GLACIER MONITORING PROTOCOL

DENALI NATIONAL PARK AND PRESERVE

NATIONAL PARK SERVICE
DEPARTMENT OF THE INTERIOR

GLACIER MONITORING PROTOCOL

DENALI NATIONAL PARK AND PRESERVE
ALASKA

James Roush
Phil Brease

National Park Service
Denali National Park and Preserve
P.O. Box 9
Denali Park, AK 99755

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INTRODUCTION

The objective of glacier monitoring in Denali National Park and Preserve is the characterization of glacier conditions in the past, present, and future. That knowledge is compared to known climatic conditions both in order to gauge current climatic trends and also to understand how glaciers may respond to potential climate changes.

Glaciers can be viewed as complex systems that constantly adjust to internal factors and external change. Because climate changes from year to year, and century to century, glaciers are always changing in an attempt to reach a steady state of equilibrium with climate by balancing gain and loss of ice mass. Because climatic conditions rarely remain constant, glacial response to changing climate can be taken as a measure of that change.

Glacier conditions in Denali are being studied for the past, monitored in the present, and compared with records of climate to determine how glaciers may behave in the future. The nature and extent of glaciation in Denali during the recent part of the Quaternary Period (the last 100,000 years) has been recorded in the surficial deposits and land forms left behind by the retreat of past glaciations and are to be studied and related to our knowledge of past climates. The glaciers which exist today are being monitored now so that we may understand their response to changing climatic variables, occurring first in glacier mass balance and in turn driving changes in glacier size and behavior. Knowledge and understanding of past and present glacial responses to climate will allow us to use glaciers to measure changing conditions, and perhaps enable a prediction of how glaciers will respond to potential global climate variations.

Denali National Park and Preserve is a unique laboratory for this research because it is extensively glaciated. Fully 17% of Denali's six million acres is currently covered by glacier ice. These glaciers exist in two distinct climatic regimes. To the south, the maritime influences of the Gulf of Alaska reach the Alaska Range south slope and undoubtedly bring a larger amount of precipitation than in the north. On the north side of the Alaska range a much dryer continental climate exists. Not only do we have the opportunity to study how glaciers respond to this orographic effect in general, but we can also study how different climatic regimes are responding to the changing global climatic conditions.

The purpose of this protocol is to describe the methods of glacier data collection and data management that are either ongoing or are soon to be implemented. Selection of sites for data collection is discussed. Sampling methods which have already been implemented are described in detail. Methods which are to be implemented in the near future are outlined. Details of sampling and data management will be revised as experience and technology dictate. The details of experimental design for Denali National Park and Preserve's glacier monitoring program are addressed in the Glacier Resources Management Plan which is currently under development.

MONITORING DESIGN CONSIDERATIONS

SITE SELECTION

Sites for glacier data collection exist on two distinct spatial scales. The first is a regional scale which encompasses all glaciated areas within Denali National Park and Preserve, and any sub-areas, which are studied with remote sensing techniques. The second is a local scale at which specific glaciers or glacier features are studied in detail with field research techniques. These local scale sites are referred to as index glaciers or index sites.

Ongoing glacier research projects have selected index glaciers or index sites (see Figure 1) for a variety of reasons which are based on the same general set of criteria, which include:

Fig 1

(GIS Fig To Be Adapted)

- glaciers which are representative of other glaciers of the same type or are in the same climatic regime or geographic region

- glaciers which exert significant stress on ecosystems in which other attributes, such as vegetative and aquatic micro-organism communities, are being monitored

- glaciers of significant public interest or particular interpretive value

- glaciers where historical data collections exist, or where collections by non-NPS researchers are planned or are ongoing

- glaciers which are currently displaying, or have significant potential for, some type of anomalous behavior, such as surges or outburst floods

- glaciers where operational logistics are reasonable and feasible, and where personal safety is not compromised in the collection of data

SAMPLING TECHNIQUE SELECTION

There is a wide range of glacier features and attributes which are of interest or importance for both natural resources management and basic scientific research. The techniques used for glacier monitoring in Denali are determined by which glacier attributes are of interest to the NPS. Glacier monitoring is carried out to meet the need for interpretation of park resources, to support park efforts at long term ecological monitoring, and to fulfill the international responsibilities of Denali as a Biosphere Reserve. These diverse mandates lead to a range of data and information needs which can be summarized as follows:

- glacier mass balance data needed to correlate glacier conditions with, and gauge, climatic conditions and trends

- data describing glacier morphologies and responses to mass balance changes

- data for the extrapolation of glacier conditions from local index sites to the entire park and regions within it

- information on how glaciers influence park ecosystems

- information on glacial threats to park visitors, personnel, and facilities, e.g. glacial outburst floods and glacier surges

These needs are met with a variety of sampling techniques which were chosen based on the following criteria:

- ability to obtain the desired information accurately and precisely

- practicality and feasibility of implementation in terms of both logistics and cost

- utilization of existing personnel, equipment, and resources

- ability to maintain a consistent long term data collection

MONITORING PROTOCOL

SAMPLING METHODS

Eight sampling techniques are used to gather information on glacier mass balance (see Appendix A), glacier morphology, and anomalous glacier behaviors. Information is gathered periodically at all times of year. See Table 1 for a listing of techniques and the type and frequency of data collected.

Satellite Image Remote Sensing

Purpose

Determination of spatial extent of glaciers in the park. Regional assessments of equilibrium line altitudes. Extrapolation of conditions from index sites and glaciers to larger regions. Monitoring of glacier surges. Delineation of glacier features.

Methods

Satellite data in the form of synthetic aperture radar images (SAR) are acquired from the Alaska SAR Facility (ASF) at the Geophysical Institute of the University of Alaska Fairbanks through a NASA approved account for Denali National Park and Preserve. These data come from any one of a number of SAR satellites now being operated by the European Space Agency, Canada, and Japan. Data from all of these satellites are received and processed for distribution at the ASF. Images for use in the study of Denali glaciers are acquired by the ASF on a regular basis although the interval can vary depending on the missions of the individual satellites. Image acquisition has been requested for key times of year at a minimum (early spring, mid-summer, late summer, mid-winter), and on a monthly basis whenever possible.

New images are ordered periodically from the ASF and are delivered on 8 mm magnetic tapes which are compatible with the UNIX workstation operated by Denali's Data Management branch of the Division of Research and Resource Preservation. Whenever images are ordered, a dry silver laser print of the image is also requested. The digital images on 8 mm tape are in a raster format which is compatible with the ARCINFO GIS software which is used for geographic data and image analysis in the Data Management Branch.

The image analysis methods used to study the SAR images fall into two major categories; feature delineation, and change detection. Feature delineation involves the identification and location of glacier features of interest in the imagery. Visual inspection of images allows feature identification, and feature location is accomplished using ARCINFO. Change detection refers to the long or short term monitoring of any feature that is changing or is expected to change. This is accomplished by successive relocation and analysis of features as they appear in sequential images.

Features that are of interest for both delineation and change detection include: terminus positions, ice marginal lakes, crevasse patterns, proglacial streams, ice surface bulges associated with surging, medial moraines, and snow/firn lines.

At the time of this writing, Denali's program of SAR image observation is in the earliest stages. This protocol will be updated with details pertaining to image acquisition and display, ARCINFO procedures for image analysis, and data management will be added after they have been developed and implemented.

