An Analysis of Probable Maximum Precipitation for the Faro Mine Site, Yukon Territory

by

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for

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on behalf of

Faro Mine Closure Planning Office
Whitehorse, Yukon Territory

January, 2006

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1 INTRODUCTION

Probable maximum precipitation (PMP) is "Theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographic location at a given time of year" as defined in US Department of Commerce, 1988 Hydrometeorological Report No. 55A (HMR-55A), "Probable Maximum Precipitation Estimates – United States Between the Continental Divide and the 103rd Meridian." PMP is used for estimating the Probable Maximum Flood (PMF), a parameter used for the design and operation of dams and spillways. PMP calculations typically involve use of actual storms modified by applying moisture maximization and storm transposition.

This report describes development of PMP estimates for the Faro Mine site in the Yukon Territory. It is based on weather station reports from Yukon Territory and adjoining provinces and U.S. states.

Figure 1.1 shows the elevations (above sea level) of Yukon Territory. Figure 1.2 shows average (1961-1990) precipitation for June, the month most likely to experience extreme precipitation events in the Faro Mine area.

1.1 Overview

The general procedure for estimating 24-hour PMP in the study area included the following steps:

- Identify relevant historical storms during summer months (the largest rain storms) and spring (lower rainfall amounts but a higher potential for rain-on-snow events);
- Create a digital Geographical Information Systems (GIS) coverage of 100-year 24-hour precipitation for the Yukon Territory;
- Determine the ratio of observed precipitation to 100-year precipitation for each storm;
- Determine precipitable water for each storm and maximum precipitable water from atmospheric soundings;
- Create 100-year precipitable water coverage for Yukon;
- Maximize storms by multiplying observed precipitation by the ratio of maximum to observed precipitable water;
- Transpose storm amounts horizontally to target area using precipitable water coverage;
- Calculate one-day PMP;
- Convert one-day values to 24-hour values;
- Determine DAD values.

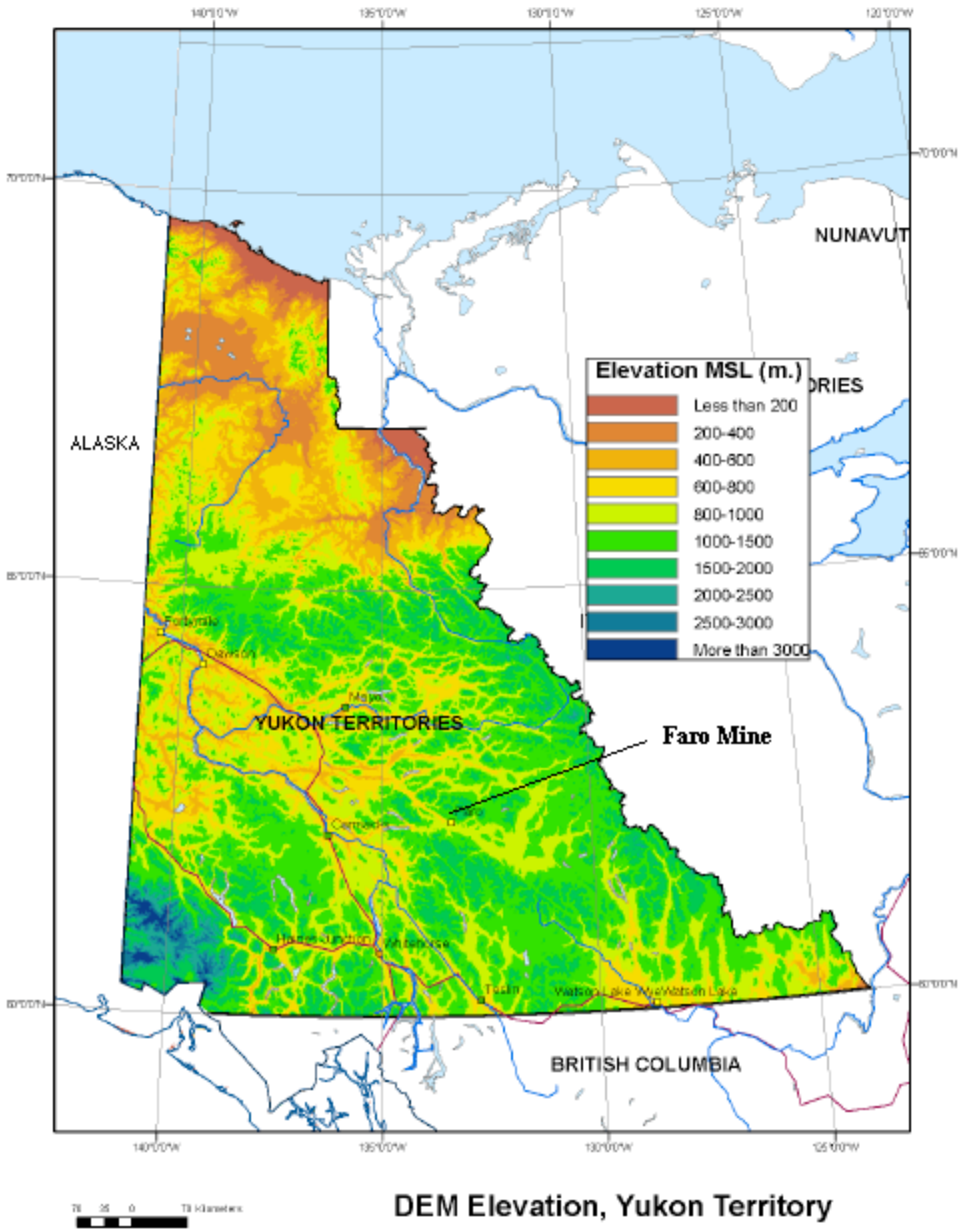

Figure 1.1 Yukon Territory Digital Elevation Model (DEM) elevations (m. above sea level)

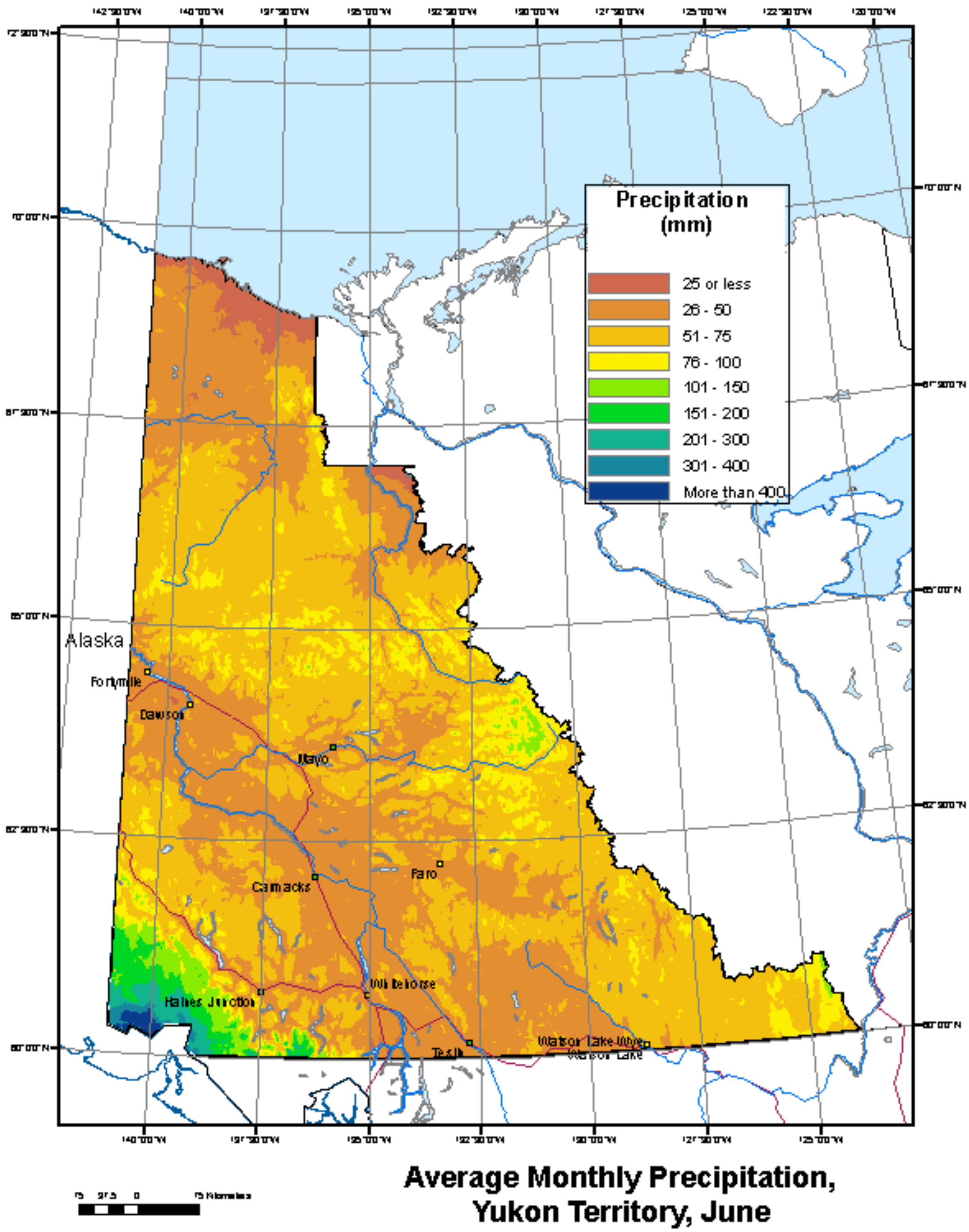

Figure 1.2. Normal (1961-1990 average) Precipitation, Yukon Territory, June
(data created for Environment Canada by C. Daly, 2001)

2. TECHNICAL APPROACH

2.1 Input Data

Canadian precipitation and temperature data were obtained from Environment Canada; Alaskan data were obtained from the U.S. National Climatic Data Center. Daily precipitation records were obtained for all stations in the study area and imported into a relational database. Hourly data, where available, were also processed.

2.2 Historical Storm Analysis

Storm analysis consisted of the following steps:

- Begin with a list of the largest storms (1-, 2- and 3-day events) in Yukon Territory, as well as adjacent areas in Alaska and surrounding Canadian provinces;
- Collect all available daily precipitation data for those events;
- Calculate the maximum 1-, 2- and 3-day total precipitation for each storm for all available stations;
- For the largest storms (based on ratios to 100-year values), create spatial coverages of storm precipitation;
- Select the most extreme storms according to the magnitude of normalized precipitation (observed divided by 100-year) and area of influence. Consider the location of the storms, choosing a sufficient number of storms to cover the entire Territory during horizontal transposition steps. Large 1-day storms were favored due to the relatively small size of the drainage basin.

All of the largest historical storms occurred during summer (June-August). We briefly examined early-season storms (March-April) to investigate the possibility of rain-on-snow events, but the much colder temperatures during those months led to sharply reduced rainfall totals. We therefore concluded that summer storms represented a worst-case situation for flooding.

Table 2.1 lists the first cut of extreme storms selected for analysis. Table 2.2 lists the final set of six storms selected for detailed analysis based on extreme 1-, 2- or 3-day precipitation totals. Figure 2.1 shows the locations of the center (highest measured precipitation) of the six final storms, labelled by year of occurrence.

Month/year	Maximum Observed 1-day Precipitation (mm)	Month/year	Maximum Observed 1-day Precipitation (mm)
June, 1956*	58.4	August, 1973*	56.6
July, 1960	34.8	July, 1975	46.7
July, 1964	27.9	July, 1977	27.2
August, 1970	39.1	July, 1978	26.2
September, 1970	37.6	July, 1984	29.0
June, 1971*	67.3	June, 1988	24.8
July, 1971	38.1	July, 1991*	50.0
August, 1971	38.1	July, 1994	30.9
July, 1972**	66.7	June, 1998*	53.4

Table 2.1 Initial set of extreme storms used in the analysis, showing maximum 1-day observed precipitation (* selected for "short list); ** adjustment; see section 3.6)

DATE	Maximum Observed 1-day Precipitation (mm)	Latitude of Maximum (deg. N)	Longitude of Maximum (deg. W)
June 19-21, 1956	58.4	67.56	139.83
June 21-25, 1971	67.3	63.16	130.20
July 20-24, 1972	66.7	61.15	133.06
August 21-24, 1973	56.6	68.95	137.21
July 26-29, 1991	50.0	60.86	135.83
June 21-23, 1998	53.4	65.35	138.31

Table 2.2 "Short List" of extreme Storms used in the analysis, showing dates, location, and maximum 1-day observed precipitation

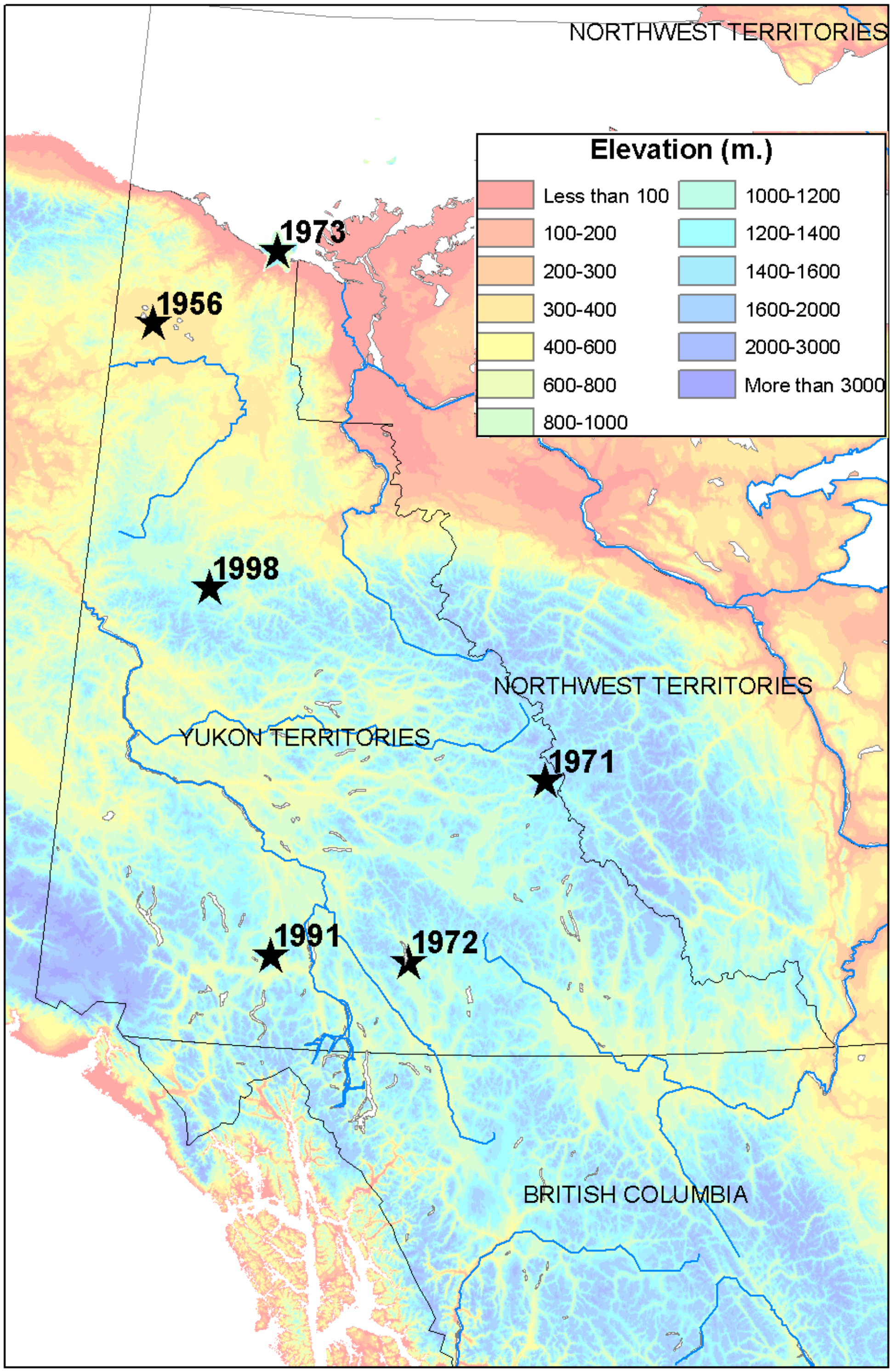

Figure 2.1. Locations of the centers of the six storms selected for detailed analysis (year of occurrence shown)

2.3 Upper-air Data

Upper-air data were obtained from "Radiosonde Data of North America" published by the National Climatic Data Center (NCDC, 1997) for the period 1946-1997; more recent data were obtained from the NOAA Forecast Systems Lab (FSL). Data were processed to determine precipitable water (Wp) for each twice-daily sounding.

National Weather Service (NWS) PMP analyses generally use 12-hour persisting dewpoints for estimating available moisture. This has the advantage of being obtainable for many more stations than those for which upper-air data are available Radiosonde data provide a direct measurement of atmospheric moisture more accurate at the measurement location. Assessment of spatial variation of maximum atmospheric moisture was aided by the use of a dew point analysis by Hopkinson (1999).

NWS suggests a 15-day temporal transposition toward the warm season for conservatism. Such a shift was analyzed, and did not change the precipitable water calculations significantly, so it was not employed in the analysis.

Upper-air data were used in the following ways:

1. Precipitable water (Wp) totals were calculated for each sounding. They were used to compute average monthly Wp for the period of record, as well as extreme (10- and 100-year) totals.
2. The ratio of 100-year values to Wp values for each storm was used in calculations of in-place moisture maximization.

Table 2.3 lists the upper-air stations in Yukon Territory and surroundings. Figure 2.2 displays the locations graphically.

ID	Station name	Longitude (deg W)	Latitude (deg N)	Years
71945	FORT NELSON UA	-122.60	58.83	37
70361	YAKUTAT STATE AIRPORT	-139.63	59.52	49
72964	WHITEHORSE	-135.06	60.72	40
74043	NORMAN WELLS	-126.80	65.28	38
72968	AKLAVIK	-135.00	68.23	11
72957	INUVIK	-133.53	68.32	33
70086	BARTER IS WSO AIRPORT	-143.63	70.13	36
74051	SACHS HARBOUR	-125.28	71.98	21
71072	MOULD BAY	-119.33	76.23	46

Table 2.3. Upper-air stations in and near Yukon Territory

For a given storm, the most representative upper-air station was used for estimating the Wp for that day; often this was the closest site, but not always. Inflow vectors were analyzed in order to estimate the upper-air site most representative of the air mass producing the extreme precipitation. In some cases, a station upwind of the site of maximum precipitation was preferred to a nearby downwind site because it was believed to better represent the character of the air mass prior to arrival at the station.

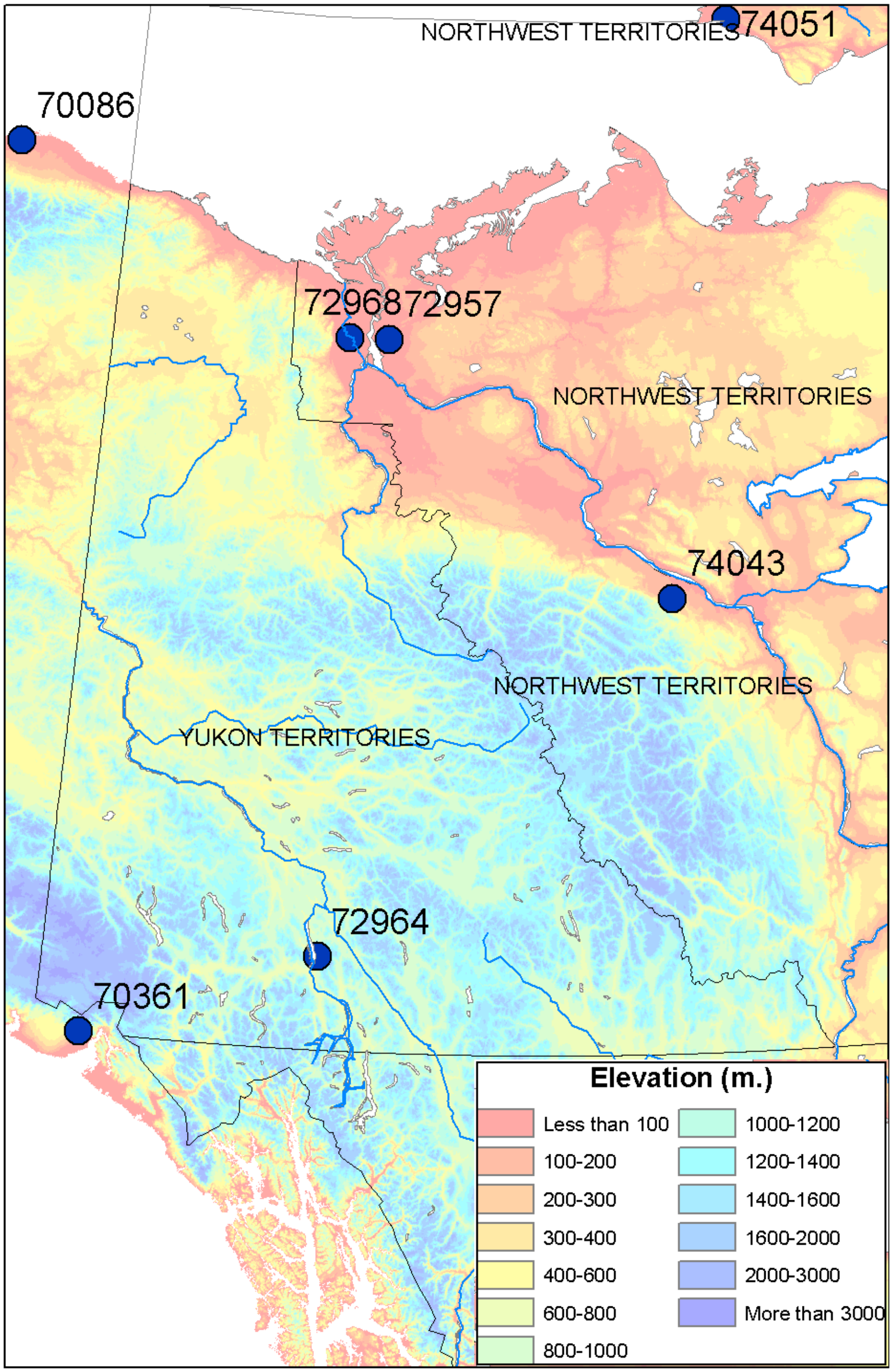

Figure 2.2. Locations of upper-air measurement stations in and around Yukon Territory

Table 2.4 lists the estimated precipitable water for 2-, 5-, 10-, 20- and 100-year return periods. These were computed using a Gumbel distribution based on data from individual twice-daily soundings. The Aklavik data, which were the highest shown, represent only 11 years of record (1950-1960) and this was considered insufficient for the study.

Some climatologists suggest using surface dewpoint data to calculate precipitable water. The authors generally prefer using atmospheric soundings, especially in areas with such sparse surface data as Yukon Territory. Sounding avoid problems from complex lapse rate situations, such as inversions. They also represent a direct calculation of precipitable water, while use of surface dewpoints can only infer those values.

		Precipitable water (mm)				
ID	Station name	2-year	5 - year	10 - year	20 - year	100 - year
71945	FORT NELSON UA	33.1	36.0	37.5	38.8	41.1
70361	YAKUTAT STATE AIRPORT	28.9	31.1	32.3	33.2	35.0
72964	WHITEHORSE	28.6	32.4	34.4	36.1	39.2
74043	NORMAN WELLS	29.4	31.9	33.2	34.2	36.3
72968	AKLAVIK*	31.3	35.8	38.2	40.1	43.8
72957	INUVIK	26.9	29.6	31.0	32.2	34.5
70086	BARTER IS WSO AIRPORT	25.9	28.8	30.3	31.6	33.9
74051	SACHS HARBOUR	24.3	28.8	31.2	33.1	36.8
71072	MOULD BAY	20.8	24.0	25.7	27.1	29.8

Table 2.4 – Extreme precipitable water values from atmospheric soundings, Yukon Territory and adjacent stations (* not considered in the analysis due to short record)

Figure 2.3 shows a map of estimated 100-year precipitable water for Yukon Territory based on the values above.

2.4 100-year Precipitation

100-year precipitation one-day values were obtained by statistically analyzing daily rainfall data for all stations in and near Yukon Territory with more than 25 years of record. A Gumbel 2-parameter analysis was used to compute the 100-year values. Each station's 100-year value was compared to gridded monthly values (an average for June-July) from precipitation "normals" coverages developed by Christopher Daly for Environment Canada (see Daly, et al, 1994 and Daly, et al, 2002). These ratios (100-year one-day value divided by monthly normal) were distributed using inverse-distance weighting with GIS software and inverse distance weighting, producing a gridded coverage for the Territory. This coverage was then multiplied by the monthly normals grid to obtain a gridded 100-year rainfall coverage consistent with orographic precipitation enhancement as identified by the PRISM mapping of monthly normal precipitation. Figure 2.4 shows the 100-year precipitation map developed for the analysis; data for individual stations are listed in Appendix 2.

