depth of water that produces discharge.

The initial head can be determined by flying over the lake and estimating the lake level based on the visible markers. The coefficient, C, and the area, A, are both unknown, but it is not necessary to determine them separately. It is only necessary to determine their product, CA, and the procedure for doing that follows.

## COMPUTATION OF OUTLET TUNNEL EXPANSION RATE

There is no practical way to measure or otherwise determine the outlet tunnel dimensions during a jokulhlaup. It is a simple procedure, however, to compute the product CA for use in the orifice formula. Referring to figure 14, the procedure is described step-by-step below.

The intervening area/base flow is similar to the base flow of a storm runoff hydrograph; it is that part of the total flow that did not come from the glacier-dammed lake. Before and after the jokulhlaup, it is the total flow. It is only necessary to sketch a line connecting a point on the hydrograph just before the event with a point just after the event. The shape of the line is an estimate of the hydrograph that would have obtained had the jokulhlaup not occurred. In most cases, the shape is similar to the concurrent Trail River hydrograph.

The glacier-dammed lake outflow is the difference between the total Snow River flow and the intervening area/base flow. The flows tabulated in these three columns are average flows for a 24 hr period. They can also be considered volumes in units of 24 hr cfs.

The accumulated outflow is the summation of the glacier-dammed lake outflows, converted to acre-ft. These are instantaneous values at the end of each day.

The lake volume remaining is simply the complement of the accumulated outflow.

The head is obtained from the storage versus head relationship using the remaining volume.

The instantaneous lake outflow at the end of the day is read from the jokulhlaup hydrograph and corresponds to the head.

The product CA is obtained from the orifice formula using the head and discharge, thus:

$$CA = Q/\sqrt{2gh}$$

Plotting CA versus accumulated outflow usually yields a straight line up to the point at which orifice control is lost. This verifies that the cross-sectional area of the tunnel is proportional to the volume of water that has passed through the tunnel. It also provides a basis upon which a forecast procedure can be developed.

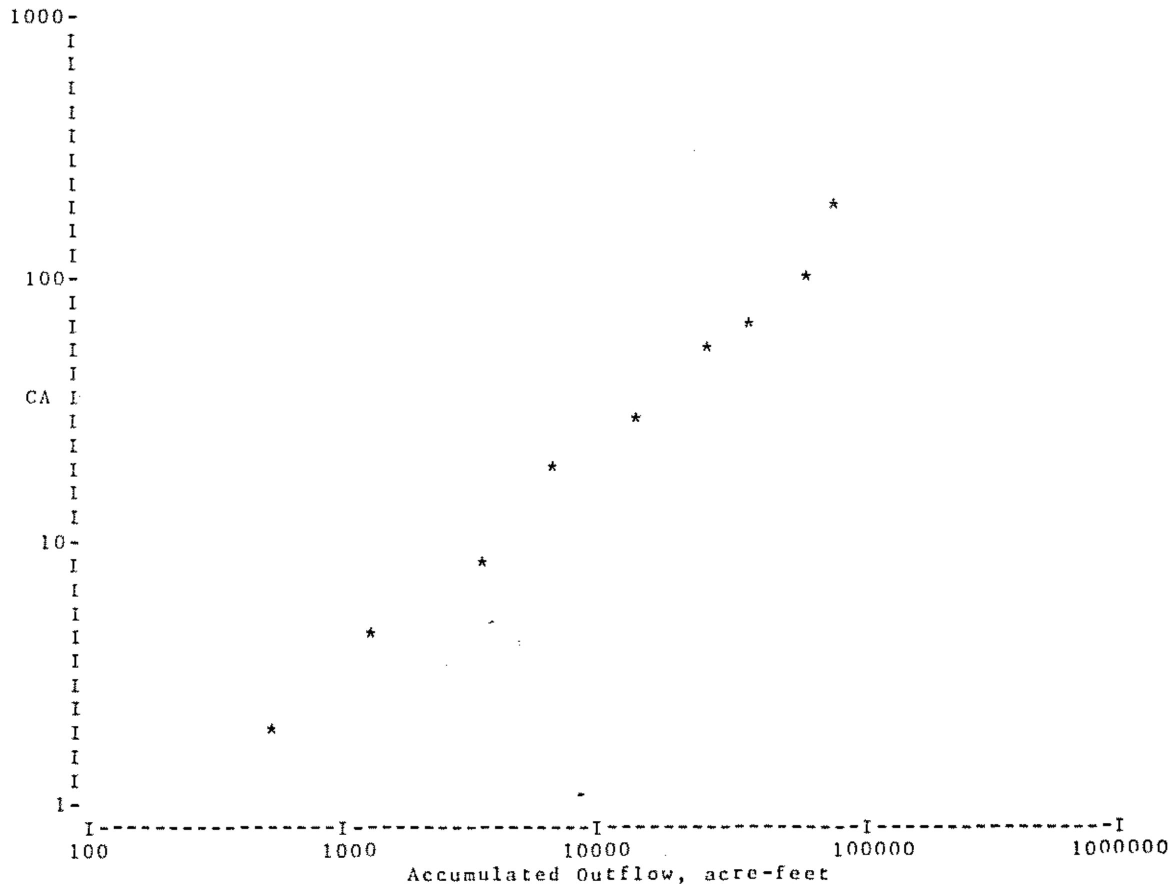
Figures 14 through 25 show the computed values and CA plots for all the Snow River jokulhlaups of record. The fact that the lake dumps rapidly on some occasions and slowly on others is reflected in the different slopes of the CA plots. Some of the plots seem to curve up near the end. Several plausible explanations can be conceived but the most likely explanation is that the storage versus head relationship is grossly inaccurate.

## JOKULHLAUP FORECAST PROCEDURE

In 1969, and in subsequent years, several lake-level markers were installed which are visible from the air. Hydrologists from the Alaskan River Forecast Center periodically fly over the lake

:0

| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
| 101749 | 1360. | 1360. | 0. | 0. | 116392. | 0. | 376.6 | 0.00 |
| 101849 | 1650. | 1650. | 0. | 0. | 116392. | 1. | 376.6 | 0.01 |
| 101949 | 1830. | 1560. | 270. | 536. | 115856. | 350. | 375.4 | 2.25 |
| 102049 | 1990. | 1530. | 460. | 1448. | 114944. | 680. | 373.3 | 4.39 |
| 102149 | 2580. | 1490. | 1090. | 3610. | 112782. | 1350. | 368.3 | 8.77 |
| 102249 | 3330. | 1480. | 1850. | 7279. | 109113. | 2905. | 359.8 | 19.08 |
| 102349 | 5400. | 1440. | 3960. | 15134. | 101258. | 5100. | 341.1 | 34.41 |
| 102449 | 7910. | 1430. | 6480. | 27987. | 88405. | 7560. | 309.0 | 53.59 |
| 102549 | 10200. | 1560. | 8640. | 45124. | 71268. | 10170. | 263.0 | 78.15 |
| 102649 | 13900. | 2200. | 11700. | 68331. | 48061. | 12850. | 193.0 | 115.25 |
| 102749 | 16400. | 2400. | 14000. | 96099. | 20293. | 14900. | 92.6 | 192.97 |
| 102849 | 11600. | 2320. | 9280. | 114506. | 1886. | 3000. | 9.8 | 119.12 |
| 102949 | 3180. | 2230. | 950. | 116390. | 2. | 475. | 0.3 | 0.00 |




***End***

Figure 14. The 1949 jokulhlaup CA versus accumulated outflow.

Otherwise, enter zero (0)

| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
| 110551 | 1500. | 1500. | 0. | 0. | 78000. | 0. | 281.6 | 0.00 |
| 110651 | 1300. | 1300. | 0. | 0. | 78000. | 50. | 281.6 | 0.37 |
| 110751 | 1300. | 1200. | 100. | 198. | 77802. | 120. | 281.0 | 0.89 |
| 110851 | 1400. | 1200. | 200. | 595. | 77405. | 250. | 280.0 | 1.86 |
| 110951 | 1500. | 1200. | 300. | 1190. | 76810. | 350. | 278.3 | 2.61 |
| 111051 | 1600. | 1200. | 400. | 1983. | 76017. | 698. | 276.2 | 5.23 |
| 111151 | 2050. | 1055. | 995. | 3957. | 74043. | 1443. | 270.7 | 10.92 |
| 111251 | 2800. | 910. | 1890. | 7706. | 70294. | 2763. | 260.2 | 21.34 |
| 111351 | 4400. | 765. | 3635. | 14916. | 63084. | 3558. | 239.4 | 28.65 |
| 111451 | 4100. | 620. | 3480. | 21818. | 56182. | 4153. | 218.7 | 34.99 |
| 111551 | 5300. | 475. | 4825. | 31388. | 46612. | 5998. | 188.3 | 54.46 |
| 111651 | 7500. | 330. | 7170. | 45610. | 32390. | 8935. | 139.1 | 94.39 |
| 111751 | 11000. | 300. | 10700. | 66833. | 11167. | 10000. | 53.7 | 170.06 |
| 111851 | 5400. | 300. | 5100. | 76949. | 1051. | 2000. | 5.6 | 104.86 |
| 111951 | 800. | 300. | 500. | 77940. | 60. | 265. | 0.6 | 0.00 |

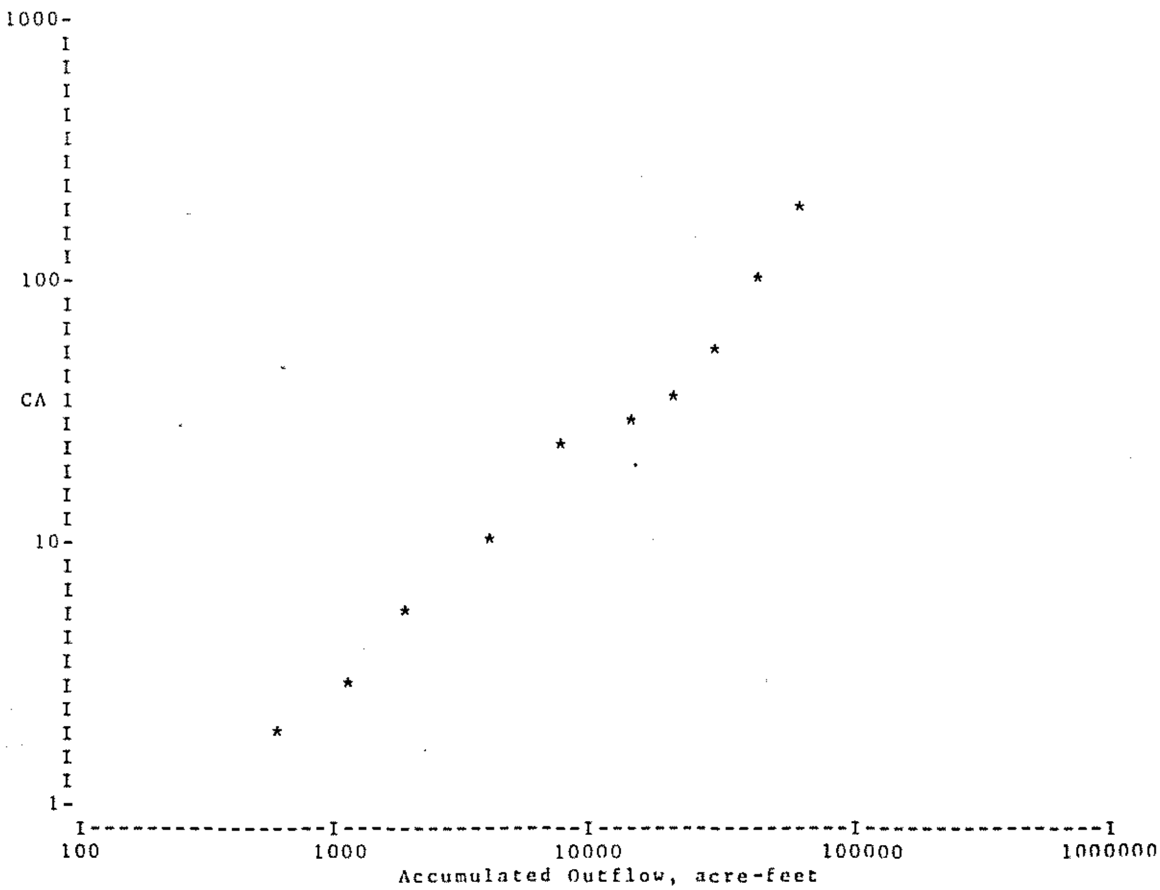



Figure 15. The 1951 jokulhlaup CA versus accumulated outflow.

