Appendix B

Memo (7 February 2001) – Review of Precipitation & Orographic Influence

Hydrology Section from the Environmental Baseline Document

Rainwater Chemistry Analysis

Memo (3 January 2002) – Mean Annual Precipitation & Runoff Assessment

Memo (28 January 2002) – Review of Snowpack Data, Pogo Mine Site & Regional Data

amec

Memo

To **Mike Davies**
From **Gary Beckstead**
Tel **(403) 235-8118**
Fax **(403) 248-1590**
Date **7 February 2001**

File No **VM00172/V-3**
cc **Bryan Nethery**
Peter Lighthall

Subject **Review of Pogo Precipitation and Orographic Influence**

SUMMARY AND CONCLUSIONS

Available meteorological information has been reviewed to examine the precipitation for the Pogo Mine Project. The following points summarize the conclusions reached from this review:

1. Published data indicate that elevation may affect the magnitude of precipitation at some locations in the interior region of Alaska and the Yukon Territory in Canada. However, the available information does not clearly indicate that this trend applies throughout the entire region. In particular, published data from the project vicinity and data collected at the site indicates an orographic effect at the site is possibly not present.

2. To provide a measure of conservatism to the hydrological analyses undertaken on this project, previous work had used methods such as the Clearwater (1996) relationship to adjust baseline data measured at long-term meteorological sites. This adjustment had been used to provide conservatism to such calculations as the net allowable precipitation.

3. The present best estimate of annual average precipitation at the Pogo Mine site is approximately 12.3 inches. This value is based on the values of 9.0 inches (rainfall) and 3.3 inches snowfall (based on 2.8 inches snow pack and 0.5 inches sublimation).

4. The following discussion presents the methodology used to assess potential elevation effects and determine an appropriate value to use for the Pogo Mine Project.

AMEC Earth & Environmental Limited
221 – 18 Street SE
Calgary, Alberta
CANADA T2E 6J5
Tel: +1 (403) 248-4331

1.0 INTRODUCTION

1.1 Definitions

The term “orographic effect” refers to the precipitation that results from an air mass rising over a topographic barrier. Our observations from this past summer indicate that the Pogo Mine site is located inland from the edge of any appreciable “barrier” (i.e., inland from the perimeter of the higher elevation land mass that is situated to the north and east of the Tanana River valley). Thus while an orographic effect may exist to the south and west of Pogo, it is suggested from our observations that the Pogo site may be far inland from the zone affected by the rising air mass However, as the project documentation has consistently defined orographic effect as the change with elevation, the use of this term will be maintained.

Information Gathered

In reviewing and updating the previous information compiled on elevation effects, the following additional information was gathered and reviewed:

- Annual and monthly precipitation summaries for the long-term NRCS & NWS meteorological stations
- Daily rainfall data on site to 2000
- Snow course data for NRCS sites to 2000

In addition, Kraig Gilkey, Science Operations Officer with the NWS in Fairbanks, and Larry Rundquist, Head of the River Forecast Center in Fairbanks were contacted to discuss the preliminary results of our analyses.

2.0 METHODOLOGY AND RESULTS

The following paragraphs discuss the techniques used to assess the data and the results of the analyses that were undertaken.

The precipitation database was separated into two components:

1. summer rainfall and
2. winter snowfall and snow pack.

Summer (May to September) precipitation was assumed to be rainfall. Winter (October to April) precipitation was assumed to be snowfall. It was considered important, in light of other analyses that are required for the project, to separate the precipitation into these components. We noted that Santeford, (1976) had indicated that trends for snow pack and rainfall with elevation in the Chena River basin were found to be similar.

2.1 Rainfall

The rainfall component was assessed by plotting the average summer rainfall for long-term meteorological stations versus elevation. Note that the recorded precipitation during these months was assumed to be rainfall, as no separate tabulation of rainfall (as opposed to total precipitation) was readily available for sites in Alaska. Several figures were prepared in this fashion, as discussed below.

Figure 1 illustrates the plot of an elevation effect derived by Clearwater (1996) for sites in interior Yukon Territory, Canada. The locations of the stations used in that assessment are indicated on Figure 5. The trend line describing the elevation effect derived by Clearwater and the associated raw data are illustrated on this figure. We noted from a detailed review of their analysis that Clearwater used the terms "average annual" and "50% probability" interchangeably, which affects the position of their trend line relative to the data. The Clearwater relationship was used previously, as it represented a trend representative of interior conditions. The data points shown on Figure 1 represent the mean annual May to September total precipitation.

Figure 2 was based on NRCS and NWS data for selected sites within the interior area of Alaska. The values plotted for these stations are the mean annual summer precipitation for the period 1950 to 1999 at each station. The data for these sties illustrate a distinctive trend of increasing precipitation with increasing elevation.

The "central interior Alaska" plot that was presented previously is now known to have been based on data that was incorrectly represented. This plot was previously illustrated on Figure 3.1-7 in the EBD (regional Average Precipitation (1961-1990) Precipitation with elevation) that was based on the published climatic normals for the long-term NRCS sites. In the EBD, AMEC accepted that the "normals" all had consistent records from 1961 to 1990, as indicated in the tabulation received from the NRCS. Subsequent detailed examination of the raw datasets indicated that some stations that were reported in the normals list had varying periods of record. Therefore, some of the differences between sites are due to year-to-year precipitation variability rather than elevation of location effects. Therefore, these data were reviewed and based on relationships with long-term sites, such as Fairbanks that have at least 30 years of records, estimates were made of long-term precipitation values for stations that had a shorter period of record. These data were plotted on Figure 2.

The average annual data for the eastern or central portion of the interior, i.e., Big Delta, Tok, Northway, Eagle) is illustrated on Figure 3. The summer precipitation data for the Pogo meteorological stations were also plotted on the same figure. The summer rainfall data indicate no discernable trend with elevation, and do not follow the trends indicated by either the Clearwater or NRCS data for the western interior area, as illustrated on Figure 4. This suggests that the true orographic effect that is prominent for the area to the west does not appear to be characteristic of the eastern area, including the Pogo site. This is similar to the conclusion reached for the summer precipitation in each of the three years that had been previously plotted in the April 2000 EBD (Figures 3.1-4, -5 and –6). Note that the points described by the triangular symbols represent the common period (1997 to 2000) of monitoring that exists for the Pogo stations (shown as diamonds). Note also that the Big Delta values plot at the upper end of the range for the interior stations; the square symbol for the period of record plots marginally to the right (greater precipitation) than the recent (1997 to 2000) value.

The lack of a trend for the central and eastern interior is also illustrated by Figure 5, which illustrates the locations of the meteorological sites and their respective mean annual rainfall depths. Note the monitoring sites to the west have significantly higher values of summer rainfall than the sites located in the central and eastern interior.

Based on discussions with Kraig Gilkey, there are three primary storm tracks during the summer:

1) Frequent summer precipitation is the result of weak systems that produce showers and thundershowers over the uplands.

2) Easterly of "back door" flow results from a low pressure system over the Gulf of Alaska. The air and moisture flow associated with these systems pass over the Gulf and the Alaska "panhandle" and the Yukon Territory. Although these systems must bass over the coastal mountain ranges, the land on the far side in the Yukon is at a high elevation, so significant drying of the air mass as it reaches the lee side of the mountains does not occur. The latter storms tend to be less modified, whereas storms from the south need to rise over the Coastal and Alaska ranges, resulting in a downwind Chinook (drying) effect as the air mass falls to elevations around 500 ft.

3) Rare but heavy summer precipitation results from low pressure systems in the Bearing Sea. These systems produce flow into the interior from the southwest. Although this storm system may not occur every year, it has been known to result in heavy precipitation that has resulted in flooding.

Mr. Gilkey indicated that the Yukon-Tanana Uplands is a preferred site for the development of summer thunderstorms, i.e., summer storm type 1. This development is repeatable every summer. These storms may develop and die over the elevated terrain in the uplands. The thundershower activity commonly occurs during the late morning and afternoon. In general, however, the storms are high-based and tend to be dry (not much rain). It is abnormal to get large amounts of rain; this generally only happens when the thunderstorms are at a lower elevation. These storms tend to be evenly distributed across the uplands; i.e., they are not generally tied to elevation.

Mr. Gilkey indicated that the mechanism of terrain is that it is a focusing feature. The slopes at higher elevations tend to warm up sooner than the same elevations over the valley floor. That is to say, elevation is a "triggering mechanism". If major storms are removed from the summer precipitation record, then thunderstorms tend to produce little rainfall.

Of the annual precipitation that ranges in the order of 10" to 15", most occurs in the late summer and fall as organized frontal or cyclonic storms from the southeast; i.e., summer storm Type 2. These significant storms generate most of the precipitation because 1) the precipitation from thunderstorms is widely distributed and generally of low magnitude (although they may be of high intensity for a short duration) and 2) less frequent frontal and cyclonic storms produce greater precipitation. The large storms will interact with the topography, but the topography does not cause them.

Type 3 weather systems may produce air flow patterns that drive moisture up the Tanana River Valley. The Tanana River valley is v-shaped (in plan); i.e., it is wide to the west and narrows to the east. Air masses moving east see the terrain as converging; the valley floor goes up in elevation as the basin gets narrower to the east. This forces the air mass up (and results in precipitation). The topographic effect of the valley diminishes significantly east of Delta Junction (Big Delta). Thus Delta Junction is the transition between the distinct valley and where the valley becomes a minor component of the landscape. This effect is illustrated by the data in

Figure 3, that indicates increasing precipitation moving east from Fairbanks via Eielson to Big Delta. Thereafter, the precipitation actually decreases moving further eastwards (and to higher elevation) to Tok and Northway, as shown on Figure 3.

The recommended value of mean annual summer precipitation is 9.0 inches, based on the Big Delta long-term record that plots at the upper end of rainfall range in Figure 2. Table 1 illustrates a comparison of the recorded Pogo data and the summer precipitation at Big Delta for a concurrent period.

Table 1
Monthly Rain Data (inches)

	1997					
	May	Jun	Jul	Aug	Sept	Total
Regional Station						
Big Delta	1.11	1.66	2.35	3.09	0.75	8.96
Local Stations						
Pogo 1SEC	1.07	1.86	2.88	2.19	0.44	8.44
Pogo 2LIE	1.08	1.38	2.98	1.74	0.33	7.51
	1998					
Regional Station						
Big Delta	0.36	0.97	5.27	1.86	0.81	9.27
Local Stations						
Pogo Evap						
Pogo 1SEC	1.05	1.54	3.56	2.14	0.66	8.95
Pogo 2LIE	0.22	0.9	3.25	2.24	0.43	7.04
Sonora	1.37	1.31	3.21	1.54	1.13	8.56
	1999					
Regional Station						
Big Delta	0.9	2.12	2.3	2.51	0.90	8.73
Local Stations						
Pogo Evap						
Pogo 1SAD	0.92	1.22	2.56	2.81	0.81	7.51
Pogo 2COL	0.83	1.26	1.95	2.74	1.65	6.78
Sonora		0.97	2.47	2.98	0.57	--
	2000					
Regional Station						
Big Delta	0.33	0.81	1.51	4.67	1.29	8.59
Local Stations						
Pogo Evap						
Pogo 2COL	2.297	1.44	2.17	4.82	1.32	12.04
Pogo 3LIE	1.93	1.15	1.8	2.35	0.01*	7.24
Sonora			3.5	5.01	1.45	--

Pogo 2PSD after August 1998 has alternatively been referred to as "Colocate".
Pogo 1SAD after August 1998 has alternatively been referred to as "Saddle".
Pogo 1TAB started operation in the fall of 1999 but ABR does not consider it to be reporting correctly, therefore it is omitted from the table.
Station 3LIE was not calibrated for 2000; hence data may not be accurate. September 2000 information clearly not accurate. To be resolved.

2.2 Snowfall

The snowfall component was assessed by first reviewing the period of record for the NRCS stations. It was determined that only some of the stations previously used actually had a thirty year record, as suggested by the normals period of 1961 to 1990. In fact, the actual period of record for the stations varied between 11 and 30 years. Hence, the plot previously provided as Figure 3.1-7 in the EBD for total precipitation) was not entirely correct as it implied more complete data in the NRCS station records than was the actual case. It was decided therefore to initially use the thirty year period for the stations that have at least 30 years record during this period.

It was further determined in conversation with Erik Pullman of ABR that the snowfall measured at the NRCS snow courses may be "enhanced" by the artificial clearing of vegetation to create an area to measure the snow pack. It has been well-documented in field research studies (Swanson et al., 1986; Hoover and Leaf, 1967, Troendle, 1982) that clearings in forested areas can capture greater amounts of snowfall than adjacent un-cleared areas. This leads to artificially higher recorded snow pack at some of the long-term snow pack sites.

In reviewing the local site snow pack surveys, the distinction was made between snow courses (local areas with marked repeatable locations for measuring snow depth and water content generally for a specific elevation and ground cover) and snow transects (a series of isolated, non-repeatable measurements, extending over a range of elevations and ground covers). The West Creek and Sonora Creek basins have snow courses, while the Liese Creek basin has three snow transects. Both snow courses and snow transects can be used to estimate the Snow Water Equivalent (SWEQ) available for runoff during freshet based on measured snow depth and density prior to snowmelt. However, neither snow course or snow transect measurements should be taken directly as the basin average snowpack. ABR has used the snowpack data from transects in a computer model to determine basin SWEQ values. No clearing of the forest cover was undertaken at any of the Pogo snow courses or snow transects.

The recent snow course data recorded at long-term NRCS sites were plotted versus elevation, as illustrated on Figure 6. This plot indicates an apparent increase in snow pack with elevation. The snow course data for the Pogo Mine Project were also plotted on Figure 6, but were not used in deriving the regression lines. The plotting position of the Pogo snow course data relative to the NRCS data is due in part to the artificially enhanced snow pack at the NRCS sites. Further examination of the data indicates that the northwestern sites have greater snow pack SWEQ values than those sites to the south and east. This is believed to be due to the prevailing winter storm directions, as discussed below.

Mr. Gilkey indicated that winter storm patterns tend to be more variable and much stronger than summer storm patterns. This is due in part to the location of the Polar front and the jet stream being closer to Alaska. Stronger frontal weather and stronger storms are also due to the greater contrast between warm and cold air that can exist around the State in the winter. Typical storm systems in the interior region can be summarized as follows:

1. Low pressure systems in the Gulf of Alaska produce flow from the Gulf to the Yukon Territory and into Alaska from the east.

2. Low pressure systems in the eastern Aleutians or the south Bering Sea can produce South to Southwest flow. These flows can result in significant snowfall and windy, strong maritime weather; i.e., world class storms.
3. Less frequently, storms can come out of the north, northeast or northwest. These storms produce less seasonal snowfall than the two storm systems mentioned previously; however, significant snowfall can result if the storms persist.

There are few topographic barriers to the winter air flow regimes from the SW, W or NW. This may indicate why there is more of an elevation effect (actually a true orographic effect) identified for the Chena basin to the west (as documented by Santeford, 1976) as it is at the west end of the uplands, and hence the incoming air mass would tend to rise up over the basin resulting in increased snowfall with elevation – a true orographic effect. This effect would diminish by the time the air mass moved further east, i.e., towards the site. This is demonstrated by the snow course data, as illustrated on Figure 7.

The relationships between the recorded snow pack at the NRCS sites (which appeared not to be affected by clearing, based on the station descriptions provided by NRCS) and the SWEQ data for the Sonora Creek snow course were compared. The Chicken Airstrip snow course station was selected, as it exhibited the best correlation with the Sonora course. The other long-term stations that were assessed did not demonstrate as good a fit as the Chicken Airstrip. Figure 8 indicates that there is little effect with elevation, as the snow course data are virtually identical.

The recorded snow pack at Chicken Airstrip was then compared to the estimated basin-average snow pack in the Sonora Basin, as computed by ABR (2000) based on snow course and snow transect data. This relationship, illustrated on Figure 9, was used to estimate the equivalent long-term mean basin-average snow pack at the Pogo site of 2.8 inches based on the long-term (36 years) average snow course depth at Chicken Airstrip of 3.1 inches.

The estimated long-term average snowfall at Pogo is equal to the average snowpack of 2.8 inches plus an allowance for sublimation loss (say something in the order of 0.5 inches. based on the general open forest cover and the "sheltered" nature of the basin that would reduce the potential for significant snow redistribution). Thus the snowfall estimate for Pogo is approximately 3.3 inches.

The recorded snowfall at Big Delta equals 42.5 inches (or 4.25 in SWEQ). The NRCS has advised that the gauge at Big Delta does not "catch" all the falling snow because the wind may blow the snow past the gauge – a common effect for precipitation gauges in the Arctic. Actual snowfall can range from 1.2 to 3 times the recorded snowfall, (Prowse et al., 1990), based on investigations in Alaska and northern Canada. Based on an estimate of the undercatch correction of 50%, the "true snowfall at Big Delta may be estimated at 6.4 inches. There is no record of "snow on ground" at Big Delta to compare with this estimate. This estimate for snowfall at Big Delta is greater than the estimate for Pogo based on the snowpack data. As there is considerable uncertainty in the snowfall data for a site like Big Delta, located on an exposed wide floodplain, it is recommended that the average annual snowfall for Pogo based on the snowpack correlation with Chicken Airstrip be adopted.

2.3 Total Precipitation

The total annual precipitation is the sum of the annual rainfall and annual snowfall. The total estimated precipitation for Pogo is 12.3 inches.

This estimate can be compared to the annual runoff from streams in the area. Based on discussions with Matt Schellekens of the USGS, additional data was analysed for the Salcha River basin to the west of the Goodpaster Basin and for the Chena River near Two Rivers gauge at the west end of the Yukon-Tanana Uplands. These data are summarized in Table 2.

TABLE 2
Annual Runoff Summary

	Annual Runoff (inches)				
Year	**Sonora (A=10.5 mi^2)**	**Central (A=115 mi^2)**	**Goodpaster (A= 677 mi^2)**	**Chena (A=937 mi^2)**	**Salcha (A=2170 mi^2)**
1997	-			5.76	6.65
1998	2.87	3.45	7.04	7.43	6.76
1999	3.69	3.85	5.42		
2000					
Long term Average				10.02	10.11
Short-term Average	4.7	5.0	7.8		

As the Chena and Salcha river basins are located to the west of the Pogo area in the western zone of the interior uplands, the greater runoff depths are considered representative for a zone with greater precipitation.

The short-term discharge records for the streams in the vicinity of the Pogo Mine, have been determined as listed in Table 2. Note the trend to increasing runoff with increasing area. In addition to the above, the measured stream discharge for Liese Creek in 2000 was approximately 50% of the measured snowpack plus rainfall. This number is reasonable for a mountain basin in an area of permafrost. A runoff coefficient of 0.49 was also computed for the Chena River basin, based on the 32 years of record for that station.

Based on the above discussion, the following parameters have been derived for the Liese Creek basin for an average year.

Parameter	Value (inches)
Total Precipitation	12.3
Runoff	5.9
Evapotranspiration	5.5
Sublimation	0.5
Infiltration	0.4

Thus the precipitation estimate of 12.3 inches appears reasonable in relation to the measured runoff.

REFERENCES

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Prowse, T.D., C.S.L. Ommanney, 1990. Northern Hydrology,: Canadian Perspectives, National Hydrology Research Institute Report No. 1, 308 pp.

Troendle, C.A., 1982. The effects of small clear-cuts on water yield from the Deadhorse watershed, Fraser, Colorado. Pages 75 to 83 in Proc. West. Snow Conf. 50th Annual Meet., April 19 to 23, 1982, Reno, Nevada.

We welcome your comments on this draft, and look forward to discussing it with you.

Yours truly,

AMEC Earth & Environmental Limited

for Gary Beckstead, M.Sc., P.Eng.
Senior Water Resources Engineer

Reviewed by:

fr. Wes J. Dick, M.Sc., P.Eng.
Reviewer

GREB/tk

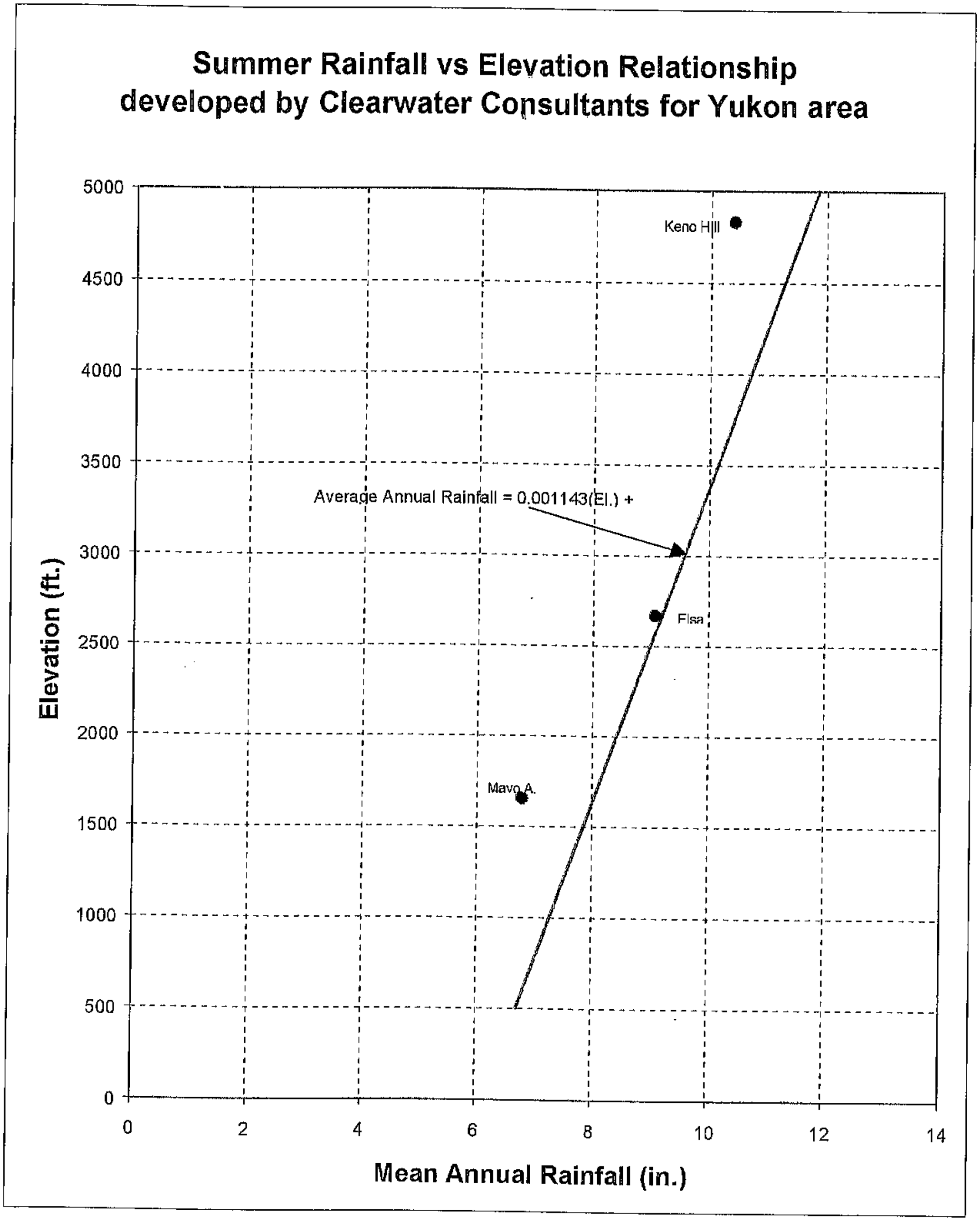

Summer Rainfall vs Elevation Relationship
developed by Clearwater Consultants for Yukon area
Elevation (ft.)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
Mean Annual Rainfall (in.)
Keno Hill
Average Annual Rainfall = 0.001143(El.) +
Elsa
Mayo A.

Figure 1

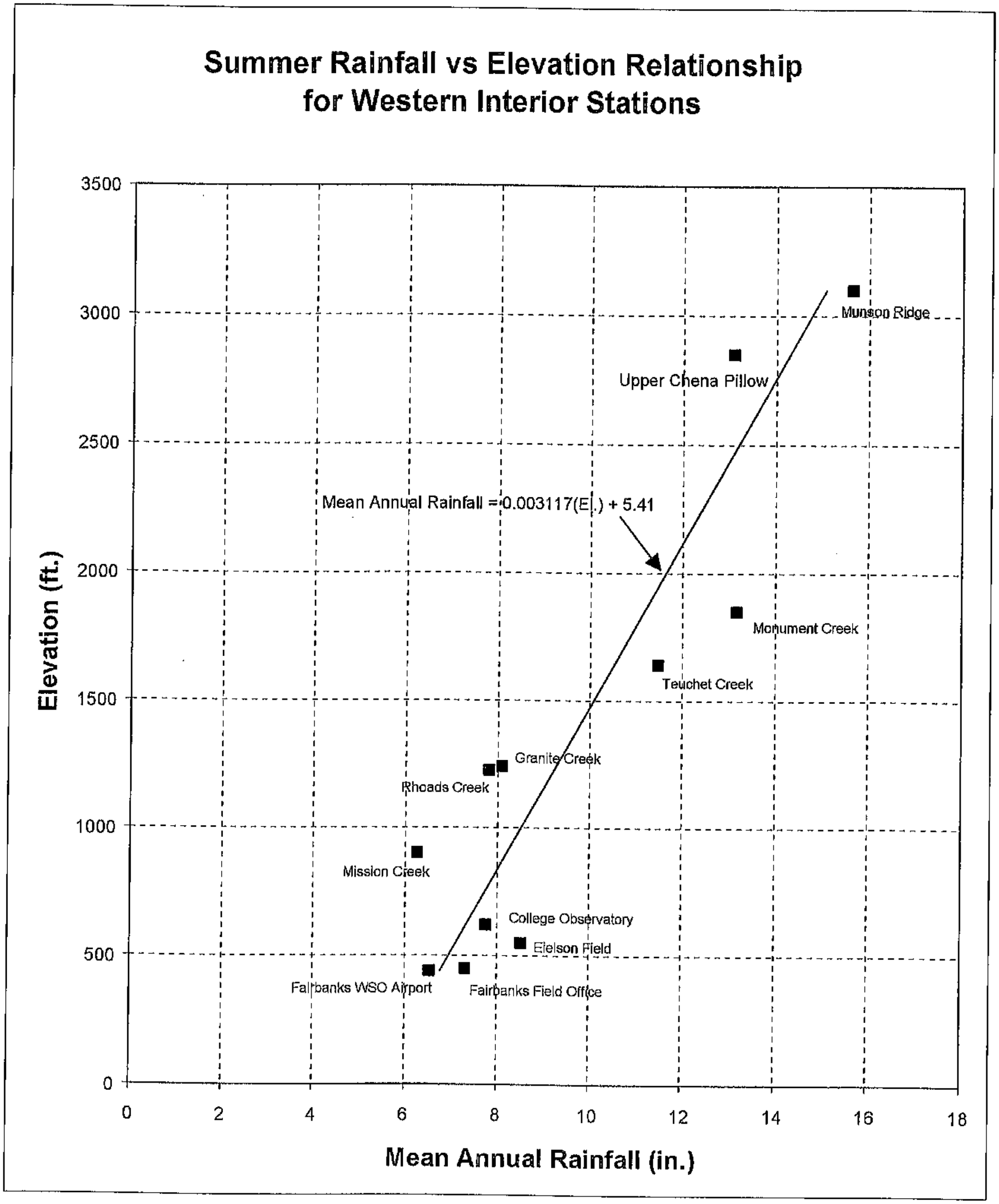

Summer Rainfall vs Elevation Relationship for Western Interior Stations
Elevation (ft.)
3500
3000
2500
2000
1500
1000
500
0
Mean Annual Rainfall (in.)
0
2
4
6
8
10
12
14
16
18
Munson Ridge
Upper Chena Pillow
Mean Annual Rainfall = 0.003117(El.) + 5.41
Monument Creek
Teuchet Creek
Granite Creek
Rhoads Creek
Mission Creek
College Observatory
Eielson Field
Fairbanks WSO Airport
Fairbanks Field Office

Figure 2

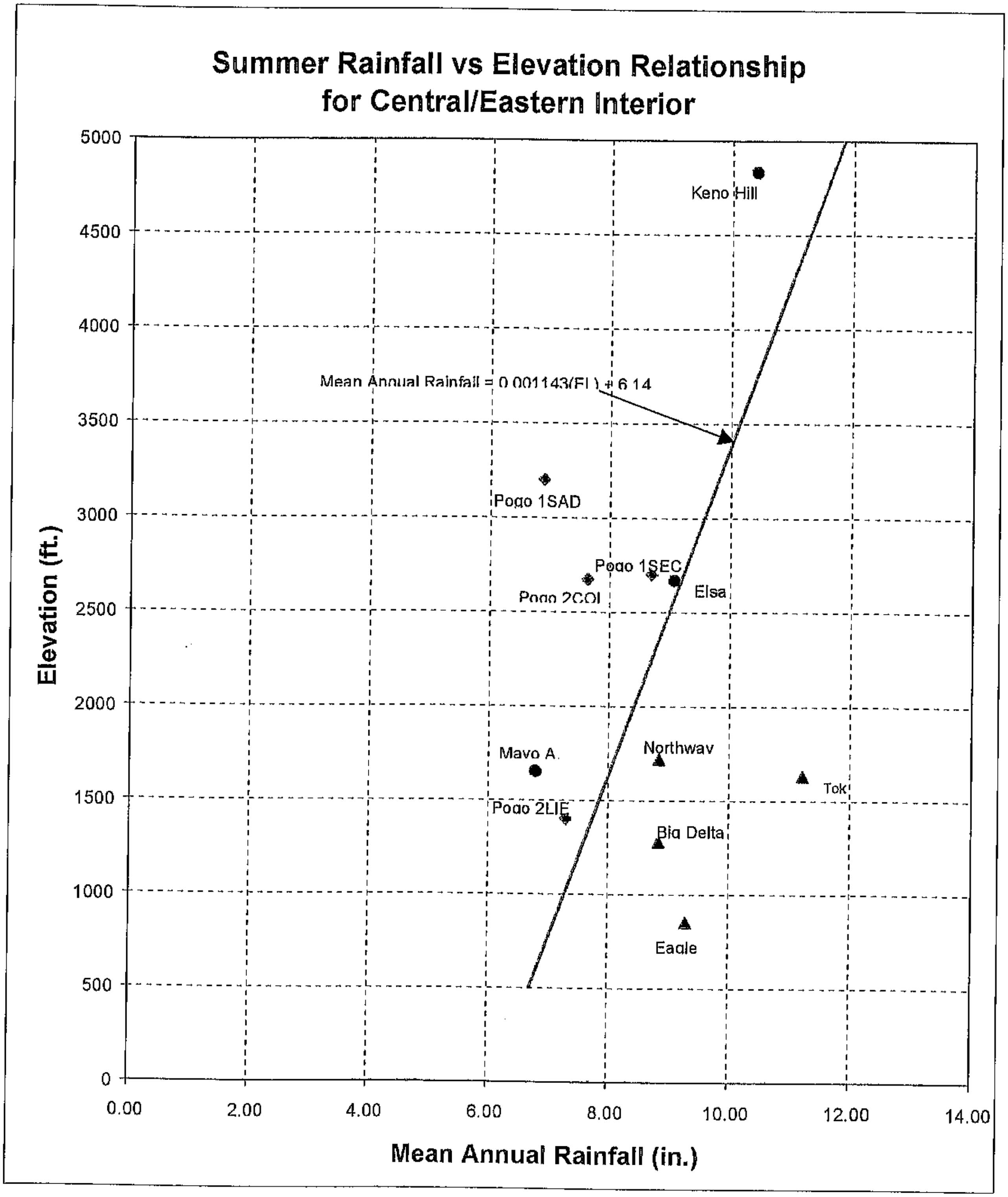

Summer Rainfall vs Elevation Relationship
for Central/Eastern Interior
Elevation (ft.)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
Mean Annual Rainfall (in.)
Keno Hill
Mean Annual Rainfall = 0.001143(EL) + 6.14
Pogo 1SAD
Pogo 1SEC
Pogo 2COL
Elsa
Mayo A.
Northway
Tok
Pogo 2LIE
Big Delta
Eagle

