Glacier and Gallop Creeks Alluvial Fan Analysis

Alluvial Fan Component of the
Lower Nooksack River
Comprehensive Flood Hazard Management Plan

Prepared for:

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FOREWORD

The Glacier and Gallop Creeks Alluvial Fan Hazard Analysis was produced as part of the Lower Nooksack River Comprehensive Flood Hazard Management Plan authorized under Work Order No. 3, Task III.4. This work was conducted under the direction of the Whatcom County Engineering Services, River and Flood Control Section and the Flood Control Zone District Advisory Committee. Companion documents in this task include: 1) *Alluvial Fan Hazards: Recommended Assessment Methodology and Regulatory Approach* and 2) *Jones Creek Alluvial Fan Analysis.*

This report is a technical resource paper summarizing the stream hazards associated with landforms in the vicinity of the lower portions of Glacier and Gallop Creeks, upon which the community of Glacier is located. Included in the report is an estimate of hazard probability and the associated impacts to development located within the hazard areas. This is not a policy document; however, the identified hazards can be used as a basis for public policy decisions on the management of development and growth. The report also serves as an example of the analytical approach and methods of alluvial fan hazard assessment prescribed in the document *Alluvial Fan Hazards: Recommended Assessment Methodology and Regulatory Approach.*

The work on this report was a collaborative effort by a number of people. Mary Raines served as project manager in addition to conducting the upper watershed research and assessment. Dr. Peter Willing led the alluvial fan mapping effort. Karen Welch provided the climatic and hydrologic assessment portions. Dr. Oldrich Hungr provided technical guidance and editing. Dr. Tony Melone, P.E., functioned as the project coordinator with Whatcom County and provided technical guidance on structural mitigation in addition to thoughtful edits. Valuable input was also provided by John Matzinger, Doug Goldthorp, and Andreas Kammereck of the Whatcom County River and Flood Control Section and the Planning Department. Roger Nichols, geologist with the Mt. Baker-Snoqualmie National Forest, provided access to slope stability mapping and historical aerial photography and was available for discussion of geologic processes. Technical support for this project included preparation of a topographic base map at a scale of 1"= 200' based on photogrammetry carried out by Walker & Associates for Whatcom County.

Lower Nooksack River
Comprehensive Flood Hazard Management Plan
Glacier and Gallop Creeks Alluvial Fan Analysis

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1.0 INTRODUCTION

1.1 Purpose and Scope of Study

This report documents evidence and rationale for delineating hazards associated with stream processes in lower Glacier and Gallop Creeks, Whatcom County, Washington. The Glacier and Gallop Creek alluvial fans are treated together in this report because the watersheds are contiguous and their historic floodplains overlap at the lower edges. The intent of this document is to:

- identify the stream hazards associated with the landforms in the vicinity of the lower portions of Glacier and Gallop Creeks;
- map the relevant physical features on the Glacier and Gallop Creek alluvial fans and upper watershed areas;
- describe the nature and probability of specific channel disturbance events;
- designate zones that indicate relative degree of stream hazard to human occupance and development;
- recommend hazard mitigation and hazard avoidance measures to limit flood and debris damage including land use control and building permit provisions.

1.2 Problem Statement

An alluvial fan is a physiographic feature formed by the accumulation of sediment and debris deposited by a stream where it exits steep, confined channels onto a flat unconfined floodplain or valley floor. Lower gradients and lack of valley wall confinement cause velocities to decrease and stream energy to dissipate resulting in the sediment load of the stream coming to rest. These materials eventually plug the channel and force the stream to find another course. The larger materials settle out first, and the finer ones continue to the edge of the active alluvial fan. The surface is gradually built up into a relatively gently-sloping cone or fan-shaped deposit.

Sediment and woody debris can be delivered to the fan by a number of stream processes including peak stream flows, mud or debris flows, log dam or landslide dam-break floods, rock falls, and snow avalanches. Fans constructed by processes other than water transported, or alluvial sediment are called debris flow or composite fans. Because of the formative processes at work on alluvial fans, the stream channels that cross them are not stable.

Alluvial fan hazard areas are addressed by the Federal Emergency Management Agency (FEMA) in their guidelines for high risk flood hazard areas (FEMA, 1987). Flood frequency estimates and alluvial fan assessment techniques currently used by FEMA to determine the regulatory 100-year flood levels for setting insurance rates are based on stream discharge frequencies (Dawdy, 1979), which show poor correlation to the frequency of channel shifting

find reference

events in the Northwest (Church and Miles, 1987). Statistical analyses do not take into account the geomorphic conditions in the upper watershed that may lead to debris flows, as an example. Nor do they consider flow obstructions on the fan such as trees, buildings, bridges, roads and other physical features which may affect inundation patterns (FEMA, 1987).

In 1992, Whatcom County inventoried alluvial fans as part of its effort to adopt a Critical Areas Ordinance pursuant to the Washington State Growth Management Act (Fox and others, 1992). This inventory identified 150 alluvial fans in Whatcom County, and field inventoried 46 that were considered active enough or developed enough to warrant detailed description.

Also in 1992, Whatcom County appealed the Flood Insurance Rate Maps that had been developed by the Federal Emergency Management Agency (FEMA) and started work toward a Comprehensive Flood Hazard Management Plan. The County contracted in 1993 with KCM Inc. of Seattle to carry out major components of the Plan. One of the components was an analysis of alluvial fans. Inadequate representation of the hazards on alluvial fans was one of the reasons which Whatcom County gave for appealing the Flood Insurance Rate Maps. In recognition of both the regulatory and physical hazard problems being experienced on alluvial fans, two fan hazard areas were chosen for detailed investigation under the auspices of the Comprehensive Flood Hazard Management Plan.