>>

| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
|---|---|---|---|---|---|---|---|---|
| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
| 120553 | 600. | 600. | 0. | 0. | 80100. | 75. | 287.2 | 0.55 |
| 120653 | 700. | 550. | 150. | 298. | 79802. | 300. | 286.4 | 2.21 |
| 120753 | 950. | 500. | 450. | 1190. | 78910. | 725. | 284.0 | 5.36 |
| 120853 | 1450. | 450. | 1000. | 3174. | 76926. | 1425. | 278.7 | 10.64 |
| 120953 | 2250. | 400. | 1850. | 6843. | 73257. | 2250. | 268.5 | 17.11 |
| 121053 | 3000. | 350. | 2650. | 12099. | 68001. | 3143. | 253.7 | 24.58 |
| 121153 | 3950. | 315. | 3635. | 19309. | 60791. | 4093. | 232.6 | 33.44 |
| 121253 | 4850. | 300. | 4550. | 28334. | 51766. | 4975. | 204.9 | 43.31 |
| 121353 | 5700. | 300. | 5400. | 39045. | 41055. | 5850. | 169.7 | 55.96 |
| 121453 | 6600. | 300. | 6300. | 51540. | 28560. | 6500. | 124.9 | 72.47 |
| 121553 | 6700. | 300. | 6400. | 64235. | 15865. | 5650. | 74.2 | 81.75 |
| 121653 | 5200. | 300. | 4900. | 73954. | 6146. | 3650. | 30.6 | 82.24 |
| 121753 | 2700. | 300. | 2400. | 78714. | 1386. | 1500. | 7.3 | 69.00 |
| 121853 | 900. | 300. | 600. | 79904. | 196. | 349. | 1.3 | 38.24 |

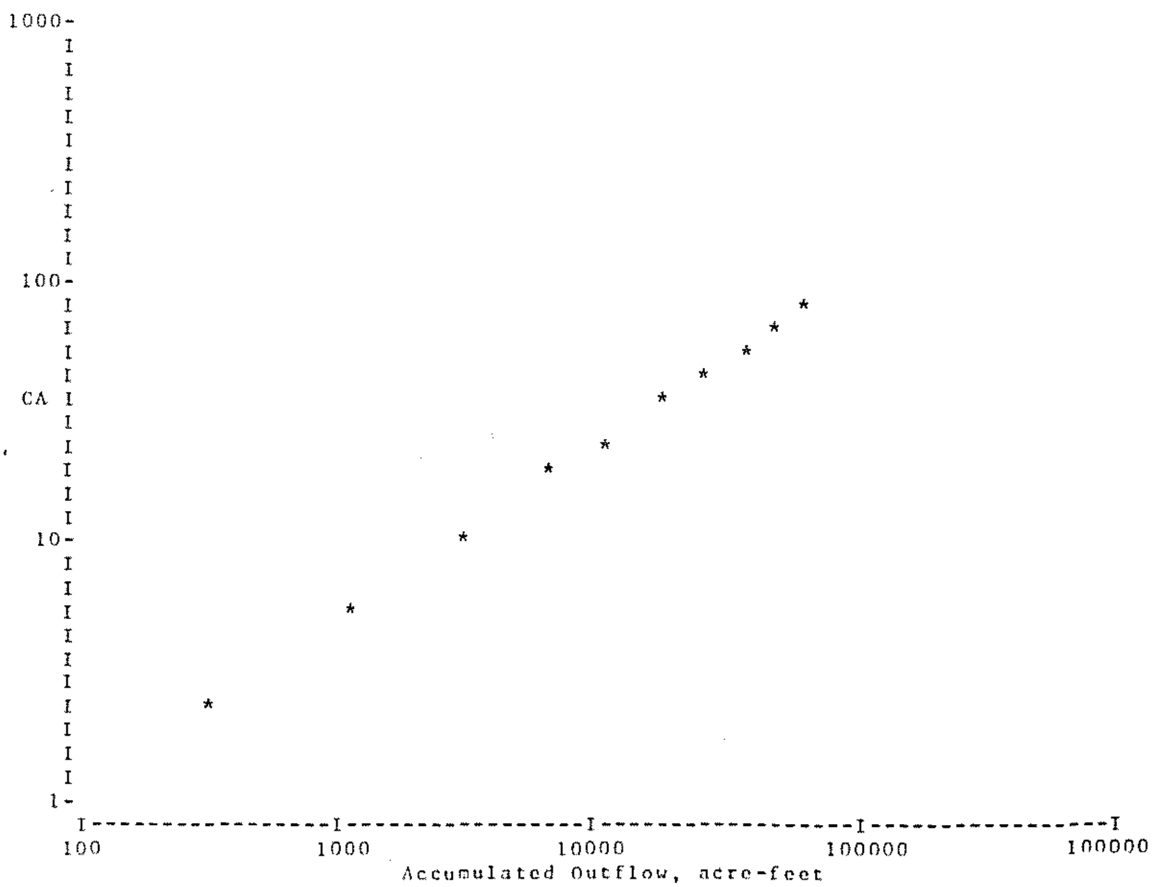
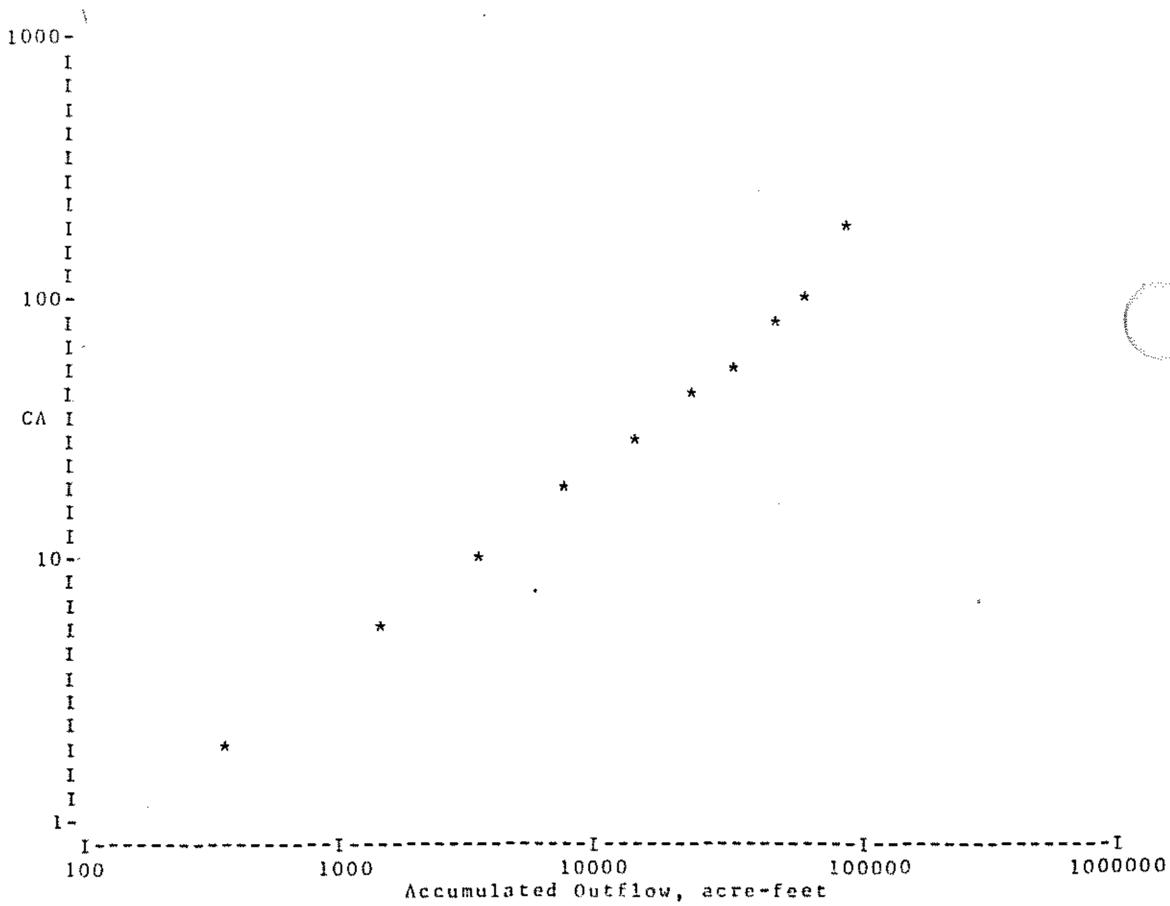



Figure 16. The 1953 jokulhlaup CA versus accumulated outflow.

| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
| 101756 | 830. | 830. | 0. | 0. | 105200. | 0. | 350.6 | 0.00 |
| 101856 | 840. | 840. | 0. | 0. | 105200. | 0. | 350.6 | 0.00 |
| 101956 | 850. | 840. | 10. | 20. | 105180. | 80. | 350.5 | 0.53 |
| 102056 | 1020. | 840. | 180. | 377. | 104823. | 300. | 349.7 | 2.00 |
| 102156 | 1300. | 750. | 550. | 1468. | 103732. | 850. | 347.1 | 5.69 |
| 102256 | 1800. | 650. | 1150. | 3749. | 101451. | 1645. | 341.6 | 11.09 |
| 102356 | 2700. | 560. | 2140. | 7993. | 97207. | 2660. | 331.2 | 18.21 |
| 102456 | 3650. | 470. | 3180. | 14301. | 90899. | 4045. | 315.4 | 28.38 |
| 102556 | 5300. | 390. | 4910. | 24040. | 81160. | 5705. | 290.1 | 41.74 |
| 102656 | 6850. | 350. | 6500. | 36932. | 68268. | 7245. | 254.5 | 56.59 |
| 102756 | 8400. | 410. | 7990. | 52780. | 52420. | 8840. | 207.0 | 76.57 |
| 102856 | 10100. | 410. | 9690. | 72000. | 33200. | 10565. | 142.1 | 110.44 |
| 102956 | 11800. | 360. | 11440. | 94691. | 10509. | 10600. | 50.7 | 185.43 |
| 103056 | 4540. | 250. | 4290. | 103200. | 2000. | 2000. | 10.4 | 77.21 |
| 103156 | 1000. | 140. | 860. | 104906. | 294. | 504. | 1.8 | 46.84 |

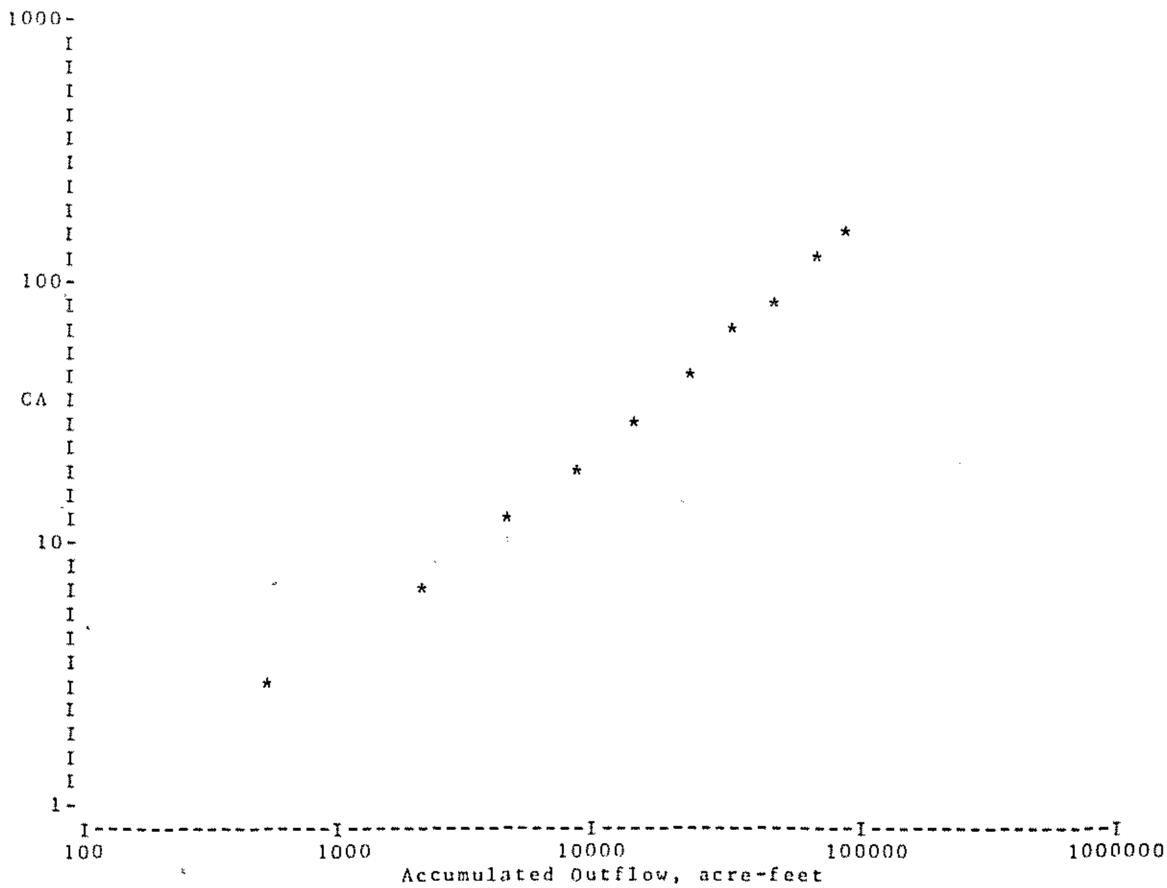



***End***

Figure 17. The 1956 jokulhlaup CA versus accumulated outflow.

