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COPPER RIVER HIGHWAY ENVIRONMENTAL IMPACT STUDIES: HYDROLOGIC ASPECTS

By

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COPPER RIVER HIGHWAYS
ENVIRONMENTAL IMPACT STUDIES:
HYDROLOGIC ASPECTS

by Stan Carrick[1], Mark Inghram[1], Roy Ireland[1], James A. Munter[1], and Richard Reger[2]

EXECUTIVE SUMMARY

Extensive glaciation, high coastal barrier mountains, and locally high snowfall are dominant features to the regions surface water hydrology. Typically, streams are high energy, steep gradient, with high sediment loads. Peak flows are usually in early summer. Flow data for the area are fragmentary. Five continuous stage monitors have been installed. Sites include the Tasnuna River, Cleave Creek, Uranatina River, lower Tiekel River, and Upper Tiekel River. Known and collected flow data are presented.

The Allen River Copper River confluence has undergone considerable change since 1965. Historical photo analysis clearly show an emerging importance of a northern connecting channel. Corridor access across this confluence may require substantial structural control and or constant maintenance.

Flood flow estimates and floodplain maps were developed to show the potential magnitude and area of high streamflows. Flooding in the project area is most commonly the result of heavy rainfall, snowmelt, or glacial outbursts. Estimates of 100-year floods range from a low of 2,600-4,000 cfs at the Uranatina River, to a high of 18,600-52,000 on the Tasnuna River.

Floodplain mapping based on color aerial photo interpretation was completed on USGS 1:63,360 maps. Areas subject to potentially significant flooding include the mouths of the Uranatina and Tiekel Rivers, Cleave Creek, lower Tasnuna River, and along the Copper River. Glacial outburst flooding would have the most pronounced effect on the Tiekel River mouth, and the Copper River downstream of Miles Glacier.

Ground water along potential road corridors is inferred to exist in a variety of aquifer types including fractured metamorphic bedrock aquifers, major and minor alluvial aquifers, alluvial fan aquifers, and mixed glacial and colluvial aquifers. Alluvial fan aquifers are probably the most significant type in the area because of their abundance, location, size, and water-yielding potential. Water tables are expected within about 30 ft of the land surface in most places, and could be intercepted by roadcuts, causing drainage or icing problems. Ground water appears to discharge in valley bottoms to streams and rivers, and is recharged in upland areas. The most significant potential impact to ground water appears to be the possibility of ground-water contamination resulting from leaks or spills of fuel.

Summer precipitation data are lacking. Winter data show significant precipitation occurring in the passes. Drifting snow may be significant in some areas.

The lower Copper River Valley experiences relatively strong, steady winds as compared to the upper region of the study area. Tributary valleys also experience strong winds and have shown some tendencies for very strong transverse winds. Strong winds can last up to 8 days or more, but normally strong winds last for less than 24 hours and more frequently occur in the late afternoon.

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INTRODUCTION

The Gulf of Alaska region in Southcentral Alaska comprises an area of approximately 39,000 square miles, with an additional 1000 square miles in Canada. This region extends along the coast from Icy Bay, northwest of Yakutat, to the southwest tip of the Kenai Peninsula. Inland, the region is bounded on the west by the Kenai, Western Chugach, and Talkeetna Mountains, to the north by the Alaska Range, and on the east by the Saint Elias mountains in Canada.

The Copper River is not only the largest drainage basin in the region (approximately 24,400 square miles), but it is the fifth largest drainage basin in the State of Alaska. Starting on the northeast flanks of Mt. Wrangell at the Copper Glacier, the Copper River flows generally southward 287 miles to the Gulf of Alaska, 15 miles east of Cordova.

The lower Copper River sub-basin of concern in this study extends from the Allen River on the south to the Uranatina River on the north. The purpose of the study is the characterization of expected hydrologic conditions along the alternative highway access routes available connecting the Richardson Highway to Cordova. This region is dominated by rugged massive east-west trending mountains separated by glacially carved valleys. Elevationally higher parts of the range are covered by ice-fields feeding valley, and piedmont glaciers.

HYDROLOGY

Extensive glaciation, high coastal barrier mountains, and locally high snowfall in the study area are dominant factors in the regions surface water hydrology. Streams are typically high energy, steep gradient, with high total sediment loads. Peak flows usually occur in early to mid summer, resulting from an optimum combination of snow-melt and precipitation. Higher flows can occur anytime during the May to September period, with consecutively lower flows for the November to April timeframe.

Glacial influence at freeze-up and break-up are particularly acute. Discharge at freeze-up would be expected to decrease quickly as temperatures drop below freezing. Conversely, during break-up discharge should increase rapidly as temperatures rise above freezing. Surface water storage in any form other than ice is insignificant in the study region.

Streamflow records for this region are fragmentary. The United States Geological Survey (USGS) made some discharge measurements in 1913 as part of a hydropower potential reconnaissance (Ellsworth and Davenport, 1913), and in later years as a few miscellaneous measurements (USGS, 1972), and some peak flow measurements (unpublished). The Alaska Department of Transportation and Public Facilities (DOTPF) may have some additional miscellaneous measurements and peak flow estimates for the Tiekel River at the Richardson Highway bridge. The Division of Water (DOW) has published a companion Public Data File 92-23 (PDF 92-23) to this entitled *Copper River Highways, Environmental Impact Studies: Water Quality of Surface Waters*, which includes miscellaneous point discharge measurements at Nels Miller Slough, and the upper Tasnuna River.

One primary mission of this study is to provide streamflow data and estimates for drainages within the study area. Quantification of expected maximum flow conditions is crucial in the access route selection process. As part of this study both the start of a streamflow data collection network, and estimates based on mathematical models have been done. Assembling an accurate streamflow database is usually best accomplished over a period of years.

Surface Water Monitoring

Four tributaries to the Copper River that drain from west to east were selected in this study (see Figure 1). The Tasnuna River, Cleave Creek, Tiekel River, and Uranatina River were all instrumented with continuous stage recorders. The Tiekel River was instrumented at two sites, one near the mouth, and one at the Richardson Highway bridge above the confluence with the Tsina River.

In all, five continuous stage monitors were installed. All installations were made with digital electronic recorders attached to pressure transducer sensors secured to the stream bottom. Four of the sites have water temperature probes, except the Tasnuna River, which has instead an air temperature probe. Data recorders were set to scan sensors every 15 minutes, with data recorded bi-hourly. Data are recorded on electronic "chips" that must be retrieved in order to download. Initial installation of all instrumentation took place in early September, 1992. No retrieval of the data stored on the chips was possible prior to freeze-up or completion of this report. Stage data recorded on the chips will be retrieved and made available as a supplemental Public Data File this coming spring or summer under separate cover.

Developing a stage discharge relation is critical in the streamflow monitoring process. At the time of the initial installation, and each succeeding servicing visit a discharge measurement is made, and the corresponding stage recorded. Values of stage and discharge are plotted, and an equation that best describes the line determined. At this time two discharge measurements have been made at all sites, with the exception of the Upper Tiekel that has only one. These are insufficient point measurements from which to determine a stage discharge relation. The confidence placed in the stage discharge relation increases as plot points are added. For this reason, and because the longer the term of monitoring the greater the variation in flow conditions are encountered, that is particularly important for the design phase, it is highly recommended to continue this valuable surface water monitoring effort for several years. Appendix 1 includes measurements collected to date at all sites.

Basin Descriptions

Tasnuna River: The most southern of the monitored basins is the Tasnuna River. The river flows generally east for approximately 32 miles from its headwaters at Marshall Pass to its confluence with the Copper River some 45 miles northeast of Cordova. Elevations range from a high at Cordova Peak of 7730 feet, to a low at the confluence of roughly 250 feet. The entire watershed drains an area of 404 square miles. The installed continuous stage monitor is located 5 river miles upstream from the confluence, immediately below the Schwann Glacier tributary, effectively monitoring 348 square miles of the watershed.

The Tasnuna River is geomorphically a classic glacial form. Glacial influence in all Copper River drainages is strongest closest to the gulf coast precipitation supply. The Schwann, Woodworth, Tasnuna, and Marshall Glaciers all drain from the wetter higher southern portion of the watershed to the north to join the Tasnuna River. Several substantially smaller unnamed glaciers drain from the north side of the watershed.

Dominant Tasnuna River channel form is braided. A single straight channel flows for approximately 1 mile immediately downstream from the Schwann Glacier tributary. The broad U-shaped valley

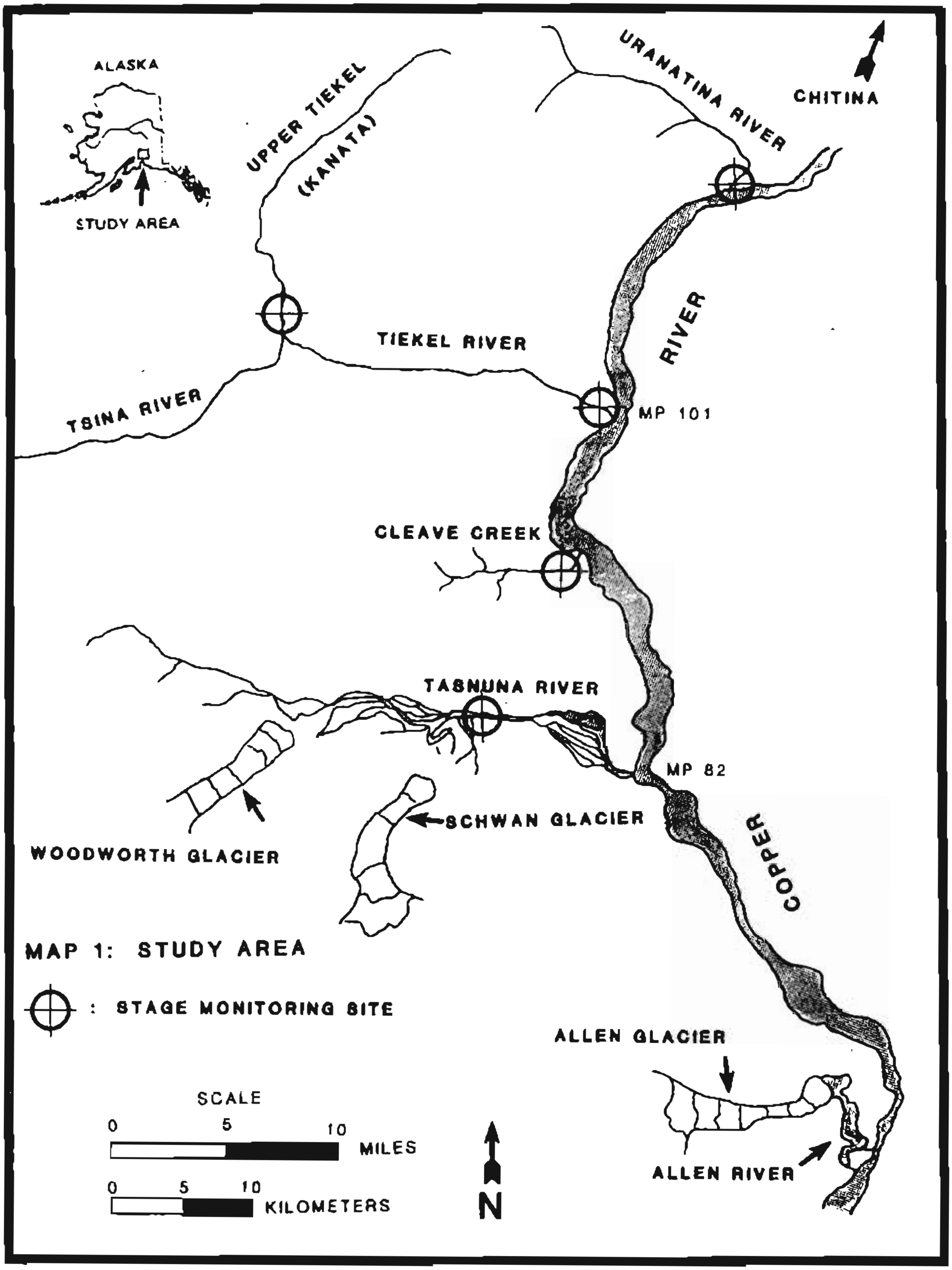


Figure 1. Map 1: Study area, stage monitoring sites.

form is a typical example of glacially carved terrain. A strong lineation exists between the Lowe River and Tasnuna River, which are joined at Marshall Pass.

The USGS has record of one miscellaneous discharge measurement made 7/27/72 on the Tasnuna River, 6 miles upstream from the confluence with the Copper River. At that point, gaging 342 square miles, discharge is listed at 8490 cfs.

Cleave Creek: Moving north, the next monitored basin is Cleave Creek. Cleave Creek is the smallest of the four monitored watersheds at 50 square miles. It headwaters at the Cleave Creek Glacier and flows east to its confluence with the Copper River 48 miles northeast of Cordova. Stage monitoring equipment is located approximately 0.5 river miles upstream of the confluence. Elevations range from a high of 6200 feet to a low of 300 feet.

Cleave Creek exhibits the typical braided channel form characteristic of glacial streams. Other than Cleave Glacier, the dominant glacial influence comes from glaciers that drain from the south of Cleave Creek.

No known discharge data have been collected on Cleave Creek.

Tiekel River: The Tiekel River watershed borders both the northern drainage divide of Cleave Creek, and a portion of the Tasnuna River. At 457 square miles in size, the Tiekel is the largest of the instrumented basins monitored. The Tiekel River proper starts near pump station 12, and flows generally south, where it joins the northeast flowing Tsina River. From that confluence, the river turns and flows east, joining the Copper River 56 miles northeast of Cordova. The USGS in 1913 referred to the upper Tiekel above the Tsina River confluence as the Kanata River. Elevations range from 7600 feet at the headwaters of the Tsina River, to 300 feet at the Copper River confluence. The route of the Richardson Highway follows down the upper Tiekel, and up the Tsina River to Thompson Pass.

Two locations in the Tiekel River watershed have been instrumented with continuous stage monitors. One site is located roughly 0.5 miles upstream from the old railroad trestle, and collects data representing the entire Tiekel River watershed. A second site is located on the upper Tiekel above the Tsina confluence, at the Richardson Highway bridge crossing (Mi. 46.9). The purpose of this second site is to allow for better differentiation between the effects of the radically different watersheds represented by the Tsina and upper Tiekel Rivers.

Geomorphically, the Tiekel River is unique within the context of lower Copper River basin watersheds. The upper Tiekel River above the Tsina confluence is free of any glacial influence, except for one small glacier on Ernestine Creek. Channel form for most of the upper Tiekel is single channel. The Tsina watershed, being further south and closer to the Gulf moisture source, is heavily glacially influenced. Large glaciers drain to the Tsina River from all directions and channel form tends to be a mix of braided and single channel.

Below the upper Tiekel Tsina River's confluence, channel form is predominantly single channel. The valley in the lower Tiekel drainage tends to be fairly narrow, with pronounced benching. Bedrock outcrops to the valley bottom are common. Glacial influence in the lower reaches tends to mimic the drainages further to the south in that glaciers favor the southern flanks of the watershed. Exposure is also a large contributing factor to the preferred slope location of glaciers.

Known discharge measurements include miscellaneous discharge measurements made by the USGS in 1913 at the Tsina, upper Tiekel (known as the Kanata River in that time), and Tiekel sites (Appendix 2). Crest gage data were collected at the upper Tiekel site for the years 1978-81 (Appendix 3).

Uranatina River: The most northerly of the monitored basins is the Uranatina River. The Uranatina watershed is 74 square miles in size, and flows approximately 12 miles from its headwaters to its confluence with the Copper River some 68 miles NE of Cordova. Elevations range from roughly 6600 feet to 400 feet. Installation of continuous stage monitoring equipment was made less than 1000 feet from the confluence with the Copper River.

As expected due to its more northerly location, glacial influence in the Uranatina basin is substantially less than any of the other studied sites, with the exception of the upper Tiekel drainage. Topography, and lack of proximity to gulf moisture is likely the reason for the lesser glacial influence. Glaciers are present in the watershed, again primarily on its southern flanks. Channel form is predominantly high gradient single channel.