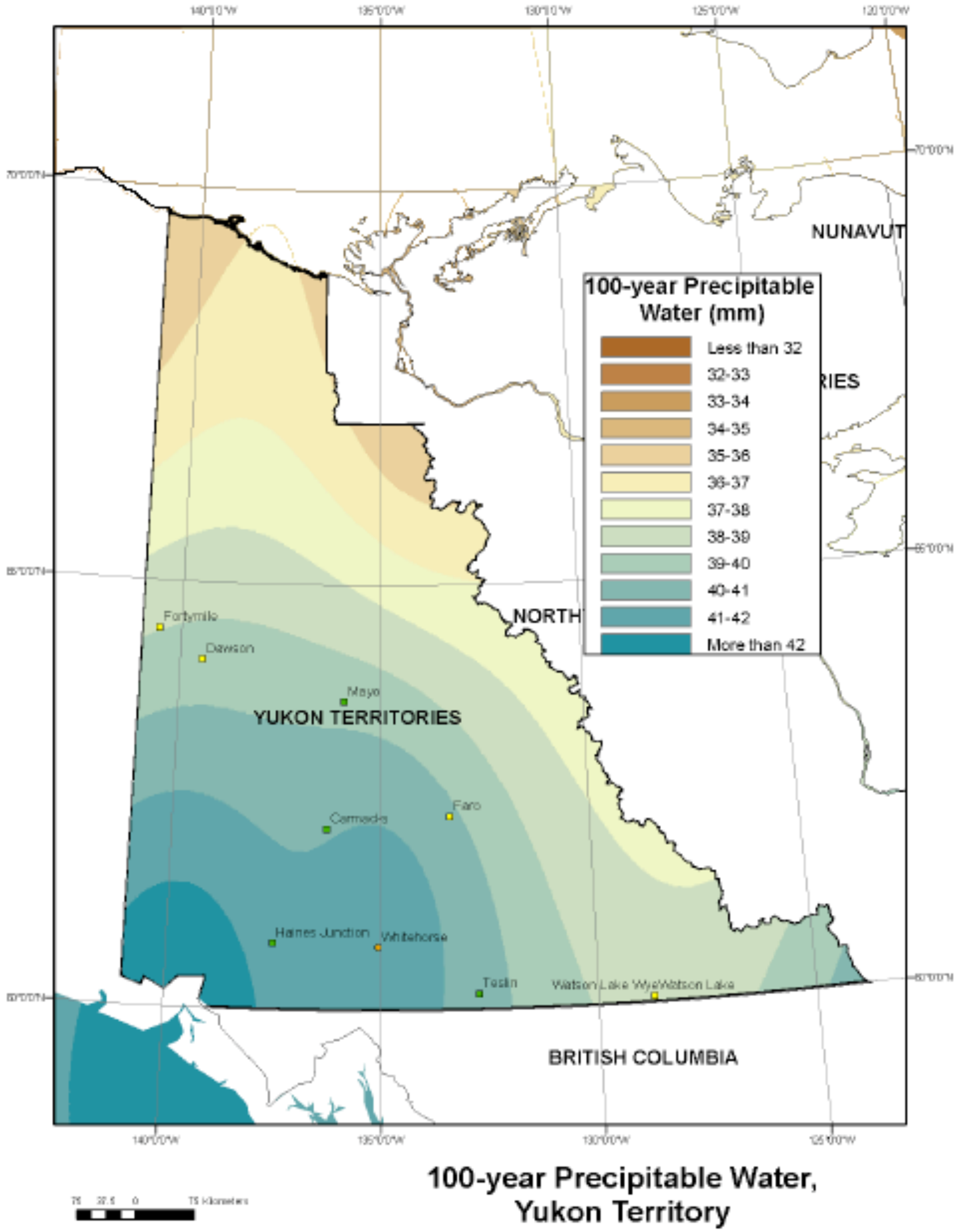

Figure 2.3. 100-year precipitable water above the surface for Yukon Territory

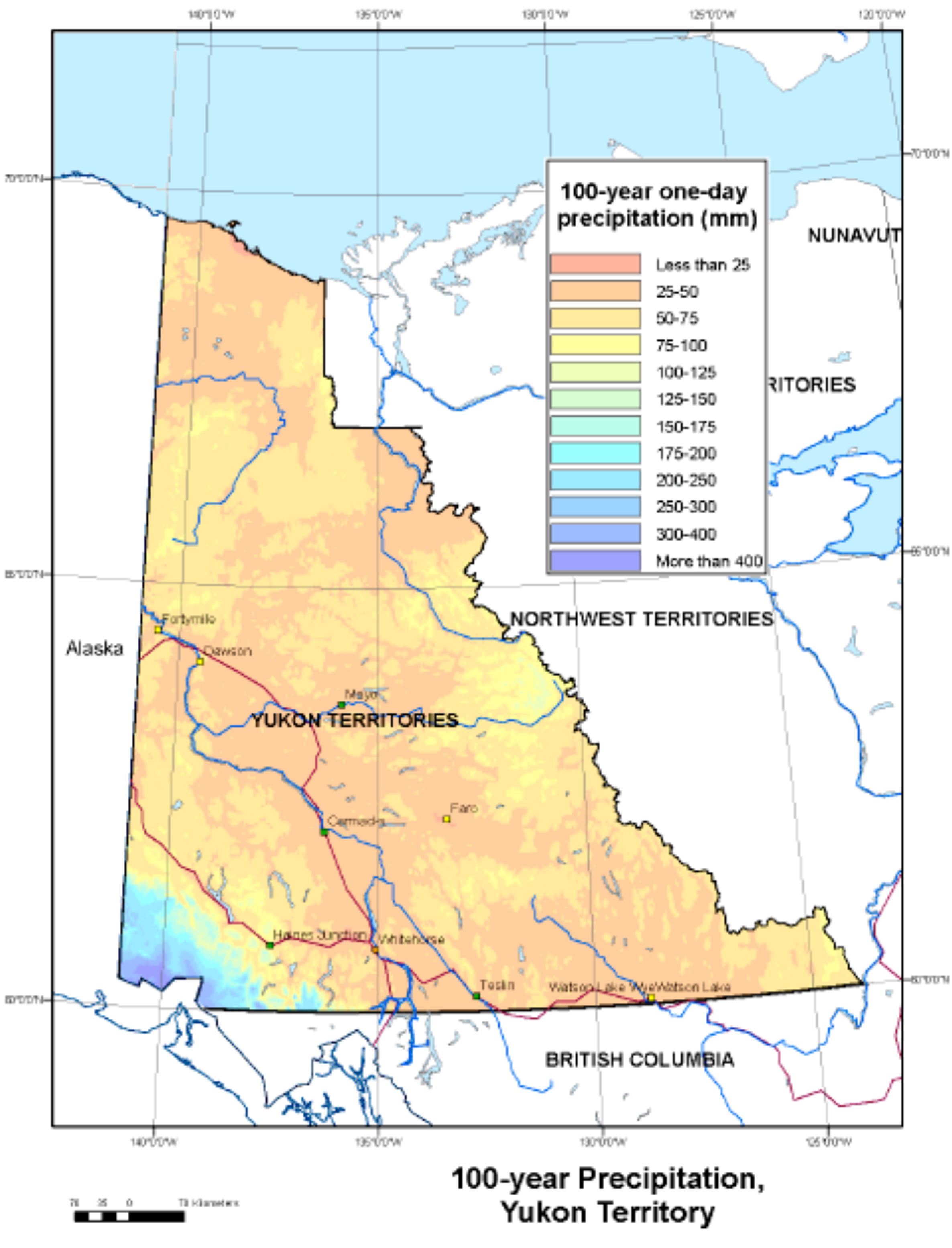

Figure 2.4. 100-year one-day precipitation for Yukon Territory

It is recognized that the number of weather stations in the Yukon Territory is relatively small. The level of detail shown in Figures 2.3, 2.4, and others in this document assumes some homogeneity among measurement stations, and represents our best estimate of the spatial distribution of the various parameters. However, some areas are far from the nearest measurement station and thus our confidence in the meteorological fields is somewhat lower.

3. CALCULATION OF 24-HOUR PMP

The National Weather Service recommends the use of "Storm Separation Methodology (SSM) for regional PMP analyses. SSM consists of separating precipitation into two components: convergence precipitation, that portion which would occur if terrain were uniform (i.e., flat); and orographic precipitation, caused by terrain uplift. Site-specific PMP studies need not employ SSM, however. In the opinion of the authors, there were significant uncertainties in estimating SSM components in Yukon due to sparse data density. Therefore the site-specific PMP approach was adopted, in which precipitation isohyetal patterns for individual storms were maximized and then transposed to the target area. The approach below outlines that procedure.

Although the authors collected data for other provinces in Canada and for Alaska, it was decided that the orographic barriers separating the Faro Mine area from those regions would have caused significant modification of the storms in those areas. Yukon is meteorologically isolated from those nearby areas, and its precipitation patterns are relatively uniform and rather dry. Storms originating in Alaska, British Columbia or Alberta are not transpositionable because they occurred in areas with significantly different climate and topographic regimes than the study area. For that reason, a decision was made to use only Yukon storms in the analysis.

3.1 Percentage of 100-year precipitation (normalization)

For each storm selected for analysis, the percentage of the maximum observed one-day precipitation to the 100-year one-day precipitation at each measurement site was computed. This normalization was done in an attempt to isolate storm precipitation from orographic effects and facilitate isohyetal analyses and storm intercomparison in orographic precipitation areas. All available daily and hourly stations were used, but only the daily amounts from hourly stations were employed in this phase of the analysis.

A coverage showing "percent of 100-year one-day precipitation" (PCT100) was created for each storm by performing an inverse-distance interpolation of the normalized values. An example of one of these maps appears in Figure 3.1.

3.2 Isohyetal Analysis

Isohyetal analyses (spatial coverages of total precipitation) were developed for each storm (for 1-, 2-, and 3-day maxima) by interpolation between recorded data using GIS. The PCT100 coverage was multiplied by the 100-year coverage to obtain the total precipitation. An example of an isohyetal map of total precipitation appears in Figure 3.2.

3.3 Horizontal transposition

GIS was used to transpose the PCT100 coverage from each storm to the study area using variations in 100-year precipitable water. The estimated value at any given transposed location was simply the original (storm center) value multiplied by the ratio of 100-year precipitable water at the transposed location to precipitable water at the storm center. Elevation differences were inherently incorporated in the analysis through the use of the PRISM coverages.

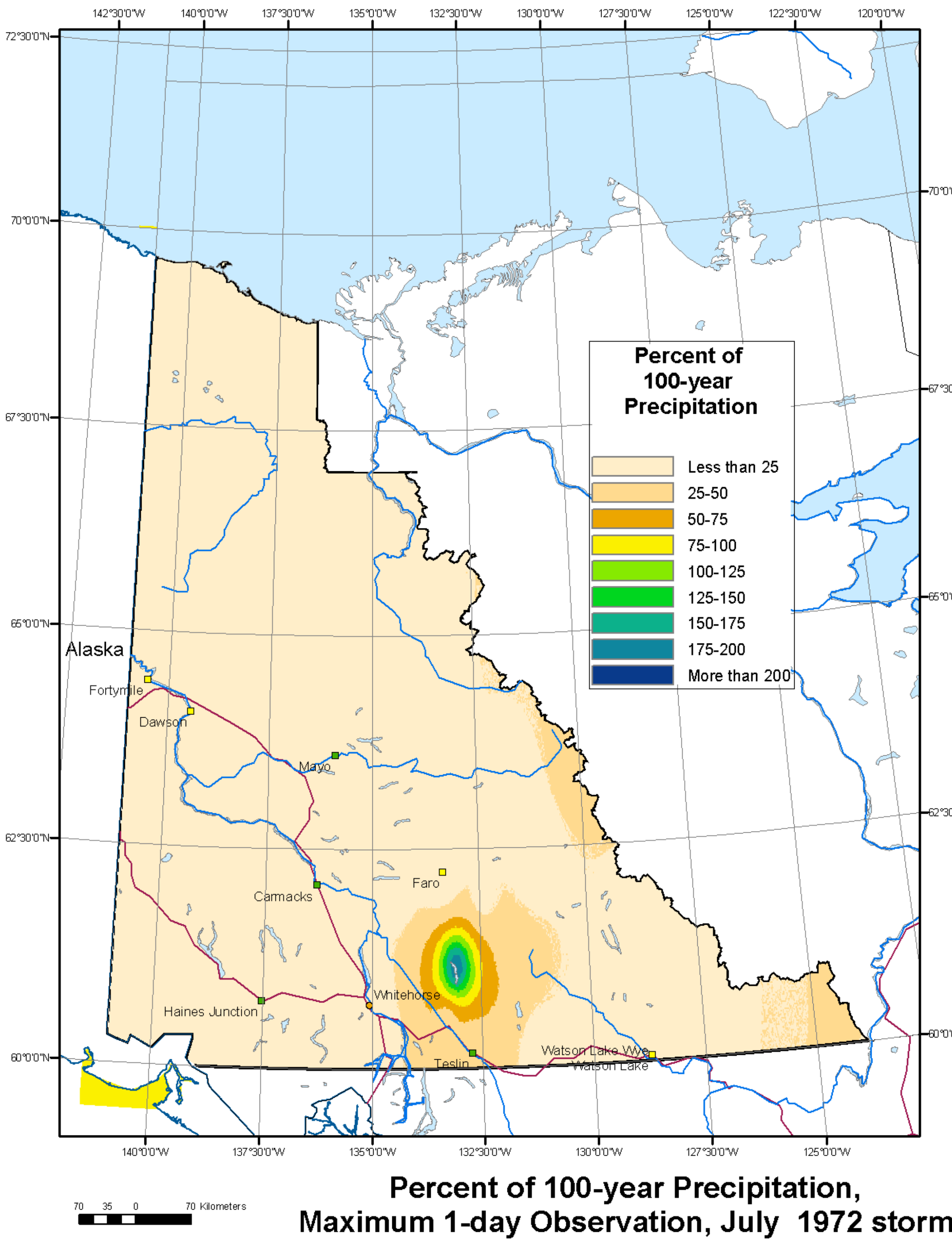

Figure 3.1. Percent of 100-year precipitation observed on the wettest day during the July, 1972 storm

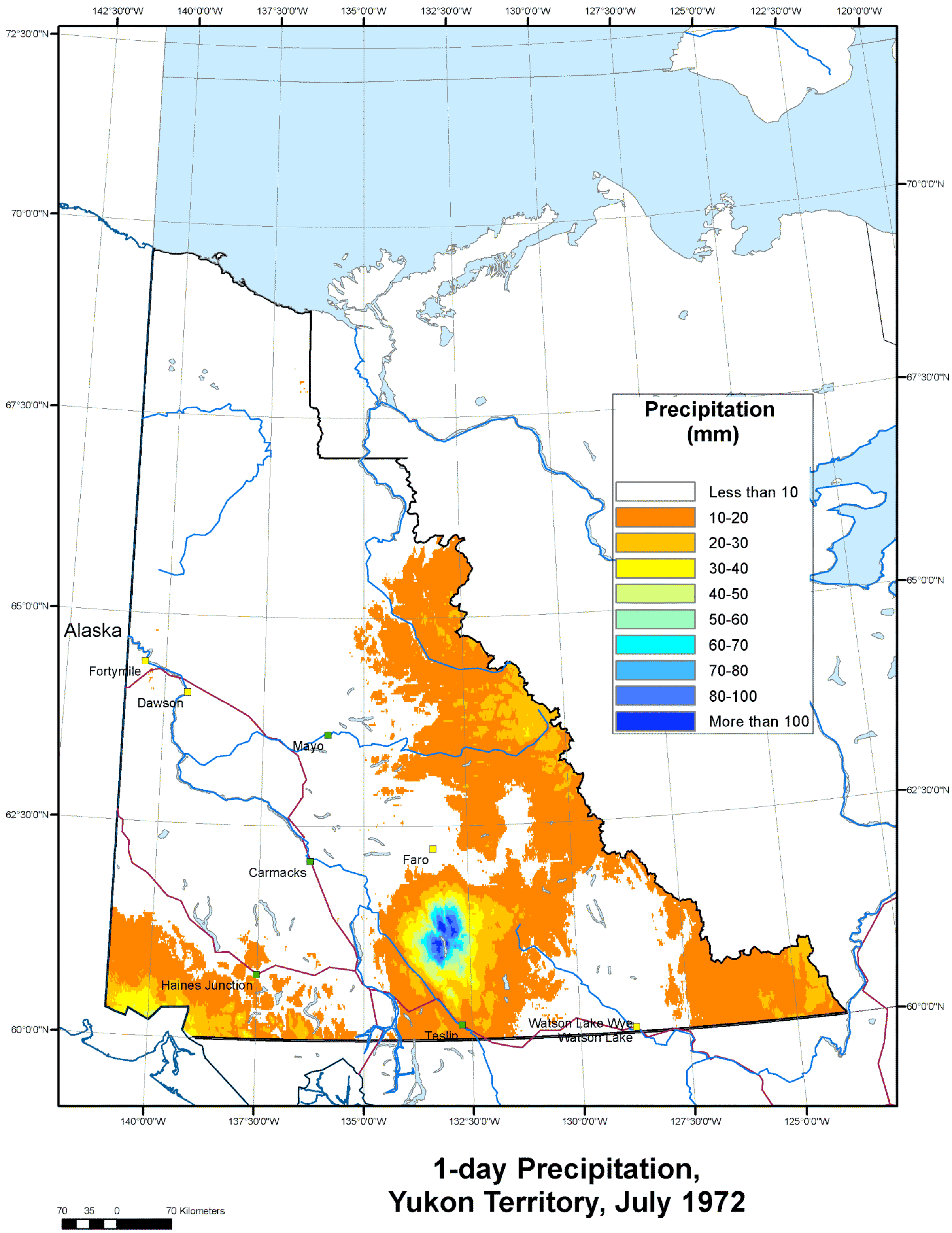

Figure 3.2 Maximum one-day precipitation, July, 1972 storm.

3.4 In-place moisture maximization.

Observed precipitation values for a given storm were multiplied by the ratio of the 100-year precipitable water for a given calendar month to the highest observed (from soundings) during a given storm. For example, if the precipitable water for given storm were 20 mm and the 100-year value for the same upper-air station estimated to be 30 mm, the observed precipitation would be multiplied by 1.5 (30 divided by 20) to estimate moisture-maximized precipitation.

3.5 24-hour adjustment.

Precipitation values based on climate-day precipitation were initially generated. These were adjusted to 24-hour values by multiplying by 1.13 to convert daily values to 24-hour estimates (U.S. Department of Commerce, 1973)

3.6 Results

Of the storms studied, the July, 1972 "Quiet Lake" storm proved to be the "24-hour controlling storm" (the largest storm transposable into the Faro Mine area, producing the greatest local 24-hour maximized precipitation).

The observations from the storm, however, were somewhat controversial. The digital one-day precipitation amount for that storm was 91.4 mm on July 23. However, the fact that no precipitation was recorded the day before caused us to be suspicious of the reported value (especially since other stations reported rain each day). Other meteorologists have analyzed the same storm and suspected that the reported value was a multi-day accumulation.

In fact, the daily data for Quiet Lake on the Environment Canada (EC) Web site does indicate that the observed value is an accumulation. Figure 3.3 is a screen snapshot of the EC Web site showing data for the month of July for Quiet Lake. The "C" symbols on the 21st and 22nd indicate that the daily values were not reported but included in a later observation, while the "A" on the 23rd indicates a multi-day accumulation.

In an attempt to distribute the three-day total rainfall, an examination was made of precipitation reported by nearby stations. The five closest stations to Quiet Lake were Johnson's Crossing, Teslin, Ross River, Faro and Anvil. All five stations reported multi-day rainfall during this storm. Based on an average of the daily values reported at the stations listed above, the average one-day value was estimated to be about 60% of the three-day total (June 21-23); for conservatism, we increased that figure to 70%, giving Quiet Lake a one-day maximum of 66.1 mm. Even with this value, the Quiet Lake storm remains the controlling 24-hour storm.

Table 3.1 lists the highest single-station values reported for the July, 1972 event. A map of estimated precipitation distribution for the Quiet Lake storm appears in Figure 3.4.

The values shown in Table 3.1 include the maximum 1-day and maximum 3-day values for the period July 20-24. Also shown are the ratio of the 1:3 day values. The average of the 11 highest

3-day observations (all stations with more than 10 mm) was .60. The highest, Boundary, was 100%, but this was observed on July 20 (Quiet Lake's 3-day event was July 21-23), and Boundary Lake is far from Quiet Lake). The estimated Quiet Lake 1-day value was 66.1 mm, which is 70% of the 3-day total, a number believed to be sufficiently conservative for the purposes here.

Number	Name	Longitude	Latitude	1-day Max (mm*10)	3-day Total (mm*10)	1:3 day ratio
2100696	MACTUNG	-130.18	63.28	315	709	.44
2100670	JOHNSONS C.	-133.30	60.48	127	267	.48
2101100	TESLIN A	-132.75	60.17	117	158	.74
2100948	SHELDON L.	-131.28	62.62	76	153	.50
2100516	FARO	-133.35	62.23	86	147	.59
2100630	HAINES JCT.	-137.58	60.75	76	145	.52
2100940	ROSS RIVER A	-132.43	61.97	69	127	.54
2100120	ANVIL	-133.38	62.37	61	119	.51
2100165	BOUNDARY	-140.35	64.23	117	117	1.00
2101081	SWIFT RIVER	-131.18	60.00	61	117	.52
2100860	PARKIN	-137.28	66.23	81	101	.80
					Average	.60
2100910	QUIET LAKE	-133.07	61.15	661	914	.70

Table 3.1. Highest reported 3-day precipitation values for July, 1972 storm, with 1:3 day ratios and adjusted Quiet Lake estimate

If the July, 1972 storm were removed from the database entirely, the estimated 24-hour point PMP would decline by about 10%.

QUIET LAKE
YUKON TERRITORY

Latitude: 61° 9' N **Longitude**: 133° 4' W **Elevation**: 820.00 m
Climate ID: 2100910 **WMO ID**: **TC ID**:

Previous Month | July 1972 Go | Next Month

Daily Data Report for July 1972

Day	Max Temp °C	Min Temp °C	Mean Temp °C	Heat Deg Days C	Cool Deg Days C	Total Rain mm	Total Snow cm	Total Precip mm	Snow on Grnd cm	Dir of Max Gust 10's Deg	Spd of Max Gust km/h
01	M	M	M	M	M	0.0	0.0	0.0			
02	M	M	M	M	M	0.0	0.0	0.0			
03	25.6	M	M	M	M	0.0	0.0	0.0			
04	25.6	3.9	14.8	3.2	0.0	0.0	0.0	0.0			
05	26.7	7.8	17.3	0.7	0.0	0.0	0.0	0.0			
06	27.8	7.2	17.5	0.5	0.0	0.0	0.0	0.0			
07	M	13.3	M	M	M	0.0	0.0	0.0			
08	M	M	M	M	M	0.0	0.0	0.0			
09	23.9	M	M	M	M	2.3	0.0	2.3			
10	21.7	6.1	13.9	4.1	0.0	2.0	0.0	2.0			
11	22.8	6.7	14.8	3.2	0.0	0.0	0.0	0.0			
12	25.6	7.8	16.7	1.3	0.0	0.0	0.0	0.0			
13	21.1	6.7	13.9	4.1	0.0	0.0	0.0	0.0			
14	M	8.9	M	M	M	0.0	0.0	0.0			
15	M	M	M	M	M	0.0	0.0	0.0			
16	20.0	M	M	M	M	6.9	0.0	6.9			
17	19.4	5.0	12.2	5.8	0.0	0.0	0.0	0.0			
18	20.6	7.2	13.9	4.1	0.0	0.0	0.0	0.0			
19	19.4	8.9	14.2	3.8	0.0	0.0	0.0	0.0			
20	20.0	6.1	13.1	4.9	0.0	4.6	0.0	4.6			
21	M	8.9	M	M	M	C	0.0	C			
22	M	M	M	M	M	C	0.0	C			
23	17.8	M	M	M	M	91.4A	0.0	91.4A			
24	14.4	5.6	10.0	8.0	0.0	3.0	0.0	3.0			
25	15.0	7.8	11.4	6.6	0.0	12.4	0.0	12.4			
26	14.4	8.9	11.7	6.3	0.0	0.0	0.0	0.0			
27	16.7	2.2	9.5	8.5	0.0	3.0	0.0	3.0			
28	M	3.9	M	M	M	0.0	0.0	0.0			
29	M	M	M	M	M	0.0	0.0	0.0			
30	17.2	M	M	M	M	16.5	0.0	16.5			
31	20.0	2.8	11.4	6.6	0.0	0.0	0.0	0.0			
Sum				71.7*	0.0*	142.2	0.0	142.2			
Avg											
Xtrm	27.8	2.2									

Figure 3.3. Screen capture from Environment Canada Web site for Quiet Lake, July, 1972. M represents missing data and C represnts missing observations whose totals are included in subsequent observations

Faro Mine PMP was estimated from the Quiet Lake storm as follows:

1. The storm was transposed horizontally using 100-year precipitable water coverage (see Figure 3.5). The storm center was placed approximately at the center of the drainage basin, and its position adjusted through a series of iterations until the highest basin-wide average was obtained. No rotation of the storm was done, since the precipitation distribution was rather circular.
2. Moisture maximized using 1.75 maximization factor (22.4 mm for storm versus 100-year value of 39.2 mm at Whitehorse, the most representative station)
3. Precipitable water transposition adjustment .9909 (Quiet Lake 100-year 40.58 mm, Faro Mine 40.21)
4. One-day to 24-hour correction: 1.13

The maximization factor listed above is slightly higher than the upper limit adopted by the National Weather Service in HMR-57 (which is 1.70), but since the difference between that and the computed 1.75 value was small it was decided to retain that value for conservatism.