>>

| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
|---|---|---|---|---|---|---|---|---|
| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
| 100758 | 580. | 580. | 0. | 0. | 104500. | 10. | 348.9 | 0.07 |
| 100858 | 860. | 580. | 280. | 555. | 103945. | 390. | 347.6 | 2.61 |
| 100958 | 1270. | 520. | 750. | 2043. | 102457. | 1050. | 344.0 | 7.05 |
| 101058 | 1840. | 490. | 1350. | 4721. | 99779. | 1710. | 337.5 | 11.60 |
| 101158 | 2530. | 460. | 2070. | 8826. | 95674. | 2530. | 327.4 | 17.42 |
| 101258 | 3420. | 430. | 2990. | 14757. | 89743. | 3870. | 312.5 | 27.28 |
| 101358 | 5150. | 400. | 4750. | 24178. | 80322. | 5785. | 287.8 | 42.49 |
| 101458 | 7200. | 380. | 6820. | 37706. | 66794. | 7780. | 250.3 | 61.28 |
| 101558 | 9100. | 360. | 8740. | 55041. | 49459. | 9900. | 197.5 | 87.78 |
| 101658 | 11400. | 340. | 11060. | 76978. | 27522. | 12000. | 121.0 | 135.94 |
| 101758 | 11400. | 320. | 11080. | 98955. | 5545. | 5800. | 27.7 | 137.26 |
| 101858 | 2930. | 300. | 2630. | 104172. | 328. | 1380. | 2.0 | 122.44 |
| 101958 | 410. | 280. | 130. | 104430. | 70. | 83. | 0.7 | 0.00 |




***End***

Figure 18. The 1958 jokulhlaup CA versus accumulated outflow.

>>

| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
| 092761 | 950. | 950. | 0. | 0. | 142000. | 0. | 432.0 | 0.00 |
| 092861 | 760. | 760. | 0. | 0. | 142000. | 0. | 432.0 | 0.00 |
| 092961 | 930. | 700. | 230. | 456. | 141544. | 500. | 431.1 | 3.00 |
| 093061 | 2840. | 660. | 2180. | 4780. | 137220. | 3200. | 422.1 | 19.41 |
| 100161 | 5300. | 640. | 4660. | 14023. | 127977. | 5495. | 402.3 | 34.14 |
| 100261 | 7050. | 720. | 6330. | 26578. | 115422. | 6565. | 374.4 | 42.28 |
| 100361 | 7800. | 1000. | 6800. | 40066. | 101934. | 7550. | 342.7 | 50.82 |
| 100461 | 9300. | 1000. | 8300. | 56529. | 85471. | 9380. | 301.4 | 67.32 |
| 100561 | 11400. | 940. | 10460. | 77276. | 64724. | 12320. | 244.2 | 98.23 |
| 100661 | 15000. | 820. | 14180. | 105402. | 36598. | 17300. | 154.2 | 173.58 |
| 100761 | 17700. | 700. | 17000. | 139121. | 2879. | 9226. | 14.8 | 298.98 |

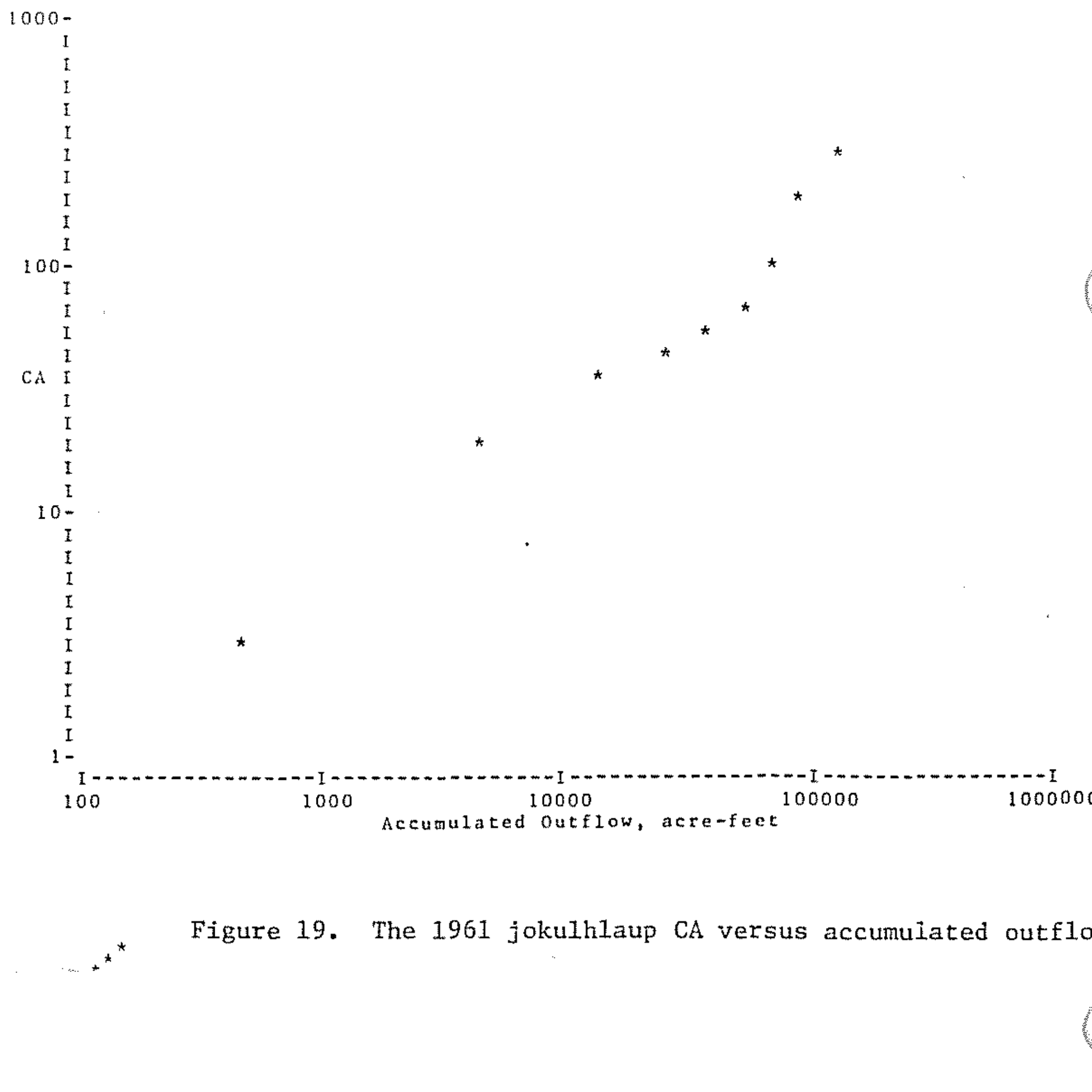
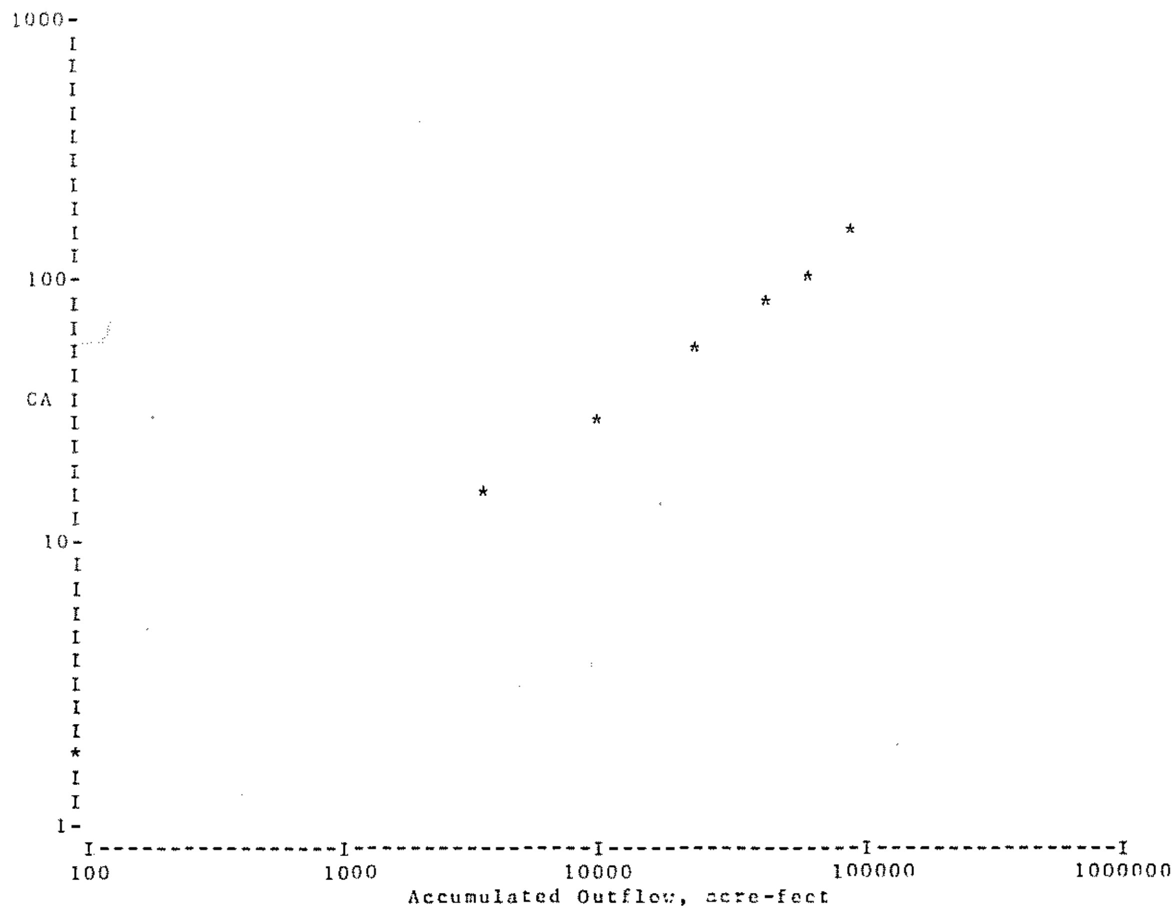



Figure 19. The 1961 jokulhlaup CA versus accumulated outflow.