No known discharge data have been collected on the Uranatina River.

Allen River

Questions have arisen in recent years regarding the stability of the confluence of the Allen River and the Copper River. Through historic times the primary channel connecting the Allen Glacier with the Copper River was near the southern downstream end of the terminal moraine that impounds water between the Allen Glacier and Copper River. Recent evidence suggests an emerging importance to a more northerly connecting channel.

DOW personnel did a reconnaissance of the confluence of the Allen and Copper Rivers on September 11, 1992. At the time of the visit it was estimated that more water was flowing through the southern channel than the northern, but that difference probably did not exceed 10-20%. DOTPF has recently conducted field work in the Allen Glacier area, and may internally have some additional survey information.

The southern channel appeared to be the more historic channel. Bank morphology on both sides appeared stable. The 1963 bridge pilings and older railroad bank revetments were surprisingly intact. Gradients were very high, with turbulent flow. Bed material was all well sorted, and armored boulder size.

The more northern channel appeared to be a relatively recent development. Gradients appeared steeper, flow more turbulent, and banks less stable. No evidence of any railroad crossing could be found, a strong indication that this channel was insignificant to non-existent during the railroad days. General topography on both sides of the channel appeared lower than the southern channel. Recent evidence of flooding to the north of the northern channel was also evident.

Field observations were confirmed through the examination of aerial photography. Historic aerial photography for 1965, 1970, 1982, and 1989 were obtained. Analyses of these photos clearly show good stability in the southern channel, and a major change occurring in the northern channel. In the 1965 photography (fig. 2) the northern channel appears to be an overflow channel. The railroad route crossing the channel was still clearly evident. Resolution in the 1970 photography (fig. 3) is poor, however it appears that changes in drainage patterns have occurred. The change is clearly evident in the 1982 photography (fig. 4). In these shots it is obvious that a substantial new channel is been carved, partially following the route of the 1965 overflow channel, and partially following a route that diverts to the north of the 1965 overflow channel. Changes evident in the 1989 photography (fig. 5) include the clear establishment of a main channel, and a complete abandonment of part of the overflow channel evident in 1965. Throughout the sequence of these 24 years of historic photos it appears little to no changes have occurred at the older southern channel.

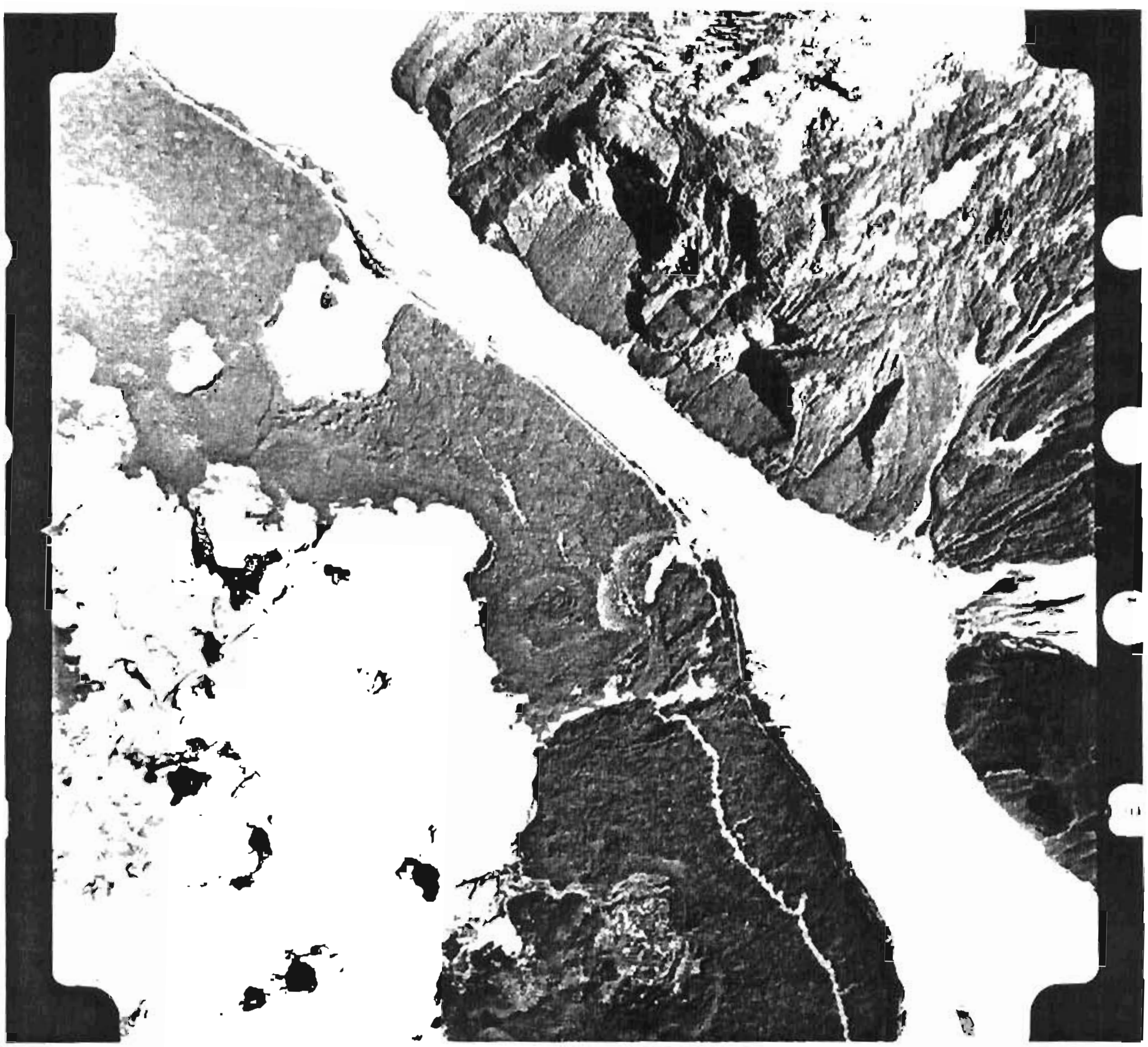


Figure 2. Photo 1: 1965 aerial, Copper River/Allen river north channel confluence (undetermined scale).

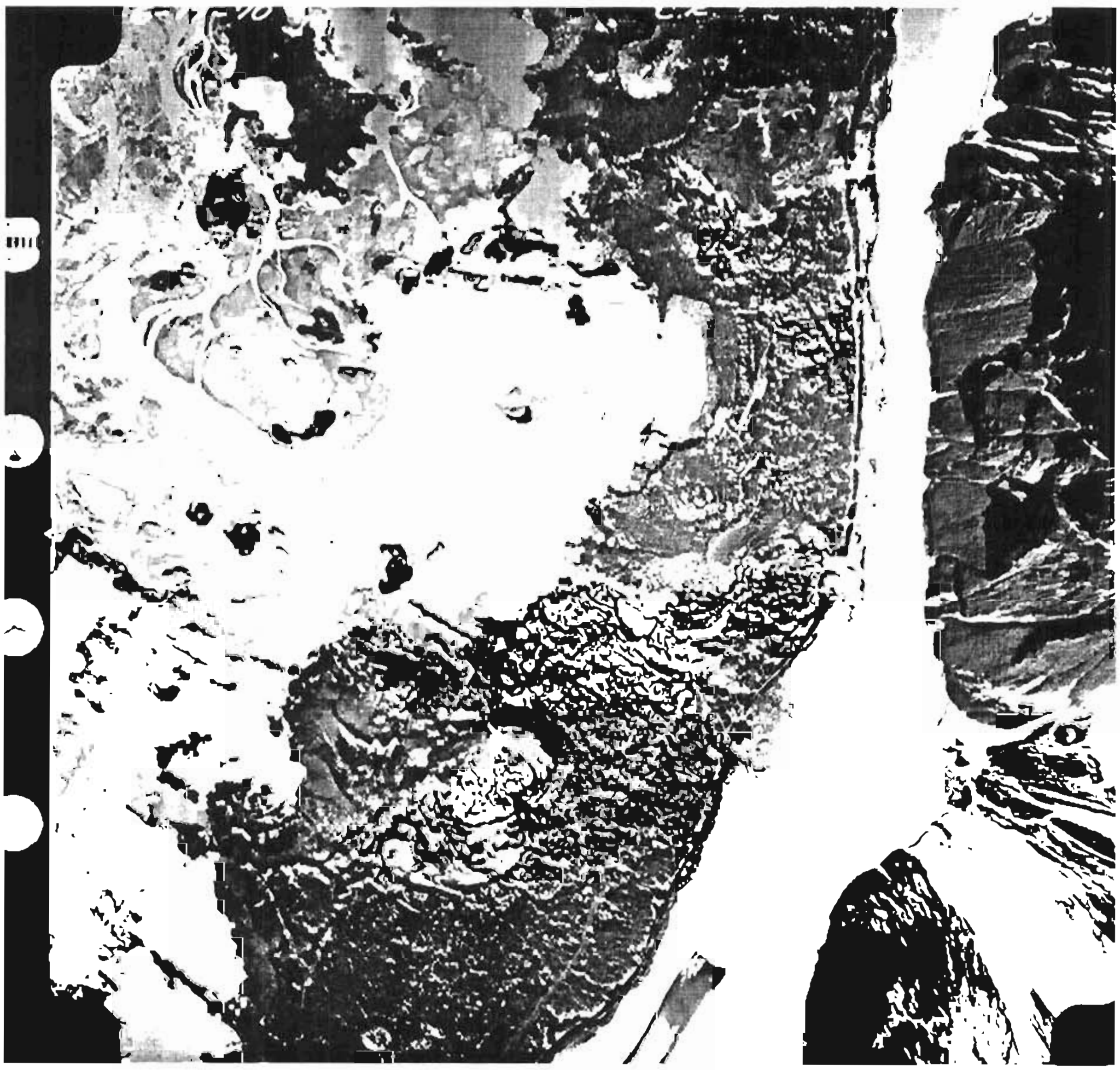


Figure 3. Photo 2: 1970 aerial, Copper River/Allen River north channel confluence (undetermined scale).

Figure 4. Photo 3: 1982 aerial, Copper River/Allen River north and south channel confluences (undetermined scale).

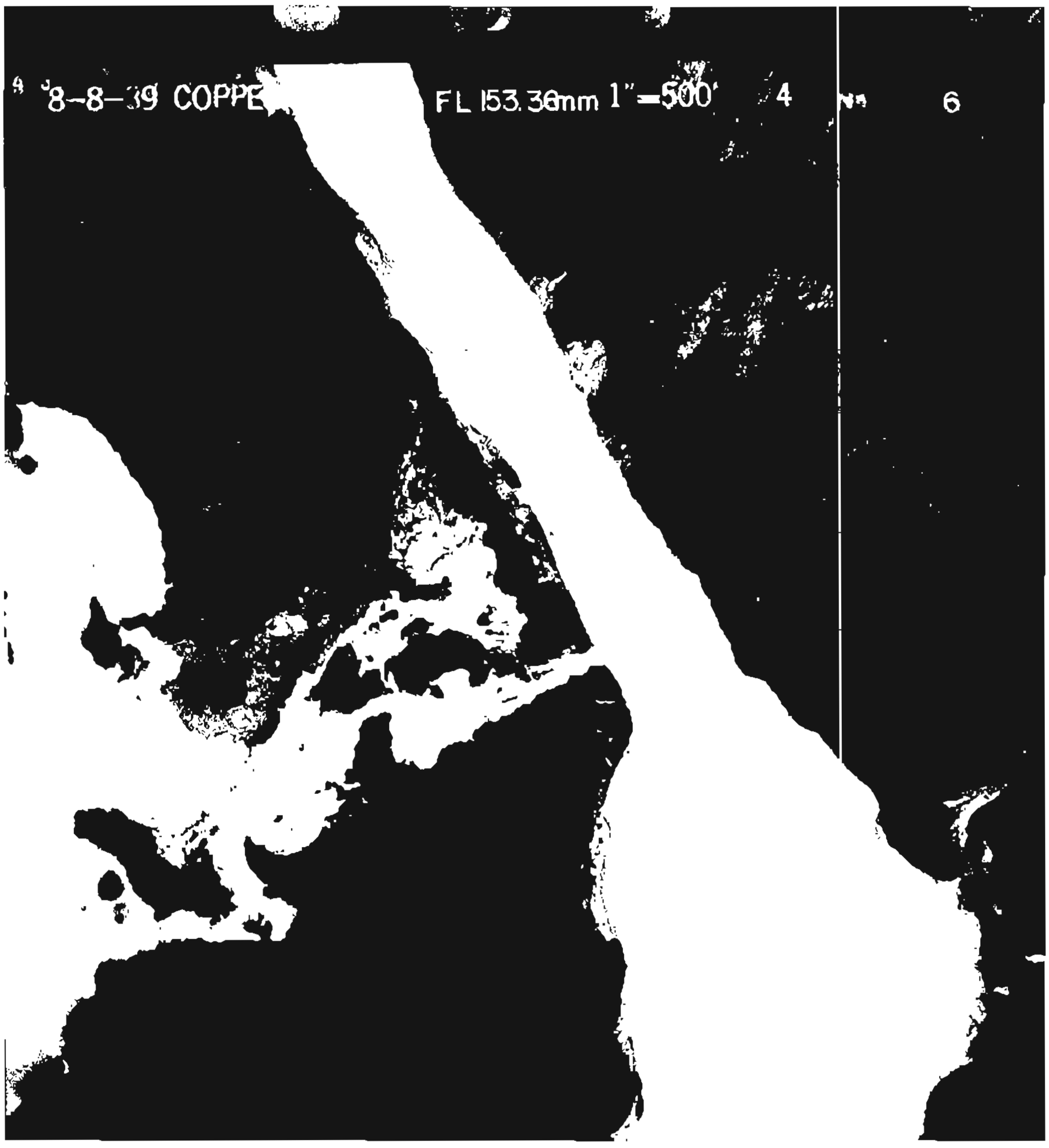


Figure 5. Photo 4: 1989 aerial, Copper River/Allen River north channel confluence (undetermined scale).

The exact mechanism responsible for the increased use of the northern channel is unknown. However, it is likely that the water impounded behind the moraine varies substantially in stage in any given season. As an example, ice jams at the older southern channel are likely. As water is impounded behind the ice jam, it rises sufficiently high to find a new outlet. It may only take one such large ice jam, or a series of them over a period of years. In any event, the northern channel is now established. The relative youth of the channel and other geomorphic evidence suggest more adjustments are likely. These changes are likely to include further incision, and some possible lateral movement. Corridor access across the Copper/Allen confluence may require substantial structural control, and/or constant maintenance.

FLOODS AND FLOODPLAINS

Floods and high streamflows are a major concern to planners and engineers. Not only is it potentially hazardous to locate structures on or near a floodplain, but a change in land use can increase flood problems downstream in areas originally outside the hazard zone. A floodplain is defined as the flat area adjoining a river channel, constructed by the river in the present climate and overflowed at times of high discharge (Dunne and Leopold, 1978). This section of the report will examine high flows, floods, and floodplain delineation.

The most common causes of flooding in this part of Alaska are:

1) rainfall--late summer and fall storms in the Gulf of Alaska can generate heavy rainfall in a short time resulting in high flows and flooding.
2) glacier and snow melt--summer flooding brought on by prolonged warm weather that causes increased runoff from snowfields and glaciers.
3) glacial outburst--meltwater impounded by a glacier breaks out suddenly causing a surge of water downstream, often resulting in catastrophic flooding (a more detailed discussion of glacial outburst flooding will be presented in a later section).
4) ice jams--during spring breakup or mid-winter thaws, river ice moving downstream can pile up at channel constrictions, bridges, or channel bends, and cause a dam that backs up flow and increases water levels upstream.
5) debris jams--logs and other debris (e.g. landslide debris) can cause the creation of temporary dams that block flows much in the same matter as ice jams.