On a local regulatory level, stream hazards of the type encountered on Glacier and Gallop Creeks are found in two sections of the Whatcom County Critical Areas Ordinance (96-017, adopted May 20, 1996). Section 16.16.280 defines alluvial fans as areas where flooding, boulder floods, or debris torrents have the potential to damage life or property. It distinguishes between high hazard areas on the "active fan," and low hazard areas on the "inactive fan" by how recent the evidence of flooding or debris torrent activity is. Section 16.16.160(B)(2) describes high hazard landslide areas where risk from a landslide due to slope failure is extreme, and includes potentially unstable slopes resulting from rapid stream incision, stream bank erosion, or undercutting by wave action.

This report attempts to address federal, state, and local requirements for identification and recommended regulation of the hazards specifically associated with stream processes in the lower reaches of Glacier and Gallop Creeks using appropriate technical and scientific analyses. These recommendations embody an attempt to reflect landscape reality in a regulatory scheme designed to prevent damage to human life, property, and resources.

For simplification and in deference to existing regulatory terminology, all fans, whether constructed by alluvial, debris flow, or a composite of these processes, will be referred to as "alluvial fans" in this report.

1.3 Overview of Methodology

The hazard analysis portion of this report consists of several components: 1) an assessment of the nature of stream hazards, 2) an estimation of the size, character, and frequency of channel disturbance events, and 3) delineation of hazard zones based on the nature and intensity of hazard processes. The identification of hazard initiation mechanisms in the upper watersheds was derived from a review of previous work in the area, historical aerial photograph analysis, and reconnaissance field checking. Prediction of the size and frequency of flood events was estimated from hydrologic and climatologic analysis.

The hazard zones were constructed to define the type and intensity of watershed and stream processes responsible for the hazards and were delineated from a synthesis of all information sources. Recommended land use planning guidelines and mitigation alternatives are based on the results of the hazard analysis, from previous work and experience by team members, and from the published literature.

This report has relied heavily on previously conducted work in the areas of Glacier and Gallop Creeks and the North Fork Nooksack River, although none of the previous work had been conducted specifically for the purpose of assessing hazard potential to alluvial fans or downstream reaches. A number of investigations have been conducted in Glacier Creek (Collins, 1985; Stoker, 1988; Harper, 1992; Carpenter, 1993; Van Siclen, 1994; Mt. Baker Ranger District, 1995) and two reports were available for Gallop Creek (DaPaul, 1994; Mt. Baker Ranger District, 1995). The Van Siclen thesis in particular focused on investigating possible mechanisms contributing to flooding and damage in Glacier Creek. The previous work was reviewed and checked by aerial photograph interpretation and field work.

The initial phase of the analysis used existing information to determine the extent to which the nature and approximate recurrence of hazards on downstream and alluvial fan reaches of Glacier and Gallop Creeks could be determined. Additional field work, interviews, and hydrologic and hydraulic analyses were subsequently performed to supplement and reconcile the existing information.

2.0 STUDY AREA CHARACTERISTICS

Glacier and Gallop Creeks are adjacent watersheds located in the north-central part of Whatcom County, Washington (Figure 2.1). Both streams flow from the south into the North Fork of the Nooksack River adjacent to the community of Glacier (Figure 2.2). The immediate areas of interest to this study include the downstream reaches of Glacier and Gallop Creeks where zoning for both recreational, residential, and municipal development is regulated. As State Highway 542 passes through the community of Glacier it crosses both creeks near their mouths. A county maintained bridge on Coal Creek road crosses Gallop Creek approximately 500 feet upstream of

