Prepared in cooperation with the
U.S. Department of Agriculture, Forest Service

Simulated Peak Inflows for Glacier Dammed Russell Fiord, near Yakutat, Alaska

Scientific Investigations Report 2004-5234

U.S. Department of the Interior
U.S. Geological Survey

Cover Photograph. Hubbard Glacier damming Russell Fiord, August 24, 1986. Photograph taken by Dennis Trabant, U.S. Geological Survey.

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
yard (yd)	0.9144	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F)) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F - 32)/1.8$$

Sea Level: In this report “sea level” refers to the National Geodetic Verical Datum of 1929—A geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929. Elevations used in this report are referenced to Mean Lower Low Water (MLLW) which is a local datum. This datum is 8.2 feet below the National Geodetic Vertical Datum of 1929.

WATER YEAR

Water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2002, is called the “2002 water year.”

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By Edward G. Neal

Abstract

In June 2002, Hubbard Glacier advanced across the entrance to 35-mile-long Russell Fiord creating a glacier-dammed lake. After closure of the ice and moraine dam, runoff from mountain streams and glacial melt caused the level in "Russell Lake" to rise until it eventually breached the dam on August 14, 2002. Daily mean inflows to the lake during the period of closure were estimated on the basis of lake stage data and the hypsometry of Russell Lake. Inflows were regressed against the daily mean streamflows of nearby Ophir Creek and Situk River to generate an equation for simulating Russell Lake inflow. The regression equation was used to produce 11 years of synthetic daily inflows to Russell Lake for the 1992-2002 water years. A flood-frequency analysis was applied to the peak daily mean inflows for these 11 years of record to generate a 100-year peak daily mean inflow of 235,000 cubic feet per second. Regional-regression equations also were applied to the Russell Lake basin, yielding a 100-year inflow of 157,000 cubic feet per second.

Introduction

Russell Fiord, commonly referred to as Russell Lake during periods of ice dam closure, is near Yakutat in southeast Alaska (fig. 1). Hubbard Glacier, which has been advancing for more than 100 years, has closed the entrance to 35-mile-long Russell Fiord twice during the last 20 years (in 1986 and 2002) by pushing ice and submarine glacial sediments across the fiord mouth (figs. 1 and 2). Both of the dams failed before the lake level rose high enough for water to spill over a low pass at the southern end of the fiord. The floods resulting from the dam failures in 1986 and 2002 had maximum peak discharges of about 4,000,000 ft^3/s and 1,850,000 ft^3/s, respectively, making them the largest recorded glacial-lake outburst flood events in historical time (Trabant and others, 2003).

If future closures of Russell Fiord were to raise the level of the lake to an elevation of about 131 feet above sea level, the water would begin to overflow into the upper reaches of Old Situk Creek (fig. 1), a tributary to the Situk River (Paul, 1988). The Situk River supports a world-class sport and commercial fishery near Yakutat. Paul (1988) estimated that overflow from Russell Lake could increase the average discharge of the Situk River by tenfold. Trabant and others (1991) stated, "Analysis of recent glacier behavior and current conditions indicates that a closure that will eventually result in overflow into the Situk is likely to occur within a decade". While such a closure has not yet occurred, the economic, social and physical impacts of such a change in the flow of the Situk River prompted this evaluation of potential flood flows into Russell Lake.

In both 1986 and 2002, the U.S. Geological Survey (USGS), in cooperation with the U.S. Forest Service (USFS), installed a gaging station (USGS Station number 15130000) to record water levels in Russell Lake subsequent to the damming of the fiord. These stage data are published in Seitz and others (1986) and in Trabant and others (2003). In the follow-up study described here, potential peak inflows to Russell Lake were computed to provide data needed to estimate the potential flood flow characteristics should Hubbard Glacier again advance and dam the fiord for an extended time. This report presents the synthetic peak inflow data, which, when used in conjunction with flood-routing models provided by the Alaska Department of Transportation, will be useful to Federal, State, and local agencies in preparing contingency plans for the potential overflow of glacier-dammed Russell Lake into the Situk River drainage near Yakutat.