TABLE 1 GLACIER MONITORING TECHNIQUES AND DATA COLLECTION FREQUENCY

GLACIER	SECTION	DATA TYPE	LAST SURV.	NEXT SURV
Cantwell	Terminous	Terminous position monitoring		
Cul-De-Sac	Terminous	Terminous position monitoring		
		Longitudinal elevations		
Kahiltna	ELA	Mass Balance Stake		
		Flow Rate		
		Emergence		
M.F. Toklat	Terminous	Terminous position monitoring	6/29/92	Sumer 1997
Muldrow	Lower	Terminous position monitoring		
		Longitudinal elevations		
		Ice Topo Features		
Muldrow	Pyramid	Longitudinal elevations		
		Topo Features		
		Target #3 Position (flow rate)		
		West Trimline		
Muldrow	Anderson	Longitudinal elevations		
		Target #2 Position (flow rate)		
Muldrow	Brooks	Longitudinal elevations		
		Target #4 Position (flow rate)		
		North Trimline		
Muldrow	Guns/McGon	Longitudinal elevations		
		Target #1 Position (flow rate)		
		North Trimline		
Polychrome	Entire			
Tatina	Terminous	Terminous position monitoring		
		Longitudinal elevations		
Tralika	ELA			
W.F. Toklat	Termious		7/24/92	

Aerial Reconnaissance and Photography

Purpose

Maintain a continuous long term aerial photographic record of every significant glacier in the park. Look for and identify anomalous glacier conditions (e.g. surges). Map the positions of late-summer season snow lines when possible. Maintain personnel familiarity with glacier conditions and extent. Collect aerial photography of glaciers where other research efforts are planned or are underway.

Materials

- 2 1:250,000 scale maps of Denali National Park and Preserve (large sheets from the USGS National Park Series).
- 2 Field notebooks with mechanical pencils
- 1 35 mm SLR camera, with a 30-100 mm zoom lens and skylight filter
- 20 Rolls of 35 mm color negative or slide film (slides preferred), 36 exposure, any major brand, 64-200 ISO (slower speeds for bright sun, higher speeds for overcast)
- 1 Hi8 video camera (or equivalent), with spare batteries and tapes

Personnel

2 One person serves as survey leader and 35 mm photographer. One person serves as videographer.

Methods

Once per year, two days of flight time in a Cessna 206 (or equivalent, preferably equipped with oxygen for high altitude flight) are scheduled with either an NPS plane and pilot, or else with an OAS certified air charter service. Ideally this should take place in the last week of August (which gives the best chance of observing late-summer season snow/fim lines in their most retreated position). In reality it will be necessary to wait for a window of clear weather and good visibility sometime near that period.

Plan to fly a route that is roughly equivalent to the one shown in Figure 2. In general, two clockwise loops should be flown around the mountainous region of Denali NP&P. The first is a large circle around the termini of Denali's largest glaciers, and around the Kichatna Mountains. The second loop should be flown midway up the length of the larger glaciers in order to cover areas not visible from the larger loop. Photography should be carried out from an altitude of at 20,000' (or lower in a non-oxygen equipped aircraft, preferably no less than 10,000').

The survey leader will operate the 35 mm camera, observe the glaciers which are visible, make note of anything interesting or unusual, and communicate with the pilot regarding course and aircraft orientation. The roll and frame numbers for each picture should be recorded in the notebook, along with a explanation of what glacier was photographed. GPS waypoints from previous flights should be used to navigate, or new waypoints should be set as the flight progresses. If new GPS waypoints are set, they should be recorded in the survey leader's notebook for future reference.

The videographer will shoot footage of glaciers whenever he or she feels it is appropriate, making sure to acquire wide angle scenes of every significant glacier that comes into view. The videographer will make note of the frame numbers which begin and end each major sequence of

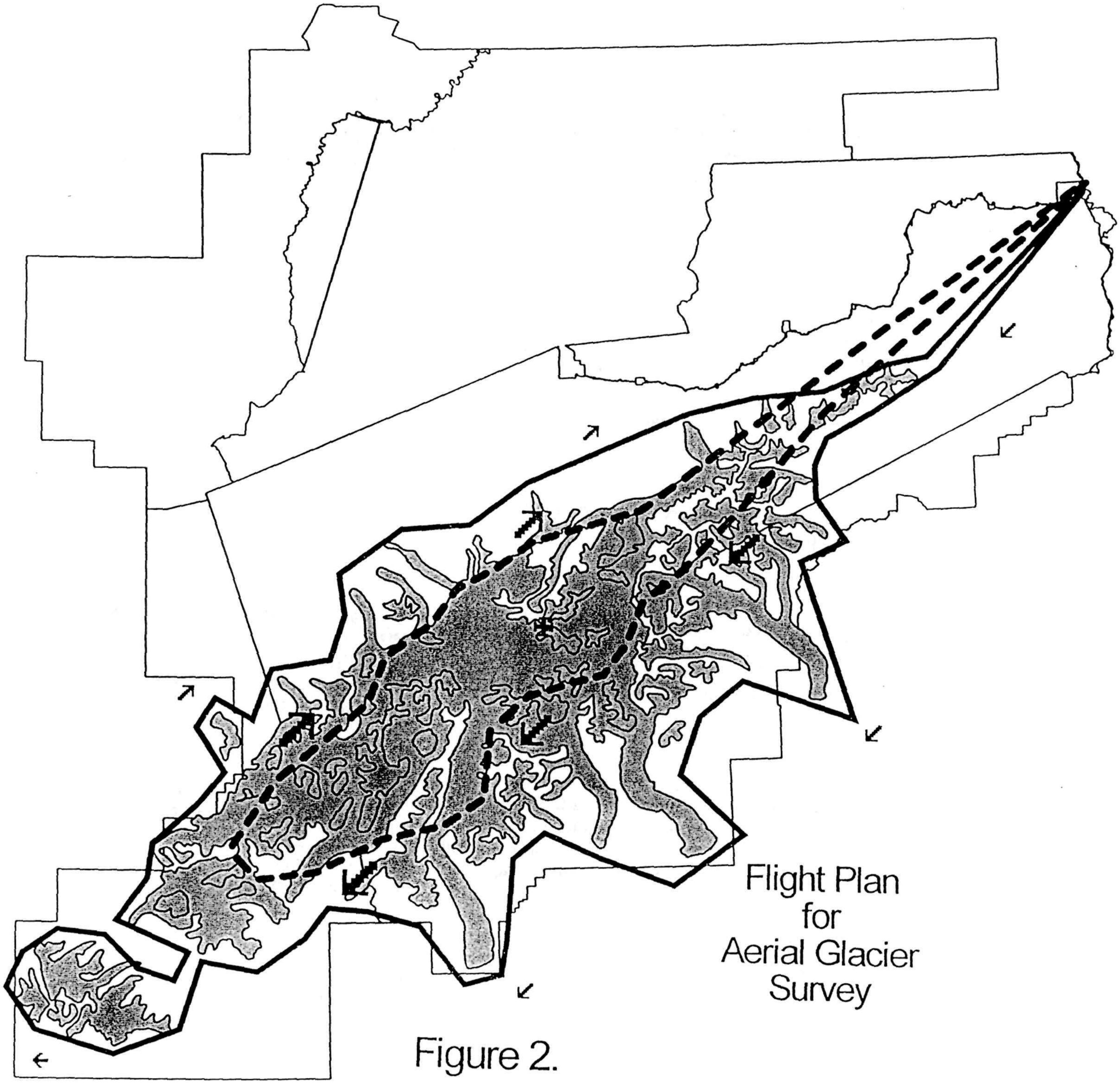


Figure 2.

video and will record that information in a notebook along with a record of which glaciers are seen and in what order.

Terrestrial Photographic Documentation

Purpose

To enhance documentation of glacier position or ice changes or to otherwise record existing glacier conditions on select glaciers from vantage points and survey monuments adjacent to those glaciers.

Materials

1 35mm or larger format camera & film

1 field notebook

1 compass or other angle measurement device

1 tape measure

Personnel

One person may take photographs. Photos are often obtained while other field data collection is ongoing, especially because existing photo-points are designated over existing survey monuments and benchmarks which are visited on an annual basis.

Methods

Photographs of glacier areas should be taken centered over control points or photo-point monuments. Notes should describe the size (focal length) of camera, the height of the camera from the monument, cardinal direction(s), elevation, date, time, type of film, no of shots, weather, field participants, and any other information that may enhance or clarify.

The information recorded for the photographs should then used in following years to duplicate the photos as accurately as possible. Only in this way is it possible to use the photographs to track changes in the glaciers being observed. Although there is no critical time interval between photographs, sites should be visited no more than once per year and no less than once in every five years.