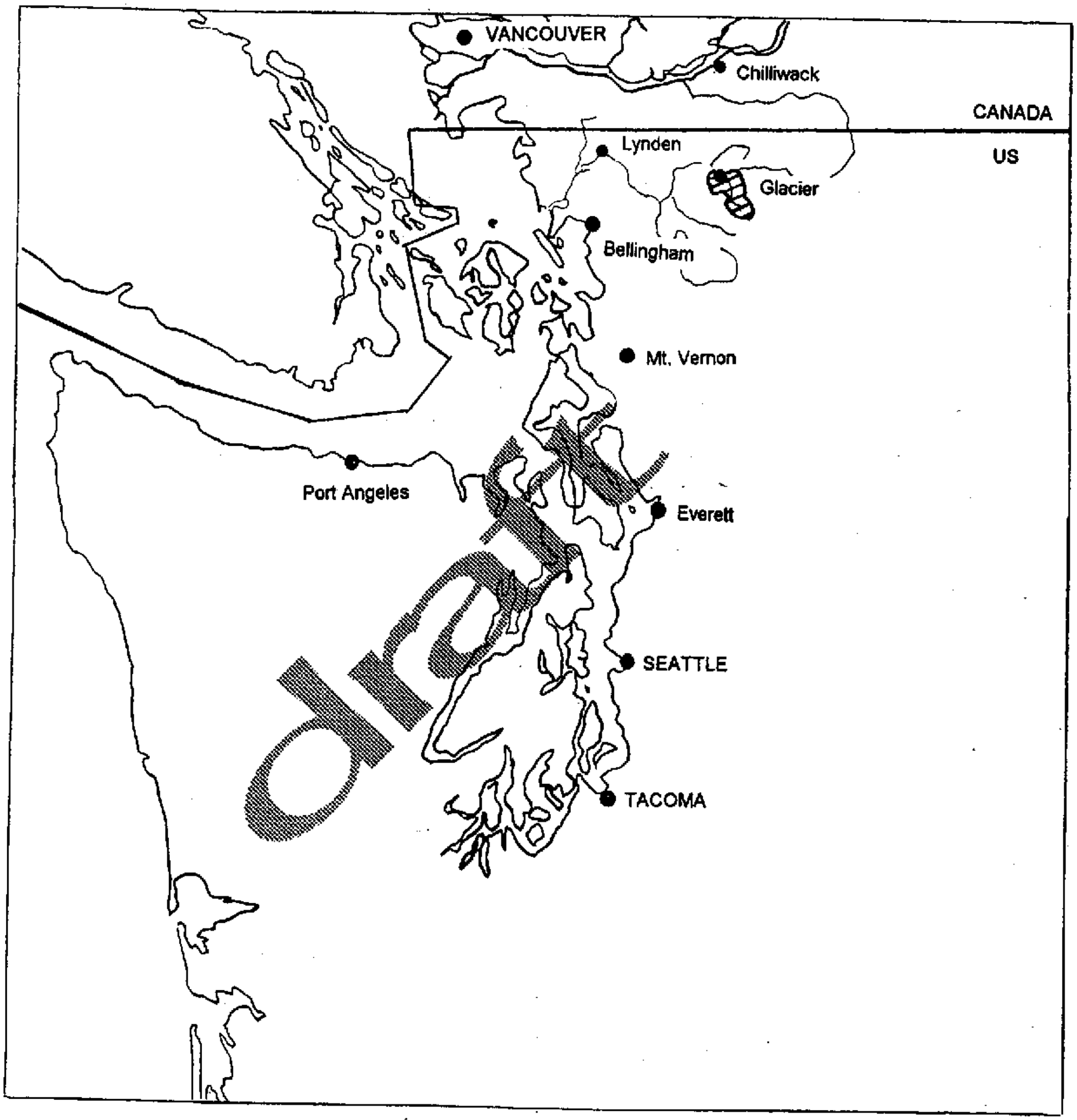


Figure 2.1 Site Location Map

Figure 2.2 Study Area Map

the highway bridge. A bridge on U.S. Forest Service road 3904 crosses upper Glacier Creek approximately 2.8 miles upstream from the highway.

The Glacier Creek study area includes the lower 1.6 miles of Glacier Creek from approximately 1,000 feet downstream of the confluence with Thompson Creek to the North Fork of the Nooksack River. Gallop Creek study area consists of the lower 3,300 feet of Gallop Creek to the confluence with the North Fork Nooksack River. The map sheets at the back of this report contain detailed maps of the study areas (Plates 1-3).

2.1 Glacier Creek Watershed

Glacier and Gallop Creeks are adjoining watersheds of markedly different size and watershed character. Glacier Creek is a major tributary of the North Fork Nooksack River and drains an area of approximately 30 mi^2. Elevations range from 10,781 feet at the top of Mount Baker to 870 feet at the confluence with the North Fork of the Nooksack River. The length of the mainstem extends in a north-south orientation approximately 9.2 miles above the mouth.

Glacier Creek originates from Mount Baker's Roosevelt and Coleman Glaciers and the snow fields and slopes of Heliotrope and Grouse Ridges. The glaciers occupy an area of 3.6 mi^2 (Harper, 1992) and together with snowfields equal 15 percent of the area of the watershed. The glaciers contribute significantly to the annual stream flow and sediment load of the stream.

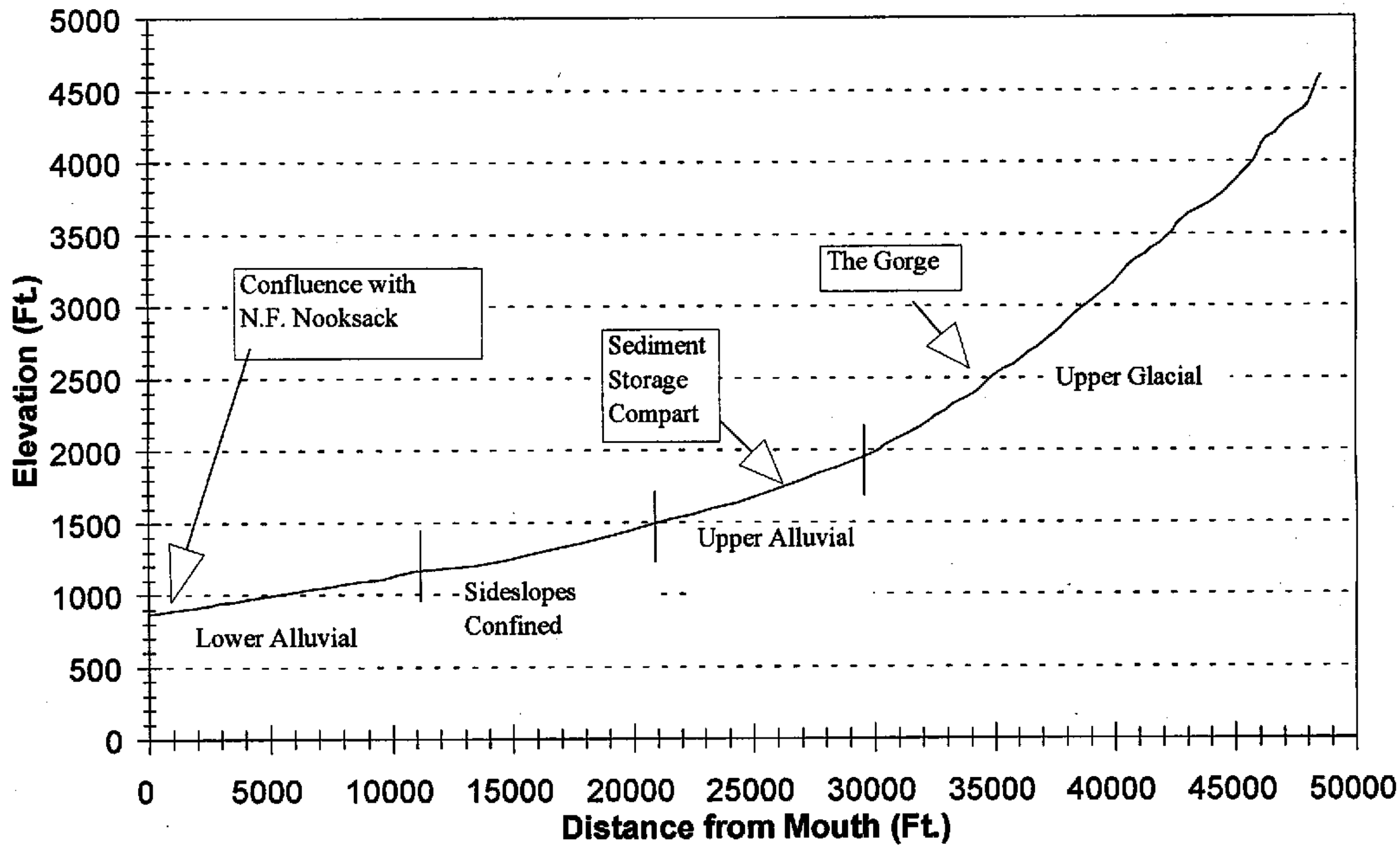
The larger tributaries of Glacier Creek include Grouse, Smith, and Falls Creeks in the headwater area and Thompson Creek in the northeast portion of the watershed near the bottom of the basin. There are five smaller, tributaries draining the western slopes of the basin and at least six tributaries draining the east slopes.