Approach

In order to determine peak inflows to Russell Lake, daily mean inflows were derived from lake stage data

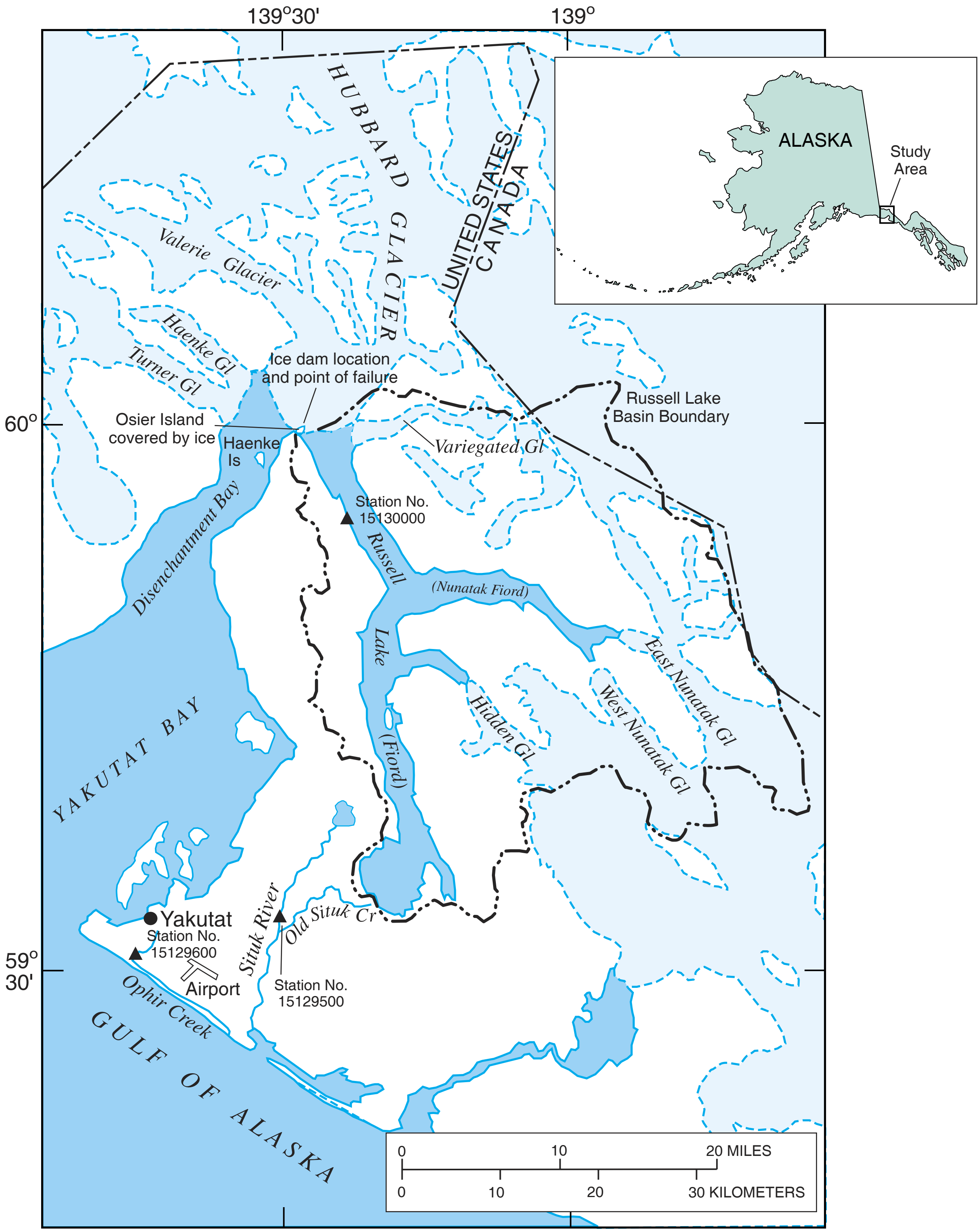

Figure 1. Location of Russell Lake drainage basin, lake-level monitoring site, and streamflow-station sites near Yakutat, Alaska.

Figure 2. Hubbard Glacier and moraine dam closing the entrance to Russell Fiord (photograph by U.S. Forest Service, July 7, 2002).

collected during the period of closure in 2002 (fig. 3). Daily mean inflows were regressed against streamflow data for nearby Ophir Creek and Situk River. The resulting regression equation was used to synthesize daily mean inflows to Russell Lake for the 1992-2002 water years, the period of concurrent record at Ophir Creek and Situk River. A flood-frequency analysis was applied to the peak daily mean inflows for each of the 11 water years to generate peak daily mean inflows of 2-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals. Regional-regression equations also were applied to the Russell Lake basin to generate peak daily mean discharges for comparison.