Figure 3

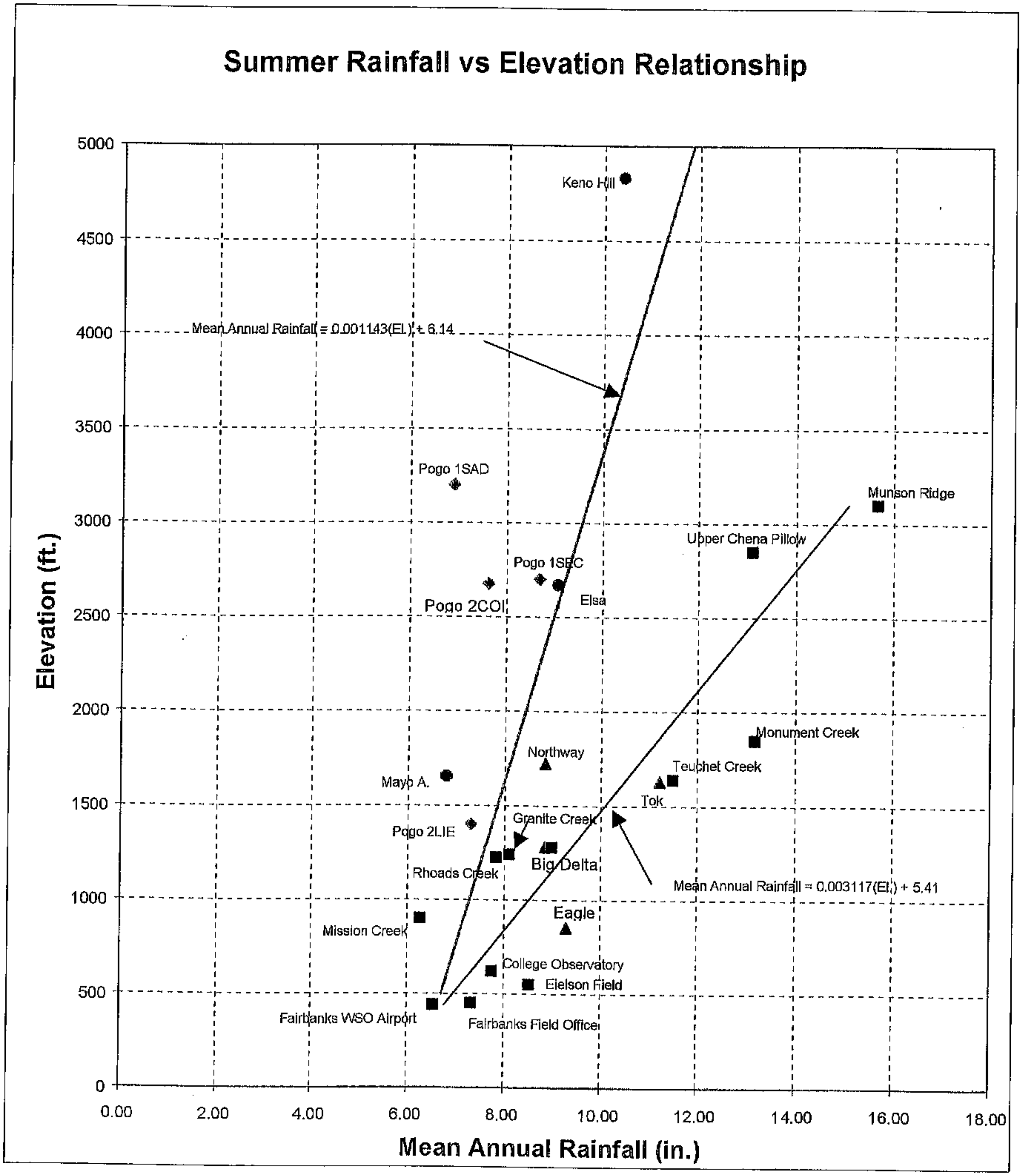
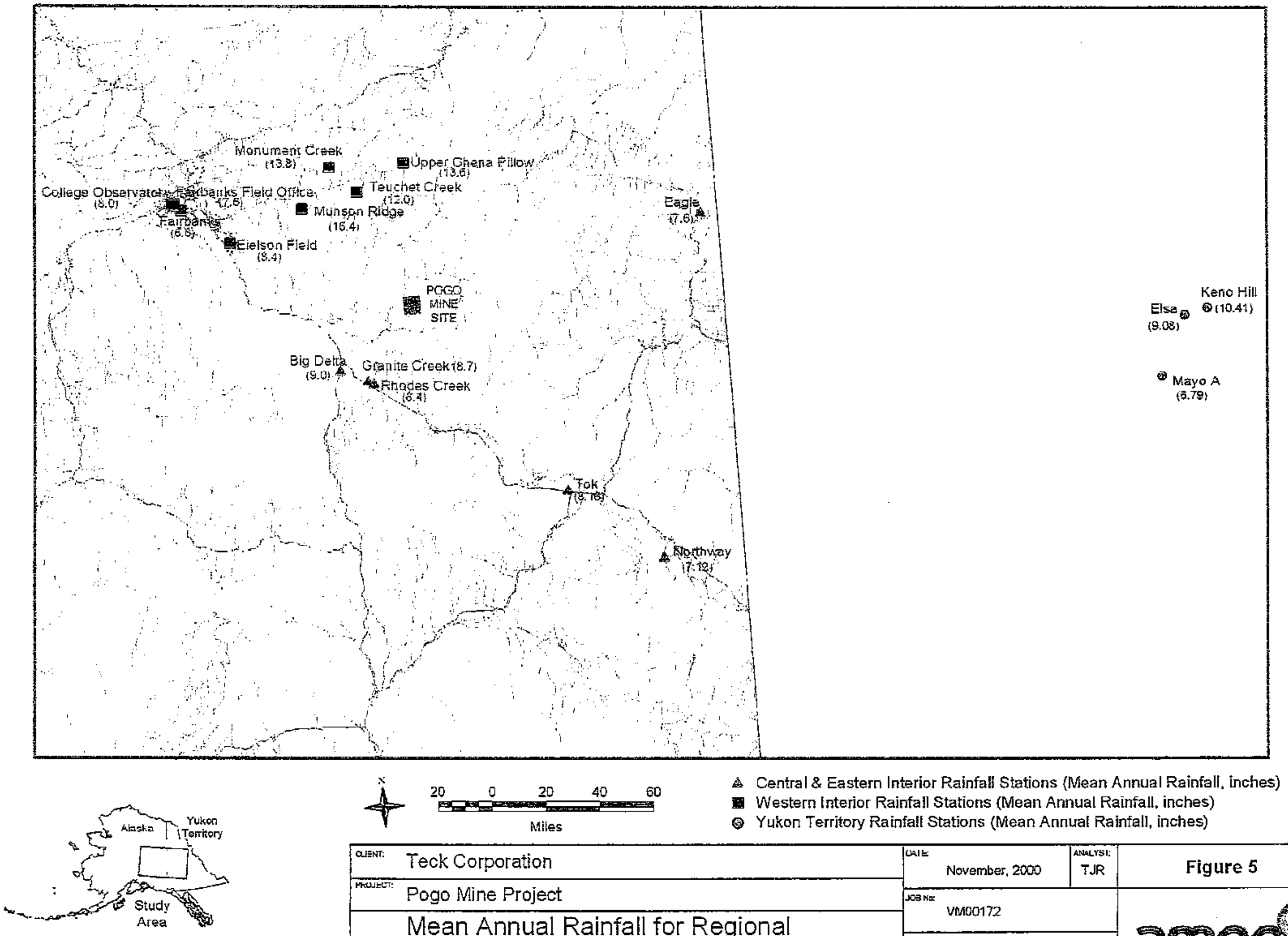

Summer Rainfall vs Elevation Relationship
Elevation (ft.)
Mean Annual Rainfall (in.)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
Keno Hill
Mean Annual Rainfall = 0.001143(EL) + 6.14
Pogo 1SAD
Munson Ridge
Upper Chena Pillow
Pogo 1SEC
Elsa
Pogo 2COI
Monument Creek
Northway
Teuchet Creek
Mayo A.
Tok
Granite Creek
Pogo 2LIE
Big Delta
Rhoads Creek
Mean Annual Rainfall = 0.003117(EL) + 5.41
Eagle
Mission Creek
College Observatory
Eielson Field
Fairbanks WSO Airport
Fairbanks Field Office

Figure 4



▲ Central & Eastern Interior Rainfall Stations (Mean Annual Rainfall, inches)
■ Western Interior Rainfall Stations (Mean Annual Rainfall, inches)
◎ Yukon Territory Rainfall Stations (Mean Annual Rainfall, inches)

CLIENT: Teck Corporation	DATE: November, 2000	ANALYST: TJR	**Figure 5**
PROJECT: Pogo Mine Project	JOB No: VM00172		amec
Mean Annual Rainfall for Regional Meteorological Stations (inc Yukon)	GIS FILE: POGO_STNS.APR		

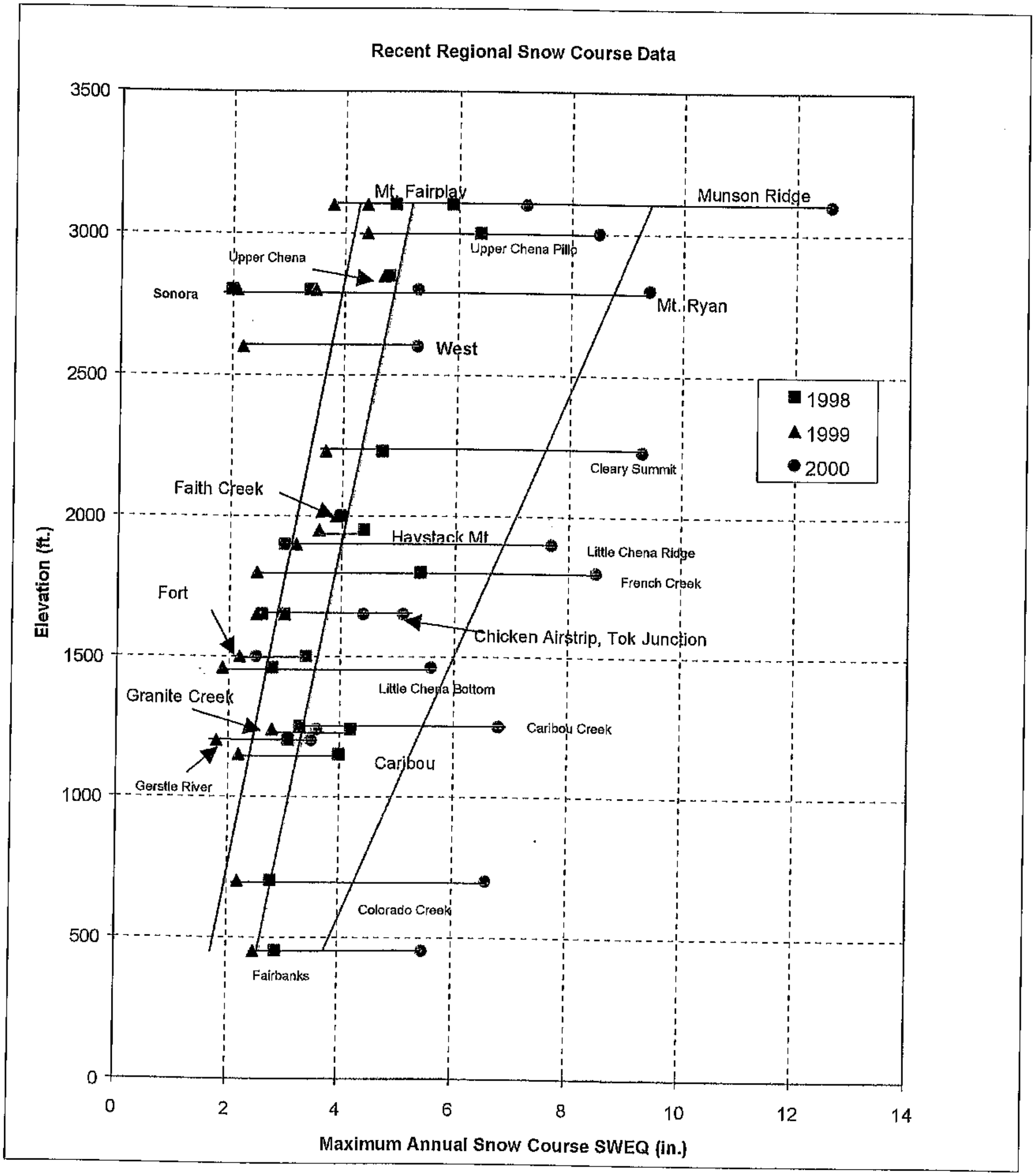
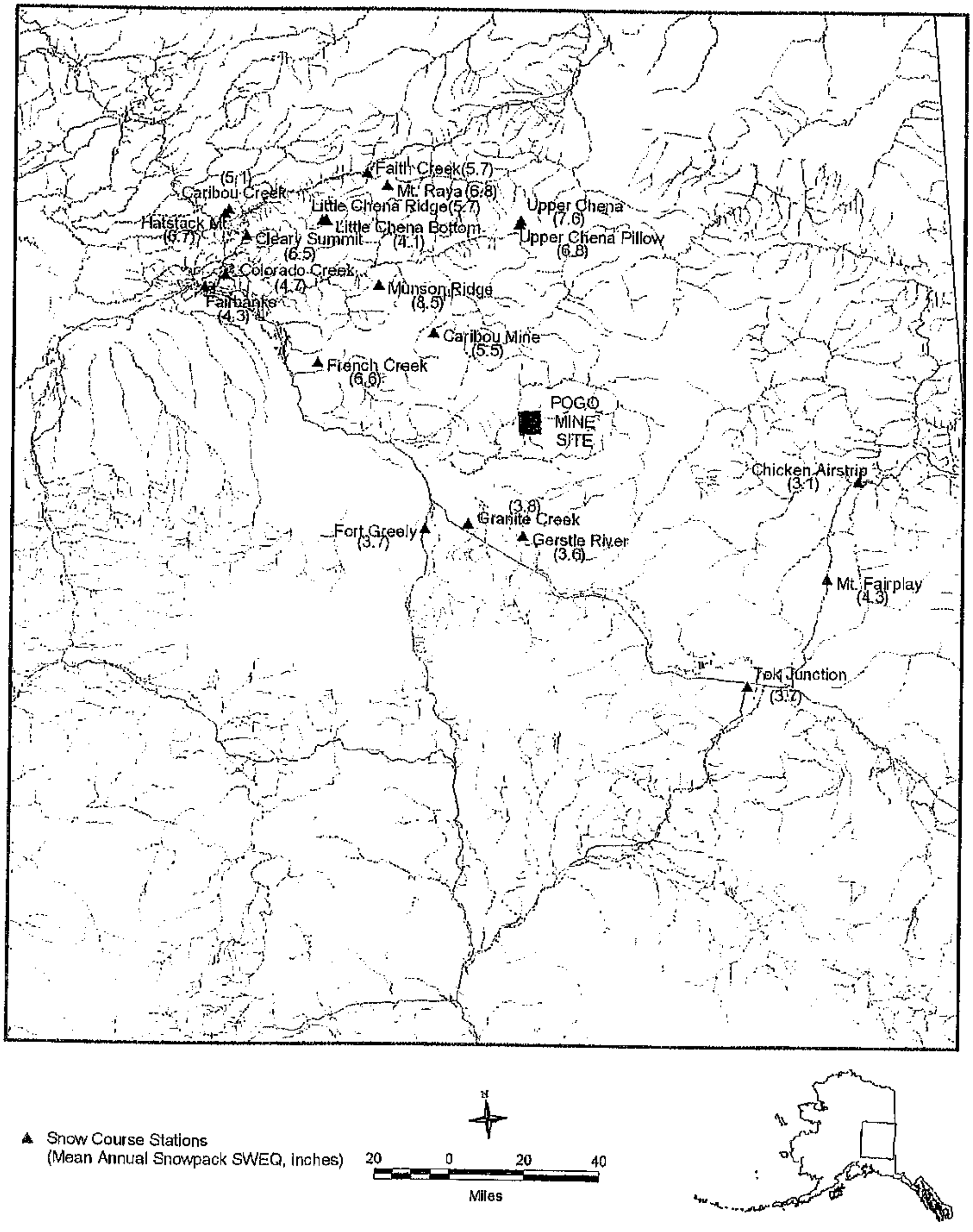

Recent Regional Snow Course Data
Elevation (ft.)
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
Maximum Annual Snow Course SWEQ (in.)
Mt. Fairplay
Munson Ridge
Upper Chena Pillo
Upper Chena
Sonora
Mt. Ryan
West
■ 1998
▲ 1999
● 2000
Cleary Summit
Faith Creek
Haystack Mt
Little Chena Ridge
French Creek
Fort
Chicken Airstrip, Tok Junction
Little Chena Bottom
Granite Creek
Caribou Creek
Caribou
Gerstle River
Colorado Creek
Fairbanks

Figure 6



CLIENT: Teck Corporation

PROJECT: Pogo Mine Project

Mean Annual Snowpack for NRCS Snow Courses

DATE: November, 2000

ANALYST: TJR

Figure 7

JOB No: VM00172

DISFILE: POGO_STNS.APR

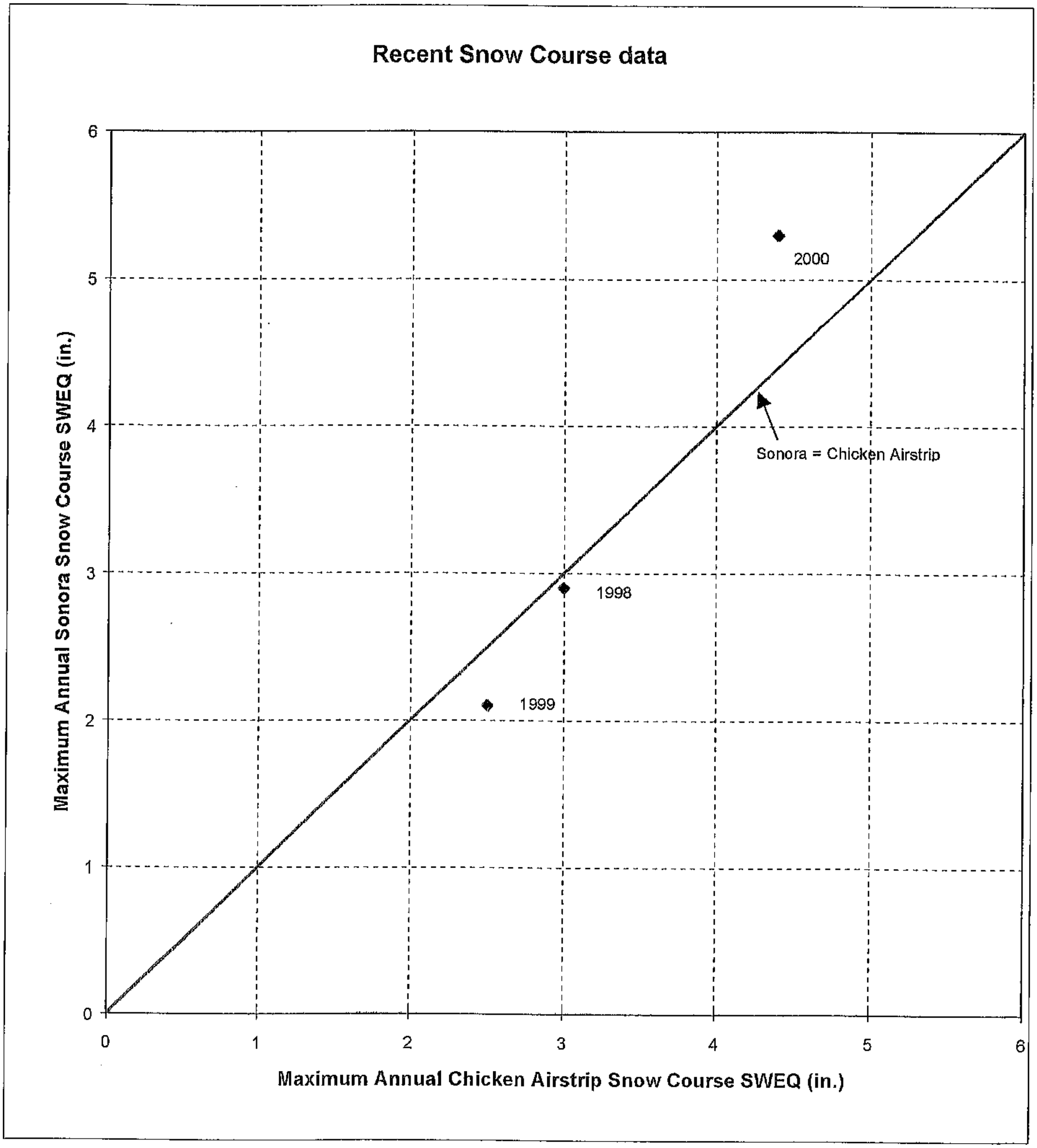

Recent Snow Course data
Maximum Annual Sonora Snow Course SWEQ (in.)
Maximum Annual Chicken Airstrip Snow Course SWEQ (in.)
0
1
2
3
4
5
6
2000
1998
1999
Sonora = Chicken Airstrip

Figure 8

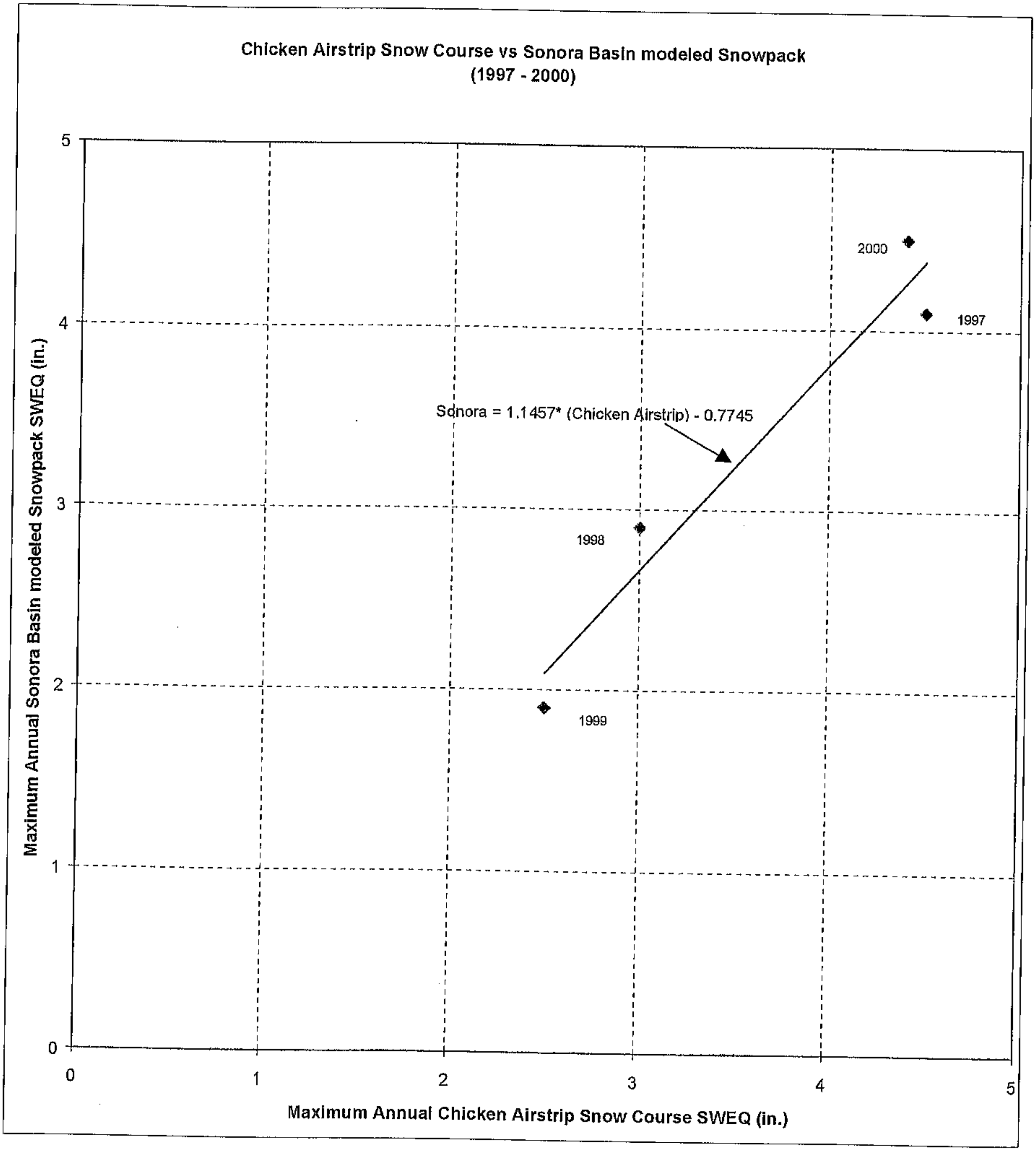

Chicken Airstrip Snow Course vs Sonora Basin modeled Snowpack
(1997 - 2000)
Maximum Annual Sonora Basin modeled Snowpack SWEQ (in.)
Maximum Annual Chicken Airstrip Snow Course SWEQ (in.)
0
1
2
3
4
5
0
1
2
3
4
5
2000
1997
1998
1999
Sonora = 1.1457* (Chicken Airstrip) - 0.7745

Figure 9

VOLUME 3 - HYDROLOGY

3.1 SURFACE WATER HYDROLOGY

Gary R. E. Beckstead, Water Resources & Civil Projects Division
AGRA Earth & Environmental, 221 - 8 Street S.E., Calgary, Alberta T2E 6J5

3.1.1 INTRODUCTION

3.1.1.1 Work History

Meteorological monitoring has been carried out on site since 1997. The monitoring has included measurements of rainfall, temperature and wind. An evaporation pan was installed in 1998. Details of the program, coordinated by ABR Inc. (ABR) and Hoeffler Consulting Group (Hoeffler), are presented in Section 3.3.

Snow surveys have been carried out each spring over the last three years. The Liese Creek and Sonora Creek basins have been monitored since 1997 by ABR. The West Creek basin was added to the snow survey in 1999. Further details are provided in Section 3.2.

Hydrometric monitoring (stream gauging) has also been carried out at site since 1997. Hay & Co. established hydrometric stations on the Goodpaster River, Central Creek and Sonora Creek, (Hay 1997, 1998a, 1998b and 1998c). Operation of these hydrometric stations was assumed by the United States Geological Survey (USGS) in July 1998. Later in the summer of 1999 two additional stations were added on Liese Creek and West Creek. Monitoring has largely been confined to the summer months, i.e., the open water period.

The initial water balance for the Pogo Project was prepared by EBA in early 1999, (EBA, 1999). The water balance considered normal and wet year scenarios for two potential tailings and mine water storage sites, one in the Liese Creek basin and the other in the West Creek basin. The initial water balance represented normal or wet conditions averaged over a complete calendar year - e.g. monthly or seasonal variations were not considered.

Subsequent to the initial water balance work, AGRA prepared a detailed water balance. This water balance was based on a monthly time step and allowed several years of variable meteorological conditions to be considered sequentially.

3.1.1.2 Study Areas

The Pogo Project site is located within the Yukon River basin, (Figure 3.1-1). Specifically the site is located within the Goodpaster River Basin, (Figure 3.1-2). The Goodpaster is tributary to the Tanana River, which is tributary to the Yukon River. The regional terrain ranges in elevation from 1200 to 5000 ft., (364 to 1500 m). The highlands are characterized by compact, flat-topped, steep-sided mountains (ABR, 1999).

Water management facilities associated with the Pogo project are to be located in the Liese Creek basin. Liese Creek is tributary to the Goodpaster River.

The Liese Creek basin is generally rectangular-shaped, with the flow to the west-northwest. Minor sub-tributary ephemeral streams drain the west-facing slope in the headwaters of the basin; a single minor sub-tributary exists on the south-facing slope. The drainage area for Liese Creek at the mouth is approximately 1500 acres (ABR, 1999) and at the USGS gauge is 690 acres (Matt Schellekens 2000a,

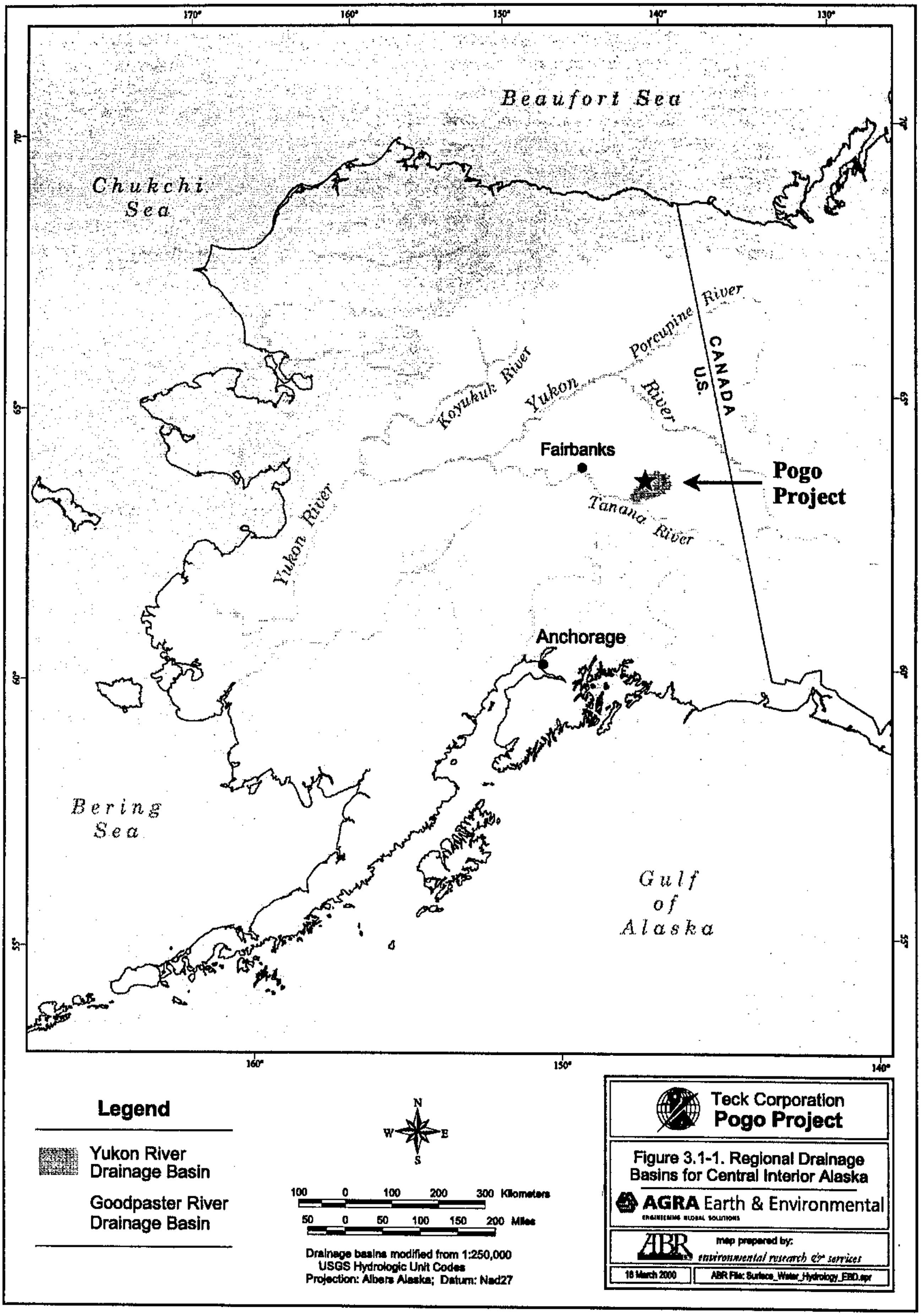
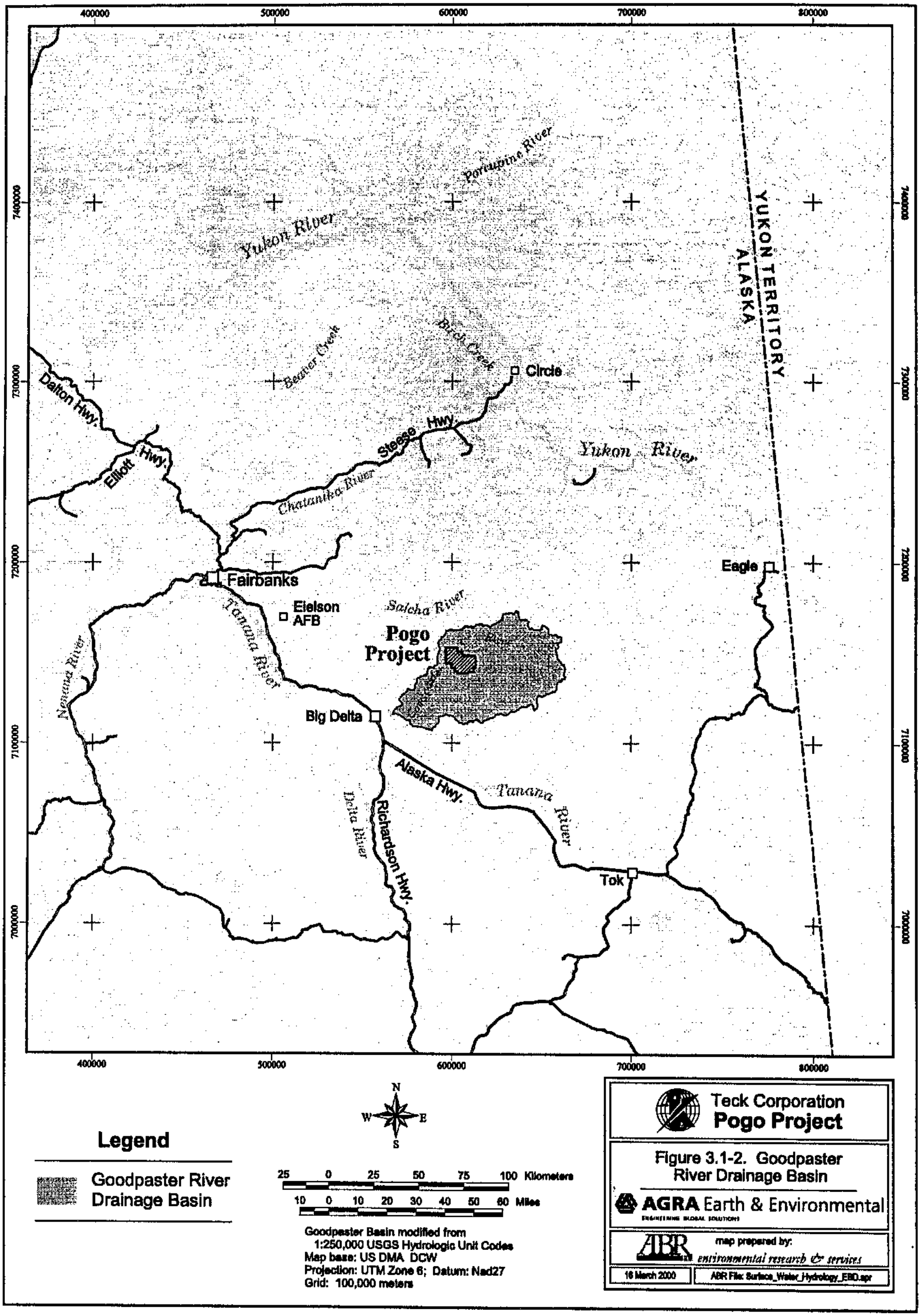


Figure 3.1-1. Regional Drainage Basins for Central Interior Alaska



Goodpaster Basin modified from
1:250,000 USGS Hydrologic Unit Codes
Map base: US DMA DCW
Projection: UTM Zone 6; Datum: Nad27
Grid: 100,000 meters

Figure 3.1-2. Goodpaster River Drainage Basin

USGS, personal communication). The elevation of the upstream portion of the Liese Creek basin ranges in elevation from 2000 to 3600 ft.