In the upper basin below the glaciers, Smith and Grouse Creeks join Glacier Creek above a narrow, bedrock gorge carved in Quaternary volcanic bedrock (Figure 2.2). Below the gorge, the mainstem flows through a steep-sided valley at an average gradient of 10 percent for 0.8 miles before joining Falls Creek in a broad, alluvial valley where the stream gradient drops to about 5 percent (Figure 2.3). The valley here widens to between 800 and 1,000 feet for 2.3 miles, and is controlled at the downstream end by a bedrock sill. Due to the drop in gradient and opening in confinement, a large amount of glacially-derived sediment is stored in this reach. Below this sediment storage compartment the stream becomes confined again by bedrock valley walls and the gradient drops to about 4 percent. The stream widens locally at and above the confluence with Thompson Creek, before emerging between bedrock banks at the top of the study area or lower alluvial segment.

Within the Glacier Creek study area, the active channel and floodplain widen downstream from 200 feet to approximately 800 feet before joining the North Fork Nooksack River. Prior to

Figure 2.3

Glacier Creek Longitudinal Profile



diking, the historic floodplain was as wide as 1,000 feet. Channel gradients average between 2 and 3 percent and are locally as high as 4 percent within the study area.

2.2 Gallop Creek Watershed

Gallop Creek lies to the west of Glacier Creek and is a small, steep mountain tributary draining the southern side slope of the North Fork Nooksack River valley (Figure 2.2). Its watershed area is approximately 2.5 mi^2, and the mainstem has approximately 3.8 miles of channel. Elevations range from 5,040 feet down to about 850 feet.

The stream flows at a steep gradient between moderate to steep valley walls until emerging into the North Fork Nooksack River valley (Figure 2.4). Glacier Creek has periodically merged with the flow of Gallop Creek below the Coal Creek Road bridge (Plate 3, observation point 95). Dikes along the left bank of Glacier Creek above the highway and both banks of Gallop Creek below the highway bridge currently prevent the merging of the two streams during most flood events.

2.3 Climate and Hydrology

Mean annual precipitation in the vicinity of Glacier Creek ranges from 66 inches in the lower watershed to more than 130 inches in the upper elevations. The majority (approximately 75 percent) of this precipitation falls as both rain and snow during the winter months of October through March. Winter storms are often characterized by warm wet frontal systems moving in off the Pacific Ocean. These storms can cause rapid melting of the transient snowpack, and thereby increase volumes of runoff by as much as 30 percent. Approximately 13 percent of the Glacier Creek watershed between the elevations of 1,400 and 2,400 feet lies within this transient rain-on-snow zone. Gallop Creek has 19 percent of watershed area within this elevation zone (DaPaul, 1994).