Determination of Daily Mean Inflows to Russell Lake

Daily mean inflows to Russell Lake during the 1986 and 2002 glacial closures of the lake were developed in several steps. Hypsometry data were derived from topographic maps to determine water storage volumes corresponding with stage, thus facilitating the development of a stage/storage rating. Daily lake storage volumes were differenced between days (midnight to midnight) to provide daily changes in storage, which were then converted to daily mean inflows. The daily mean inflows calculated in this study compared well with those developed by Trabant and others (2003).

Regression Model of Russell Lake Inflow

Daily mean inflows to Russell Lake were regressed against daily mean flows of Ophir Creek near Yakutat (USGS Station number 15129600), Situk River near Yakutat (15129500), Alsek River near Yakutat (15129000) and daily precipitation at Yakutat. Significant correlation coefficients were developed using the data from these sites independently or in step-wise multiple regressions. The coefficient of determination (R^2) was reduced and standard error increased, however, when the flow of Alsek River and precipitation at Yakutat were used as variables in the equation. Therefore, the flows of Ophir Creek and Situk

River were the only two independent variables used in the generation of the regression equation. The regression equation was developed using the Missing Streamflow Estimation program (MISTE) within the USGS Automated Data Processing System (ADAPS) (U.S. Geological Survey, 2003).

Initial regression analyses revealed problems in accurately predicting inflows to Russell Lake immediately following initial closure of the dam in 2002. Examination of aerial photographs taken subsequent to the closure indicated some overflow over the moraine dam was occurring throughout most of the period that the Russell Lake stage was being recorded. Trabant and others (2003) reported relatively small amounts of water spilling over the dam during the 2002 closure. In this investigation, however, the overflow was great enough to exert a strong influence on initial regression models. Inspection of photographs taken by the USGS, the National Park Service, and the USFS revealed that the amount of the overflow was highly variable. Overflow generally decreased from the date of the initial closure in June 2002 until about July 21, 2002, when the dam closed completely and no overflow was visible. A series of photographs is available for inspection at www. fs.fed.us/r10/tongass/forest_facts/photogallery/hubbard_photos.html. The moraine dam was photographed less frequently after July 21, 2002, and photographs taken August 2, 2002 indicate the closure was probably still intact. Sometime between August 2 and August 10, water again began to flow over the moraine dam. Photographs taken on August 10 indicate flow over the moraine dam, which may have continued until the dam failed on August 14, 2002. Because of the dynamic nature of the fiord closure and erosional processes of the moraine dam, it was determined that there was no reliable method available to estimate discharge over the moraine dam.

To reduce regression error associated with flow over the moraine dam the aerial photographs of the closure point were examined to identify a period when flow over the dam was minimal. It was determined that the period July 16 to August 13 was most suitable for use in the

