Colville River Flood Frequency Analysis Update

Revised September 2002
March 2002

Submitted to

ConocoPhillips

By

Baker

Michael Baker Jr., Inc.
4601 Business Park, Blvd., Suite 42
Anchorage, Alaska 99503

Hydroconsult
EN3 Services Ltd.

Hydroconsult
Calgary, Alberta, Canada

EXECUTIVE SUMMARY

The 1998 Colville River flood frequency analysis, completed by Michael Baker Jr., Inc. (MBJ) was updated based on five additional years of flood peak data. The 2002 flood frequency update was completed through a join effort between MBJ and Hydroconsult.

The first flood frequency analysis for the Colville River was completed in 1996 (Shannon & Wilson, Inc.), and then updated in 1998 (MBJ). The Colville River is the largest river on the North Slope with a drainage area over 20,670 square miles, however, there are limited flood peak data available. Thus, a correlation to the Kuparuk and Sagavanirktok (Sag) Rivers was therefore developed to extend the record length of the Colville and improve the accuracy of the flood frequency estimation. Based on the additional data since 1998, the correlation to the Kuparuk River improved while the correlation to the Sag River was poorer. The Sag river correlation was therefore dropped and only the correlation to the Kuparuk was used for the updated analysis. It was determined appropriate to continue with a record extension of the Colville River given the limited flood peak data of the Colville (14 years) and the high magnitude (200-year) design events used for the project.

While minor changes to the flood frequency analysis were noted, no changes to the recommended flood frequency design values are deemed warranted. The recommended values are:

Recommended Flood Frequency Design Values	
Return Period	Flood Peak Discharge (cfs)
2-year	240,000
5-year	370,000
10-year	470,000
25-year	610,000
50-year	730,000
100-year	860,000
200-year	1,000,000

The analysis was initially submitted in March of 2002 and contained three additional years of data from 1998, 1999, and 2000. In July 2002, the analysis was updated to include five additional years of data from 1998, 1999, 2000, 2001, and 2002. Estimates of 2002 data were preliminary and as of this writing final values have not been published.

This report presents the entire updated Colville River flood frequency analysis. Section 1 and Section 2 contain the July 2002 update project note and the March 2002 report, respectively.

Project Note

To: Bruce St .Pierre, Craig Dotson	Date: July 16, 2002
From: Jeff Baker	Project: CD-Satellites
Subject: Colville River Flood Frequency Update	

The 2002 Colville River flood frequency analysis has been updated with two additional years of data, 2001 and 2002:

Colville River
2001 Peak Discharge = 300,000 cfs[1]
2002 Peak Discharge = 320,000 cfs[2]

Kuparuk River
2001 Peak Discharge = 59,000 cfs[3]
2002 Peak Discharge = 60,000 cfs[4]

The results for both the single station analysis and the extended data set (Line of Organic Correlation (LOC) or Maintenance of Variance Extension, Type 1) are presented in the following tables. This is the same method used to extend the Colville data set for the 1996, 1998, and previous 2002 analyses.

Flood Frequency Discharge with Single Station Data Only (cfs)				
Return Period Event	Computed Colville with 12 years data	Expected Probability with 12 years data	Computed Colville with 14 years data	Expected Probability with 14 years data
2	229,000	229,000	***241,000***	***241,000***
5	335,000	350,000	***346,000***	***357,000***
10	426,000	467,000	***430,000***	***460,000***
20	531,000	624,000	***522,000***	***586,000***
50	696,000	939,000	***661,000***	***814,000***
100	846,000	1,310,000	***781,000***	***1,050,000***
200	1,020,000	1,890,000	***917,000***	***1,380,000***

[1] *Alpine Facilities 2001 Spring Breakup and Hydrologic Assessment*, by Michael Baker Jr., Inc, August 2001 for Phillips Alaska, Inc.
[2] Preliminary estimate by Michael Baker Jr., Inc.
[3] A maximum daily flow of 55,000 cfs was provided by the USGS. This was converted to an instantaneous peak flow using a factor of 1.073. This factor was based on an average of 4 historical instantaneous to daily ratios at about the same discharge.
[4] Preliminary estimate based on conversations with the USGS.

The updated single station results are considered better with a shifting up of the curve at the lower return periods (due to above average flows in 2001 and 2002) and a downshifting of the curve at the 200 year return period. For the 200-year design event, the base curve value is now 917,000 vs. 1,020,000 cfs (a drop of 10%) and the expected probability is now 1,380,000 vs. 1,890,000 cfs (a drop of 27%). The adopted skew has reduced significantly from 0.933 to 0.728, although this is still high.