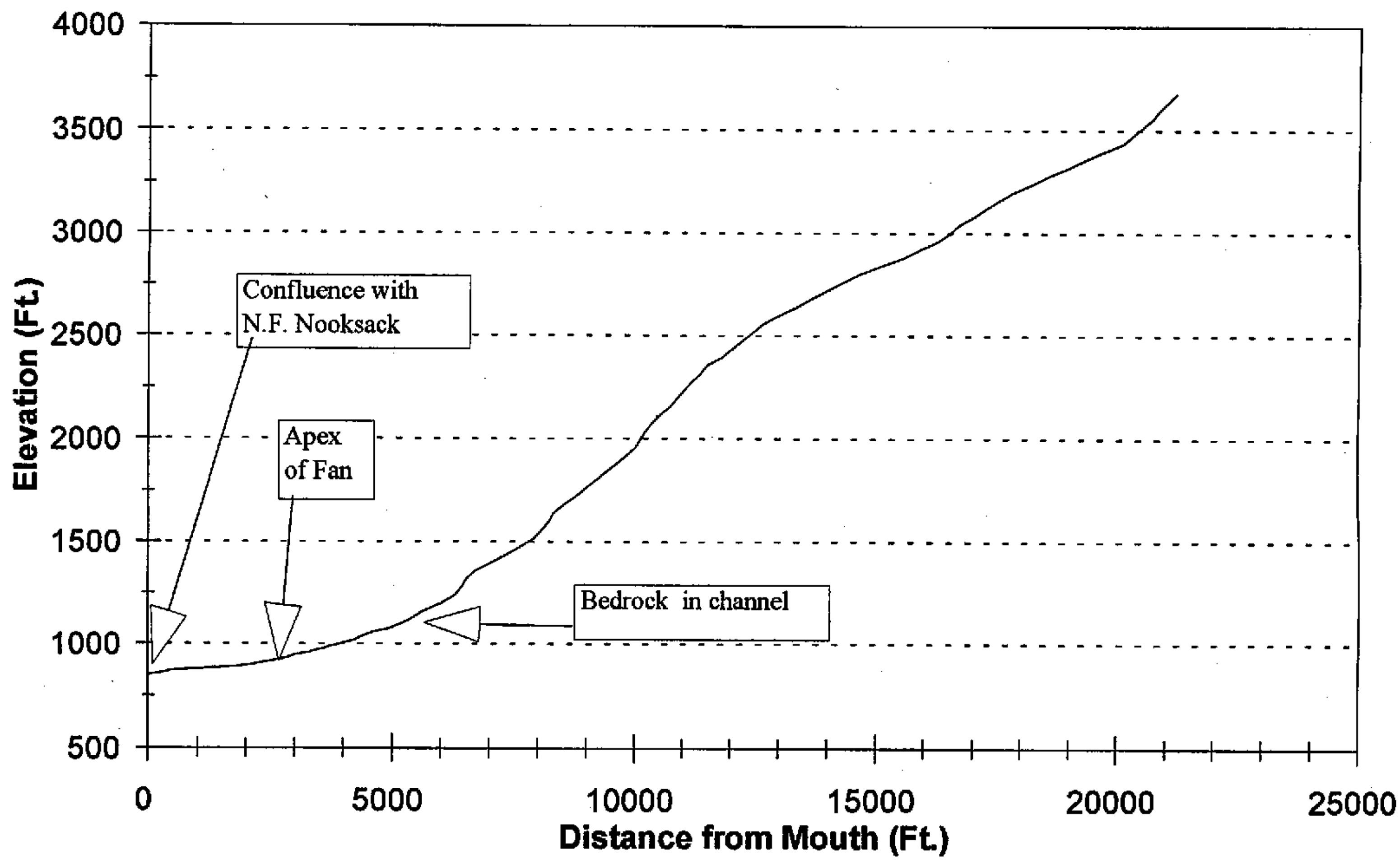
2.4 Geology and Geomorphology

The geology of the study area is shown in Figure 2.5. The Glacier Creek basin is underlain primarily by rocks of the Nooksack Group which consists of volcanic-rich sandstones and siltstones black to brown in color (Brown and others, 1986). These rocks have been slightly metamorphosed and are highly fractured. The mainstem of Glacier Creek flows essentially parallel to the axis of a large anticline or fold in the Nooksack Group rocks (Van Siclen, 1994). Differential erosion along the west limb of the anticline produces lower gradient slopes on the east side of the stream where bedrock is parallel to the slope.

The Nooksack Group rocks are fault-bounded on the northwest by Chuckanut Formation sandstones, siltstones, and shale. The Chuckanut Formation has been folded and faulted but has not undergone the metamorphism of the Nooksack Group rocks. Gallop Creek is underlain by

Figure 2.4

Gallop Creek Longitudinal Profile



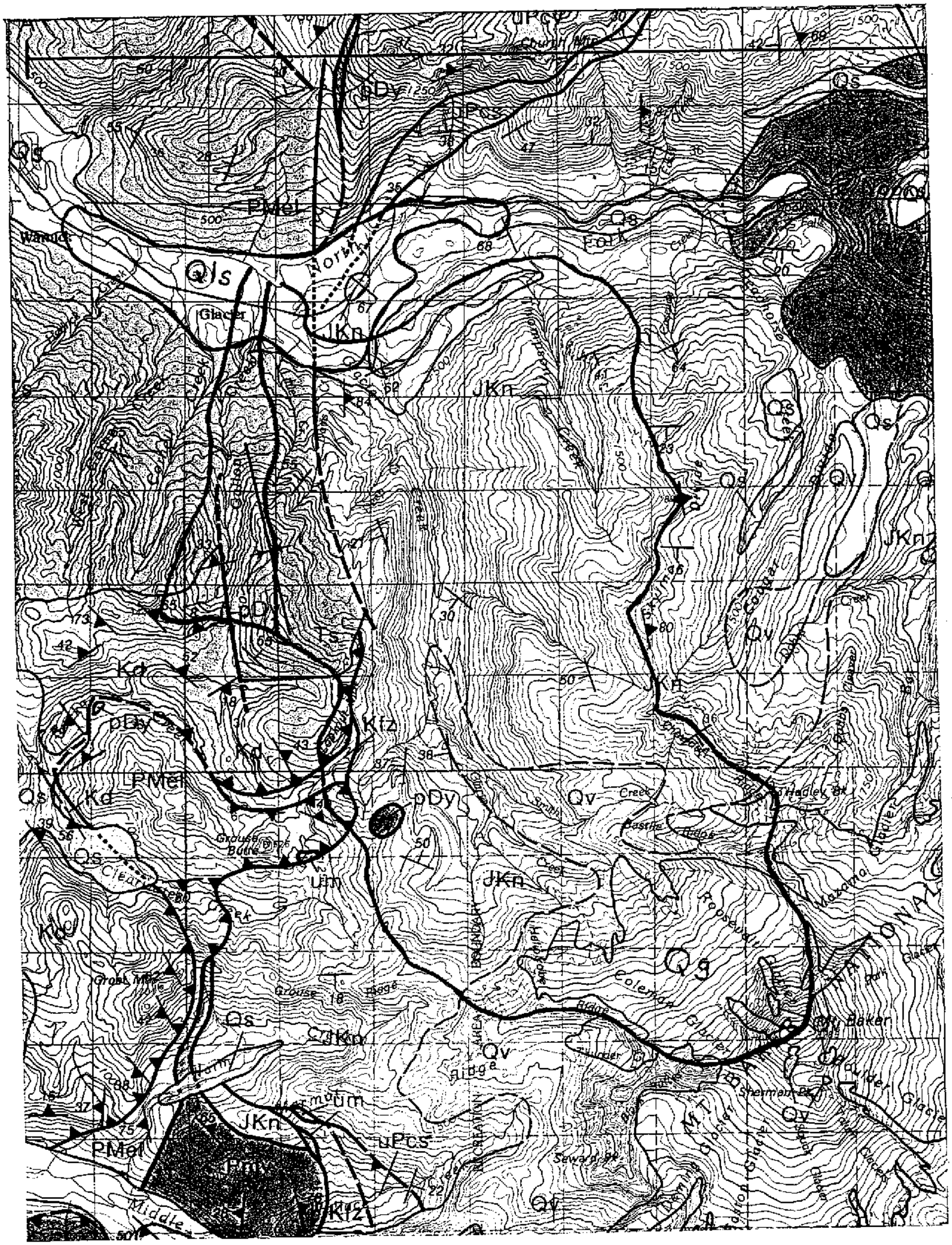


Figure 2.5 Geology of the study area (from Brown and others, 1987). Red lines are watershed boundaries of Glacier and Gallop Creeks. Qs, unconsolidated sediments including alluvium, glacial outwash, and colluvium; Qls, landslide deposit (Carpenter, 1993); Qg, glacier ice; Qv, Mt. Baker volcanic rocks; Ts, Chuckanut Formation; Kfz, fault zone of sheared rock; Kd, Darrington Phyllite; Jkn, Nooksack Group volcanic sandstone and siltstone; Pmel, Elbow Lake Formation; pDy, Yellow Aster Complex.