|  | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume, (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
| 091564 | 760. | 760. | 0. | 0. | 125600. | 0. | 397.1 | 0.00 |
| 091664 | 720. | 720. | 0. | 0. | 125600. | 25. | 397.1 | 0.16 |
| 091764 | 860. | 810. | 50. | 99. | 125501. | 300. | 396.9 | 1.88 |
| 091864 | 3000. | 1100. | 1900. | 3868. | 121732. | 2825. | 388.6 | 17.86 |
| 091964 | 6000. | 2250. | 3750. | 11306. | 114294. | 5300. | 371.8 | 34.25 |
| 092064 | 9200. | 2350. | 6850. | 24893. | 100707. | 9120. | 339.8 | 61.65 |
| 092164 | 13500. | 2110. | 11390. | 47484. | 78116. | 12370. | 281.9 | 91.81 |
| 092264 | 15400. | 2050. | 13350. | 73964. | 51636. | 14015. | 204.5 | 122.13 |
| 092364 | 16700. | 2020. | 14680. | 103081. | 22519. | 14000. | 101.5 | 173.13 |
| 092464 | 11500. | 1980. | 9520. | 121964. | 3636. | 3000. | 18.5 | 86.90 |
| 092564 | 3430. | 1900. | 1530. | 124998. | 602. | 915. | 3.4 | 62.13 |
| 092664 | 2080. | 1780. | 300. | 125593. | 7. | 152. | 0.3 | 0.00 |

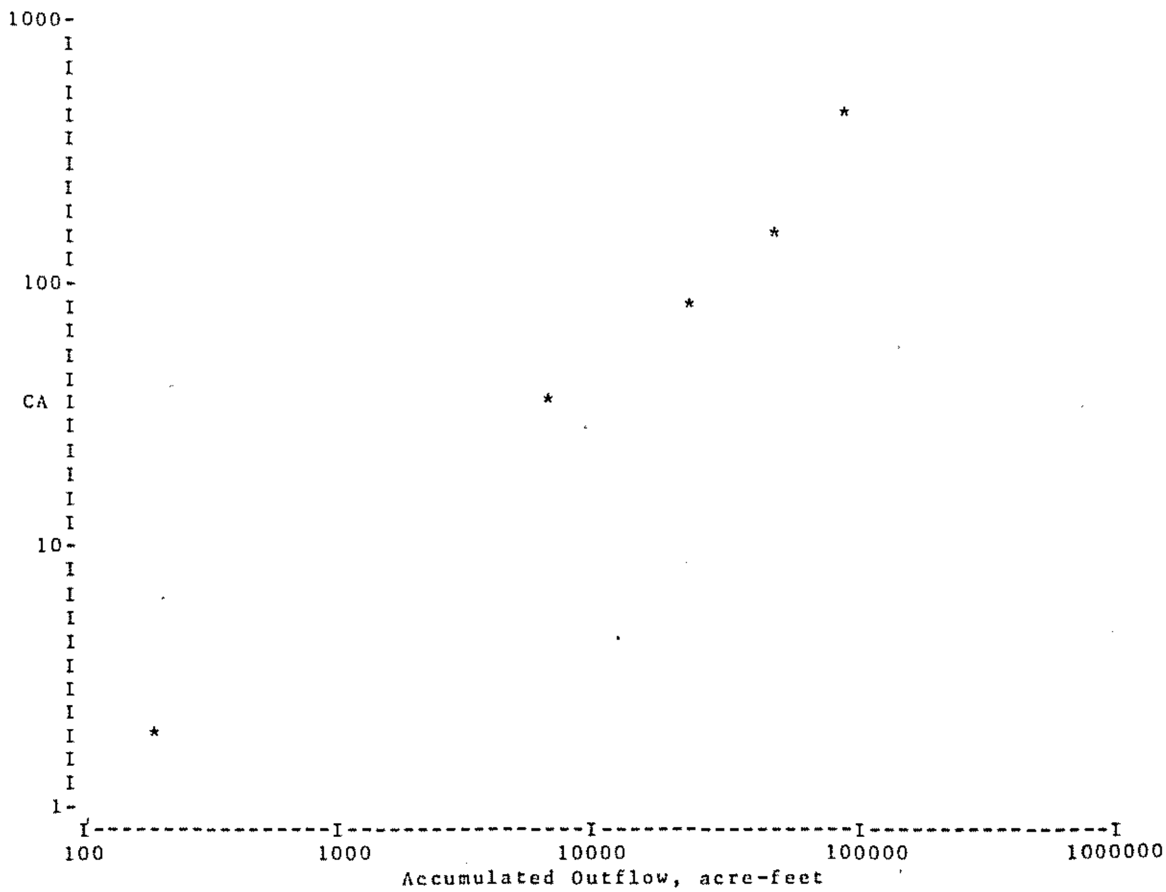



***End***

Figure 20. The 1964 jokulhlaup CA versus accumulated outflow.

>>

| Date | 24-hr Average Values: Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Values at End of 24-hr Period: Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
|---|---|---|---|---|---|---|---|---|
| 082667 | 4300. | 4300. | 0. | 0. | 122000. | 1. | 389.2 | 0.01 |
| 082767 | 3300. | 3200. | 100. | 198. | 121802. | 300. | 388.8 | 1.90 |
| 082867 | 5400. | 2000. | 3400. | 6942. | 115058. | 6200. | 373.6 | 39.97 |
| 082967 | 11700. | 1600. | 10100. | 26975. | 95025. | 13800. | 325.8 | 95.27 |
| 083067 | 18200. | 1600. | 16600. | 59901. | 62099. | 21800. | 236.5 | 176.63 |
| 083167 | 27500. | 1800. | 25700. | 110876. | 11124. | 28000. | 53.5 | 477.01 |
| 090167 | 7500. | 1900. | 5600. | 121983. | 17. | 800. | 0.4 | 0.00 |




***End***

Figure 21. The 1967 jokulhlaup CA versus accumulated outflow.

| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
| 090870 | 1300. | 1300. | 0. | 0. | 153000. | 0. | 454.3 | 0.00 |
| 090970 | 1290. | 1290. | 0. | 0. | 153000. | 30. | 454.3 | 0.18 |
| 091070 | 1300. | 1240. | 60. | 119. | 152881. | 120. | 454.0 | 0.70 |
| 091170 | 1380. | 1200. | 180. | 476. | 152524. | 260. | 453.3 | 1.52 |
| 091270 | 1500. | 1160. | 340. | 1150. | 151850. | 485. | 452.0 | 2.84 |
| 091370 | 1750. | 1120. | 630. | 2400. | 150600. | 925. | 449.5 | 5.44 |
| 091470 | 2300. | 1080. | 1220. | 4820. | 148180. | 1620. | 444.6 | 9.57 |
| 091570 | 3060. | 1040. | 2020. | 8826. | 144174. | 2520. | 436.5 | 15.03 |
| 091670 | 4020. | 1000. | 3020. | 14817. | 138183. | 3750. | 424.1 | 22.69 |
| 091770 | 5440. | 960. | 4480. | 23702. | 129298. | 5550. | 405.2 | 34.36 |
| 091870 | 7540. | 920. | 6620. | 36833. | 116167. | 8070. | 376.1 | 51.85 |
| 091970 | 10400. | 880. | 9520. | 55716. | 97284. | 11090. | 331.4 | 75.91 |
| 092070 | 13500. | 840. | 12660. | 80826. | 72174. | 13630. | 265.5 | 104.23 |
| 092170 | 15400. | 800. | 14600. | 109785. | 43215. | 15170. | 177.0 | 142.08 |
| 092270 | 16500. | 760. | 15740. | 141005. | 11995. | 10545. | 57.4 | 173.47 |
| 092370 | 6070. | 720. | 5350. | 151616. | 1384. | 2980. | 7.3 | 137.20 |

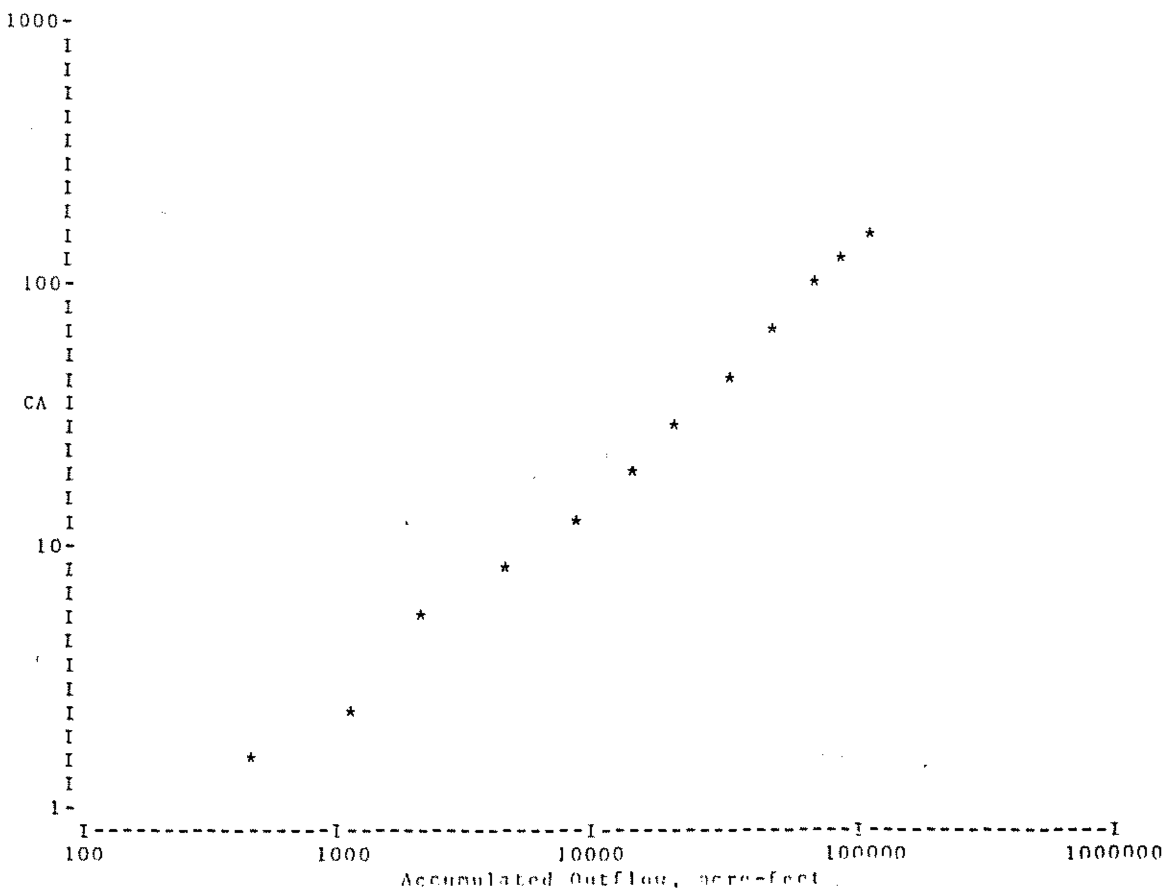



Figure 22. The 1970 jokulhlaup CA versus accumulated outflow.