Flood Frequency Discharge with Extended Data Set (cfs)				
Return Period Event	Computed Colville with w/o 2001/02	Expected Probability with w/o 2001/02	Computed Colville with with 2001/02	Expected Probability with with 2001/02
2	241,000	241,000	***246,000***	***246,000***
5	391,000	397,000	***393,000***	***398,000***
10	502,000	517,000	***497,000***	***510,000***
20	655,000	688,000	***601,000***	***625,000***
50	772,000	830,000	***740,000***	***787,000***
100	896,000	987,000	***848,000***	***918,000***
200	1,030,000	1,160,000	***957,000***	***1,060,000***

The results of the LOC extended data set has a marginally poorer correlation than before and the results have minimal change. For the 200-year design event, the base curve value is now 957,000 vs. 1,030,000 cfs (a drop of 7%) and the expected probability is now 1,060,000 vs. 1,160,000 cfs (a drop of 9%).

A two-station comparison based on the procedures outlined in Bulletin 17B was performed and showed very little improvement over the single station analysis. Only the mean would be adjusted using the two-station comparison procedure and there would be no adjustment to the standard deviation. The equivalent years of record for the mean, based on the methods in Appendix 7 of Bulletin 17B, is only increased by one and consequently the expected probability adjustment to the base curve produces an unrealistically high estimate for the extreme flood events.

Overall, this shows the unreliability of using a short period of record with a high skew to predict extreme flood events. Comparing the base curves, it can be seen that the base curve for the single station analysis is actually lower than that computed for the extended record. However, the shorter period of record has a greater uncertainty (due to the smaller sample size) and thus the expected probability correction is much greater.

Based on these results and the comparisons to the extreme regional data[5] the recommended Flood Frequency Design Values remain unchanged and are as follows:

Recommended Flood Frequency Design Values	
Return Period	Flood Peak Discharge (cfs)
2-year	240,000
5-year	370,000
10-year	470,000
25-year	610,000
50-year	730,000
100-year	860,000
200-year	1,000,000

We suggest that the 2002 report be re-issued with the inclusion of the 2001 and 2002 discharge data once final results are available for the 2002 Colville and Kuparuk peak discharges. These data are likely to be available in August.

[5] *Colville River Flood Frequency Analysis Update*, by Michael Baker Jr., Inc. and Hydroconsult, March 2002, prepared for Phillips Alaska, Inc.

March 13, 2002

Phillips Alaska, Inc.
700 G Street
Anchorage, AK 99501

Attn: Mr. Bruce St Pierre

RE: COLVILLE RIVER DELTA, UPDATED FLOOD FREQUENCY ANALYSIS

The 1998 flood frequency analysis of the Colville River has been updated with three more years of flood data, 1998, 1999, and 2000. This work began in the spring of 2001 and was nearly complete; however, the flood frequency report was never finalized. A draft report was prepared and submitted to the U.S. Army Corps of Engineers (USACE) for review in late March of 2001. Comments were received and discussions were held to resolve questions presented by the USACE. The last conference call between the USACE and the authors of this report was conducted on April 27, 2001. This final report is based on the draft prepared in March of 2001 incorporating responses to comments generated during the April 27 conference call.

I trust this will be sufficient for your purposes at this time. Please do not hesitate to call if you have any questions or comments.

Thank you for the opportunity to work on this project.

Sincerely,

MICHAEL BAKER JR., INC.

Jeffrey A. Baker, PE
Senior Engineer

Colville River
Flood Frequency Analysis
Update

March 2002

Submitted to

PHILLIPS Alaska, Inc.
A Subsidiary of PHILLIPS PETROLEUM COMPANY

By

Michael Baker Jr., Inc.
4601 Business Park, Blvd., Suite 42
Anchorage, Alaska 99503

Hydroconsult
Calgary, Alberta, Canada

COLVILLE RIVER
FLOOD FREQUENCY ANALYSIS

MARCH 2002

Prepared for:

PHILLIPS 66

ALASKA

Prepared By:

Hydroconsult

File: 499

TABLE OF CONTENTS

Transmittal Letter

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Previous flood frequency estimates (Michael Baker Jr., Inc. and Shannon & Wilson, Inc., June 1998 and Shannon & Wilson, 1996) for the Colville River were conducted to assist with oil field development planning and design in the Colville River Delta. Since these studies, 3 years of additional annual peak discharge data (1998-2000 inclusive) are now available and a minor adjustment in the 1997 flood peak on the Colville River was made by Michael Baker Jr, Inc.. This report provides an update of the flood-frequency analysis for the Colville River considering the previous work and the additional and revised data now available.

The Colville River is the largest river on the North Slope of Alaska with a drainage area of 20,670 square miles near Nuiqsut. The drainage basin extends over three physiographic regions with approximately 22% in the Brooks Range, 70% in the Foothills and 8% in the Coastal Plain. Other smaller but major North Slope rivers are the Kuparuk (near Deadhorse, Station 15896000) and Sagavanirktok (Sag) Rivers (near Pump Station 3, Station 15908000) with drainage areas of 3130 square miles and 1860 square miles respectively at their gaging stations. These rivers have a longer period of recorded flow data available than the Colville. They are therefore investigated in an effort to extend the Colville data and improve the flood frequency analysis for the Colville. This is discussed in the following sections.