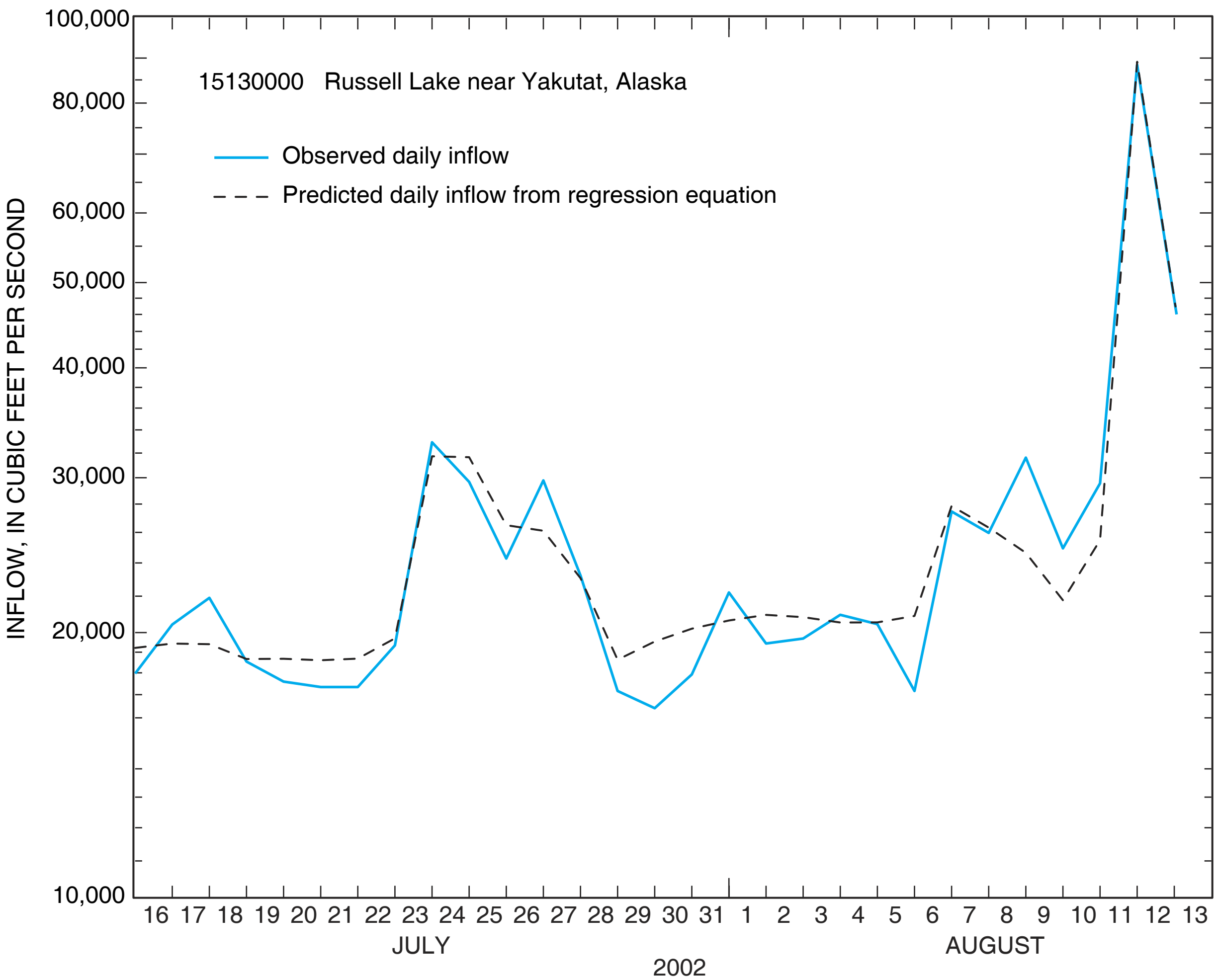

Figure 3. Daily mean inflow into Russell Lake and predicted daily mean inflow from regression equation.

regression analysis. The following regression equation was developed utilizing daily mean streamflow data from Ophir Creek and Situk River. It was found that the coefficient of determination increased and the standard error decreased with Situk River data was lagged by one day.

$$Q_{Russell} = 16003 + 2798\ (Q_{Ophir}) - 23.806\ (Q_{Situk})$$

where

$Q_{Russell}$ = daily mean inflow into Russell Lake, in ft^3/s (cubic feet per second),

Q_{Ophir} = daily mean discharge of Ophir Creek, in ft^3/s

and,

Q_{Situk} = daily mean discharge of Situk River, in ft^3/s.

The coefficient of determination of the equation is 0.97 and the standard error 2,410 ft^3/s. Plots of the regression analysis are shown in figures 3-5. This equation was used to generate synthetic daily mean inflows for Russell Lake for the 1992-2002 water years, the years of concurrent record at Ophir Creek and Situk River.

Further attempts to develop an optimum regression model involved regressing the Russell Lake inflow data for 1986 against several stream gages that were operational in 1986. Again, this inflow hydrograph compared well with that developed by Trabant and others (2003) and Seitz and others (1986). During the 1986 Russell Fiord closure, gaging stations were not being operated on the Situk River or Ophir Creek; therefore, regression equations were developed using flow data from the following stations as predictors:

Power Creek near Cordova (station 15216000)
Klehini River near Klukwan (station 15056560)
Skagway River at Skagway (station 15056100)
Mendenhall River near Auke Bay (station 15052500)

While these stream gaging stations are all located in southeast Alaska, none are within 100 miles of the Russell Lake basin. None of these stations either combined or independently, yielded regressions suitable for further analysis.

Reliability and Limitations of Estimating Equation

Although the computed value of the coefficient of determination of the regression equation is very high (0.97), the asymmetric distribution of the 29 daily inflow values for Russell Lake used in the analysis suggests that the statistical reliability of the equation should be considered to be only fair to poor. The inflows determined for August 12 (88,400 ft^3/s) and August 13 (45,800 ft^3/s) are considerably larger than the other 27 values, which range from about 16,000 to 33,000 ft^3/s. Consequently, both the slope and intercept of the resulting equation are strongly influenced by the two greatest discharges.