Because of the remoteness of the project area, information on flooding is sparse. Aside from recorded peak flows at the USGS Chitina (1950-1990) and Million Dollar Bridge (1988-present) gaging sites, the only published references to flooding in the study area is the mention of glacial outburst floods. Janson (1975) writes about the catastrophic flooding caused by the draining of a glacially dammed lake on Miles Glacier in February, 1909 during the construction of the Copper River and Northwestern Railway. Post and Mayo (1971) discuss glacial outburst floods in the project area, as well as the rest of the state.

Flow Estimate Methodology

Peak flows have not been actually measured or recorded at any of the DOW gage sites, because instrumentation has only been in place since September, 1992. Future field visits and data retrievals will shed more light on the magnitude of tributary peak flows. For the purposes of this report, peak flow figures will be based on empirically-derived streamflow estimate equations and channel surveys.

One accepted method of peak flow estimate is the, "slope-area method," (Riggs, 1976). Using field channel surveys of slope, cross-sectional area, and high water marks, streamflow estimates can be calculated on a site specific basis. The study reach should be uniform in width, slope, and bed material. This method was applied to the Tasnuna and Tiekel Rivers only, because at the other gage sites, reach characteristics did not sufficiently fit the channel selection criteria.

Four additional methods, based primarily on regression equations, were evaluated for this study. All four regression techniques model various flow magnitudes using drainage basin characteristics rather than channel characteristics. The regression approach is more regional in scope than the slope-area method, but it is relatively quick and easy to apply when field data and long-term records are lacking.

The first regression method by Orsborn and Storm (1991) models streamflow for the Tongass and Chugach National Forests. The Chugach National Forest was subdivided into four regions, Cordova, Seward, Kenai, and Kodiak. The Cordova region is closest to the project area, so regression equations developed for the region were evaluated. Unlike the other three regression methods discussed below, Orsborn and Storm (1991) do not rely on precipitation for input data, but do include other basin characteristics, such as elevation, and basin area.

Ott Water Engineers (1979) published a streamflow atlas using regression equations to predict flows on ungaged streams in the Tongass and Chugach National Forests. However, in contrast to the Orsborn and Storm regressions, Ott Water Engineers (Ott) divided the study into just two regions, the Tongass and Chugach National Forests. The project area lies in the Chugach region. In addition, Ott included precipitation as part of the input data, along with basin area and percent of basin in main channel lakes.

The USGS has published two documents presenting regression equations that estimate streamflows for Alaska. Lamke (1979) divided the state into two regions, with one maritime region (Area I) stretching from Ketchikan to Kodiak, and the other region (Area II) encompassing the remainder of the state. The Copper River Highway project area falls within Area II. Input data for Lamke's regressions include basin area, precipitation, percent of lakes in the basin, percent of basin forested, and mean January temperature.

Parks and Madison (1985) divided the state into six subregions based on hydrologic units. The project area is in the Southcentral region, and uses basin area and precipitation as input data.

Flow Estimate Results

Channel cross sections were surveyed for all five DOW gage sites in September, 1992. With the exception of the Upper Tiekel River site, which was previously studied for the construction of the Richardson Highway bridge, all cross sections include measurements of high water evidence. Appendix 4 show the surveyed cross section for each site with current water level and high water, or maximum evident flow (MEF), evidence shown. Also depicted on the cross sections, are lines showing the approximate bankfull stage. Bankfull stage is equivalent, in most cases, to the channel flowing full, and is the flow level that is most dominant in constructing and maintaining the channel. Bankfull stage is typically reached every 1.5-2 years.

The lack of historical data makes quantifying flood flows difficult. And it is even more difficult to correlate discharge estimates with certain water levels at a given point along a stream channel. Aerial photos and maps are used for interpretation of the lateral extent of flood waters, but the maps don't show the depth of flood waters. Floodplain mapping is addressed in the next section.

High flow estimates using techniques discussed above by Lamke (1979), Parks (1985), and Ott (1979) are shown in Table 1. The estimates give a range of flows based on the different regression method used, the mean annual precipitation (MAP) input data, and the recurrence interval. The recurrence interval is the average interval, in years, between flow events equaling or exceeding a given magnitude (Dunne and Leopold, 1978). For comparison, the maximum evident

TABLE 1: Division of Water Gage Site Flow Estimates

Site:	MAQ *	2-year *	5-year *	10-year *	25-year *	50-year *	100-year *
Cleave Creek	143-259	1311-2722	1889-4321	2603-5627	2879-7052	3225-8912	3764-6298
Tasnuna River	990-1786	8675-13352	11355-18966	14916-23327	15675-27982	16736-33304	18646-52719
Tiekel River	1004-1689	5148-13677	7314-19095	9882-23254	10802-27587	11862-32573	13517-35165
Upper Tiekel River	355-613	2243-4797	3188-7265	4363-9231	4810-11333	5352-13973	6192-12314
Uranatina River	165-274	673-2053	1146-3238	1634-4196	1895-5209	2196-6575	2633-4028

* Flow estimates above are given in cubic feet per second (cfs); MAQ=mean annual discharge or flow.

Site	Basin Area (sq mi)	Mean Annual Precipitation (in.)
Cleave Creek	50	60
Tasnuna River	348	70
Tiekel River	457	40
Upper Tiekel River	122	50
Uranatina River	74	30

Note: Flow estimates are presented in recurrence interval ranges based on the different results derived from the three regression analyses taken from Lamke (1979), Ott (1979), and Parks and Madison (1985), using the above area and precipitation input data.

"Slope-area" method calculations (Riggs, 1976) yielded the following MEF or mean evident flood flows:

Site	MEF (cfs)
Tasnuna River	14673
Tiekel River	8242

flows calculated using survey data and the slope-area method for the Tasnuna and Tiekel Rivers is presented in Table 1 also.

The 2-year recurrence interval discharge data given in Table 1 approximates a water level near bankfull; in other words the discharge and level that above which the water in the stream will overflow its banks. In some instances, however, the stream may be confined by high banks, and the bankfull discharge will not actually overflow the channel. For example, the Uranatina River is confined by high bedrock walls immediately upstream of the cross-section site, and there is no field evidence of bank overflow. At precisely the point where the bedrock walls end, the stream flows out onto its alluvial fan, and at discharges at or even slightly below bankfull stage there is evidence of overbank flow and a spreading of water throughout the adjacent woods.

The 5-, 10-, and 25-year recurrence interval discharges given in Table 1 are likely the results of a few days of heavy rains or unusually warm weather increasing glacier and snowpack melting. Channel changes and damage from flows of this magnitude are typically minimal to moderate. When discharges reach the 50- or 100-year recurrence interval, it results from very unusual heavy rains over a short period of time, often accompanied by high rates of snowmelt. A 50- or 100-year flow usually has catastrophic effects, and the impacts to structures or the natural channel morphology is moderate to severe and long-lasting.

Additional data collection at the DOW gage sites will help to more adequately define the magnitude and extent of high flows. In addition, site-specific precipitation information will allow more refined high-flow regression analyses.

Floodplain Mapping Methodology

Floodplain mapping for the study area is nonexistent, except for a Floodplain Management Study done by the USDA Soil Conservation Service (SCS) for Copper River communities from Lower Tonsina to Gakona (1991). Therefore, the Division of Geological and Geophysical Surveys used aerial photo interpretation to estimate the potential lateral extent of high flows or floodplains, and the results were transferred to USGS topographic maps. Floodplain mapping was accomplished by interpreting 41 photocopies of 1:60,000-scale false-color infrared aerial photographs, supplemented by interpreting 635 photocopies of 1:6,000-scale color aerial photographs. All of the 1:6000-scale photographs were taken in 1989, with the exception of the Tasnuna River corridor, photographed in 1992. The interpreted limits of floodplains of active streams within 1 mile of proposed centerlines for three alternate routes of the Copper River Highway were transferred to the 1:63,360-scale topographic maps. These maps include the Cordova C-2, C-3, D-2, D-3, and Valdez A-3, A-4, A-5, B-2, B-3, B-4 and C-2 quadrangles. The attached maps, Sheets 1-11, are suitable for digitizing. Copies of floodplain maps (sheets 1-11) are not available for general distribution. Originals of the maps can be inspected at DOTPF offices in Fairbanks, or DOW offices in Eagle River.

For the purposes of the maps, a floodplain is defined as the stream-marginal surface that is periodically flooded by stream waters. Parameters used to identify floodplains include (1) the presence of unvegetated or partially vegetated stream deposits (alluvium), (2) the presence of planar or terraced landforms produced by recent stream activity, or the recent deposition of alluvium, and (3) the presence of young, sparse to dense stands of riparian vegetation (primarily willow and alder shrubs and black cottonwood trees). Typically, the floodplain limit is delineated by a low terrace scarp or by an abrupt change in ground cover to older, more established vegetation that includes slow-growing spruce trees.

The accuracy of the photo-interpretive maps is affected by (1) the lack of field data and field verification, (2) a lack of accurately plotted centerlines on the 1:6,000-scale photography, (3) the lack of general hydrologic data for the project area, and (4) the lack of very recent (less than one year old) aerial photography for most of the routes.

On Sheets 1-11, centerlines are shown in red pencil and corridor limits are indicated in lead pencil. Floodplains are designated by the symbol "FP" in lead pencil. Floodplain-marginal lakes, the levels of which directly fluctuate with changes in stage level of the nearby stream, are considered to be part of the floodplain of that stream, even if the lake has no surface connection with the stream.

Floodplain Mapping Results

Errors in the locations of floodplain margins due to historic channel changes will be very minor in reaches where streams are walled by bedrock. However, there have been significant changes in floodplain configuration since 1950 in the terminal areas of Allen, Heney, Schwan, and Woodsworth Glaciers due to the melting of massive bodies of buried, stagnant glacial ice. The terminal areas of these glaciers will continue to change, depending on the movement of the glaciers, climate, and runoff patterns. Ponds, lakes, and multiple meltwater channels will shift over time and make long term, specific floodplain predictions difficult. Combining the attached floodplain maps with future aerial photography should aide in the prediction of trends in channel changes at the glacier termini.

In the braided reaches of lower Tasnuna River, channel shifting is continuous, a typical feature of glacial streams that carry high sediment load. Floodplain width varies from a few hundred yards to approximately 1.5 mi near the terminus of the Schwan Glacier. The Tasnuna channel is mostly singular for 2 mi before spreading out into numerous distributaries at its confluence with the Copper River. At the mouth of the Tasnuna River, the mapped floodplain is up to 0.5 mi wide, but much of the entire confluence delta area has wetland characteristics, with numerous bogs, ponds, and distributary channels.

Cleave Creek's 7 mi of channel is high gradient and braided, but is relatively narrowly confined by bedrock valley walls. The lower mile of Cleave Creek flows out of the narrow valley and onto its alluvial fan. This alluvial fan spreads out into the Copper River approximately 0.5 mi, forcing the Copper to flow around the fan to the east. The active floodplain on Cleave Creek ranges from 500-3000 ft wide, but historically the floodplain has shifted over an area nearly 1 mi wide. Cleave Creek is the most dynamic of the gaged streams and has a very high bedload. Flood and erosion debris litters the active and inactive channels. With Cleave Creek's steep terrain, lack of surface water storage, and large percentage of glaciers in the basin, either heavy rains or unusually warm weather could result in widespread channel changes and flooding on the alluvial fan.

Downstream of the Richardson Highway, the Tiekel River flows through a deep bedrock valley, and the stream has no floodplain beyond the narrow, active channel. At the confluence with the Copper River, The Tiekel flows out onto its fan where the floodplain width varies from 500-2500 ft. Again, the Tiekel River fan spills out into the Copper River, forcing the Copper to the east side of the valley during lower flows.

The Uranatina River is also narrowly confined by bedrock for the entire length, except for the lower 1200-1400 ft of the channel where the stream flows out of the mountains and onto its alluvial fan. The floodplain ranges from 150-500 ft wide, with the present width of the floodplain at the road crossing measuring approximately 250 ft. At this road crossing, the floodplain width is essentially fixed, because it lies immediately downstream of the confined channel and has no room for significant channel realignment.

Along the main channel of the Copper River, the floodplain is basically confined to the width of the active channel by bedrock or topography. Where major glaciers encroach on the Copper River channel, the floodplain does broaden beyond the general active channel. Small tributary alluvial fans up and down the Copper River have limited floodplains (Sheets 1-11); nonetheless, a few of the tributaries, such as Jackson Creek or Nels Miller Slough, have small floodplains that are mapped.

Glacial Outburst Floods

Glacial outburst floods occur when ice-dammed lakes overtops, undermines, or otherwise breaks through its confining dam. The ensuing flood is often catastrophic and hazardous. The lakes usually form in blocked off tributary valleys or in depressions on or next to glacial ice. Post and Mayo (1971) have mapped 750 glacier dammed lakes in Alaska, with 3 major and 6-8 minor lakes occurring in the project area.

Many glacier dammed lakes are small, but rapid draining of the lakes can produce major flooding. The Tsina Glacier dams Trap Lake, a small lake that drains sub-glacially and releases to the Tsina at irregular intervals (Post and Mayo, 1971). Most of the flood hazard would be on the Tsina River because the channel isn't confined by bedrock or valley walls in many places. However, flood flows from the Tsina would be contained in the Tiekel River channel down to the mouth, where widespread flooding could take place on the Tiekel alluvial fan.

Larger glacier dammed lakes produce outburst floods that can rival 100-year floods. Miles Glacier dams Van Cleve Lake which also drains subglacially, every 1-3 years (Post and Mayo, 1971). Floodwaters from Van Cleve Lake have been reported to raise the Copper River 20 ft (Janson, 1975). An unnamed lake dammed by McPherson Glacier, south of Miles Glacier, has had catastrophic releases in the 1960's that impacted Sheep Creek and the Copper River delta (Post and Mayo, 1971).

Predicting the magnitude and frequency of glacial outburst floods is difficult. Glaciers can advance, retreat, stagnate, thin, or thicken, or the amount of lake storage can vary, leading to changes in the level and timing of outburst floods. For the project area, as mapped by Post and Mayo (1971), the entire lengths of the Tsina, Tiekel, and Copper Rivers are subject to glacier dammed lake outburst flooding, with the potential for locally extreme hazard. The major glacial outburst flood hazard potential for the project area is at the mouth of the Tiekel River, along the length of the Copper River downstream of the Chitina River, and at the mouth of the Copper River below Miles Glacier. Of these sites, the Tiekel River mouth and Copper River below Miles Glacier have the highest hazard potential. Increased monitoring of the above named glacier dammed lakes is recommended.

Impacts

Site-specific impacts of high flows and floods are beyond the scope of this document until additional streamflow data are collected and analyzed, and specific highway alignments have been identified by DOTPF. Potential impacts to the road will be determined during the design phase of the project. High flows, whether from snowmelt, rains, glacial outbursts, or ice jams can result in localized inundation, erosion damage, ice damage, and heavy deposition of sediment.

The Copper River basin is generally quite rugged, with numerous small streams having steep gradients and high sediment loads. Any of these streams can experience moderate to severe flooding in a matter of hours, depending on the preceding weather. The eventual highway alignment will have to contend with a number of these small mountain streams and their potential for severe erosion and sedimentation during flood events.

Along the Copper River, high flows are essentially bank-to-bank in numerous locations upstream of the Tasnuna River. In July of 1992, the Copper River was flowing high and against the valley walls, or at the old railroad grade level, in many locations on the west bank. Impacts from such high flows would primarily come from inundation and sedimentation, though channel changes in the braided stream could also be responsible for increased erosion as well. Otherwise, potential impacts from flooding on the Copper River would be most noticeable where glaciers terminate at the river banks. The combination of a nearby glacier that could be surging or rapidly retreating, ice-cored terminal moraines, easily erodible glacial outwash deposits, and high water in the Copper River, could make for unpredictable and relatively complex flood effects. Channel changes through erosion and sedimentation are possible, along with inundation of previously dry ground.

Of the four main tributary streams in the project area, the Tasnuna River has the greatest flood potential along its length above the confluence with the Copper River. The dominant high water impact would be from shifting channels and erosion in the braided channel system of the mid and lower Tasnuna River. Although flooding can occur along the length of Cleave Creek and sections of the Uranatina River, potential hazards to the proposed road would occur only at the stream mouths where the road crosses. Flood hazard along the Tiekel River between the Richardson Highway and the mouth are negligible because the stream is incised in a narrow bedrock valley considerably below any proposed road alignment. All four tributary streams could impact structures built on or near the alluvial fans at the confluence with the Copper River.