Southeast-facing slopes have closed forests of aspen, birch and white spruce. Open communities of dwarf black spruce and birch are found on the north-facing slopes. The west-facing slopes in the headwaters of the Liese basin have open stands of white spruce at lower elevations and alder at higher elevations. Exposed rubble and short-stature alpine vegetation characterize the surface of the ridges surrounding the basin (ABR, 1999). For the most part, vegetation is influenced by limited amounts of soil cover and discontinuous permafrost within much of the basin.

In addition to the ongoing stream monitoring in Liese Creek, monitoring is ongoing in other basins, namely West, Sonora and Central Creeks. Stream discharge is also monitored on the Goodpaster River near the existing airstrip. The location of these gauging sites is presented on Figure 3.1-3.

3.1.1.3 Agency Involvement

The most significant public agency involved in the hydrological components of this project has been the USGS. This agency is in charge of hydrometric monitoring for the stream gauging sites on the Goodpaster River, Liese Creek, West Creek, Central Creek and Sonora Creek. USGS personnel generated data and provided reports, (e.g., Jones, *et al.*, 1994).

The National Weather Service (NWS) has provided climatological data (obtained from web sites) and information, (e.g., Craig Gilkey, 1999).

The Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA) also provided climatological data and information, (NRCS, undated).

The University of Alaska, Fairbanks, provided background information regarding hydrology from the general opinions offered by Faculty and by their library resources. The documents provided by the University of Alaska are tabulated in Section 3.1.5.

The U. S. Department of the Interior, Bureau of Land Management (BLM), through the Alaska State office, provided a report on the water resources of the Fortymile River, adjacent to the Goodpaster River basin, (Kostohrys *et al.*, 1999).

3.1.2 METHODOLOGY

3.1.2.1 Study Procedures

The following work components represent the scope of the hydrological work undertaken to date:

- Various site reconnaissance efforts
- Data compilation and review
- Water Balance model development
- Rainfall analyses
- Stream discharge monitoring (1997 to date)

Each of these components is described below.

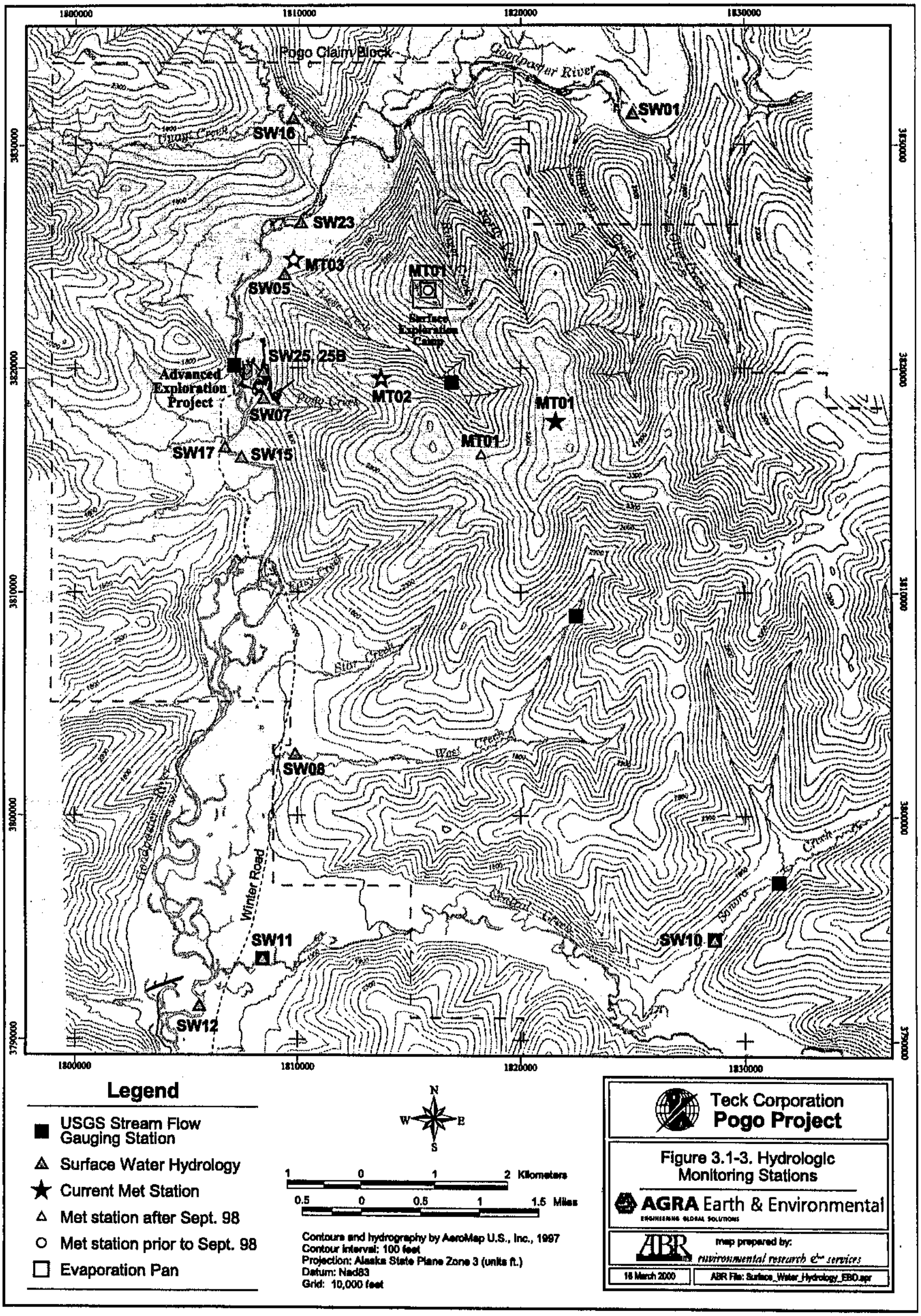


Figure 3.1-3. Hydrologic Monitoring Stations

Site Reconnaissance Work

There have been a number of individuals on site in support of hydrological data collection. For efforts specific to the development of the current water balance, personnel from AGRA visited the site in the summer of 1999. The 1999 work was to observe the hydrological setting of the two basins, Liese and West, then considered the most probable for potential development of tailings and water management facilities based on a regional assessment. Overall regional observations were also made though these were made primarily from helicopter. A June reconnaissance permitted a thorough on-ground evaluation of the two watersheds, which was not possible in July. Although weather conditions in July permitted landing in the creek bottoms, low cloud cover at the time of July reconnaissance work did not permit the upper portions of the watersheds to be observed.

Data Compilation and Review

Data were compiled from the following sources:

- Teck Corporation files provided previous stream gauging, climate monitoring and water balance reports.
- Matt Schellekens of the USGS provided recent recorded stage hydrographs and computed discharge hydrographs for streams (Schellekens, 2000b).
- Rick McClure of the Natural Resources Conservation Service (NRCS) provided monthly precipitation averages for the period 1961 to 1990 for 45 climate stations operated by the NRCS, (NRCS, undated)
- NWS web sites were searched and relevant regional climatological data were accessed.
- Jon Kostohrys of the BLM provided a report on the Water Resources of the Fortymile River basin, adjacent to the Goodpaster basin, (Kostohrys, *et al.*, 1999).
- An Internet Search was conducted to obtain relevant publications describing the regional hydrology of the interior of Alaska.
- Relevant articles were obtained from the University of Alaska, Fairbanks. These documents are listed in Section 3.1.5.
- Kraig Gilkey of the NWS forecast office in Fairbanks provided information on rainfall orographic effects, (Gilkey, 1999).
- Bob Burrows of the USGS in Fairbanks discussed orographic effects and regional stream discharges gauges that could be used to characterize streamflow characteristics of the Goodpaster River, (Burrows, 1999b).
- Larry Hinzman of the Water Environmental Research Center, University of Alaska, Fairbanks, provided information on orograpohic effects and the water balance of interior Alaska drainage basins, (Hinzman, 1999).

- Larry Rundquist of the National Weather Service provided information on regional flow relationships, (Rundquist, 1999) and on orographic effects, (Rundquist, 2000).

QA/QC

On-site hydrological data was reviewed for accuracy and value to the water balance. Monthly total rainfall was computed from daily and hourly data collected on site. These results were used to check the accuracy of instrument calibration parameters.

The USGS has reviewed the discharge computations undertaken by Hay & Co. as a part of the initial hydrometric monitoring for the project. Based on this review, the historical monitoring data have been classified with respect to monitoring standards established by the USGS and the data meeting minimum standards has been catalogued in the agency's database.

Monthly flow estimates and rainfall totals were available for the Sonora Creek basin based on data collected by Hay & Co. and ABR for Teck. These data were used to compute estimates of seasonal runoff coefficients. The consistency of the computed values suggested that the flow estimates and rainfall totals together were reasonable measures of the hydrological regime.

Based on a critical review by the USGS, additional flow monitoring will be necessary to derive a reliable representative rating curve at the Liese Creek gauging site. The installation of more sensitive equipment has been undertaken on Liese Creek to improve records of creek water level stages, and the installation of similar equipment on West Creek is planned prior to breakup in 2000. Once a reliable rating curve is established for Liese Creek, recorded creek stage measurements can be analyzed to produce acceptable calculations of stream discharge. The resulting data will be used to test assumptions made in the existing water balance and to derive other parameters to support detailed design of water management facilities.

3.1.3 RESULTS AND DISCUSSION

Site Observations

Key observations made during site reconnaissance trips include:

1. There was a significant difference in the vegetation types found on the north and south facing slopes. The height of trees on south facing slopes was generally greater than on north-facing slopes. Vegetation density may actually be greater on the north-facing slopes than on the south facing slopes.

2. A thin layer (less than 4 inches) of moss and organic materials overlying mineral soil characterized surficial and near-surface materials observed along the south valley wall of Liese Creek. The mineral soil was composed of fractured bedrock (colluvium) in a matrix of other fine-grained soils.

3. Both Liese and West Creeks are situated in deep V-shaped valleys, typical of non-glaciated terrain. Virtually no floodplain exists along either stream, which suggests low rates of sediment transport in the streams.

4. The profile along both creeks appears to exhibit an irregular longitudinal profile. This irregularity likely results in the intermittent stream flow observed along both streams. Alluvial fans exist at the downstream ends of both streams, where no surface flow was evident. Surface flow was absent at intermediate-elevations along both streams. Flow was observed in the upstream reaches. In consideration of the irregularity in flow observed along both channels it was determined that the best location for the proposed USGS stream gauging stations would be immediately downstream of the proposed containment dam site alternatives.

5. Aufeis was also considered as another issue that the USGS would address in determining the most feasible gauging site(s). Aufeis is the seasonal accumulation of ice that forms over an existing ice cover on rivers and streams and over adjacent flood plains if the ice accumulation fills and overtops the stream channel (Slaughter, 1990).

6. Small areas of ice (aufeis deposits) and snow were observed in portions of the valleys of both Liese and West creeks. Although small relative to the overall drainage area, these deposits can prolong the period of runoff from snowmelt. It was reported by Teck field personnel that the aufeis deposits in the upper reaches of Liese Creek lasted throughout the entire summer and fall, (D. Herzog, personal communication). As an example of how this issue can influence hydrometric monitoring, the flow information for the winter of 1998-1999 at the Sonora Creek gauge was impacted as a result of aufeis. Subsequent observations by USGS personnel indicated that an ice-free reach on Sonora Creek had been observed upstream of the present monitoring location. Plans were being made to move the Sonora Creek gauge upstream following the 2000 monitoring season, (Matt Schellekens, personal communication).

7. The channel of Liese Creek was observed to be 3 to 10 feet wide and approximately 2 feet deep. The bed and banks were composed primarily of boulders and cobbles. Little to no sand and other fine-grained materials were observed. The boulders and cobbles were sub-angular indicating that they were derived from colluvium.

8. Despite the periodic withdrawal of water from Liese Creek for the surface exploration camp water supply, the surface flow in Liese Creek sometimes appeared to be greater than that in West Creek but this is difficult to ascertain due to the pervious nature of the subsurface in both basins.

Meteorological Data

Meteorological monitoring continues in the Liese Creek drainage basin, where the majority of the Pogo Project facilities are to be located. Monitoring also continues in neighboring basins. The existing precipitation data network covers an adequate range of elevation. The rain gauge network extends from the Goodpaster River floodplain (elevation 1400 ft.) to the Table Top site along a ridge above the Liese Creek basin (elevation 3550 ft.). Table 3.1-1 presents the elevation and monitoring periods for each of the local meteorological stations.

The local precipitation network is illustrated on Figure 3.1-3.

The Pogo rainfall data were separated according to the various station locations. The Pogo 1 gauge moved from Surface Exploration Camp (SEC) to the Saddle location (SAD) at the end of August, 1998. Similarly, the Pogo 2 gauge moved from Lower Liese Creek (LIE) to the PSD site (PSD) in August 1998.

Table 3.1-1. Local Precipitation Data.

	Elevation (ft)	Period of Record
Pogo 1SEC	2700	1997 - 1998
Pogo 1SAD	3200	1999
Pogo 1TAB	3550	1999
Pogo 2LIE	1400	1997 - 1998
Pogo 2PSD	2675	1999
Sonora	1500	1998 - 1999

This gauge was subsequently moved to the Table Top site in the fall of 1999. Significant changes in elevation were associated with the Pogo 2 move; less so for Pogo 1. These station moves significantly restricted the amount of data available for correlation.

The period of record for the precipitation information obtained at Pogo is relatively short, 1997 to date. The three years of available data are considered insufficient to provide a good estimate of long-term mean. At the same time, site-specific data are always of tremendous value in assessing correlations to regional databases. The site-specific database will continue to grow as the project proceeds.

To assist in relating short-term local precipitation measurements to long-term climatic characteristics, regional meteorological data were assembled. Table 3.1-2 presents the regional long-term meteorological station characteristics.

The locations of the regional meteorological stations are illustrated on Figure 3.1-2.

Table 3.1-3 presents the available precipitation data for long-term meteorological stations in the interior region of Alaska. The averages presented in Table 3.1-3 are for the 30-year period from 1961 to 1990.

A significant portion of the available precipitation data available for the Interior region of Alaska is gathered at readily accessible sites located in the river valleys. Unfortunately, there is little available information for locations in steep, mountainous terrain resulting in lesser orographic correlative data than would be preferred for the Pogo Project.

Correlations were derived between the annual total precipitation data for all regional long-term meteorological stations and the Pogo stations. The raw rainfall data for each month of record for the Pogo gauges is presented in Table 3.1-4. Also shown are the total precipitation data for the regional long-term meteorological stations for the concurrent period. The right side of the table gives correlation coefficients.

Table 3.1-2. Regional Precipitation Data.

	Elevation (ft)	Period of Record
Big Delta	1268	1941 - 1999
Circle City	600	1979 - 1999
College	620	1951 - 1999
Eagle	850	1951 - 1999
Eielson	550	1951 - 1999
Fairbanks	440	1951 - 1999
Nenana	360	1951 - 1996
Northway	1710	1951 - 1999
Tok	1620	1959 - 1999

Table 3.1-3. Monthly Precipitation Averages (inches), NWS and NRCS Stations (1961-1990).

Sta.	**Elev.**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual Total**
National Weather Service (NWS)														
Fairbanks WSO Airport	436'	0.47	0.40	0.37	0.32	0.61	1.37	1.87	1.96	0.95	0.90	0.80	0.85	10.87
Eagle	850'	0.48	0.45	0.30	0.38	0.86	1.74	2.05	1.85	1.17	1.02	0.71	0.73	11.74
Eielson Field	547'	0.56	0.44	0.46	0.38	0.69	1.73	2.52	2.34	1.30	1.00	0.78	0.73	12.93
Tok	1620'	0.38	0.34	0.17	0.18	0.56	1.79	2.24	1.18	0.91	0.59	0.49	0.32	9.15
Big Delta	1268'	0.33	0.28	0.25	0.29	0.92	2.56	2.72	1.92	1.06	0.71	0.52	0.40	11.96
Natural Resources Conservation Service (NRCS)														
Fairbanks Field Office	450	0.6	0.4	0.4	0.4	0.7	1.5	2.1	2.2	1.1	1.1	0.9	0.9	12.3
Granite Creek	1240	0.5	0.5	0.3	0.3	1.1	2.3	2.4	1.8	1.1	1.1	0.7	0.7	12.8
Mission Creek	900	0.6	0.5	0.4	0.4	0.8	1.4	1.9	1.6	1.1	1.0	0.8	0.8	11.3
Monument Creek	1850	0.9	0.7	0.5	0.4	1.3	2.9	3.9	3.9	1.8	1.6	1.4	1.3	20.6
Munson Ridge	3100	1.3	0.8	0.8	0.9	1.4	3.0	4.8	4.8	2.4	2.3	1.8	1.5	25.8
Rhoads Creek	1225	0.4	0.4	0.3	0.3	0.9	2.2	2.4	1.8	1.1	1.1	0.7	0.6	12.2
Teuchet Creek	1640	0.8	0.7	0.4	0.4	1.1	2.6	3.5	3.3	1.5	1.3	1.1	1.1	17.8
Upper Chena Pillow	2850	1.1	0.8	0.5	0.5	1.5	2.8	3.7	3.7	1.9	1.8	1.5	1.5	21.3

Big Delta correlates best with the SEC and LIE sites. Big Delta is only marginally less better correlated than Circle City with the SAD and PSD sites. It was concluded that it is appropriate to use Big Delta as a baseline station for estimating long-term rainfall at Pogo. Big Delta is the closest long-term NWS meteorlogical station to the Pogo Mine Project site.

Orographic Effects

To help clarify the relationships between the data, the seasonal data from Table 3.1-4 have been plotted as illustrated in Figures 3.1-4, 5, and 6. These figures include a trend line derived from work conducted by Clearwater Consultants Ltd. (1996) for a proposed gold mine heap leach facility in the central Yukon Territory of Canada. The hydrological analyses established an "orographic factor" which indicated that the average long-term annual total precipitation increases at a rate of approximately 11% per 305 ft. (100 m) rise in elevation above the elevation of the base station (Mayo A.). Clearwater Consultants also indicated that the proportion of total annual precipitation represented by rainfall appeared to decrease with increasing elevation. Similar trends in precipitation have been documented in the Chena basin, Alaska, by Santeford, (1976).

Based on Figures 3.1-4, 5, and 6, the following conclusions were made:

The seasonal data for 1997 (Figure 3.1-4) show that both Pogo sites had lower precipitation than Big Delta. Note also the increase in precipitation between LIE and SEC.

Similar trends are apparent for 1998 (Figure 3.1-5).

In 1999 both Pogo gauges, (then moved to higher elevations) had marginally greater precipitation than Big Delta (Figure 3.1-6).

Table 3.1-4. Monthly Rain Data (inches).

	1997						1998					1999							Correlation Coefficient with Pogo Stations			
	Monthly					Total	Monthly				Total	Monthly						Total May-Aug				
	May	Jun	Jul	Aug	Sept	May-Sept	May	Jun	Jul	Aug	May-Aug	Sept	May	Jun	Jul	Aug	Sept					
Regional Stations																			1SEC	1SAD	2LIE	2PSD
Big Delta	**1.11**	1.66	2.35	3.09	0.75	8.96	0.36	0.97	5.27	1.86	8.46	0.81	0.9	2.12	2.3	2.51		7.83	**0.96**	0.87	**0.96**	0.90
Circle City	0.2	0.12	1.01	0.99	0.46	2.78	0	0.67	1.19	1.95	3.81	0.05	0.03	0.48	0.55	1.15		2.21	0.84	**0.88**	0.87	**0.96**
College	0.17	1.29	2.11	2.61	0.96	7.14	0.74	1.5	3.86	3.02	9.12	1.4	0.52	2.21	2.06	1.98		6.77	0.95	0.58	0.95	0.58
Eagle	1.56	3.02	2.97	2.52	0.66	10.73	2.29	3.18	1.46	2.54	9.47	0.91	1.08	0.17	2.19	2.1		5.54	0.91	0.83	0.87	0.71
Eielson	0.65	0.43	0	2.58	0.71	4.37	0.54	1.28	3.52	3.3	8.64	1.29	0.89	2.33	1.94	1.84		7	0.71	0.49	0.71	0.53
Fairbanks	0.07	1.03	1.08	1.7	0.48	4.36	0.41	1.33	3.35	3.18	8.27	1.19	0.31	1.3	2.11	1.85	1.85	5.57	0.82	0.61	0.83	0.71
Nenana	0.18	0	0.65	0.8	0	1.63	0	0	0	0	0	0	0	0	0	0	1.28		0.84	-0.36	0.83	0.10
Northway	0.6	1.21	3.24	2.51	0.1	7.66	0.18	1.11	1.5	0.49	3.28	0.66	1.17	2.91	2.19	2.26	0.77	8.53	0.94	0.63	0.93	0.51
Tok	0.37	1.78	4.27	1.35	0.62	8.39	0	1.66	1.89	0.5	4.05	0.62	0.92	3.85	2.27	2.64		9.68	0.93	0.45	0.92	0.55
Local Stations																						
Pogo 1SEC	1.07	1.86	2.88	2.19	0.44	8.44	1.05	1.54	3.56	2.14	8.29											
Pogo 1SAD												0.66	0.92	1.22	2.56	2.81	0.81	7.51				
Pogo 1FOO																						
Pogo 2LIE	1.08	1.38	2.98	1.74	0.33	7.51	0.22	0.9	3.25	2.24	6.61											
Pogo 2PSD												0.43	0.83	1.26	1.95	2.74	1.65	6.78				
Sonora							1.37	1.31	3.21	1.54	7.43	1.13		0.97	2.47	2.98	0.57	6.42				

Notes:

1. Pogo 2PSD after August 1998 has alternatively been referred to as "Colocate".
2. Pogo 1SAD after August 1998 has alternatively been referred to as "Saddle".
3. Pogo 1TAB started operation in the fall of 1999; therefore insufficient information was available to perform a correlation.
4. Bold numbers identify the highest correlation coeffcient.

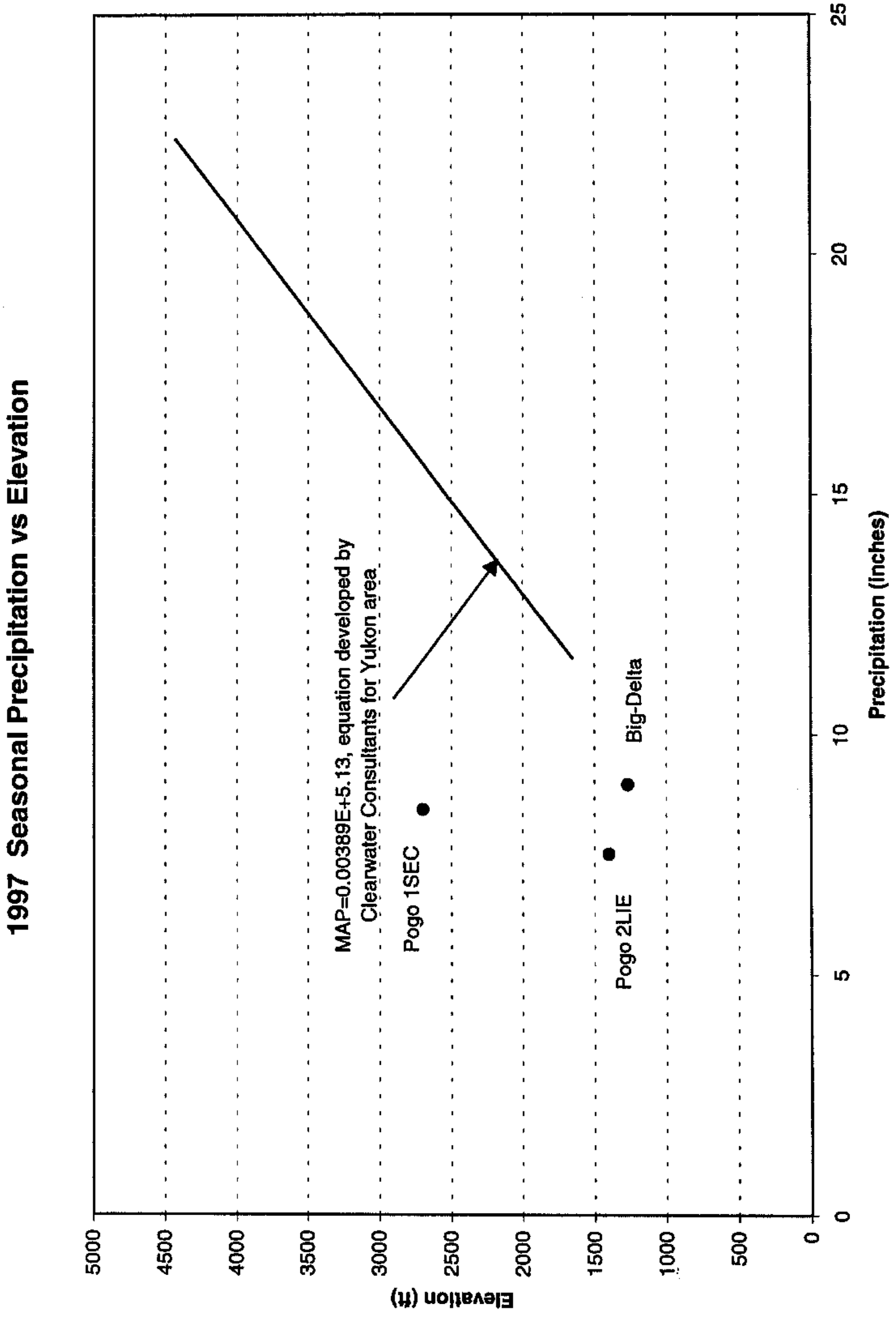


Figure 3.1-4. 1997 Seasonal Precipitation vs Elevation.

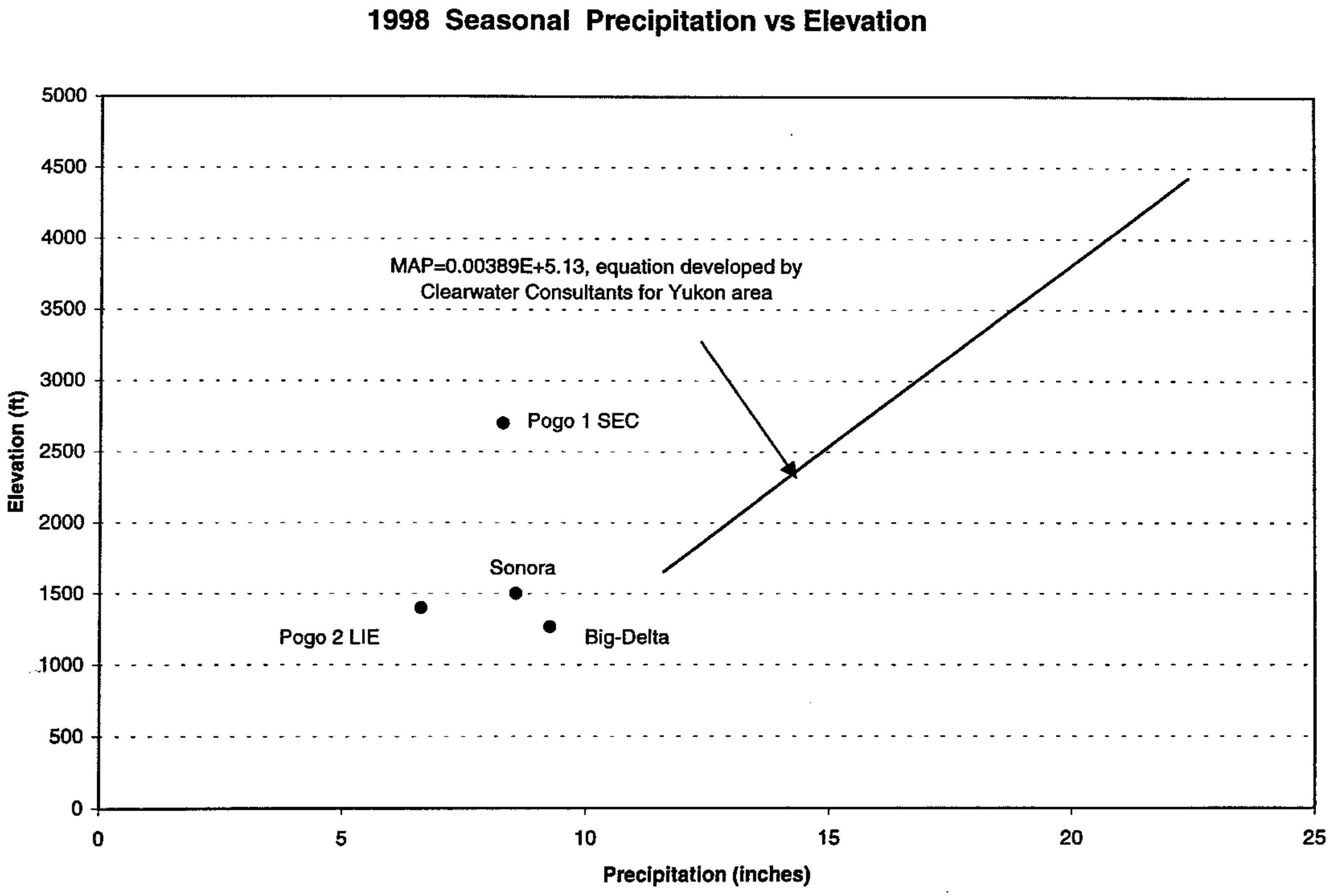


Figure 3.1-5. 1998 Seasonal Precipitation vs Elevation.