The regression equation may not be applicable beyond the range of discharges used to derive the equation. Extrapolation beyond the range of computed inflow for Russell Lake may yield estimates with large errors. Additional limitations to the predictive capabilities of the equation include seasonal variability in hydrologic relations between the predictor sites (Ophir Creek and Situk River), moraine/ice-dam overflow, and uncertainty of stable runoff contributions from Hubbard Glacier including the possibility of glacial outburst floods contributing inflow to Russell Lake.

Flood-Frequency Analysis of Annual Maximum Russell Lake Inflows

Annual maximum daily mean inflow values were selected from the synthetic inflow record for Russell Lake for the 1992-2002 water years and analyzed using the USGS program PEAKFQ. PEAKFQ performs statistical flood-frequency analyses of annual-peak flows following procedures recommended in Bulletin 17B of the U.S. Interagency Advisory Committee on Water Data (1982). Bulletin 17B procedures characterize the magnitude and frequency of instantaneous annual peak flows. Typically these procedures are applied to instantaneous peak streamflows; for the purposes of this analysis, however, the maximum daily mean inflows were assumed to be equivalent to instantaneous peaks for the Russell Lake drainage.

PEAKFQ generates estimates of annual peak flows for recurrence intervals of 1.5, 2, 2.33, 5, 10, 25, 50, 100, 200, and 500 years. Although the recurrence interval represents the long-term average period between floods of a specific magnitude, large floods could occur at shorter intervals or even within the same year. The probability of a flood of a given recurrence interval occurring in a specified time period can be determined using the equation given by Zembrzuski and Dunn (1979, p. 22):

$$P = 1-(1-1/t)^n,$$

where

P = the probability of at least one exceedence within the specified time period,

n = the specified time period,

and

t = the recurrence interval.