Any construction on or near a floodplain is subject to damage from floodwaters, erosion, and sedimentation. The best solution to development in river valleys is not building on floodplains. Undeveloped floodplains actually reduce flood hazard potential by allowing the high flows to spread out, decrease velocity, and deposit sediment. Flood impacts are mitigated by proper siting and design of structures, i.e. locating structures outside or above floodplain boundaries where possible, and sizing the structure to keep from artificially constricting stream channels. Further impacts can be reduced by minimizing disturbances to the active stream channel and floodplain, while keeping construction time as short as possible.

Flood impacts can also be mitigated by river engineering, where necessary and compatible the aquatic habitats. Bank erosion can be reduced or prevented by lining the bank with rip rap made of cobbles or boulders; sheet piling or concrete is used for heavier bank and bridge foundation protection as well. Groins or spur dikes are often constructed as deflectors to direct current away from eroding stream banks, or to induce channel changes by promoting local channel scour and/or sedimentation. Glacial outburst floods are potentially difficult and costly to engineer protection because of the rapid release and catastrophic magnitude of the flood flows. Properly sited and sized dikes or levees can provide protection to stream banks and nearby structures.

GROUND WATER

Ground-water data for the Allen Glacier-Wood Canyon reach of the Copper River and Tasnuna and Tiekel River tributaries are limited. Except for test hole data along the Trans Alaska Pipeline corridor, no well or ground-water quality data exist in the U.S. Geological Survey's Ground Water Site Inventory or Quality of Water databases or the Alaska Hydrologic Survey Well Log Tracking System. Information presented in this report regarding ground-water is inferred from a regional geologic map (Beikman, 1980), topographic maps (U.S. Geological Survey 1:250,000 and 1:63,360 scale), air photos (1:63,360 and 1:6000 scales), maps of icings (Dean, 1984), and general principles of ground water occurrence and movement in Alaska, such as described by Williams (1970) and Nelson and Munter (1990).

Aquifer Types

Ground water along potential Copper River road corridors occurs under a variety of conditions in several different types of aquifers. These aquifers can be classified into the following major categories: bedrock aquifers, major alluvial aquifers, minor alluvial aquifers, alluvial fan aquifers, and glacial drift and colluvial aquifers. General characteristics of these aquifers are discussed below, followed by corridor selection considerations.

Predominant rock types in the region are graywacke, slate, argillite, minor conglomerate, volcanic detritus, and interbedded mafic volcanic rocks. The rocks are mildly metamorphosed, locally to greenschist facies (Beikman, 1980). These rocks are exposed sporadically throughout the region and underlie glacial and alluvial deposits in major valleys. As aquifers, these metamorphic rocks transmit water predominantly through fractures and joints. These fractures and joints, however are not expected to be sufficiently large, dense, or interconnected to result in a high or even moderately high bulk permeability for the aquifer. Thus, most wells tapping this aquifer would be expected to yield less than about 10 gallons per minute (gpm) of water. Discontinuous permafrost may restrict ground-water movement or recharge in some areas.

Large alluvial aquifers consisting predominantly of sand, gravel and cobbles occupy the Copper River and lower Tasnuna River valleys. These deposits are probably perennially thawed in most places. Water levels throughout the major alluvial aquifers are probably within 1 to 30 feet of the land surface owing to the relatively flat valley floors. The aquifer is expected to have a relatively high permeability and thickness up to a few hundred feet. Expected yields to wells from this aquifer could readily exceed 1000 gpm.

Minor alluvial aquifers probably consisting of sand, gravel and cobbles with interbedded silty sediments are found near smaller streams throughout the region and near the Tiekel and upper Tasnuna Rivers where the rivers are closely confined by valley walls. These aquifers are probably thin (less than 30 feet) and thawed. These aquifers could probably be tapped for water supply by infiltration galleries close to the stream.

Alluvial fans are commonly found where small streams and rivers enter larger drainages throughout the project area. These fans tend to have gently and uniformly sloping surfaces and probably consist of variable mixtures of silt, sand and gravel. The alluvial fans are significant aquifers in the area because they are located beneath land surfaces that are generally well suited to construction activities. Ground water commonly enters alluvial fan aquifers at the head of the fan through loss of water from streams, and discharges from the perimeter, or "toe" of the fan into numerous small clear-water rivulets. The water table on alluvial fans probably ranges from about 0 to 30 feet below land surface. Permafrost may be locally present on alluvial fans.

Glacial drift and colluvial aquifers occur discontinuously throughout the region, typically between alluvial deposits on valley floors and higher altitude bedrock outcrop areas. These aquifers may be common in the Tiekel river valley. Glacial drift and colluvial aquifers are probably relatively thin and consist of tills, outwash sands and gravels, colluvium and related deposits. These deposits contain water because the underlying bedrock typically has a much lower permeability, retarding downward flow of ground water. Ground-water discharge and flow through these deposits is characteristically low, although locally prolific discharges from this aquifer are possible. These aquifers may be locally confined by till or colluvial confining units or permafrost.

Ground-water discharge from all the aquifers described above contributes to base flow in streams and rivers during the winter months. Springs, seeps and gaining rivulets are probably common throughout the region in topographically low areas as a result of relatively high precipitation and large topographic relief in the area.

Corridor Selection Considerations

Road construction and use impacts on ground water can be considered primary and secondary, respectively. Primary impacts include: interception of the water table by roadcuts; excavation of borrow pits to or below the water table; and leakage, spillage or discharge of harmful substances to ground water or overlying land. These are addressed separately below.

Interception of the water table by roadcuts: Roadcuts through bedrock slopes are likely to result in leakage of ground water from fractures to the cutface, and some reduction in hydrostatic pressure behind the cutface. The quantities of water and pressure reductions will probably be small because of the low permeability of the aquifer. Seasonal icings similar to those occurring on the Seward Highway between Anchorage and Portage may occur, however. These effects are likely to be too minor to warrant mitigation.

Roadcuts in non-lithified deposits could result in the interception of ground water and diversion of the water through a drainage system. As a result of the generally flat terrain where non-lithified deposits are most common, these types of cuts are likely to be small or infrequent and the amount of the diversions only small fractions of the total discharges of the flow systems. The absence of wells near potential road corridors eliminate concern for well failures caused by any lowering of the water table associated with roadcut drainage systems. Interceptions of ground water can be mitigated by minimizing the depths of roadcuts below the water table.

Excavation of borrow pits to or below the water table: Construction of the roadbed will probably require aggregate and fill material in excess of material removed from roadcuts. This may require the development of sand and gravel pits near the road alignment. These pits may expose the water table in the pit bottom and increase the vulnerability of the water to contaminated by refuse or other material. These effects can be mitigated by controlling subsequent dumping of refuse into pits or by filling in deep parts of pits with low-permeability material.

Leakage, spillage, or discharge of harmful substances to ground-water or overlying land: Road construction activities rely almost entirely on machines using diesel and gasoline fuels. These fuels have been shown to be the most common source of ground water contamination in Alaska (Alaska Department of Environmental Conservation, 1990). Contamination can result from small quantity spills and leaks arising from common means of transporting, storing, and transferring fuels. Most ground water along potential road alignments occurs under unconfined conditions with relatively thin and permeable soils above the water table. As a result, ground water is relatively susceptible to contamination from fuels. Ground water could also become contaminated from disposal of sewage from construction worker facilities. Mitigation measures could include: training workers to avoid spills and leaks, engineering safety systems for fuel transport and storage facilities, and designing sewage disposal facilities to minimize ground-water contamination.

Secondary Impacts of road construction potentially include local contamination of ground water from development associated with the road such as gas stations, residential development, campground or commercial facilities and road salt storage areas. Impacts resulting from water use associated with development are expected to be inconsequential. Mitigation measures could include: leak detection systems at gas stations, adherence to sanitary regulations for habitation development, and covering road salt storage areas.

METEOROLOGY

The purpose of this portion of the project is to determine precipitation and surface wind patterns and velocities within the region of the Copper River north of the Allen River and south of the Uranatina River. Much of the region is exposed to winds. Severe drifting of snow does occur and rime ice has been encountered. Dust clouds may develop and the physical force of winds on both stationary and mobile structures must be considered. Due to the size of the river, wind stacking of water during floods is possible.

DOTPF wind data exist for the "Million Dollar" bridge and the USGS has data for the lower floodplain area. DOTPF has monitored wind at Thompson Pass for several years. Historical data probably exist for the defunct railroad although its location unknown. DOTPF and the Soil Conservation Service have precipitation data records for Thompson Pass corridor and for other areas adjacent to the project area. Such data will be reviewed and included if pertinent to the current project.

Precipitation

Due to a short lead time and lack of pre-acquired equipment, it was impossible to install any precipitation monitoring equipment. The necessary devices have been acquired and are ready to be installed, most likely shortly after breakup. Snow surveys will be performed at each scheduled maintenance trip to the Copper River wind stations. These maintenance trips will occur at roughly 80 day intervals till the cessation of the project.

Scattered precipitation data exist for adjacent areas. DOTPF, AEIDC and the Soil Conservation Service have records for Thompson Pass corridor and other sites within the region. Such data will be reviewed and included if pertinent to the current project.

A brief review of the "Alaska Climate Summaries" shows a dramatic difference between average annual precipitation at a site near Wortmanns, 43 inches, and the top of Thompson Pass, 77 inches, less than four miles away. Tonsina lodge, 44 miles inland, has an average annual precipitation of 12 inches. These figures reflect the strong capturing affect of the mountains on moisture carried by winds to the region. Wortmanns has a low altitude but a close proximity to the pass and so has a moderate precipitation. Thompson pass is effective in capturing 75% more moisture. The depleted air is able to deliver less than a third of Wortmanns' precipitation to Tonsina Lodge.

The Copper River Valley and tributary valleys should show a similar pattern, with the more maritime region getting a moderate precipitation, the high passes getting the most precipitation and the continental interior regions getting the least. This will be modified to the extent that moisture is carried up through the Copper River Valley rather than, essentially, over it.

Analysis of the amounts of snow on the ground each month shows that the maximum accumulation occurs in February, with melt strongly advanced in May and depletion by June. Snow tentatively returns in September and a snow cover is well established by October. The "Alaska Climate Summaries" shows that at Thompson Pass actual snow depths can reach 118 inches although total cumulative precipitation may be much greater; it is expected that similar conditions may prevail at Marshall Pass. Maximum depths at Wortmanns and Tonsina Lodge reach 68 inches and 40 inches respectively. Similar snow depths may occur at the Allen Glacier wind station and at the Uranatina wind station, respectively. Snow measurements are taken at sites protected from wind effects such as drifting and ablation. Actual observed depths at other sites may vary greatly, as snow drifts in and is compacted, or alternately, blows away.

Wind Monitoring

Sites were selected on the following criteria: local wind exposure, helicopter accessibility, vandalism protection, and protection from elements such as floods and avalanches. Typical exposed locations were preferred rather than sites exposed to most extreme winds. Due to high installation costs and restrictive time scheduling, a minimal coverage of four wind stations were installed. Sites were chosen to cover both the main valley of the Copper River and two major tributary valleys, the Tiekel valley and the Tasnuna valley (see Figures 6, 7, and 8).

An upstream site near the Uranatina River, on the right side bank of the Copper River essentially at floodplain level, provides information regarding the interior portion of the valley, where the widening valley should moderate winds.

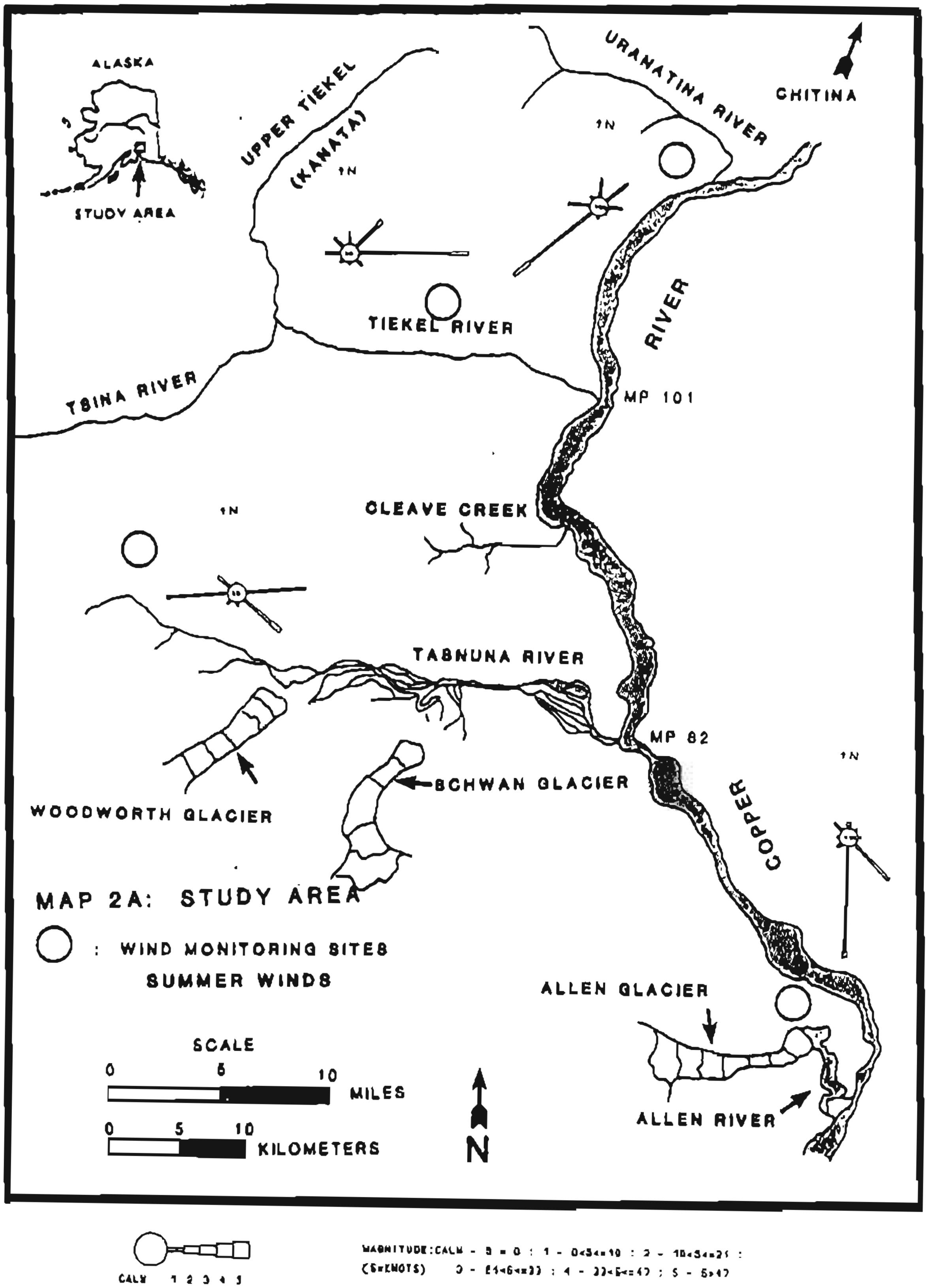
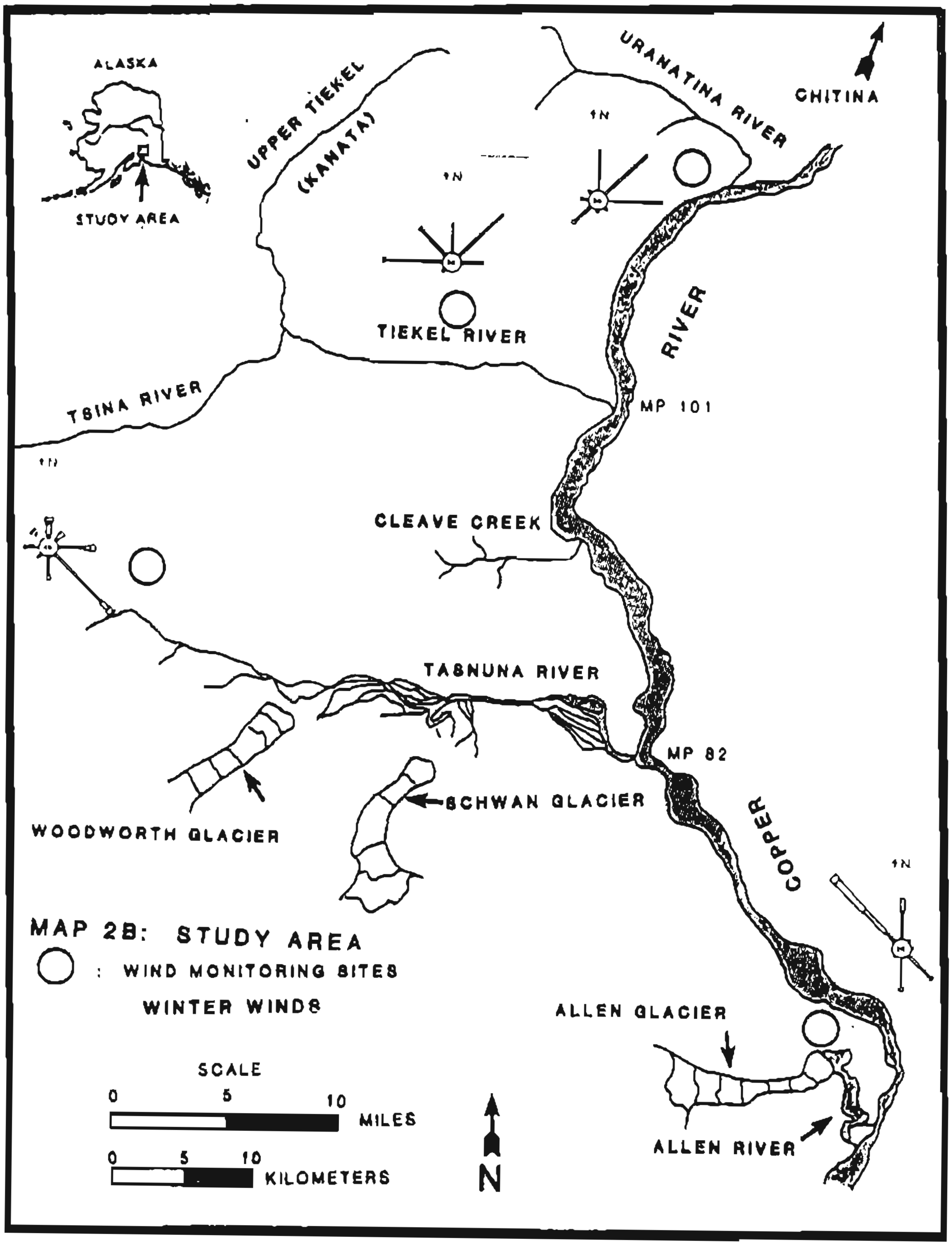
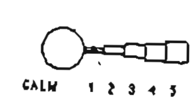