2.0 PREVIOUS ANALYSIS

The previous flood frequency analysis work investigated three approaches:

1. Frequency analysis of 9 years of data on the Colville River itself with one of those years – 1989, as a historic event with an estimated return period of 128 years (as discussed below);

2. Extension of the Colville River data based on a correlation of 7 annual peaks with the Kuparuk River to provide a total of 28 years of data (the 1989 flood data was excluded from the correlation analysis because "the 1989 Colville River data are less precise and of a different nature than the other data"); and

3. Extension of the Colville River data based on a correlation with 7 maximum daily spring peaks (excluding the 1989 data in the correlation, as note above) on the Sagavanirktok (Sag) River to provide a total of 25 years of data.

The correlation analysis used the Line of Organic Correlation (LOC) from Hirsch (1982) as opposed to a least squares regression analysis because it minimizes deviations in both the X and Y directions.

The U.S. Army Corps of Engineer's Flood-Frequency Program HEC-FFA (USACE, 1992) was applied to the above three data sets. A regional or generalized skew of 0.13 and a standard error of the generalized skew of 1.15 based on Jones and Fahl (1994) were applied to provide weighted skews.

The 1989 event on the Colville River was incorporated in the analysis as a historic flood peak. This event was estimated to have a recurrence interval of 128 years (± 32 years) based on sediment deposition and radiocarbon dating techniques (ABR Inc. and Shannon & Wilson Inc., 1996 and ABR, Inc. 1997). A peak discharge of 775,000 cfs was estimated for this event based on the high water marks and hydraulic computations (Shannon & Wilson, 1997). (Our present review of the investigations suggests that the estimated return period was appropriate based upon the evidence presented and is therefore adopted in the analysis presented below.)

The recommended flood frequency relationship used in the previous studies was based on a weighted averaging of the frequency relations from 2 and 3 above. This weighting was based on the proportions of the drainage basins in the Brooks Range and the Foothills physiographic regions – the primary regions considered to generate flood peaks on the Colville. The computed weighting was 65% Kuparuk and 35% Sag.

3.0 ANALYSIS

3.1 Updated Data

The currently available data for the three North Slope rivers are summarized in Figure 1 and Table 1. The data revisions and extensions since the 1998 study are as follows:

- three additional years of data collected by Michael Baker Jr. and/or the U.S. Geological Survey (USGS) including a significant event in 2000 of 580,000 cfs on the Colville River and a preliminary peak estimate of 88,600 cfs on the Kuparuk River (December, 2000 USGS website data).

- the 1997 recorded peak discharges on the Colville and Kuparuk were revised from 173,000 to 177,000 (Michael Baker Jr. files) and from 65,800 to 62,700 cfs (USGS), respectively.

Coincident data are now available for 11 years (1977, 1989, and 1992-2000) on the Colville, Kuparuk and Sag rivers. Additional spring breakup data are available on the West Channel of the Sag River delta from 1971-1983 (G. N. McDonald & Associates, 1983). However, these data were not used because only one year of data are coincident with the Colville (1977) and only one year (1970) could be added to the overall database provided by the USGS stations on the Kuparuk and Sag rivers.

Table 1 Annual Peak Discharge Data (cfs)

Year	Colville River(1)	Kuparuk River	Sagavanirktok River(2)	Extended Colville(3)
1962	215,000			
1971		77,000	13,300	446,716
1972		45,800	17,200	249,126
1973		82,000	7,740	478,381
1974		24,000	8,600	111,067
1975		22,600	6,360	102,201
1976		55,000	9,890	307,390
1977	407,000	66,800	18,900	
1978		118,000	15,500	706,369
1979		24,300	9,290	112,967
1980		40,500		215,562
1981		27,500		133,233
1982		104,000		617,707
1983		68,400	20,000	392,252
1984		56,800	7,720	318,789
1985		34,500	2,500	177,564
1986		38,000	8,400	199,729
1987		15,500	6,000	57,237
1988		38,700	7,800	204,162
1989	775,000	75,400	10,000	
1990		70,000	8,400	402,385
1991		37,100	10,000	194,029
1992	188,000	28,000	10,000	
1993	379,000	52,300	14,000	
1994	159,000	36,500	1,700	
1995	233,000	20,600	10,100	
1996	160,000	58,100	13,800	
1997	177,000	62,700	12,200	
1998	213,000	51,700	14,800	
1999	203,000	22,400	20,800	
2000	580,000	88,600	15,400	

(1) Additional data since the 1998 report added for 1998-2000 and the 1997 value revised from 173,000 to 177,000 cfs.