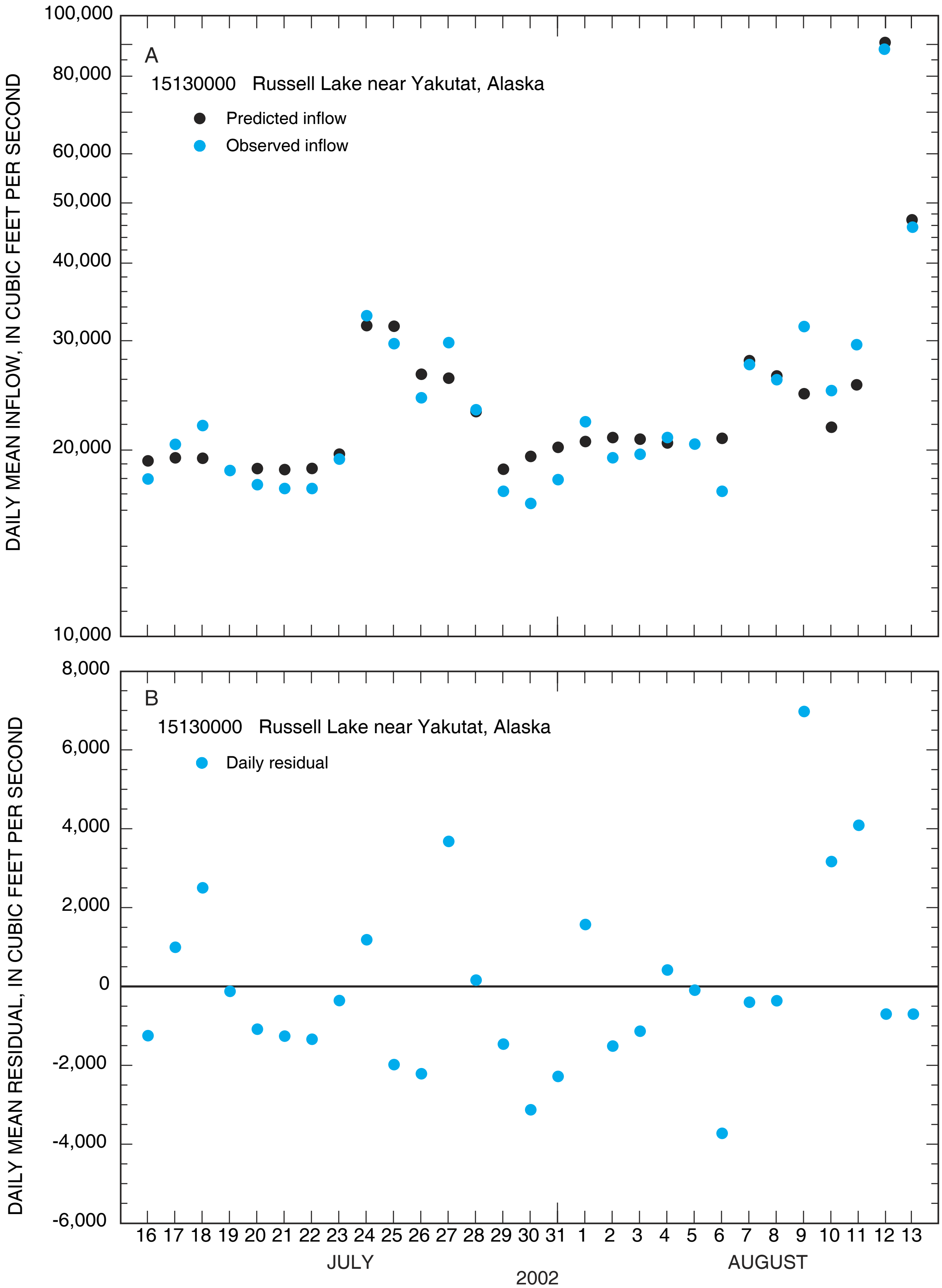

Figure 4. (A) Plot of predicted and observed daily mean inflow into Russell Lake and (B) Graph of residuals for Russell Lake regression equation.