Figure 6. Map 2A: Study Area, wind monitoring sites, summer winds.





MAGNITUDE:CALM - 5 = 0 : 1 - 0<S<=10 : 2 - 10<S<=21 :
(S=KNOTS) 3 - 21<S<=33 : 4 - 33<S<=47 : 5 - S>47

Figure 7. Map 2B: Study Area, wind monitoring sites, winter winds.

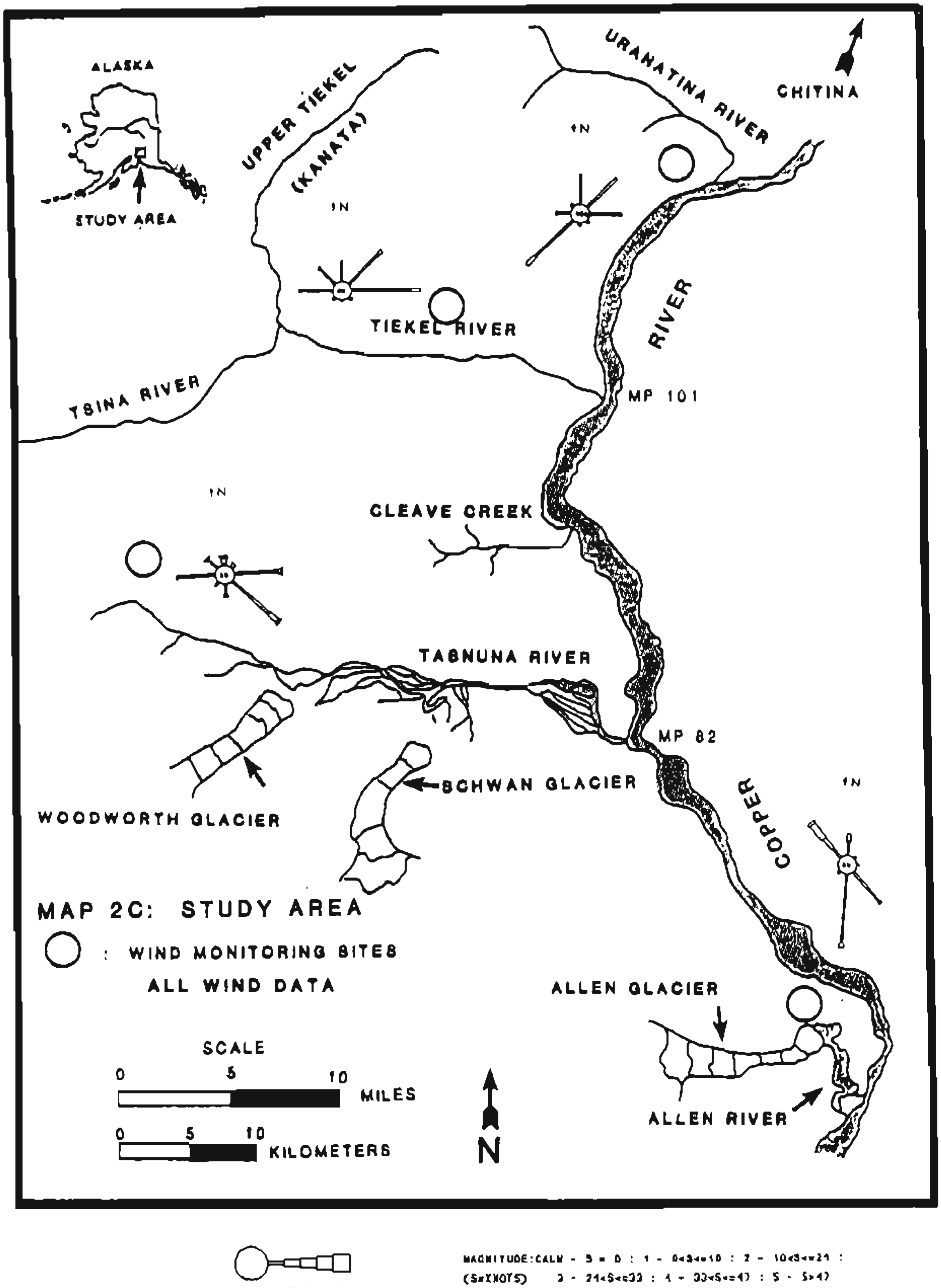


Figure 8. Map 2C: Study Area, wind monitoring sites, all wind data.

The downstream site is on the bluff of the exposed floodplain on an Allen Glacier moraine. This site is expected to experience severe snow drifting. Rime ice may occur due to the proximity to the maritime region.

The Tiekel River and Tasnuna River valleys provide the largest tributary wind corridors. Wind stations were sited near crests of the passes in each valley to monitor channeled winds. Significant winds perpendicular to the passes were not expected, yet may occur due to winds spilling in over the tops of the ridges and from the smaller tributary valleys. The Tiekel valley connects to the interior via a series of passes, while the Tasnuna valley connects to the maritime region over Marshall Pass and Lowe River. It is also connected to the interior over Thompson Pass and so may reveal characteristics common to both the interior and maritime regions.

Wind Monitoring Equipment

A standard site consists of a 36 foot (11 meter) tower and mast assembly, a pre-cast concrete base, a grounding rod, a Stratavane wind sensor and an Omnidata International DP214 data logger. The concrete base is dug into the ground to provide a solid, fixed mounting for the tower that is further supported by three steel guy wires. Towers are flagged and marked for visibility and safety. The sensor is attached to the small mast at the top of the tower and is connected by wire to the recorder attached to the bottom of the tower.

Stratavanes are propeller driven wind sensors resembling small wingless airplanes. They measure both wind speed and direction. Recorders are solid state electronic dataloggers. Dataloggers interrogate wind sensors at five minute intervals over a two hour period. Every two hours, the true vectorial average wind speed and direction, and the greatest observed speed and its associated direction, are recorded. Data are recorded on eprom chips with capacities of 2047 recordings. At current data recording rates, the eprom chips reach their capacity in 85 days and must be replaced.

All four wind stations were installed between 07/28/92 and 07/30/92. The first chips were retrieved on 09/30/92. Wind roses are used to graphically illustrate wind data because interrelationships of cyclic data are often hidden in a standard tabular report. Each wind rose has a key describing it's features and the cumulative wind percentages used in its production . The accompanying tables present the same data in the standard format.

Preliminary Results

Due to the short duration of the available data, these findings are preliminary. While data are valid, the short-term record limits the extent of any interpretation. Generally, an overall pattern of flow from the interior valleys to the coastal area occurred in the summer months with a net reversal of flow in the winter months. The seasonal change occurred in August; it remains to be seen when the summer season starts. A strong storm system produced the strongest winds, which may be typical given the nature of low pressure systems moving in from more southerly regions. Appended to this report are several cumulative percentage wind summaries and maps showing dominant wind features (Appendix 5). Raw data are included in the form of ASCII files on an "IBM" type floppy disk.

<u>Uranatina River:</u> At the Uranatina River site, the overall average wind speed was 3.7 mph with a standard deviation of 3.23 and a maximum of 30 mph. Direction was bimodal, being south-west in summer and north-east in winter with the strongest winds from the south-west. It is apparent that the Uranatina site experiences lower wind velocities than the other sites, possibly due to its location in the wider upper Copper River valley.

<u>Marshall Pass:</u> Overall average wind speed at Marshall Pass was 6.9 mph with a standard deviation of 6.34 and a maximum of 86 mph. Direction was bimodal in summer, being west and

east-south-east. In winter the dominant direction was from the south-east, but strong winds occurred from all directions except south-west, with the strongest winds being aligned north-south. The Marshall Pass site reflects the conditions seen at the Allen site, but with increased velocities. Marshall Pass experienced the strongest winds observed during the study period, at an unexpected north-south vector.

Allen Glacier: At the Allen Glacier site, the overall average wind speed was 8.1 mph with a standard deviation of 8.38 and a maximum of 58 mph. Direction was bimodal, being south-south-east in summer and north-west in winter with the strongest winds from the north-west. The Allen site receives strong winds from the gulf and the maritime environment and is in the principal wind corridor. The surface material at the site gives some evidence of exposure to stronger winds.

Tiekel River: Overall average wind speed at the Tiekel River site was 5.1 mph with a standard deviation of 3.33 and a maximum of 45 mph. Direction was east-north-east in summer and in winter, but with a strong west component in winter. While the strongest wind was from the north, strong winds occurred from all dominant directions. The Tiekel compliments the Uranatina by mirroring the effects of exposure to the interior but experiences greater velocities. The Tiekel is the most consistently windy site.

The duration of strong wind events is often revealed by studies over long periods; in this instance insufficient data are available for reliable analysis. For gusts over 10 mph, Allen River had a continuous event lasting 168 hours while the average event lasted 36 hours. Similarly, at Marshall Pass the longest event endured 192 hours with an average event of 48 hours; at Tiekel River, the longest event was 92 hours with an average of 40 hours and, finally, at the Uranatina River site the longest enduring wind event was 52 hours with an average of 24 hours. These averages do not include wind events of less than 16 hours, which appear to be normal diurnal fluctuations.

An analysis of daily wind patterns indicate lower winds from midnight to about 2 pm with wind speed rising in the afternoon to a peak between 4 pm and 8 pm and then a decline to midnight. This pattern holds for all sites although the data are distorted by storms moving in at random times. As the period of record increases, diurnal fluctuations in wind will become more apparent as anomalous events are smoothed out.

Wind effects that need to be considered include the following:

a) Cornice development on mountain ridges downwind of the dominant winds and wind loading of avalanche slopes. Adequate separation from such slopes must be provided.

b) Snow drifting. In open unrestricted areas drifts form perpendicularly to the direction of the wind, while elongated drifts may form downwind of major obstructions to the flow of wind. Strategically placed snow fences may provide protection from drifting snow.

c) Strong gusts can destroy structures poorly orientated in relation to such gusts; similarly, vehicles experiencing a steady wind from one direction may be forced from the road by a sudden gust from another direction.

d) Dust is not expected to be severe in the tributary valleys, but in the Copper River Valley the extensive fluvial deposits are susceptible to wind erosion, especially if disturbed by motorized vehicles.

e) Blown debris and fallen trees will probably be of small concern with adequate separation from sources of blown objects.

f) Rime ice development is enhanced under some wind and temperature conditions and could be a severe winter problem in the lower Copper River Valley.

Conclusions

Basin characteristics at each site facilitate the flow of wind to and from the interior, with a net southerly flow in the summer months and a net northerly flow in the winter months. The Copper River valley between confluences of the Tasnuna and the Tiekel Rivers carries the combined winds of the interior system (the Tiekel and upper Copper valley) to and from the coastal system (the Tasnuna and the lower Copper valley). These observations are made by comparing the winds observed at each of the four sites. All observations are preliminary due to the short monitoring period, as are the assumptions that the summer patterns end in August.

During a single event, a wind speed of 86 mph was measured in Marshall Pass while the speed was only 58 mph at the Allen site. These measurements coincided with a state-wide storm and confirmed the forecasts by the National Weather Service for the area.

Similar to hydrologic data, meteorologic data have a five years standard minimum threshold of data collection, although longer records are often more desirable. Shorter periods may result in information distorted by one-time or otherwise unusual events. This project should be continued so that seasonal variations can be detected and recorded, and to allow for better data analysis given a longer period of record.

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Appendix 1: Lower Copper River Tributary Discharge Measurements.

Data collected by DOW staff, September 1992.

SITE	DATE	TIME	AVG DEPTH (ft)	AVG VELOC (ft/sec)	TOT WIDTH (ft)	STAGE (ft)	DISCHARGE (cfs)
TASNUNA RIVER	10-Sep-92	1400	3.59	3.93	193.0	92.95	2775.6
	30-Sep-92	1130	1.77	1.89	174.0	90.94	568.2
CLEAVE CREEK	10-Sep-92	1100	1.49	2.86	57.0	94.87	251.9
	30-Sep-92	1330	0.83	1.68	53.0	94.28	80.6
TIEKEL RIVER	09-Sep-92	1530	2.16	2.71	170.0	94.92	1300.5
	30-Sep-92	1600	1.89	2.06	124.0	93.41	529.6
URANATINA RIVER	09-Sep-92	1200	1.53	2.02	46.0	95.85	146.1
	30-Sep-92	1700	2.12	1.07	33.5	95.47	76.1
U. TIEKEL RIVER	29-Sep-92	1400	1.47	1.24	68.8	94.95	128.7

Parameter Descriptions:

AVG DEPTH: Arithmetic average of a minimum of 20 point depth measurements.
AVG VELOC: Arithmetic average of a minimum of 20 point velocity measurements.
TOT WIDTH: Measured distance across channel on water surface at discharge cross-section.
STAGE: Measured elevation of water surface at cross section with respect to arbitrary datum elevation.
DISCHARGE: Total measured streamflow at specific point in time (reported in cubic feet per second (cfs)).

Instrumentation Descriptions:

Stage data collected with Omnidata International EasyLogger model 800 or 900, with INW model 700 or 900 pressure transducer sensor. Velocity measurements were made with Price AA, or Pygmy current meters.