Figure 3.6 shows the 100-year one-day precipitation coverage for the Faro Mine area. The maximum value in the Faro Mine watershed is 66 mm. The Quiet Lake one-day total (66.1 mm) represents 142% of the 100-year value (46.6 mm) for that station. Multiplying the 66.1 mm by 1.42 yields 94 mm. Maximizing that value, we get

> 94 mm (transposed) X 1.75 (moisture maximization) X .9909 (precipitable water adjustment) X 1.13 (one-day to 24-hour) = 184 mm.

Which represents our estimated maximum "point PMP" for one grid cell (approximately 2 sq. km.) A map of 24-hour "design storm" PMP for the site appears in Figure 3.7. This is obtained by applying the percentage of 100-year precipitation observed at Quiet Lake to the Faro area and maximizing. Figure 3.8 shows the PMP coverage obtained by multiplying the 100-year precipitation by the 142% figure at every grid cell, not just the center cell.

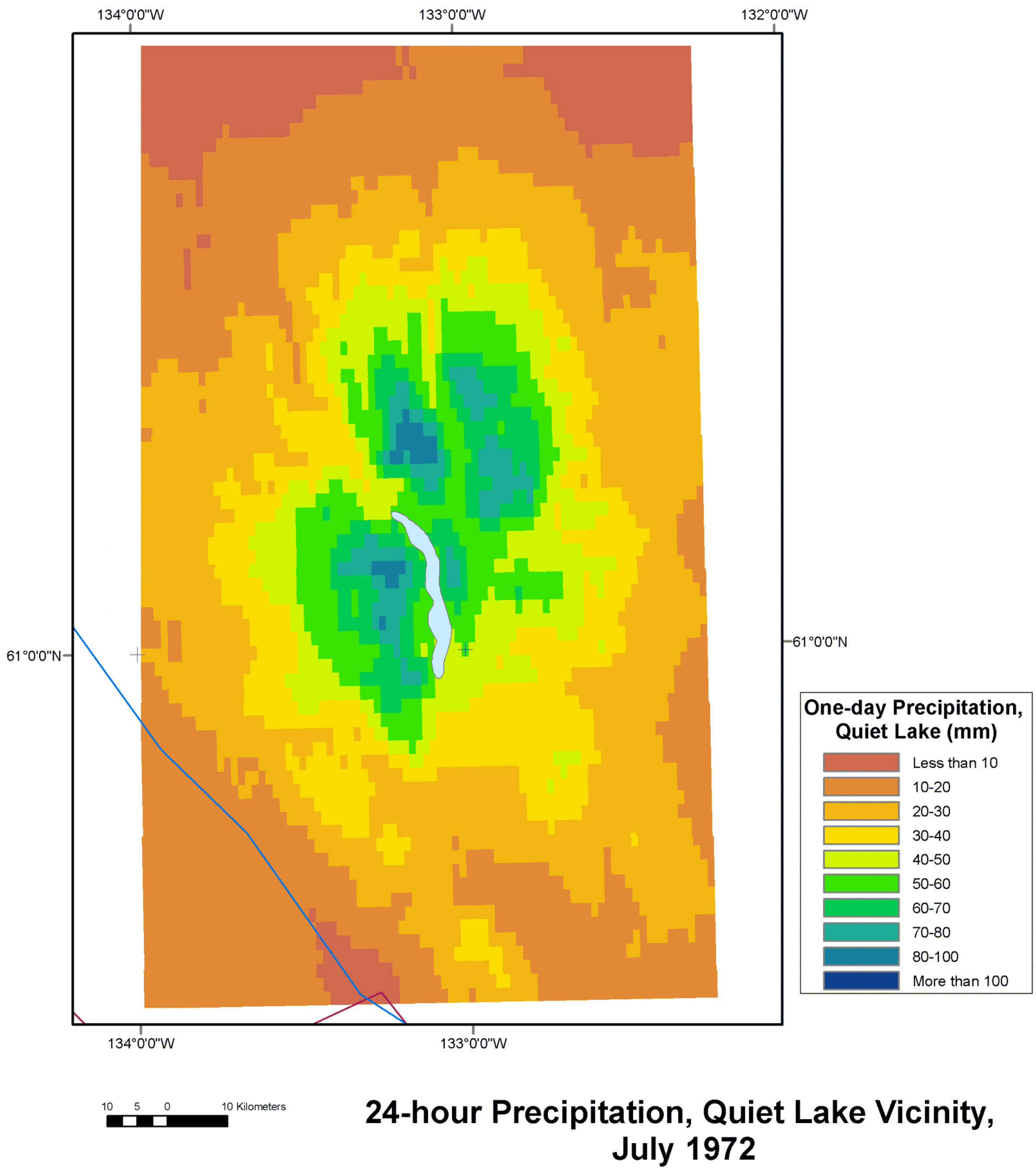

Figure 3.4. Modeled one-day precipitation for the July, 1972 storm

Transposed 1-Day Precipitation, July, 1972 Storm

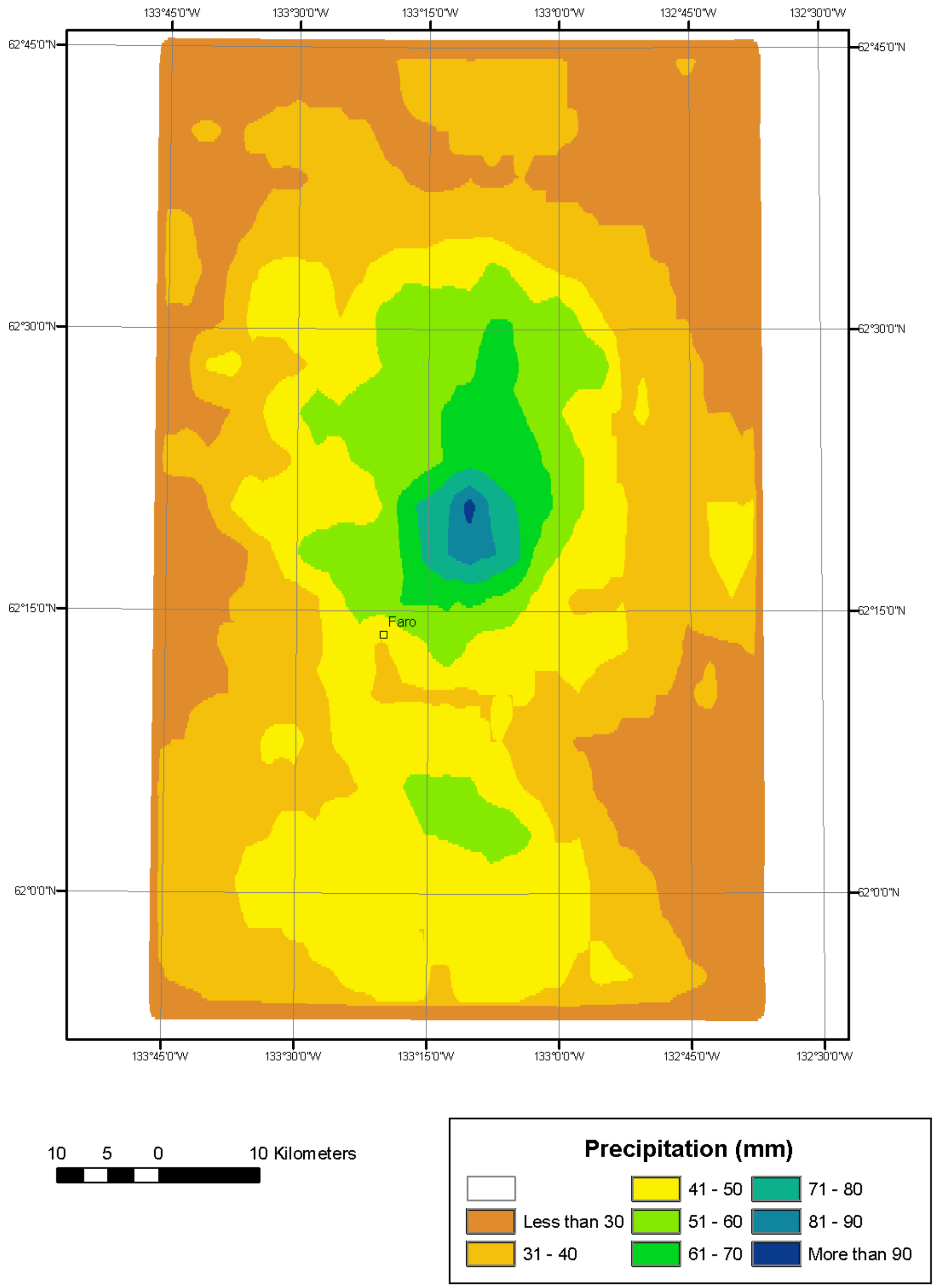

Figure 3.5. One-day precipitation for the July, 1972 storm, transposed to the Faro Mine vicinity.

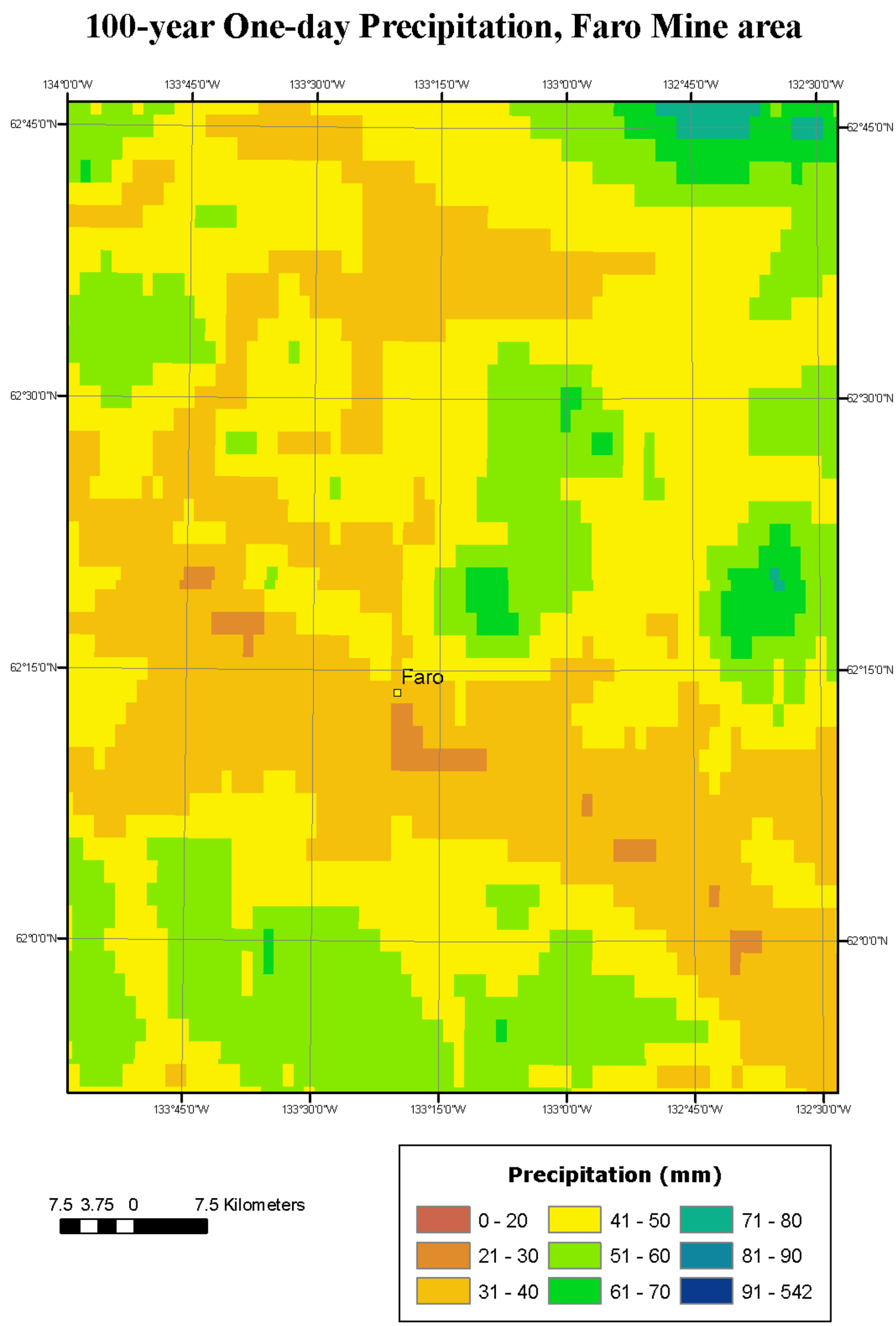

Figure 3.6. Estimated one-day 100-year precipitation for the Faro Mine vicinity.

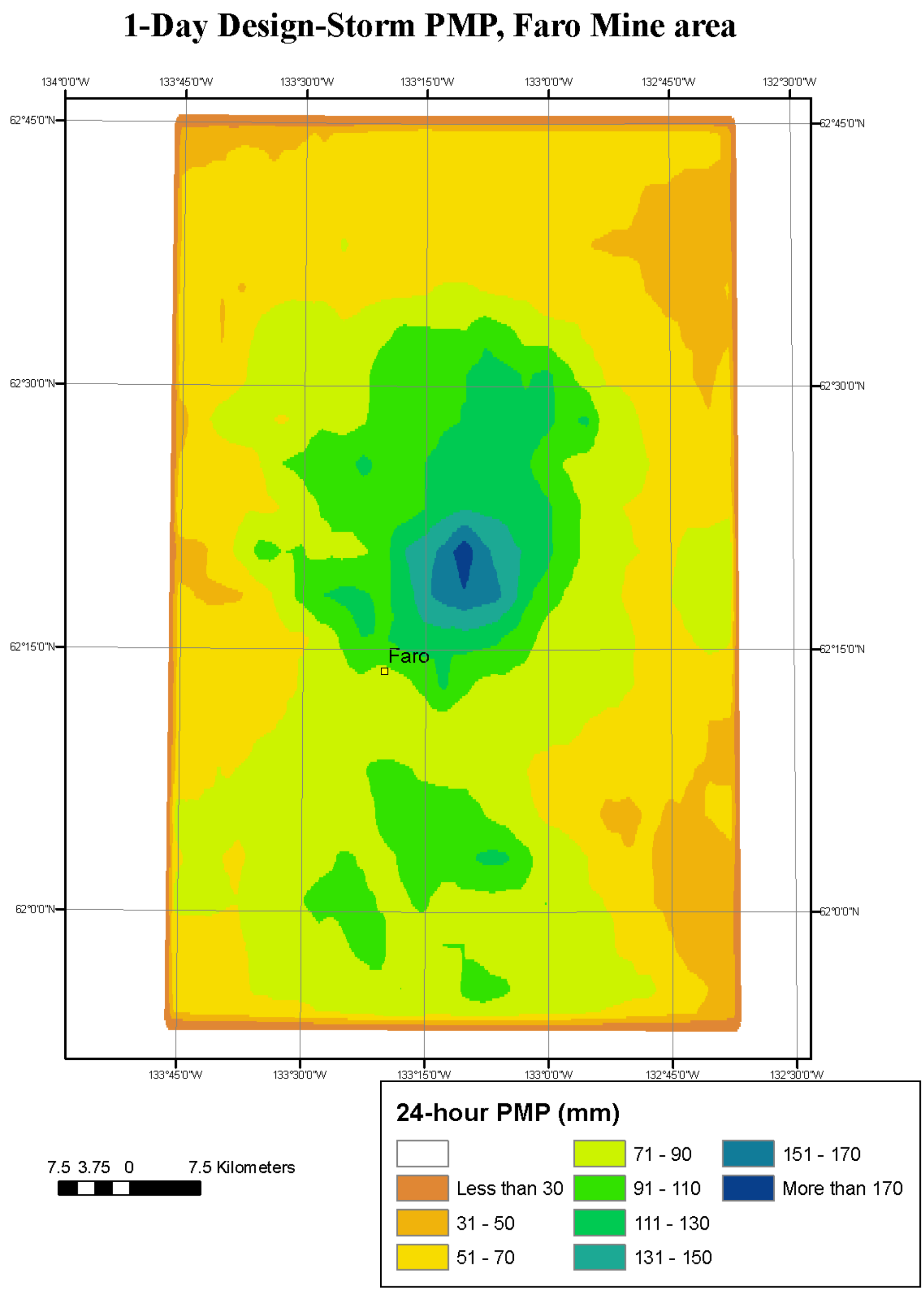

Figure 3.7. Maximized 24-hour PMP for the Faro Mine vicinity using July, 1972 "design storm" distribution

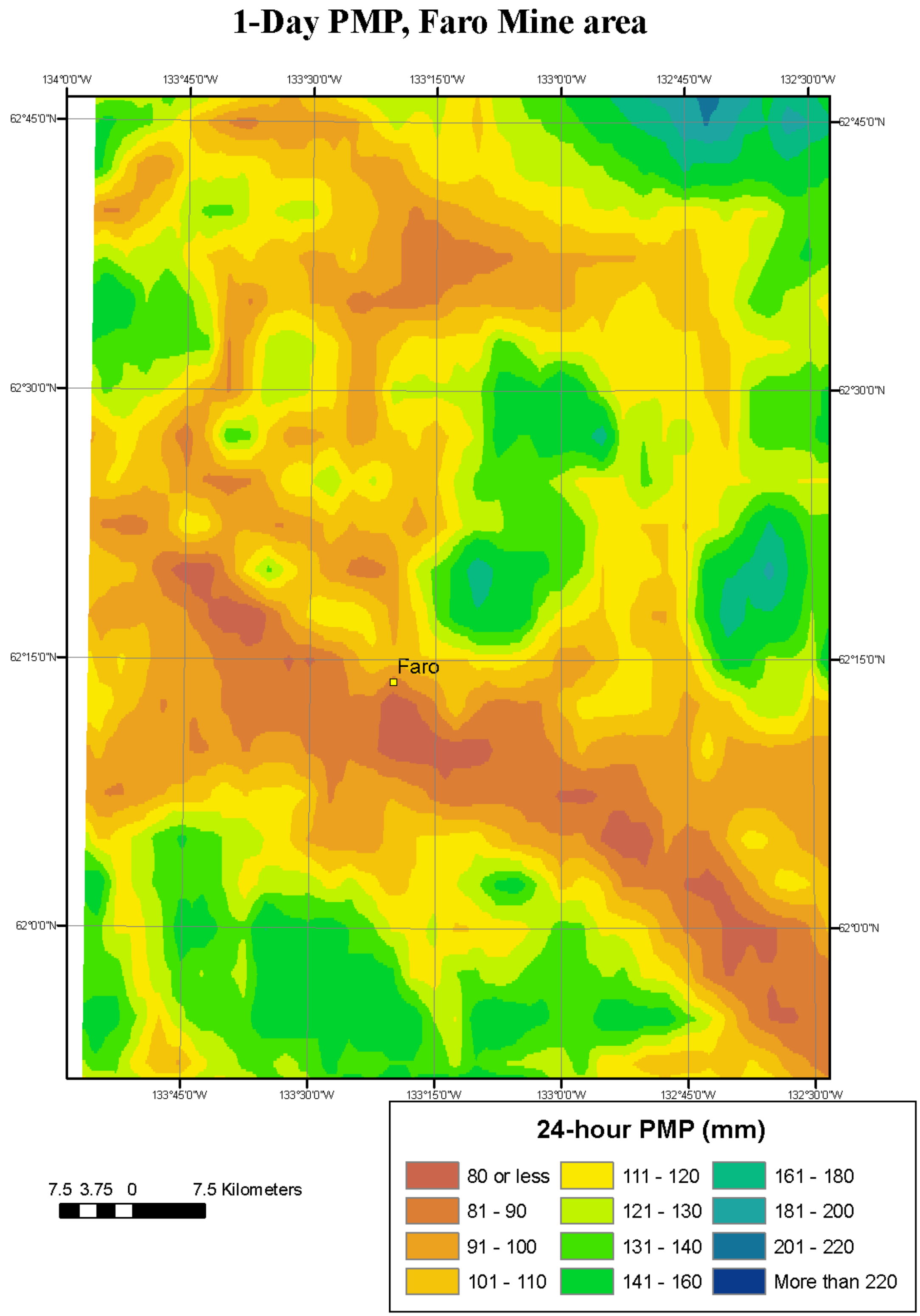

Figure 3.8. 24-hour PMP for the Faro Mine vicinity, using maximum 100-year "isopercentile" applied to every point in the domain.

3.7 Seasonality

The calculations described above were conducted using annual 100-year one-day values, calculated by using the annual maximum one-day value for each year of record. It is prudent to assess seasonal precipitation probabilities as well, especially since rain events falling on snow-covered ground have been known to cause extreme flood conditions in some areas.

Large precipitation events are most likely in the Faro Mine area (and in most of Yukon, in fact) during the warm season, with July the peak month for extreme events. In late spring (May through early June) snow depth can be significant, especially at higher elevations. June actually qualifies as both a "warm season" month and a "spring" month.

Figure 3.9 shows the distribution of monthly precipitation events at Faro (station A2100517) for return periods of 2 through 100 years, based on a Gumbel distribution of the maximum observed events in each calendar month (1978-2001). May, June and July are the months most likely to see large precipitation events. It would appear that May or early June rainstorms could produce significant rain-on-snow events if the snow water equivalent of the snowpack were sufficiently large.

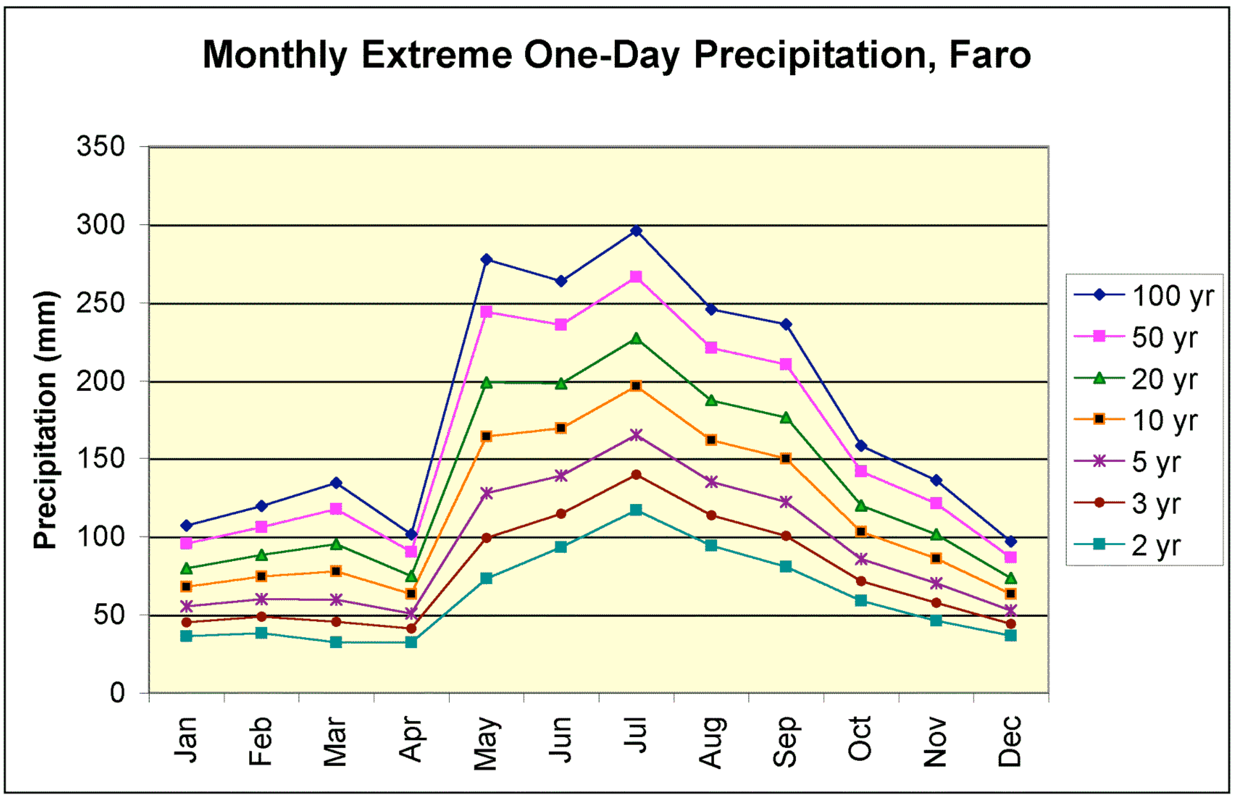

Figure 3.9. One-day precipitation extremes by month for Faro (station A2100517)

4. DEPTH-AREA DURATION (DAD)

The 24-hour PMP maps shown in Figures 3.7 and 3.8 represent point PMP estimates (actually, for a single grid cell, with area of roughly 2 sq. km.) for a 24-hour duration. For modelling the Probable Maximum Flood, information on the PMP for other durations is required together with data on the distribution of PMP across the watershed. Storm depth-area relationships are normally developed on the basis of total precipitation.