rocks of the Chuckanut Formation with a minor amount of Darrington phyllite in the upper headwaters. Extending slightly into the Glacier Creek drainage at Lookout Mountain are limited exposures of Darrington Phyllite, a fault zone of sheared rock, and the Elbow Lake Formation.

Mount Baker volcanics make up the balance of rock types. Quaternary volcanism in Glacier Creek is represented in andesite flows from Mount Baker, which includes pyroclastic and lahar deposits. Van Siclen (1994) suggests that the volcanic deposits in Glacier Creek are more extensive than previously mapped (Brown and others, 1986). More detailed mapping of Mount Baker volcanics by the U.S. Geological Survey is currently in progress.

The regional landscape has also been sculpted by repeated glaciations during the Pleistocene Epoch that carved steep valley walls in both Glacier Creek and the North Fork Nooksack River and filled the valleys with outwash. Soils mapping indicates an extensive veneer of dense glacial till on the valley side slopes, both at shallow depths and covered with varying thicknesses of failed slope material, ash, and less consolidated glacial sand and gravel (Snyder and Wade, 1970). Exposures of glacially-derived deposits within Glacier Creek have also been described by Stoker (1988) and Van Siclen (1994).

Ancient Landslides

The landscape mapped within the study areas has been identified as part of a large, ancient landslide deposit originating from the Church Mountain area (Cary, et. al., 1992; Carpenter, 1993). This deposit is estimated by Carpenter to cover an area of 3.7 mi^2 with an average thickness decreasing from at least 180 feet at the upstream end to 13 feet in the vicinity of Glacier Creek. The surface of the deposit is characterized by hummocky, irregular topography, closed depressions, and irregular drainage. The approximate boundary of the landslide deposit is shown in Figure 2.6. The geologic term for a catastrophic landslide deposit of this size derived from the collapse of a mountainside is "sturzstrom."

Trees buried in the deposit yield a radiocarbon date of 2,340 ± 60 years before the present based on samples collected in 1992 by Robert Schuster of the U.S. Geological Survey (personal communication, 1996). The dates obtained by Schuster on samples from two different trees were identical and therefore thought to be fairly accurate. Dates reported earlier (Cary and others, 1992; Carpenter, 1993) range between 2,450 ± 80 and 2,890 ± 90 years before the present and samples did not include the outer-most part of the tree, as did the Schuster samples. A typical tree trunk exposure in the landslide deposit is shown in Figure 2.7.

Portions of the surface of the landslide deposit in the vicinity of Glacier and Gallop Creeks are overlain by alluvial sand and gravel interpreted by Carpenter (1993) to have been deposited in response to a temporary drainage blockage and ponding of Glacier Creek streamflow following deposition of the landslide material. It is the presence of this alluvial sand and gravel veneer over the landslide deposit that lead to earlier interpretation of this landform as alluvial in origin.