Appendix 2: Lower Copper River Tributary Discharge Measurements.

Data collected by USGS, 1913.

SITE	DATE	DISCHARGE (cfs)
TSINA RIVER	20-Oct-13	87.0
	09-Nov-13	50.0
	10-Nov-13	134.0
TIEKEL RIVER	13-Jun-13	5820.0
	01-Jul-13	8480.0
	10-Sep-13	819.0
U. TIEKEL RIVER (KANATA RIVER)	19-Oct-13	146.0
	10-Nov-13	69.0

Source: Ellsworth, C. E., Davenport, R. W., Hoyt, J.C., 1915,
A Water Power Reconnaissance in South Central Alaska
USGS Water Supply 372, 1915, 173 pages.

Appendix 3: Upper Tiekel River Crest Gage Data.

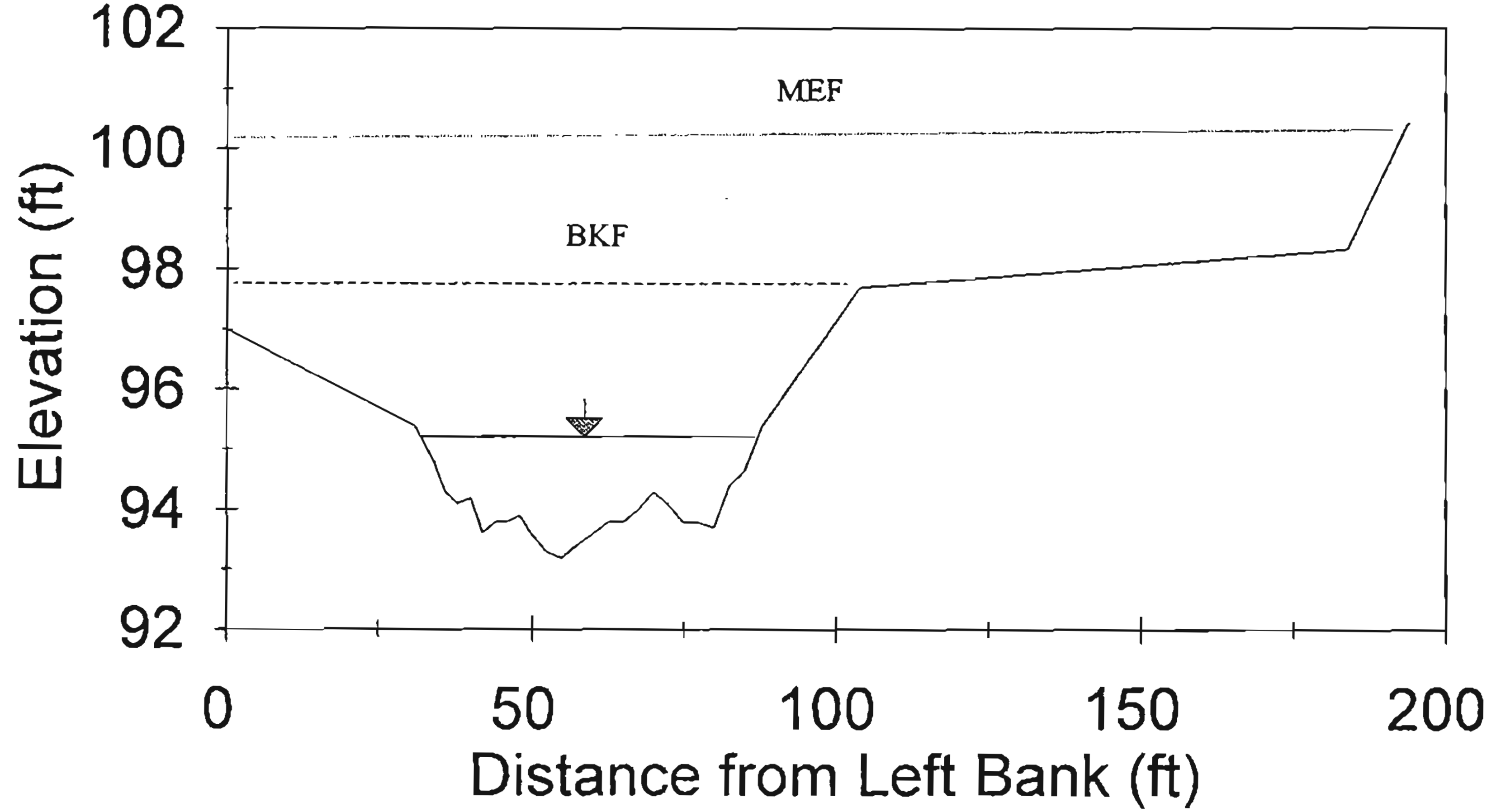
Data collected by USGS.

SITE	DATE	DISCHARGE (cfs)
U. TIEKEL RIVER (KANATA RIVER)	1978	1330.0
	Jun-79	1390.0
	08-Jun-80	3000.0
	07-Aug-81	4880.0

Source: Unpublished data from USGS records.

APPENDIX 4: CLEAVE CREEK CROSS SECTION

Sep 2, 1992

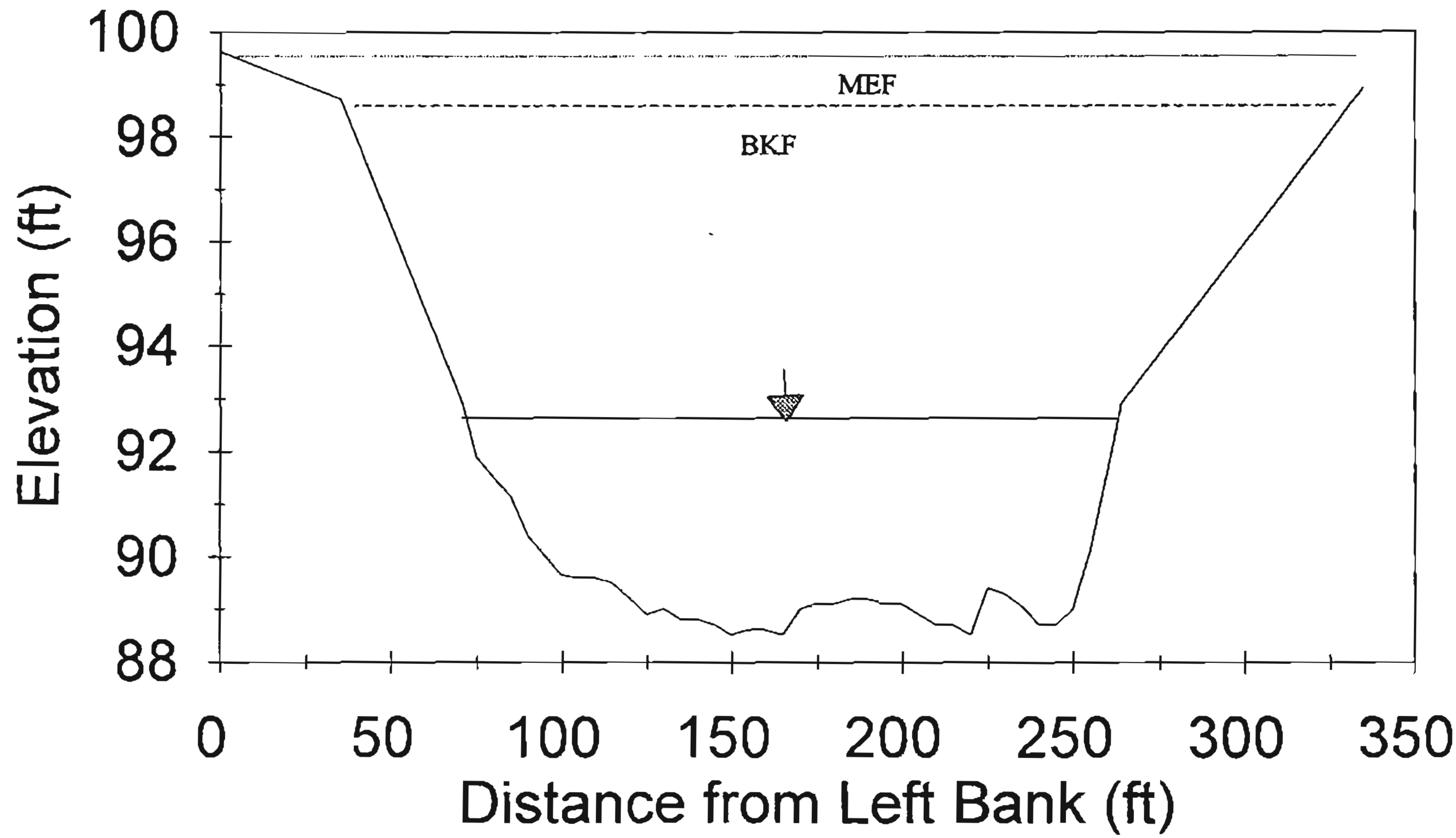


Note: elevation is from arbitrary benchmark datum set at 100 ft;

MEF=mean evident flood; BKF=bankfull.

APPENDIX 4:TASNUNA RIVER CROSS SECTION

Sep 10, 1992

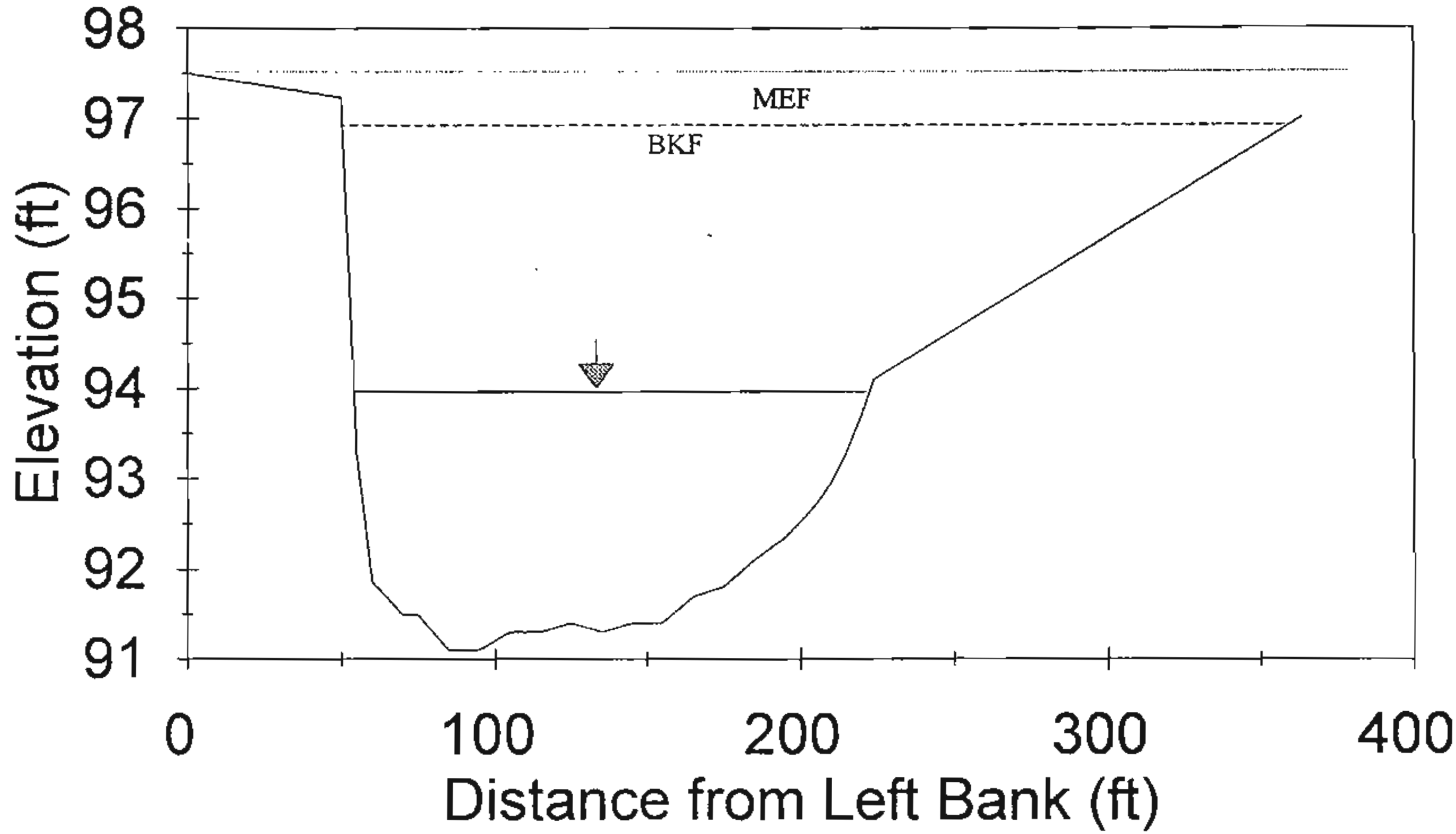


Note: elevation is from arbitrary benchmark datum set at 100 ft;

MEF=mean evident flood; BKF=bankfull.

APPENDIX 4: TIEKEL RIVER CROSS SECTION

Sep 9, 1992

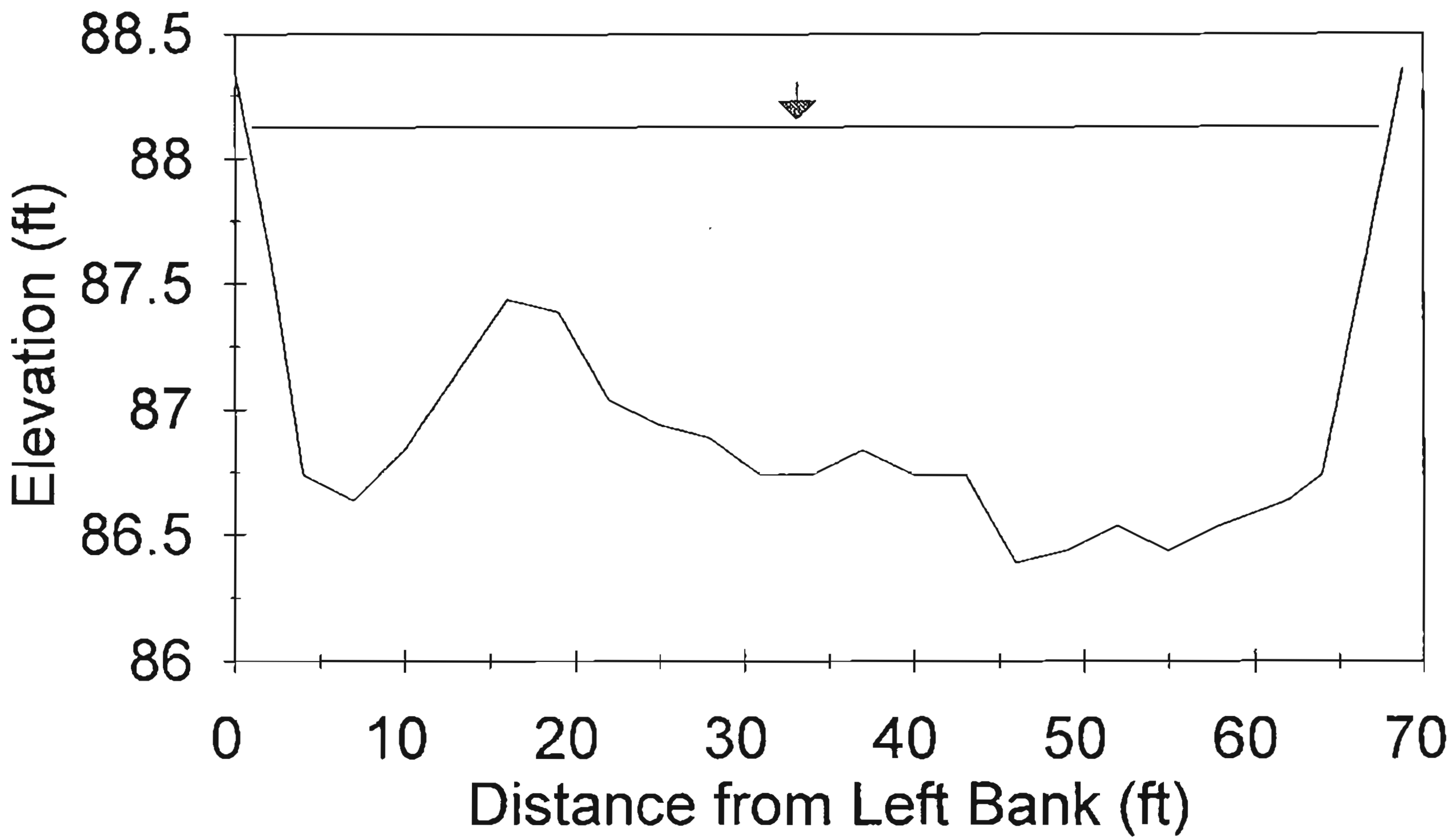


Note: elevation is from arbitrary benchmark datum set at 100 ft;

MEF=mean evident flood; BKF=bankfull.