4.1 24 to 72 hours

Gridded PMP values for each storm listed in Table 2.2 were contoured using GIS and converted to shape files and then to polygons, and the areas of the various contours were obtained from the GIS software. Areas and contour amounts (e.g., the area within an area averaging 100 mm) were plotted and a regression line formula determined. This allowed determination of depth-area statistics for any precipitation amount. An “envelope” approach was used whereby the highest estimated values for each duration was selected, and a composite curve created.

Figures 4.1 through 4.3 show depth-area values for each candidate storm for 24-, 48-, and 72-hour periods, respectively. Also shown is an envelope curve representing the maximum depth-area for each duration. The envelope values for various areas are listed in Table 4.1.

Area (sq. km)	**24-hour (mm)**	**48-hour (mm)**	**72-hour (mm)**
2	184	306	375
10	172	301	369
100	154	300	353
500	152	270	335
1000	137	255	310
2000	128	240	294
5000	125	225	275

Table 4.1 Depth-area table for 24-, 48-, and 72-hour PMP “envelope” values.
Units of areas are in square kilometres.

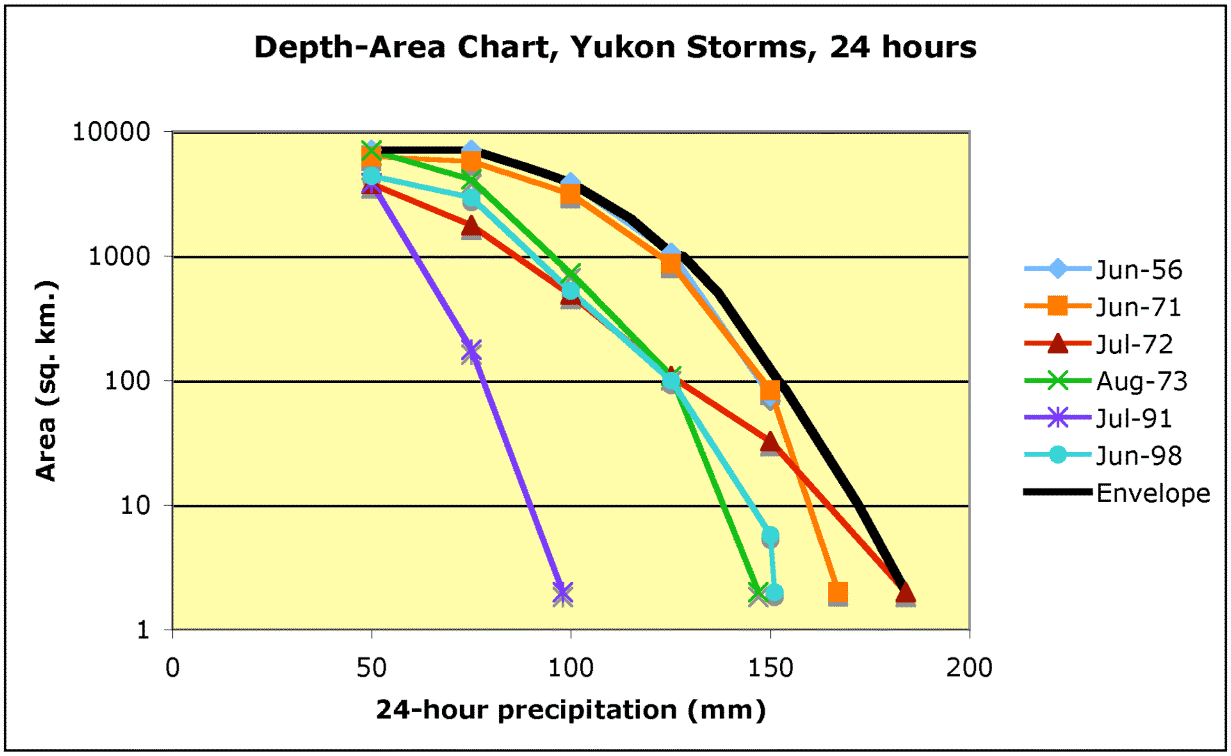

Figure 4.1. Depth-area chart for 24-hour PMP values

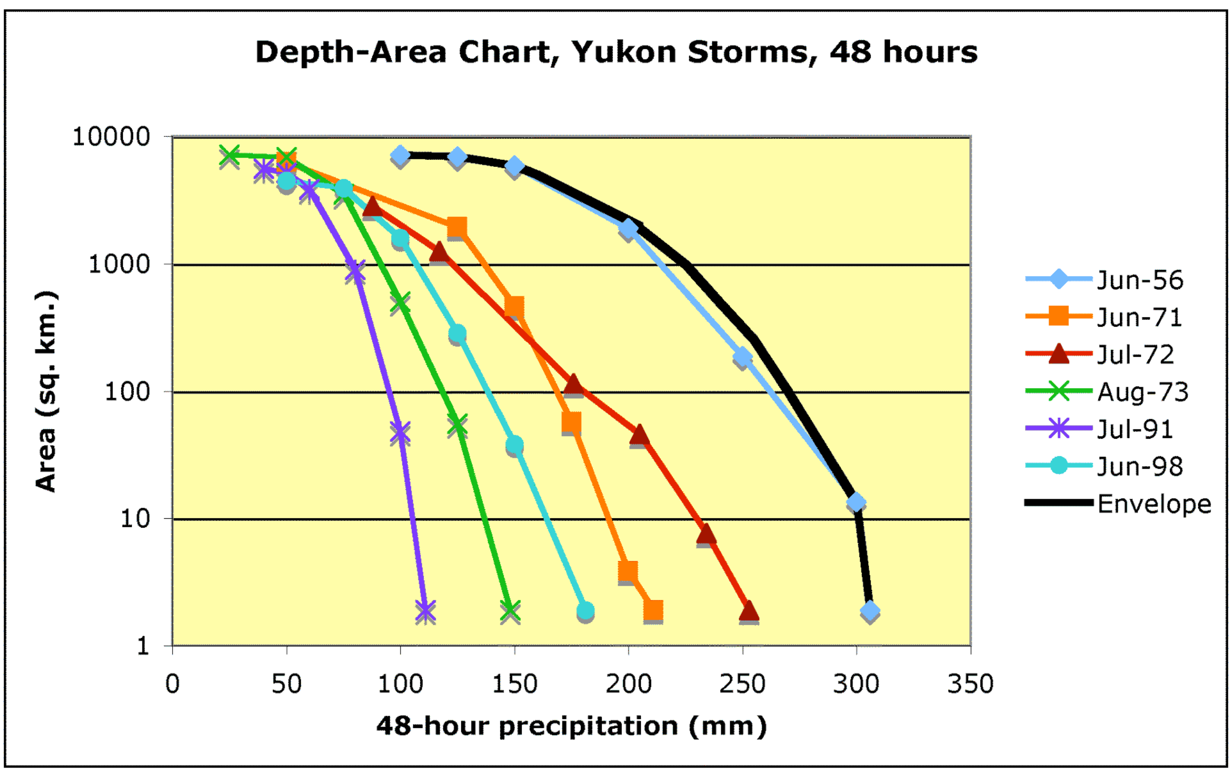

Figure 4.2. Depth-area chart for 48-hour PMP values

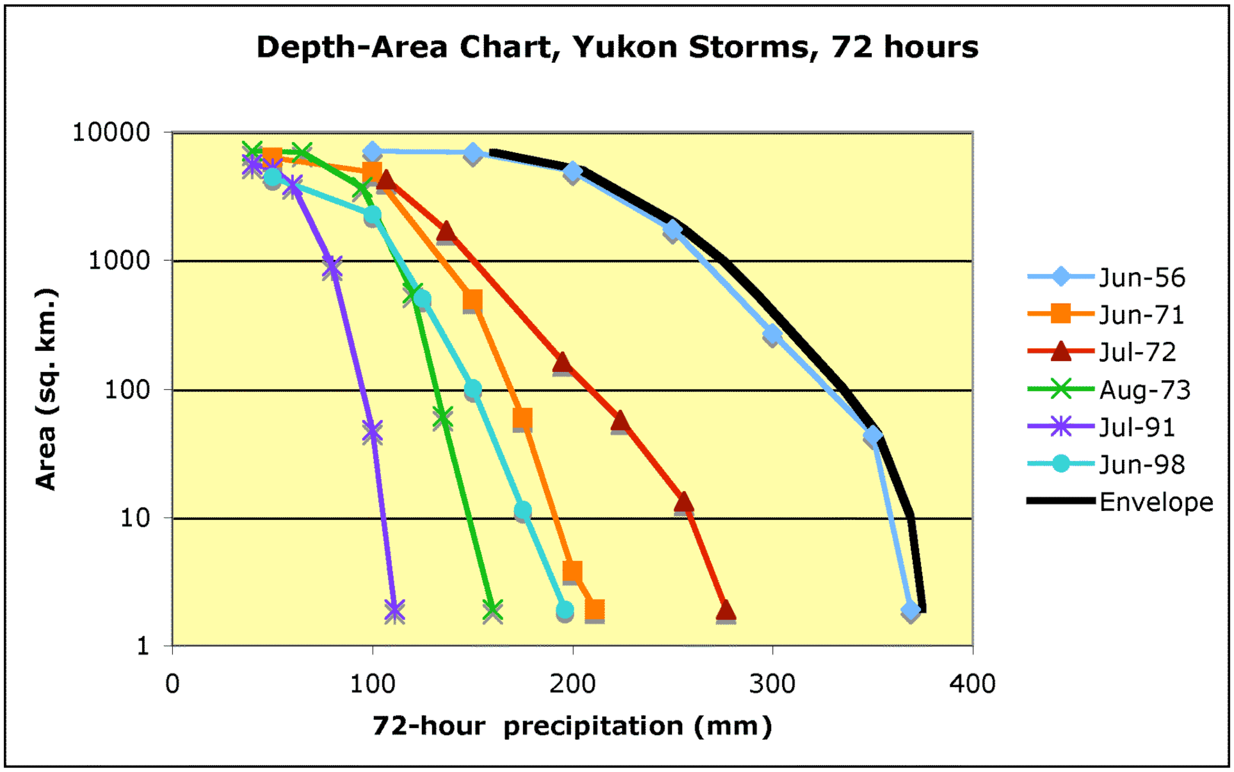

Figure 4.3. Depth-area chart for 72-hour PMP values

4.2 Periods less than 24 hours

Daily data for Yukon Territory are quite sparse, and hourly data are even more so. Rather than attempting to compute sub-daily depth-durations using Yukon hourly data, the results from extensive U.S. National Weather Service analyses was adopted. The study most applicable to the Yukon region is HMR-57, "Probable Maximum Precipitation – Pacific Northwest States" (U.S. Department of Commerce, 1994). That report listed depth-duration curves for subregions east and west of the Cascades.

The Faro Mine site is geographically similar to areas of the Northwest U.S. east of the Cascades due to its location east of the coastal mountains. This results in significant diurnal and annual temperature variability as well as warm-season precipitation maxima. Zone 7 in HMR-57 was chosen as the best match for Yukon Territory; this represents much of the eastern half of Washington. It also had the highest percentages of 1- and 6-hour precipitation compared with 24-hour values, so it also was the most conservative of those listed.

Figure 4.4 shows estimated depth-area relationships for each duration period, expressed as percentages of 24-hour 2 sq. km. PMP. Figure 4.5 shows similar data, expressed in depth units (mm). The 1- to 24-hour ratio was assumed to be 0.20, and the 6- to 24-hour ration 0.59, regardless of area.

Using a best-fit logarithm curve, estimated values representing the fraction of 24-hour PMP were obtained for other averaging periods. These are shown in Table 4.2.

Averaging period (hours)	Ratio
1	0.20
2	0.36
3	0.46
6	0.59
8	0.70
12	0.80
18	0.91
24	1.00

Table 4.2. Fraction of 24-hour PMP for various averaging periods

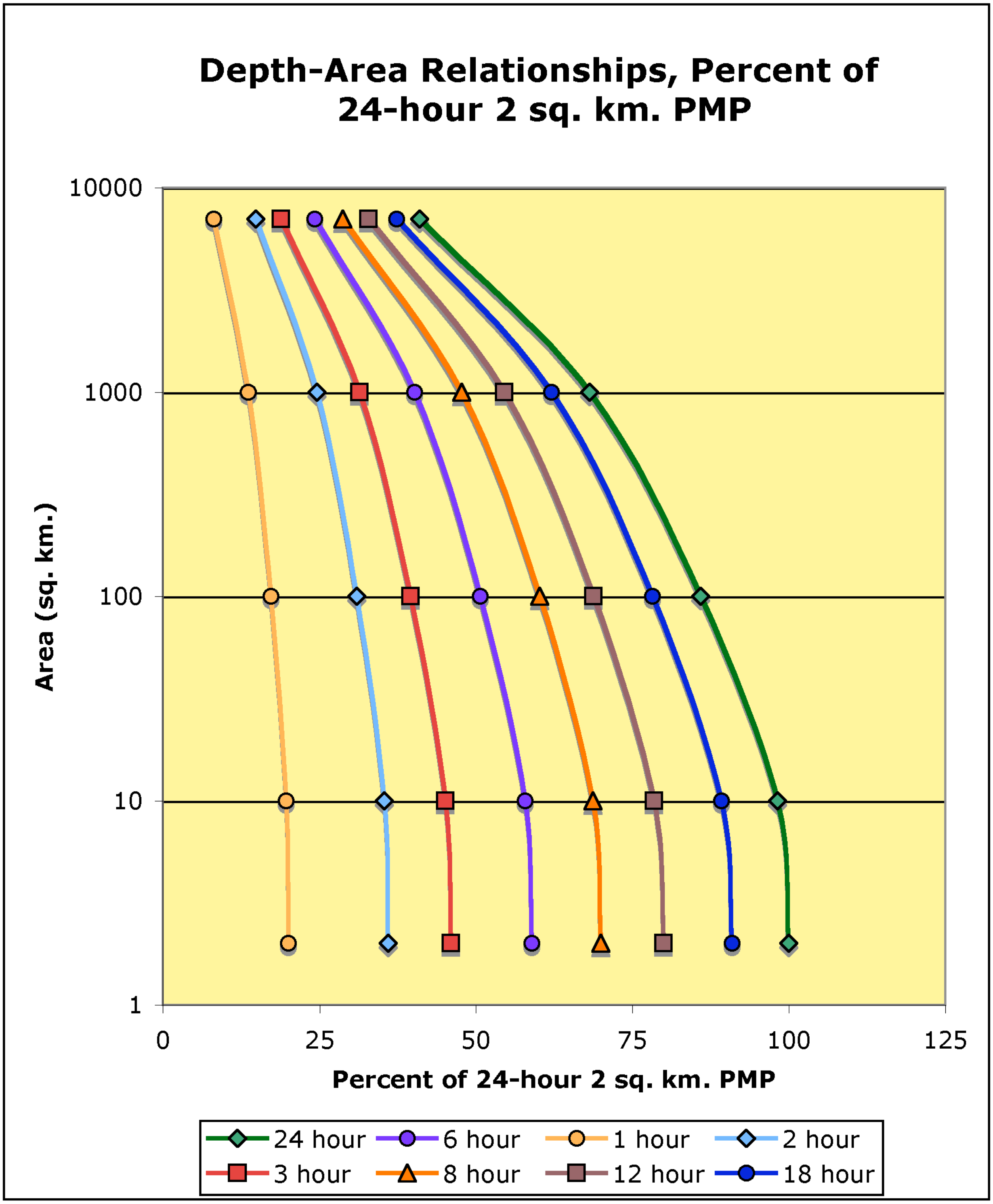

Figure 4.4. Percent of 24-hour 2 sq. km. PMP for periods less than 24 hours

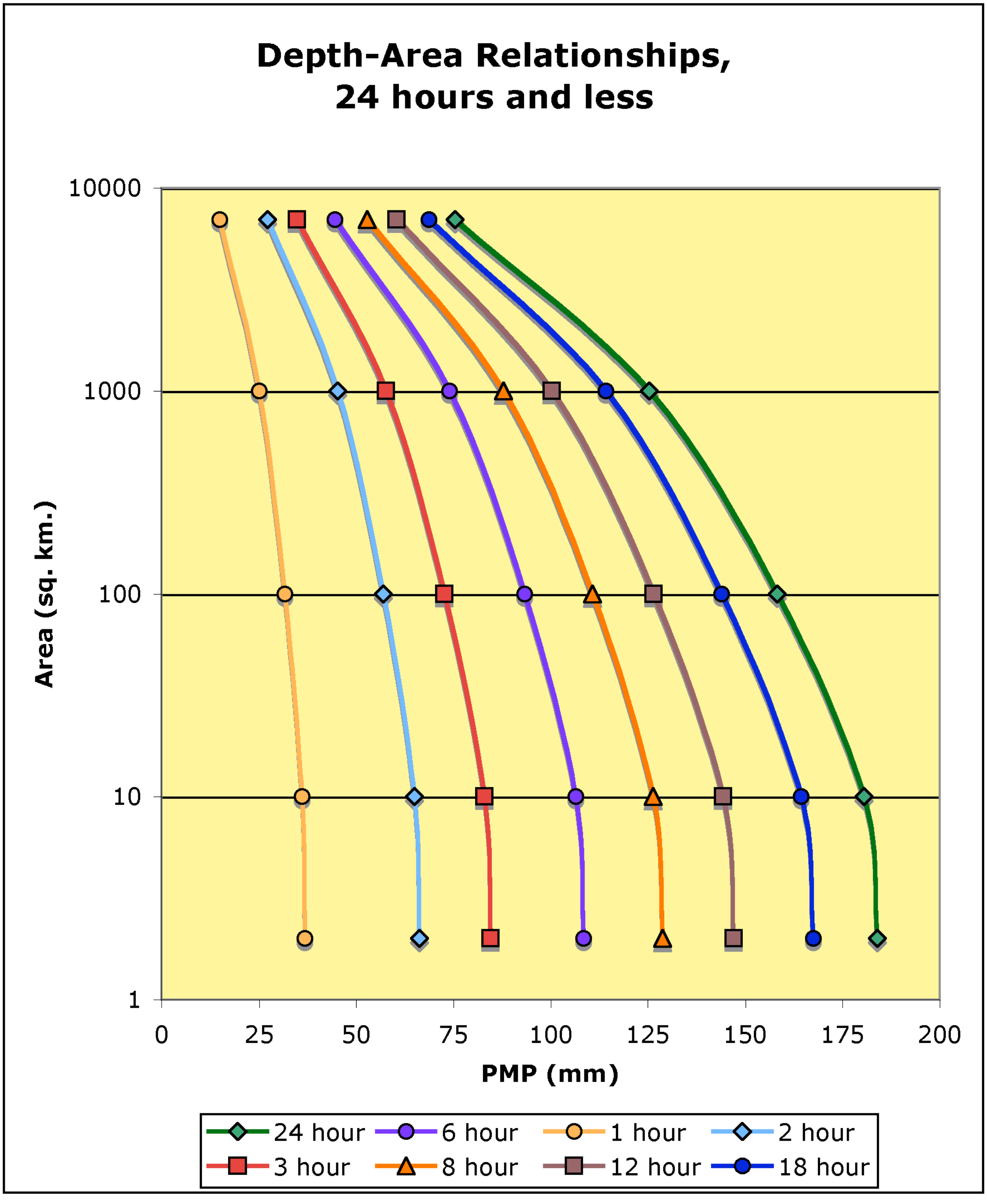

Figure 4.5. Depth-Area Estimates of PMP for periods less than 24 hours

5. FUTURE CONDITIONS

There has been speculation that future warming of the climate of Canada will cause changes in the hydrological cycle, including sharp increases in precipitation rate and amount. Wang and Whitfield, for example, stated in their abstract:

> "Methods for estimating PMP are usually estimated based on the present available historical data; however, by definition, any possible factors that may influence PMP should be taken into account. In this study, we focus on how future climate change (temperature and precipitation) might be accounted for in determining future PMP and PMF. Using the Coupled Global Climate Models (CGCM) with grid boxes centering at locations of hydrometric stations in Yukon, we found that, by the end of this century, maximum increases of temperature may vary from 4.4°C to 6.8°C and maximum increases of precipitation from 5% to nearly 20% depending on the locations of the watersheds in the territory, compared to the 1961-1990 baseline. Maximum increases of precipitation and temperature show a clear spatial pattern in Yukon with greatest increases in the north and smallest in the south. These findings may have important implications to determining PMP and PMF in Yukon."

The statements above assume that computer model projections for the next century, which assume higher temperatures due to greenhouse gas enhancement, are accurate. Let us examine several aspects of historical Yukon (and nearby regions) climate, and also comment on the models used for projecting current climate into the future.

Appendix 3 has a lengthy discussion of this issue and its applicability to Yukon precipitation. The conclusions from our analysis are:

1. There has been significant variability of temperatures in the past, and current temperatures are within the range of natural variability over the last millennium

2. There has been significant variability of temperatures in the past, and current temperatures are within the range of natural variability over the last century.

3. Climate models remain rather inadequate for simulating past climate and predicting future climate.

4. We believe that the temperature and precipitation increases suggested by Wang and Whitfield are unreasonably high.

5. The twentieth century has seen no significant change in precipitation intensity, in spite of marked variations in climate. Heavy rains over the past few centuries have been more extreme during cold periods rather than warm ones. A warmer world may not be a wetter one.

6. CONCLUSIONS

Probable maximum precipitation (PMP) values were computed for the Faro Mine in the Yukon Territory, based on weather station reports from Yukon Territory and adjoining provinces and U.S. states. PMP calculations are essential for proper design of dams, tailings ponds, reservoirs, and other water catchment devices.

Major historical storms were identified. The largest storm transferable to the Faro Mine area was the event of July, 1972, which produced a maximum one-day precipitation total of 66.1 mm. Maximizing moisture and transposing the observed data to the Faro Mine area produced a PMP estimate of 184 mm for 24 hours.

Depth-area duration (DAD) estimates were completed for 24-, 48-, and 72-hour periods based on percentages of single-cell (2 sq. km.) PMP. DAD ratios for averaging periods less than 24 hours were estimated using the results of previous studies in the Pacific Northwest.

It is very difficult to predict future climate change; quite simply, we do not know how climate will change in the next 100 years. At this point we cannot recommend the predictions from climate models due to recognized inadequacies in them.

Analysis of the last century and the last millennium leads us to believe that current temperatures are well within temperature variability from prior periods, in spite of steady growth of greenhouse gas concentrations. This suggests that the very large future temperature increases predicted by climate models may be much too high, and that the feared enhancement of the hydrologic cycle (including much heavier rains) may be unrealistic. Historical rainfall data for Canada suggests that even if warming does occur, increased rainfall intensities may not occur.