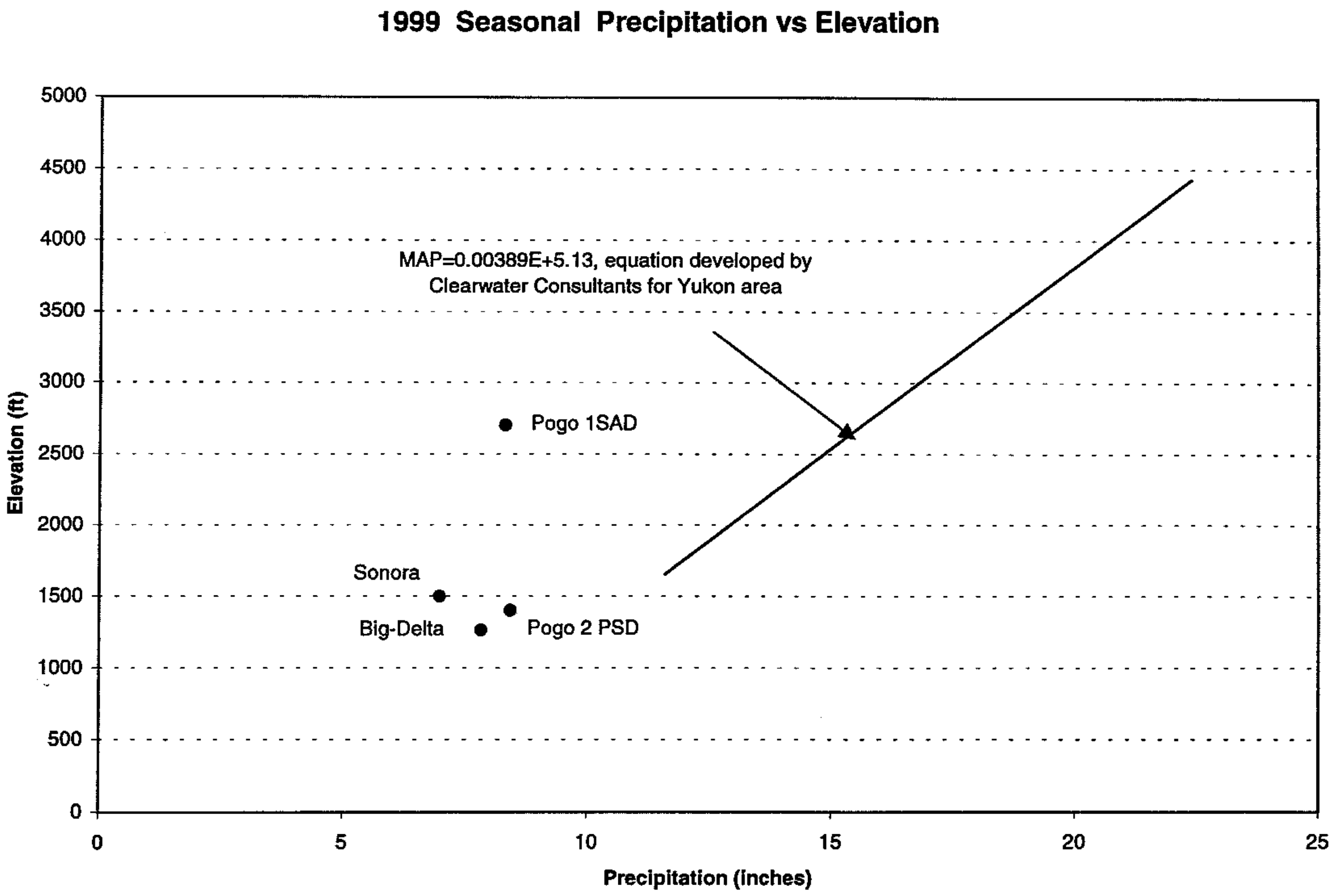


Figure 3.1-6. 1999 Seasonal Precipitation vs Elevation.

Although implied by the regional information available, there is no strong evidence of a trend to increasing precipitation with elevation from these data. It is possible that the path of individual storm systems could affect the variability in precipitation over short time periods. This aspect is of importance to the Pogo Project as the potential precipitation gain with elevation is close to 50% of the average annual precipitation at Big Delta.

For the purposes of this report, the meteorological data from Table 3.1.3 that represent the recorded annual precipitation for the period 1961 to 1990 were used to develop a regional relationship for the interior of Alaska. The following equation was computed as illustrated on Figure 3.1-7: $MAP = 0.0051\ E + 7.5$ where MAP = mean annual precipitation (inches) E = elevation (feet).

Figure 3.1-8 is a copy of a drawing extracted from Plate 2 of the USGS Water Resources Investigations Report 93-4179 by Jones and Fahl (1994). This plot for Alaska and Conterminous Basins of Canada was based on data from 304 climatological stations, 102 snow surveys and 223 streamflow stations west of longitude 141°. Figure 3.1-8 illustrates the following:

a) Lower precipitation values are typical of lower elevation valleys, as exhibited for the Tanana River. Conversely, higher precipitation values are common for higher elevation areas upslope from these valleys.

b) The higher the elevation of the upland areas, the greater the mean annual precipitation. The precipitation in the Mount Hayes area of the Alaska Range (where the peak elevation is 4216 ft.) exceeds 80 inches, whereas the mean annual precipitation for Mount Harper, at the headwaters of the Goodpaster River and Healy Creek (peak elevation 1994 ft.) is between 20 and 30 inches.

c) The estimated mean annual precipitation for the Pogo project site is between 15 and 20 inches. A value of 18.7 inches has been interpolated from the isolines.

Based on the information presented above, Figure 3.1-9 has been prepared to illustrate the recommended trend line for mean annual precipitation versus elevation, for use at Pogo. This figure uses the slope of 0.004 from the Clearwater investigation. The slope from Figure 3.1-7 was believed to be overly conservative from a water management perspective, as it would produce higher than reasonable estimates of precipitation at Pogo. This trend line was located to pass through the long-term average precipitation (11.7 inches) at Big Delta (elevation 1268 ft.). This resulted in the computed intercept (for zero elevation) of 6.6 inches.

The computed mean annual precipitation for Pogo ranges from 16.6 inches (at 2500 ft.) to 21 inches (at 3600 ft.). Based on Figure 3.1-9, the mean annual precipitation of 17.4 inches was derived for the Liese Creek Basin.

Seasonal Distribution of Rainfall

The seasonal distribution of rainfall measured on site is illustrated on Figures 3.1-10, 11, and 12. Figure 3.1-13 illustrates the seasonal distribution of precipitation (snowfall plus rainfall) measured at Big Delta over its period of record. A comparison of the site data and the Big Delta data indicates that similar precipitation trends exist at each site. In most cases, precipitation measurements at Pogo are limited to rainfall during the summer months. Monthly snowfall data are not available. Long-term records at Big Delta indicate 37% of the annual precipitation occurs as snowfall.

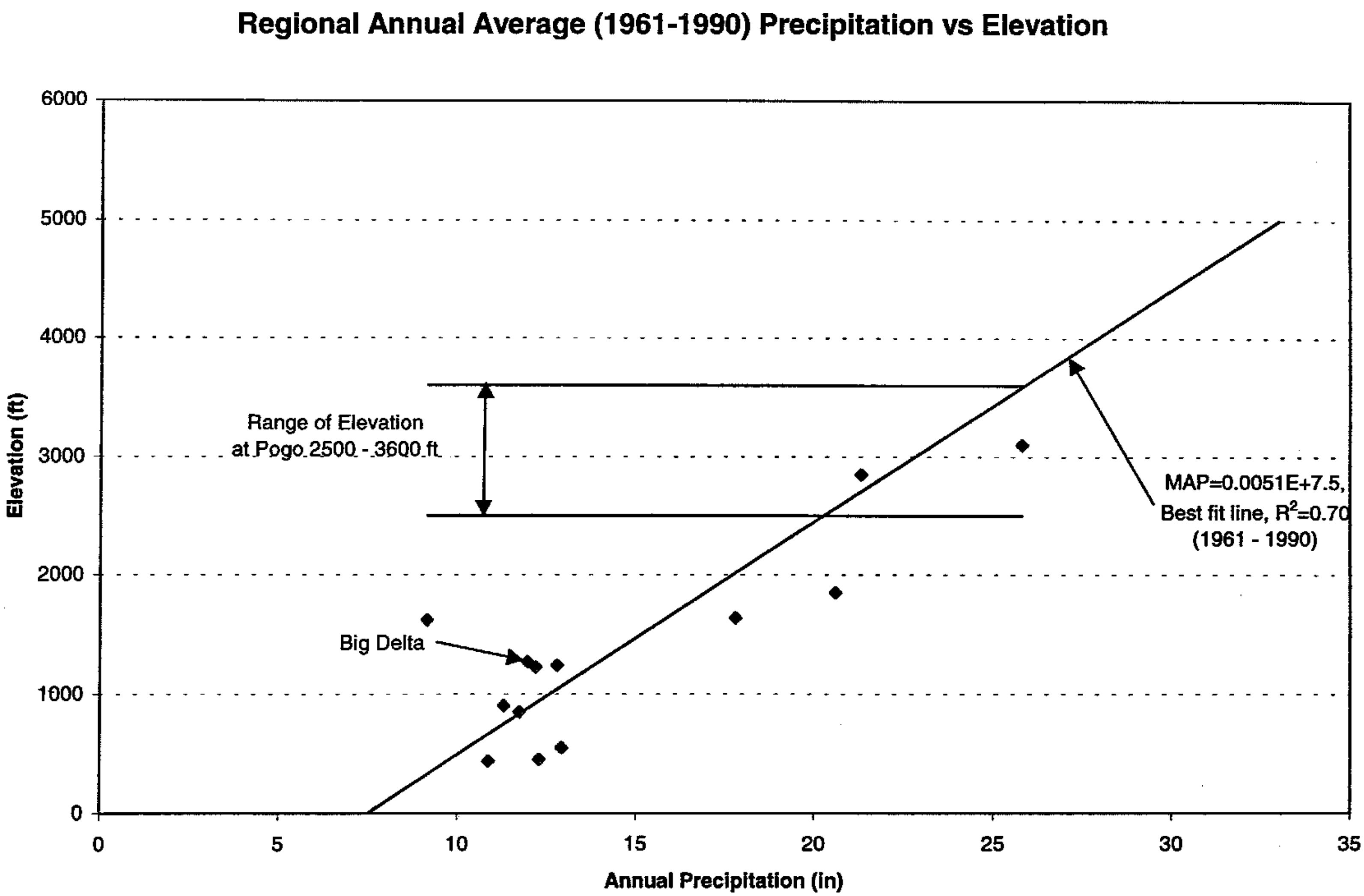
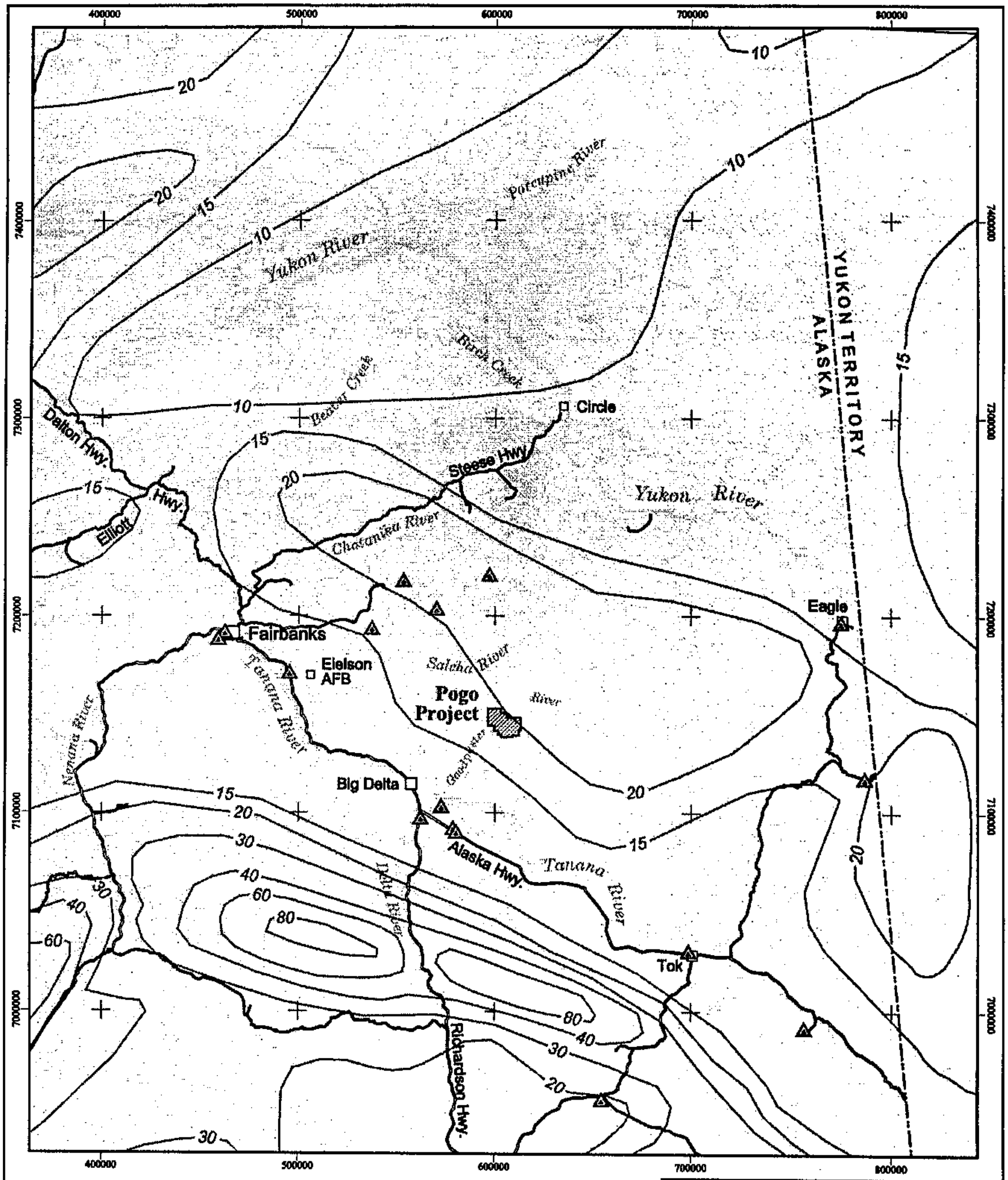


Figure 3.1-7. Regional Annual Average (1961-1990) Precipitation vs Elevation.



Legend

Mean Annual Precipitation (in)

▲ NWS and NRCS Meteorological Stations

Precipitation contours (in) after USGS 1993;
1:2,000,000 scale
Map base: US DMA DCW
Projection: UTM Zone 6; Datum: Nad27
Grid: 100,000 meters

Teck Corporation
Pogo Project

Figure 3.1-8. Mean Annual Precipitation (in)

AGRA Earth & Environmental
ENGINEERING GLOBAL SOLUTIONS

ABR map prepared by:
environmental research & services

18 March 2000 | ABR File: Surface_Water_Hydrology_EBD.apr

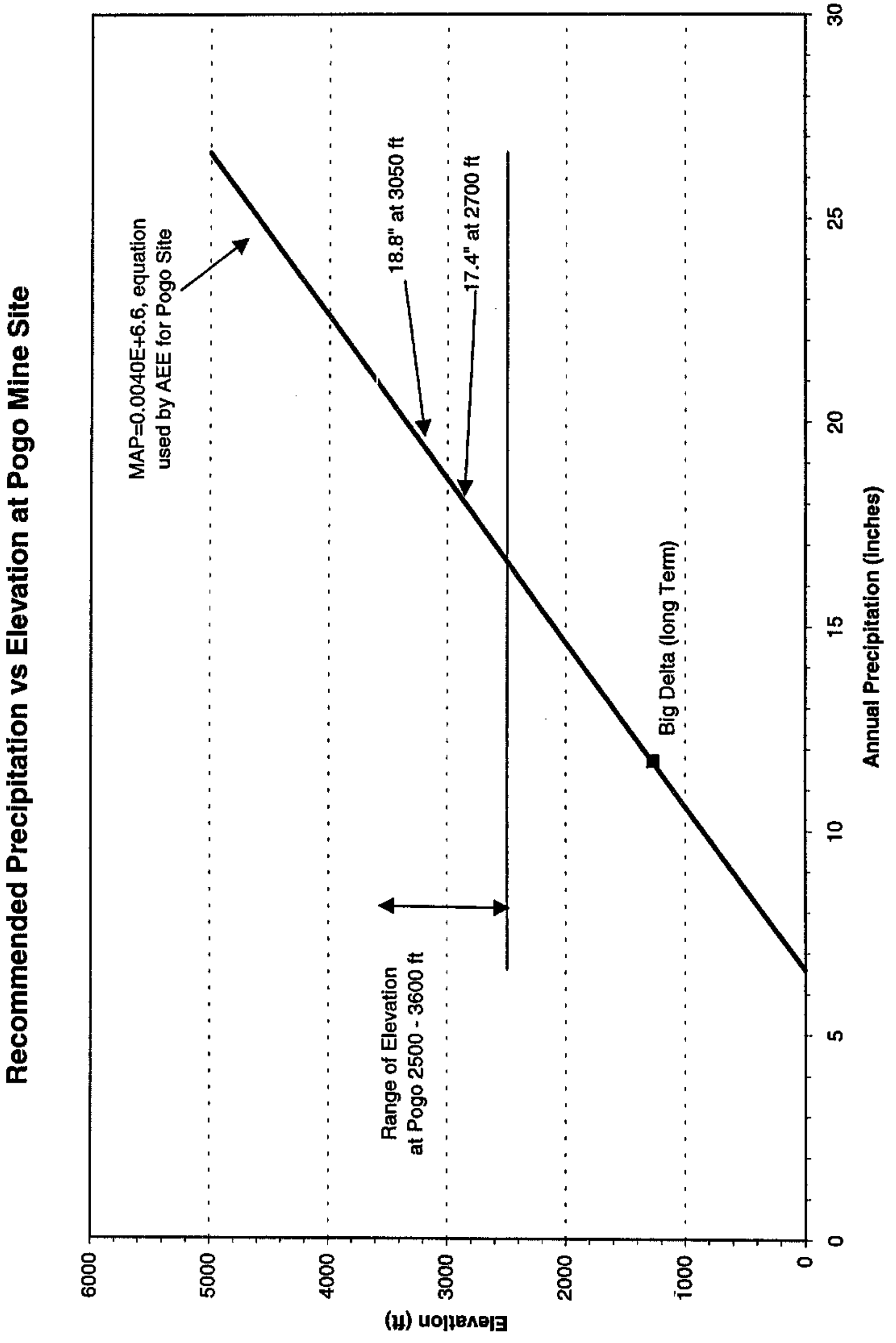


Figure 3.1-9. Recommended Precipitation vs Elevation at Pogo Mine Site.

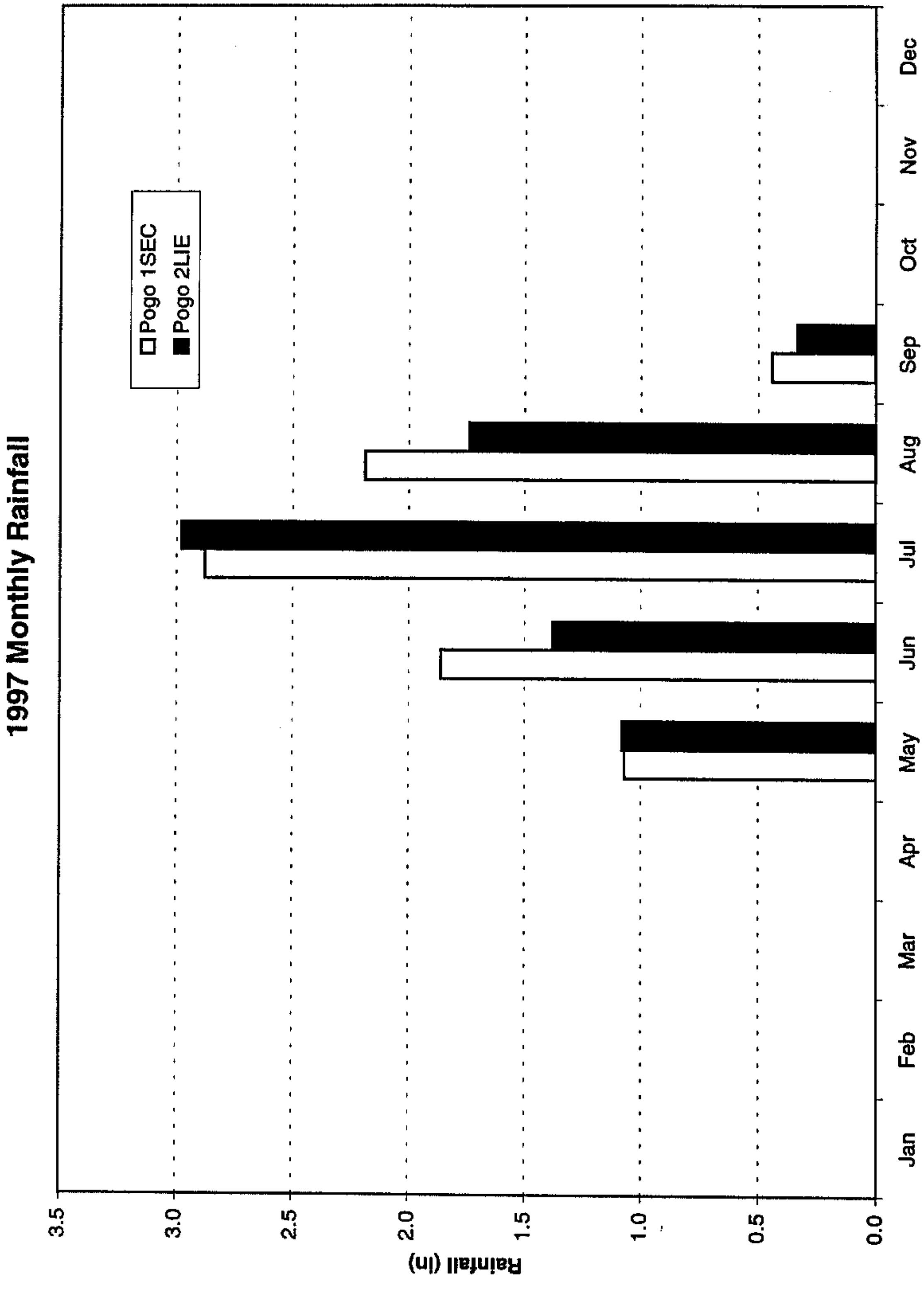


Figure 3.1-10. 1997 Monthly Rainfall.

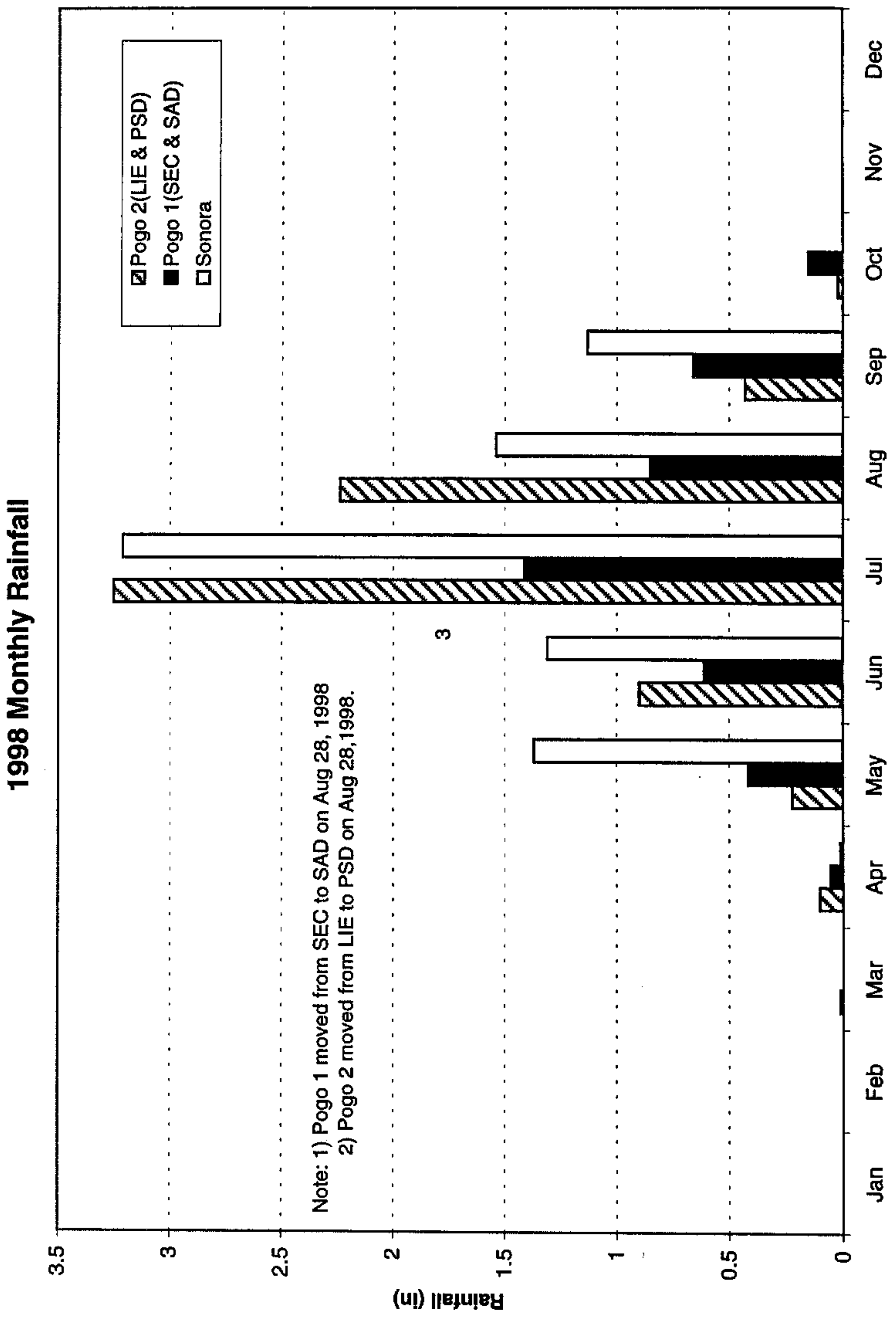


Figure 3.1-11. 1998 Monthly Rainfall.

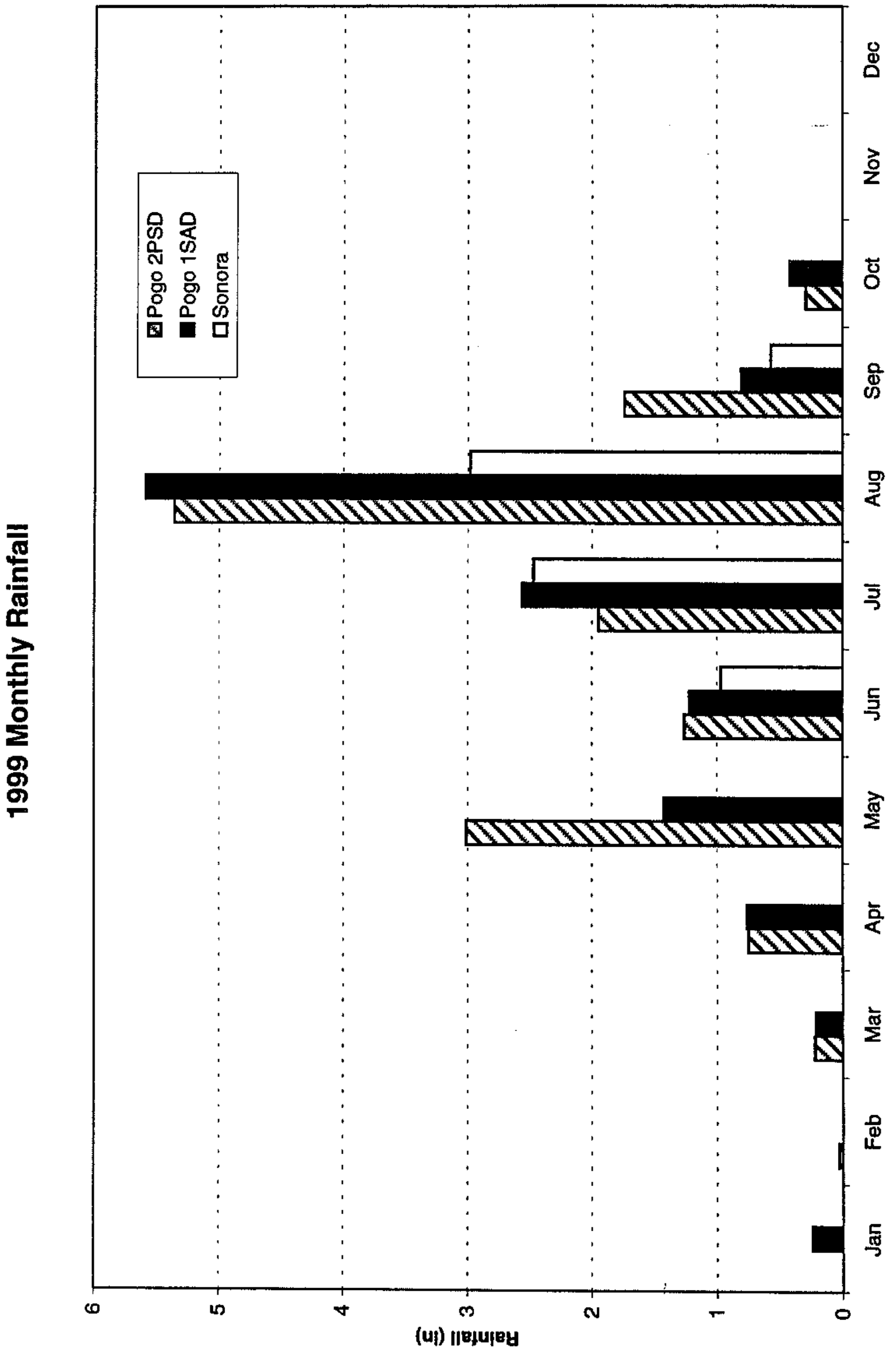


Figure 3.1-12. 1999 Monthly Rainfall.