APPENDIX 4: UP TIEKEL R CROSS SECTION

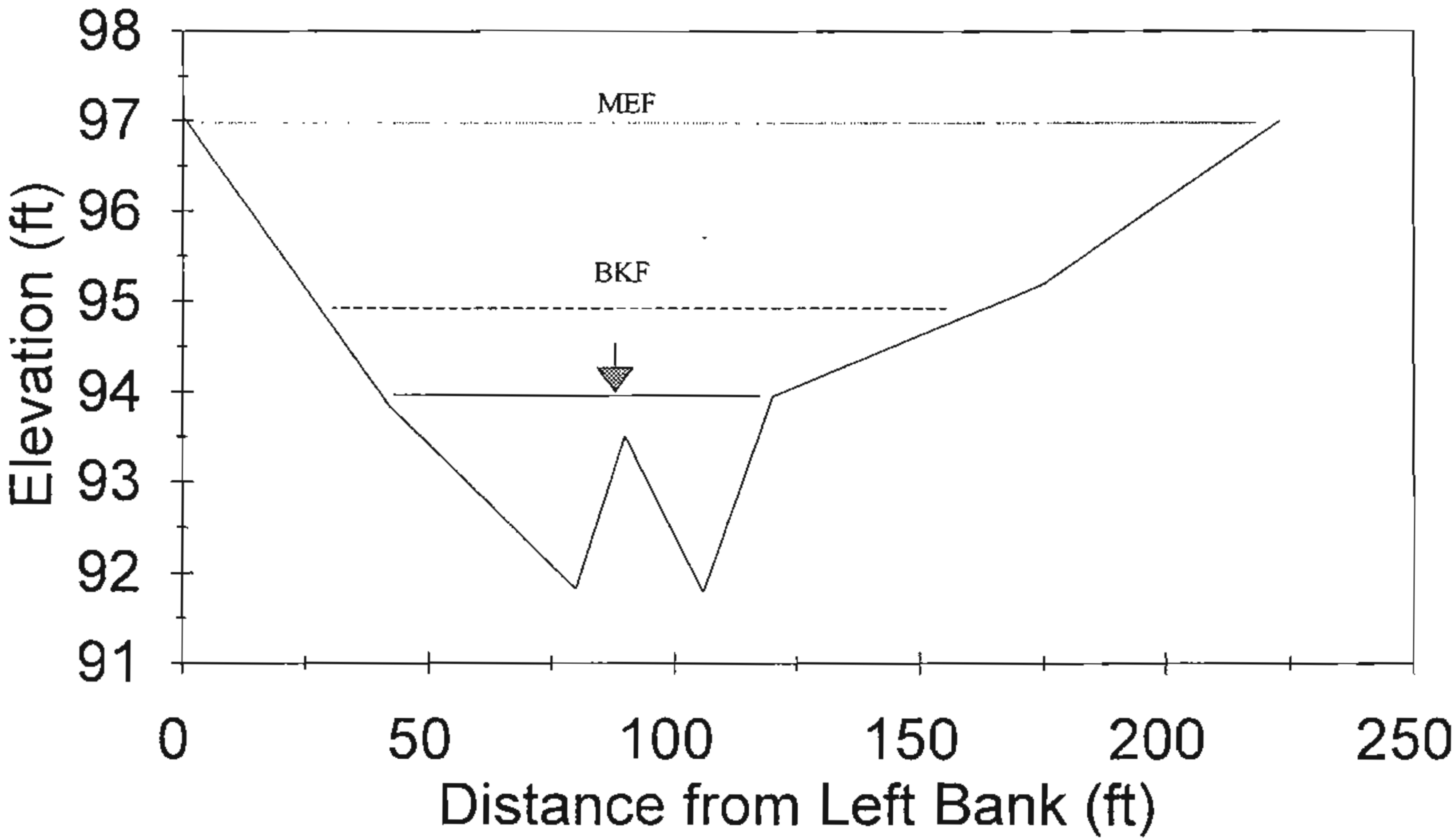
Sep 29, 1992



Note: elevation is from arbitrary benchmark datum set at 100 ft.

APPENDIX 4: URANATINA R CROSS SECTION

Sep 9, 1992



Note: elevation is from arbitrary benchmark datum set at 100 ft;

MEF=mean evident flood; BKF=bankfull.

APPENDIX 5:

STATE OF ALASKA, NATURAL RESOURCES, DIVISION OF WATER
URANITINA RIVER, AVERAGE WINDS, FROM 07/29/92 TO 09/30/92

CUMULATIVE PERCENT WIND SPEED SUMMARY

WIND SPEED CLASSES (S MILES PER HOUR)
CALM, S=0; 1) 0<S<=10; 2) 10<S<=21; 3) 21<S<=33; 4) 33<S<=47; 5) S>47

ALL JULYS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	7.14	0.00	0.00	0.00	0.00	7.14
NORTHEAST	7.14	0.00	0.00	0.00	0.00	7.14
EAST	14.29	0.00	0.00	0.00	0.00	14.29
SOUTHEAST	0.00	0.00	0.00	0.00	0.00	0.00
SOUTH	0.00	0.00	0.00	0.00	0.00	0.00
SOUTHWEST	42.86	28.57	0.00	0.00	0.00	71.43
WEST	0.00	0.00	0.00	0.00	0.00	0.00
NORTHWEST	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	71.43	28.57	0.00	0.00	0.00	100.00

PERCENT WINDS 100.00, PERCENT CALM 0.00, OBSERVATIONS 14

ALL AUGUSTS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	9.24	0.00	0.00	0.00	0.00	9.24
NORTHEAST	13.59	0.00	0.00	0.00	0.00	13.59
EAST	5.98	0.00	0.00	0.00	0.00	5.98
SOUTHEAST	1.09	0.00	0.00	0.00	0.00	1.09
SOUTH	1.63	0.00	0.00	0.00	0.00	1.63
SOUTHWEST	37.50	7.61	0.00	0.00	0.00	45.11
WEST	10.33	0.54	0.00	0.00	0.00	10.87
NORTHWEST	2.17	0.00	0.00	0.00	0.00	2.17
TOTALS	81.52	8.15	0.00	0.00	0.00	89.67

PERCENT WINDS 89.67, PERCENT CALM 10.33, OBSERVATIONS 184

ALL SEPTEMBERS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	18.86	0.00	0.00	0.00	0.00	18.86
NORTHEAST	26.29	0.00	0.00	0.00	0.00	26.29
EAST	25.14	0.00	0.00	0.00	0.00	25.14
SOUTHEAST	2.29	0.00	0.00	0.00	0.00	2.29
SOUTH	1.71	0.00	0.00	0.00	0.00	1.71
SOUTHWEST	9.71	1.71	0.00	0.00	0.00	11.43
WEST	3.43	0.00	0.00	0.00	0.00	3.43
NORTHWEST	1.71	0.00	0.00	0.00	0.00	1.71
TOTALS	89.14	1.71	0.00	0.00	0.00	90.86

PERCENT WINDS 90.86, PERCENT CALM 9.14, OBSERVATIONS 175

APPENDIX 5:

STATE OF ALASKA, NATURAL RESOURCES, DIVISION OF WATER
URANITINA RIVER, AVERAGE WINDS, FROM 07/29/92 TO 09/30/92

CUMULATIVE PERCENT WIND SPEED SUMMARY

WIND SPEED CLASSES (S MILES PER HOUR)
CALM, S=0; 1) 0<S<=10; 2) 10<S<=21; 3) 21<S<=33; 4) 33<S<=47; 5) S>47

ALL DATA IN DATASET

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	13.67	0.00	0.00	0.00	0.00	13.67
NORTHEAST	19.30	0.00	0.00	0.00	0.00	19.30
EAST	15.28	0.00	0.00	0.00	0.00	15.28
SOUTHEAST	1.61	0.00	0.00	0.00	0.00	1.61
SOUTH	1.61	0.00	0.00	0.00	0.00	1.61
SOUTHWEST	24.66	5.63	0.00	0.00	0.00	30.29
WEST	6.70	0.27	0.00	0.00	0.00	6.97
NORTHWEST	1.88	0.00	0.00	0.00	0.00	1.88
TOTALS	84.72	5.90	0.00	0.00	0.00	90.62

PERCENT WINDS 90.62, PERCENT CALM 9.38, OBSERVATIONS 373

ALL SUMMERS (INCLUDING MONTHS 5 THROUGH 8)

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	9.09	0.00	0.00	0.00	0.00	9.09
NORTHEAST	13.13	0.00	0.00	0.00	0.00	13.13
EAST	6.57	0.00	0.00	0.00	0.00	6.57
SOUTHEAST	1.01	0.00	0.00	0.00	0.00	1.01
SOUTH	1.52	0.00	0.00	0.00	0.00	1.52
SOUTHWEST	37.88	9.09	0.00	0.00	0.00	46.97
WEST	9.60	0.51	0.00	0.00	0.00	10.10
NORTHWEST	2.02	0.00	0.00	0.00	0.00	2.02
TOTALS	80.81	9.60	0.00	0.00	0.00	90.40

PERCENT WINDS 90.40, PERCENT CALM 9.60, OBSERVATIONS 198

ALL WINTERS (EXCLUDING MONTHS 5 THROUGH 8)

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	18.86	0.00	0.00	0.00	0.00	18.86
NORTHEAST	26.29	0.00	0.00	0.00	0.00	26.29
EAST	25.14	0.00	0.00	0.00	0.00	25.14
SOUTHEAST	2.29	0.00	0.00	0.00	0.00	2.29
SOUTH	1.71	0.00	0.00	0.00	0.00	1.71
SOUTHWEST	9.71	1.71	0.00	0.00	0.00	11.43
WEST	3.43	0.00	0.00	0.00	0.00	3.43
NORTHWEST	1.71	0.00	0.00	0.00	0.00	1.71
TOTALS	89.14	1.71	0.00	0.00	0.00	90.86

PERCENT WINDS 90.86, PERCENT CALM 9.14, OBSERVATIONS 175

APPENDIX 5:

STATE OF ALASKA, NATURAL RESOURCES, DIVISION OF WATER
TIEKEL RIVER, AVERAGE WINDS, FROM 07/28/92 TO 09/30/92

CUMULATIVE PERCENT WIND SPEED SUMMARY

WIND SPEED CLASSES (S MILES PER HOUR)
CALM, S=0; 1) 0<S<=10; 2) 10<S<=21; 3) 21<S<=33; 4) 33<S<=47; 5) S>47

ALL JULYS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	5.00	0.00	0.00	0.00	0.00	5.00
NORTHEAST	10.00	0.00	0.00	0.00	0.00	10.00
EAST	45.00	0.00	0.00	0.00	0.00	45.00
SOUTHEAST	15.00	0.00	0.00	0.00	0.00	15.00
SOUTH	5.00	0.00	0.00	0.00	0.00	5.00
SOUTHWEST	5.00	0.00	0.00	0.00	0.00	5.00
WEST	0.00	0.00	0.00	0.00	0.00	0.00
NORTHWEST	5.00	0.00	0.00	0.00	0.00	5.00
TOTALS	90.00	0.00	0.00	0.00	0.00	90.00

PERCENT WINDS 90.00, PERCENT CALM 10.00, OBSERVATIONS 20

ALL AUGUSTS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	5.98	0.00	0.00	0.00	0.00	5.98
NORTHEAST	14.13	3.80	0.00	0.00	0.00	17.93
EAST	42.39	9.78	0.00	0.00	0.00	52.17
SOUTHEAST	2.72	0.00	0.00	0.00	0.00	2.72
SOUTH	0.54	0.00	0.00	0.00	0.00	0.54
SOUTHWEST	1.63	0.00	0.00	0.00	0.00	1.63
WEST	7.61	0.00	0.00	0.00	0.00	7.61
NORTHWEST	5.98	0.00	0.00	0.00	0.00	5.98
TOTALS	80.98	13.59	0.00	0.00	0.00	94.57

PERCENT WINDS 94.57, PERCENT CALM 5.43, OBSERVATIONS 184

ALL SEPTEMBERS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	13.61	0.00	0.00	0.00	0.00	13.61
NORTHEAST	27.81	0.00	0.00	0.00	0.00	27.81
EAST	10.06	0.00	0.00	0.00	0.00	10.06
SOUTHEAST	0.00	0.00	0.00	0.00	0.00	0.00
SOUTH	0.00	0.00	0.00	0.00	0.00	0.00
SOUTHWEST	1.78	0.00	0.00	0.00	0.00	1.78
WEST	26.04	1.18	0.00	0.00	0.00	27.22
NORTHWEST	16.57	0.59	0.00	0.00	0.00	17.16
TOTALS	95.86	1.78	0.00	0.00	0.00	97.63

PERCENT WINDS 97.63, PERCENT CALM 2.37, OBSERVATIONS 169

APPENDIX 5:

STATE OF ALASKA, NATURAL RESOURCES, DIVISION OF WATER
TIEKEL RIVER, AVERAGE WINDS, FROM 07/28/92 TO 09/30/92

CUMULATIVE PERCENT WIND SPEED SUMMARY

WIND SPEED CLASSES (S MILES PER HOUR)
CALM, S=0; 1) 0<S<=10; 2) 10<S<=21; 3) 21<S<=33; 4) 33<S<=47; 5) S>47

ALL DATA IN DATASET

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	9.38	0.00	0.00	0.00	0.00	9.38
NORTHEAST	20.11	1.88	0.00	0.00	0.00	21.98
EAST	27.88	4.83	0.00	0.00	0.00	32.71
SOUTHEAST	2.14	0.00	0.00	0.00	0.00	2.14
SOUTH	0.54	0.00	0.00	0.00	0.00	0.54
SOUTHWEST	1.88	0.00	0.00	0.00	0.00	1.88
WEST	15.55	0.54	0.00	0.00	0.00	16.09
NORTHWEST	10.72	0.27	0.00	0.00	0.00	10.99
TOTALS	88.20	7.51	0.00	0.00	0.00	95.71

PERCENT WINDS 95.71, PERCENT CALM 4.29, OBSERVATIONS 373

ALL SUMMERS (INCLUDING MONTHS 5 THROUGH 8)

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	5.88	0.00	0.00	0.00	0.00	5.88
NORTHEAST	13.73	3.43	0.00	0.00	0.00	17.16
EAST	42.65	8.82	0.00	0.00	0.00	51.47
SOUTHEAST	3.92	0.00	0.00	0.00	0.00	3.92
SOUTH	0.98	0.00	0.00	0.00	0.00	0.98
SOUTHWEST	1.96	0.00	0.00	0.00	0.00	1.96
WEST	6.86	0.00	0.00	0.00	0.00	6.86
NORTHWEST	5.88	0.00	0.00	0.00	0.00	5.88
TOTALS	81.86	12.25	0.00	0.00	0.00	94.12

PERCENT WINDS 94.12, PERCENT CALM 5.88, OBSERVATIONS 204

ALL WINTERS (EXCLUDING MONTHS 5 THROUGH 8)