Stake Net Surveys

Purpose

To collect data pertaining to annual ice gain or loss to determine long term changes in net mass balance. To determine surface flow rates and directions for characterization of glacier flow conditions. To determine, and detect changes in, ice surface elevations.

Materials

1 Complete set of conventional survey equipment (see section on "Topographical Surveys")

1 Steam driven ice drill

Multiple survey stakes (3/4" aluminum piping in sections of varying length, fitted together with steel couplings)

Snow and glacier travel and camping equipment as needed for all personnel

1 Snow shovel

1 Snow depth probe

1 Ice Ax

1 Snow sampling kit

1 Metric tape measure

Field notebooks for survey data and snow sample data

Methods

Measurements of accumulation, ablation, surface elevation, and flow will be made at individual stakes in the stake networks. Index glaciers, or glaciers on which field study will be conducted, have not been selected as of this writing. Once index glaciers have been chosen and stake networks are installed, procedures for making these measurements will be adapted primarily from the manual by G. Østrem and M. Brugman (1991) entitled "Glacier Mass-Balance Measurements: A Manual for Field and Office Work". This manual is on file in Denali's Research and Resource Preservation Division and the reader of this protocol is referred to it. After implementation of a program glacier mass balance measurements on index glaciers, this protocol will be updated to detail the techniques from Østrem and Brugman as employed at Denali.

Stream Gauging

Purpose

To perform both short and long term checks on glacier ablation measurements. To monitor the amount of erosion at the glacier bed. To support concurrent hydrologic studies and runoff modeling which may take place in the same drainage basin.

Materials

Automatic data loggers, weather proof housings, solar panels and batteries, data storage modules, satellite telemetry transmitters

Acoustical depth sounders

Air temperature and relative humidity sensors

Automatic water sampling device

Methods

Following the selection of index glaciers for field monitoring, it will be desirable to obtain data on both the discharge of glacial water and the amount of sediment transported in that water. Monitoring the amount of runoff from the glacier basin will allow a measure of ablation if the amount of precipitation is also know (see section on Automated Weather Monitoring). The hydrologic mass balance method provides a useful check on direct measurement using stake networks. Runoff data may also be useful for other researchers conducting studies in or neat the index glacier basin. Measurements of sediment load will provide data on the rate of erosion at the glacier bed and will also benefit researchers investigating water quality.

The most effective way to collect these data on a long term basis will be with the use of acoustical depth sounders with automatic data loggers, and with automatic water samplers. This will allow continual data collection during the summer season at each index site. Prior to the selection of index glaciers and the total development and implementation of a program of hydrological measurements, the reader of the protocol is referred to relevant sections of Østrem and Brugman (1991), "Glacier Mass-Balance Measurements: A Manual for Field and Office Work", for a general summary of the principles and techniques involved. Once a program of measurements has been implemented this protocol will be updated to reflect the methods that are employed.

Automated Weather Monitoring

Purpose

To collect data on meteorological conditions in support of, and for correlation with, other glacier data collections and ecological monitoring efforts.

Materials

Automatic data loggers

Solar panels and batteries

Rugged, transportable, towers which can be solidly anchored in ice or rock

Various sensors for meteorological monitoring including air temperate, relative humidity, precipitation, snow depth, solar radiation, wind speed and direction, and barometric pressure

Data storage modules and satellite telemetry transmitters

Methods

Following the selection of index glaciers for field monitoring, weather data will be collected in at least one representative location within the glacier basin. These data will be used in combination with meltwater runoff measurements to calculate the percentage of ice melt in the total water volume of water discharged from the basin. Weather data will also be used for correlation with observed trends in glacier mass balance.

Procedures for the operation and maintenance of automated weather stations are discussed in the Weather Monitoring Protocol for the Long Term Ecological Monitoring program of Denali National Park and Preserve. The reader of this protocol is referred to that document for information pertaining to the methods necessary for the administration of a network of weather stations. After selection of index glaciers and the implementation of a glacier monitoring program at those sites, this protocol will be updated to include the details of operating and maintaining the automated weather stations.

Topographic Surveys

Purpose

To determine changes in glacier morphology and to locate land form/glacier feature relationships on or near selected glaciers.

Materials

If Conventional Survey: Total Station theodolite, transet and/or level.

If GPS Survey: 2 (or more) GPS Units (prefer survey grade).

All Accessories: (legs, batteries, prisms, range poles, tape measures, thermometers, altimeter/barometer, compass & plastic bags).

Table 2 Glacier Control Points (2 pages).

Maps 1-6 (location maps for specific glaciers)

Other Equipment Necessary: (radios, maps/photos, notebooks, monuments (rebar), stakes, lath, flagging, camera & film, & binoculars).

Personnel

Conventional Survey: 1 instrument operator and 2 (or more) prism holders.

GPS Survey: 1 operator (assuming one base station set-up and single roving unit) or 1 operator per roving unit. (Note: two or more survey grade GPS units are required for precision differential GPS data).

Methods

CONVENTIONAL SURVEY: Locate (or relocate) instrument monument at a specific region of glacier survey (see Table 2 Glacier Survey Control Points), backsite to appropriate monument (see Table 2 or establish appropriate backsite), and turn to intended foresites (longitudinal profiles, cross-sections, specific geomorphologic features, surface targets, and/or terminus positions). All data is recorded in ordinary survey notebooks (ie "Write in the Rain"), an example of which can be found in Figure 3. At instrument set-up, the recorded data includes:
*survey section name, date, start time, personnel, *temperature, *pressure, *height of instrument, *height of prism, **instrument or backsite coordinates*, and casual observations of the *weather*.
(* items commonly entered into total station. ** items optionally entered into total station)

Recorded data during the survey (foresites) includes:

Station name, horizontal angle, vertical angle, slope distance, horizontal distance, vertical distance, northing, easting, elevation, and any special *notations*.
The station name or notations should have reference to "type" of station (i.e. longitudinal profile, cross-section, land form feature, surface flow target, terminus position, or other) and a position descriptor when necessary (i.e. lower trim line, westerly medial moraine etc.). Note the "*end of survey*" and *time* when all shots are completed at the close of each set-up.

TABLE 2 GLACIER SURVEY CONTROL POINTS

GLACIER	MONUMENT (function)	GPS COORDINATES LAT.	GPS COORDINATES LONG.	GPS COORDINATES ELEV	SURVEY/PLOT COORDINATES LAT.	SURVEY/PLOT COORDINATES LONG.	ELEV (m)	ELEV (ft)
Cantwell	Cant #1 (inst)							
	Cant #2 (bs)							
Cul-De-Sac								
Kahiltna	Hunt							
	Fork							
	Acre							
M. F. Toklat	MFT.1 (inst)							
	MFT.2 (bs)							
Muldrow (Lower)	Ben VABM (bs)			3086.9'	3,440,925.503	433,052.177	940.900	3,086.905
	Carl VABM (inst & bs)				3,430,566.276	438,669.184	1,128.300	3,701.730
	Up VABM (bs)	*63 23 46	150 34 62	2472.7'	3,432,294.939	405,771.918	753.700	2,472.700
	Up View (ins & bs)	*63 23 03	150 31 64					
	L. Muldrow (inst & bs)	**63 22 57.17	150 29 37.83					
	L. Cone (inst & bs)	*63 22 07	150 20 30					
Muldrow (Pyramid)	Pyramid (inst)	*63 19 78	150 26 41	3925.6'	3,409,654.400	427,816.970	1,195.540	3,925.600
	Granite (bs)	*63 18 65	150 24 60	3829.1'	3,402,796.500	433,065.750	1,167.120	3,829.100
	Grassy (inst or bs)	*63 20 80	150 21 70	4338.9'	3,415,658.810	440,905.820	1,322.510	4,338.900
	Target #3 (7-22-96)	**63 20 11.05	150 23 55.95	3493				
Muldrow (Anderson)	Bench Old (bs)	**63 15 55.09	150 21 36.08	5017.0'	3,385,727.577	440,756.221	1,529.200	5,017.000
	Bench New (inst)	**63 15 55.09	150 21 36.08					
	Opp Bench (bs)							
	Anderson (bs)	*63 17 48	150 18 35	4624.6'	3,395,673.740	450,056.630	1,409.600	4,624.600
	Dome (inst)	*63 18 62	150 19 14	4382.0'	3,402,403.660	447,839.680	1,305.470	4,283.000
	L. Small Corner (bs)	*63 18 04	150 22 95	4144.0'				
	Target #2							
Muldrow (Brooks)	Oastler (inst)	**63 14 30.07	150 40 21.88	5730.6'	3,377,611.909	389,058.762	1,746.700	5,730.600
	Brooks (bs)							
	Opp Oastler	**63 14 53.64	150 37 20.61	5435	[3,379,914.05]	[397,399.13]	1,653.380	5,424.400
	Brooks EE (inst or bs)	**63 13 05.50	150 34 14.69	5386.7'	3,368,847.260	405,796.840	1,608.300	5,276.500
	Bend (bs)	**63 15 4.02	150 32 49.28	5095	[3,380,343.48]	[409,145.49]	1,516.980	4,976.900
	Target #4							
Muldrow (Guns/McG)	McGonagall (inst & bs)	**63 13 59.85	150 43 20.44	5967.8'	3,374,636.155	380,892.334	1,819.000	5,967.800
	Tatum B (inst & bs)	**63 12 34.60	150 46 07.61	6338.9'	3,366,043.050	373,095.780	1,932.120	6,338.900