(2) Sagavanirktok River data near Pump Station 3 are maximum daily spring peak values.

(3) Colville River extended data based on correlation with Kuparuk River data using method by Hirsch and excluding the 1989 event in the correlation.

3.2 Correlation Analysis

3.2.1 Two-Station Correlation Analyses

Two-station correlation analyses were investigated to extend the 12-years of data on the Colville River using the Kuparuk River data. The equation used, as shown in Figure 2, is based on the Line of Organic Correlation as previously applied in the 1998 study. The correlation coefficient (r) is 0.68, based on the 11 years of concurrent flow data (with the 1989 flow excluded).

The Sag River data no longer have as good a correlation with the Colville as the Kuparuk, as shown by the plot in Figure 3. The correlation coefficient for the Sag and Colville data is now less than 0.40 based on the 11 years of data. This poorer correlation is expected because of the significant difference in basin size and the higher proportion of the Sag basin upstream of Pump Station 3 that is located in the Brooks Range as opposed to the Colville basin (78% versus 22%). The Sag River data are no longer recommended for record extension in this analysis because of the improved correlation with the Kuparuk and poorer correlation with the Sag based on the data now available.

3.2.2 Two-Station Comparison

The two-station comparison procedure, as outlined in Bulletin 17B, was investigated as an alternative to the record extension based on the Line of Organic Correlation.

The Correlation Coefficient (r) based on the logarithms of flows, as applied in the two station comparison, is 0.576 with the 11 years of concurrent data including the 1989 event (r = 0.504 excluding the 1989 event). As a result, only the mean would be slightly adjusted using the two-station comparison procedure and there would be no adjustment to the standard deviation. The equivalent years of record (N_e) for the mean, using the equation given in Appendix 7 of Bulletin 17B, is only increased by one to 13 years using the two-station comparison procedure. The Colville currently has 12 years of annual maximum data - the 1962 data point on the Colville does not have a concurrent data point on the Kuparuk.

Based on this minor adjustment to the mean, the two-station comparison procedure does not provide any significant improvement over the single station analysis results. The LOC method results are therefore applied to extend the Colville data. The extended data are shown in Table 1.

3.3 Flood Frequency Analyses

Flood frequency analyses using HEC-FFA (May 1992) were conducted on the 12 years of data on the Colville River alone and on the 31 year extended data sets indicated in Table 1. The regional skew (0.13) and standard error of the generalized skew (1.15) were applied to provide weighted skews. The 1989 event was applied as a historic adjustment with a return period of 128 years. The expected probability adjustment is applied to the computed curve similar to the previous study and as indicated in Bulletin 17B (US Water Resources Council, 1982) "to incorporate the effects of uncertainty in application of the curve". The flood frequency analysis results for the extended data are summarized in Table 2 along with the previous design flood frequency results.

Table 2 Summary of Colville River Flood Frequency Analyses

Recurrence Interval (years)	Peak Flow Estimates (cfs)		
	1998 Design Flood Frequency Results	Computed Curve with Extended 31 Years Data	Expected Probability Curve with Extended 31 Years Data
2	240,000	241,000	241,000
5	370,000	391,000	397,000
10	470,000	502,000	517,000
25	610,000	655,000	688,000
50	730,000	772,000	830,000
100	860,000	896,000	987,000
200	1,000,000	1,030,000	1,160,000

The standard error of the discharge estimates, using the equation in Kite (1988) for the log-Pearson Type III distribution, are summarized in Table 3. It should be noted that this is simply the standard error for the distribution values based on the extended database and it does not account for errors in the record extension itself. The upper 95% confidence limit values, computed as 1.65 times the Standard Error in log units, are also provided in Table 3.

Table 3 Standard Error and Upper 95% Confidence Limits

Recurrence Interval (years)	Standard Error (cfs)	Upper 95% Confidence Limit
2	24,000	281,000
5	42,000	461,000
10	66,000	607,000
20	96,000	774,000
50	157,000	1,034,000
100	219,000	1,264,000
200	384,000	1,549,000

3.4 Comparison to Previous Study Results

The design flood frequency values from the 1998 study and the expected probability curve results for the extended period, as presented above, differ by less than 1% at the 2-year flood to 16% at the 200-year flood. The updated analysis results based on the extended data are slightly higher than the previous (1998) study because of:

- the revised data and addition of the three years of data and particularly the large event in 2000 which tend to increase the predicted flood peaks on the Colville; and

- the exclusion of the Sag River data in the final results due to the poorer correlation versus the improved Kuparuk correlation.

The analysis results in this study are based on an improved correlation with 11 years of coincident data on the Kuparuk and Colville rivers. This improves the confidence in the data extension results and in turn the flood frequency results. Based upon the minor differences in the flood frequency results (up to 16% at the 200 year return period) versus the standard error in the estimates (up to 33% at the 200 year return period) and the comparison with the historical extreme flood data discussed in the following section, no revisions to the original design flood frequency values are recommended at this time. The impact of differences in flood frequency estimates in terms of design standards and flood levels are discussed in Section 4.