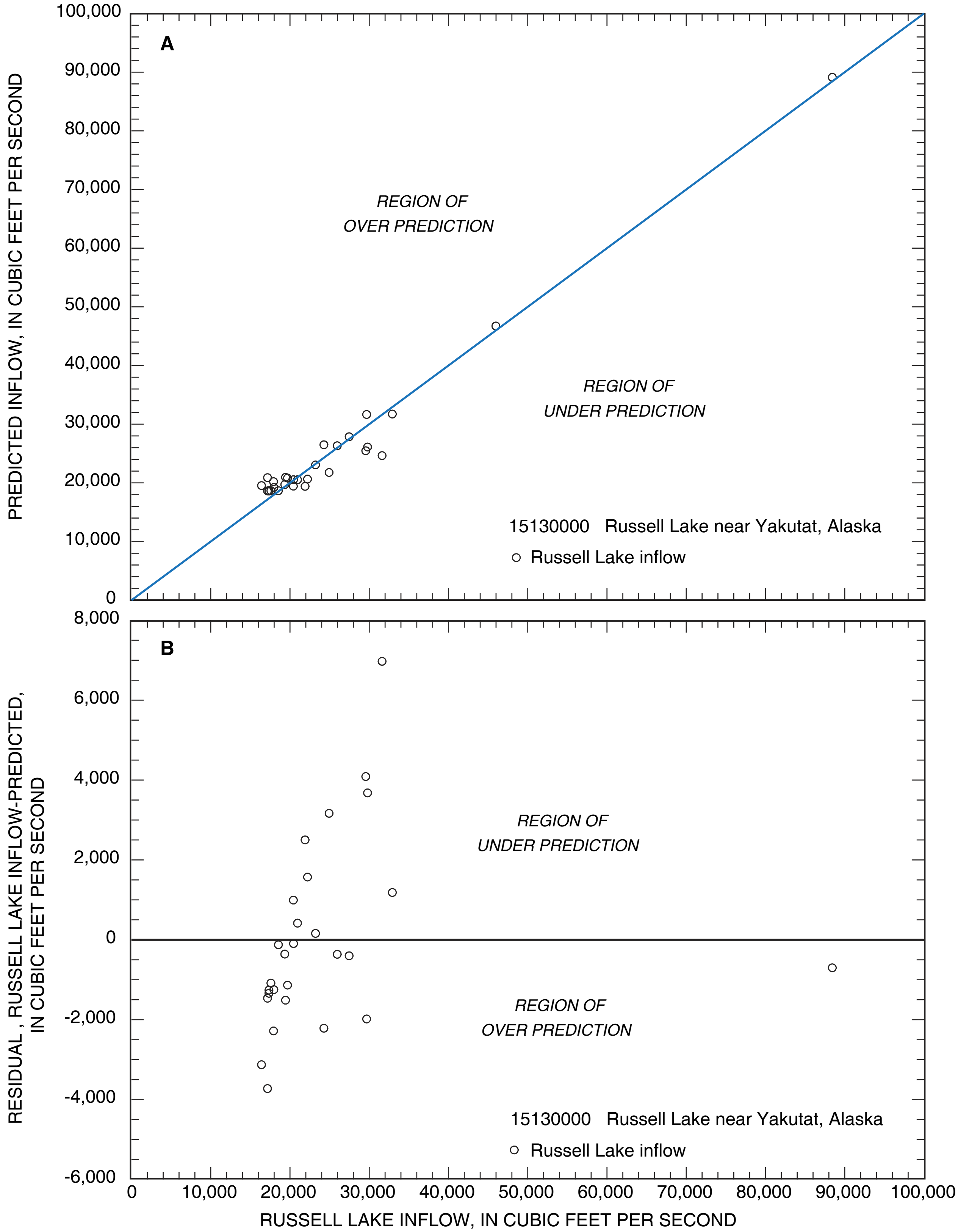

Figure 5. (A) Regression plot of Russell Lake daily mean inflow, using Ophir Creek and Situk River as predictors, and (B) Graph of residuals for the regression equation.

P can be multiplied by 100 to obtain chance of exceedence. For example, the risk of having a flood that equals or exceeds the 100-year flood (1 percent chance of annual occurrence) in any 50-year period is about 40 percent, and for any 90-year period, the risk increases to about 60 percent.

When using an estimating program such as MISTE to generate a statistical flow model, it would be preferable to compare modeled flow to actual flow over the range of seasons. This would allow for a quantitative analysis of the model's sensitivity to changes in flow conditions with changes in season. One would expect seasonal variability in the flow relation between inflow to Russell Lake, and the flow of Ophir Creek and Situk River, due to differences in basin characteristics and climate. Because seasonal inflow data for Russell Lake was unavailable, an alternative approach was used to determine if the synthetic peak inflow data were reasonable

Ophir Creek and Situk River, which originate within the Yakutat Forelands at elevations near sea level, are both strongly influenced by warmer maritime climate conditions. The Russell Lake drainage has a mean elevation of about 680 feet and cooler climatic conditions, as evidenced by glaciers that cover over one-third of the basin. Inspection of the discharge hydrographs for the Alsek River near Yakutat (station 15129000) and the Mendenhall River near Auke Bay (station 15052500)—two glacially influenced streams in approximately the same region—indicate that peak flows seldom, if ever, occur in these systems from about mid-October through about mid-May of each year.

Table 1. Annual synthetic peak inflows occurring between May 15 to October 15 for Russell Lake, water years 1992-2002. [ft^3/s, cubic feet per second]

Water year	Date (mm/dd/yy)	Inflow (ft^3/s)
1992	10/04/91	172,000
1993	10/07/92	119,000
1994	10/09/93	98,800
1995	09/22/95	162,000
1996	09/25/96	142,000
1997	09/23/97	130,000
1998	09/12/98	133,000
1999	09/18/99	172,000
2000	09/28/00	165,000
2001	10/15/00	205,000
2002	08/21/02	127,000

Most of the precipitation in the elevated regions of these drainages falls as snow during this period, thus reducing the probability of the occurrence of large peak flows. Therefore, synthetic Russell Lake peak inflows were used in the flood-frequency analysis only if they occurred from May 15 to October 15. Utilizing these criteria, 11 peak flows were selected from the synthetic Russell Lake inflow data, one for each of the 1992-2002 water years (table 1).

Results of the flood-frequency analyses generated using PEAKFQ are shown in table 2. The 100-year peak inflow into Russell Lake is 235,000 ft^3/s and the 95 percent confidence limits for a flow of this magnitude are shown to be between 201,000 and 320,000 ft^3/s. Although the confidence intervals provided are not directly applicable to the Russell Lake inflows — because the peak inflow data were generated using a regression equation — they do illustrate the range of uncertainty of the flood frequency analysis.

Table 2. Summary of peak inflow of selected recurrance intervals at Russell Lake, Alaska. [ft^3/s, cubic feet per second; --, not determined]

		Bulletin 17B[1] inflow estimates and corresponding 95 percent confidence limits		
Annual exceedence probability	Recurrance interval (years)	Russell Lake inflow (ft^3/s)	Lower (ft^3/s)	Upper (ft^3/s)
0.5	2	145,000	130,600	162,000
0.2	5	173,000	155,000	203,000
0.1	10	189,000	168,000	231,000
0.04	25	208,000	182,000	267,000
0.02	50	222,000	192,000	294,000
0.01	100	235,000	201,000	320,000
0.005	200	248,000	209,000	347,000
0.002	500	264,000	219,000	382,000
0.6667	1.5	133,000	--	--
0.4292	2.33	150,000	--	--

[1]U.S. Interagency Advisory Committee on Water Data (1982)