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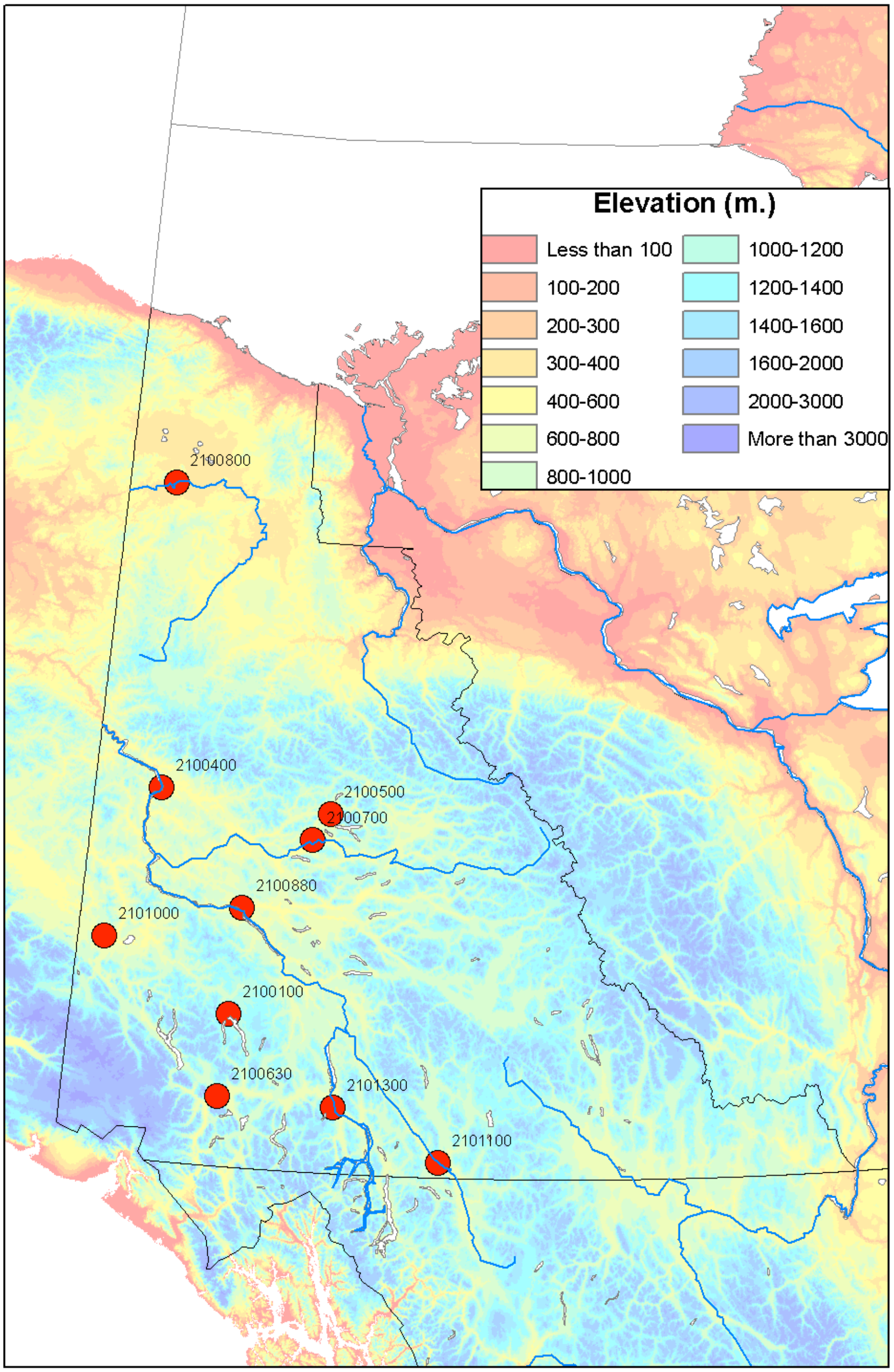
Appendix 1

Listings of Observed Precipitation for Selected Storms

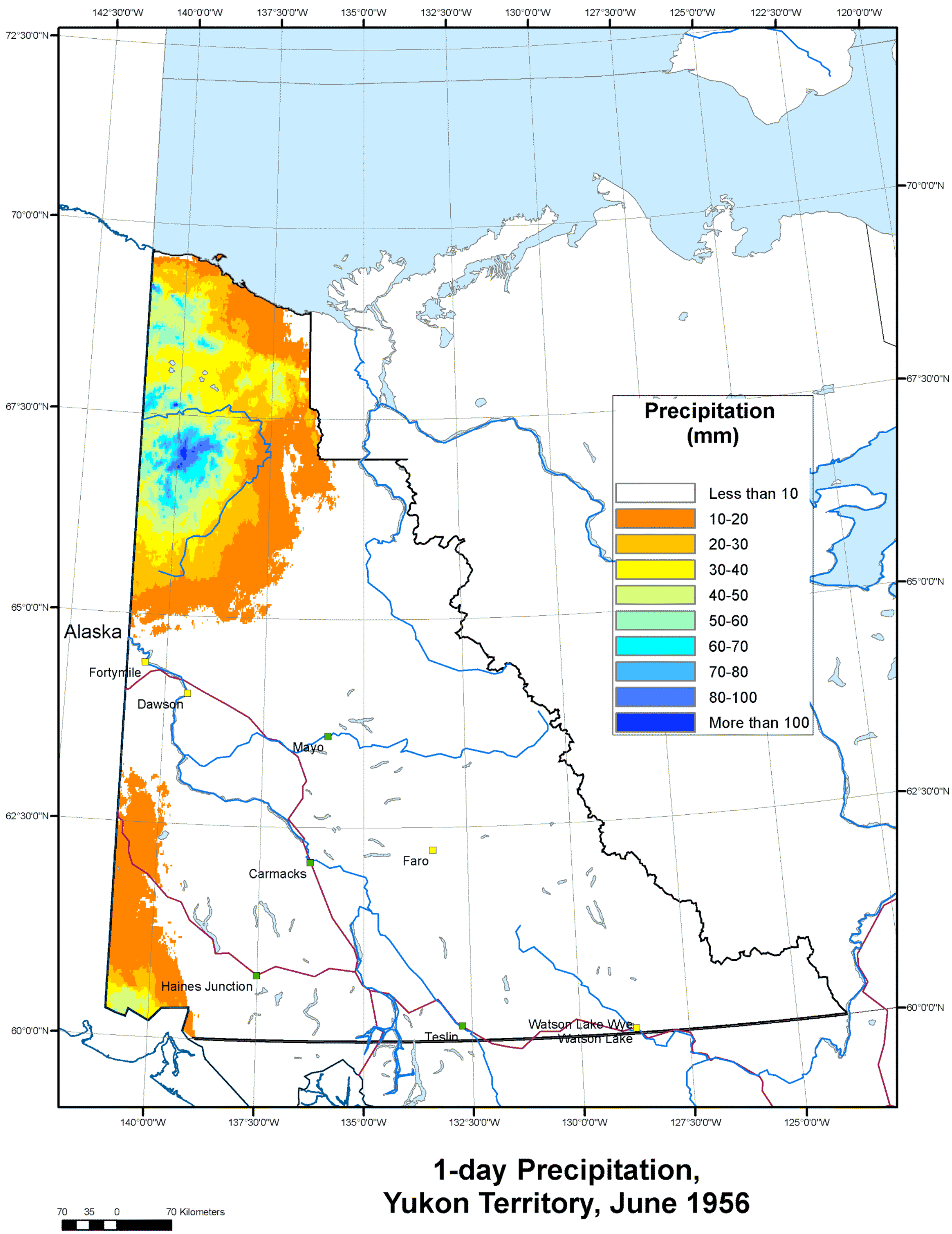
Listed below are the stations used in the analysis of the most significant Yukon storms, including the maximum 1-, 2-, and 3-day totals for each storm. Units of precipitation are in tenths of mm. Following each station list is a map showing the locations of individual stations, and a map showing maximum one-day precipitation estimates for each storm.

June 19-21, 1956

Station	Station Name	Max 1-day	Max 2-day	Max 3-day
2100100	AISHIHIK A	0	0	0
2100400	DAWSON	20	38	38
2100500	ELSA	0	0	0
2100630	HAINES JUNCTION	0	0	0
2100700	MAYO A	0	0	0
2100800	OLD CROW A	584	813	1219
2100880	FORT SELKIRK	0	0	0
2101000	SNAG A	180	183	183
2101100	TESLIN A	13	13	13
2101300	WHITEHORSE A	13	13	13



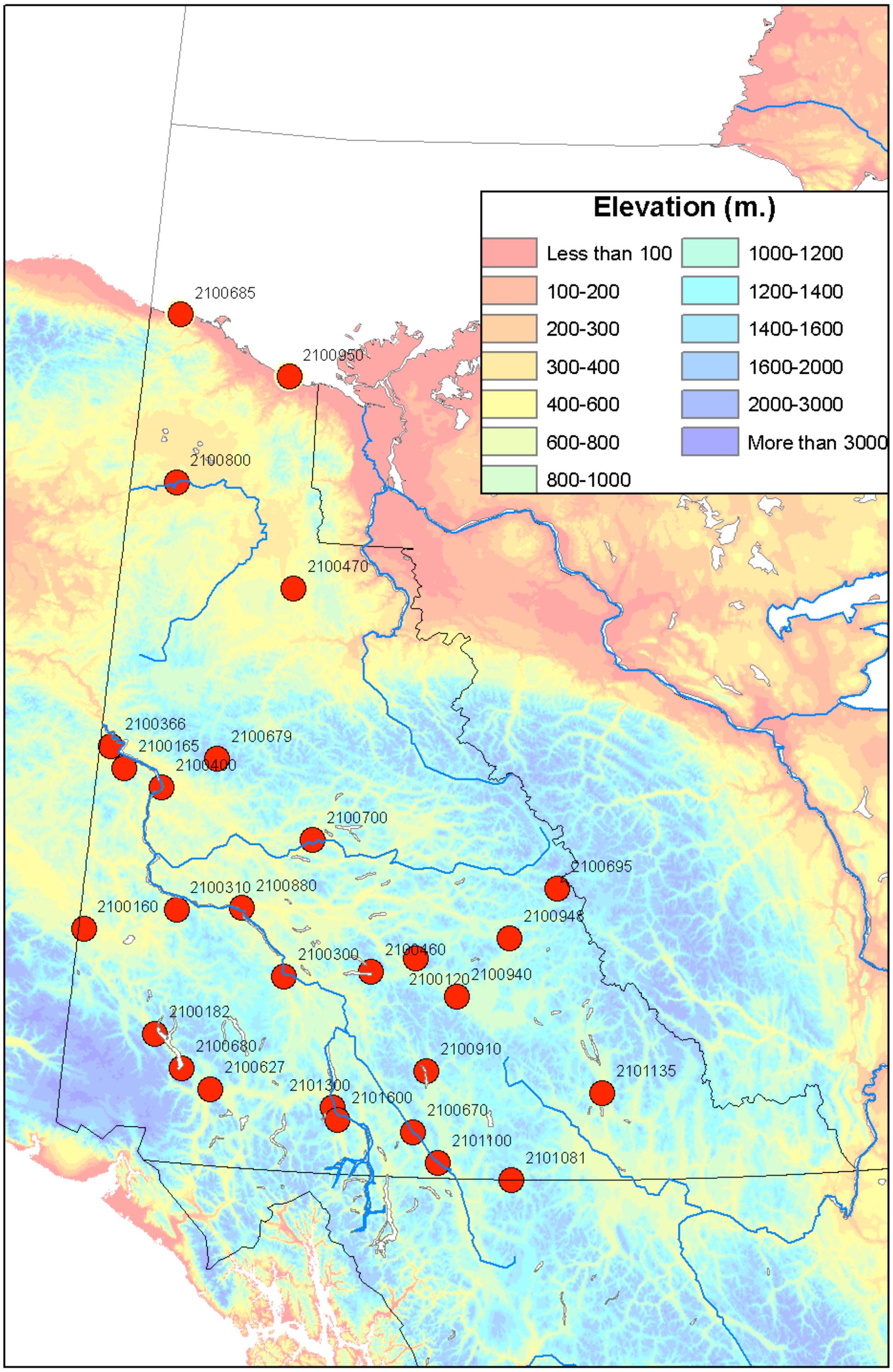
Monitoring stations used for precipitation analysis for June, 1956 storm



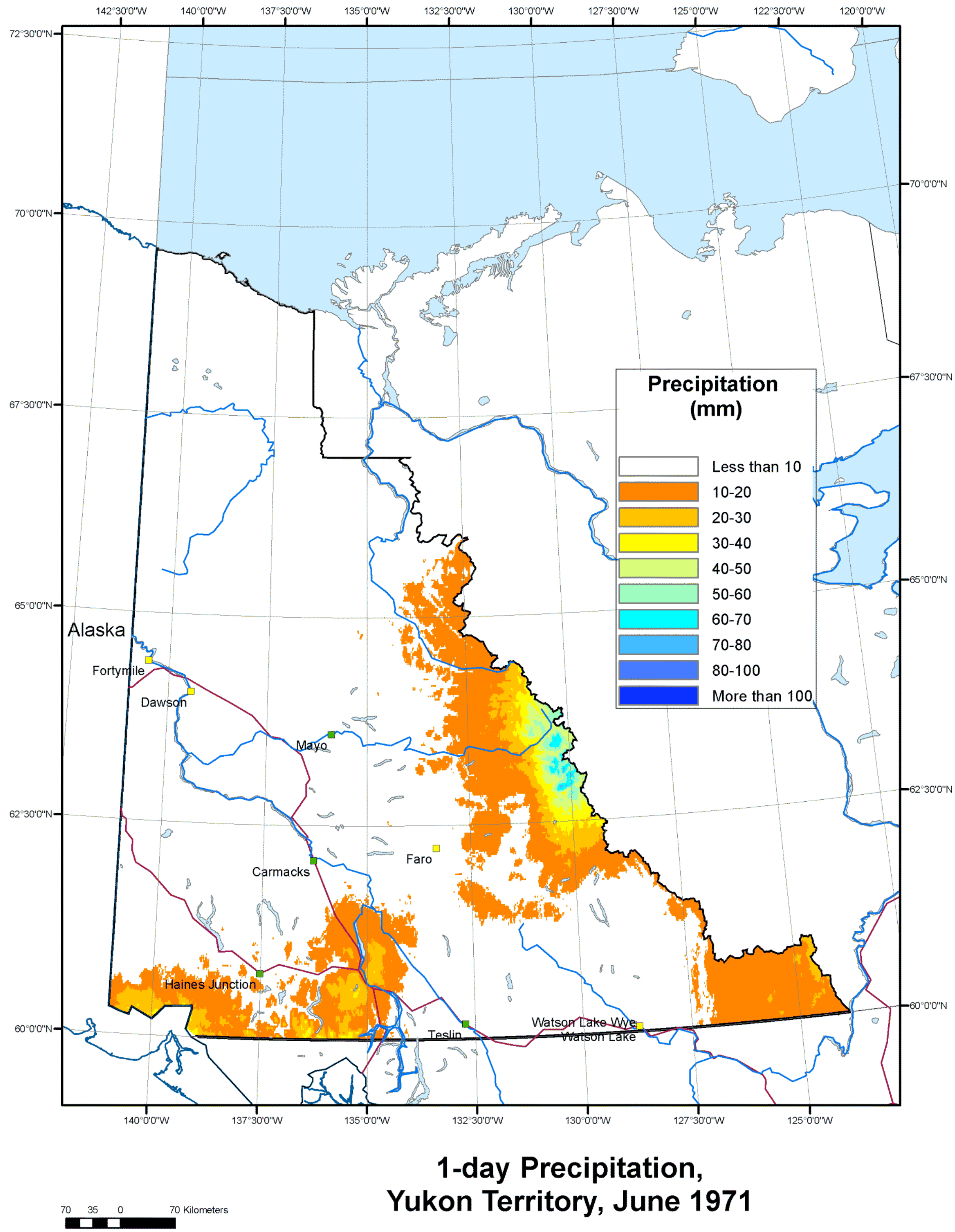
1-day Precipitation,
Yukon Territory, June 1956

June 21-25, 1971

Station	Station Name	Max 1-day	Max 2-day	Max 3-day
2100120	ANVIL	89	107	112
2100160	BEAVER CREEK AAAA	0	0	0
2100165	BOUNDARY	0	0	0
2100182	BURWASH A	18	18	23
2100300	CARMACKS	20	30	30
2100310	CASINO CREEK	0	0	0
2100366	CLINTON CREEK	0	0	0
2100400	DAWSON	0	0	0
2100460	DRURY CREEK	43	43	43
2100470	EAGLE RIVER	0	0	0
2100627	HAINES APPS #4	69	130	194
2100670	JOHNSONS CROSSING	5	5	5
2100679	KLONDIKE	43	43	
2100680	KLUANE LAKE	53	101	142
2100685	KOMAKUK BEACH A	5	5	5
2100695	MACMILLAN PASS	673	864	864
2100700	MAYO A	20	36	38
2100800	OLD CROW A	0	0	0
2100880	FORT SELKIRK	0	0	0
2100910	QUIET LAKE	25	30	30
2100940	ROSS RIVER A	117	127	165
2100948	SHELDON LAKE	107	158	188
2100950	SHINGLE POINT A	3	3	3
2101081	SWIFT RIVER	0	0	0
2101100	TESLIN A	25	25	25
2101135	TUCHITUA	10	10	10
2101300	WHITEHORSE A	180	251	251
2101600	WOLF CREEK	193	193	193



Monitoring stations used for precipitation analysis for June, 1971

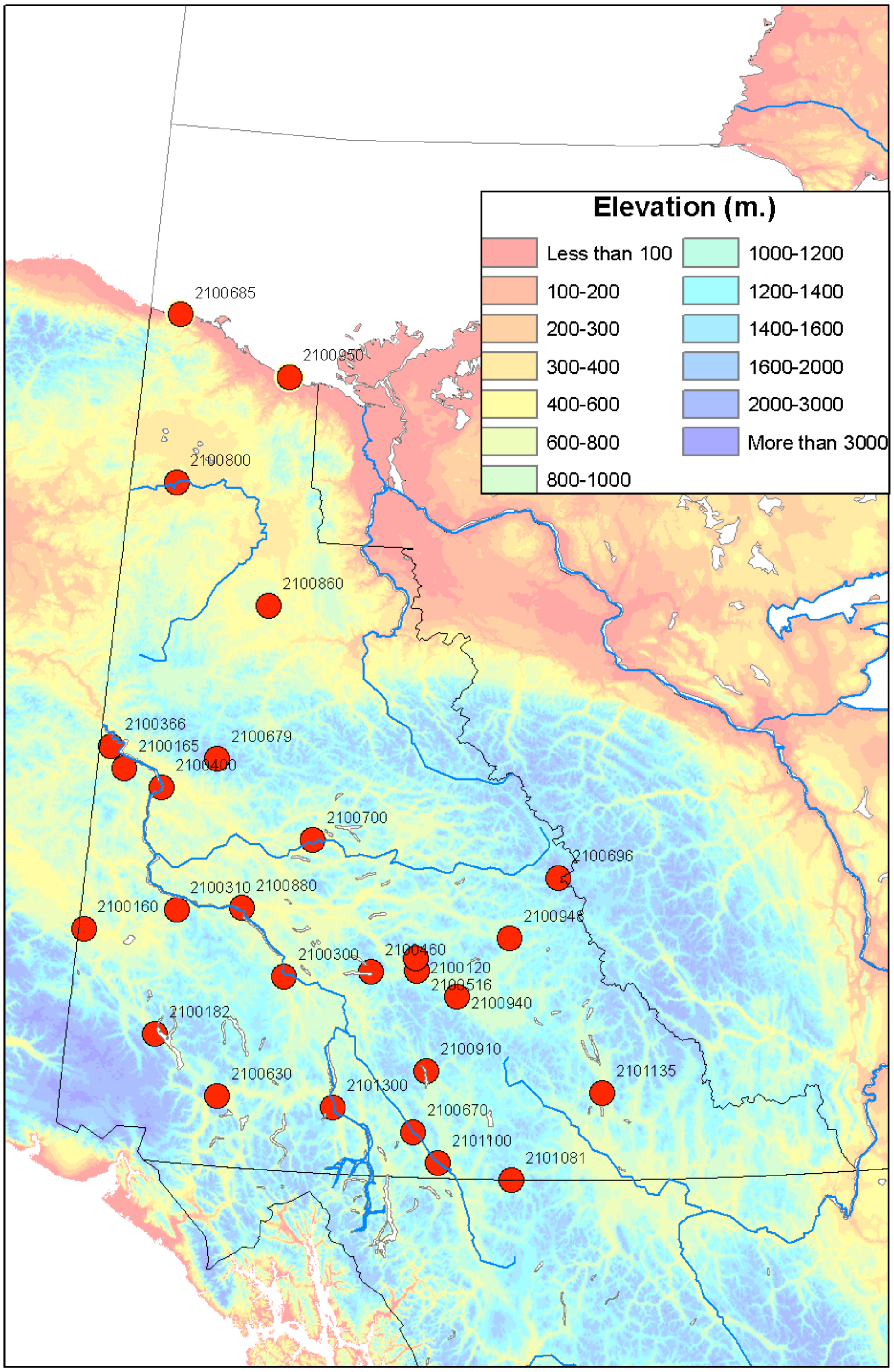


1-day Precipitation, Yukon Territory, June 1971

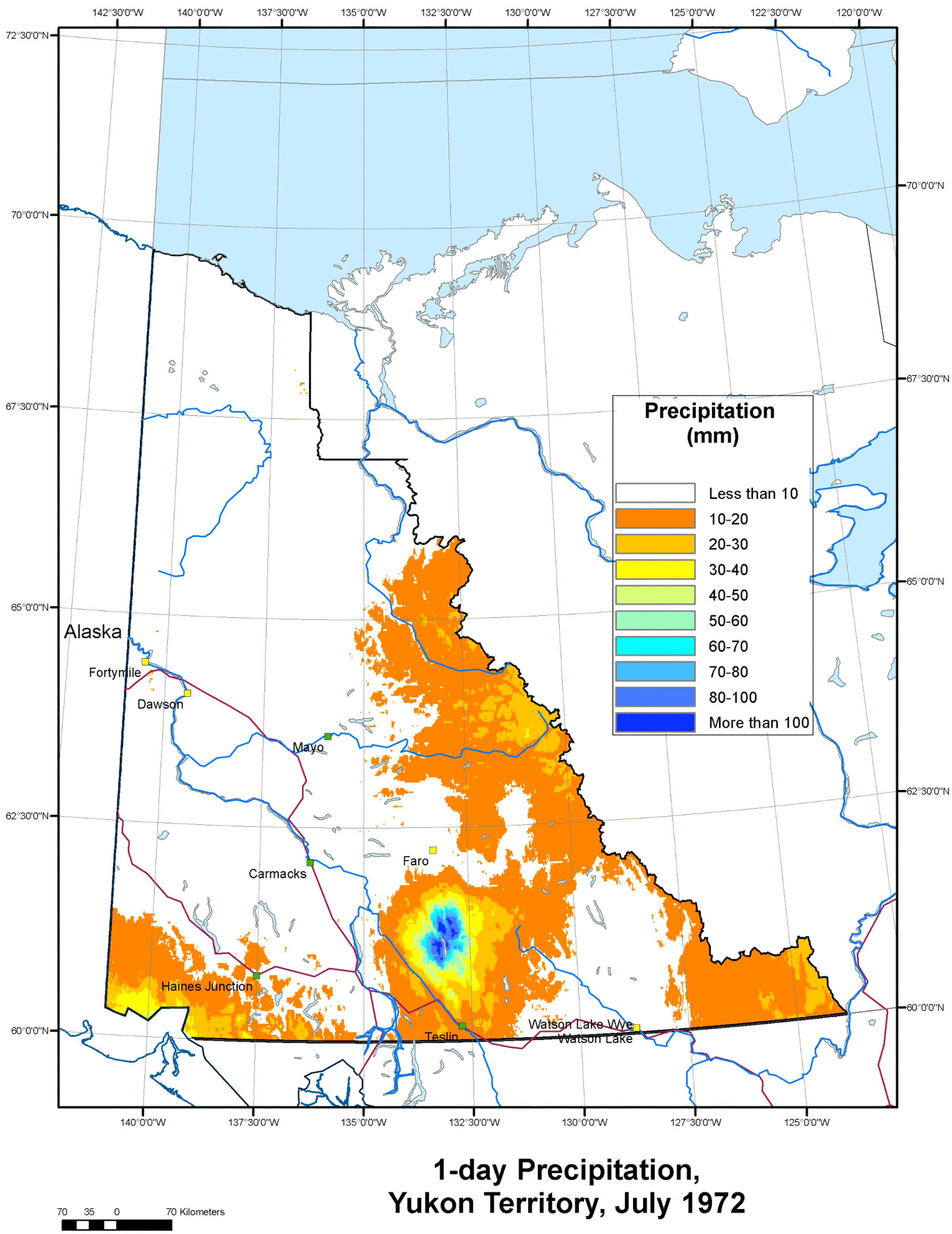
July 20-24, 1972*

Station	Station Name	Max 1-day	Max 2-day	Max 3-day
2100120	ANVIL	61	109	119
2100160	BEAVER CREEK AAAA	36	49	49
2100165	BOUNDARY	117	117	117
2100182	BURWASH A	41	54	54
2100300	CARMACKS	25	46	61
2100310	CASINO CREEK	51	51	51
2100366	CLINTON CREEK	53	53	53
2100400	DAWSON	0	13	13
2100460	DRURY CREEK	36	36	36
2100516	FARO	86	122	147
2100630	HAINES JUNCTION	76	145	145
2100670	JOHNSONS CROSSING	127	201	267
2100679	KLONDIKE	15	15	15
2100685	KOMAKUK BEACH A	0	0	0
2100696	MACTUNG	315	577	709
2100700	MAYO A	15	23	23
2100800	OLD CROW A	0	0	0
2100860	PARKIN	81	101	101
2100880	FORT SELKIRK	58	66	79
2100910	QUIET LAKE*	661	914	944
2100940	ROSS RIVER A	69	117	127
2100948	SHELDON LAKE	76	117	153
2100950	SHINGLE POINT A	58	58	58
2101081	SWIFT RIVER	61	94	117
2101100	TESLIN A	117	145	158
2101135	TUCHITUA	76	97	97
2101300	WHITEHORSE A	30	83	98