3.5 Comparison with Regional Extreme Flood Data

The 200-year design flow of 1,000,000 cfs for the Colville River was compared to the envelope curve presented Jones and Fahl (1994). Additionally three recent major floods, familiar to Hydroconsult's staff, were added to the data as illustrated in Figure 4. The additional data are as follows:

- the 1994 flood on the Koyukuk River of 330,000 cfs at Hughes and 42,700 cfs on the Middle Fork Koyukuk near Wiseman for drainage areas of 18,700 square miles and 1,426 square miles, respectively[1];

- the 1997 glacier dam release flood on the Tazlina of 121,000 cfs for a drainage area of 2,670 square miles[2]; and

---

[1] The 1994 Koyukuk flood was believed to be in the order of about a 1:100 year flood at Hughes (conversations by Wim Veldman with the USGS in 1994 as background for some river work for TAPS). The peak flows are as published by the USGS.

[2] The 1997 Tazlina River flood was caused by the simultaneous release of three glacier-dammed lakes in its watershed (conversations by Wim Veldman with USGS in late 1997) and heavy antecedent rainfall. From preliminary high water marks and rating curve information at the Richardson Highway Bridge, as supplied by ADOTPF to Wim Veldman in 1997, the peak flow was estimated. (The 1997 peak was two times the previous highest flow in a 24-year period of record).

- the estimated 1992 Sag River rainfall-induced peak of 300,000 cfs representing the total flow at the mouth of the West and East (or Main) Channels for a drainage area of 4,550 square miles[3].

The 1992 Sag River flood plots slightly above the envelope curve as does the Colville River 200-year design flow of 1,000,000 cfs. The 1989 flood on the Colville (estimated return period of 128 years from paleoflood indicators) plots below the envelope curve. The major peaks on the Middle Fork Koyukuk (at Wiseman) and the Koyukuk River (at Hughes) plot below the curve as does the 1997 historic peak on the Tazlina River.

In assessing the validity of the computed 200-year flood in the Colville River, the following points are noted:

- the envelope curve was based on the maximum evident flood as determined by USGS. Jones and Fahl indicate that "if large floods have occurred in the recent past (within the last 50 years) flood marks are usually evident" (Childers and Kernodle, 1981). Thus although the recorded period of record may be less than 50 years, the maximum evident flood is believed to be the most severe in the last fifty years.

- Jones and Fahl also indicate that "maximum known floods affected by natural dams such as glacier dammed lake outburst floods…commonly plot above the envelope curves". Glacier dammed lake outburst floods are common on the Tazlina River. Ten outburst floods occurred between 1953 and 1971 (as documented in "Summary Report, River and Floodplain Design Criteria for the Trans Alaska Pipeline System", 1974). The estimated 1997 flood peak was about 2.2 times the previous highest peak. As it still just plots below the envelope curve, it is apparent the curve envelopes a number of extreme events.

- The 1992 flood on the Sag River was an extreme event as evidenced by:

  - the estimated peak flow of 300,000 cfs was more than two times the Pipeline Design Flood (PDF) computed for the TAPS.
  - The PDF was defined in the approved TAPS Design Criteria as follows: "The PDF represents an extremely infrequent flood magnitude, one considerably more than the 50 year flood. The PDF is based on the Standard Project Flood concept and as such

[3] The 1992 Sag River flood was primarily due to extreme rainfall in the Ivishak River watershed, a major tributary draining the Brooks Range. The peak flow was estimated from a stage-discharge curve at the road / pipeline bridges across the West Channel at Prudhoe. (Peak water levels as supplied by ARCO in 1992 to Wim Veldman who, with Giles McDonald, P.E., developed a rating curve at this bridge from about five years of flow measurements in the late seventies – early eighties during breakups). The total flow was determined assuming a 50/50 flow split between the West and East (Main) Channels (from numerous overflights by Wim Veldman).

represents floods that may be expected from the most severe combination of meteorologic and hydrologic conditions that are considered reasonably characteristic of the geographical region involved, excluding extremely rare combinations". In the Sag River basin, 100 percent of the Probable Maximum Precipitation values were used, in combination with the HEC-1 model, to compute the PDF.

Although it may be argued that flow data on the north slope are still limited, at least with respect to determining extreme flood events, the 1992 and 1997 floods on the Sag and Tazlina Rivers clearly demonstrate that extreme and rare events plot just below or just above the Jones and Fahl envelope curve. Therefore, a computed 200-year flow of 1,000,000 cfs for the Colville River, which plots above the envelope curve, is conservative and there can be little or no hydrologic argument for considering any design values significantly above this magnitude.