	Gunsight Shelf (bs)	**63 12 39.81	150 50 35.95	3,366,737.890	360,801.950	2,127.860	6,981.100
	Target #1 (8/6/95)	*63 13 04	150 46 62				
	Tatum A (bs)			3,367,194.960	379,299.640	1,847.170	6,060.200
	Gunsight Peak (bs)			3,368,621.335	362,268.070	2,273.400	7,458.600
Polychrome							
Tatina							
Tralieka	Brown						
	Stuck						
	Spot						
W.F. Toklat							

* helicopter GPS coordinates
** PLGR GPS coordinates

Figure 3.

TAR. HT.=6.0, 38°F   3840 FT., 4.8 FT = HI.

MULDROW SURVEY - PYRAMID SECT. 8-5-95, 9:30 AM PHIL BREASE, JOHN SALES, 885 ME

⊼ PYRAMID

STA	HA	VA	SD	HD	VD	N	E	ELEV	Comments
BS @ GRAN	00 00 25	90 38 59	8638.46	8637.94	-96.42	8637.94	1.05	-92.42	SH=.8FT.
IND	180 01 10	269 20 26	8638.41	8637.83	-97.37				PYR 3925.6
DIR	00 00 30	90 38 48	8638.40	8637.89	-95.76	8637.89	1.26	-91.97	GRN - 3829.1
IND	180 01 10	269 20 27	8638.41	8637.88	-97.85				96.5
DIR	00 02 6	90 38 56	8638.41	8637.89	-96.30	8637.89	1.09	-92.30 → 92.23	[illegible]
				8637.90	[illegible]				= 4.[illegible]
PYRAM DIR	289 03 54	93 35 44	6976.25	6962.61	-436.51	2274.27	-6580.71	-438.20	SH=6.0 (6.5)
IND	269 03 43	95 35 25	6976.15	6962.59	-435.86	2273.91	-6580.89	-437.56	
PT 1	245 22 23	93 56 53	6353.62	6338.66	-436.64	2716.18	-5727.22	-438.34	moraine w glacier (crest)
PT 2	302 49 19	93 55 44	6275.00	6258.38	-429.01	3392.23	-5259.28	-430.21	" "
PT 3	311 32 44	93 13 18	7127.92	7116.78	-399.54	4719.96	-5326.40	-401.24	" "
PT 4	316 17 23	92 55 59	7861.63	7851.51	-400.25	5675.41	-5425.49	-401.94	BASIN ON moraine
PT 5	319 05 12	92 25 34	8674.05	8666.63	-360.60	4550.21	-5674.97	-362.30	" "
PT 6	321 47 04	91 41 03	9620.83	9616.12	-303.24	7555.28	-5948.74	-304.94	" "
PT 7	277 52 53	93 51 08	6540.17	6525.52	-438.52	894.80	-6463.88	-440.22	1ST DOWN GLACIER mound
PT 8	265 26 29	93 15 50	7713.78	7701.42	-437.97	-612.10	-7677.06	-439.66	" " " ~~mound~~
PT 9	258 27 48	92 35 06	8959.29	8950.33	-402.43	-1790.02	-8769.51	-404.13	" " " MUCH LOCAL RELIEF
PT 10	252 28 40	93 12 02	10667.27	10650.92	-593.24	-3206.73	-10156.72	-594.94	" " "
PT 11	251 58 53	92 45 58	11893.77	11880.21	-571.08	-3674.86	-11297.56	-572.78	" " "
BS TO GRAN	0 00 11	90 38 58	8638.40	8637.88	-96.38	8637.88	0.46	-92.38	SH=.8FT

For all conventional survey data, the precision requirements are as follows:

Angular Precision: $\pm$ 0°00'30"
Linear Precision: $\pm$ 0.5' in 4000'

GPS SURVEY (survey grade differential GPS): Setup one unit at an appropriate base station (see Table 2 Glacier Survey Control Points), and additional units are then located at foresites or monuments as necessary. Precision is greatly increased by using two base stations at known control points. Data collection should run a minimum of 1 hour at control points (assuming 1 second or more frequent logging), and instantaneous collections at foresites. Procedures and note keeping will be customized to the brand & model of GPS used and the type of survey performed. Most data logging GPS units require the user to input a file name and slant height, as well as offering a selection of data logging parameters.

If using a hand held GPS unit (non data logging), position note keeping should include time, temperature, and elevation (from station altimeter other than GPS), and other station details, as suggested for conventional surveys. Initial and final readings should be taken at one or more control points during the survey session. Typical notes are shown in Figure 4.

Time Required

Conventional surveys of the Muldrow Glacier require 3 to 4 days time (one day each section) with dedicated helicopter transportation. Conventional terminus surveys take one day each for each glacier. The time required for GPS surveys will vary depending upon the size of the glacier selected for survey, and the extent of the points surveyed.

Survey Tasks

(see table 1) for survey type and frequency.

DATA MANAGEMENT

Satellite Imagery and Derived Products

Satellite SAR images are delivered from the Alaska SAR Facility on high capacity 8 mm magnetic tapes. Because the original full resolution images have a file size of approximately 64 Megabytes, it is not possible to keep all images "on line" on a hard drive attached to the GIS computer system. Therefore, original images delievered from ASF are archived on the 8 mm tapes and those tapes should be stored in a fireproof cabinet. Tapes should be labeled with information pertaining to the image ID number (which is determined by ASF), the date of the image acquisition, the area covered by the image, and any other relevant details (such as features of particular interest within the image).

As soon as an ordered imaged is received from ASF, it should be copied onto a mass storage peripheral (large hard disk) that is dedicated to processing and storage of SAR image data. The image should then be displayed to check it quality and to ensure that it was properly processed before delivery. The image should then be deleted from mass storage (unless analysis is begun immediately) and the tape should be archived.

Figure 4.

E-1. GPS NOTES AND GPS SURVEY PROCEDURES - ELEVATION SURVEYS

Equipment Needs:

2 - GPS receivers (one left at Muldrow VABM as base station)
1 - Station altimeter (helicopter or other altimeter can subst.)
1 - Thermometer
1 - Watch (must be single timekeeper)
? - Number of maps required to accurately identify station locations.

FIELD NOTES

GPS Survey - Muldrow Glacier 6/14/91
K. Echelmeyer P. Brease - Helicopter hops.