* Following adjustment



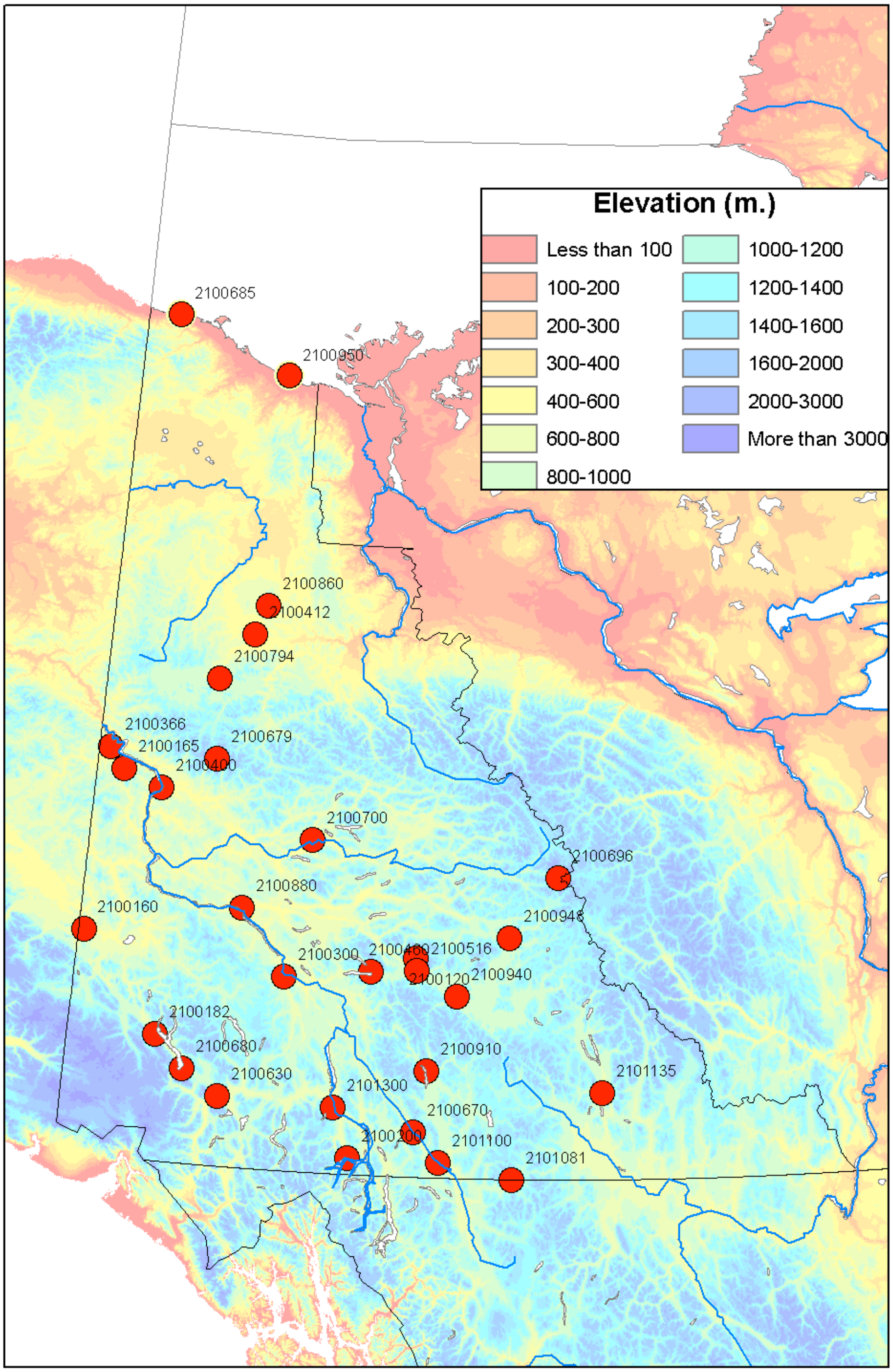
Monitoring stations used for precipitation analysis for July, 1972 storm



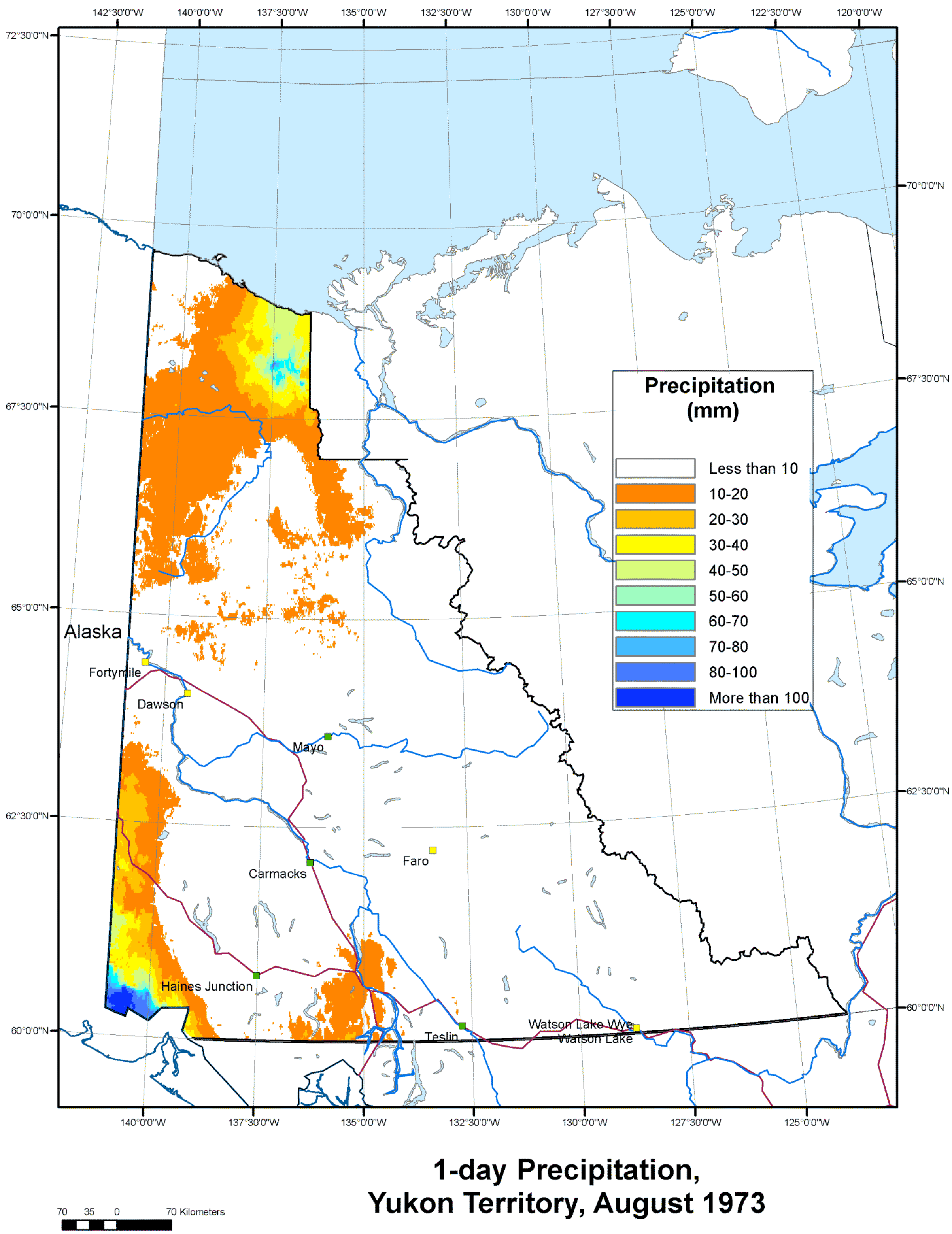
1-day Precipitation, Yukon Territory, July 1972

August 21-24, 1973

Station	Station Name	Max 1-day	Max 2-day	Max 3-day
2100120	ANVIL	28	51	51
2100160	BEAVER CREEK AAAA	340	396	396
2100165	BOUNDARY	43	81	117
2100182	BURWASH A	18	18	18
2100200	CARCROSS	124	124	124
2100300	CARMACKS	38	63	63
2100366	CLINTON CREEK	74	99	112
2100400	DAWSON	81	109	147
2100412	DEMPSTER 177	64	100	115
2100460	DRURY CREEK	15	23	23
2100516	FARO	30	38	53
2100630	HAINES JUNCTION	0	0	0
2100670	JOHNSONS CROSSING	48	48	86
2100679	KLONDIKE	69	87	100
2100680	KLUANE LAKE	13	18	18
2100685	KOMAKUK BEACH A	28	53	61
2100696	MACTUNG	64	92	92
2100700	MAYO A	61	91	119
2100794	OGILVIE RIVER	99	119	119
2100860	PARKIN	150	193	244
2100880	FORT SELKIRK	30	40	50
2100910	QUIET LAKE	5	5	5
2100940	ROSS RIVER A	10	20	25
2100948	SHELDON LAKE	48	73	86
2100950	SHINGLE POINT A	566	602	605
2101081	SWIFT RIVER	36	51	51
2101100	TESLIN A	53	61	64
2101135	TUCHITUA	46	46	61
2101300	WHITEHORSE A	109	114	114



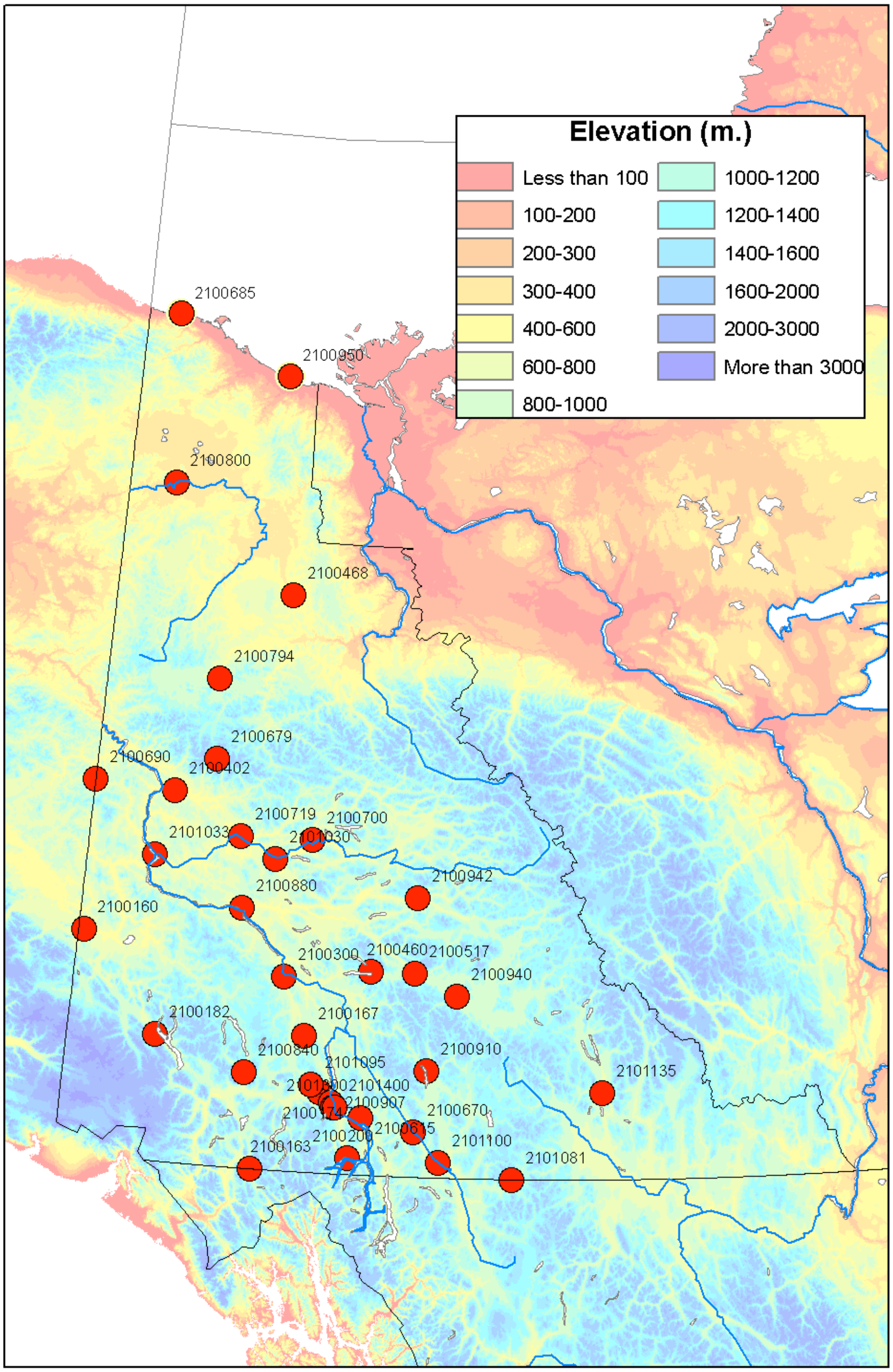
Monitoring stations used for precipitation analysis for August, 1973 storm



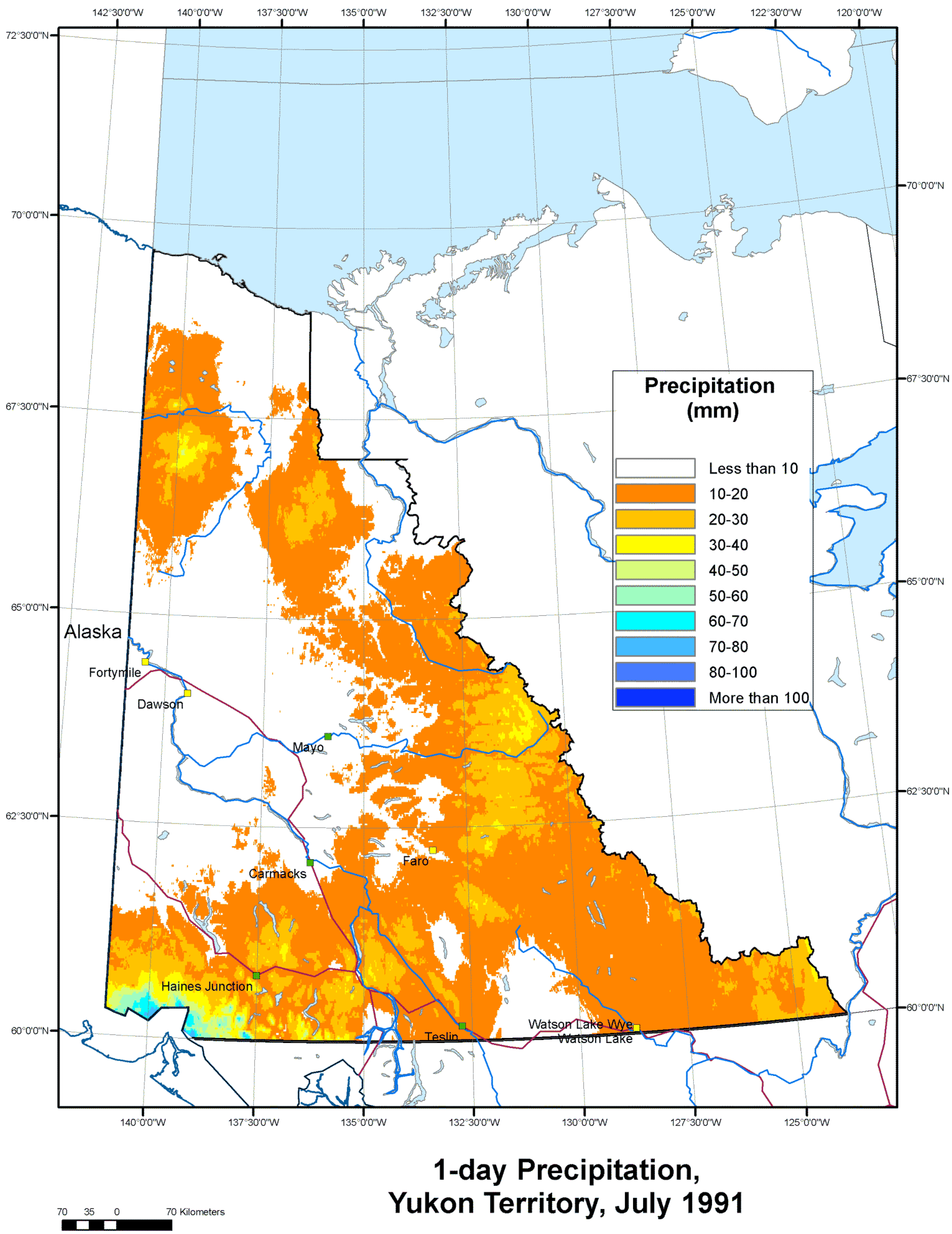
1-day Precipitation, Yukon Territory, August 1973

July 26-29, 1991

Station	Station Name	Max 1-day	Max 2-day	Max 3-day
2100160	BEAVER CREEK AAAA	30	30	30
2100163	BLANCHARD RIVER	500	550	590
2100167	BRAEBURN	96	180	200
2100174	BRYN MYRDDIN FARM	280	426	518
2100182	BURWASH A	92	122	134
2100200	CARCROSS	2	0	0
2100300	CARMACKS	11	0	0
2100402	DAWSON A	10	10	10
2100460	DRURY CREEK	40	0	0
2100468	EAGLE PLAINS	300		0
2100517	FARO A	238	440	452
2100615	GOLDEN HORN	232	335	349
2100670	JOHNSONS CROSSING	148	200	208
2100679	KLONDIKE	40	40	40
2100685	KOMAKUK BEACH A	0	0	0
2100690	LITTLE GOLD CREEK	44	74	74
2100700	MAYO A	76	76	76
2100719	MCQUESTEN	60	66	68
2100794	OGILVIE RIVER	44	56	56
2100800	OLD CROW A	172	200	236
2100840	OTTER FALLS NCPC	236	442	457
2100880	FORT SELKIRK	132	132	132
2100907	PORTER CREEK WAHL	0	0	0
2100910	QUIET LAKE	0	0	0
2100940	ROSS RIVER A	204	269	0
2100942	RUSSELL CREEK	128	178	262
2100950	SHINGLE POINT A	0	0	0
2101030	STEWART CROSSING	0	0	0
2101033	STEWART RIVER	4	4	4
2101081	SWIFT RIVER	10		0
2101095	TAKHINI RIVER RANCH	174	306	360
2101100	TESLIN A	116	156	156
2101135	TUCHITUA	250	342	387
2101300	WHITEHORSE A	232	322	324
2101400	WHITEHORSE RIVERDALE	256	334	336



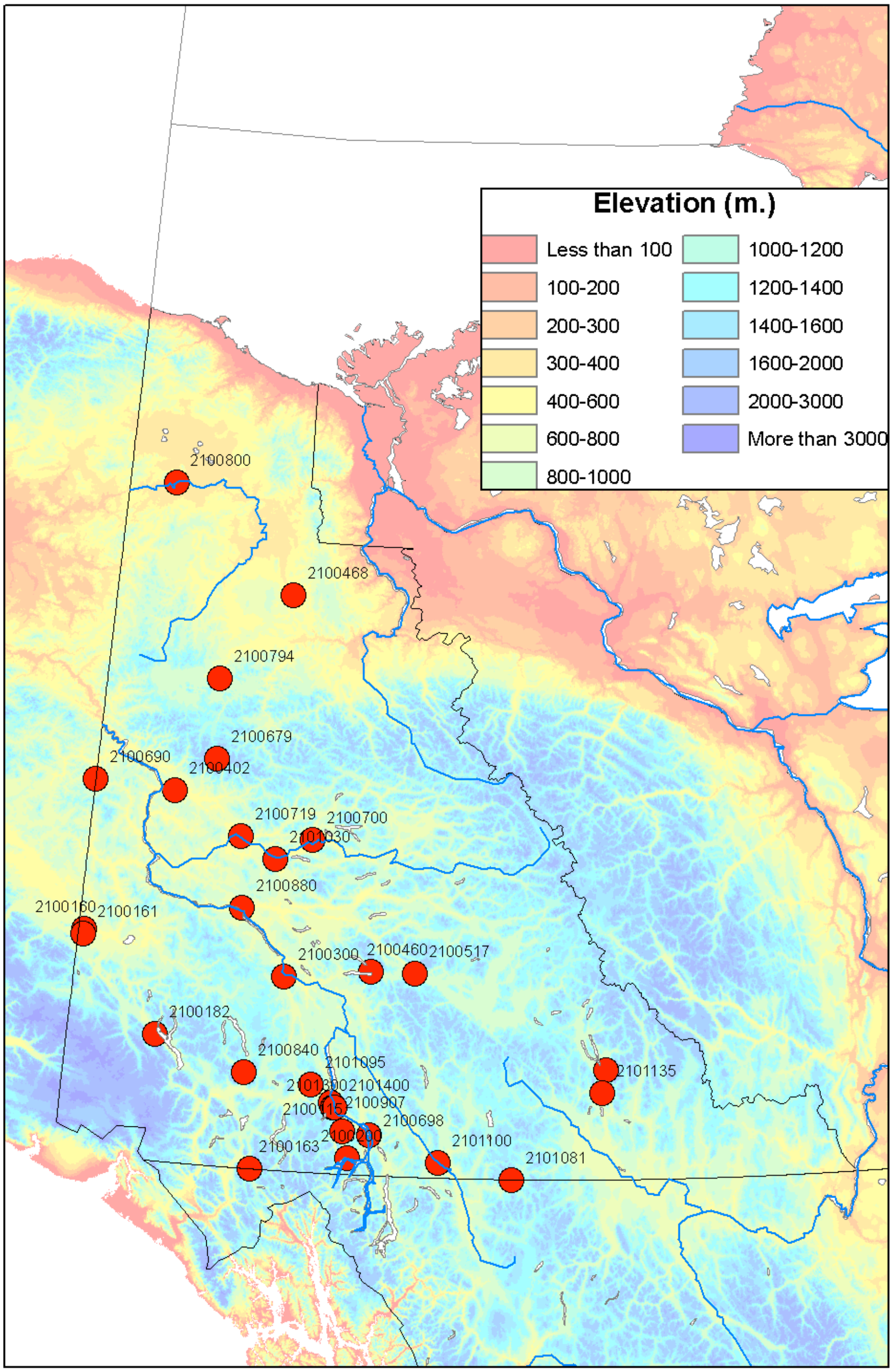
Monitoring stations used for precipitation analysis for July, 1991 storm