4.0 CONCLUSIONS

No adjustment of the Colville River design flood frequency values from the 1998 study is deemed warranted at this time.

In a major multi-year project such as Phillips Colville River development, periodic review and updating of the hydrologic analysis is prudent and sound. A change (either a decrease or an increase) in the computed flows for various return periods, from the 1998 value to that outlined herein for example, is not surprising since the additional 3 years of data and the high 2000 breakup flow are both significant determinants in computing the flows, particularly for the higher return period floods.

If the design flows increase in the future, periodic retrofitting of the already constructed facilities is not feasible. If the design flows decrease – 3-5 years of relatively low flows in the future could produce this result – "downgrading" the design of the existing facilities obviously would not be contemplated either. No adjustments in the design values used in the 1998 study are deemed warranted unless substantial new information is obtained that would impact on current design standards.

The recommended flood frequency values for the Colville River at Nuiqsut remain unchanged and are presented in Table 4.

Table 4 Recommended Flood Frequency Values

Return Period	Flood Peak Discharge (cfs)
2-year	240,000
5-year	370,000
10-year	470,000
25-year	610,000
50-year	730,000
100-year	860,000
200-year	1,000,000

The extreme event values indicated above are believed to be conservative, based on their comparison to a USGS-generated envelope curve for extreme floods.

Considering the number of years of data applied in this study, it is recommended that these design flood values be re-visited again in 5 years time. If a significant flood event occurs (e.g. greater than the 580,000 cfs event that occurred in 2000) in the interim, it may warrant an earlier investigation.

5.0 REFERENCES

ABR, Inc. and Shannon & Wilson, Inc. 1996. *Geomorphology and Hydrology of the Colville River Delta, Alaska, 1995.* Prep. for ARCO Alaska Inc., Anchorage, AK

ABR, Inc. and Geophysical Institute of the University of Alaska. 1997. *Geomorphology and Hydrology of the Colville River Delta, Alaska, 1996.* Fifth Annual Report. Prep. for ARCO Alaska Inc., Anchorage, AK

G. N. McDonald & Associates, 1983. *Lisburne Development 1983 Summer Hydrology,* Prep. for ARCO Alaska Inc., Anchorage, AK

Hirsch R. M., 1982. *A Comparison of Four Streamflow Record Extension Techniques.* Water Resources Research. 18(4): 1081-1088.

Jones, S. H. and C. B. Fahl. 1994. *Magnitude and Frequency of Floods in Alaska and Conterminous Basins of Canada.* U.S. Geological Survey, Anchorage, AK

Kite, G. W. 1988 *Frequency and Risk Analysis in Hydrology.* Water Resources Publications. Colorado, U.S.A.

Michael Baker Jr., Inc. and Shannon & Wilson, Inc. 1998. *Colville River Flood-Frequency Analysis North Slope, Alaska,* Prep. for ARCO Alaska Inc., Anchorage, AK

Shannon & Wilson, Inc. 1996. *Flood-Frequency Analysis for the Colville River North Slope, Alaska.* Prep. for Michael Baker Engineering, Anchorage, AK

Shannon & Wilson, Inc. 1997. Letter to Keith Meyer, Michael Baker Jr., Inc. concerning *Return Period Associated with 1989 Flood Event.* Dated June 3^{rd}.

U.S. Army Corps of Engineers. 1982. *HEC-FFA Flood Frequency Analysis Computer Program.* Hydrologic engineering Centre. Davis, CA

U.S. Water Resources Council. 1981. *Guidelines for Determining Flood Flow Frequency,* Hydrology Committee Bulletin 17B, Washington D.C.