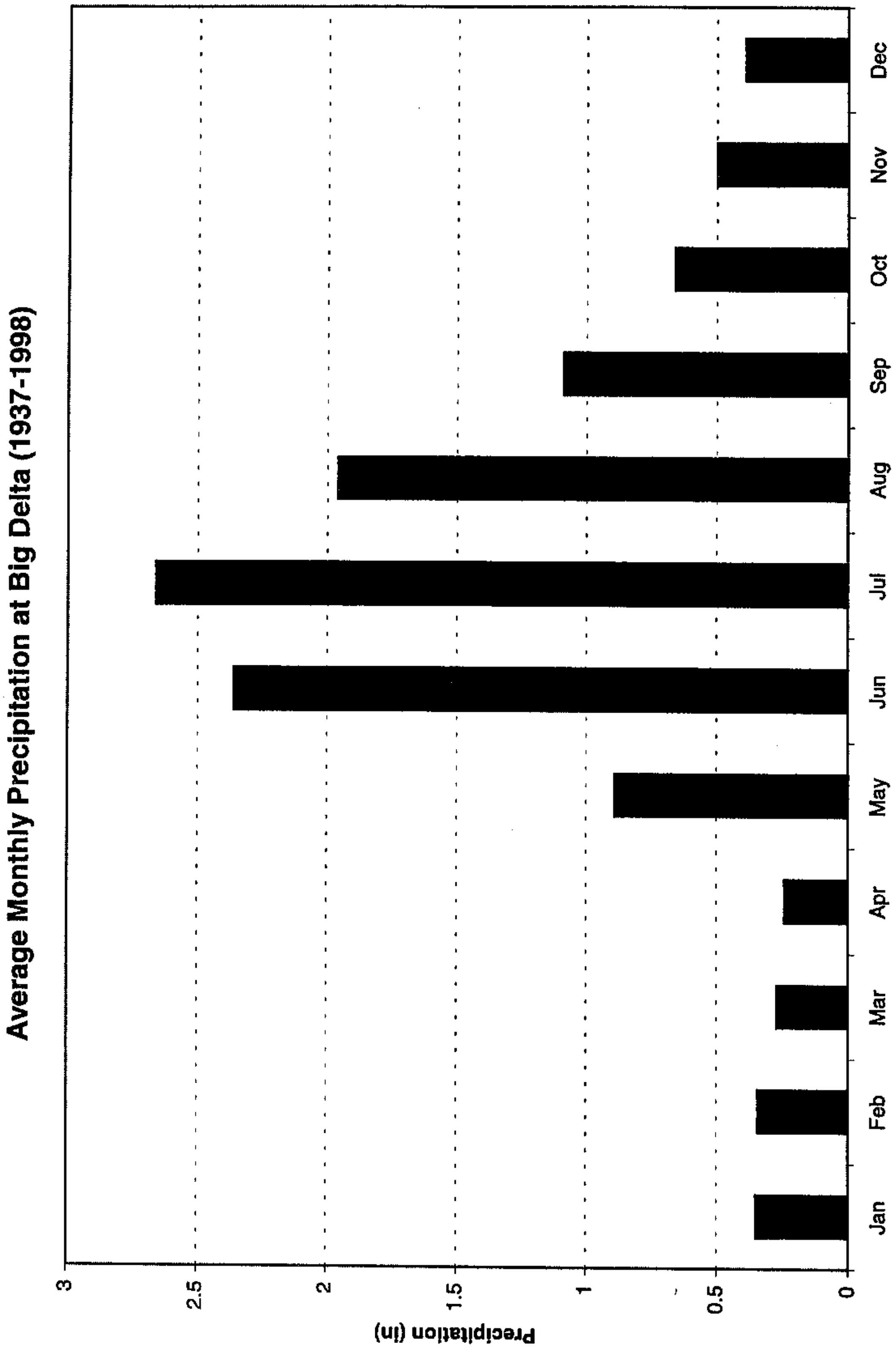


Figure 3.1-13. Average Monthly Precipitation at Big Delta (1937-1998).

Precipitation Frequency

The computation of the return interval for various duration of annual precipitation events was analyzed using the following methodology:

1. The values used for the frequency assessment at the Pogo Mine site were transformed to values representative of the precipitation at the Big Delta meteorological station. The data for this station had been used to estimate the long-term precipitation regime at the Pogo site.
2. The baseline dataset of recorded annual precipitation for Big Delta was reviewed. Based on significant missing data for the period prior to 1940 and following 1989, the decision was made to use the period 1940 to 1989 as the dataset for analysis.
3. Cumulative total precipitation for durations of 2 through 6 and 12 years were computed for the data used at Pogo. The cumulative 2-year duration precipitation was obtained by adding the total precipitation for years 1 and 2, 2 and 3, 3 and 4, etc. The remaining cumulative totals were derived in a similar manner.
4. The Big Delta dataset was analyzed to prepare cumulative annual precipitation totals for durations of 1 through 6 and 12 years. These totals were analyzed to provide frequency estimates for each duration analyzed, as illustrated in Table 3.1-5.

Figures 3.1-14 and 3.1-15 present the results of the analysis for durations from 2 to 6 and to 12 years, respectively. Note that there is a trend to lower frequency estimates (i.e., lower average precipitation per year) for the longer duration periods, as these longer duration periods include not only wet years but average and below average precipitation years.

Stream Discharges

Stream discharges have been measured at the sites listed in Table 3.1-6 and located as illustrated on Figure 3.1-3

1. This site is a winter flow measurement site supplementary to the primary Sonora Creek near Big Delta site)

Table 3.1-5. Frequency Analysis for Cumulative Precipitation (inches) at Big Delta FAA.

	Years of Cumulative Precipitation						
Return Period	**1**	**2**	**3**	**4**	**5**	**6**	**12**
200	21.4	36.5	51.9	63.8	78.2	89.4	153.0
100	20.1	34.9	49.7	61.7	75.5	86.8	151.0
50	18.8	33.2	47.4	59.5	72.7	84.2	150.0
20	16.9	30.8	44.2	56.3	68.9	80.4	147.0
10	15.5	28.8	41.6	53.6	65.8	77.3	145.0
5	13.9	26.5	38.7	50.6	62.3	73.9	142.0
2	11.3	22.6	33.8	45.4	56.6	68.1	136.0

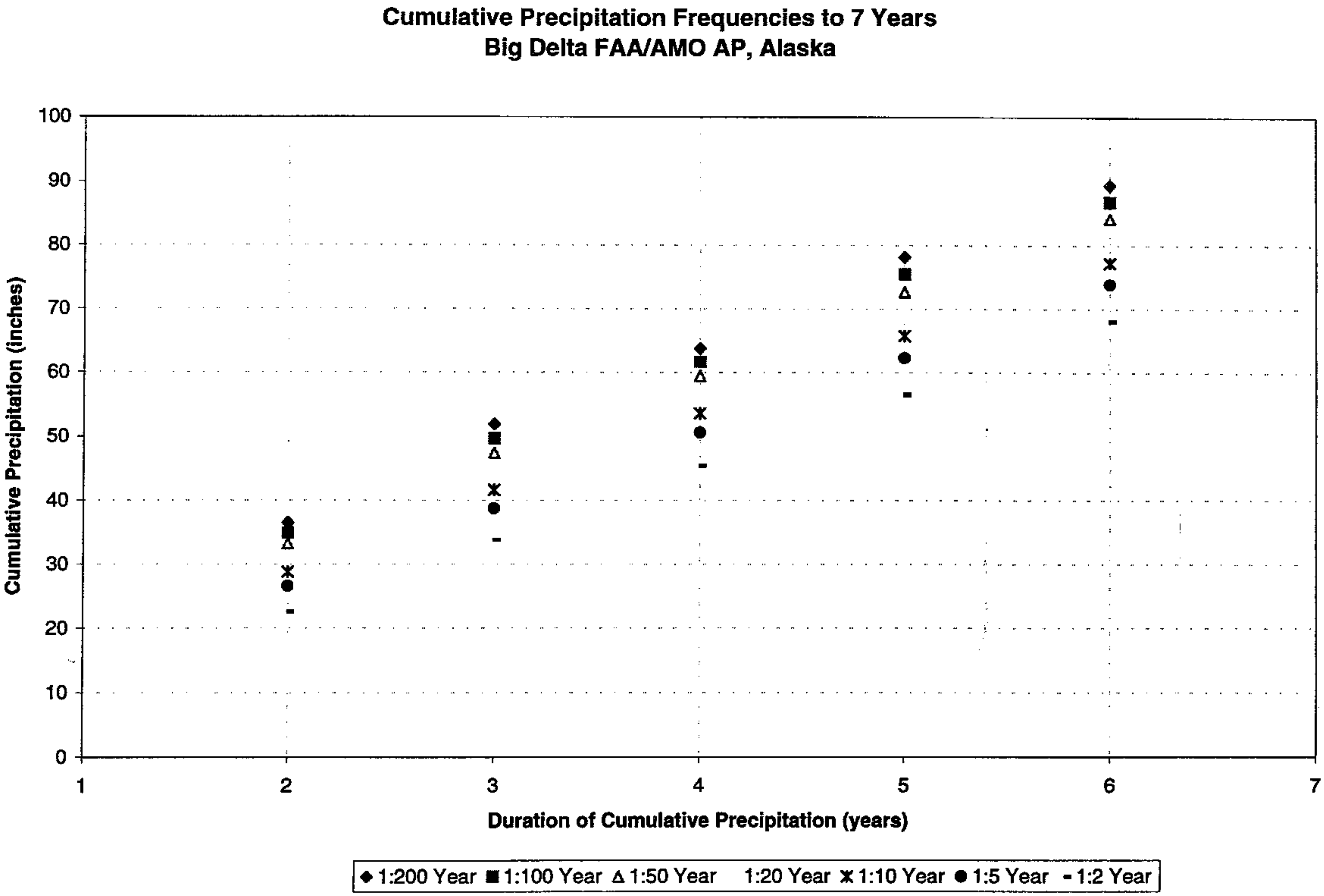


Figure 3.1-14. Cumulative Precipitation Frequencies to 7 Years Big Delta FAA/AMO AP, Alaska.

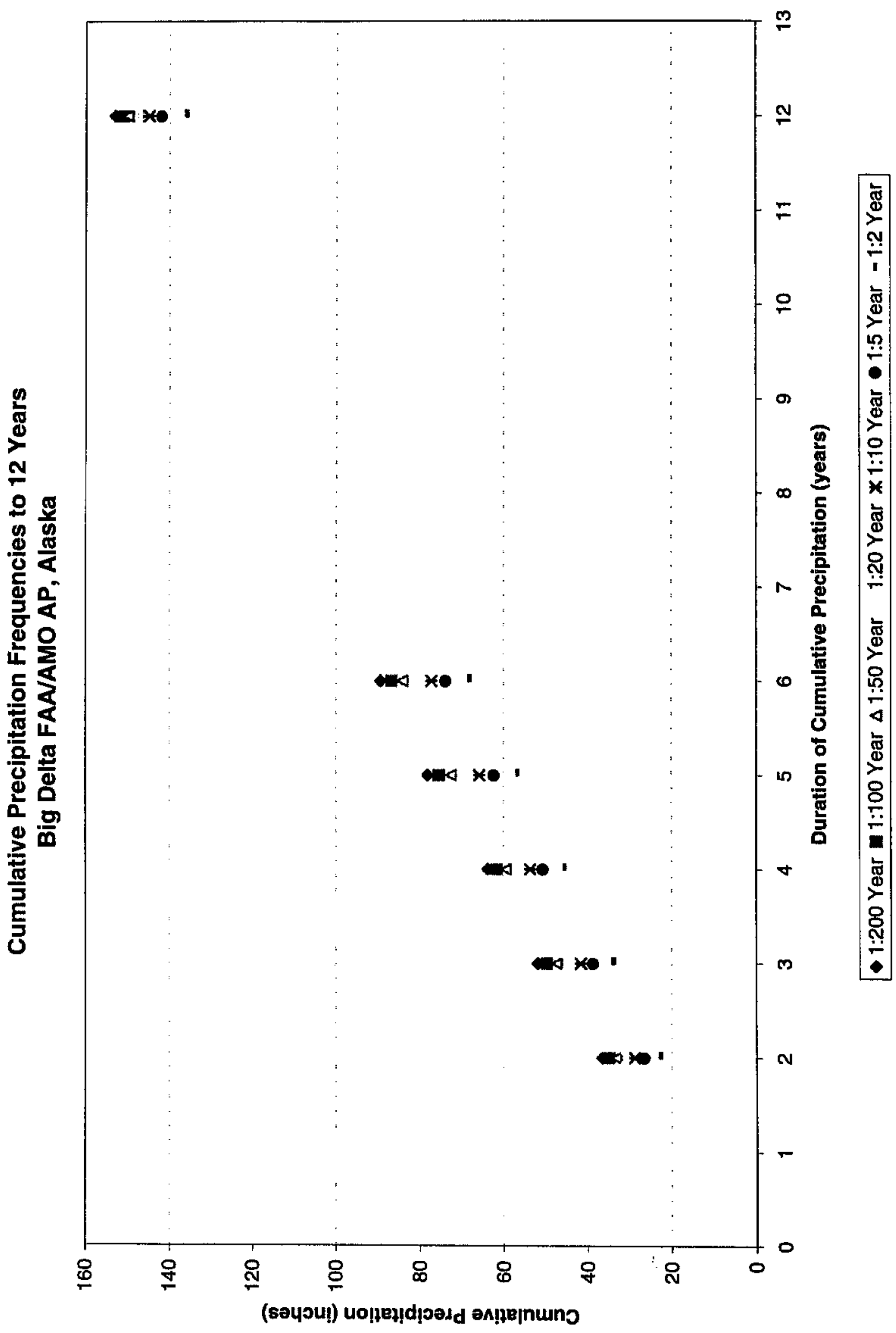


Figure 3.1-15. Cumulative Precipitation Frequencies to 12 Years Big Delta FAA/AMO AP, Alaska.

Table 3.1-6. Local Stream Gauge Locations.

Name	USGS Sta. ID	Hydrologic Unit	Drainage Area (sq. mi.)	Latitude (deg./min./sec.)	Longitude (deg./min./sec.)
Goodpaster River near Big Delta	15477740	19040503	677	64 27 02	144 56 32
Central Creek near Big Delta	15477790	19040503	115	64 22 37	144 56 35
Sonora Creek near Big Delta	15477770	19040503	10.5	64 22 40	144 48 41
Sonora Creek Above Tributary near Big Delta [1]	15477768	19040503	9.84	64 23 09	144 47 27
Liese Creek near Big Delta	15477730	19040503	1.08	64 26 53	144 52 59
Upper West Creek near Big Delta	15477761	19040503	1.64	64 25 01	144 50 55

Stream discharge data were provided by the USGS, following extensive review of flow measurements, recorded water levels and gauge datum surveys undertaken by Hay and Co. (prior to May 1999) and by the USGS following that date. Stream discharge data files were prepared for the Goodpaster River, Central Creek and Sonora Creek. The files contain mean daily flow as well as instantaneous maximum and minimum daily flows for each site. Only mean daily flows are available for the winter period when the discharges are estimated.

At the present time, acceptable stage records exist for Liese Creek only for the period October 1, 1999 to November 18, 1999. Prior to that date, the gauge height record appears incorrect, (Matt Schellekens, 2000b) and after that date the gauge was shut down for the winter. Table 3.1-7 presents the recorded discharge measurements for Liese Creek, (Schellekens, 1999). Each of these has an estimated error of approximately +/- 8%.

Figures 3.1-16, 17 and 18 illustrate computed mean monthly discharges based on the daily mean discharges provided by the USGS. These data from plots were converted to runoff depths to produce Figure 3.1-19 that indicates the following stream flow characteristics:

1. Low flows occur during the winter. The variability in the low flows appears to be greater for the larger streams (e.g., Goodpaster River) than for the smaller streams (Sonora and Central Creek).

2. Flows rise rapidly through April and May as a result of snowmelt. Annual maximum discharges appear to occur on the creeks during this period.

3. At all gauging sites, the flows recede through June and July. Flows increase in August, likely due to summer rain events. For two out of the three years of available data, the Goodpaster River reached its annual maximum discharge in late summer as a result of rainfall events.

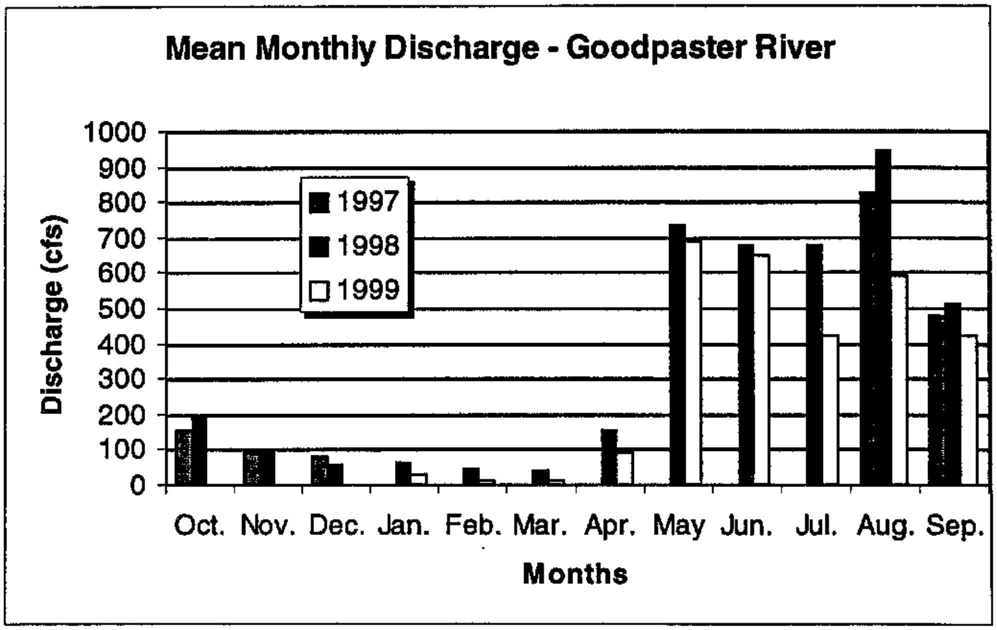


Figure 3.1-16. Mean Monthly Discharge - Goodpaster River.

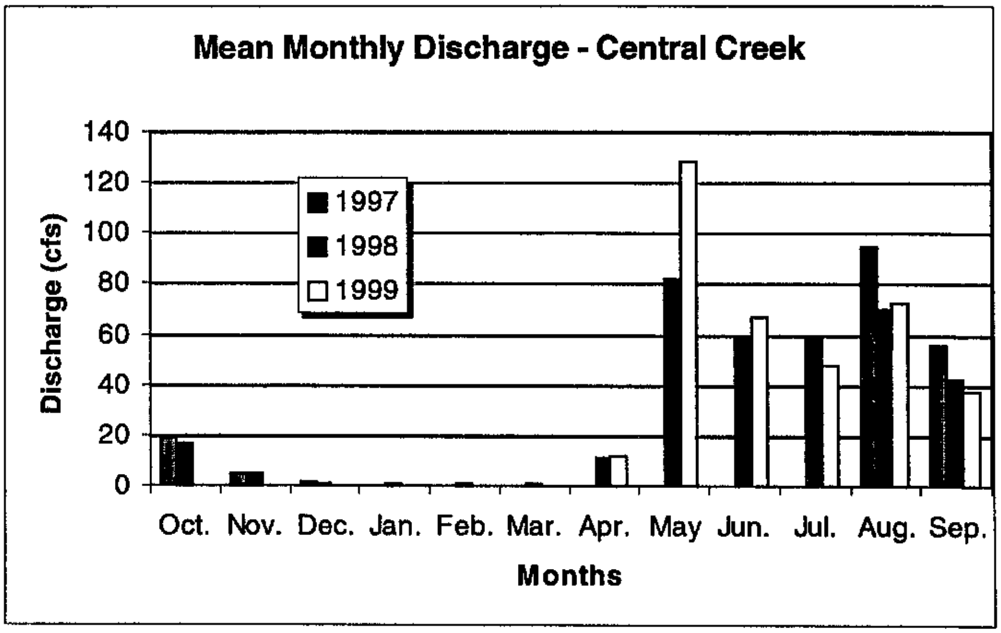


Figure 3.1-17. Mean Monthly Discharge - Central Creek.

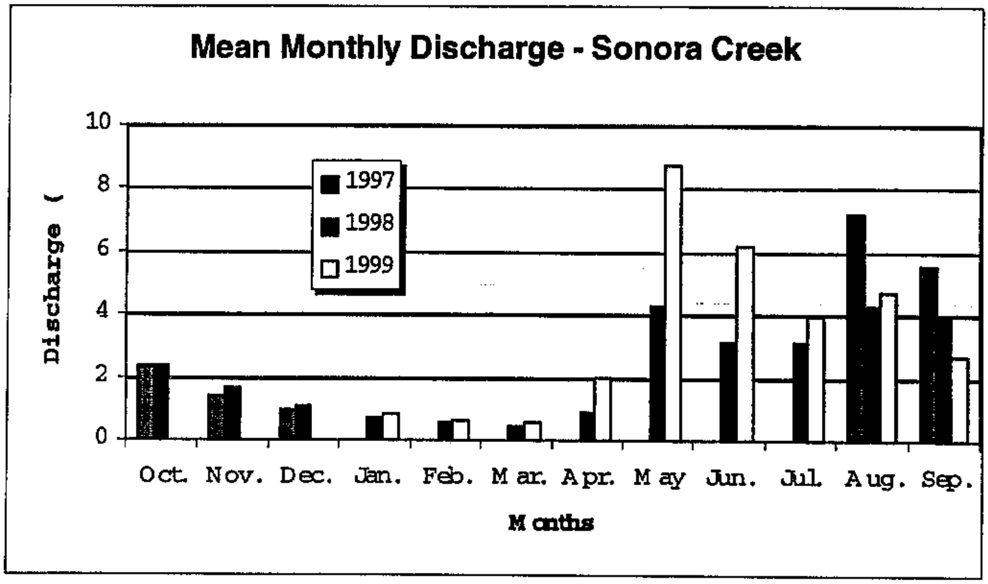


Figure 3.1-18. Mean Monthly Discharge - Sonora Creek.

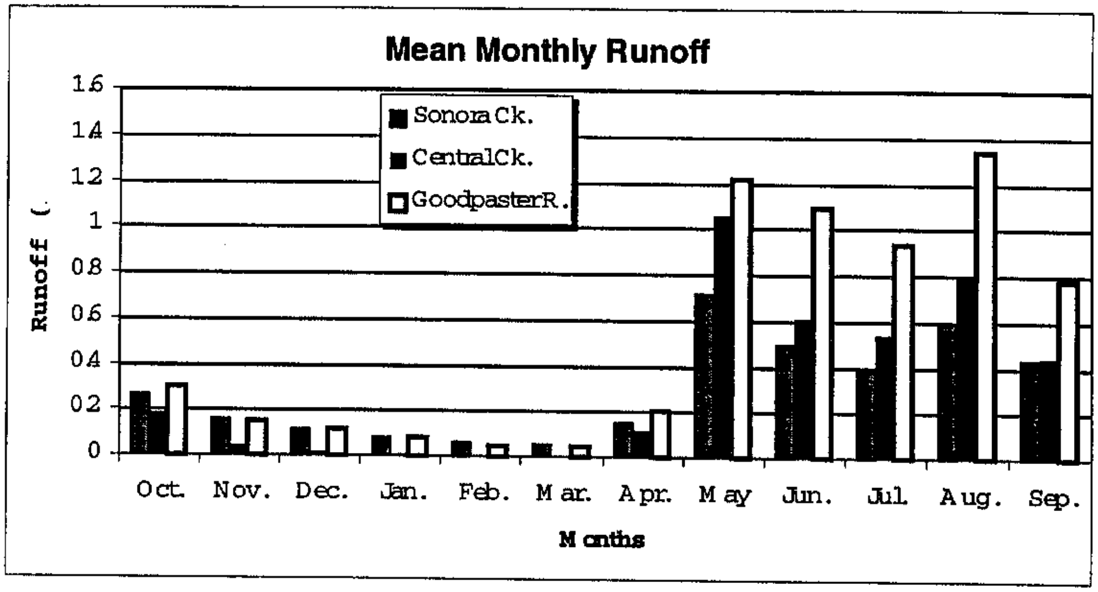


Figure 3.1-19. Mean Monthly Runoff.

4. Flows recede through the late summer and fall to mid-winter minimum flows.

The recorded data indicates that the creeks have an annual runoff of 3.5 to 3.8 inches, as computed by dividing the annual flow volume by the drainage area. The recorded runoff for the Goodpaster River is greater, at approximately 6.2 inches. The difference between these two values may be due to the amount of flow that is lost to sub-surface flow in the smaller catchments; however, a detailed water balance for these basins has not been undertaken to verify this hypothesis.

Figures 3.1-20, 21 and 22 illustrate the computed daily mean discharges for the period of record at the three gauged sites. Based on these data, a composite plot of unit discharge (cfs/sq.mi.) was prepared, as illustrated on Figure 3.1-23. This figure indicates that the Goodpaster River produces the highest unit peak discharge in most cases, (with the exception of the mid-May, 1999 snowmelt event). Summer flows are higher in the Goodpaster River on a unit flow basis. The Creeks tend to recede quicker after flood peaks than does the Goodpaster River.

Pan evaporation data has been gathered on site since 1998. Figure 3.1-24 illustrates the recorded monthly pan evaporation data.

3.1.4 2000 WORK PLANS

The following work items are proposed for 2000 to advance the hydrological information for project development:

- Continued site-specific collection for climatological and hydrometric data provides valuable information for the assessment of hydrological processes to support the design of water management facilities. Data collected to data has included evaporation, temperature, precipitation (rainfall), snowpack, and streamflow. Precipitation data cover a broad range of elevations adjacent to the Liese Creek basin, the primary focus of water management facility design. Stabilization of the monitoring gauge locations will assist in the interpretation and analysis of climatic trends in the project area.

- Continued emphasis on QA/QC for data measurements and interpretation will aid in the optimal design of water management facilities.

- A site reconnaissance during or just after the peak of the spring freshet; possibly mid-May. This would allow observation of snowmelt patterns and runoff conditions in the streams, especially Liese Creek, during the freshet period. Site observations will be useful in assessing how representative the Liese Creek gauging site is relative to other channel reaches upstream and downstream.

- The USGS will continue to monitor stream discharges at the gauging sites established in the vicinity of the Pogo Mine Project. When sufficient hydrometric monitoring data has been obtained at the Liese Creek site, calculations of creek discharges will be provided. These data will be analyzed to verify runoff coefficients for the basin, assess stream response to snowmelt and rainfall inputs and in general to verify assumptions used in hydrological modeling and in hydraulic design components.

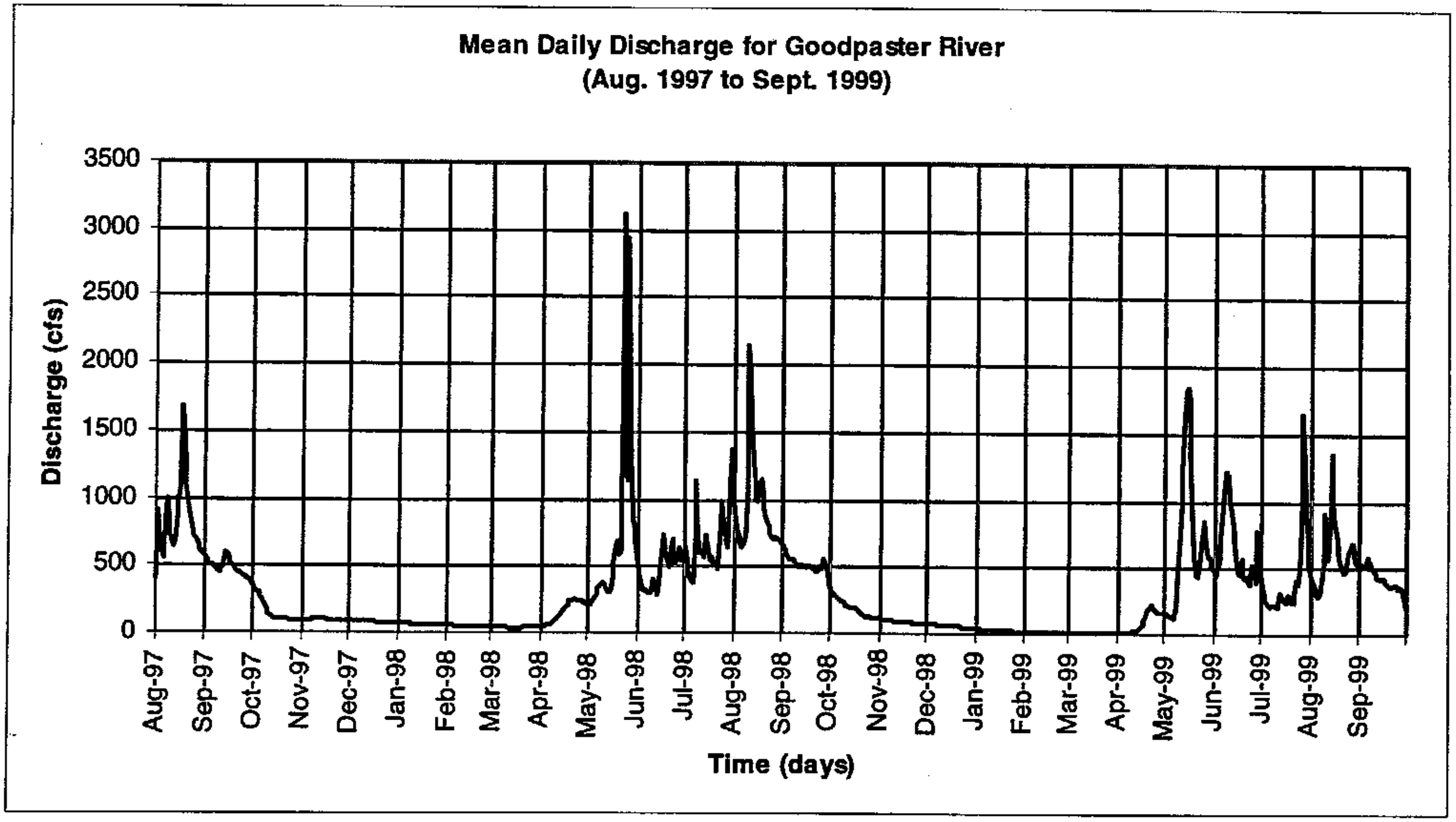


Figure 3.1-20. Mean Daily Discharge for Goodpaster River (Aug. 1997 to Sept. 1999).

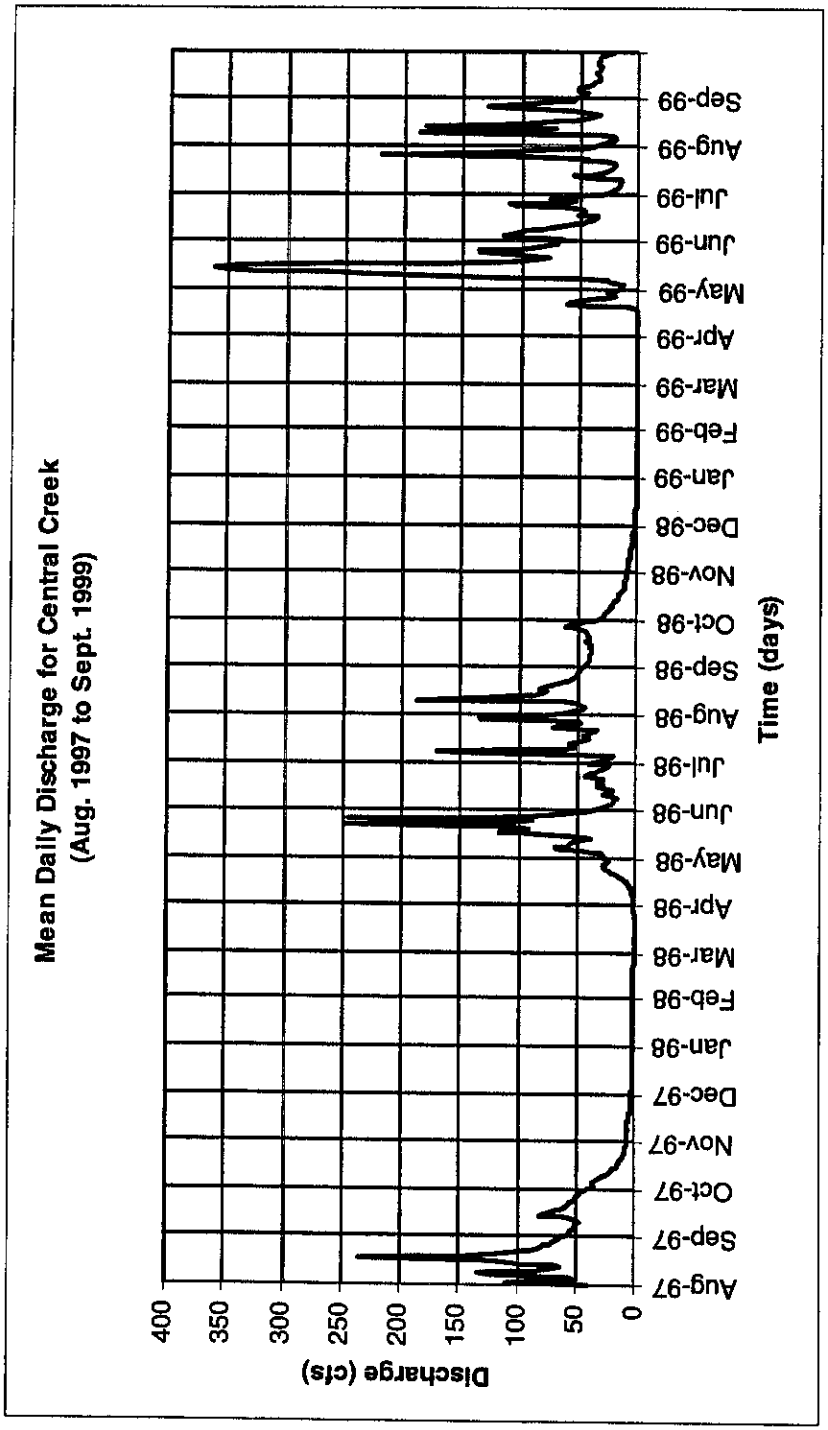


Figure 3.1-21. Mean Daily Discharge for Central Creek (Aug. 1997 to Sept. 1999).