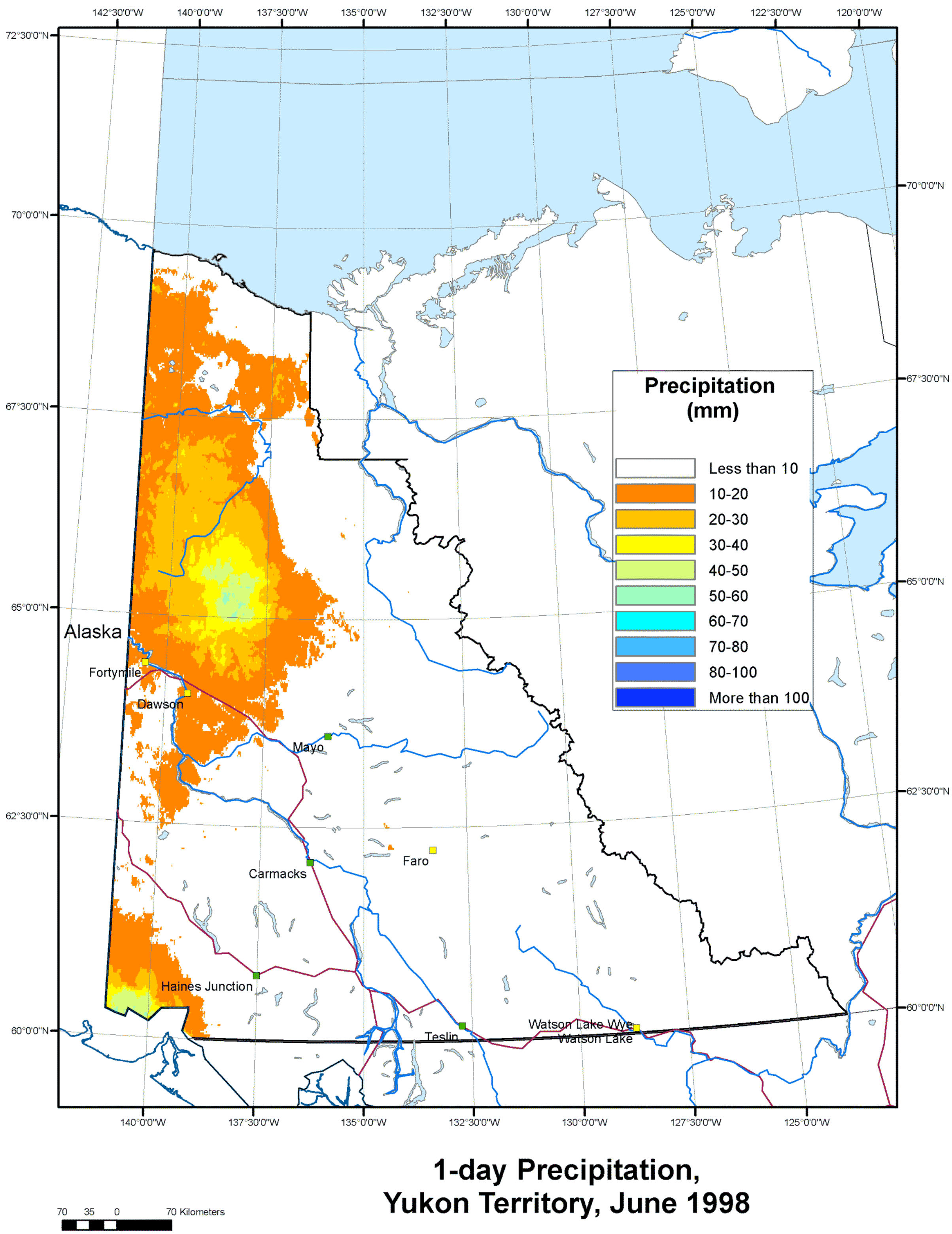
1-day Precipitation, Yukon Territory, July 1991

June 21-23, 1998

Station	Station Name	Max 1-day	Max 2-day	Max 3-day
2100115	ANNIE LAKE ROBINSON	20	22	34
2100160	BEAVER CREEK AAAA	76	76	152
2100161	BEAVER CREEK YTG	72	72	144
2100163	BLANCHARD RIVER	10	20	30
2100182	BURWASH A	32	42	74
2100200	CARCROSS	14	14	18
2100300	CARMACKS	3	5	6
2100402	DAWSON A	170	228	398
2100460	DRURY CREEK	60	84	144
2100468	EAGLE PLAINS	4	6	
2100517	FARO A	42	50	92
2100679	KLONDIKE	202	362	564
2100690	LITTLE GOLD CREEK	150	200	350
2100698	MARSH LAKE	50	50	72
2100700	MAYO A	2	2	4
2100719	MCQUESTEN	110	116	226
2100794	OGILVIE RIVER	534	672	1122
2100800	OLD CROW A	103	103	206
2100840	OTTER FALLS NCPC	32	38	70
2100880	FORT SELKIRK	34	54	78
2100907	PORTER CREEK WAHL	26	34	60
2100FCG	HOUR LAKE	16	16	
2101030	STEWART CROSSING	0	0	
2101081	SWIFT RIVER	39	47	86
2101095	TAKHINI RIVER RANCH	12	22	34
2101100	TESLIN A	30	30	30
2101135	TUCHITUA	10	10	10
2101300	WHITEHORSE A	30	30	40
2101400	WHITEHORSE RIVERDALE	19	21	27



Monitoring stations used for precipitation analysis for June, 1998 storm



1-day Precipitation, Yukon Territory, June 1998

Appendix 2

100-year Daily Precipitation Estimates

100-year precipitation was estimated from daily observations at Yukon measurement stations. For each station, the annual maximum value was determined, and these were used to estimate 100-year return values using the Gumbel 2-parameter method.

In probability theory and statistics the Gumbel distribution is used to find the minimum (or the maximum) of a number of samples of various distributions. For example, it might be used to find the maximum level of a river in a particular year if we had the list of maximum values for the past ten years. It is therefore useful in predicting the chance that an extreme earthquake, flood or other natural disaster will occur. It is commonly used in Canada for estimating extreme values of precipitation.

Gumbel distribution is a special case of the Fisher-Tippett distribution, also known as the log-Weibull distribution.

Table A2-1 lists estimated 100-year daily precipitation for Yukon stations with 10 or more years of record

Table A2-1. Estimated 100-year daily precipitation for stations with 10 or more years of record

Number	Station Name	Years of record	Longitude (deg W)	100-year precip (mm)	Years of record
2100100	AISHIHIK A	61.65	137.48	46.0	23
2100115	ANNIE LAKE	60.47	134.83	33.1	10
2100120	ANVIL	62.37	133.38	39.6	18
2100160	BEAVER CREEK A	62.42	140.87	53.2	30
2100163	BLANCHARD RIVER	60.00	136.77	79.2	14
2100165	BOUNDARY	64.23	140.35	74.2	11
2100167	BRAEBURN	61.47	135.78	42.6	20
2100182	BURWASH A	61.37	139.05	52.1	34
2100200	CARCROSS	60.18	134.70	43.3	57
2100300	CARMACKS	62.10	136.30	43.3	36
2100400	DAWSON	64.05	139.43	48.3	79
2100402	DAWSON A	64.05	139.13	33.0	24
2100460	DRURY CREEK	62.20	134.38	38.8	30
2100468	EAGLE PLAINS	66.37	136.70	63.4	21
2100500	ELSA	63.92	135.48	40.1	31
2100517	FARO A	62.20	133.38	33.7	22
2100630	HAINES JUNCTION	60.75	137.58	62.8	41
2100670	JOHNSONS CROSSING	60.48	133.30	34.0	30
2100679	KLONDIKE	64.45	138.22	31.8	29
2100685	KOMAKUK BEACH A	69.58	140.18	41.2	34
2100700	MAYO A	63.62	135.87	35.6	73
2100719	MCQUESTEN	63.60	137.52	43.9	13
2100794	OGILVIE RIVER	65.35	138.32	46.7	23
2100800	OLD CROW A	67.57	139.83	36.5	34
2100840	OTTER FALLS NCPC	61.03	137.05	49.6	20
2100880	PELLY RANCH	62.82	137.37	40.5	47
2100907	PORTER CREEK WAHL	60.77	135.12	33.2	11
2100910	QUIET LAKE	61.15	133.07	46.6	27
2100940	ROSS RIVER A	61.97	132.43	32.8	27
2100950	SHINGLE POINT A	68.95	137.22	50.3	35
2101000	SNAG A	62.37	140.40	61.1	23
2101030	STEWART CROSSING	63.38	136.68	52.0	20
2101033	STEWART RIVER	63.32	139.43	52.0	15
2101070	SWEDE CREEK	64.10	139.75	37.9	11
2101081	SWIFT RIVER	60.00	131.18	45.9	34
2101095	TAKHINI R. RANCH	60.95	135.57	32.4	18
2101100	TESLIN A	60.17	132.75	40.0	52
2101135	TUCHITUA	60.93	129.22	22.5	27
2101300	WHITEHORSE A	60.72	135.07	36.7	56
2101400	WHITEHORSE RIVDL	60.72	135.02	46.5	27

Appendix 3

Comments on Future Climate Projections

There has been speculation that future warming of the climate of Canada will cause changes in the hydrological cycle, including sharp increases in precipitation rate and amount. Wang and Whitfield, for example, stated in their abstract:

> "Methods for estimating PMP are usually estimated based on the present available historical data; however, by definition, any possible factors that may influence PMP should be taken into account. In this study, we focus on how future climate change (temperature and precipitation) might be accounted for in determining future PMP and PMF. Using the Coupled Global Climate Models (CGCM) with grid boxes centering at locations of hydrometric stations in Yukon, we found that, by the end of this century, maximum increases of temperature may vary from 4.4°C to 6.8°C and maximum increases of precipitation from 5% to nearly 20% depending on the locations of the watersheds in the territory, compared to the 1961-1990 baseline. Maximum increases of precipitation and temperature show a clear spatial pattern in Yukon with greatest increases in the north and smallest in the south. These findings may have important implications to determining PMP and PMF in Yukon."

The statements above assume that computer model projections for the next century, which assume higher temperatures due to greenhouse gas enhancement, are accurate. Let us examine several aspects of historical Yukon (and nearby regions) climate, and also comment on the models used for projecting current climate into the future.

A3.1. Past climate

If enhanced greenhouse gas concentrations were a primary driver of past changes, we would expect to have seen significant changes so far. Carbon dioxide (CO_2) concentrations have increased from about 260 parts per million (PPM) in pre-industrial times to about 375 ppm today (see Figure A3-1). Indeed, since the 1970s there has been a general warming, often blamed on rising CO_2. Many scientists have speculated that if the trends for the last 30 years continued for the next 50-100 years, significant rises in temperature would occur (and the 4.4°C to 6.8°C described in the abstract above would certainly be significant, and unprecedented).

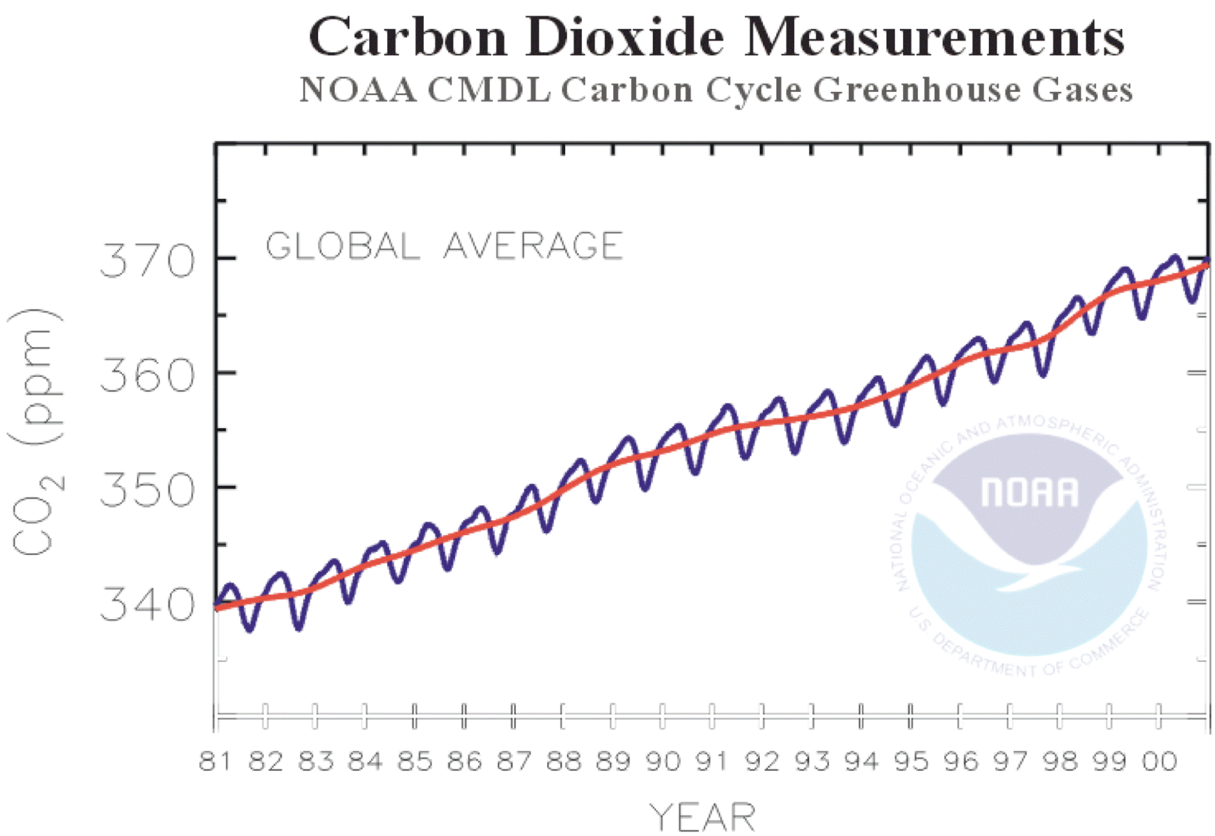


Figure A3-1. Carbon dioxide concentrations measured at Mauna Loa, Hawaii since 1981 (from the National Oceanic and Atmospheric Administration web site)

To predict the future, one must understand the past. Climate history helps us define cause-and-effect relationships pertaining to climate, and also to place today's conditions in historical perspective. Below are reviews of several periods in the past, showing measured or estimated temperature trends.

A3.1.2 Temperatures of the last millennium

The thermometer was invented about 300 years ago. To estimate earlier conditions, one must use "proxy" methods – measurable parameters that approximate or mimic temperature. These include such things as tree rings, sediments, ice cores and isotope measurements.

Figure A3-2, from the 1990 IPPC report, is an example of the "accepted" history of temperatures of the last millennium. Many scientists and authors have produced similar histories. Furthermore, written history confirms the generally cold period known as the "Little Ice Age" and the earlier "Medieval Warm Period," also known as the "Climate Optimum" because civilizations have tended to flourish during such periods. Histories such as that shown in Figure A3-2 suggest that earlier temperatures were as warm as, or warmer than, those observed nowadays.

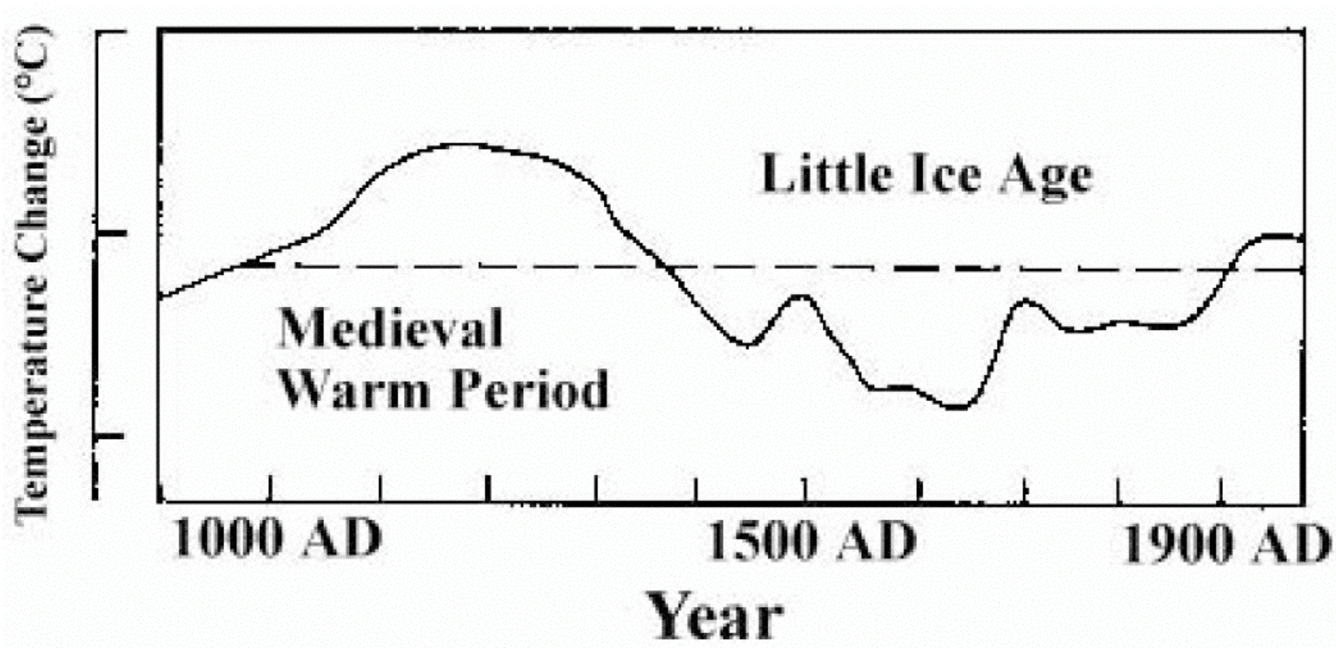


Figure A3-2. Global temperatures of the last 1000 years (IPCC, 1990)

In 1998, a very different temperature history was released, the work of Michael Mann and co-authors. In this new chart, current temperatures were shown to be the highest of the millennium, and the Medieval Warm Period was no longer visible (Mann claimed it was a regional phenomenon only). Mann's chart appears in Figure A3-3. It was quickly adopted by IPCC, who used it in their Third Assessment Report, minus the error bars (Figure A3-4).

Recently, however, it has become evident that the Mann analysis was seriously flawed in several ways. Three journal articles have been released in the past year, which have attempted to "correct" the Mann data. Two of these are shown in Figures A3-5 and A3-6. Errors in the Mann analysis would reaffirm the accuracy of the 1990 chart and suggest that current temperatures are not unique. That implies that the same natural mechanisms which caused earlier warming and cooling may dominate future climates as well.

Regarding the mechanism for change, Gedalof and Smith (2001) compiled a transect of six tree ring-width chronologies from stands of mountain hemlock growing near the treeline that extends from southern Oregon to the Kenai Peninsula, Alaska, analyzing the data to help determine annual variations in the North Pacific ocean-atmosphere system. The period covered by their study spanned the period from from 1599 to 1983.

It was determined that "much of the pre-instrumental record in the Pacific Northwest region of North America is characterized by alternating regimes of relatively warmer and cooler SST [sea surface temperature] in the North Pacific, punctuated by abrupt shifts in the mean background state," which were found to be "relatively common occurrences." The authors concluded, for example, that "regime shifts in the North Pacific have occurred 11 times since 1650" and that "another regime-scale shift in the North Pacific is almost certainly imminent."

Conclusions: there has been significant variability of temperatures in the past, and current temperatures are within the range of natural variability over the last millennium.

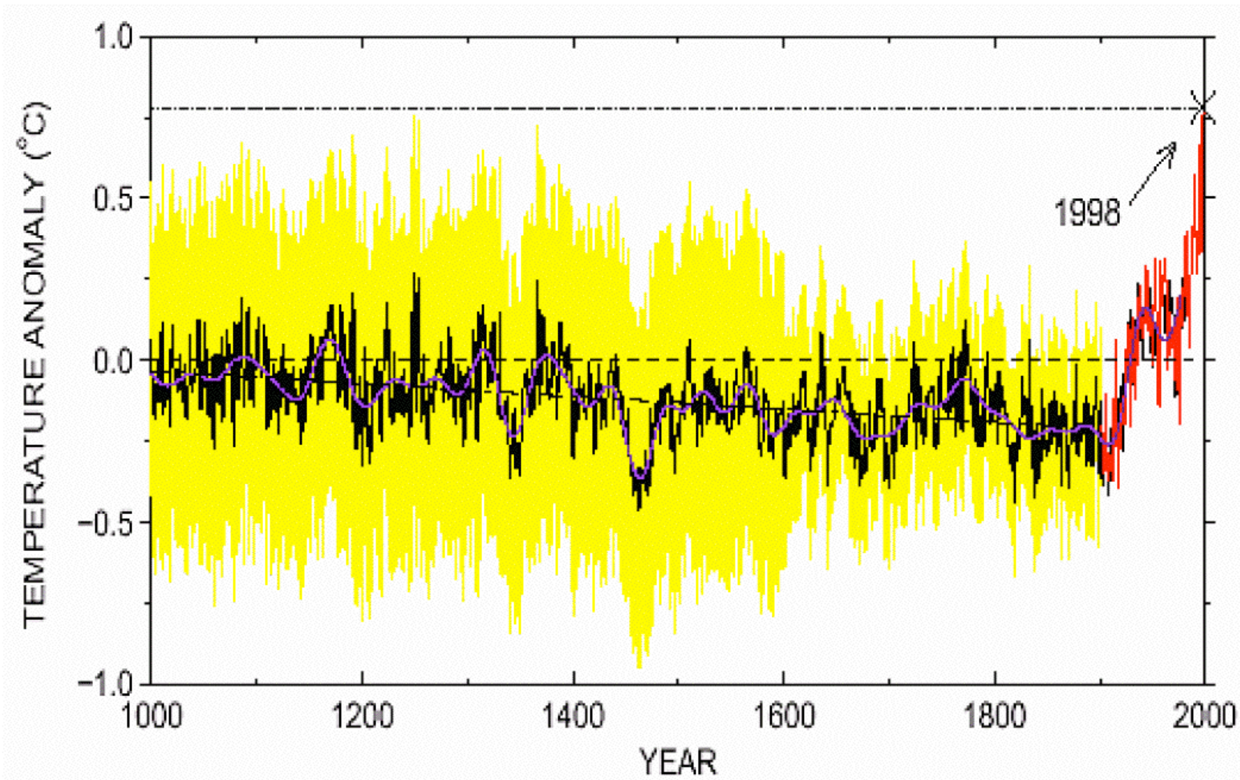


Figure A3-3. Global temperatures since 1000 A.D. (Mann, et al, 1998)

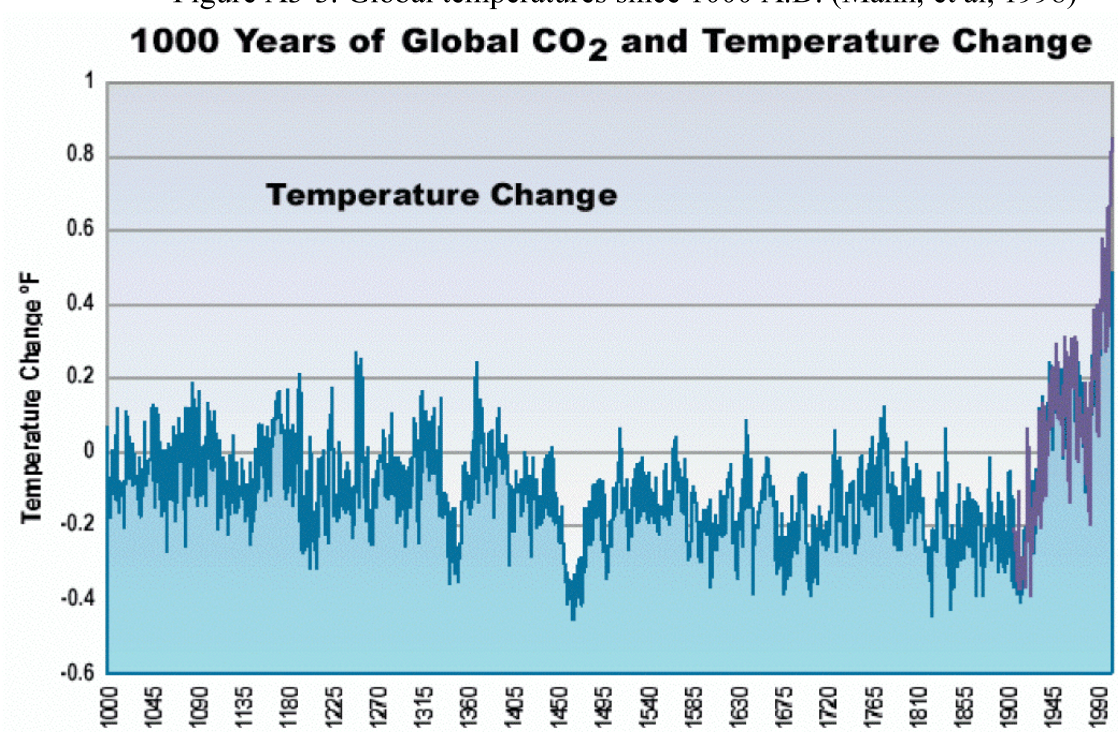


Figure A3-4. Global temperatures since 1000 A.D. (IPCC 2000)