FIGURES

Figure 1 Historical Spring Peak Streamflow Data

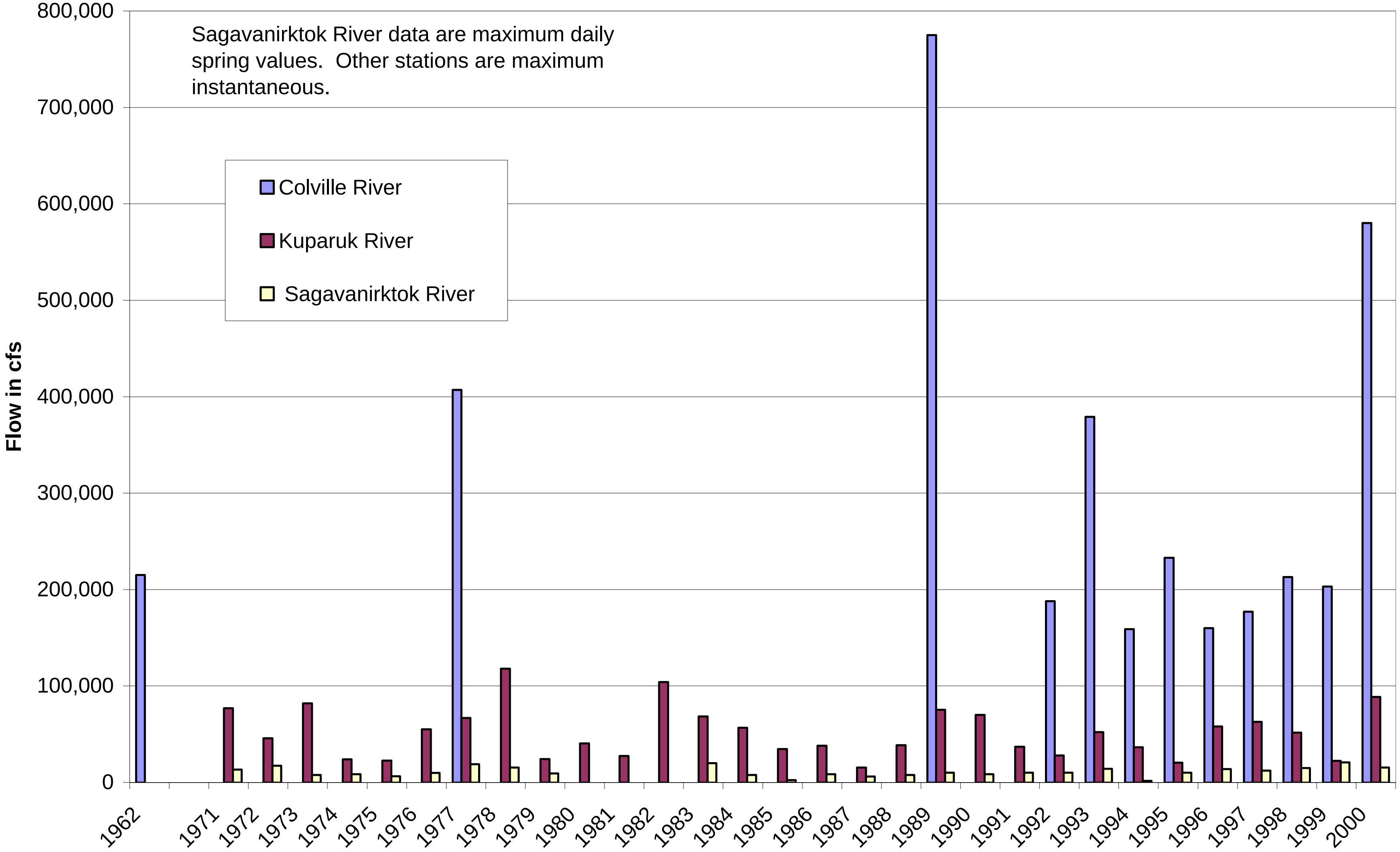

Figure 2 Kuparuk River Peaks versus Colville River Peaks

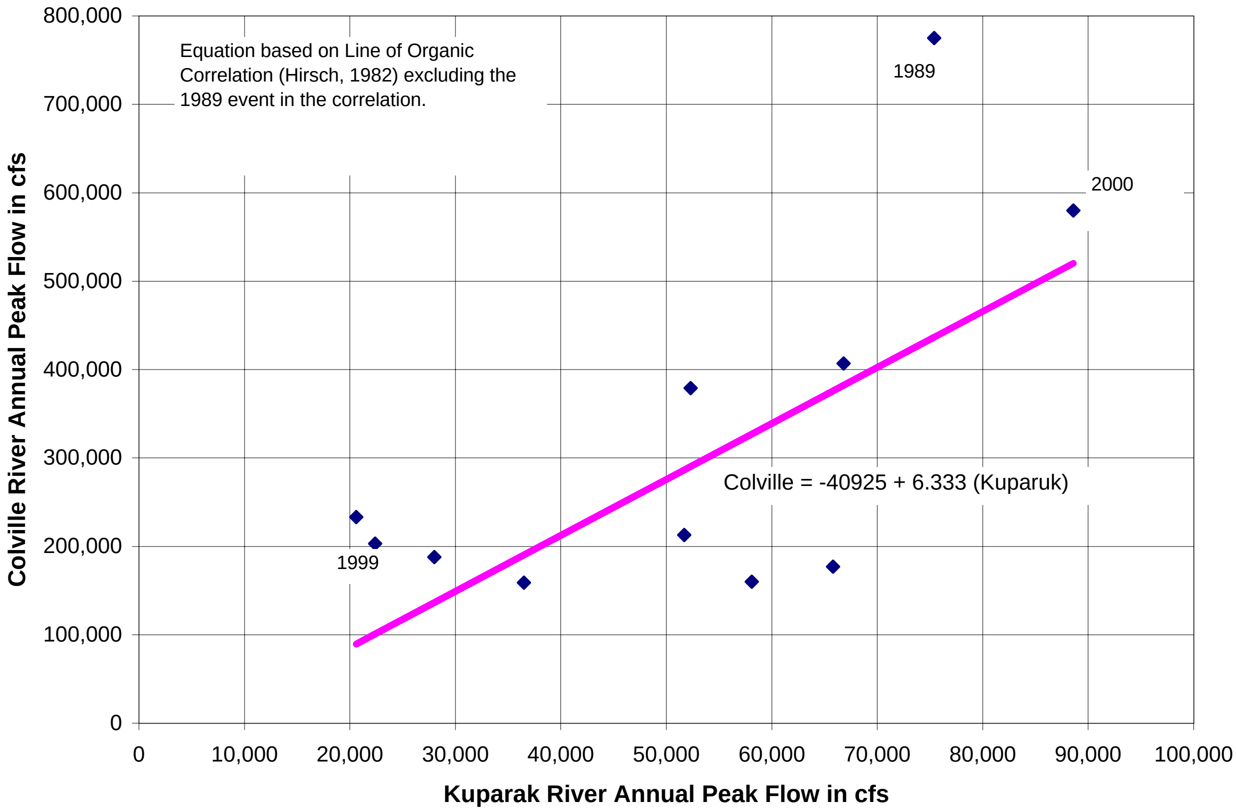

Figure 3 Sagavanirktok River Spring Peaks versus Colville River Peaks