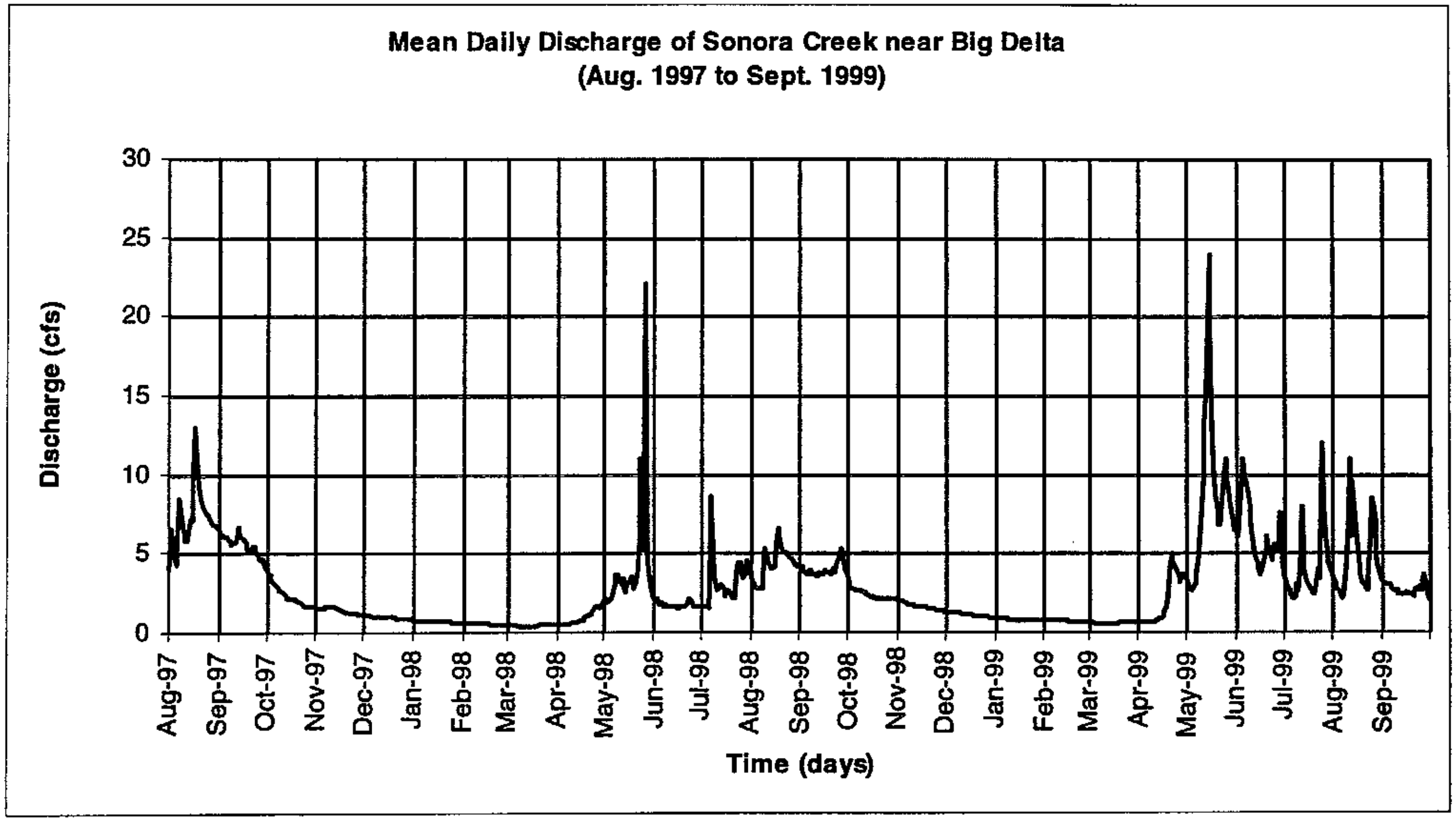


Figure 3.1-22. Mean Daily Discharge of Sonora Creek near Big Delta (Aug. 1997 to Sept. 1999).

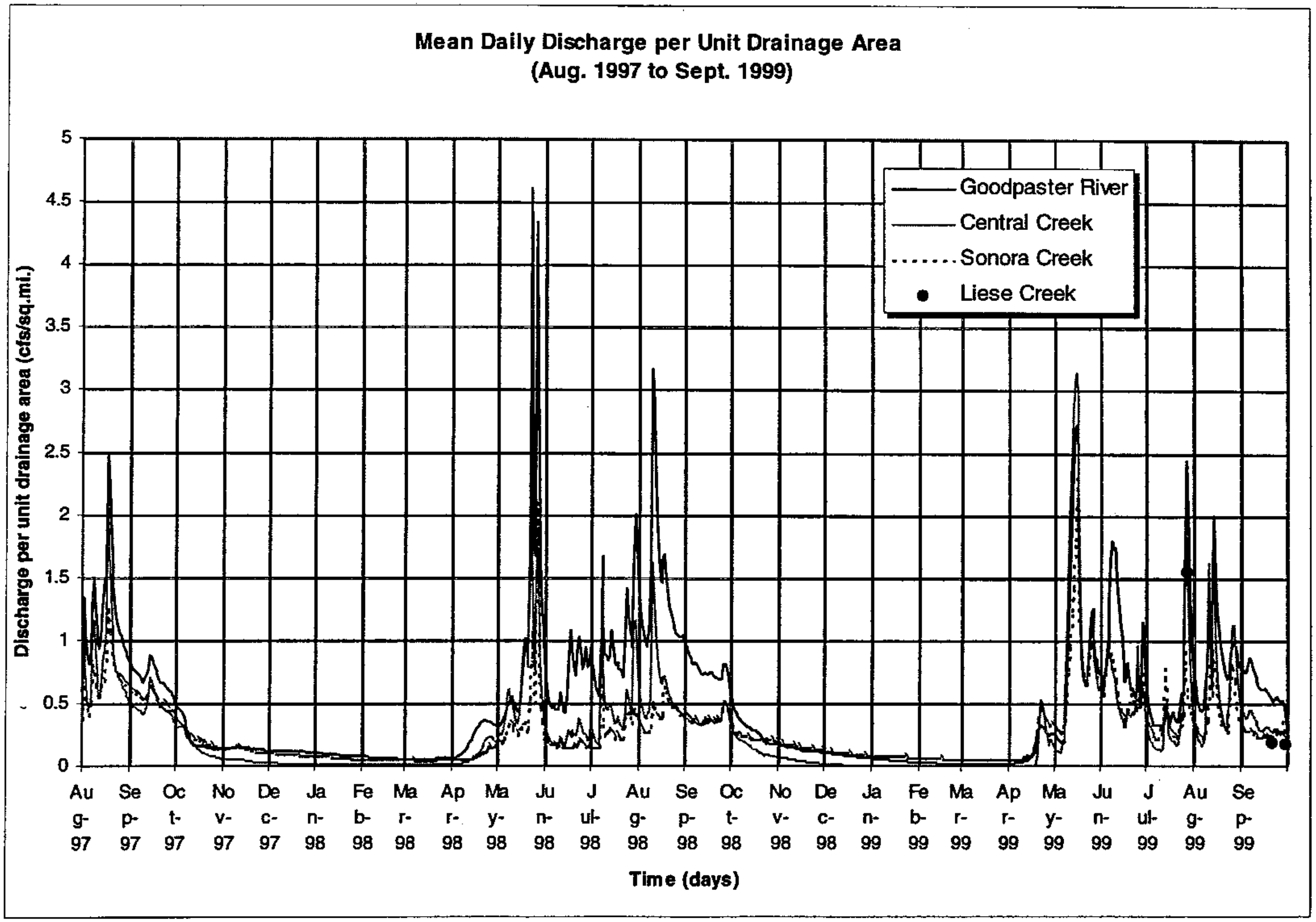


Figure 3.1-23. Mean Daily Discharge per Unit Drainage Area (Aug. 1997 to Sept. 1999).

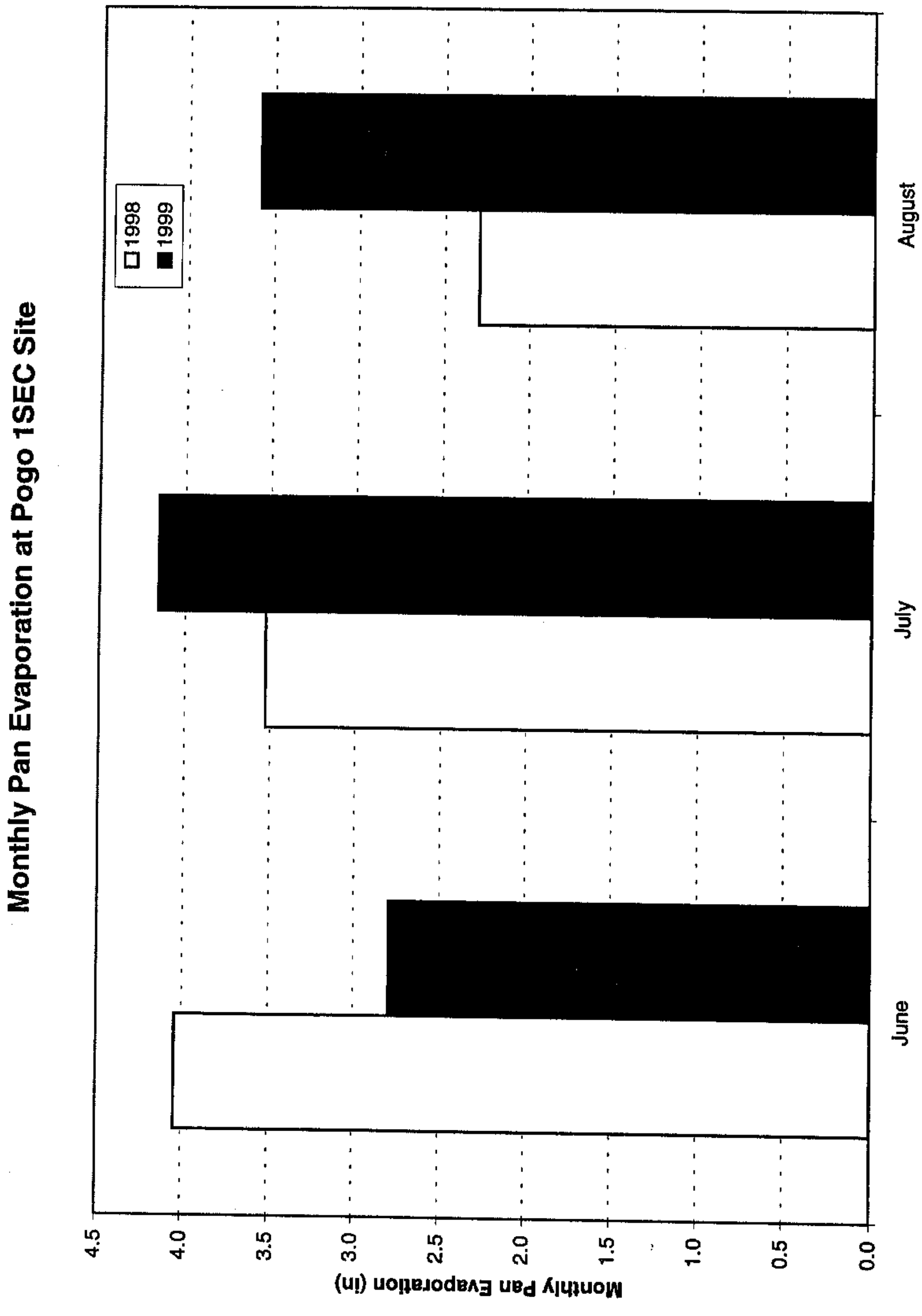


Figure 3.1-24. Monthly Pan Evaporation at Pogo 1SEC Site.

3.1.5 FIELD DATA AND BIBLIOGRAPHY

3.1.5.1 Field Data

Hay and Co. initiated the primary hydrometric data collection program for the Pogo Project in 1997. In 1998 the USGS assumed responsibility for the program. The data from this primary hydrometric data program were presented and discussed in Section 3.1.3. Other miscellaneous hydrometric data from the site are presented in this section. Table 3.1-8 presents miscellaneous discharges measured by HBR during their water quality investigations. The locations of the surface water (SW) monitoring locations are indicated on a Figure in Volume

2.3.1.5.2 Bibliography

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Larry Hinzman

Fax 604-294-4664

Larry Hinzman
P.O. Box 755860
306 Skarland Building
Water and Environmental Research Center
University of Alaska Fairbanks
Fairbanks, Alaska 99775-5860
e-mail ffldh@uaf.edu
phone 907-474-7331
fax 907-474-7979
<http://www.uaf.edu/water/>

Hope this helps,

Mike

Michael P. Davies, Ph.D., P.Eng., P.Geo.
AGRA Earth & Environmental
2227 Douglas Road, Burnaby, B.C. V5C 5A9
Direct (Burnaby) 604-473-5304
Fax (Burnaby) 604-294-4664
michael.davies@agra.com
www.agra.com

National Atmospheric Deposition Program/National Trends Network
1999 Annual & Seasonal Data Summary for Site AK01
Page 1: Summary of Sample Validity and Completeness Criteria
(Printed 07/13/2000)

Site Identification

Site Name	Poker Creek
Site ID	AK01
State	AK
County	Fairbanks North Star
Operating Agency	USFS-Pacific NW Exp. Stn
Sponsoring Agency	USFS
Latitude	65:09:17
Longitude	147:29:10
Elevation	230 m

Sample Validity for Annual Period

Sampling Intervals	52
Valid Samples	36
with precipitation	27
with full chemistry*	24
without chemistry	3
without precipitation	9
Invalid Samples	16
with precipitation	16
missing precipitation data	0

Summary Period Information

	Annual	Winter*	Spring*	Summer*	Fall
First summary day	12/29/1998	12/01/1998	03/02/1999	06/01/1999	08/31/1999
Last summary day	12/28/1999	03/02/1999	06/01/1999	08/31/1999	11/30/1999
Summary period (days)	364	91	91	91	91
Sampling intervals	52	13	13	13	13
Measured precipitation (cm)	29.2	2.7	1.9	13.3	9.8
Valid samples with full chemistry**	24	4	4	6	8
Valid field pH measurements	17	2	2	6	7

NADP/NTN Completeness Criteria

	Annual	Winter*	Spring*	Summer*	Fall
1.Summary period with valid samples (%)	81.9	53.8	67.0	46.2	84.6
2.Summary period with precip coverage (%)	100.0	100.0	100.0	100.0	100.0
3.Measured precipitation with valid samples (%)	80.6	32.2	82.8	67.3	93.2
4.Collector efficiency (%)	76.9	87.5	62.6	97.6	78.8
Precip with full chemistry and valid field pH (%)	68.1	16.8	69.6	67.3	92.4

---

* = Data do not meet NADP/NTN Completeness Criteria for this period.

** = Valid samples for which all Laboratory Chemical measurements were made (The ONLY samples described by the percentile distributions in the Statistical Summary of Precipitation Chemistry for Valid Samples).

*** = Measured precipitation for sample periods during which precipitation occurred and for which complete valid laboratory chemistry . data are available

National Atmospheric Deposition Program/National Trends Network
1999 Annual & Seasonal Data Summary for Site AK01

Page 2: Statistical Summary of Precipitation Chemistry for Valid Samples

Precipitation-Weighted Mean Concentrations

	Ca	Mg	K	Na	NH4	NO3	Cl	SO4	H(lab)	H(fld)	pH(lab)	pH(fld)
							mg/L					
Annual	0.04	0.003	0.008	0.007	0.05	0.17	0.02	0.13	4.63E-03	5.22E-03	5.33	5.28
Winter*	0.03	0.007	0.007	0.017	0.02	0.66	0.11	0.12	1.18E-02	1.17E-02	4.93	4.93
Spring*	0.12	0.011	0.020	0.023	0.01	0.14	0.04	0.32	4.11E-03	7.28E-03	5.39	5.14
Summer*	0.04	0.004	0.014	0.004	0.11	0.22	0.02	0.17	4.91E-03	5.78E-03	5.31	5.24
Fall	0.03	0.002	0.003	0.006	0.01	0.12	0.02	0.09	4.00E-03	4.06E-03	5.40	5.39

Deposition

	Ca	Mg	K	Na	NH4	NO3	Cl	SO4	H(lab)	H(fld)	pH(lab)	pH(fld)
							kg/ha					
Annual	0.10	0.009	0.023	0.020	0.14	0.50	0.07	0.38	1.35E-02	1.52E-02	--	--
Winter*	0.01	0.002	0.002	0.005	0.01	0.18	0.03	0.03	3.22E-03	3.19E-03	--	--
Spring*	0.02	0.002	0.004	0.004	0.00	0.03	0.01	0.06	7.90E-04	1.40E-03	--	--
Summer*	0.05	0.005	0.019	0.005	0.15	0.29	0.03	0.23	6.55E-03	7.71E-03	--	--
Fall	0.03	0.002	0.003	0.006	0.01	0.12	0.02	0.09	3.94E-03	4.00E-03	--	--

Weekly Sample Concentrations

	Ca	Mg	K	Na	NH4	NO3	Cl	SO4	H(lab)	H(fld)	pH(lab)	pH(fld)
							mg/L					
Minimum value	0.01	0.001	0.001	0.003	0.02	0.03	0.01	0.03	2.24E-03	1.17E-03	4.79	4.47
Percentile 10	0.01	0.002	0.002	0.003	0.02	0.04	0.03	0.04	2.69E-03	2.41E-03	4.93	4.85
Percentile 25	0.02	0.003	0.003	0.003	0.02	0.06	0.03	0.06	3.37E-03	3.55E-03	5.26	5.01
Percentile 50	0.03	0.004	0.004	0.006	0.02	0.12	0.03	0.11	4.13E-03	5.50E-03	5.39	5.26
Percentile 75	0.06	0.008	0.008	0.014	0.02	0.30	0.04	0.15	5.46E-03	9.77E-03	5.47	5.45
Percentile 90	0.16	0.021	0.024	0.025	0.02	0.70	0.08	0.44	1.20E-02	1.42E-02	5.57	5.62
Maximum value	0.33	0.031	0.040	0.032	0.39	0.89	0.18	0.80	1.62E-02	3.39E-02	5.65	5.93
Arithmetic mean	0.06	0.007	0.008	0.010	0.04	0.21	0.04	0.16	5.26E-03	7.52E-03	5.28	5.12
Arith. std dev	0.07	0.008	0.009	0.008	0.08	0.24	0.03	0.18	3.45E-03	6.99E-03	--	--
Below detection	0	6	3	3	19	2	11	0	--	--	--	--

Other Parameters

	Measured Precipi-tation*** cm	Conduc-tivity uS/cm	Equivalence Ratios		
			SO4 / NO3	SO4+NO3 / H	Cation / Anion
Minimum value	0.08	2.0	0.12	0.49	0.92
Percentile 10	0.09	2.0	0.22	0.63	0.96
Percentile 25	0.22	2.2	0.40	0.74	1.14
Percentile 50	0.63	2.8	1.06	1.10	1.64
Percentile 75	1.64	4.2	3.31	1.30	1.96
Percentile 90	2.43	6.9	4.95	2.42	2.51
Maximum value	3.13	8.7	5.92	4.75	3.06

Annual and Seasonal Equivalence Ratios

	SO4 / NO3	SO4+NO3 / H	Cation / Anion
Annual	0.96	1.18	1.60
Winter*	0.24	1.12	0.98
Spring*	3.06	2.15	1.30
Summer*	0.99	1.44	1.79
Fall	0.96	0.92	1.53

Please see page 1 for footnotes.

Memo

To	**Michael Davies**	File No	**VM00172/V-3**
From	**Gary Beckstead/Andrew Chan**	cc	**Karl Hanneman – Teck Cominco**
Tel	**(403) 235-8118**		
Fax	**(403) 248-1590**		
Date	**3 January 2002**		

Subject **Pogo Project**
Mean Annual Precipitation and Runoff Assessment

The following memo presents the results of our analyses to compare the existing published USGS contour map of mean annual precipitation (Jones and Fahl, 1994) to recorded runoff data for streams in the vicinity of the Pogo project. The second portion of the analysis compares the recorded mean annual precipitation to the basin mean annual runoff and estimates the likely range of mean annual precipitation at the Pogo Mine site from the regional information.

1.0 INTRODUCTION

1.1 Objective

The objective of this analysis was to compare and explain the differences between the existing published U.S. Geological Survey (USGS) contour map of mean annual precipitation with the published table of mean annual precipitation for individual drainage basins from the same document (Jones and Fahl, 1994), as well as evaluate the regional recorded precipitation data in the vicinity of the Pogo project with mean annual discharges at corresponding streamflow gauges.

1.2 Background

The published USGS map of regionalized mean annual precipitation by Jones and Fahl (1994) was derived from 340 climatological stations (long-term daily precipitation and snowfall), 102 snow surveys, and 223 streamflow records from various sources. Data in Alaska were obtained from the National Oceanic and Atmospheric Administration (NOAA), Natural Resource Conservation Service (NRCS), and the U.S. Geological Survey (USGS). Data for Yukon Territory were obtained and the Atmospheric Environment Service (AES), Department of Indian and Northern Affairs (DIAND), and the Yukon Weather Office. Climate records with short periods of record were adjusted to the 30-year normal period of 1951-1980 as recommended by the WMO (1983). Mean annual precipitation lines were modified to create uniform intervals and smooth lines in the St. Elias Mountains, Coast Mountains, and the Alaska-Yukon border. In addition, Jones and Fahl (1994) prepared estimates of mean annual precipitation for individual drainage basins from their equal precipitation map (Plate 2 in their report) using the grid sampling method (values shown in Column 4 of Table 1). The discussion in Jones and Fahl (1994) does not indicate the detailed procedures used to derive either the tabulated or mapped values, (other than to indicate that the records for short-duration stations were adjusted to a selected 30-year duration). Discussions with Mr. Fahl (C. B. Fahl, personal communications) did not provide any insight as he inferred that Mr. Jones, retired, was the main contributor to that portion of the work. However, continuing communications led to fruitful discussions with other USGS personnel (Dave Meyer, personal communications) who indicated that Mr. Jones overlaid the basin map on the mean annual precipitation isoline plot (Plate 2). Although he was unsure of the exact details, Mr. Meyer assumed that the average precipitation reported in the table was derived from the following (based on what procedures are typically used by the USGS):

- A precipitation of 25 inches was conservatively assigned to that portion of the basin situated beyond the 20" isoline;
- A precipitation of 17.5 inches was assigned to the portion of the basin lying between the 15" and 20" isolines; and
- A precipitation of 12.5 inches was assigned to that portion of the basin below the 15" isoline.

The tabulated mean annual precipitation for each basin was the average value for the entire drainage area, determined to the nearest 1.0 inch.

The above procedure, while a good approximation for regional trends, could clearly mask local precipitation patterns and could result in a variance of as much as 2 to 5 inches for a small basin.

2.0 METHODS

2.1 Average Precipitation from Jones and Fahl Map

For the current analysis, in order to develop an independent estimate of the mean annual precipitation for the stream flow gauges analyzed, the river watersheds were outlined and these were drawn on a copy of the map from Jones and Fahl (1994), photo-reduced to the same scale. Interpolated precipitation contours (1-inch interval) were drawn between the 15" and 20" precipitation contours drawn by Jones and Fahl (1994). For areas where the precipitation was in excess of 20", a smooth line interpolation was used to estimate 1" interval isolines. A similar procedure was used for areas with less than 15" precipitation. The area of the drainage basin within each precipitation interval was measured and multiplied by the value of the interval. The sum of the interval products was divided by the total area to derive an estimate of the average precipitation over the basin.

2.2 Average Precipitation from Basin Climatic Data

Hypsometric curves were derived for the basins of interest and components of the basins within elevation ranges were related to recorded precipitation from regional stations to estimate basin recorded mean annual precipitation.

2.3 Comparison of Mean Annual Precipitation Estimates

The mean annual precipitation estimates described based on the recorded precipitation (Section 2.2) was compared to the precipitation estimates from integration of the map values (Section 2.1) and the tabulated values in Jones and Fahl (1994), and assessed.

The mean annual precipitation from Jones and Fahl (1994) and estimates from the recorded mean annual precipitation were compared to the recorded mean annual runoff. Patterns and scatter in the plots were assessed.

The results from the analyses were reviewed and used to characterize the likely range of mean annual precipitation at the Pogo Mine site.

3.0 RESULTS

The following results were obtained for each of the steps outlined for this work:

1. Based on the contour map (Plate 2) of mean annual precipitation in Jones and Fahl (1994) the mean annual precipitation for the gauged basins examined by Jones and Fahl ranged from 16.9 to 19.7 inches, as summarized in Table 1. The low value was for the Chena River at Fairbanks and the Fortymile River near Steele Creek and the high value was for the Chena River near Two Rivers.

TABLE 1
Summary of Mean Annual Precipitation for Selected Basins

Station	Drainage Area (sq. mi.)	Mean Basin Elevation (ft.) Jones and Fahl (1994), (Table 5, p.84,89)	Mean Annual Precipitation (in.)			
			Note 1	Jones and Fahl, (1994, Table 5, p.84, 89)	Difference Between AMEC Integration and Jones and Fahl Table Value	Estimates From Climatic Data (Section 2.2)
(1)	(2)	(3)	(4)	(5)	(6) = (4) – (5)	(7)
Salcha River near Salchaket	2170	2520	18.5	15	3.5	15.3
Chena River near Two Rivers	937	2270	19.7	16	3.7	18.8
Chena River near North Pole	1430	1930	17.9	15	2.9	Note 2
Little Chena River near Fairbanks	372	1480	16.3	15	1.3	15.9
Chena River at Fairbanks	1995	1770	17.1	15	2.1	17.9
Fortymile River near Steele Creek	5880	2940	16.9	17	-0.1	12.6

Note 1. Integrated from Jones and Fahl map by AMEC based on interpolation described in Section 2.0 above.

Note 2. Mean annual precipitation was not computed from climatic data for this basin, as there are limited runoff data for this site to relate to mean annual precipitation estimates.

2. Estimates of basin mean annual precipitation were determined from meteorological stations that had total precipitation data available within the gauged basins. For basins where no stations with total precipitation data are available, basin mean annual precipitation was estimated from recorded snowpack data from a nearby station in an adjacent basin and the value factored up based on snowpack as a percentage of total precipitation. The mean annual precipitation estimates from this procedure are summarized in Table 1.

   i) Mean annual precipitation estimates for each basin were estimated based on meteorology stations within each basin or from meteorology stations adjacent to the basin.

      Salcha River Basin:
      The Caribou Mine site is the only meteorological monitoring site in the Salcha River basin. Only snowpack is monitored at the Caribou Mine site.

      a. Snowpack data from stations that also have total precipitation data in the adjacent Chena River basin to the west were examined to determine which of the stations would best correlate to the Caribou Mine station snowpack data. The stations examined were Munson Ridge, Teuchet Creek, Upper Chena Pillow, Monument Creek, and Fairbanks Field Office.

      b. The Fairbanks Field Office snowpack data correlated best with Caribou Creek snowpack data with a correlation coefficient of 0.902. Fairbanks long-term average snowpack is 35.9% of mean annual precipitation.

      c. Long-term Caribou Mine snowpack data (1965-1999) has an average value of 5.50 inches. Therefore, if the Fairbanks FO ratio were used to infer the mean annual precipitation of the Salcha River basin, the mean annual precipitation estimate would be 15.33 inches.

      d. The corresponding recorded (1965-1999) mean annual runoff for the Salcha River basin near Salchaket is 9.59 inches.

      Chena River near Two Rivers:
      The Chena River near Two Rivers basin has four stations with total precipitation data: Munson Ridge (EL. 3100 ft.), Teuchet Creek (EL. 1640 ft.), Monument Creek (EL. 1850 ft.), and Upper Chena Pillow (EL. 2900 ft.). A regression analysis of long-term mean annual precipitation versus elevation ($r^2 = 0.67$) was performed for these stations and applied to a basin hypsometric curve to determine the estimated mean annual precipitation. The mean annual precipitation for the Chena River near Two Rivers basin is estimated to be 18.79 inches. The corresponding recorded long-term mean annual runoff for the Chena River near Two Rivers basin is 9.97 inches.

Little Chena River near Fairbanks:
The Little Chena Ridge site is the only meteorological monitoring site in the Little Chena River near Fairbanks basin. Only snowpack is monitored at the Little Chena Ridge site.

a. Snowpack data from stations that have total precipitation data in the adjacent Chena River basin were examined to determine which of the stations would best correlate to the Little Chena Ridge station snowpack data. The stations examined were Munson Ridge, Teuchet Creek, Monument Creek, and Fairbanks Field Office.

b. Fairbanks Field Office snowpack data correlated best with Little Chena Ridge snowpack data with a correlation coefficient of 0.890. Fairbanks long-term average snowpack is 35.9% of mean annual precipitation.

c. Long-term Little Chena Ridge snowpack data (1962-2000) has an average value of 5.72 inches. Therefore, if Fairbanks FO were used to infer the mean annual precipitation of the Little Chena River near Fairbanks basin, the mean annual precipitation would be 15.93 inches.

d. The corresponding recorded (1967-2000) mean annual runoff for the Little Chena River basin near Fairbanks basin is 7.58 inches.

Chena River at Fairbanks:
The Chena River at Fairbanks basin has four stations with total precipitation data: Fairbanks FO (EL. 450 ft.), Munson Ridge (EL. 3100 ft.), Teuchet Creek (EL. 1640 ft.), Monument Creek (EL. 1850 ft.), and Upper Chena Pillow (EL. 2900 ft.). A regression analysis of long-term mean annual precipitation versus elevation ($r^2 = 0.82$) was performed for these stations and applied to a basin hypsometric curve to determine the estimated mean annual precipitation. The mean annual precipitation for the Chena River at Fairbanks basin is estimated to be 17.88 inches. The corresponding long-term mean annual runoff for the Chena River at Fairbanks basin is 9.57 inches.

Fortymile River near Steele Creek:
The Fortymile River near Steele Creek basin has three meteorological monitoring stations within the basin: Mission Creek (EL. 450 ft.), Chicken Airstrip (EL. 1650 ft.), and Mt. Fairplay (EL. 3100 ft.). Total precipitation data is only available from the Mission Creek station.

a. Snowpack data from Mt. Fairplay and Chicken Airstrip were examined to determine which of these two stations would best correlate to the snowpack data from Mission Creek station.

b. The Mt. Fairplay snowpack data correlated best with the Mission Creek snowpack data with a correlation coefficient of 0.750. The Mission Creek long-term average snowpack is 34.3% of the mean annual precipitation.

c. The long-term Mt. Fairplay snowpack data (1970-2000) has an average value of 4.32 inches. Therefore, if Mission Creek is used to infer the mean annual precipitation of the Fortymile River near Steele Creek basin, the mean annual precipitation would be 12.60 inches. For comparison purposes, the long-term mean annual precipitation at Mission Creek is 12.19 inches.

d. The mean annual runoff at Fortymile River near Steele Creek for the period of record (1976 to 1982) is 6.29 inches.

3. The results from 1. and 2. above were compared as illustrated on Figure 1. In general there is good correlation only for the three points within the Chena River basin, probably due to the fact that there are five meteorological stations in the Chena basin that were used to estimate total annual precipitation. The precipitation for the Salcha River near Salchaket and Fortymile River basins appear to be less than those suggested by the Jones and Fahl map (1994). The Salcha basin precipitation is about 3 inches less than depicted by the map, while the Fortymile River basin is about 4 inches less. As there is less precipitation data available in these two basins, there is uncertainty associated with these latter two precipitation estimates.

   The addition of a sublimation allowance (say 0.5 inches) would not the change the relative plotting position of the points appreciably.

4. Mean annual runoff was compiled for the gauged streams, based on long-term records from the USGS. The periods of record for the gauged streams varied widely, from 53 years (1947 to 2000 for the Chena River at Fairbanks) to 6 years (1976 to 1982 for the Fortymile River near Steele Creek gauge). Mean annual runoff at these gauges varied between a low of 6.3 inches (Fortymile River near Steele Creek basin to the east) and a high of 10.1 inches for the Salcha River near Salchaket. The data in Table 2 indicates the variations between the mean annual runoff for selected periods of record.