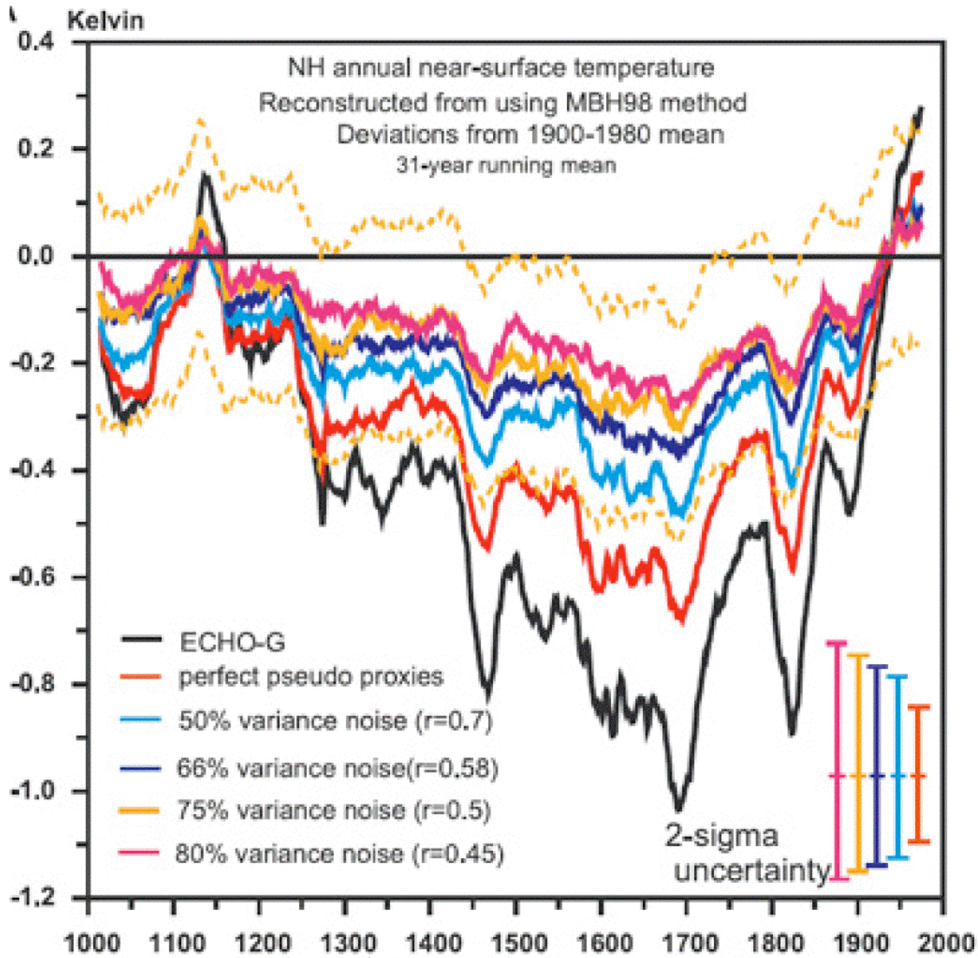


Figure A3-5. Temperature histories of the last 100 years from von Storch (2004), based on Mann, et al data set

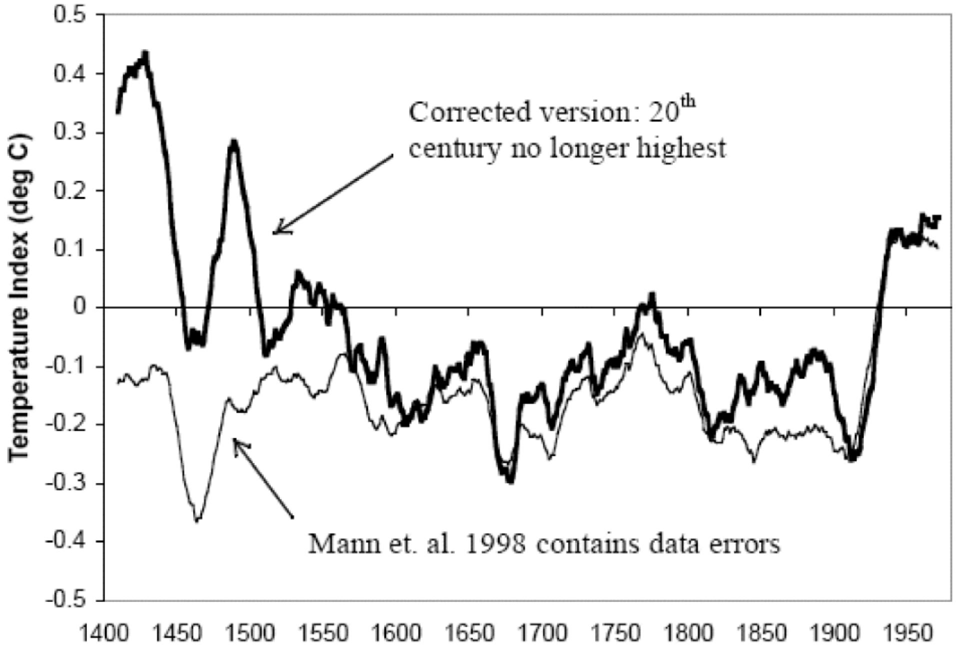


Figure A3-6. Original and corrected Mann, et al temperature history (McIntyre & McKitrick, 2004)

A3.1.3Temperatures of the last century in North America, Yukon and the Arctic

Looking back over the last 100 years we see a very different picture than what the last several decades tells us. Figure A3-7 shows temperature trends since 1880 in the United States. Whereas temperatures have indeed risen since the 1970s, the warmest decade in the last 120 years was the 1930s, and the warmest year was 1934.

Figure A3-8 shows Arctic-wide temperatures from Polyakov et al (2002). This graph looks very similar to the U.S. chart, with a rise over the last 30 years preceded by a much warmer period peaking in the late 1930s.

Turning to Yukon, we see annual temperatures from Whitehorse in Figure A3-9, showing very little change since 1980.

In nearby Alaska (Figure A3-10), the temperature history since 1949 is characterized by two very distinct periods with little change (1949-1976 and 1977-current) separated by the well-known “Pacific Regime Shift” of 1976-77.

Conclusions: there has been significant variability of temperatures in the past, and current temperatures are within the range of natural variability over the last century.

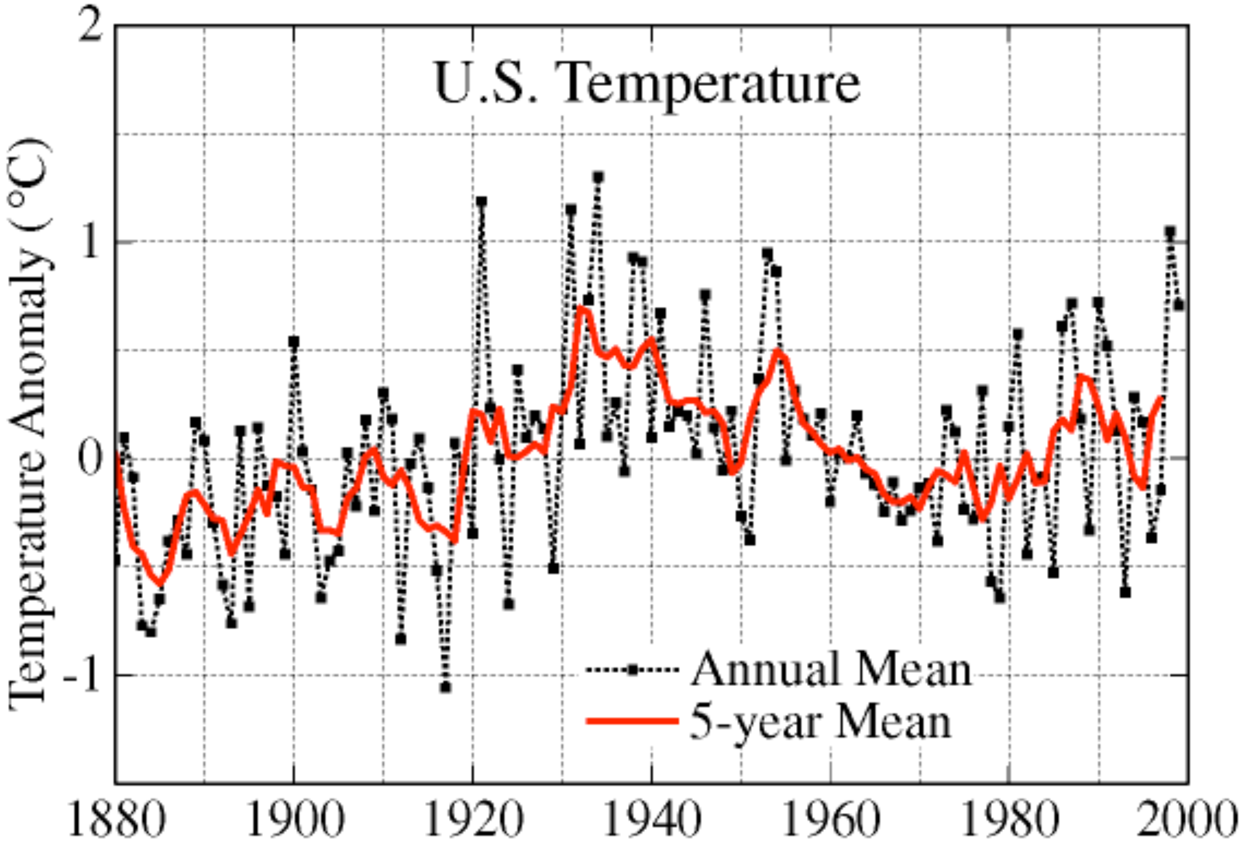


Figure A3-7. Average annual temperatures, United States, 1880-2000
(from NASA Goddard Institute of Space Science, http:www.giss.nasa.gov)

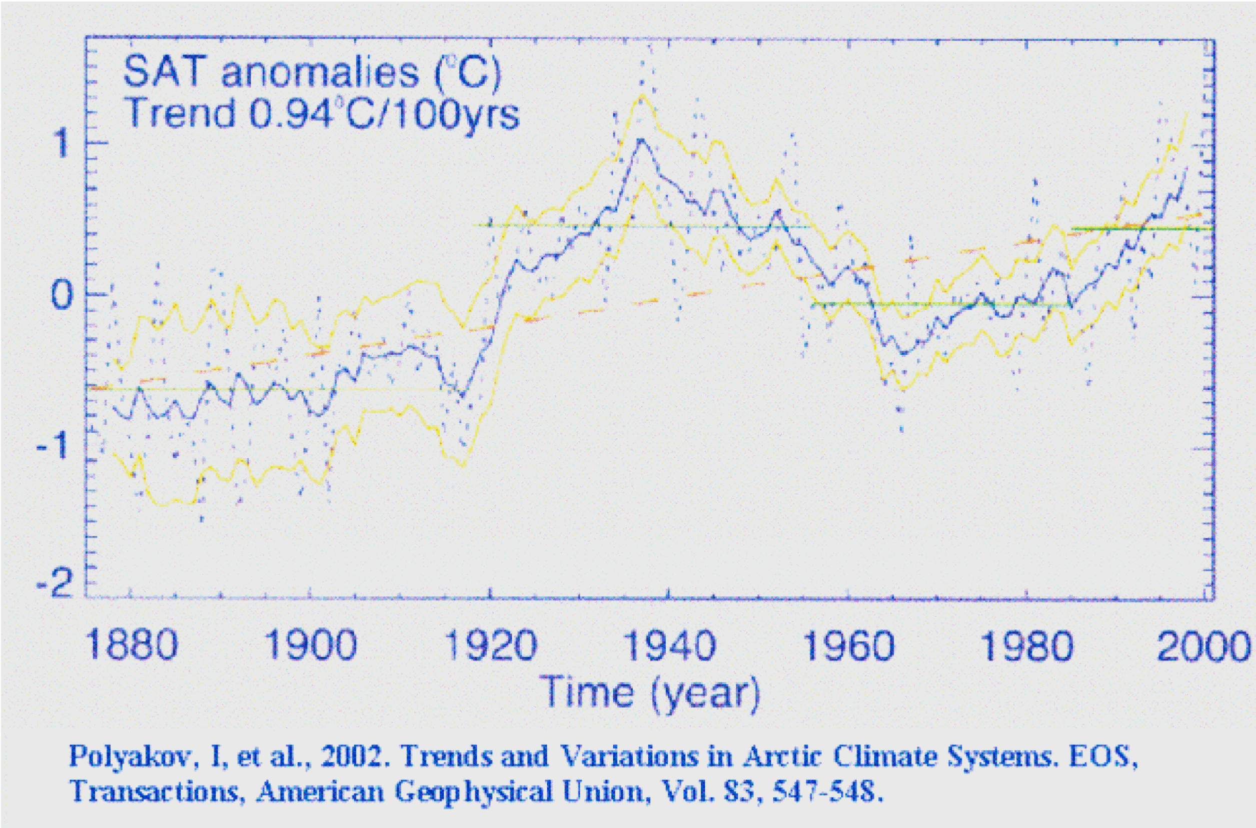


Figure A3-8. Temperature trends in the Arctic, 1880-2000 (Polyakov, 2002). Dashed blue lines represent individual years, solid blue line a 6-year running average, dashed red line the linear trend for the entire data set, yellow the 95% confidence limits, and green lines the means for positive and negative LFO phases.

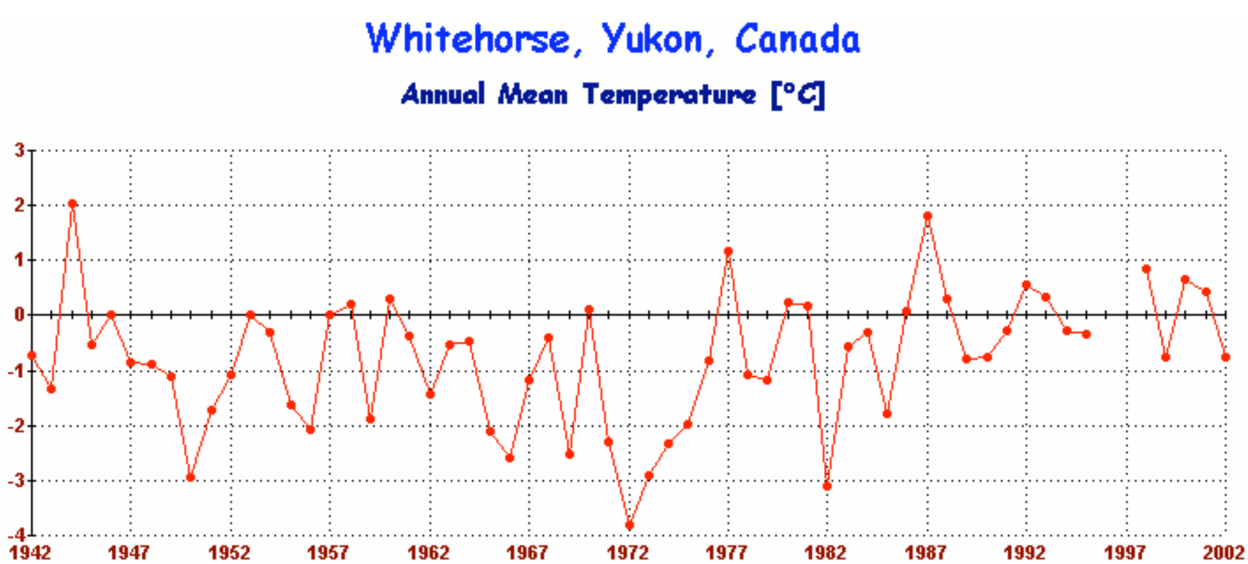


Figure A3-9. Annual mean temperature, Whitehorse, Yukon

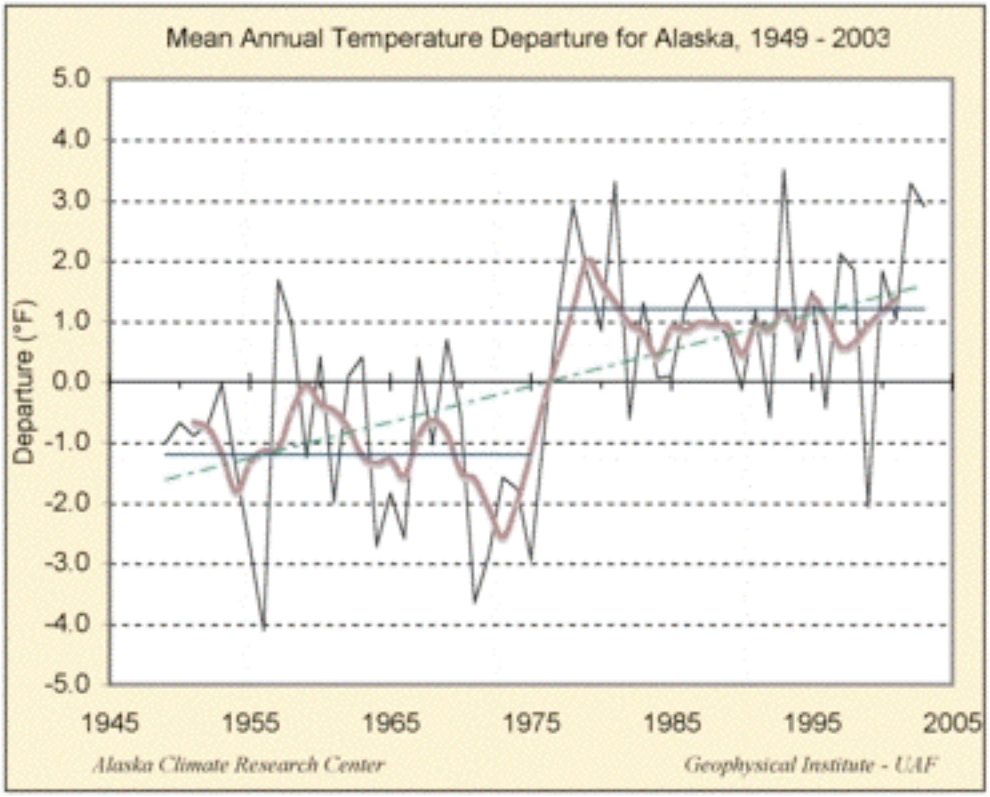


Figure A3-10. Mean annual temperature departures for Alaskan stations, 1949-2003. Thin black lines are individual years, red line the 5-year running average, and dashed line the linear trend for the entire period.

A3.3 Using computer models to estimate the future

While climate models represent a great deal of promise when it comes to predicting future climate, they are considered to be inadequate for many purposes due to limitations in resolution, radiative properties, cloud characterization, ocean conditions, solar radiation, and other parameters.

GCMs suggest that temperatures in the next century will rise significantly, mostly due to GHG increases. However, there are many variables known to affect climate, which GCMs are unable to adequately simulate. These are shown in Figure A3-11.

Note that only one variable is known with a "high" degree of certainty, while two-thirds are known with a "very low" certainty.

Schwartz (2002) reviewed the history of climate model predictions of greenhouse-gas-induced global warming and the uncertainties involving aerosols, stating that the broad uncertainties in the range of future predictions “"raises questions regarding claims of [the models] having reproduced observed large-scale changes in surface temperature over the 20th century."

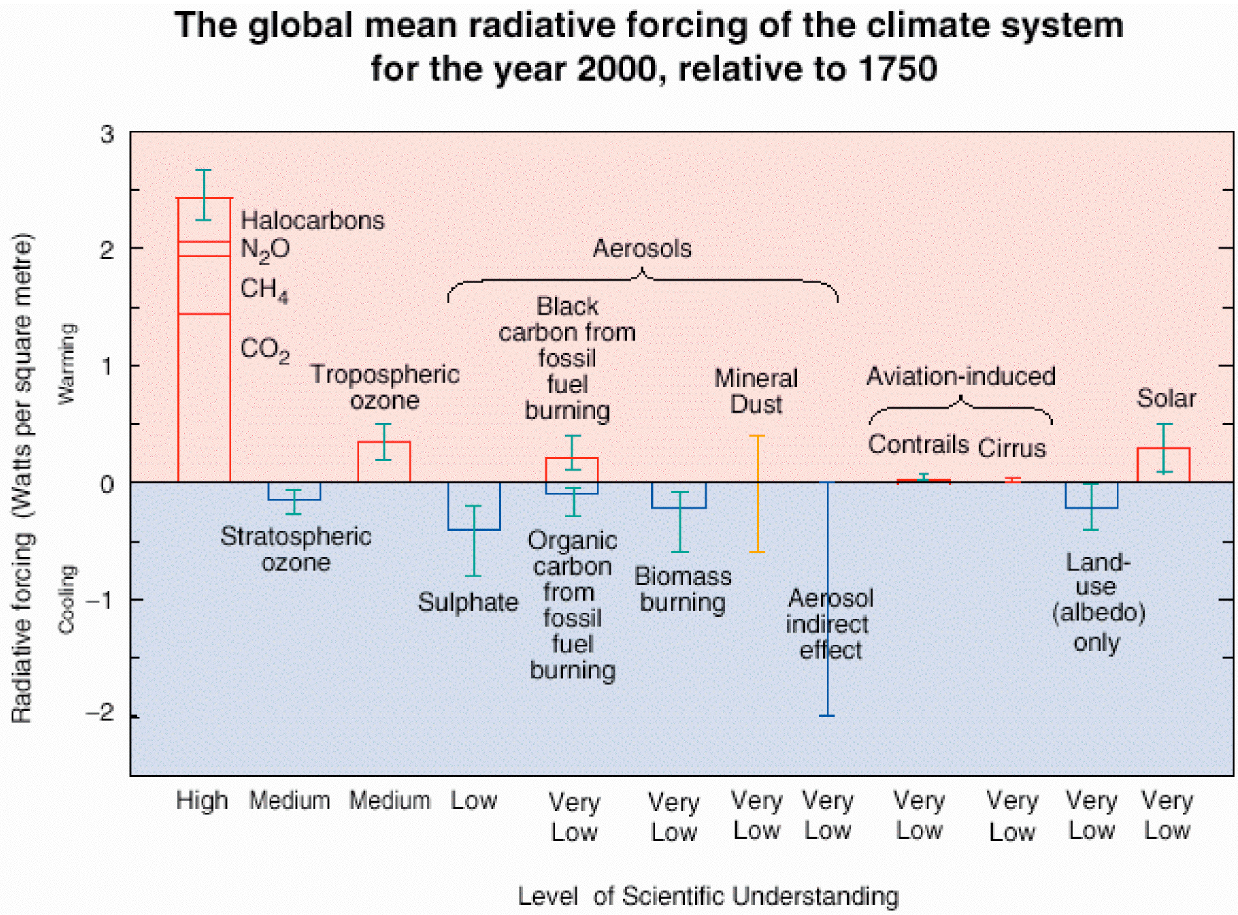


Figure A3-11. The level of scientific understanding of variables known to affect climate (IPCC)

Hoar, et al (2004) conducted "an evaluation of the performance over western Europe of an ensemble of General Circulation Models (GCMs) used to simulate climates" in the present and the past. They concluded that "a more realistic simulation of the ocean…**widened** (emphasis ours) the difference between simulated and proxy derived winter temperatures in western Europe." In other words, modern coupled ocean-atmosphere models make model projections worse.

Chase, et al (2004) analyzed the ability of state-of-the-art models to simulate the observed vertical temperature trends in the atmosphere. The models were unable to do so, causing the authors to conclude, "significant errors in the simulations of globally averaged tropospheric temperature structure indicate likely errors in tropospheric water-vapor content and therefore total greenhouse-gas forcing, precipitable water and convectively forced large-scale circulations." Furthermore, "such errors argue for extreme caution in applying simulation results to future climate-change assessment activities and to attribution studies and call into question the predictive ability of recent generation model simulations."

Conclusion: climate models remain rather inadequate for simulating past climate and predicting future climate.

A3.4 Historic trends in Canadian precipitation

It is worthwhile to assess the history of precipitation intensities in Canada, since the relationship between past climate trends and observed precipitation may give us clues about future conditions.

Lamoureux (2000) analyzed varved lake sediments obtained from Nicolay Lake, Cornwall Island, Nunavut, Canada. Results were compared with rainfall events recorded at a nearby weather station over the period 1948-1978. This comparison allowed the author to reconstruct a rainfall history for this location over the 487-year period from 1500 to 1987. The data showed a small, but statistically insignificant, increase in rainfall over the course of the record. Heavy rainfall was most frequent during the 17th and 19th centuries, which were the coldest periods of the past 400 years in the Canadian High Arctic, as well as the Arctic as a whole. In addition, says the author, "more frequent extremes and increased variance in yield occurred during the 17th and 19th centuries, likely due to increased occurrences of cool, wet synoptic types during the coldest periods of the Little Ice Age."

Zhang, et al (2001) analyzed the spatial and temporal characteristics of extreme precipitation events over Canada for the period 1900-1998, using what they describe as "the most homogeneous long-term dataset currently available for Canadian daily precipitation." Decadal-scale variability was found to be a dominant feature of both the frequency and intensity of the annual number of extreme precipitation events, but there was "no evidence of any significant long-term changes" in these indices during the 20th century. When the annual data were broken down into seasonal data, however, an increasing trend in the number of extreme autumn snowfall events was noted. Finally, an investigation into precipitation totals (extreme and non-extreme) revealed a slightly increasing trend across Canada during the period of study, which was attributed to increases in the number of non-heavy precipitation events.

Conclusion: the twentieth century has seen no significant change in precipitation intensity, in spite of marked variations in climate. Heavy rains over the past few centuries have been more extreme during cold periods rather than warm ones.

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