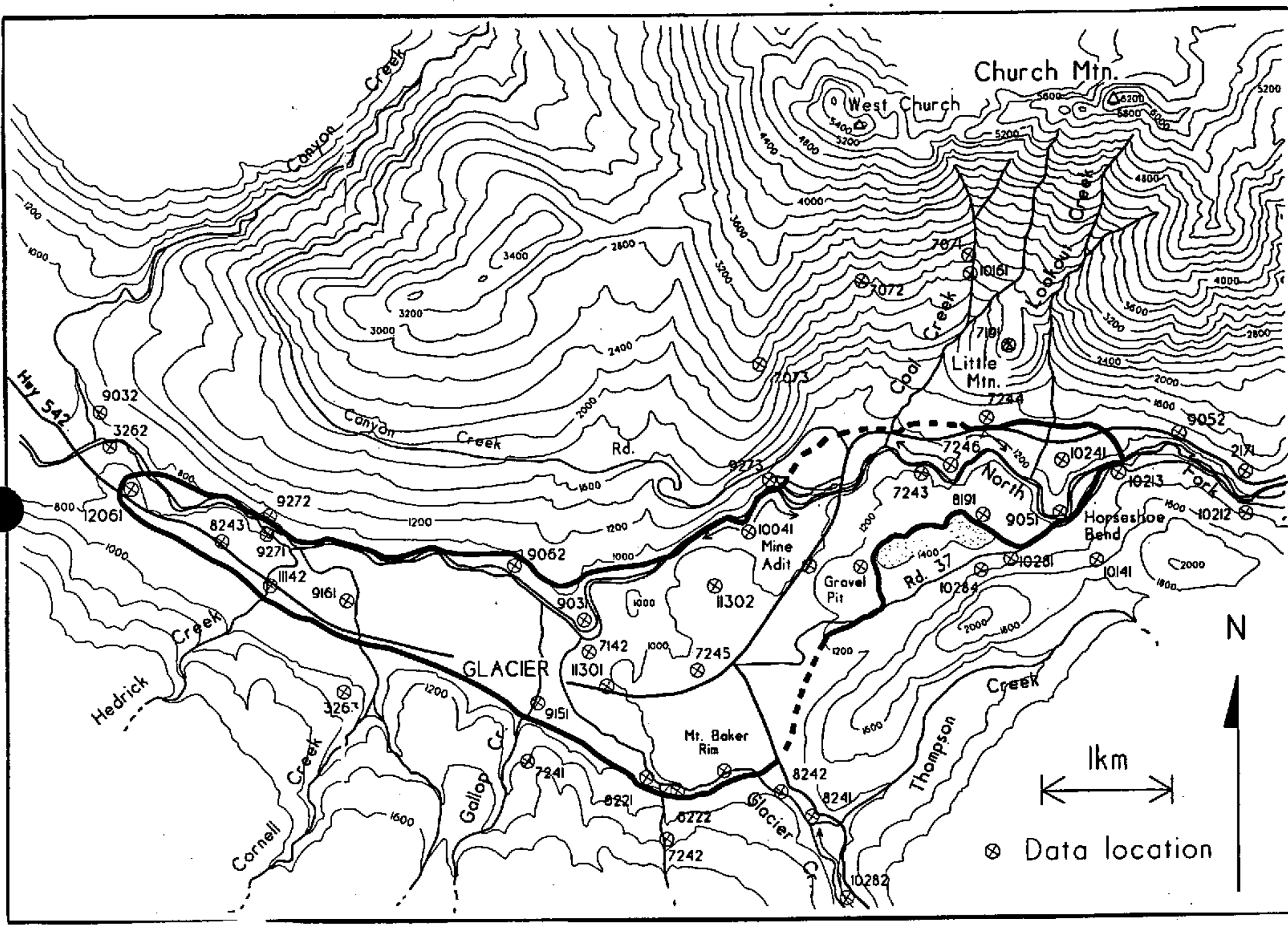


Figure 2.6 : Boundary of the Church Mountain Landslide deposit. Where solid, error in location of the boundary is estimated as <100 m; where dashed the error is <300 m (from Carpenter, 1993).

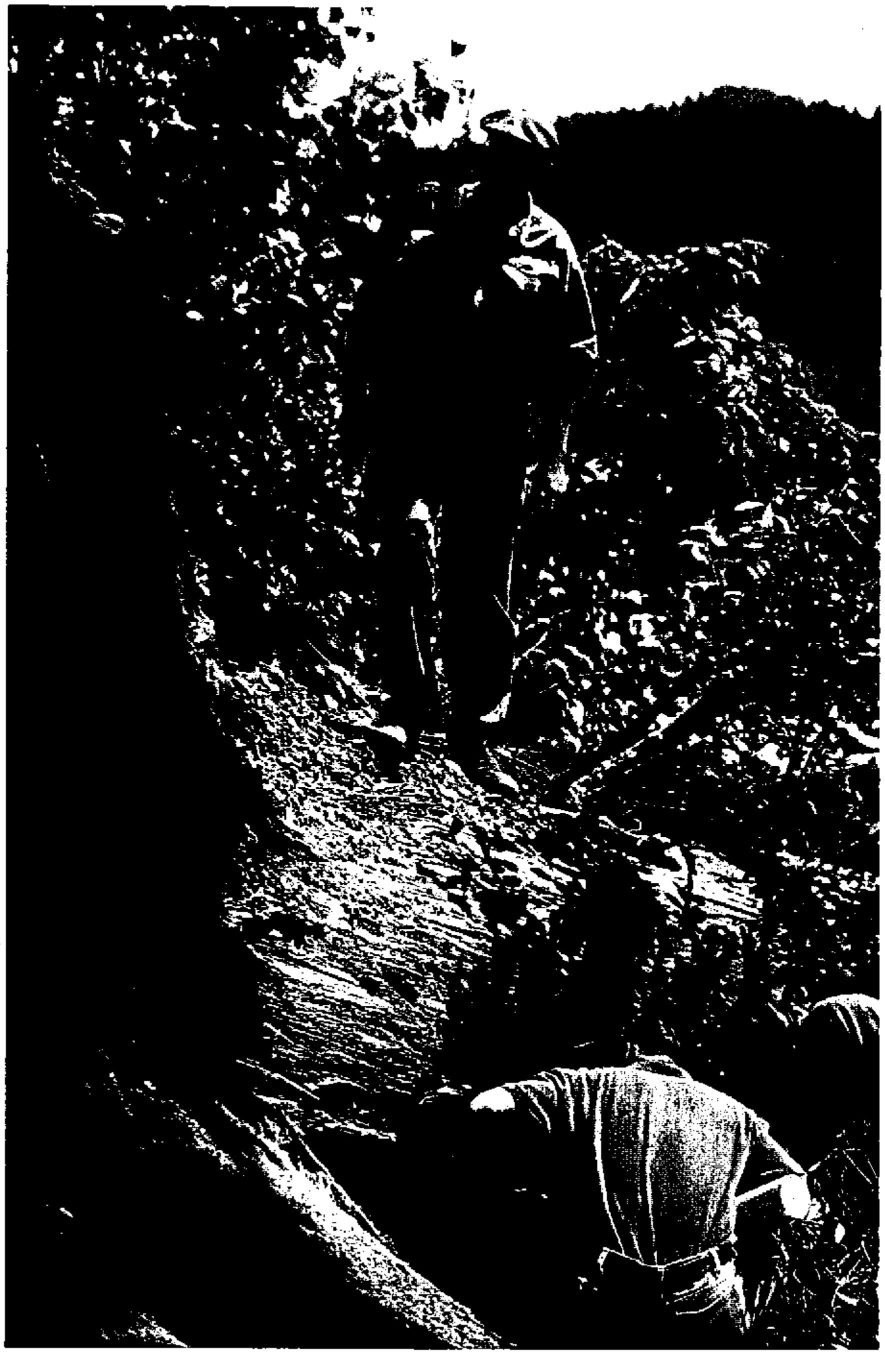


Figure 2.7 Photograph of tree buried in the Church Mountain landslide deposit. Photo by P. Willing, 1995.