TABLE 2
Summary of Computed Basin Runoff

Streamflow Gauging Station Name	Drainage Area (sq. mi.)	Period of Record	Mean annual Runoff (in.)				
			1998 to 2000	1976 to 1982	1968 to 2000	1951 to 1980	Period of Record
Salcha River near Salchaket	2170	1948 to 2000	8.09	8.35	9.3	10.15	10.06
Chena River near Two Rivers	937	1968 to 2000	8.38	8.22	9.97	10.89E	9.97
Chena River near North Pole	1430	1972 to 1980	N/A	-	-	-	6.99
Little Chena River near Fairbanks	372	1966 to 2000	5.91	6.13	7.35	8.12E	7.58
Chena River at Fairbanks	1995	1947 to 2000	10.65	7.08	8.74	9.38	9.57
Fortymile River near Steele Creek	5880	1976 to 1982	N/A	6.29	7.49E	7.99E	6.29
Recently Gauged Local Basins:							
Central Creek near Big Delta	115	1998 to 2000	5.31	-	-	-	5.31
Sonora Creek near Big Delta	10.5	1998 to 2000	4.77	-	-	-	4.77
Goodpaster River near Big Delta	677	1997 to 2000	8.03	-	-	-	8.03

Note: Data not shown for Chena River at North Pole due to short period of record (1972 to 1980) that is not coincident with other periods of record under consideration.
E indicates estimated values based on regional average ratio of runoff for period of interest to the runoff for the concurrent period

5. The mean annual precipitation values from Jones and Fahl (1994) were plotted against the annual runoff for the period 1951 to 1980 from 4. above, as illustrated in Figure 2. This plot suggests a range of runoff coefficients of 0.55-0.47. The runoff coefficient is approximately 0.55 for the two basins that operated during the same period as the precipitation data.

6. The tabulated mean annual precipitation from Jones and Fahl (1994) was plotted against runoff in Figure 3. This plot suggests a range of runoff coefficients of 0.47 to 0.67, a wider scatter than Figure 2. This may be due to the computational method used by Jones and Fahl (1994). Note also the one-inch increment of precipitation inherent in their tabulated data.

7. Figure 4 was prepared by plotting the mean annual precipitation from rainfall and snowpack record versus runoff for a different time period. This plot suggests a range of runoff coefficients (0.46 to 0.61).

   The Salcha and Goodpaster Rivers had near identical runoff over the last four years (8.09 inches vs. 8.03 inches in Table 1.4-2). The long-term runoff for the Salcha River is 10.1 inches. Because the recent short-term annual runoff values were near identical for both basins, and because the upper portions of the basins are adjacent, the long-term runoff for the Goodpaster River is also estimated to be 10.1 inches.

8. The plots (Figures 2 to 4) of regional flow data versus mean annual precipitation were assessed to determine if the runoff from basins could be used as a basis for checking published mean annual precipitation estimates. The flow monitoring results from the basins appear to indicate a reasonable relationship with mean annual precipitation estimates. Hence, it is believed that reasonable estimates of long-term precipitation can be inferred from estimates of annual runoff.

   The basins in the region appear to have an average annual runoff coefficient of 0.46 to 0.67. This compares with Salcha River runoff ratios of 55% of precipitation on Figure 2, 67% of total precipitation on Figure 3, and 61% on Figure 4. If one assumes that the Goodpaster has the same long-term runoff and runoff coefficients as the Salcha River, the mean annual precipitation for the Goodpaster basin can be estimated to be in the range of 15.1 to 18.4 inches.

   Monitoring in the Liese Creek basin in 2000 and 2001 provided runoff coefficient values of 0.48 and 0.39, respectively. These local values are slightly lower than the regional values. Considering permafrost distribution and other factors affecting runoff coefficients, it may be reasonable to expect that values for small basins may not necessarily mirror values for large basins. Considering these short-term values and the results for the regional basins, a runoff coefficient value of 0.5 is still expected to be reasonable for modeling of the runoff in the Liese Creek basin.

9. If the estimated long-term annual runoff for the Salcha River and Goodpaster River basins are assumed to be near identical at 10.1 inches (see Result 8) and if one assumes that the basin characteristics are similar, it follows that the mean annual precipitation for the basins must be similar. The range of mean annual precipitation for the Salcha River basin from Jones and Fahl (1994) ranges from 15 inches in the Jones and Fahl (1994) table to 18.5 inches based on the Jones and Fahl (1994) map). If we take the ratio of the long-term (1948 to 2000) to recent (1998 to 2000) runoff 10.1/9.3 = 1.09 and multiply that ratio by the estimated short-term precipitation from correlation with the local snowpack monitoring site for the Salcha River basin (15.33"), we get a value of 16.7 inches as the estimated long-term precipitation mean for the Goodpaster Basin at Pogo.

10. The Jones and Fahl (1994) precipitation map was prepared to illustrate precipitation trends. It was not intended to portray accurate precipitation values for the specific location, (Meyer, personal communication, 2001). Hence, spot precipitation values may not be accurate. For instance, the map value for Delta Junction is approximately 13 inches, which is 17% greater than the 1951 to 1980 average of 11.1 inches. (The period of record average is 11.7 inches.) Thus it may not be reliable to use the precipitation values directly from the Jones and Fahl (1994) map.

    There is a marked decrease in winter snowpack moving west to east from the Chena River basin to the Salcha River basin and a further decrease in snowpack moving east to the Fortymile River basin. (AMEC, 2002). The estimated mean annual runoff for the Salcha River near Salchaket is 10.1 inches with a basin mean annual precipitation estimate of 16.7 inches, as mentioned above. The estimated long-term mean annual runoff for the Fortymile River near Steele Creek is 6.3 inches and the basin mean annual precipitation is estimated to be 12.6 inches. As the Pogo Mine site and the Goodpaster River basin are situated between the Salcha and the Fortymile River basins, and as a trend to lower mean annual precipitation in a west to east direction is evident, the mean annual precipitation for the Pogo Mine site may be estimated to be between the estimates for the Salcha River and Fortymile River basins, i.e., between 12.6 inches and 16.7 inches. On this basis a mean annual precipitation value for the Pogo Mine site of 15 inches appears to be a reasonable estimate.

4.0 CONCLUSIONS

The results obtained from the comparison of regional precipitation and runoff information can be summarized as follows:

a. The 1994 USGS report by Jones and Fahl (1994) provided tabulated mean annual precipitation values for gauged basins that is less than the calculated values obtained by overlaying the Jones and Fahl precipitation contour plan over the basin outlines and computing the average basin precipitation using 1" interval interpolated values. The differences between the tabulated values and mean values measured from the map range from –0.1 inches to +3.7 inches (-0.01% to +23%), as illustrated in Table 1. Thus the map results in a larger mean annual precipitation for five out of six basins than the basin estimates presented by the same authors in tabular form. The Jones and Fahl report does not clearly identify the derivation of the precipitation plot, and Fahl was unable to provide additional details. This discrepancy may be due to the differences in the methods and assumptions used.

b. There are significant differences between the mean annual precipitation values calculated from the Jones and Fahl map and the precipitation estimates derived from actual field data. For the Salcha basin, the field data imply approximately 3" less precipitation than inferred by the map, while the Fortymile basin field data implies approximately 4" less than inferred by the map.

c. Comparison of mean annual precipitation estimates with measured stream discharges suggests mean annual precipitation for the gauged basins in the region is in the range 13 to 19 inches based on the following estimates:

   i) 12.6 to 18.8 inches based on regional rainfall and snowpack data. These data are based on the closest available regional long-term precipitation and snowpack monitoring sites. The plot of these data (Figure 4) provides a reasonable relationship between runoff and precipitation. There is a trend to lower precipitation moving east from the Chena River Basin to the Fortymile River basin.
   ii) 15 to 17 inches based on the Jones and Fahl (1994) table. These estimates were based on grid measurements for the gauged drainage basins using Plate 2 from the 1994 Jones and Fahl report. This estimate is based on precipitation and stream discharge measurements for the 30-year period 1951 to 1980.
   iii) 16.3 to 19.7inches based on an analysis using the Jones and Fahl (1994) map.

d. Review of the runoff and precipitation data provides a reasonable basis for estimating a range of mean annual precipitation for the Goodpaster Basin as follows:

   i) 15.1 to 18.4 inches based on the application of the range of Salcha basin runoff coefficients to the estimated long-term runoff for the Goodpaster River basin.

ii) 16.7 inches by pro-rating the short-term precipitation for the Salcha River basin up by 9% to represent a long-term average.
iii) between the estimates for the Salcha River and Fortymile River basins, i.e., between 12.6 inches and 16.7 inches., or approximately 15 inches.

From this it may be concluded that based on available data and published interpretation of that data, 19 inches appears to be somewhat high for a realistic upper bound for the mean annual precipitation in the Goodpaster basin. Measured stream discharges and regional information, including the published information included in the table by Jones and Fahl, are more supportive of a value in the range of 15-17 inches. Furthermore, based upon AMEC (2002), although the snowpack in certain areas of interior Alaska has been 15% below normal during the last 4 years, these trends do not apply to the east of Pogo and may not apply at Pogo. In any event, since the data do not show a strong correlation between snowpack values and total annual precipitation for this region of Alaska, there is no justification to suggest that if snowpack trends change, the total annual precipitation would change as well.

Yours truly,

AMEC Earth & Environmental Limited

Andrew Chan, M.Sc., P.Eng.
Water Resources Engineer

Gary R. E. Beckstead, M.Sc., P.Eng.
Senior Water Resources Engineer

AMC/tk

Attachments

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Meyer, David F., 2001. Hydrologist (Surface Water Specialist), USGS, Anchorage, AK, Personal Communication, telephone conversation, 21 November 2001.

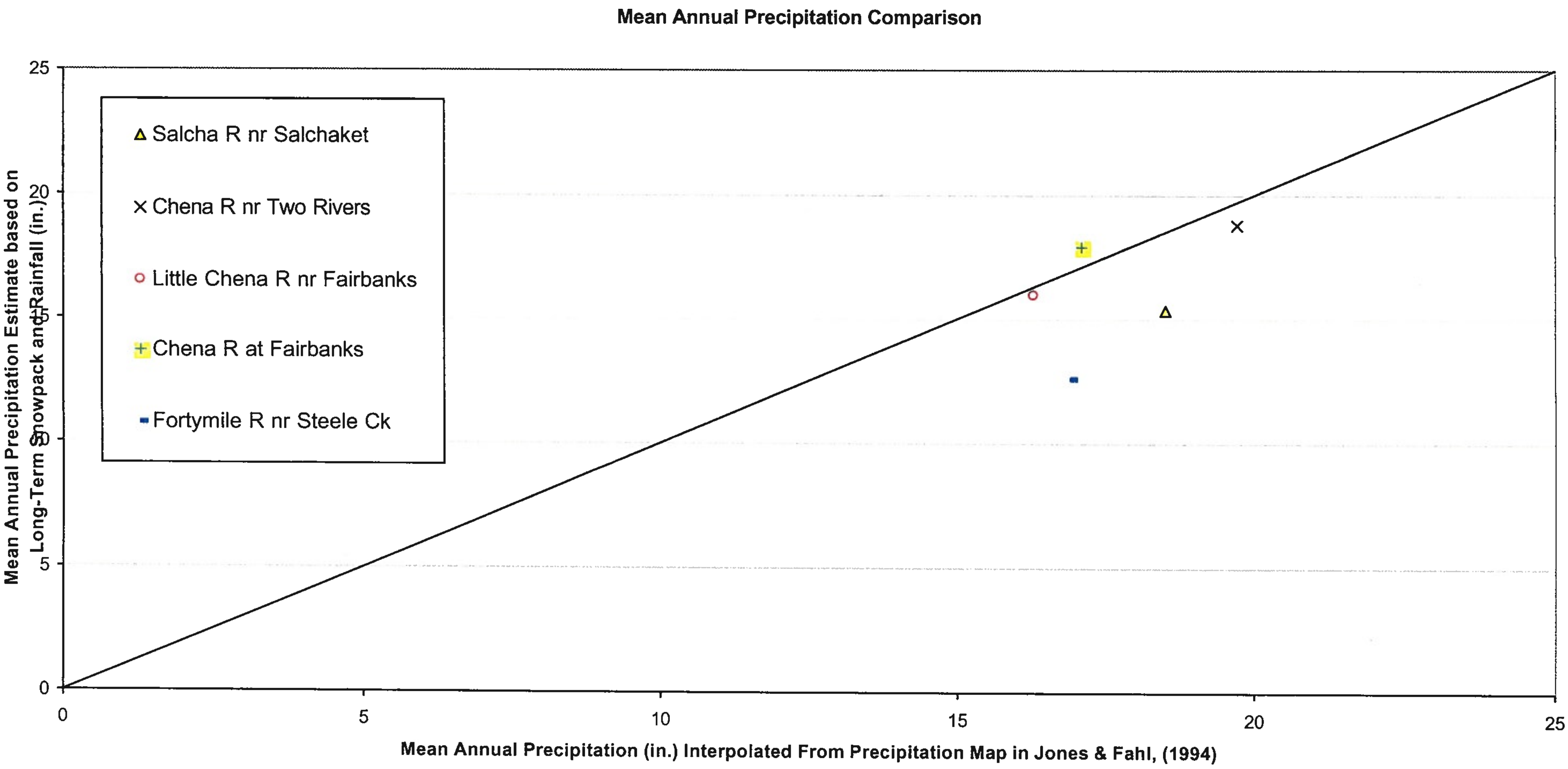
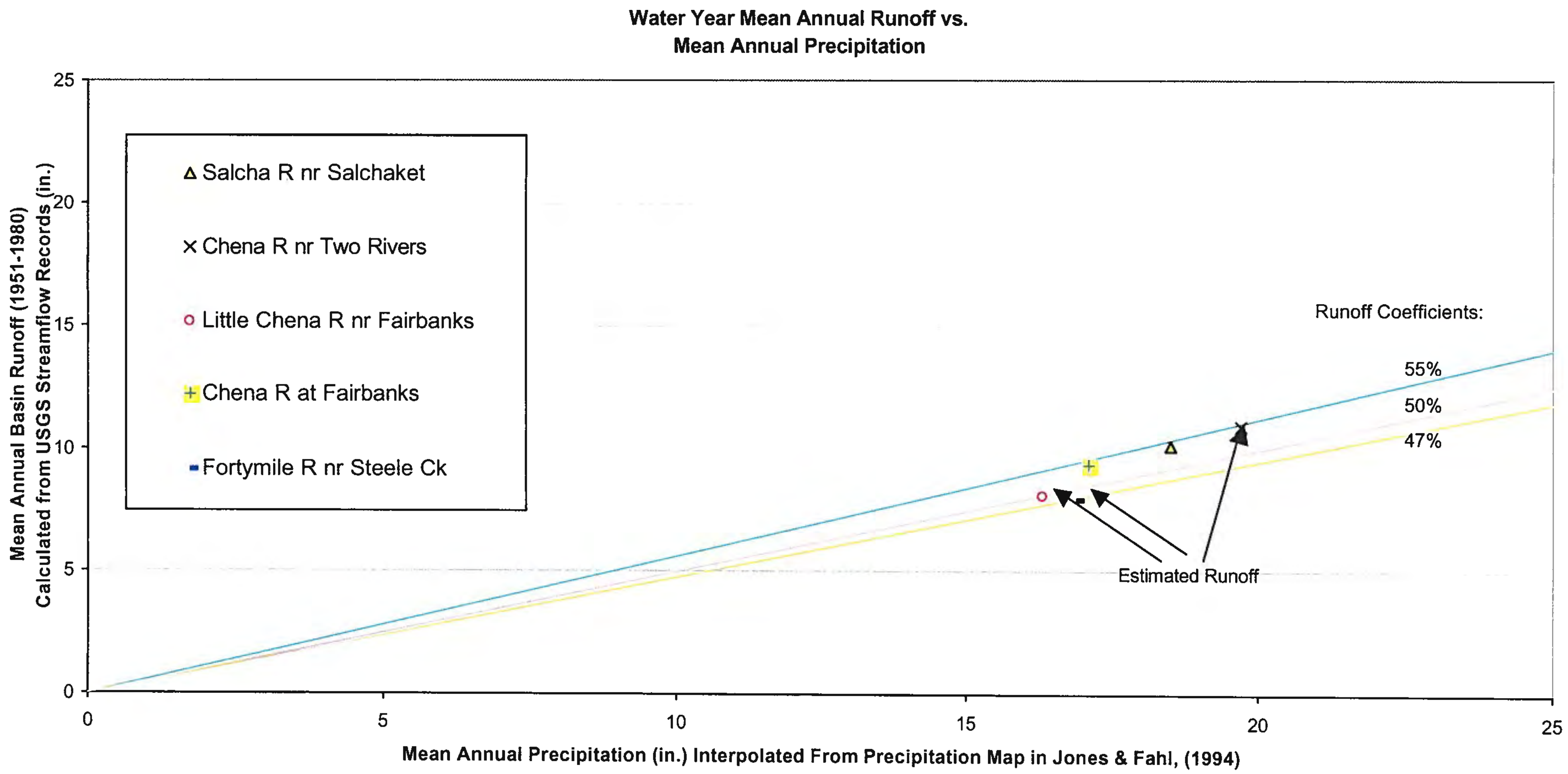

Mean Annual Precipitation Comparison
Mean Annual Precipitation Estimate based on Long-Term Snowpack and Rainfall (in.)
Mean Annual Precipitation (in.) Interpolated From Precipitation Map in Jones & Fahl, (1994)
0
5
10
15
20
25
△ Salcha R nr Salchaket
× Chena R nr Two Rivers
○ Little Chena R nr Fairbanks
+ Chena R at Fairbanks
▬ Fortymile R nr Steele Ck

Figure 1



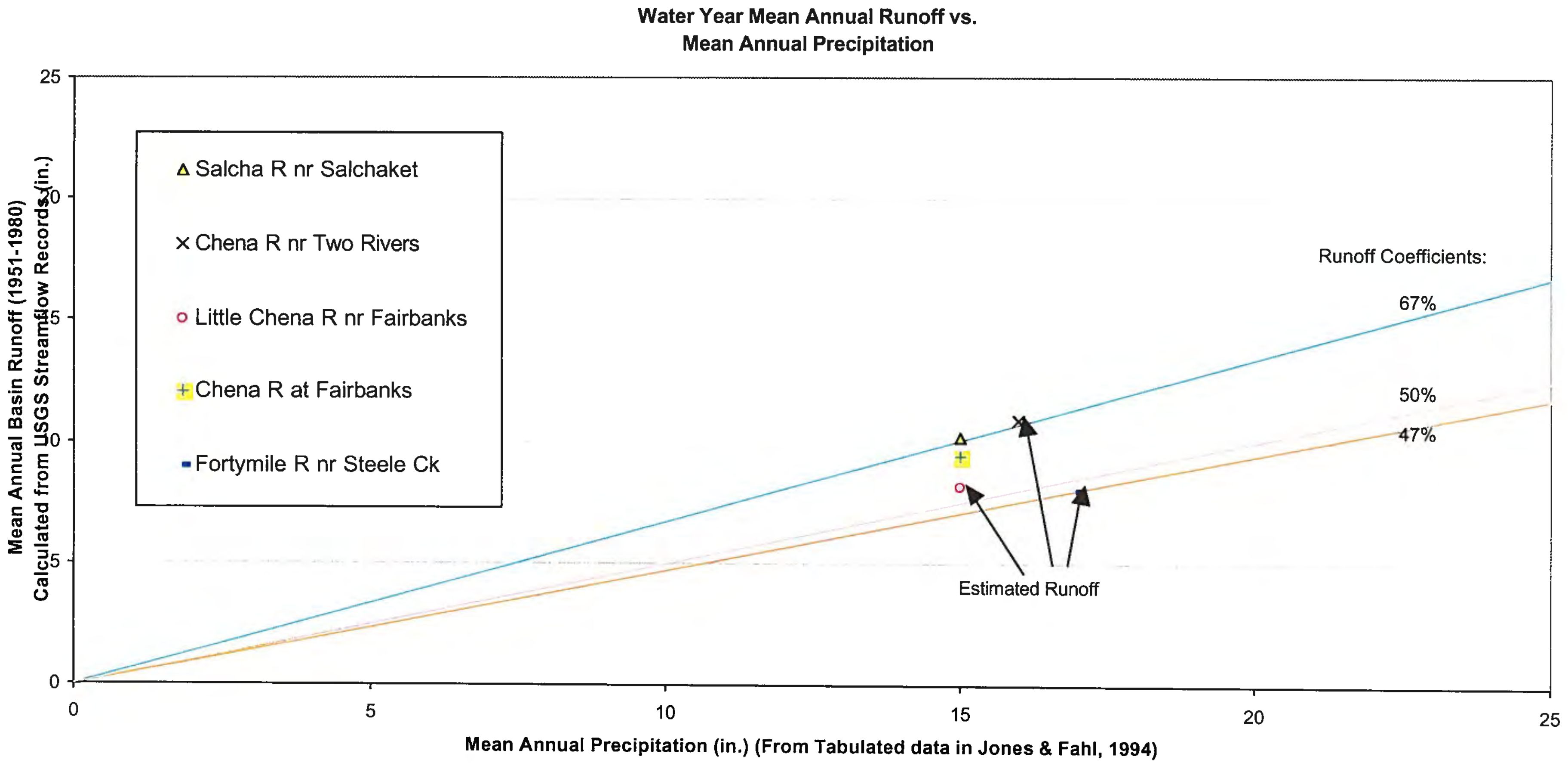

Water Year Mean Annual Runoff vs.
Mean Annual Precipitation
Mean Annual Basin Runoff (1951-1980)
Calculated from USGS Streamflow Records (in.)
25
20
15
10
5
0
△ Salcha R nr Salchaket
× Chena R nr Two Rivers
○ Little Chena R nr Fairbanks
+ Chena R at Fairbanks
▪ Fortymile R nr Steele Ck
Runoff Coefficients:
67%
50%
47%
Estimated Runoff
0
5
10
15
20
25
Mean Annual Precipitation (in.) (From Tabulated data in Jones & Fahl, 1994)

Figure 3

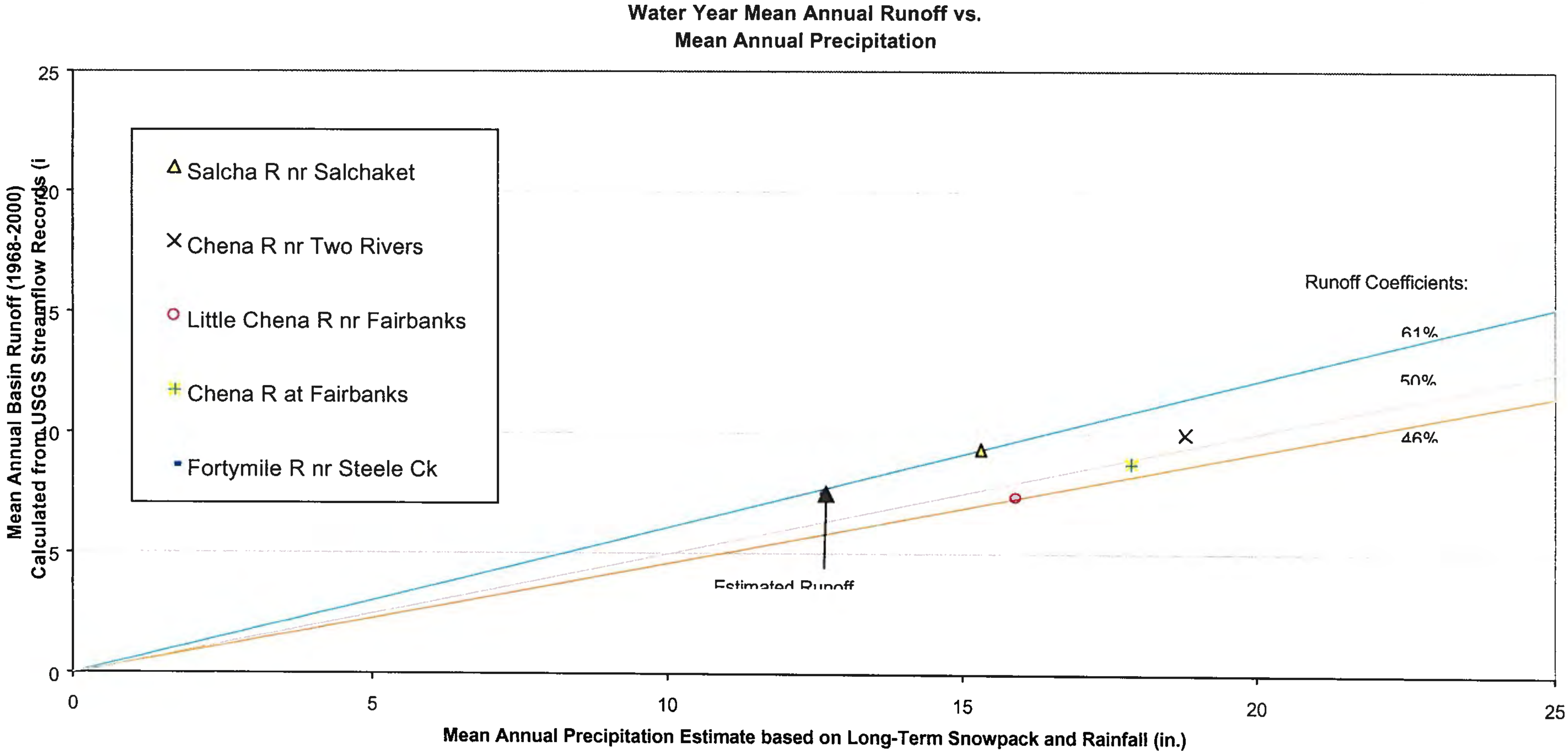

Water Year Mean Annual Runoff vs.
Mean Annual Precipitation
Mean Annual Basin Runoff (1968-2000)
Calculated from USGS Streamflow Records (i
0
5
10
15
20
25
0
5
10
15
20
25
Mean Annual Precipitation Estimate based on Long-Term Snowpack and Rainfall (in.)
△ Salcha R nr Salchaket
× Chena R nr Two Rivers
○ Little Chena R nr Fairbanks
+ Chena R at Fairbanks
▪ Fortymile R nr Steele Ck
Runoff Coefficients:
61%
50%
46%
Estimated Runoff

Figure 4

Memo

To	**Karl Hanneman**	File No	**VM00172/V-3**
From	**Gary Beckstead**	cc	**Michael Davies** **Peter Lighthall**
Tel			
Fax			
Date	**28 January 2002**		

Subject **Review of Snowpack Data**
Pogo Mine Site and Regional Data

Karl,

In response to your request, the snowpack data in the vicinity of the Pogo Mine site have been reviewed. The following text presents a discussion of:

a) The snowpack measured at the Pogo Mine site in relation to regional snowpack, and
b) The regional snowpack characteristics in relation to the total annual precipitation.

1.0 Pogo Mine Site Snowpack Data

Snowpack data for the Pogo Mine site have been reviewed. Specifically, we have addressed the relationship between the Sonora snowcourse and the Liese basin values. As illustrated on Figure 1, for snowcourse data up through 2001 that was received from Erik Pullman of ABR, there is a strong correlation between the these locations ($r^2 = 0.89$). Hence, the estimation of snowpack for Liese basin can be credibly determined directly from the data for Sonora basin.

The relationship that had originally been derived between the measured Sonora snowcourse and the Chicken snowcourse was reviewed. As shown on Figure 2, with the 2001 data the fit is not as good as previous ($r^2 = 0.999$), but still is strong nevertheless ($r^2 = 0.87$).

We then prepared Figure 3 to compare the snowcourse at Chicken to the modeled basin snowpack at Sonora. This relationship has weakened with the additional data ($r^2 = 0.73$) compared to the previous derivation ($r^2 = 0.95$)

To check that we don't have a better relation with other long-term snowcourses, we plotted the Sonora snowcourse versus other Interior Alaska snowcourses, including not only those used by Erik Pullman in his annual snow reports, but also Mt. Fairplay and Chicken to the east. The geographical distribution of the correlation coefficients is plotted on a plan map on Figure 4, with the relationship for Mt. Fairplay shown on Figure 5. The best fit that we obtained was with Chicken (r^2=0.87) followed by Mt. Fairplay ($r^2 = 0.82$), and Mt. Ryan ($r^2 = 0.71$) and others with lower correlation coefficients.

We have noted that snowcourse measurements at Pogo do not necessarily occur at the time of maximum snowpack. So to confirm that the relationship in Figure 2 is appropriate, we related

AMEC Earth & Environmental Limited
221 – 18 Street SE
Calgary, Alberta
CANADA T2E 6J5
Tel: +1 (403) 248-4331
Fax: +1 (403) 248-1590
www.amec.com

the NRCS snowpack data for the same measurement period (usually late March or early April) with the Pogo data. For stations with good correlation with the Sonora snowcourse data (Chicken: $r^2 = 0.87$ and Mt. Fairplay: $r^2 = 0.82$), the difference between using maximum annual and late-March/early-April NCRS snowcourse data was minimal. For snowcourse locations where the correlations were poor with maximum annual snowpack, the late-March/early-April relations resulted in lower correlation coefficients.

To test the effect of using Chicken and Mt. Fairplay long term records to estimate the long-term snowpack for the Sonora snowcourse, the derived equations with the greatest correlation coefficients were used with the long-term snowpack records as summarized in Table 1. The estimated snowpack for Liese basin was then determined by adjusting the Sonora snowcourse data using the relationship between Sonora snowcourse and Liese basin as given in Figure 1.

Table 1
Summary of Snowpack Estimates

Snowcourse	**Mean Long-term Snowpack (in.) (through 2001)**	**Estimated Sonora Long-term Snowcourse Snowpack (in.)**	**Estimated Liese Long-term Snowpack (in.)**
Chicken Airstrip	3.13	3.41	3.24
Mt. Fairplay	4.35	2.84	2.70

The Chicken airstrip relation through 2001 gives a result that is close to that determined previously, i.e., 2.8 inches was estimated in February 2001. The Mt. Fairplay data (to 2001) gives a similar result. Both of these snowcourses are located to the east of Pogo.

It is important to recognize that ABR has considered only snowcourses that are located to the west of Pogo. Snowcourses to the east have not been considered by ABR. Figure 3.2-10 in the ABR report indicates the significant year-to-year variability of snowpack at the NRCS sites that were considered; (for instance the standard deviation of snowpack at French Creek is approximately 3.5 inches). There is less year-to-year variability at the snowcourses to the east; (the standard deviation of annual maximum snowpack at Chicken airstrip is 0.8 inches). This difference in variability is illustrated on Figure 6; (in this figure the French Creek snowcourse data has been plotted as being representative of the snowcourses to the west). It appears as though the recorded data at Liese and Sonora follow the data for the Chicken airstrip to the east more closely. Although there are only 5 years of data to compare, the snowcourses at Pogo and to the east (at Chicken) did not vary as significantly in 2000, as did the sites to the west. It is clearly indicated by the data in Figure 6 that a higher average annual snowpack may be expected in the basins to the west; the average snowpack at French Creek is approximately 6.9 inches compared to Chicken airstrip at 3.1 inches. This trend is similar to the trend in regional precipitation in general.

From this assessment it may be concluded that data for snowcourses to the west, such as those considered by ABR, indicate a greater year-to-year variability. In general, average snowpack SWEQ values are greater to the west and lesser to the east. Hence, there appears to be an east-west gradient, with the Pogo site in between the long-term regional snowcourse sites located to the east and west.

The regional average snowpack, based on all stations considered within the Yukon-Tanana upland, is approximately 5.6 inches. This includes the greater values to the west and the lesser values to the east. The recorded snowpack at Pogo is less than for the sites to the west. Over the last five years the average annual snowpack at the Liese basin has been 0.2 inches greater than at Chicken airstrip (only one inch difference in five years). Hence the recorded data suggest snowpack for Pogo that is closer to that defined by stations to the east than those to the west.

Correlations of coincident snowpack measurements at Pogo and with the stations to the west are weaker than with the stations to the east. There is a good correlation between snowpack values measured on site and the regional long-term monitoring snowcourses to the east of Pogo. The best correlation is with Chicken airstrip. Based on this correlation, the estimated average snowpack for the Liese basin is approximately 3.2 inches. The corresponding Standard Deviation to go with this average is 0.8 inches, based on the recorded coefficient of variation for the Chicken Airstrip snowcourse dataset (36 years).