>>

| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
| 090974 | 1340. | 1340. | 0. | 0. | 195000. | 0. | 532.6 | 0.00 |
| 091074 | 1900. | 1800. | 100. | 198. | 194802. | 265. | 532.2 | 1.43 |
| 091174 | 4030. | 3600. | 430. | 1051. | 193949. | 690. | 530.7 | 3.73 |
| 091274 | 6950. | 6000. | 950. | 2936. | 192064. | 1750. | 527.4 | 9.50 |
| 091374 | 6550. | 4000. | 2550. | 7993. | 187007. | 3070. | 518.4 | 16.80 |
| 091474 | 6690. | 3100. | 3590. | 15114. | 179886. | 4295. | 505.5 | 23.80 |
| 091574 | 12100. | 7100. | 5000. | 25031. | 169969. | 5900. | 487.1 | 33.31 |
| 091674 | 10800. | 4000. | 6800. | 38519. | 156481. | 8150. | 461.2 | 47.29 |
| 091774 | 11100. | 1600. | 9500. | 57362. | 137638. | 11450. | 422.9 | 69.38 |
| 091874 | 14400. | 1000. | 13400. | 83940. | 111060. | 16200. | 364.3 | 105.76 |
| 091974 | 20000. | 1000. | 19000. | 121626. | 73374. | 20900. | 268.9 | 158.83 |
| 092074 | 23800. | 1000. | 22800. | 166849. | 28151. | 18000. | 123.4 | 201.93 |
| 092174 | 19700. | 6500. | 13200. | 193031. | 1969. | 3700. | 10.3 | 143.93 |
| 092274 | 7700. | 6707. | 993. | 195000. | 0. | 0. | 0.0 | 0.00 |
| 092374 | 5150. | 5150. | 0. | 195000. | 0. | 0. | 0.0 | 0.00 |

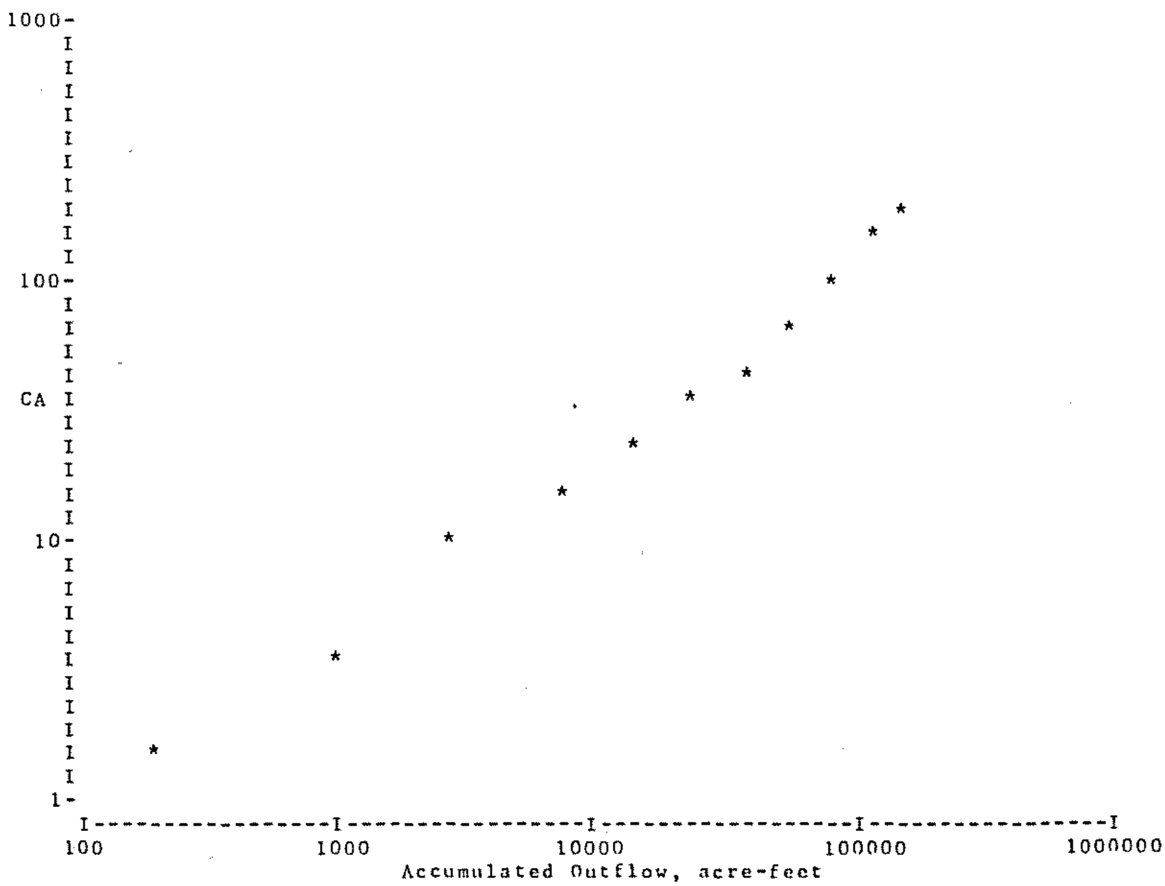
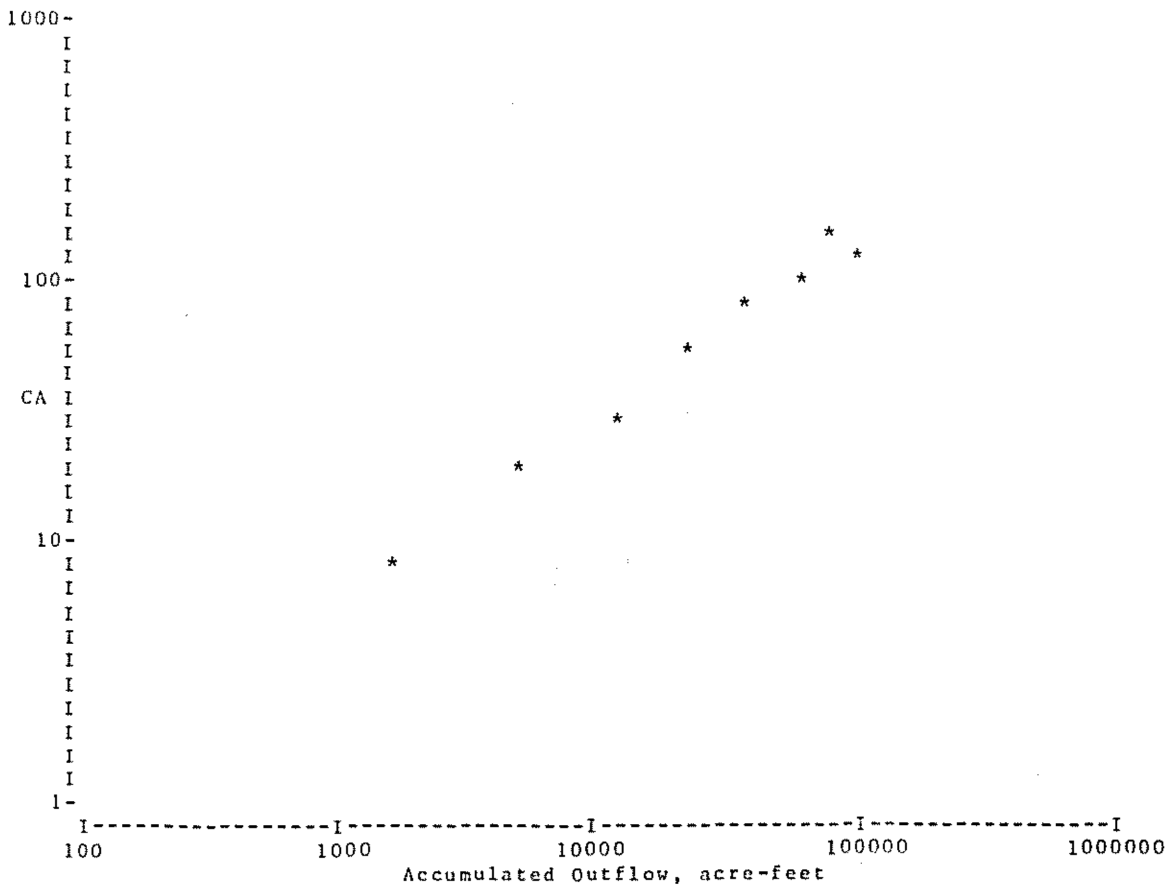



Figure 23. The 1974 jokulhlaup CA versus accumulated outflow.

>>

| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
| 082977 | 4540. | 4540. | 0. | 0. | 122500. | 0. | 390.3 | 0.00 |
| 083077 | 5000. | 4200. | 800. | 1587. | 120913. | 1350. | 386.8 | 8.55 |
| 083177 | 5800. | 3900. | 1900. | 5355. | 117145. | 2770. | 378.3 | 17.75 |
| 090177 | 7240. | 3600. | 3640. | 12575. | 109925. | 4670. | 361.7 | 30.60 |
| 090277 | 9100. | 3400. | 5700. | 23881. | 98619. | 7250. | 334.7 | 49.38 |
| 090377 | 12000. | 3200. | 8800. | 41336. | 81164. | 10150. | 290.1 | 74.26 |
| 090477 | 14500. | 3000. | 11500. | 64145. | 58355. | 12300. | 225.3 | 102.11 |
| 090577 | 15900. | 2800. | 13100. | 90129. | 32371. | 13900. | 139.1 | 146.88 |
| 090677 | 13300. | 2600. | 10700. | 111352. | 11148. | 7555. | 53.6 | 128.58 |
| 090777 | 6810. | 2400. | 4410. | 120099. | 2401. | 2810. | 12.4 | 99.39 |

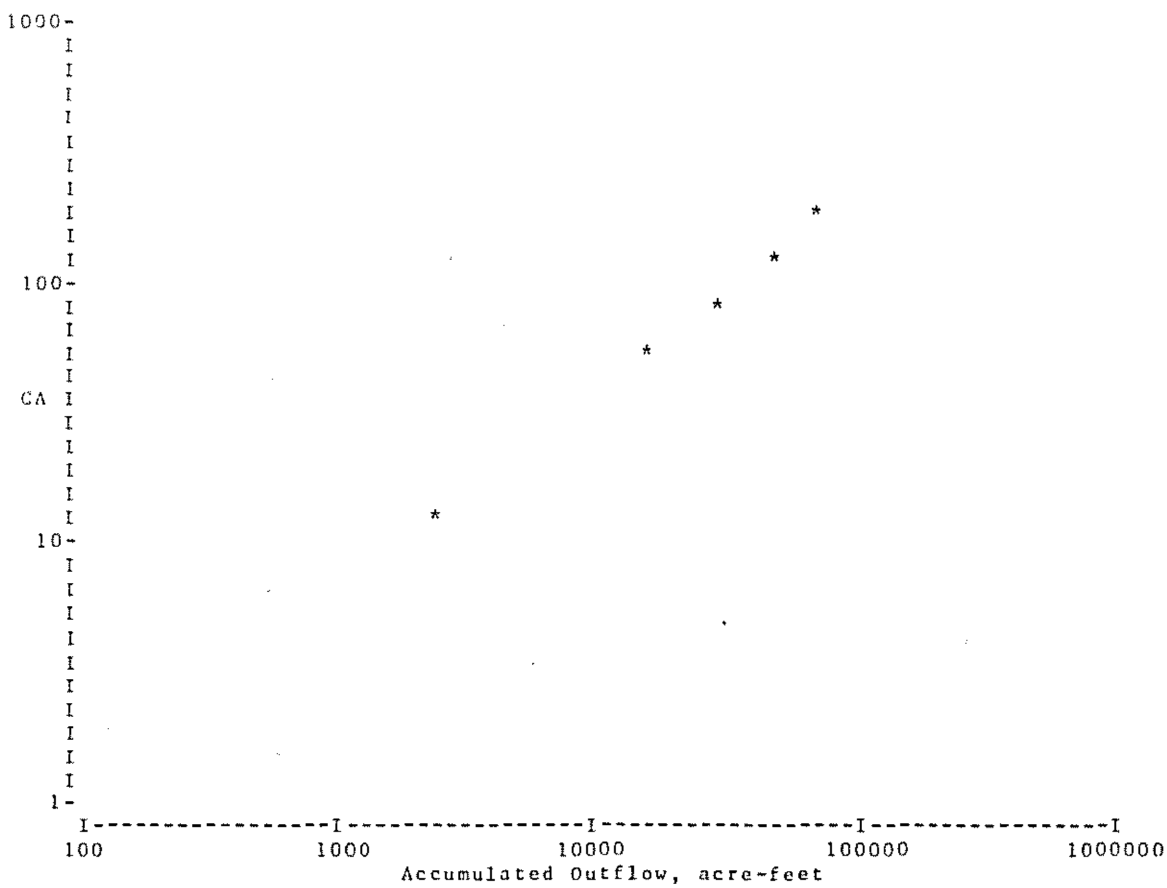



***End***

Figure 24. The 1977 jokulhlaup CA versus accumulated outflow.