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	13.61	0.00	0.00	0.00	0.00	13.61
NORTHEAST	27.81	0.00	0.00	0.00	0.00	27.81
EAST	10.06	0.00	0.00	0.00	0.00	10.06
SOUTHEAST	0.00	0.00	0.00	0.00	0.00	0.00
SOUTH	0.00	0.00	0.00	0.00	0.00	0.00
SOUTHWEST	1.78	0.00	0.00	0.00	0.00	1.78
WEST	26.04	1.18	0.00	0.00	0.00	27.22
NORTHWEST	16.57	0.59	0.00	0.00	0.00	17.16
TOTALS	95.86	1.78	0.00	0.00	0.00	97.63

PERCENT WINDS 97.63, PERCENT CALM 2.37, OBSERVATIONS 169

APPENDIX 5:

STATE OF ALASKA, NATURAL RESOURCES, DIVISION OF WATER
MARSHALL PASS, AVERAGE WINDS, FROM 07/30/92 TO 09/30/92

CUMULATIVE PERCENT WIND SPEED SUMMARY

WIND SPEED CLASSES (S MILES PER HOUR)
CALM, S=0; 1) 0<S<=10; 2) 10<S<=21; 3) 21<S<=33; 4) 33<S<=47; 5) S>47

ALL JULYS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	0.00	0.00	0.00	0.00	0.00	0.00
NORTHEAST	0.00	0.00	0.00	0.00	0.00	0.00
EAST	15.38	0.00	0.00	0.00	0.00	15.38
SOUTHEAST	0.00	0.00	0.00	0.00	0.00	0.00
SOUTH	15.38	0.00	0.00	0.00	0.00	15.38
SOUTHWEST	7.69	0.00	0.00	0.00	0.00	7.69
WEST	53.85	0.00	0.00	0.00	0.00	53.85
NORTHWEST	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	92.31	0.00	0.00	0.00	0.00	92.31

PERCENT WINDS 92.31, PERCENT CALM 7.69, OBSERVATIONS 13

ALL AUGUSTS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	0.54	0.00	0.00	0.00	0.00	0.54
NORTHEAST	0.00	0.00	0.00	0.00	0.00	0.00
EAST	29.03	0.00	0.00	0.00	0.00	29.03
SOUTHEAST	17.74	6.45	0.00	0.00	0.00	24.19
SOUTH	1.08	0.00	0.00	0.00	0.00	1.08
SOUTHWEST	2.15	0.00	0.00	0.00	0.00	2.15
WEST	25.81	1.08	0.00	0.00	0.00	26.88
NORTHWEST	8.06	0.00	0.00	0.00	0.00	8.06
TOTALS	84.41	7.53	0.00	0.00	0.00	91.94

PERCENT WINDS 91.94, PERCENT CALM 8.06, OBSERVATIONS 186

ALL SEPTEMBERS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	1.15	5.17	1.15	1.72	0.00	9.20
NORTHEAST	1.15	2.87	1.15	0.00	0.00	5.17
EAST	12.07	2.87	2.30	0.00	0.00	17.24
SOUTHEAST	30.46	4.60	2.30	0..57	0.00	37.93
SOUTH	8.62	2.30	0.00	0.00	0.00	10.92
SOUTHWEST	2.87	0.00	0.00	0.00	0.00	2.87
WEST	6.32	0.57	0.00	0.00	0.00	6.90
NORTHWEST	4.02	1.72	0.00	0.57	0.00	6.32
TOTALS	66.67	20.11	6.90	2.87	0.00	96.55

PERCENT WINDS 96.55, PERCENT CALM 3.45, OBSERVATIONS 174

APPENDIX 5:

STATE OF ALASKA, NATURAL RESOURCES, DIVISION OF WATER
MARSHALL PASS, AVERAGE WINDS, FROM 07/30/92 TO 09/30/92

CUMULATIVE PERCENT WIND SPEED SUMMARY

WIND SPEED CLASSES (S MILES PER HOUR)
CALM, S=0; 1) 0<S<=10; 2) 10<S<=21; 3) 21<S<=33; 4) 33<S<=47; 5) S>47

ALL DATA IN DATASET

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	0.80	2.41	0.54	0.80	0.00	4.56
NORTHEAST	0.54	1.34	0.54	0.00	0.00	2.41
EAST	20.64	1.34	1.07	0.00	0.00	23.06
SOUTHEAST	23.06	5.36	1.07	0.27	0.00	29.76
SOUTH	5.09	1.07	0.00	0.00	0.00	6.17
SOUTHWEST	2.68	0.00	0.00	0.00	0.00	2.68
WEST	17.69	0.80	0.00	0.00	0.00	18.50
NORTHWEST	5.90	0.80	0.00	0.27	0.00	6.97
TOTALS	76.41	13.14	3.22	1.34	0.00	94.10

PERCENT WINDS 94.10, PERCENT CALM 5.90, OBSERVATIONS 373

ALL SUMMERS (INCLUDING MONTHS 5 THROUGH 8)

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	0.50	0.00	0.00	0.00	0.00	0.50
NORTHEAST	0.50	0.00	0.00	0.00	0.00	0.00
EAST	28.14	0.00	0.00	0.00	0.00	28.14
SOUTHEAST	16.58	6.03	0.00	0.00	0.00	22.61
SOUTH	2.01	0.00	0.00	0.00	0.00	2.01
SOUTHWEST	2.51	0.00	0.00	0.00	0.00	2.51
WEST	27.64	1.01	0.00	0.00	0.00	28.64
NORTHWEST	7.54	0.00	0.00	0.00	0.00	7.54
TOTALS	84.92	7.04	0.00	0.00	0.00	91.96

PERCENT WINDS 91.96, PERCENT CALM 8.04, OBSERVATIONS 199

ALL WINTERS (EXCLUDING MONTHS 5 THROUGH 8)

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	1.15	5.17	1.15	1.72	0.00	9.20
NORTHEAST	1.15	2.78	1.15	0.00	0.00	5.17
EAST	12.07	2.87	2.30	0.00	0.00	17.24
SOUTHEAST	30.46	4.60	2.30	0.57	0.00	15.29
SOUTH	8.62	2.30	0.00	0.00	0.00	15.29
SOUTHWEST	2.87	0.00	0.00	0.00	0.00	0.59
WEST	6.32	0.57	0.00	0.00	0.00	0.00
NORTHWEST	4.02	1.72	0.00	0.57	0.00	41.18
TOTALS	66.67	20.11	6.90	2.87	0.00	93.53

PERCENT WINDS 96.55, PERCENT CALM 3.45, OBSERVATIONS 174

APPENDIX 5:

STATE OF ALASKA, NATURAL RESOURCES, DIVISION OF WATER
NEAR ALLEN GLACIER, AVERAGE WINDS, FROM 07/30/92 TO 09/30/92

CUMULATIVE PERCENT WIND SPEED SUMMARY

WIND SPEED CLASSES (S MILES PER HOUR)
CALM, S=0; 1) 0<S<=10; 2) 10<S<=21; 3) 21<S<=33; 4) 33<S<=47; 5) S>47

ALL JULYS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	0.00	0.00	0.00	0.00	0.00	0.00
NORTHEAST	0.00	0.00	0.00	0.00	0.00	0.00
EAST	0.00	0.00	0.00	0.00	0.00	0.00
SOUTHEAST	22.22	0.00	0.00	0.00	0.00	22.22
SOUTH	44.44	22.22	0.00	0.00	0.00	66.67
SOUTHWEST	0.00	0.00	0.00	0.00	0.00	0.00
WEST	0.00	0.00	0.00	0.00	0.00	0.00
NORTHWEST	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	66.67	22.22	0.00	0.00	0.00	88.89

PERCENT WINDS 88.89, PERCENT CALM 11.11, OBSERVATIONS 8

ALL AUGUSTS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	1.08	1.62	0.00	0.00	0.00	2.70
NORTHEAST	1.08	0.00	0.00	0.00	0.00	1.08
EAST	1.62	0.00	0.00	0.00	0.00	1.62
SOUTHEAST	22.70	0.54	0.00	0.00	0.00	23.24
SOUTH	49.19	2.16	0.00	0.00	0.00	51.35
SOUTHWEST	2.70	0.00	0.00	0.00	0.00	2.70
WEST	1.08	0.00	0.00	0.00	0.00	1.08
NORTHWEST	5.41	0.00	0.00	0.00	0.00	5.41
TOTALS	84.86	4.32	0.00	0.00	0.00	89.19

PERCENT WINDS 89.19, PERCENT CALM 10.81, OBSERVATIONS 185

ALL SEPTEMBERS ON RECORD

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	12.94	5.88	0.00	0.00	0.00	18.82
NORTHEAST	1.18	0.00	0.00	0.00	0.00	1.18
EAST	1.18	0.00	0.00	0.00	0.00	1.18
SOUTHEAST	14.71	0.59	0.00	0.00	0.00	15.29
SOUTH	13.53	1.76	0.00	0.00	0.00	15.29
SOUTHWEST	0.59	0.00	0.00	0.00	0.00	0.59
WEST	0.00	0.00	0.00	0.00	0.00	0.00
NORTHWEST	5.88	14.12	18.24	2.94	0.00	41.18
TOTALS	50.00	22.35	18.24	2.94	0.00	93.53

PERCENT WINDS 93.53, PERCENT CALM 6.47, OBSERVATIONS 170

APPENDIX 5:

STATE OF ALASKA, NATURAL RESOURCES, DIVISION OF WATER
NEAR ALLEN GLACIER, AVERAGE WINDS, FROM 07/30/92 TO 09/30/92

CUMULATIVE PERCENT WIND SPEED SUMMARY

WIND SPEED CLASSES (S MILES PER HOUR)
CALM, S=0; 1) 0<S<=10; 2) 10<S<=21; 3) 21<S<=33; 4) 33<S<=47; 5) S>47

ALL DATA IN DATASET

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	6.59	3.57	0.00	0.00	0.00	10.16
NORTHEAST	1.10	0.00	0.00	0.00	0.00	1.10
EAST	1.37	0.00	0.00	0.00	0.00	1.37
SOUTHEAST	18.96	0.55	0.00	0.00	0.00	19.51
SOUTH	32.42	2.47	0.00	0.00	0.00	34.89
SOUTHWEST	1.65	0.00	0.00	0.00	0.00	1.65
WEST	0.55	0.00	0.00	0.00	0.00	0.55
NORTHWEST	5.49	6.59	8.52	1.37	0.00	21.98
TOTALS	68.13	13.19	8.52	1.37	0.00	91.21

PERCENT WINDS 91.21, PERCENT CALM 8.79, OBSERVATIONS 364

ALL SUMMERS (INCLUDING MONTHS 5 THROUGH 8)

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	1.03	1.55	0.00	0.00	0.00	2.58
NORTHEAST	1.03	0.00	0.00	0.00	0.00	1.03
EAST	1.55	0.00	0.00	0.00	0.00	1.55
SOUTHEAST	22.68	0.52	0.00	0.00	0.00	23.20
SOUTH	48.97	3.09	0.00	0.00	0.00	52.06
SOUTHWEST	2.58	0.00	0.00	0.00	0.00	2.58
WEST	1.03	0.00	0.00	0.00	0.00	1.03
NORTHWEST	5.15	0.00	0.00	0.00	0.00	5.15
TOTALS	84.02	5.15	0.00	0.00	0.00	89.18

PERCENT WINDS 89.18, PERCENT CALM 10.82, OBSERVATIONS 194

ALL WINTERS (EXCLUDING MONTHS 5 THROUGH 8)

CLASS	1)	2)	3)	4)	5)	TOTALS
NORTH	12.94	5.88	0.00	0.00	0.00	18.82
NORTHEAST	1.18	0.00	0.00	0.00	0.00	1.18
EAST	1.18	0.00	0.00	0.00	0.00	1.18
SOUTHEAST	14.71	0.59	0.00	0.00	0.00	15.29
SOUTH	13.53	1.76	0.00	0.00	0.00	15.29
SOUTHWEST	0.59	0.00	0.00	0.00	0.00	0.59
WEST	0.00	0.00	0.00	0.00	0.00	0.00
NORTHWEST	5.88	14.12	18.24	2.94	0.00	41.18
TOTALS	50.00	22.35	18.24	2.94	0.00	93.53

PERCENT WINDS 93.53, PERCENT CALM 6.47, OBSERVATIONS 170

Figure 4. Photo 3: 1982 aerial, Copper River/Allen River north and south channel confluences (undetermined scale).

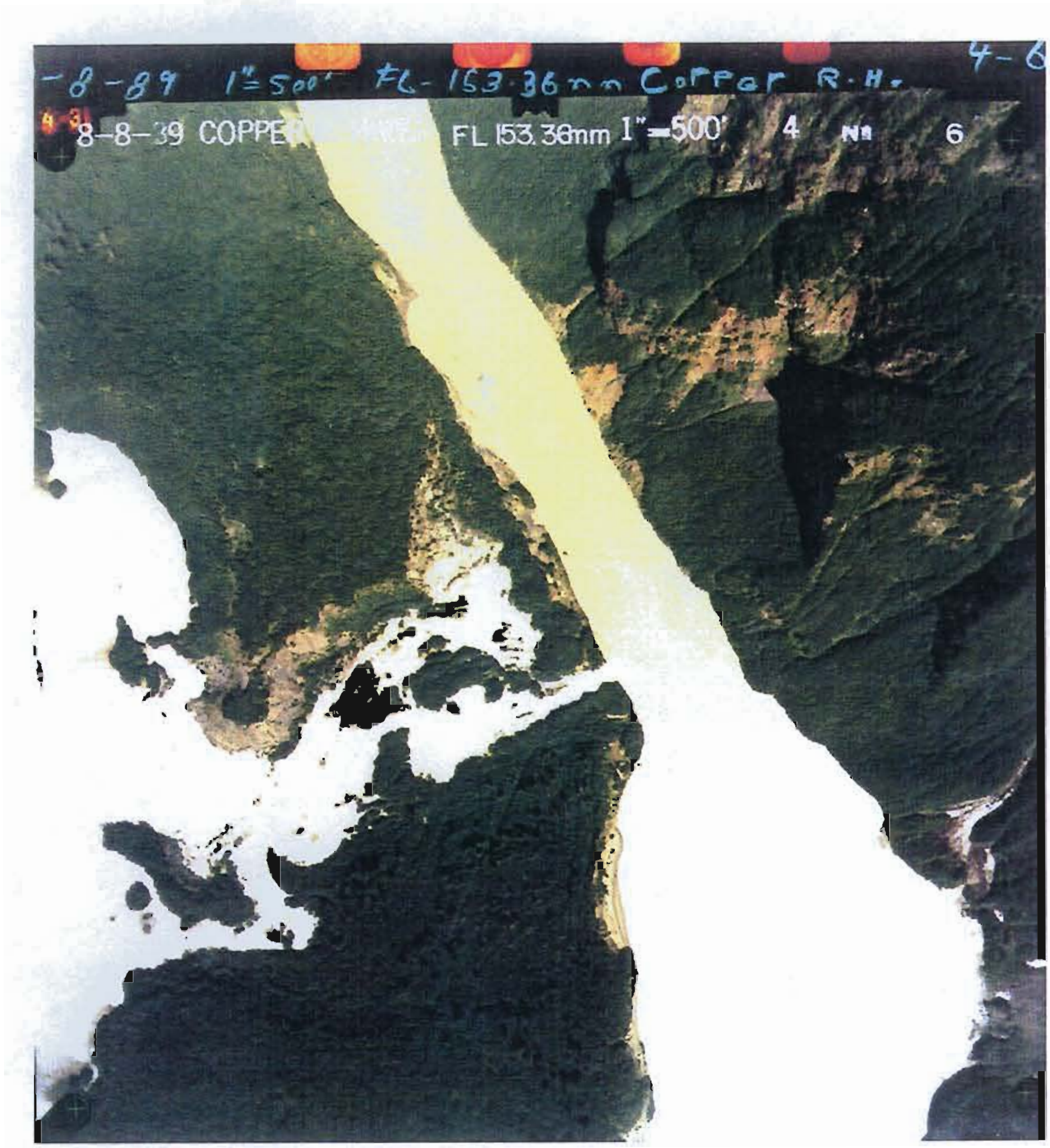


Figure 5. Photo 4: 1989 aerial, Copper River/Allen River north channel confluence (undetermined scale).