STA	PLACE	TIME	TEMP	ALT.ELEV	GPS ELEV
	Muldrow VABM	9:34AM	55F	1520m	
1.	Mound (off glacier)	9:47	53	1011	776.079
2.	Mt. Eielson	9:55	54	1215	985.962
3.	Mid-ice (GPS in chopper)	10:00	57	1266	1056.01
4.	Muddy (near bend)	10:04	58	1393	1189.431
5.	Brooks (mostly 2d)	10:07	59	1562	1339.852
6.	Butress 63.14.53.8 150.30.21.4	10:11	60	1686	1454.026
7.	Brooks Glacier	10:16	61	1796	1566.905
8.	Tri corner	10:20	62	1866	1635.8
9.	Tri gate (2d fix)	10:25	64	1933	1702.4
10.	1st. Bend	10:32	64	2070	1838.916
11.	Tri-fork	10:37	65	2278	1988.542
12.	Avalanche (2d fix)	10:43	67	2386	2153.3
13.	Avalanche block (no position)	10:48	67	2580	2347.3
Close	Muldrow VABM	11:12	65	1524	

Image analysis which takes place on the GIS workstation should be conducted in file space and directories on the mass storage peripheral. This is the appropriate location for temporary data and files that are created during image processing and analysis and this should be treated as a "working directory." Furthermore, on the same mass storage peripheral, any and all derived products should be archived in an orderly fashion. Written notes should be kept which explain the directory structure and contents of the information archived in mass storage. The entire contents of the mass storage peripheral should be backed up on 8 mm tape on a weekly basis and that tape should be archived in a fire proof cabinet.

Images deleivered in digital form from ASF are accompanied by a laser print version of the same scene. These prints are used to aid in the organization and search capabilities of the SAR image archive. The prints should be filed in a central location, preferrably in a fire proof cabinet. The prints are used to identifiy which SAR images are of interest for a particular task and, therefore, are used as a reference for the images archived on 8 mm tape. It should be possible to identify the SAR scene of interest and go directly to the tape on which the digital version is stored.

Data derived from the SAR imagery (such as pixel brightness values or geographic feature coordinates) shoud entered into spreadsheets in Microsoft EXCEL. Any statistical analyses should then be carried out in EXCEL and the final versions of these files should be stored in a directory under D:\I&M_DATA\GLACIERS\EXCEL on the Inventory and Monitoring program computer in the Research and Resource Preservation Division. The files in this computer are backed up to tape on a regular basis and those tapes are stored in a fire proof cabinet.

Photography

Photography of any type, collected both by aerial reconnaissance and during field study on the ground, must be archived in an orderly fashion and stored in a central location in a fire proof cabinet. Photographs, whether slides,prints, or color negatives, should be labeled in such a way that anyone may easily retreive photos of a specific glacier, taken at a specific time. As successive years of photography are accumulated, the archive should be structured so that photographs of individual glaciers are stored together in date order. An inventory of photography should be created which assigns a specific number to each glacier photographed and an additional set of numbers showing the year and Julian day of the image. A listing of the photographs should be updated yearly to reflect the contents of the archive and this information should be stored in the Microsoft Access database program. A printed copy of the inventory should be filed with the photographs for easy referrence. Field notes taken at the time of the photography, which are used to provide information for the inventory, should be archived near the photos in a fire proof cabinet.

Stake Net Survey Data

Data from glacier field work will exist primarily in the form of hand written notes taken at the time of observation on the glacier. Anticipated types of data include: geopgraphic coordinate data for survey stakes acquired with the use of conventional survey equipment, geographic coordinates for survey stakes acquired with GPS receivers, snow depth and density measurements, and ice surface heights relative to increments on the survey stakes.

This information must be transcribed from the field notes immediately upon completion of the field work. Numerical data should be entered in the Microsoft EXCEL and all files should be stored under D:\I&M_DATA\GLACIERS\EXCEL, on the Inventory and Monitoring computer, under directories and with file names that indicate in logical fashion what data they contain from specific field sites and on what dates those data were collected. The contents of the computers hard disk are backed up on a regular basis and the back up tapes are stored in a central fire proof cabinet.

Hydrologic and Meteorologic Data

Data for both stream discharge studies and weather monitoring will come from automatic data loggers either via satellite telemetry or from retrievable data storage modules. These data will be in a comma delineated ascii format that can easily be viewed in Microsoft Access or EXCEL. Upon reception of data by telemetry, or retrieval of the storage modules, data files should be given a unique identifiying name which indicates the station of origin, and the year and Julian date on which the record began. These files are to be stored in directories for each station under D:\I&M_DATA\GLACIER\EXCEL and \ACCESS for later processing. Preliminary data checking for outliers, missing, and or bad data should be conducted at the time of data download to the I&M computer.

Statistical analysis should be carried out in either Access or EXCEL and any data summaries or files which are generated fron the analysis should be stored in the same location as the raw data files in a lower directory.

A detailed referrence for weather data management procedures is the Weather Monitoring Protocol of the Long Term Ecological Monitoring program of Denali National Park and Preserve.

Topographic Survey Data

Raw topographic data in the form of field notes or data sheets are photo copied and stored in the I&M fireproof files. Raw data is also transcribed into EXCEL spreadsheets for purposes of storage, precision and quality control and analysis. Accepted values and confidence intervals are determined for each measurement parameter. The file names and storage locations of the transcribed data is as follows:

C:\DATA\SPREAD\MULDROW SURVEY RECORD
....\M.F. TOKLAT SURVEY RECORD
....\W.F.TOKLAT SURVEY RECORD
....\CANTWELL SURVEY RECORD
....\CUL-DE-SAC & TATINA SURVEY RECORD

These files are stored on both the user and I&M computers.

Spatial or graphic topographic data are entered, analyzed and stored in AUTOCAD files. These files are established with state plane or other "best available" control when at all possible. The file names and storage locations of the Autocad files are as follows:

C:\ACAD\ADRAW\GLACIERS\CANTWELL.DWG
........\MFT.DWG
........\WFT.DWG
........\CANTWELL.DWG
........\MULDROW4.DWG
........\CUL-TATINA.DWG

LITERATURE CITED

Østrem, G., and M. Brugman, 1991, *Glacier Mass-Balance Measurements: A Manual for Field and Office Work,"* NHRI Science Report No. 4, Minister of Supply and Services Canada, Saskatoon.