\>>

| | 24-hr Average Values | | | Values at End of 24-hr Period | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Lake Out-flow (cfs) | Head (ft) | CA (sqft) |
| 101779 | 4000. | 4000. | 0. | 0. | 103000. | 0. | 345.3 | 0.00 |
| 101879 | 3600. | 3600. | 0. | 0. | 103000. | 0. | 345.3 | 0.00 |
| 101979 | 4400. | 3100. | 1300. | 2579. | 100421. | 2000. | 339.1 | 13.53 |
| 102079 | 9200. | 2600. | 6600. | 15669. | 87331. | 7500. | 306.3 | 53.40 |
| 102179 | 10500. | 2100. | 8400. | 32331. | 70669. | 9900. | 261.3 | 76.32 |
| 102279 | 13000. | 1600. | 11400. | 54942. | 48058. | 12400. | 193.0 | 111.22 |
| 102379 | 14500. | 1100. | 13400. | 81521. | 21479. | 14400. | 97.4 | 181.84 |
| 102479 | 11500. | 671. | 10829. | 103000. | 0. | 0. | 0.0 | 0.00 |
| 102579 | 400. | 400. | 0. | 103000. | 0. | 0. | 0.0 | 0.00 |




***End***

Figure 25. The 1979 jokulhlaup CA versus accumulated outflow.

to determine whether it is near the level at which it may dump. If it has reached that level, a jokulhlaup is imminent, but it is still not possible to predict just when it will occur. The frequency of aerial observation is then increased, noting the lake level, photographing everything that might be of value in later studies, looking closely at the lake edges for evidence of falling stage, and observing the glacier terminus for signs of lake drainage. At the RFC, the operational Snow River hydrograph is watched closely for any change that might indicate the start of the jokulhlaup. When that change appears, an aerial reconnaissance will be made, weather permitting, to verify that the jokulhlaup has started. The river observer will be asked to make two or more stage readings per day and to report them immediately to the RFC.

On the second or third day, while the lake outflow is still small, the CA versus accumulated outflow relationship will already have been established and the total jokulhlaup hydrograph can be forecast.

The forecast procedure is simple, but tedious if done manually. A computer program was developed which requires as input the observed Snow River flows up to date, the forecast non-jokulhlaup flows (same as routine daily runoff forecasts), the beginning lake elevation or storage, and the slope and intercept of the logarithmic equation of CA versus accumulated outflow as defined at the time. While the slope and intercept determination could be programmed, better estimates may be made visually, especially early in the event and when CA is less than 1.0.

The program works by selecting a discharge expected 24 hr after the last observation or determination. With those two values, the average flow determines the volume of outflow for the day which in turn determines the remaining lake volume and the head. Applying the orifice formula, a value for CA is obtained which corresponds to the selected discharge and the head. Another CA value is obtained from the CA versus accumulated outflow relationship. If the two values of CA are alike (within 1%), the selected discharge is correct. If they are not alike, another discharge is systematically selected and the procedure repeated until agreement is reached. The program then proceeds to the next day and the next. Eventually, agreement cannot be reached because orifice control will have been lost due to low head. Then the program projects the hydrograph in a straight line to zero flow, the line being sloped to contain the remaining lake volume which is small. The forecast is updated daily as better definition of the CA versus accumulated outflow relationship evolves.

## PROGRAM TO FORECAST SNOW RIVER JOKULHLAUPS

The computer program for forecasting jokulhlaups on Snow River is written for the Cromemco microcomputer in 32K Structured

Basic. The program follows, along with sample output shown in tables 2 through 5.

## FORECAST PROCEDURE VERIFICATION

For verification of the forecast procedures, the 1970 and 1977 events, which had different dump rates, were used. Each was computed on two dates and the resulting flows are compared with the recorded flows at the Snow River gage and at Cooper Landing in tables 6 through 9. The flows are not strictly comparable as the computed flows are instantaneous values at the daily observation times while the recorded flows are mean daily values. The stages at Cooper Landing are also compared, based on the computed and observed flows and the discharge rating curve presently in use by the RFC, which is not necessarily the rating curve in use during the actual events. Since the purpose of this exercise is to test the jokulhlaup forecast procedure, not the procedures for forecasting Trail River and other areas, observed values were used for Trail River and near-perfect hindcasting was used for the other areas excepting the glacier-dammed lake. The results suggest that the jokulhlaup forecast procedure is an unusually reliable procedure.

## CONCLUSION

It has been demonstrated that, during a jokulhlaup on Snow River, the cross-sectional area of the outlet of the glacier-dammed lake is proportional to the amount of water that has passed through the outlet. That proportion differs from event to event but it reveals itself early in each event, and that enables forecasting the total jokulhlaup several days in advance of the peak flow. A computer program was developed which produces that forecast, the output from which can be entered directly into the Kenai River forecast procedures.

A common question that arises is: Will this method work on other glacier-dammed lakes? Probably yes, if they drain through subglacial outlets and if the necessary data are available. The latter condition usually rules in the negative, however.

```
>>

 10    Rem: FILE "JOKLP" : Cromemco 32K Structured Basic
 20    Rem: Program to forecast Snow River jokulhlaups
 30    Rem: D. Chapman   12/15/80
 40    Rem: Date of last change: 12/18/80
 50    Rem
 60    Dim Snowq(30),Baseq(30),Eodq(30)
 70    Dim Avout(30),Accout(30),Remvol(30),H(30),Ca(30),Cf(30)
 80    Integer Mo(30),Day(30),Yr(30),J,K,Kk
 90    K=0 : J=1
100    Open\1,30\"KENLKQS"
110    Input"If this is a new event, enter Y: ",A$
120    If Binor(A$="Y",A$="y") Then  Do
130      Input"Enter starting date (Mo,Day,Yr): ",Mo(K),Day(K),Yr(K)
140      @ : @"Enter observed daily discharges. (Enter 1E7 to end.)" : @
150      If Mo(K)=2 Then 180
160      Numdays=30.5+0.5*(-1**(Int(Abs(Mo(K)-7.5))))
170      Goto 230
180      If Fra(Yr(K)/4.0) Then  Do
190        Numdays=28
200        Else
210        Numdays=29
220        Enddo
230        Repeat
240        If Day(K)<=Numdays Then 280
250        Day(K)=1 : Mo(K)=Mo(K)+1 : If Mo(K)>12 Then 270
260        Goto 280
270        Mo(K)=1 : Yr(K)=Yr(K)+1
280        @ Using"###",Mo(K);Day(K);Yr(K);
290        Input" SNOWQ: ",Snowq(K) : Lastq=Snowq(K)
300        Day(K+1)=Day(K)+1 : Mo(K+1)=Mo(K) : Yr(K+1)=Yr(K) : K1=K : K=K+1
310        Until Lastq>=1000000.0
320      K=0 : If J>1 Then K=K2
330      On J Goto 340,480
340        For Kk=0 To K1
350        Put\1,Kk\Mo(Kk),Day(Kk),Yr(Kk),Snowq(Kk)
360        Next Kk
370      Else
380      @ : @ : @"These are the flows in the file:"
390        Repeat
400        Get\1,K\Mo(K),Day(K),Yr(K),Snowq(K),Baseq(K)
410        @ Using"###",Mo(K);Day(K);Yr(K); : @ Tab(20);Snowq(K)
420        K=K+1
430        Until Snowq(K-1)=0
440      @"If flows need revising, rerun as a new event."
450      @ : @"Update observed flows. (Enter 1E7 to end) "
460      J=2 : K2=K-1 : K=K2 : Goto 150
470      Enddo
480    @ : @"Enter lake surface elevation in feet or" ·
490    Input"beginning storage in acre-feet:  ",Poolelev
500    If Poolelev>3000.0 Then 550
510    Starting^head=Poolelev-2300
520    If Starting^head<0 Then @"Bad entry" : Goto 480
530    Starting^storage=((Starting^head+748.0)^3.0)/8620.0-48600.0
540    Goto 560
550    Starting^storage=Poolelev
560    Kk=0 : @ : @"Enter new estimated intervening area/base flows,"
570    @"or re-enter values used in previous run."
580      Repeat
590      @ Using"###",Mo(Kk),Day(Kk),Yr(Kk)
600      @"SNOW RIVER Q..................."; : @ Using"#####",Snowq(Kk)
610      @"PREVIOUSLY USED INT. AREA Q..."; : @ Using"#####",Baseq(Kk)
620      Input"NEW ESTIMATED INT. AREA Q..... ",Baseq(Kk)
630      Eodq(Kk)=Snowq(Kk)-Baseq(Kk)
640      If Kk=0 Then Avout(Kk)=0 : Accout(Kk)=0 : Goto 670
650      Avout(Kk)=1.98347*0.5*(Eodq(Kk-1)+Eodq(Kk))
660      Accout(Kk)=Accout(Kk-1)+Avout(Kk)
670      Remvol(Kk)=Starting^storage-Accout(Kk)
680      H(Kk)=(Remvol(Kk)*8620.0+419000000.0)^(1.0/3.0)-748
690      If H(Kk)<1 Then Ca(Kk)=0 : H(Kk)=0 : Goto 720
700      Ca(Kk)=Eodq(Kk)/Sqr(64.4*H(Kk))
710      Kk=Kk+1
720      Until Snowq(Kk)>=1000000.0
730    J=1
740    K=0
750      Repeat
```

>>

```
760   Put\1,K\Mo(K),Day(K),Yr(K),Snowq(K),Baseq(K),Eodq(K)
770   K=K+1
780   Until Snowq(K-1)>=1000000.0
790   On J Goto 800,1480
800   @ : @ Tab(6);"Instantaneous Values at Time of Daily Observation"
810   @"-------------------------------------------------------------"
820   @ Tab(10);"Snow    Int.A    Lake      Accum    Remain"
830   @ Tab(10);"River   /Base    Out-      Out-     Volume    Head     CA"
840   @" Date      Flow    Flow     flow      flow"
850   @ Tab(10);"(cfs)  (cfs)    (cfs)     (acft)   (acft)    (ft)   (sqft)"
860   @"-------------------------------------------------------------"
870   @ : K=0
880     Repeat
890     @ Using"&&",Mo(K);Day(K);Yr(K);
900     @ Tab(9); : @ Using"#####.",Snowq(K);
910     @ Tab(17); : @ Using"####.",Baseq(K);
920     @ Tab(24); : @ Using"#####.",Eodq(K);
930     @ Tab(33); : @ Using"######.",Accout(K);
940     @ Tab(42); : @ Using"######.",Remvol(K);
950     @ Tab(50); : @ Using"###.#",H(K);
960     @ Tab(55); : @ Using"####.##",Ca(K)
970     K=K+1
980     Until Snowq(K)>=1000000.0
990   @"-------------------------------------------------------------"
1000  On J Goto 1010,1410
1010  @ : @ : @"Plot CA vs. Accum. Outflow on log grid."
1020  @"Choose best-fit straight line."
1030  @"Determine slope,M, and intercept,B, in the"
1040  @"equation Log CA = M*Log(Accum Outflow)+B."
1050  @"(Base 10 logs. B may require a minus sign.)"
1060  Input"Enter slope,intercept.  ",M,B
1070  Rem
1080  Rem Jokulhlaup forecast procedure follows:
1090  Rem
1100  Incr=1000.0 : Tryq1=0.0 : J=0 : J1=0 : Cf(K-1)=1000.0
1110  Day(K)=Day(K-1)+1 : Mo(K)=Mo(K-1) : Yr(K)=Yr(K-1)
1120  If Day(K)<=Numdays Then 1140
1130  Day(K)=1 : Mo(K)=Mo(K)+1 : If Mo(K)>12 Then Mo(K)=1 : Yr(K)=Yr(K)+1
1140  Tryq2=Tryq1+Incr*J1
1150  Accout(K)=0.5*(Eodq(K-1)+Tryq2)*1.98347+Accout(K-1)
1160  Remvol(K)=Starting'storage-Accout(K)
1170  If Remvol(K)<0 Then 1270
1180  H(K)=(Remvol(K)*8620.0+419000000.0)^(1.0/3.0)-748
1190  If H(K)<1 Then Ca(K)=0 : H(K)=0 : Goto 1410
1200  Ca(K)=Tryq2/Sqr(64.4*H(K))
1210  Testca=10.0^(M*Log(Accout(K))/Log(10)+B)
1220  Cf(K)=Testca-Ca(K)
1230  If Cf(K)>Cf(K-1) Then 1270
1240  If Abs((Ca(K)-Testca)/Testca)<=0.01 Then 1290
1250  J=J+1 : If J>=60 Then 1300
1260  If Ca(K)<Testca Then Tryq1=Tryq2 : J1=1 : Goto 1140
1270  If Incr<1E-05 Then K=K-1 : Goto 1300
1280  Incr=Incr/10.0 : J1=1 : Goto 1140
1290  Eodq(K)=Tryq2 : Snowq(K)=0 : Baseq(K)=0 : K=K+1 : Goto 1100
1300  Basetime=2.0*(Remvol(K-1)/1.98347)/Eodq(K-1)
1310  If Basetime>1.0 Then 1350
1320  Eodq(K)=0 : Accout(K)=Starting'storage : Remvol(K)=0 : H(K)=0
1330  Ca(K)=0 : Snowq(K)=0 : Baseq(K)=0 : Snowq(K+1)=10000000.0
1340  J=2 : Goto 800
1350  Eodq(K)=(Basetime-1.0)*(Eodq(K-1)/Basetime)
1360  Accout(K)=Accout(K-1)+0.5*(Eodq(K-1)+Eodq(K))*1.98347
1370  Remvol(K)=Starting'storage-Accout(K)
1380  If Remvol(K)<0 Then H(K)=0
1390  H(K)=(Remvol(K)*8620.0+419000000.0)^(1.0/3.0)-748
1400  Ca(K)=0 : Snowq(K)=0 : Baseq(K)=0 : K=K+1 : Goto 1300
1410  Snowq(K)=0.0
1420    For Kk=K-1 To K+7
1430    Day(Kk)=Day(Kk-1)+1 : Mo(Kk)=Mo(Kk-1) : Yr(Kk)=Yr(Kk-1)
1440    If Day(Kk)<=Numdays Then 1470
1450    Day(Kk)=1 : Mo(Kk)=Mo(Kk)+1 : If Mo(Kk)>12 Then Mo(Kk)=1 : Yr(Kk)=Yr(Kk)+1
1460    Put\1,Kk\Mo(Kk),Day(Kk),Yr(Kk)
1470    Next Kk
1480    For Kk=0 To K+7
1490    Put\1,Kk\Mo(Kk),Day(Kk),Yr(Kk),Snowq(Kk),Baseq(Kk),Eodq(Kk)
1500    Next Kk
1510  Close\1\
```