2.0 Recent Trends in Mean Maximum Snowpack and Mean Annual Rainfall

The objective of this snowpack/rainfall comparative analysis was to evaluate the recent (last 4 years) snowpack, rainfall, and total rainfall plus snowpack to long-term averages.

Long-term mean rainfall (May – September) and maximum observed snowpack depths were examined at various meteorological stations (Table 2). Ratios of the long-term mean rainfall and snowpack to mean values from 1997 to 2000 for the various stations were plotted on Figures 7 and 8, respectively. The mean annual summer (May to September) rainfall during the last four years (1997 to 2000) has generally been about the same (3% higher) as the long-term mean, although there is considerable variation in this ratio within small areas, e.g., near Big Delta. The mean maximum snowpack depth for the same period has been generally 15% lower than the long-term mean for the 22 stations examined. As illustrated on Figure 8, the stations to the west show a distinct trend to lower recent snowpack (ratios are greater than unity), while south and east of the Pogo Mine site, the ratios varied among the widely spaced monitoring sites averaged near unity. Interpolation of a representative value for Pogo is difficult.

The net result is that the total of rainfall and snowpack (total precipitation available for runoff) has been 97% of normal for those sites where total precipitation has been measured. While the maximum snowpack depth during the recent period can be stated to be less than the long-term average, the same cannot be said for the rainfall and hence the total precipitation. In other words, year-to-year trends in recorded snowpack are not necessarily mirrored by similar trends in rainfall or, more importantly, total precipitation. As it is total precipitation that is of the most practical importance to water management (i.e. facility sizing), the fact that recent trends are consistent with the long-term database is a very important observation to consider when assessing the value of the site-specific data available from the past four years.

TABLE 2: Long-Term and 4-Year Mean Rainfall and Snowpack

	Snowpack			Rainfall			Snowpack + Rainfall			
Station Name	Long-Term Mean Max. SWEQ	4-Yr Mean Max. SWEQ	Long-Term/ 4-Yr Mean	Long-Term Mean	4-Yr Mean	Long-Term/ 4-Yr Mean	Long-term Mean	4-Yr Mean	Long-Term/ 4-Yr Mean	Elevation
	(in.)	(in.)		(in.)	(in.)		(in.)	(in.)		(ft)
Munson Ridge	10.25	7.25	1.41	16.62	16.43	1.01	26.87	23.68	1.13	3100
Upper Chena Pillow	7.20	6.48	1.11	12.71			19.91			2900
Monument Cr	5.16	5.55	0.93	14.14	11.70	1.21	19.30	17.25	1.12	1850
Tok / Tok Junction	3.71	3.73	1.00	7.42	8.95	0.83	11.13	12.68	0.88	1650
Teuchet Creek	4.68	4.50	1.04	11.22	10.43	1.08	15.90	14.93	1.06	1640
Granite Cr	3.79	3.28	1.16	9.17	10.40	0.88	12.96	13.68	0.95	1240
Mission Creek	4.18	4.10	1.02	8.01	9.88	0.81	12.19	13.98	0.87	900
Fairbanks FO	4.33	3.68	1.18	7.74	6.53	1.19	12.07	10.21	1.18	450
Mt. Fairplay	4.32	5.08	0.85							3100
Upper Chena	8.15	6.93	1.18							3000
Cleary Summit	7.01	5.85	1.20							2230
Little Chena Ridge	6.07	4.80	1.26							2000
Haystack Mtn.	6.92	4.70	1.47							1950
Faith Creek	5.78	4.65	1.24							1900
French Creek	6.88	5.38	1.28							1800
Little Salcha	5.56	discontinued								1700
Chicken Airstrip	3.13	3.60	0.87							1650
Fort Greely	3.65	2.70	1.35							1500
Little Chena Bottom	4.23	3.50	1.21							1460
Caribou Creek	5.05	4.97	1.02							1250
Gerstle River	3.64	2.70	1.35							1200
Caribou Mine	5.46	3.63	1.50							1150
Colorado Creek	4.77	3.90	1.22							700
Mt. Ryan				7.49	5.23	1.43				2800
Paxson				12.80	11.52	1.11				2700
Slana				10.03	12.03	0.83				2420
Summit FAA				11.22						2410
Trims Camp				17.81						2410
McKinley Park				10.29	11.77	0.87				2090
Northway				7.60	8.75	0.87				1720
Gulkana WSO				7.14	8.73	0.82				1580
Tanacross				8.30						1500
Big Delta				8.95	8.94	1.00				1280
Rhoads Cr				8.17	10.37	0.79				1240
Gilmore Creek				9.79	10.69	0.92				970
College 5 NW				8.87	9.15	0.97				950
Circle Hot Springs				7.76						940
Eagle				8.09	9.83	0.82				850
College Obs.				7.82	8.82	0.89				620
Eielson Field				8.54	7.70	1.11				550
Fairbanks WSO				6.75	7.12	0.95				440
Central 2				7.22	8.15	0.89				440
Fort Yukon				3.82						440
Nenana Mun AP				7.72						350

Yours truly,

AMEC Earth & Environmental Limited

Gary Beckstead
Senior Water Resources Engineer

GREB/tk

Mean Snow Water Equivalent between Liese Basin and Sonora Snow Course
1998 - 2001

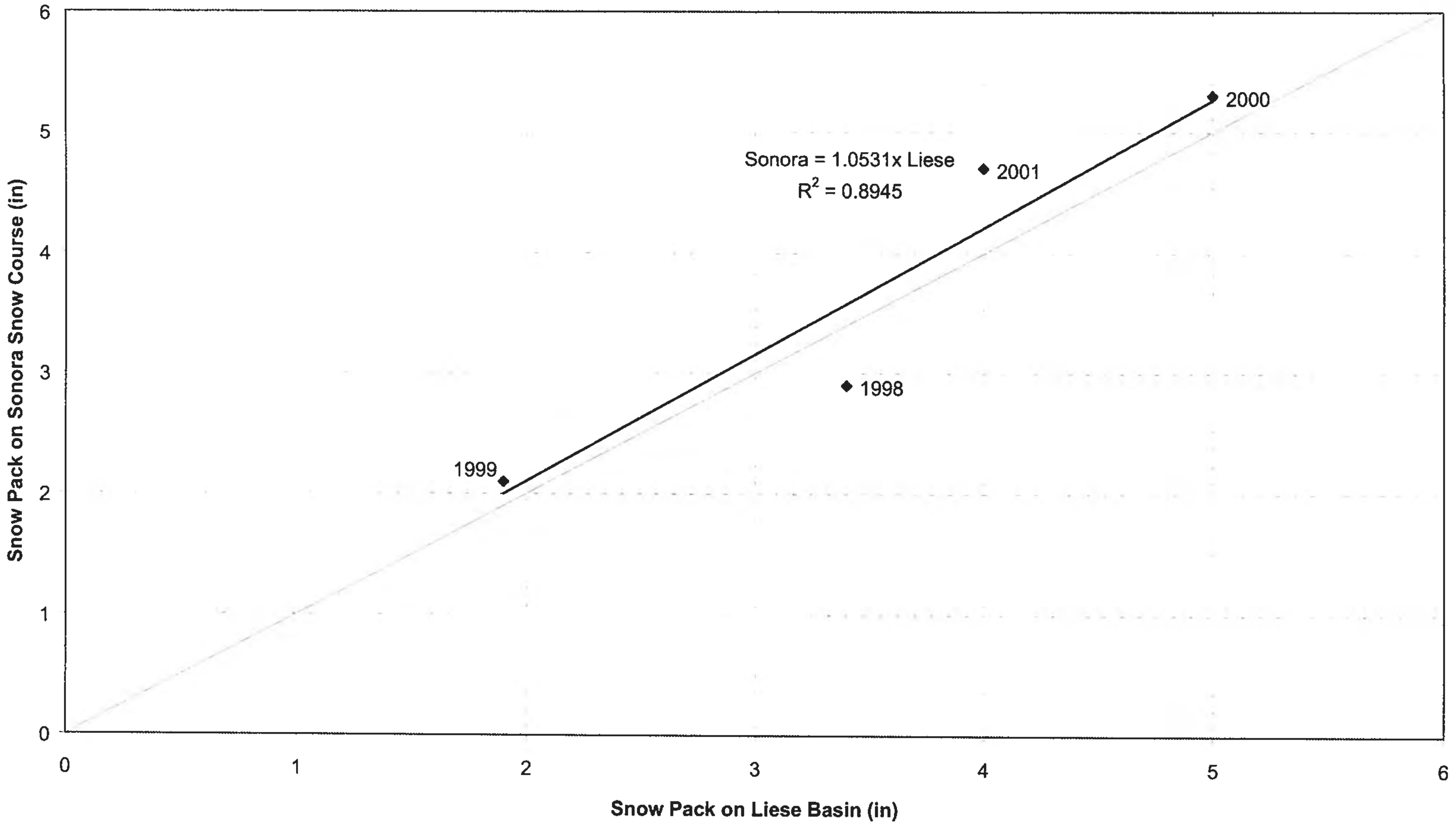


Figure 1

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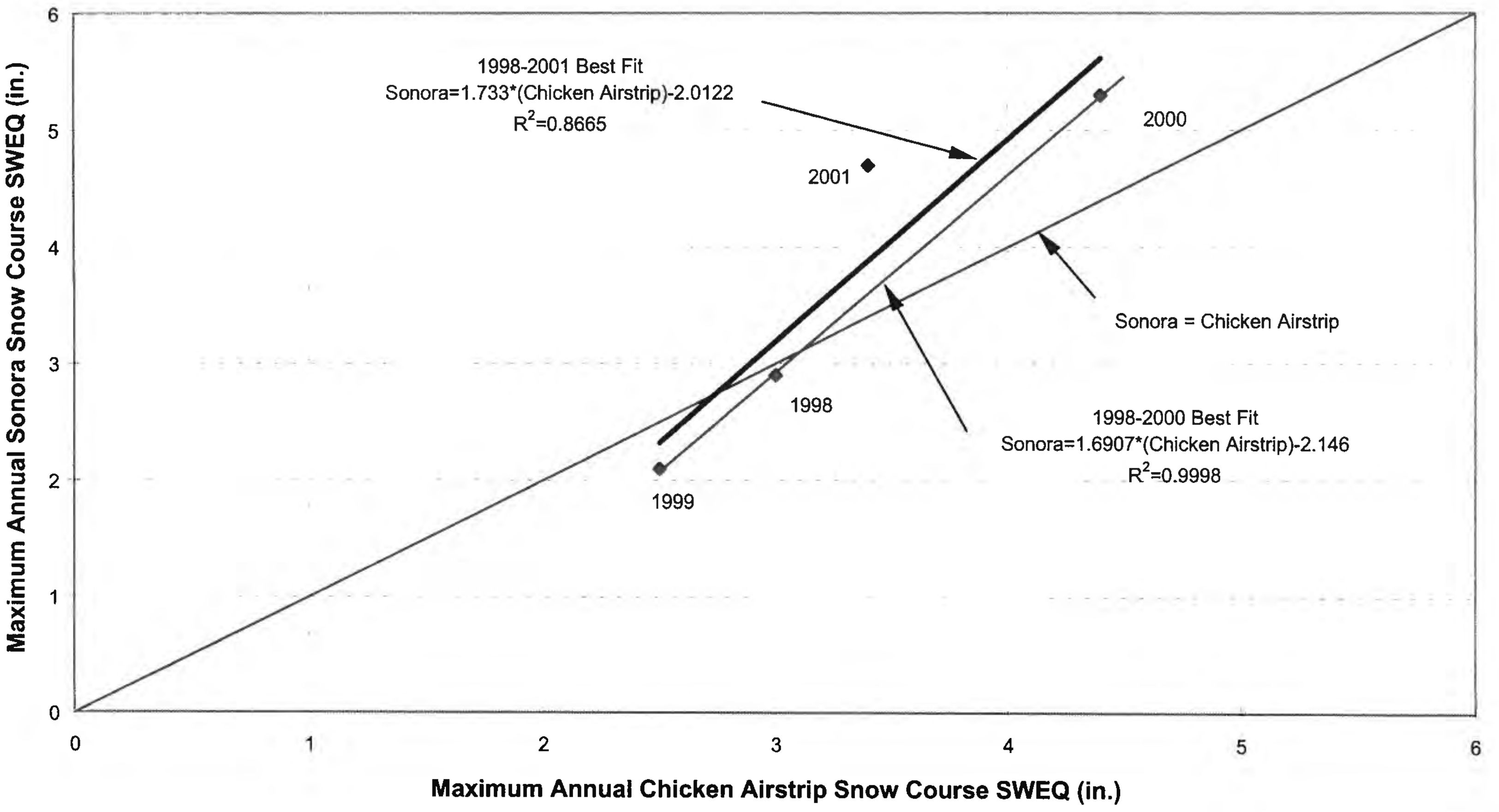


Recent Snow Course data

Figure 2

Chicken Airstrip Snow Course vs Sonora Basin Modeled Snowpack (1997 - 2001)

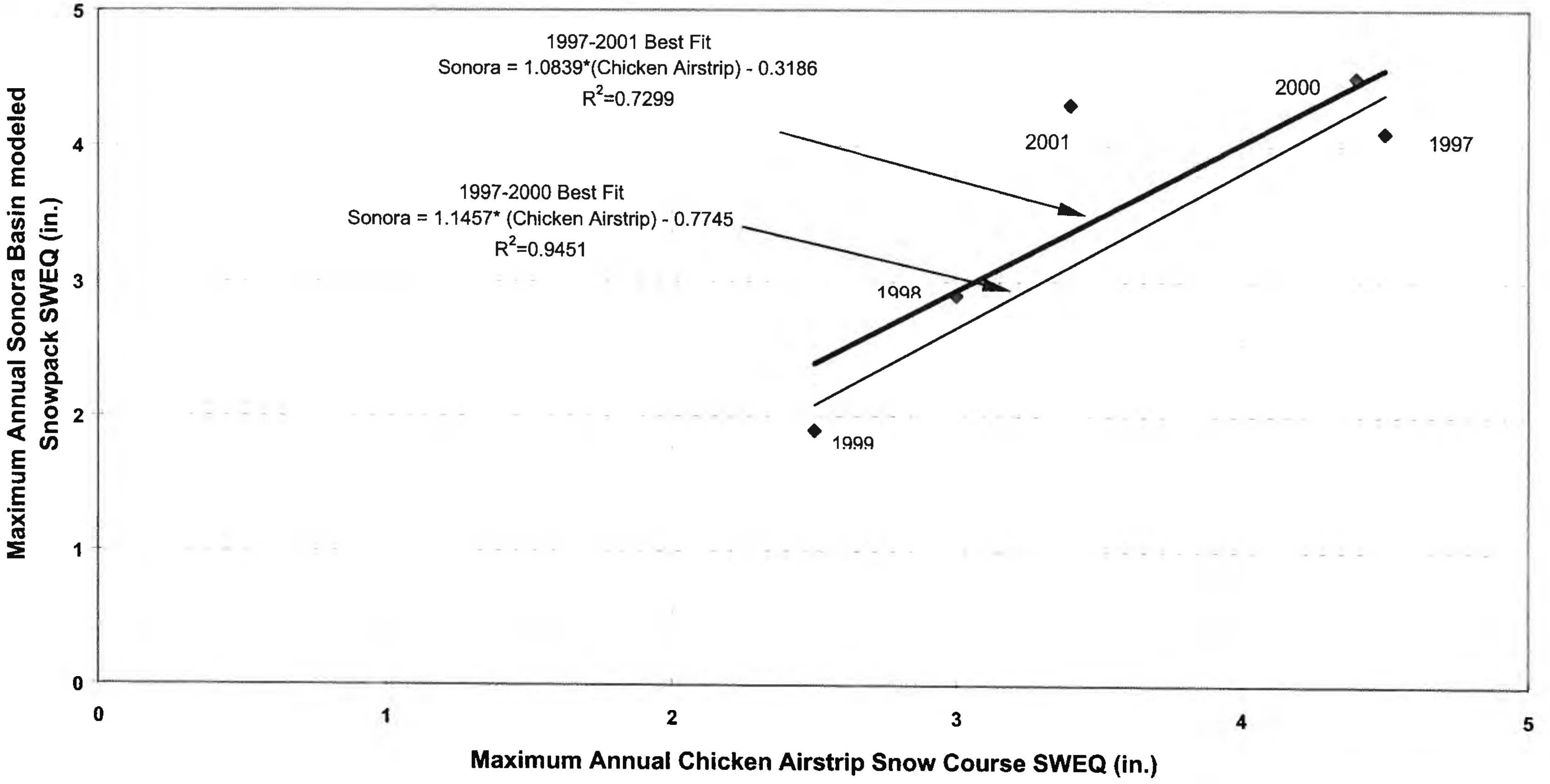
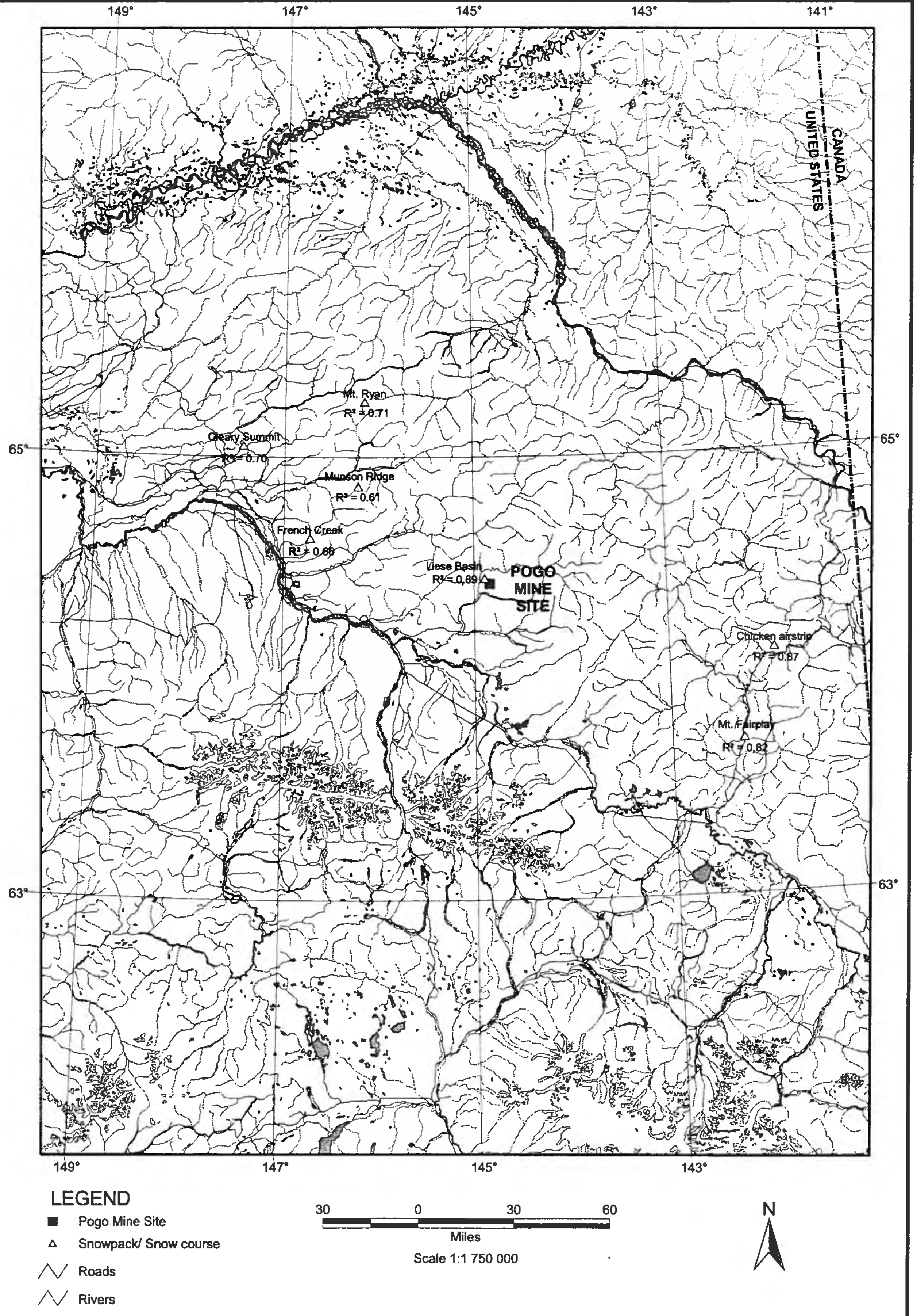
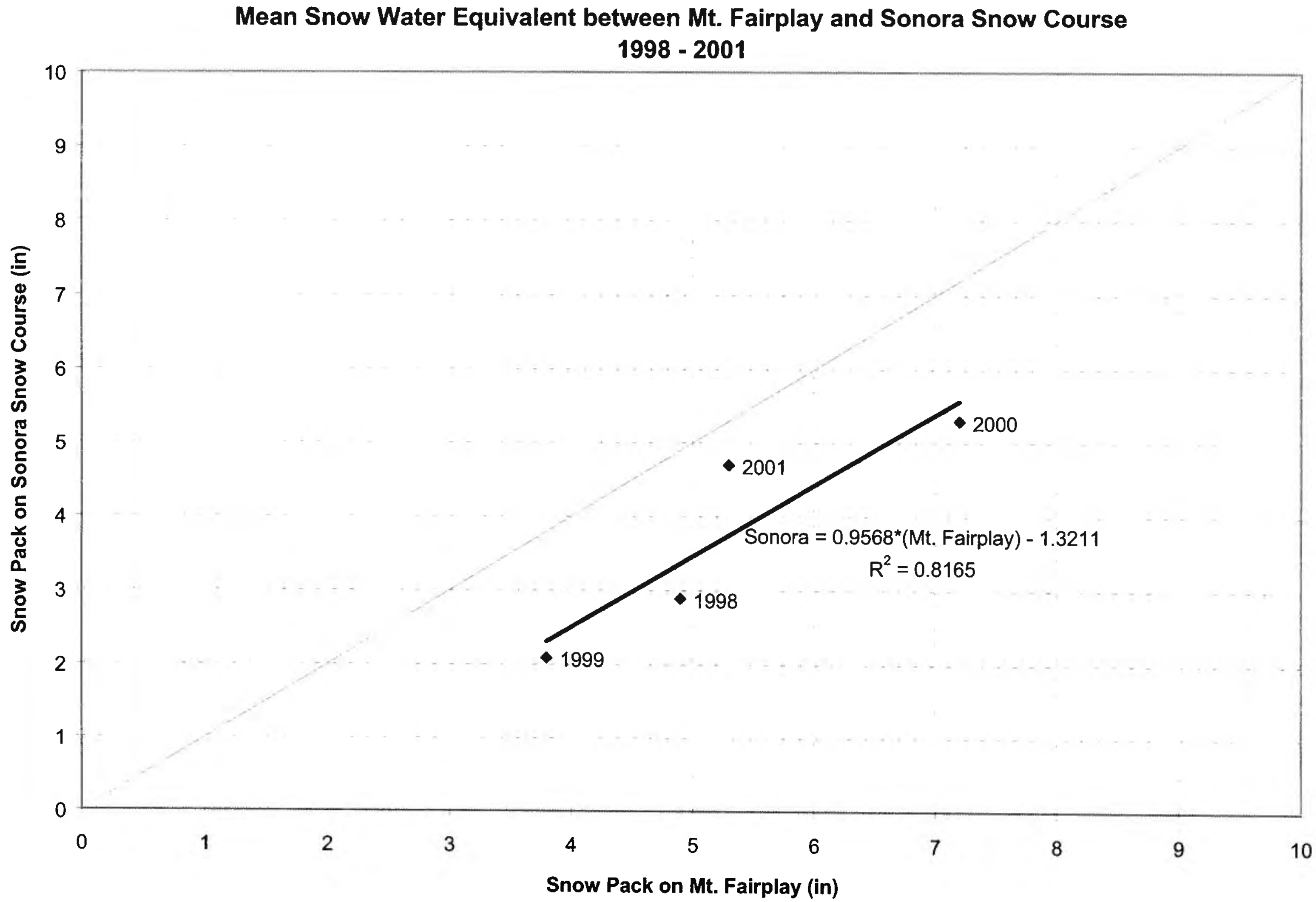


Figure 3

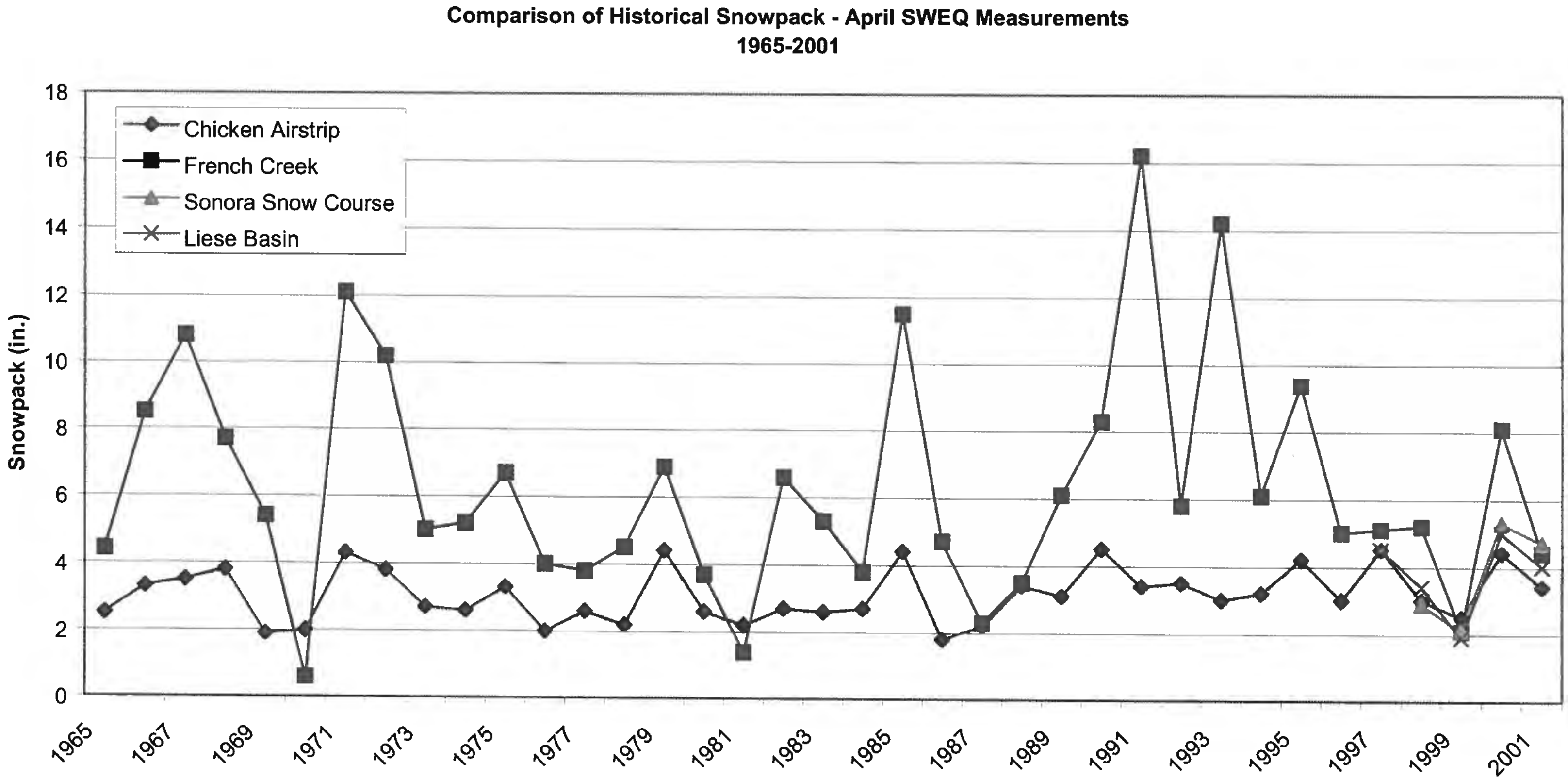


CLIENT: Teck Cominco Ltd	DATE: October, 2001	ANALYST: JBM	Figure 4
PROJECT: Pogo Project	JOB No: VM00172/V-3		
Snowpack Regressions - Sonora Snow Course Data (1997 - 2001)	GIS FILE: POGO1.APR		amec



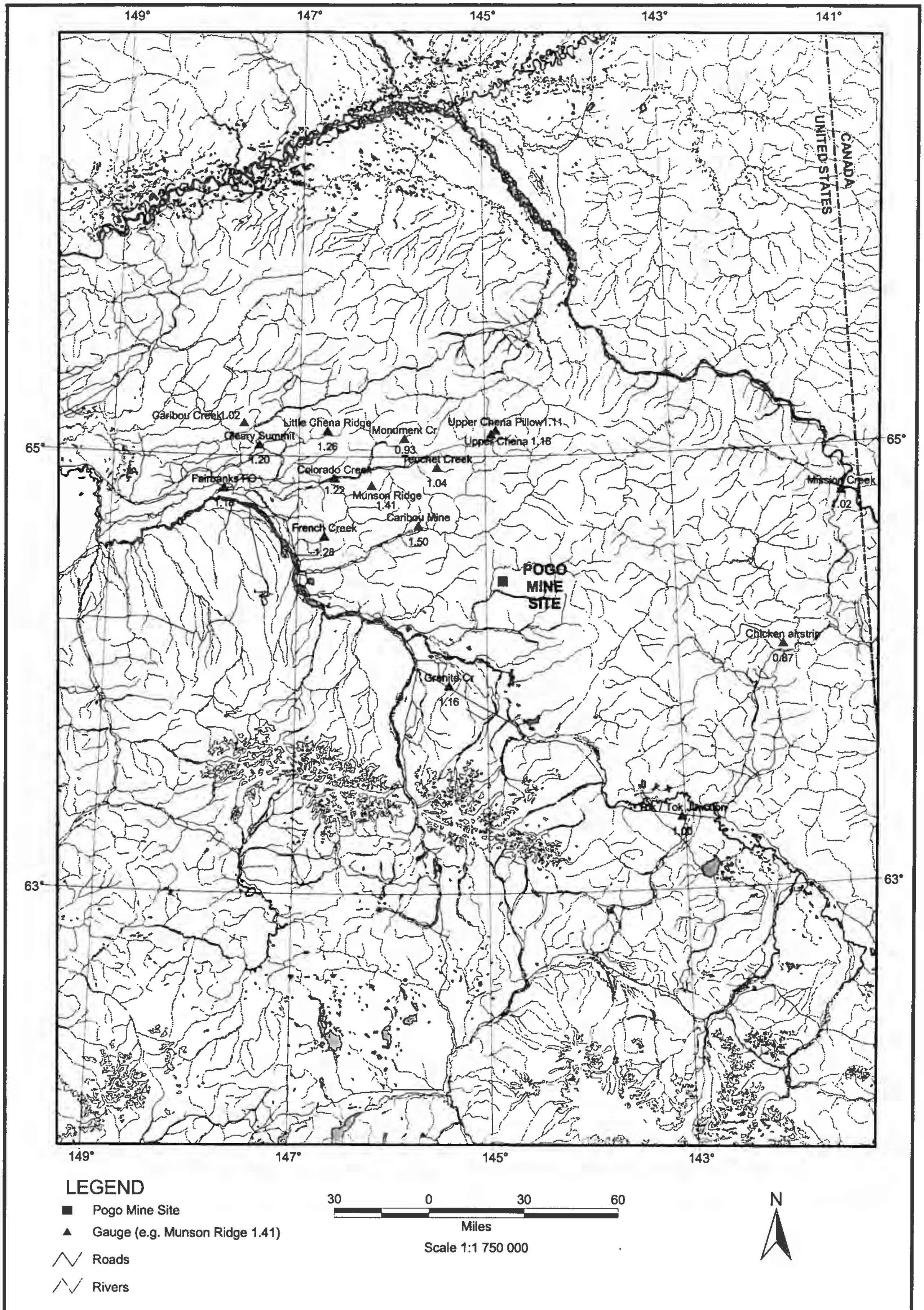
Mean Snow Water Equivalent between Mt. Fairplay and Sonora Snow Course
1998 - 2001

Figure 5



Comparison of Historical Snowpack - April SWEQ Measurements
1965-2001

Figure 6



CLIENT: Teck Cominco Ltd	DATE: September, 2001	ANALYST: JBM	Figure 7
PROJECT: Pogo Project	JOB No: VM00172/V-3		amec
Ratio of May-September Long-Term to 4-year (1997-2000) Mean Snowpack	GIS FILE: POGO1.APR		