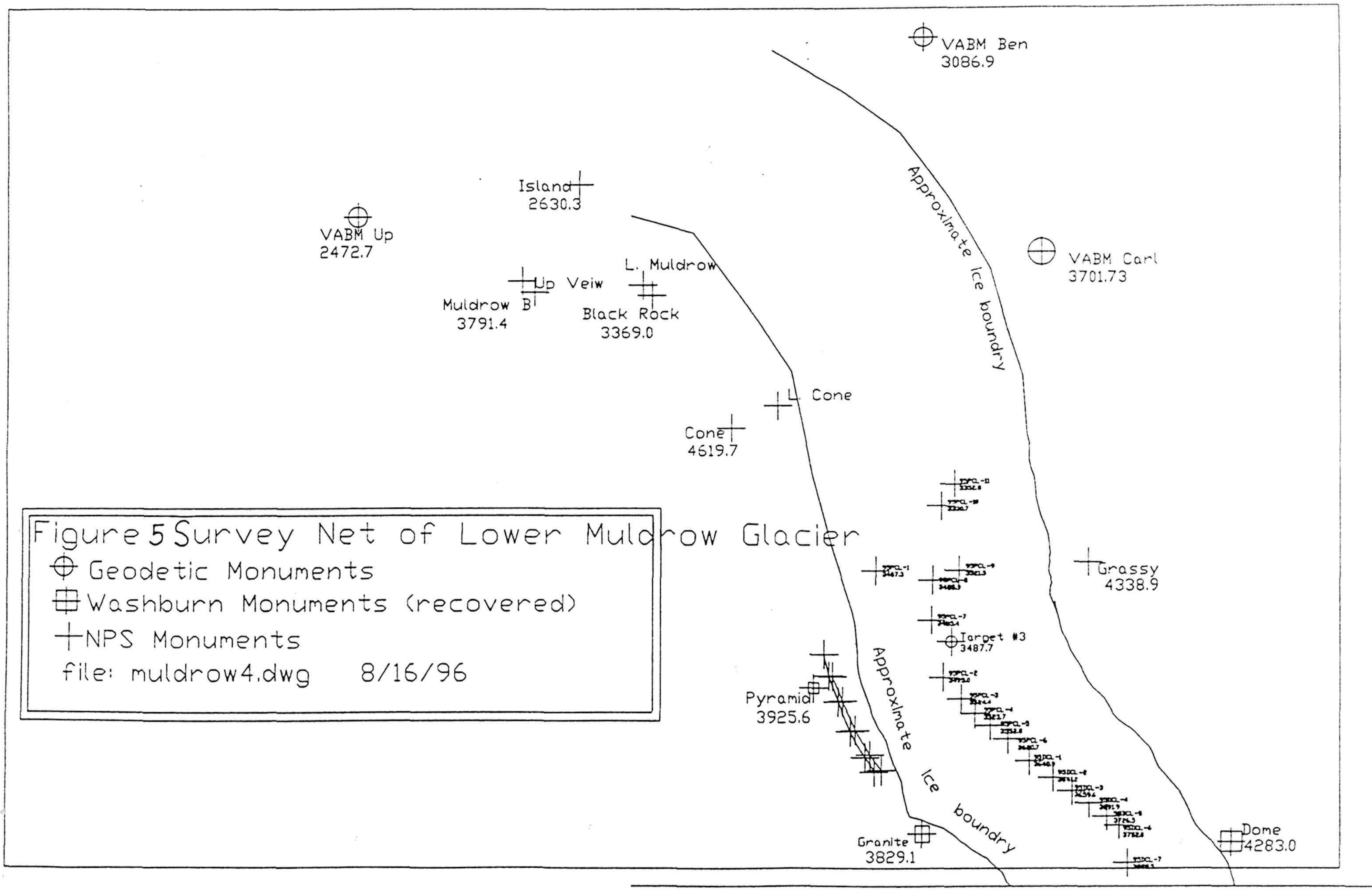


Figure 5 Survey Net of Lower Muldrow Glacier

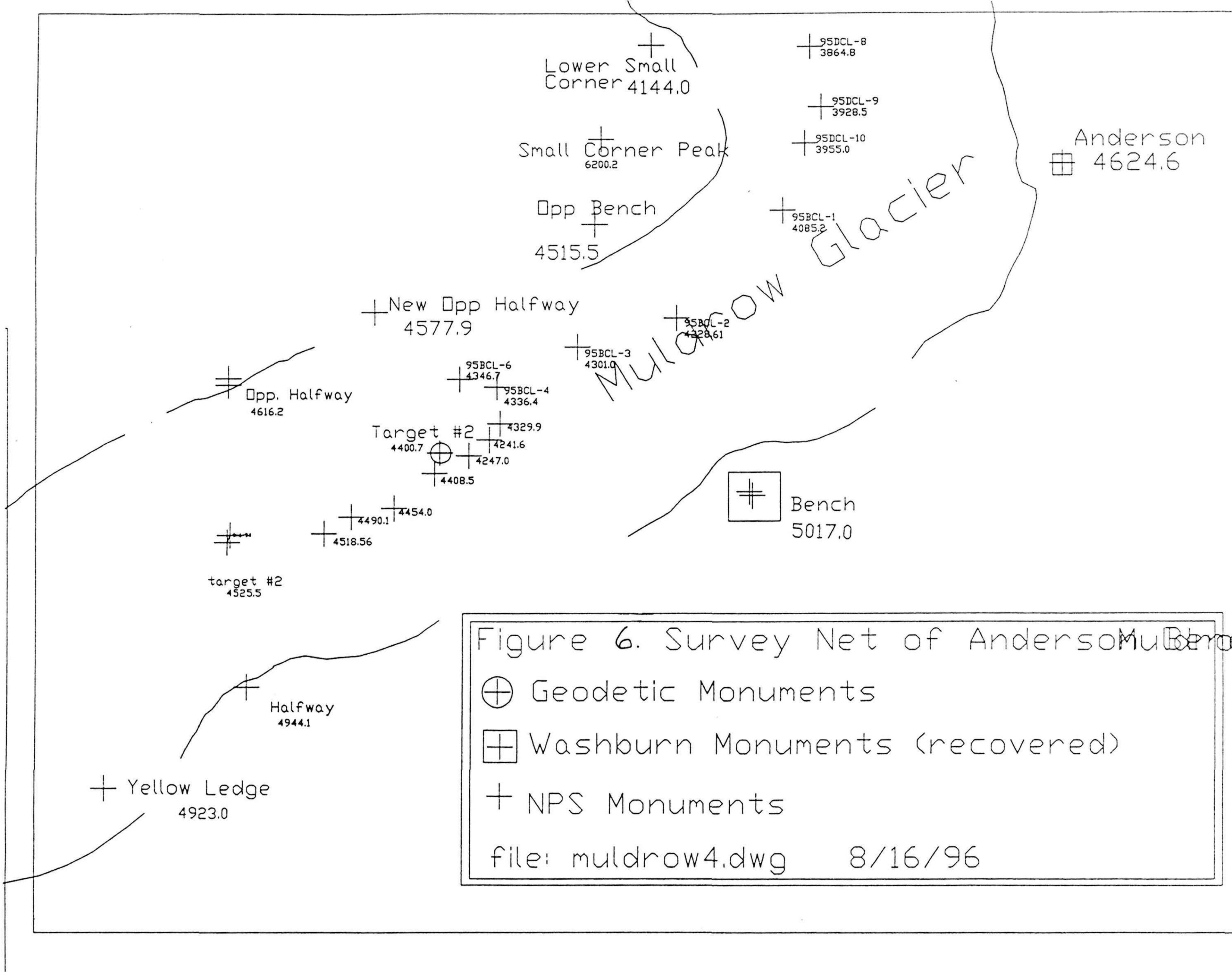


Figure 6. Survey Net of Anderson Muldrow, (