TABLE 2

Output from Jokulhlaup Forecast Program
Date of Forecast: 9 12 70

>>

Instantaneous Values at Time of Daily Observation

| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Head (ft) | CA (sqft) |
|---|---|---|---|---|---|---|---|
| 090870 | 1300. | 1300. | 0. | 0. | 153000. | 454.3 | 0.00 |
| 090970 | 1290. | 1290. | 0. | 0. | 153000. | 454.3 | 0.00 |
| 091070 | 1300. | 1240. | 60. | 60. | 152940. | 454.2 | 0.35 |
| 091170 | 1380. | 1200. | 180. | 298. | 152702. | 453.7 | 1.05 |
| 091270 | 1500. | 1160. | 340. | 813. | 152187. | 452.7 | 1.99 |
| 091370 | 0. | 0. | 810. | 1954. | 151046. | 450.4 | 4.76 |
| 091470 | 0. | 0. | 1510. | 4255. | 148745. | 445.8 | 8.91 |
| 091570 | 0. | 0. | 2600. | 8331. | 144669. | 437.5 | 15.49 |
| 091670 | 0. | 0. | 4100. | 14975. | 138025. | 423.7 | 24.82 |
| 091770 | 0. | 0. | 6100. | 25091. | 127909. | 402.2 | 37.90 |
| 091870 | 0. | 0. | 8400. | 39471. | 113529. | 370.1 | 54.41 |
| 091970 | 0. | 0. | 11000. | 58711. | 94289. | 324.0 | 76.16 |
| 092070 | 0. | 0. | 13000. | 82512. | 70488. | 260.8 | 100.31 |
| 092170 | 0. | 0. | 13400. | 108694. | 44306. | 180.7 | 124.23 |
| 092270 | 0. | 0. | 11200. | 133091. | 19909. | 91.0 | 146.29 |
| 092370 | 0. | 0. | 4951. | 149109. | 3891. | 19.7 | 0.00 |
| 092470 | 0. | 0. | 0. | 153000. | 0. | 0.0 | 0.00 |

***End***

TABLE 3

Output from Jokulhlaup Forecast Program
Date of Forecast: 9 19 70

>>

Instantaneous Values at Time of Daily Observation

| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Head (ft) | CA (sqft) |
|---|---|---|---|---|---|---|---|
| 090870 | 1300. | 1300. | 0. | 0. | 153000. | 454.3 | 0.00 |
| 090970 | 1290. | 1290. | 0. | 0. | 153000. | 454.3 | 0.00 |
| 091070 | 1300. | 1240. | 60. | 60. | 152940. | 454.2 | 0.35 |
| 091170 | 1380. | 1200. | 180. | 298. | 152702. | 453.7 | 1.05 |
| 091270 | 1500. | 1160. | 340. | 813. | 152187. | 452.7 | 1.99 |
| 091370 | 1750. | 1120. | 630. | 1775. | 151225. | 450.7 | 3.70 |
| 091470 | 2300. | 1080. | 1220. | 3610. | 149390. | 447.1 | 7.19 |
| 091570 | 3060. | 1040. | 2020. | 6823. | 146177. | 440.6 | 11.99 |
| 091670 | 4020. | 1000. | 3020. | 11821. | 141179. | 430.3 | 18.14 |
| 091770 | 5440. | 960. | 4480. | 19259. | 133741. | 414.7 | 27.41 |
| 091870 | 7540. | 920. | 6620. | 30268. | 122732. | 390.8 | 41.73 |
| 091970 | 10400. | 880. | 9520. | 46274. | 106726. | 354.2 | 63.03 |
| 092070 | 0. | 0. | 12400. | 68013. | 84987. | 300.2 | 89.19 |
| 092170 | 0. | 0. | 14400. | 94592. | 58408. | 225.5 | 119.50 |
| 092270 | 0. | 0. | 13800. | 122559. | 30441. | 132.0 | 149.69 |
| 092370 | 0. | 0. | 7596. | 143778. | 9222. | 44.9 | 0.00 |
| 092470 | 0. | 0. | 1391. | 152690. | 310. | 1.9 | 0.00 |
| 000000 | 0. | 0. | 0. | 153000. | 0. | 0.0 | 0.00 |

***End***

TABLE 4

Output from Jokulhlaup Forecast Program
Date of Forecast: 9 2 77

>>

Instantaneous Values at Time of Daily Observation

| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Head (ft) | CA (sqft) |
|---|---|---|---|---|---|---|---|
| 082977 | 4540. | 4540. | 0. | 0. | 122500. | 390.3 | 0.00 |
| 083077 | 5000. | 4200. | 800. | 793. | 121707. | 388.5 | 5.06 |
| 083177 | 5800. | 3900. | 1900. | 3471. | 119029. | 382.6 | 12.10 |
| 090177 | 7240. | 3600. | 3640. | 8965. | 113535. | 370.1 | 23.58 |
| 090277 | 9100. | 3400. | 5700. | 18228. | 104272. | 348.4 | 38.06 |
| 090377 | 0. | 0. | 8000. | 31815. | 90685. | 314.9 | 56.18 |
| 090477 | 0. | 0. | 10000. | 49666. | 72834. | 267.4 | 76.21 |
| 090577 | 0. | 0. | 11200. | 70691. | 51809. | 205.0 | 97.47 |
| 090677 | 0. | 0. | 10800. | 92509. | 29991. | 130.3 | 117.90 |
| 090777 | 0. | 0. | 8000. | 111154. | 11346. | 54.5 | 135.04 |
| 090877 | 0. | 0. | 2406. | 121474. | 1026. | 5.5 | 0.00 |
| 090977 | 0. | 0. | 0. | 122500. | 0. | 0.0 | 0.00 |

***End***

TABLE 5

Output from Jokulhlaup Forecast Program
Date of Forecast: 9 4 77

>>

Instantaneous Values at Time of Daily Observation

| Date | Snow River Flow (cfs) | Int.A /Base Flow (cfs) | Lake Out-flow (cfs) | Accum Out-flow (acft) | Remain Volume (acft) | Head (ft) | CA (sqft) |
|---|---|---|---|---|---|---|---|
| 082977 | 4540. | 4540. | 0. | 0. | 122500. | 390.3 | 0.00 |
| 083077 | 5000. | 4200. | 800. | 793. | 121707. | 388.5 | 5.06 |
| 083177 | 5800. | 3900. | 1900. | 3471. | 119029. | 382.6 | 12.10 |
| 090177 | 7240. | 3600. | 3640. | 8965. | 113535. | 370.1 | 23.58 |
| 090277 | 9100. | 3400. | 5700. | 18228. | 104272. | 348.4 | 38.06 |
| 090377 | 12000. | 3200. | 8800. | 32608. | 89892. | 312.8 | 62.00 |
| 090477 | 14500. | 3000. | 11500. | 52740. | 69760. | 258.7 | 89.09 |
| 090577 | 0. | 0. | 12300. | 76344. | 46156. | 186.8 | 112.14 |
| 090677 | 0. | 0. | 11000. | 99451. | 23049. | 103.6 | 134.65 |
| 090777 | 0. | 0. | 5794. | 116106. | 6394. | 31.8 | 0.00 |
| 090877 | 0. | 0. | 587. | 122434. | 66. | 0.6 | 0.00 |
| 000000 | 0. | 0. | 0. | 122500. | 0. | 0.0 | 0.00 |

***End***

TABLE 6

Verification of Jokulhlaup Forecast Procedure

Date of forecast: 9 12 70

| Date | Glac. Lake Dump (cfs) | Int.A /Base Flow (cfs) | Snow Comp Flow (cfs) | River Obsv Flow (cfs) | Trail River Flow (cfs) | Local Area Flow (cfs) | Cooper Landing Computed Flow (cfs) | Cooper Landing Computed Stage (ft) | Cooper Landing Observed Flow (cfs) | Cooper Landing Observed Stage (ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| 090870 | 0. | 1300. | 1300. | 1300. | 1090. | 1960. | 5310. | 10.28 | 5310. | 10.28 |
| 090970 | 0. | 1290. | 1290. | 1290. | 961. | 1730. | 5033. | 10.12 | 5090. | 10.15 |
| 091070 | 60. | 1240. | 1300. | 1300. | 861. | 1550. | 4793. | 9.98 | 4820. | 9.99 |
| 091170 | 180. | 1200. | 1380. | 1380. | 785. | 1410. | 4566. | 9.83 | 4630. | 9.88 |
| 091270 | 340. | 1160. | 1500. | 1500. | 735. | 1320. | 4368. | 9.71 | 4480. | 9.78 |
| 091370 | 810. | 1120. | 1930. | 1750. | 716. | 1290. | 4245. | 9.63 | 4430. | 9.75 |
| 091470 | 1510. | 1080. | 2590. | 2300. | 734. | 1320. | 4254. | 9.64 | 4480. | 9.78 |
| 091570 | 2600. | 1040. | 3640. | 3060. | 781. | 1410. | 4448. | 9.76 | 4670. | 9.90 |
| 091670 | 4100. | 1000. | 5100. | 4020. | 812. | 1460. | 4873. | 10.03 | 4910. | 10.05 |
| 091770 | 6100. | 960. | 7060. | 5440. | 789. | 1420. | 5679. | 10.49 | 5270. | 10.26 |
| 091870 | 8400. | 920. | 9320. | 7540. | 773. | 1390. | 6814. | 11.08 | 5890. | 10.61 |
| 091970 | 11000. | 880. | 11880. | 10400. | 754. | 1360. | 8247. | 11.76 | 6760. | 11.06 |
| 092070 | 13000. | 840. | 13840. | 13500. | 712. | 1280. | 9859. | 12.47 | 7920. | 11.61 |
| 092170 | 13400. | 800. | 14200. | 15400. | 658. | 1180. | 11441. | 13.12 | 9540. | 12.34 |
| 092270 | 11200. | 760. | 11960. | 16500. | 597. | 1070. | 12479. | 13.53 | 11400. | 13.10 |
| 092370 | 4951. | 720. | 5671. | 6070. | 538. | 970. | 11844. | 13.28 | 12100. | 13.38 |
| 092470 | 0. | 700. | 700. | 1290. | 503. | 910. | 9906. | 12.49 | 10300. | 12.65 |
| 092570 | 0. | 704. | 704. | 704. | 467. | 840. | 8009. | 11.65 | 8680. | 11.95 |
| 092670 | 0. | 960. | 960. | 960. | 451. | 810. | 6584. | 10.97 | 7260. | 11.30 |
| 092770 | 0. | 930. | 930. | 930. | 449. | 810. | 5525. | 10.40 | 6140. | 10.74 |
| 092870 | 0. | 841. | 841. | 841. | 460. | 830. | 4764. | 9.96 | 5270. | 10.26 |
| 092970 | 0. | 704. | 704. | 704. | 473. | 850. | 4234. | 9.62 | 4650. | 9.89 |
| 093070 | 0. | 664. | 664. | 664. | 471. | 850. | 3794. | 9.32 | 4110. | 9.54 |
| 100170 | 0. | 0. | 0. | 0. | 448. | 810. | 3374. | 9.02 | 3700. | 9.26 |
| 100270 | 0. | 0. | 0. | 0. | 434. | 780. | 3023. | 8.74 | 3360. | 9.01 |