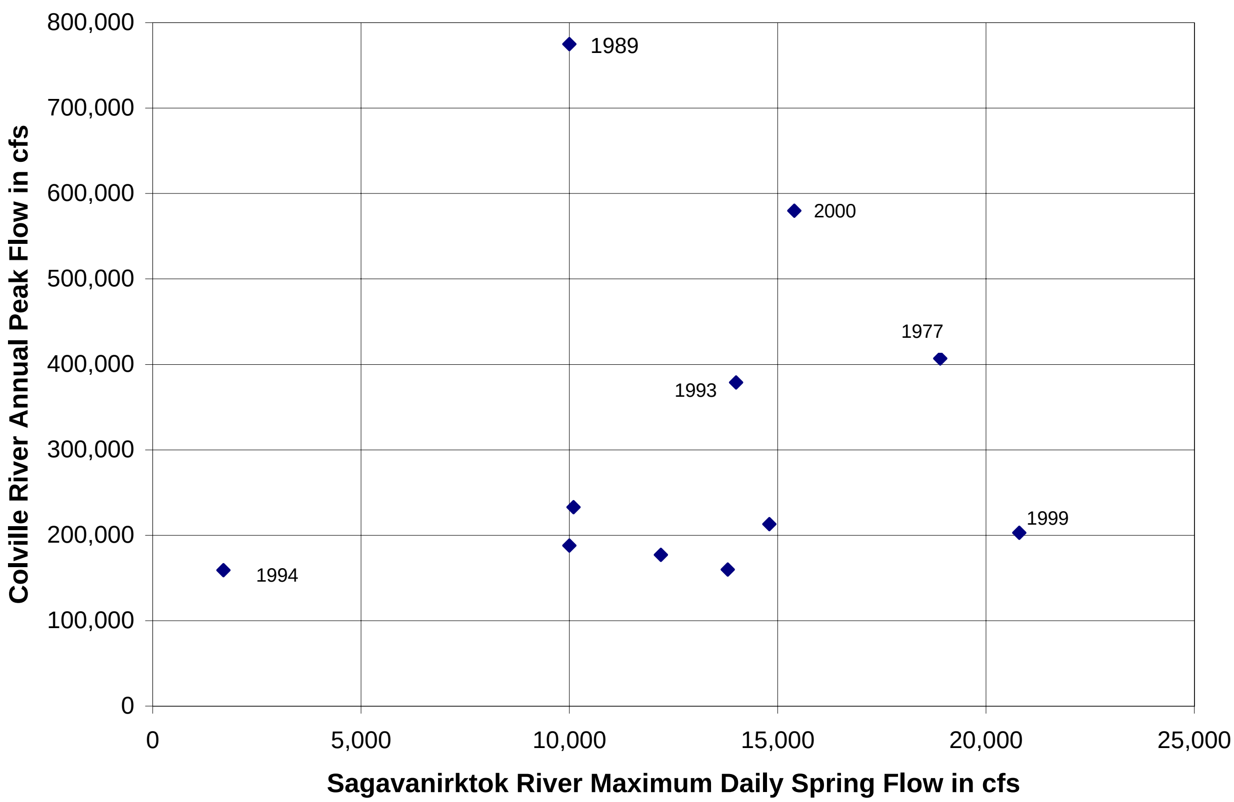

Figure 4. Peak discharge as a function of drainage area and envelope curve for rainfall and snowmelt runoff floods in flood-frequency area 3, Alaska and Canada (from Jones and Fahl, 1994).