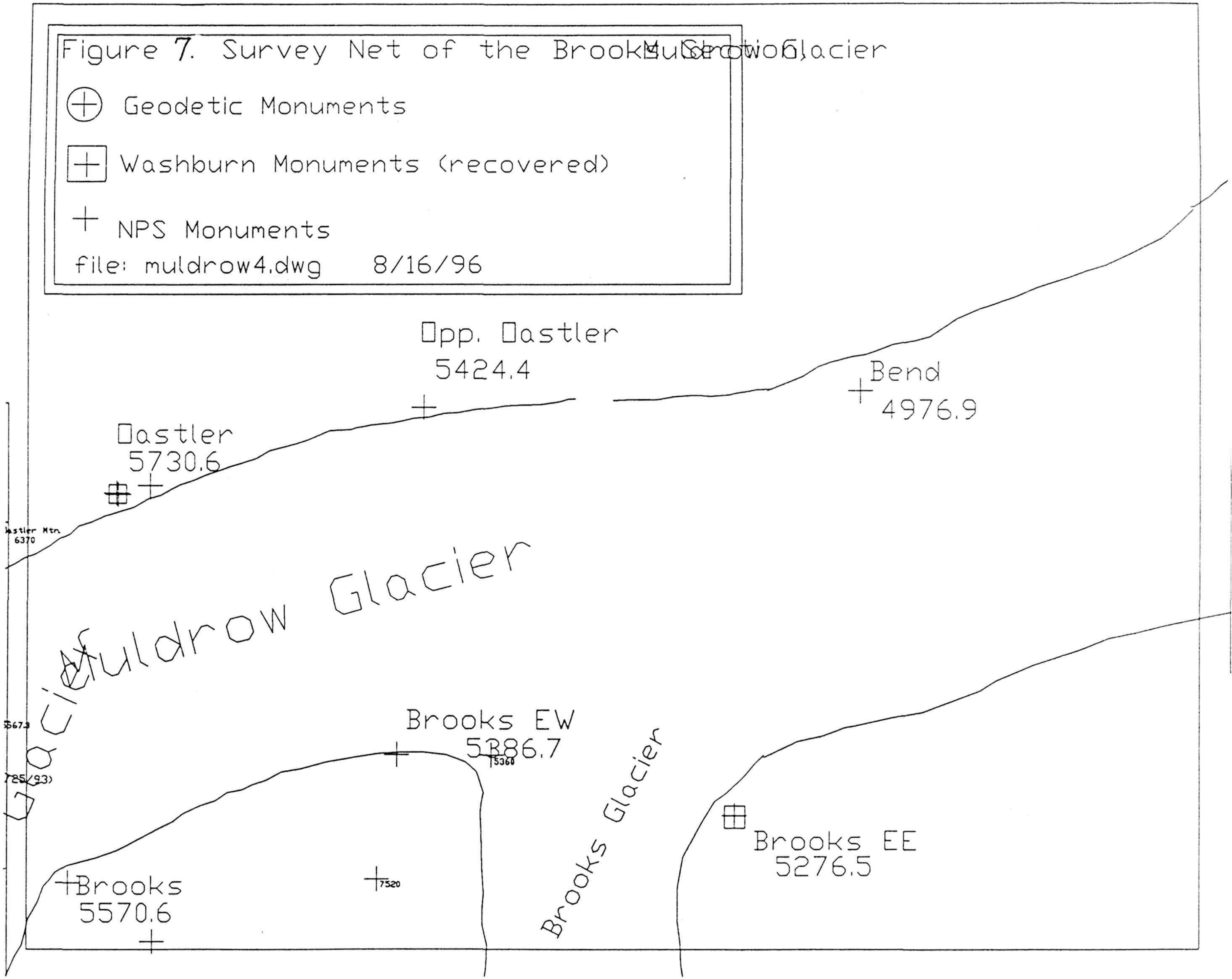


Figure 7. Survey Net of the Brooks Section, Muldrow Glacier

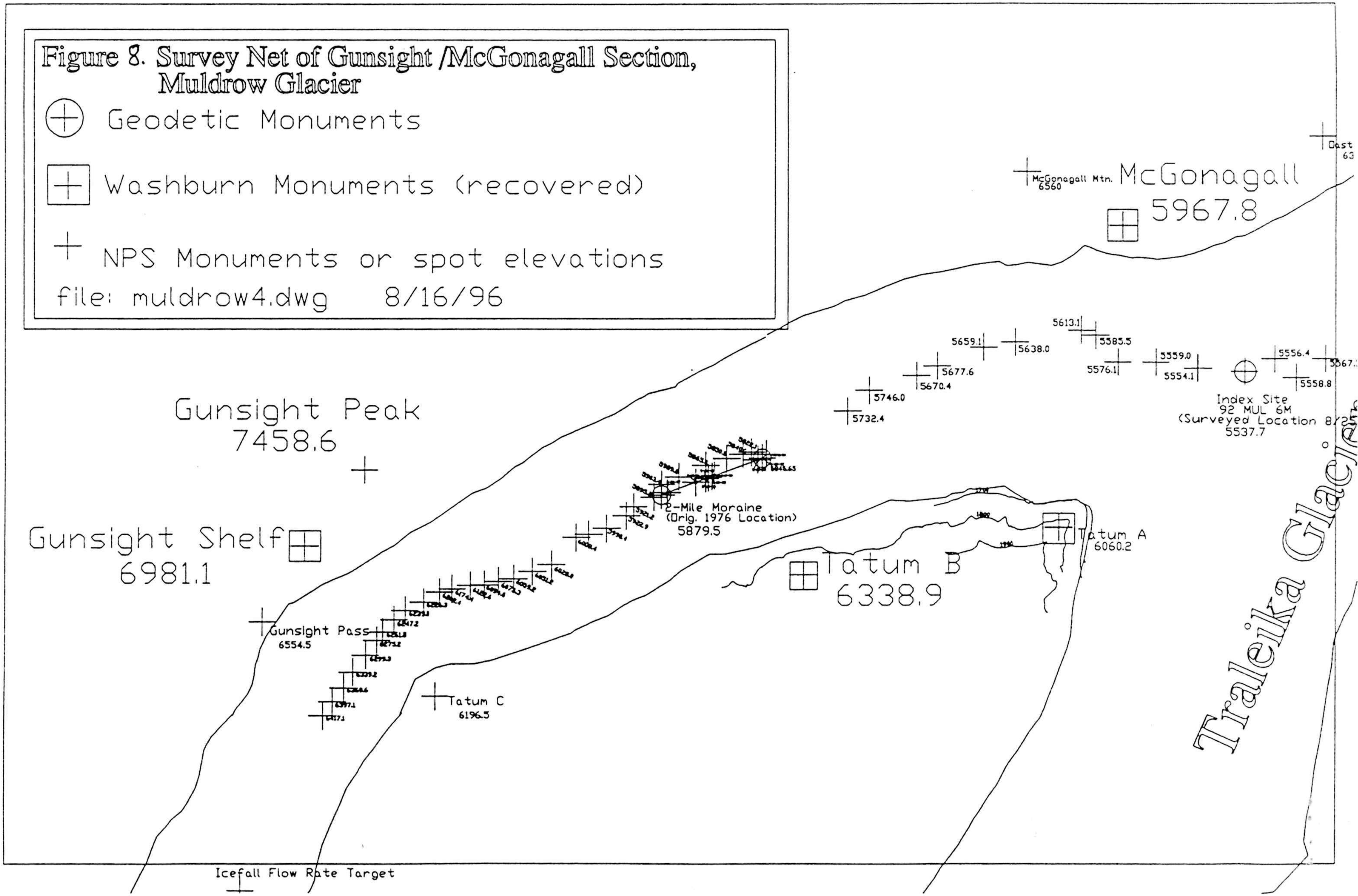
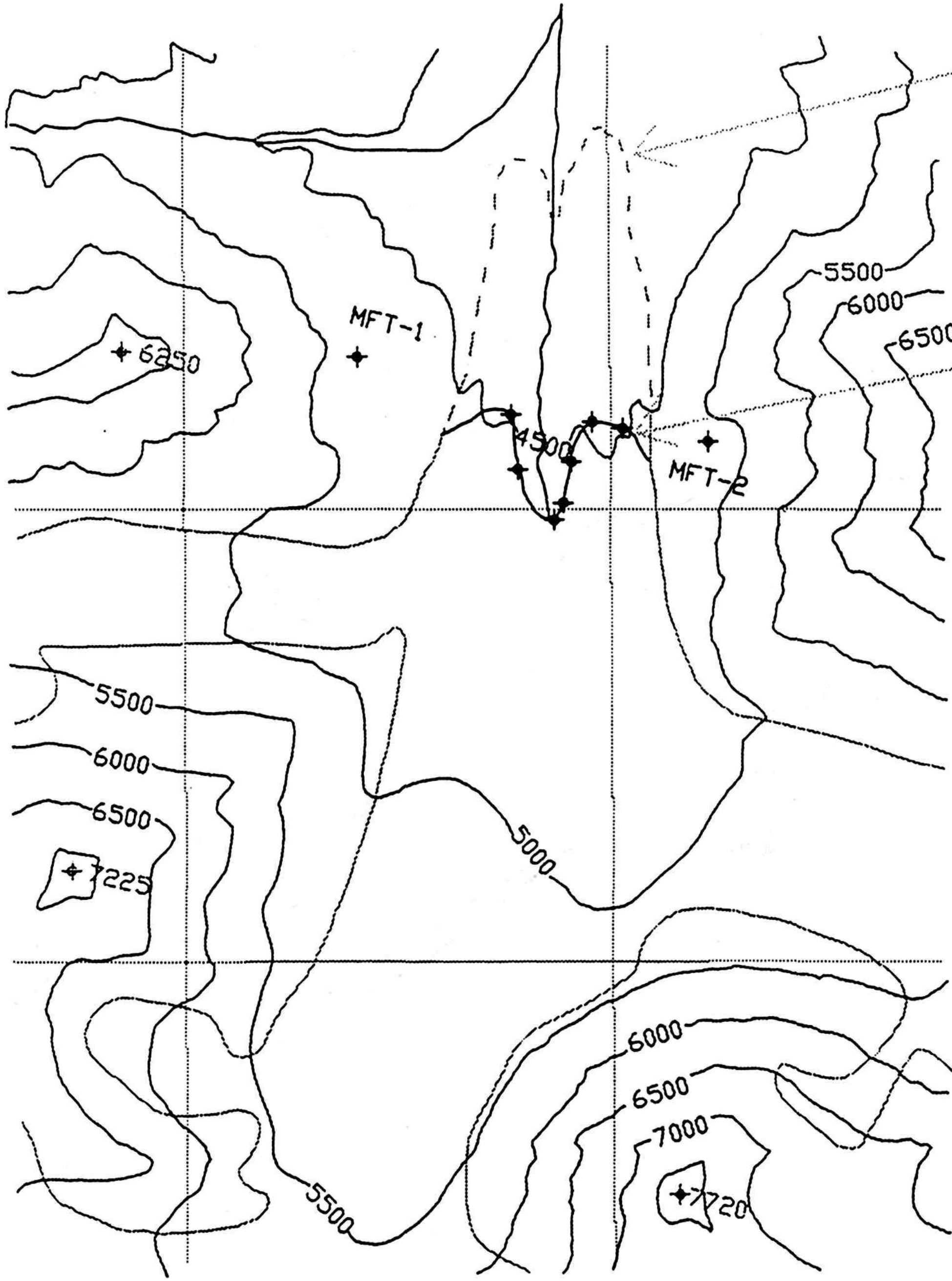