TABLE 7

Verification of Jokulhlaup Forecast Procedure

>>

Date of forecast: 9 19 70

| | Glac. | Int.A | Snow River | | Trail | Local | Cooper Landing | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Lake | /Base | Comp | Obsv | River | Area | Computed | | Observed | |
| Date | Dump (cfs) | Flow (cfs) | Flow (cfs) | Flow (cfs) | Flow (cfs) | Flow (cfs) | Flow (cfs) | Stage (ft) | Flow (cfs) | Stage (ft) |
| 090870 | 0. | 1300. | 1300. | 1300. | 1090. | 1960. | 5310. | 10.28 | 5310. | 10.28 |
| 090970 | 0. | 1290. | 1290. | 1290. | 961. | 1730. | 5033. | 10.12 | 5090. | 10.15 |
| 091070 | 60. | 1240. | 1300. | 1300. | 861. | 1550. | 4793. | 9.98 | 4820. | 9.99 |
| 091170 | 180. | 1200. | 1380. | 1380. | 785. | 1410. | 4566. | 9.83 | 4630. | 9.88 |
| 091270 | 340. | 1160. | 1500. | 1500. | 735. | 1320. | 4368. | 9.71 | 4480. | 9.78 |
| 091370 | 630. | 1120. | 1750. | 1750. | 716. | 1290. | 4227. | 9.62 | 4430. | 9.75 |
| 091470 | 1220. | 1080. | 2300. | 2300. | 734. | 1320. | 4193. | 9.60 | 4480. | 9.78 |
| 091570 | 2020. | 1040. | 3060. | 3060. | 781. | 1410. | 4314. | 9.68 | 4670. | 9.90 |
| 091670 | 3020. | 1000. | 4020. | 4020. | 812. | 1460. | 4602. | 9.86 | 4910. | 10.05 |
| 091770 | 4480. | 960. | 5440. | 5440. | 789. | 1420. | 5085. | 10.15 | 5270. | 10.26 |
| 091870 | 6620. | 920. | 7540. | 7540. | 773. | 1390. | 5953. | 10.64 | 5890. | 10.61 |
| 091970 | 9520. | 880. | 10400. | 10400. | 754. | 1360. | 7200. | 11.27 | 6760. | 11.06 |
| 092070 | 12400. | 840. | 13240. | 13500. | 712. | 1280. | 8813. | 12.02 | 7920. | 11.61 |
| 092170 | 14400. | 800. | 15200. | 15400. | 658. | 1180. | 10584. | 12.77 | 9540. | 12.34 |
| 092270 | 13800. | 760. | 14560. | 16500. | 597. | 1070. | 12350. | 13.48 | 11400. | 13.10 |
| 092370 | 7596. | 720. | 8316. | 6070. | 538. | 970. | 12557. | 13.56 | 12100. | 13.38 |
| 092470 | 1391. | 700. | 2091. | 1290. | 503. | 910. | 10785. | 12.85 | 10300. | 12.65 |
| 092570 | 0. | 704. | 704. | 704. | 467. | 840. | 8844. | 12.03 | 8680. | 11.95 |
| 092670 | 0. | 960. | 960. | 960. | 451. | 810. | 7217. | 11.28 | 7260. | 11.30 |
| 092770 | 0. | 930. | 930. | 930. | 449. | 810. | 6005. | 10.67 | 6140. | 10.74 |
| 092870 | 0. | 841. | 841. | 841. | 460. | 830. | 5075. | 10.14 | 5270. | 10.26 |
| 092970 | 0. | 704. | 704. | 704. | 473. | 850. | 4470. | 9.77 | 4650. | 9.89 |
| 093070 | 0. | 664. | 664. | 664. | 471. | 850. | 3983. | 9.46 | 4110. | 9.54 |
| 100170 | 0. | 631. | 631. | 0. | 448. | 810. | 3579. | 9.17 | 3700. | 9.26 |
| 100270 | 0. | 599. | 599. | 0. | 434. | 780. | 3269. | 8.94 | 3360. | 9.01 |

TABLE 8

Verification of Jokulhlaup Forecast Procedure

>>

Date of forecast: 9 2 77

| Date | Glac. Lake Dump (cfs) | Int.A /Base Flow (cfs) | Snow River Comp Flow (cfs) | Snow River Obsv Flow (cfs) | Trail River Flow (cfs) | Local Area Flow (cfs) | Cooper Landing Computed Flow (cfs) | Cooper Landing Computed Stage (ft) | Cooper Landing Observed Flow (cfs) | Cooper Landing Observed Stage (ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| 082977 | 0. | 4540. | 4540. | 4540. | 1560. | 2810. | 8210. | 11.74 | 8210. | 11.74 |
| 083077 | 800. | 4200. | 5000. | 5000. | 1490. | 2680. | 8411. | 11.83 | 8100. | 11.69 |
| 083177 | 1900. | 3900. | 5800. | 5800. | 1350. | 2430. | 8644. | 11.94 | 8100. | 11.69 |
| 090177 | 3640. | 3600. | 7240. | 7240. | 1290. | 2320. | 9024. | 12.11 | 8340. | 11.80 |
| 090277 | 5700. | 3400. | 9100. | 9100. | 1230. | 2210. | 9670. | 12.39 | 8780. | 12.00 |
| 090377 | 8000. | 3200. | 11200. | 12000. | 1150. | 2070. | 10591. | 12.77 | 9820. | 12.46 |
| 090477 | 10000. | 3000. | 13000. | 14500. | 1090. | 1960. | 11930. | 13.31 | 11200. | 13.02 |
| 090577 | 11200. | 2800. | 14000. | 15900. | 1040. | 1870. | 13322. | 13.87 | 13100. | 13.78 |
| 090677 | 10800. | 2600. | 13400. | 13300. | 979. | 1760. | 14497. | 14.28 | 14900. | 14.43 |
| 090777 | 8000. | 2400. | 10400. | 6810. | 1110. | 2000. | 14621. | 14.33 | 14600. | 14.32 |
| 090877 | 2406. | 2200. | 4606. | 3510. | 1320. | 2380. | 13266. | 13.85 | 12700. | 13.62 |
| 090977 | 0. | 2110. | 2110. | 2110. | 1350. | 2430. | 11379. | 13.09 | 10900. | 12.90 |
| 091077 | 0. | 2250. | 2250. | 2250. | 1270. | 2290. | 9942. | 12.50 | 9540. | 12.34 |
| 091177 | 0. | 3020. | 3020. | 3020. | 1320. | 2380. | 9053. | 12.12 | 8740. | 11.98 |
| 091277 | 0. | 1900. | 1900. | 1900. | 1390. | 2500. | 8376. | 11.82 | 8120. | 11.70 |
| 091377 | 0. | 1805. | 1805. | 0. | 1290. | 2320. | 7706. | 11.51 | 7360. | 11.35 |
| 091477 | 0. | 1715. | 1715. | 0. | 1220. | 2200. | 7118. | 11.23 | 6710. | 11.03 |
| 091577 | 0. | 1629. | 1629. | 0. | 1150. | 2070. | 6604. | 10.98 | 6260. | 10.80 |
| 091677 | 0. | 1548. | 1548. | 0. | 1080. | 1940. | 6146. | 10.74 | 5920. | 10.62 |
| 091777 | 0. | 1470. | 1470. | 0. | 1050. | 1890. | 5745. | 10.52 | 5660. | 10.48 |

TABLE 9

Verification of Jokulhlaup Forecast Procedure

>>

Date of forecast: 9 4 77

| Date | Glac. Lake Dump (cfs) | Int.A /Base Flow (cfs) | Snow Comp Flow (cfs) | River Obsv Flow (cfs) | Trail River Flow (cfs) | Local Area Flow (cfs) | Cooper Landing Computed Flow (cfs) | Cooper Landing Computed Stage (ft) | Cooper Landing Observed Flow (cfs) | Cooper Landing Observed Stage (ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| 082977 | 0. | 4540. | 4540. | 4540. | 1560. | 2810. | 8210. | 11.74 | 8210. | 11.74 |
| 083077 | 800. | 4200. | 5000. | 5000. | 1490. | 2680. | 8411. | 11.83 | 8100. | 11.69 |
| 083177 | 1900. | 3900. | 5800. | 5800. | 1350. | 2430. | 8644. | 11.94 | 8100. | 11.69 |
| 090177 | 3640. | 3600. | 7240. | 7240. | 1290. | 2320. | 9024. | 12.11 | 8340. | 11.80 |
| 090277 | 5700. | 3400. | 9100. | 9100. | 1230. | 2210. | 9670. | 12.39 | 8780. | 12.00 |
| 090377 | 8800. | 3200. | 12000. | 12000. | 1150. | 2070. | 10688. | 12.81 | 9820. | 12.46 |
| 090477 | 11500. | 3000. | 14500. | 14500. | 1090. | 1960. | 12374. | 13.49 | 11200. | 13.02 |
| 090577 | 12300. | 2800. | 15100. | 15900. | 1040. | 1870. | 14156. | 14.16 | 13100. | 13.78 |
| 090677 | 11000. | 2600. | 13600. | 13300. | 979. | 1760. | 15305. | 14.57 | 14900. | 14.43 |
| 090777 | 5794. | 2400. | 8194. | 6810. | 1110. | 2000. | 14740. | 14.37 | 14600. | 14.32 |
| 090877 | 587. | 2200. | 2787. | 3510. | 1320. | 2380. | 12709. | 13.62 | 12700. | 13.62 |
| 090977 | 0. | 2110. | 2110. | 2110. | 1350. | 2430. | 10754. | 12.84 | 10900. | 12.90 |
| 091077 | 0. | 2250. | 2250. | 2250. | 1270. | 2290. | 9568. | 12.35 | 9540. | 12.34 |
| 091177 | 0. | 3020. | 3020. | 3020. | 1320. | 2380. | 8769. | 12.00 | 8740. | 11.98 |
| 091277 | 0. | 1900. | 1900. | 1900. | 1390. | 2500. | 8161. | 11.72 | 8120. | 11.70 |
| 091377 | 0. | 1805. | 1805. | 0. | 1290. | 2320. | 7543. | 11.43 | 7360. | 11.35 |
| 091477 | 0. | 1715. | 1715. | 0. | 1220. | 2200. | 6994. | 11.17 | 6710. | 11.03 |
| 091577 | 0. | 1629. | 1629. | 0. | 1150. | 2070. | 6510. | 10.93 | 6260. | 10.80 |
| 091677 | 0. | 1548. | 1548. | 0. | 1080. | 1940. | 6074. | 10.70 | 5920. | 10.62 |
| 091777 | 0. | 1470. | 1470. | 0. | 1050. | 1890. | 5691. | 10.50 | 5660. | 10.48 |

*End***

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# APPENDIX

## Conversion Factors
## English to S.I.

| Multiply: | by: | to obtain: |
|---|---|---|
| Acres | 0.40468564 | Hectares |
| Acre feet | 1233.4818 | Cubic meters |
| Cubic feet/second | 0.028316847 | Cubic meters/second |
| Feet | 0.3048 | Meters |
| Feet/second$^2$ | 0.3048 | Meters/second$^2$ |
| Miles | 1.609344 | Kilometers |
| Square miles | 2.5899881 | Square kilometers |