Regional Equations for Peak Streamflow Estimation

Because of the paucity of data available to develop reliable regression equations for estimating Russell Lake inflows, additional calculations of peak flows were generated on the basis of recently developed regional-regression equations (Curran and others, 2003) for comparison with the estimates made using the Russell Lake inflow regression equation. Curran and others (2003) provided a computer program to compute peak-streamflow frequencies, standard errors of prediction, confidence limits, and equivalent years of record for ungaged sites. A critical distinction must be made between the values generated from synthetic inflow data and those generated using regional-regression equations. The flood-frequency analyses completed from the inflow data do not include a storage component for Russell Lake. Therefore, the computed inflows will undoubtedly be significantly larger than flows measured at the lake outlet, which are likely to be controlled in part by the geometry and hydraulic properties of the lake outlet.

Regional regression equations developed by Curran and others (2003) include the area of lakes and ponds in a drainage basin as a significant variable in the equations. The inflow values in tables 3 and 4 were generated with the equations developed by Curran and others (2003) using the basin characteristics of Russell Lake in conjunction with a precipitation of 220 inches and a mean minimum January temperature of 15^{o}F as given by Jones and Fahl (1994). Table 3 includes the 75.6 mi^2 surface of Russell Lake as the area of lakes and ponds, which represents a storage component in the equation. Table 4 does not include the area of the lake as a storage component in the regional regression equation.

The tables indicate a substantial difference in peak flows due to the inclusion of a storage component for Russell Lake. The 100-year flood is reduced by 93,100 ft^3/s when a storage component for Russell Lake is included in the calculations.

Table 3. Peak inflows to Russell Lake for selected recurrence intervals, developed from regional regression equations[1] and using a storage component for the drainage basin.

[ft^3/s, cubic feet per second; SE, standard error; %, percent]

Recurrance Interval (years)	Inflow (ft^3/s)	SE (+%)	SE (-%)	Confidence Intervals	
				5%	95%
2	31,800	46.3	-31.7	16,900	59,900
5	40,000	45.6	-31.3	21,400	74,600
10	45,700	46.0	-31.5	24,400	85,800
25	53,000	47.6	-32.2	27,800	101,000
50	58,600	49.3	-33.0	30,100	114,000
100	63,900	51.5	-34.0	32,100	127,000
200	69,700	54.0	-35.1	34,000	143,000
500	77,100	57.8	-36.6	36,200	164,000

[1]Curran and others, 2003

Table 4. Peak inflows to Russell Lake for selected recurrence intervals, developed from regional regression equations[1] without inclusion of a storage component for the drainage basin.

[ft^3/s, cubic feet per second; SE, standard error; %, percent]

Recurrance Interval (years)	Inflow (ft^3/s)	SE (+%)	SE (-%)	Confidence Intervals	
				5%	95%
2	76,400	47.2	-32.1	40,200	145,000
5	97,900	46.5	-31.7	52,000	185,000
10	113,000	46.9	-31.9	59,400	213,000
25	131,000	48.5	-32.7	67,800	252,000
50	144,000	50.3	-33.5	73,300	284,000
100	157,000	52.5	-34.4	77,900	317,000
200	171,000	55.1	-35.5	82,300	354,000
500	188,000	59.0	-37.1	86,900	405,000

[1]Curran and others, 2003

Although the magnitude of the 100-year flood generated using the regional-regression equations (without storage component) is substantially lower than the 100-year flood generated using the flood-frequency analysis of the synthetic inflow data (157,000 ft^3/s as opposed to 235,000 ft^3/s), the synthetic inflow 100-year discharge does lie within the confidence intervals computed for the regional-regression equation 100-year discharge. It is also important to note that the drainage area of Russell Lake basin is 744 mi^2, which is considerably larger than the drainage area of any basin used in development of the regional-regression equations.

Summary

In June 2002, Hubbard Glacier advanced across the entrance to the 35-mile-long Russell Fiord, creating a glacier-dammed lake. Water flowing into the lake from mountain streams and glacial melt caused the lake level to rise. Daily inflows to the lake were derived using stage data and Russell Lake hypsometry data. A regression equation simulating Russell Lake inflow was developed using the daily mean inflows to the lake and daily mean streamflows of nearby Ophir Creek and Situk River. The regression equation was then used to generate 11 years of synthetic inflow data for Russell Lake. A flood-frequency analysis was applied to the peak daily mean inflows for each of the 11 water years to generate a 100-year peak daily mean inflow of 235,000 cubic feet per second. Regional-regression equations also were applied to the Russell Lake basin; these equations yielded a 100-year peak inflow of 157,000 cubic feet per second.

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