Figure 8. Survey Net of Gunsight /McGonagall Section, Muldrow Glacier



Terminus Location
USGS Healy B-6 1954 w/minor rev. 1981

Terminus Location
As of 6/29/92 survey

MFT-1 INSTRUMENT STATION

A .5" diam. 24" long steel rebar placed 20" into angular gravel & bedrock w/4" protruding. At 4890' elevation.

A 3' high rock carin was built with rebar and affixed aluminum tag located at base on west (uphill) side.

To Peak 7400' – Horz 349° 16' 00" Vert 71° 58' 56"
To Peak 7720' – Horz 56° 57' 02" Vert 74° 18' 15"
To Peak 6260' – Horz 173° 29' 13" Vert 63° 38' 15"
To MFT-2 – Horz 0° 0' 00" Vert 97° 11' 06" 3377.6'SD

MFT-2 BACKSIGHT

A .75" diam. 24" long steel rebar on a ledge below bedrock in steep, unstable alluvial material in avalanche chute. At 4470' elevation. Rebar & tag are under 2' rock carin.

MIDDLE FORK TOKLAT

GLACIER TERMINUS MONITORING

Surveyed – June 29, 1992	Plotted – Jan. 24, 1994
P. Brease, G. Probst, J. Ross	File Name:
A. Lowery, G. Henry, L. Alsted	C:\ACAD\ADRAW\MFT

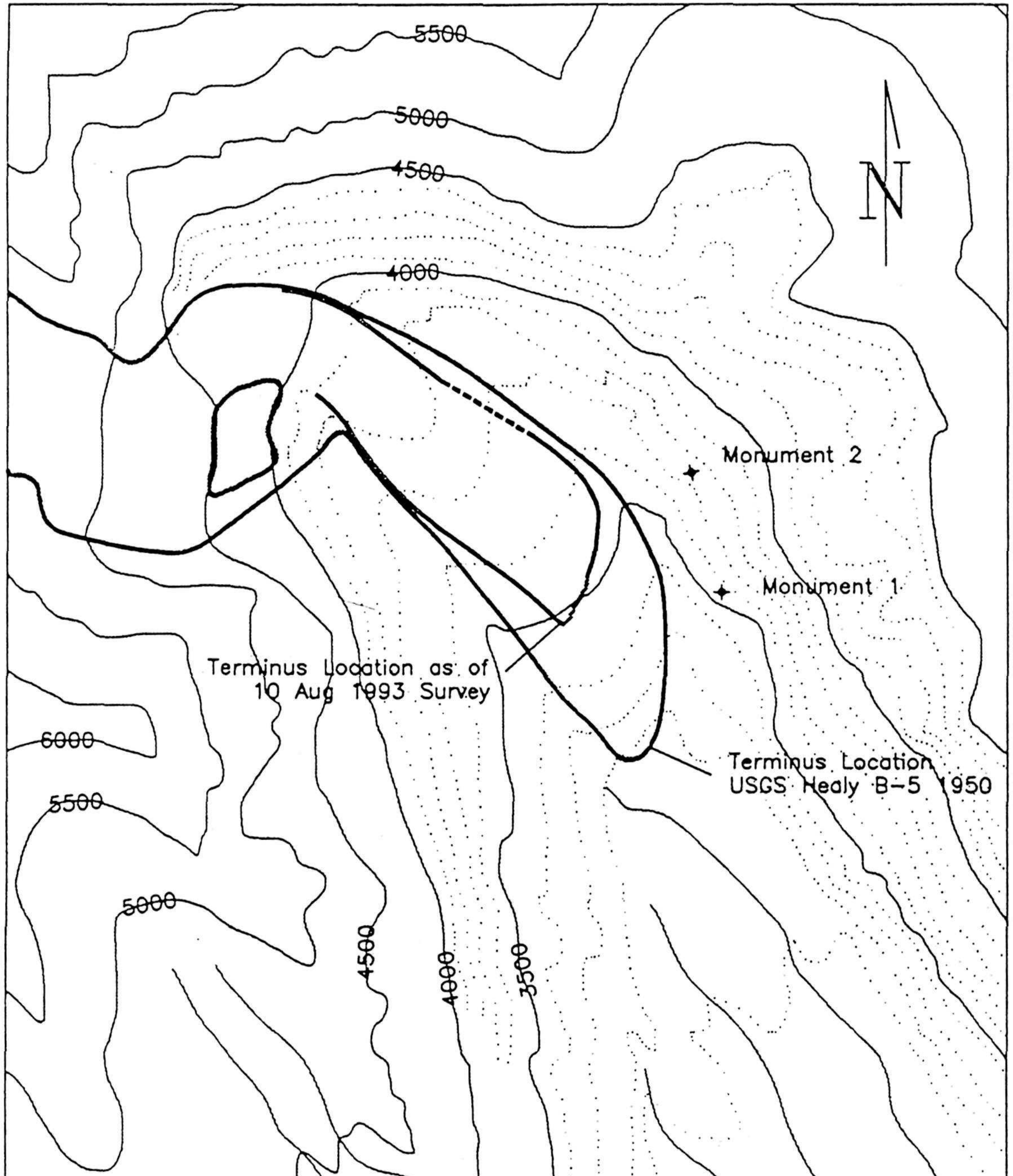
500 1000 2000 3000

Scale in Miles

500 Foot Contour Interval

Base map data – USGS 1:63,360 Healy B-6

N



CANTWELL GLACIER TERMINUS MONITORING

Surveyed and monumented 10 August 1993
G. Probst, P. Atkinson, R. Pilkington

Re-monumented 30 July 1994
P. Atkinson, M. Perdue

Plotted 24 February 1995
File Name: C:\ACAD\ADRAW\GLACIERS\CANTWELL

0 feet 5000

0 meters 1500

Contour interval 500 feet
Base map data – USGS 1:63,360 Healy B-5 1950
(photography 1949)

Monument 1 (Instrument Station)
Located on a limestone bedrock outcrop which extends 150–200 feet above the monument. A rushing creek springing from talus lies adjacent to the north. Monument is marked with a rock cairn next to a piece of steel rebar (0.5 inch diameter by 24 inches long) pounded approximately 20 inches into the ground.

Monument 2 (Backsight)
Located at the bottom edge of a relatively flat, grass-covered slope and above a huge, very obvious boulder. Monument is marked with a rock cairn next to a piece of steel rebar (0.5 inch diameter by 24 inches long) pounded approximately 20 inches into the ground.