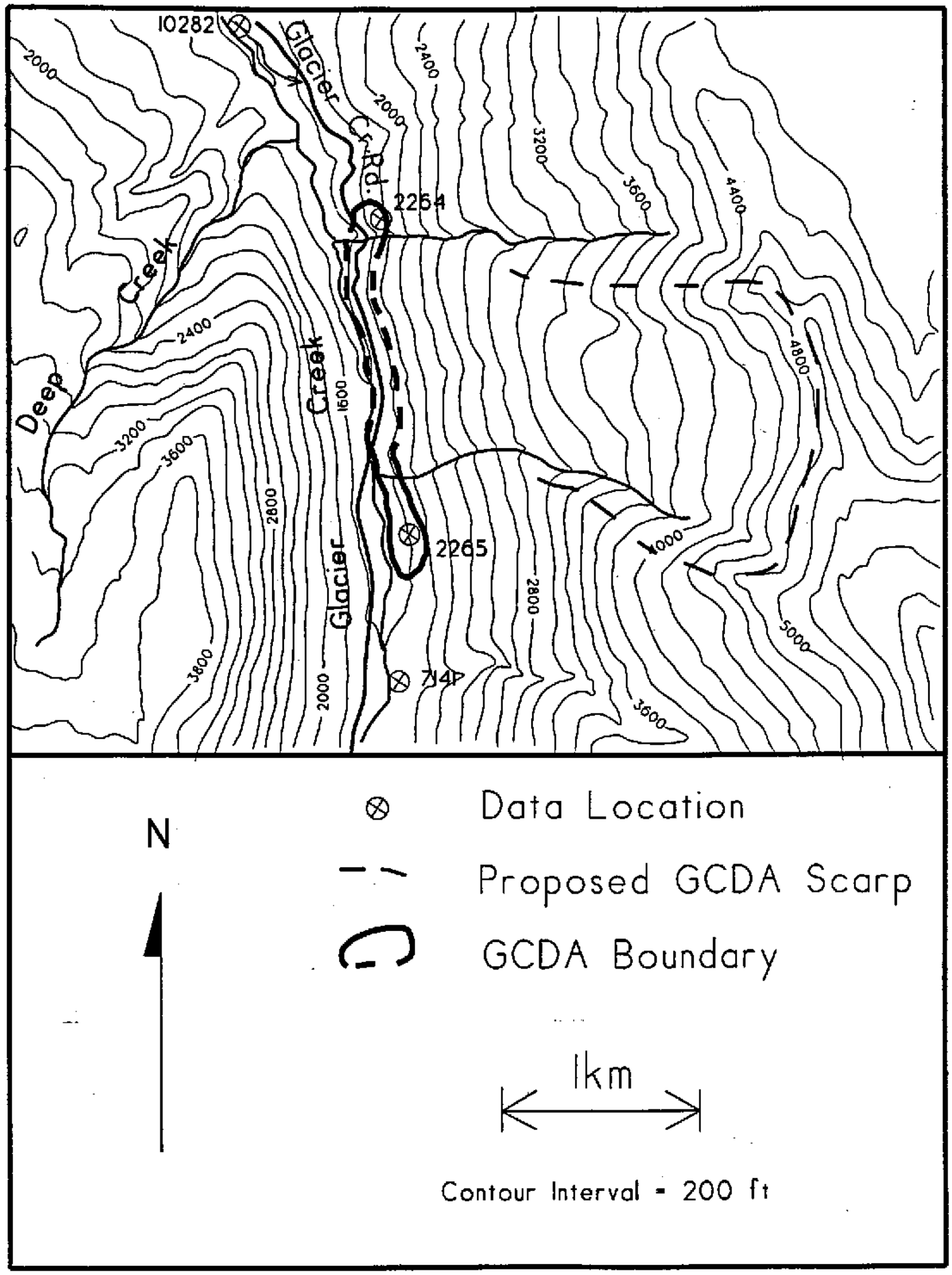
Both the mainstream North Fork Nooksack River and Glacier Creek have reestablished channels within the landslide material. Thus, dating of the landslide deposit also dates the development of the Glacier Creek channel in the study area. Interpretation of the landforms composing the study area are significant to understanding the active stream processes at work and the range of hazard potential to the area.

Gallop Creek has constructed an alluvial fan upon the surface of the landslide deposit visible in streambank exposures immediately upstream and downstream of the Coal Creek Road bridge (Plate 3, observation point 95). The Gallop Creek alluvial fan has been truncated in the past by Glacier Creek immediately downstream of the Coal Creek Road bridge where the floodplains of the two streams merge.

A landslide deposit complex of approximately 100 acres in size has also been identified in the mid-Glacier Creek watershed originating from the west slope of Skyline Divide (Figure 2.8) (Cary and others, 1992; Carpenter, 1993). A thicker, lower landslide deposit is separated from a thinner, upper deposit by a thin clay layer. Buried wood exposed within the upper landslide deposit was radiocarbon dated from a single wood sample at 2,060 ± 80 years before the present (Cary and others, 1992). It is not known from what portion of the tree the wood sample was from; consequently, as an estimate of the landslide age, this date is not well constrained. The lower exposure of the deposit has not been dated. Soil surveys also describe the lower slopes in Glacier Creek as composed of slope colluvium, usually derived from landsliding and soil creep, which is common in this type of terrain.

Van Siclen (1994) hypothesizes that the lower landslide deposit temporarily dammed the Glacier Creek channel, forming a lake and depositing the clay layer. The lake depth and volume were not estimated by Van Siclen (1994) or Carpenter (1993). The landslide dam may have then been overtopped and the lake subsequently drained. From the volume of trees and woody material rooted in the clay and sand layer, a period of time elapsed before the second slide buried this surface. The downstream implications of a landslide dam failure were not hypothesized by Van Siclen, but could be a source of the alluvial material mantling the Church Mountain landslide deposit.

The topography of the Deep Creek drainage on the slope opposite the proposed source area for the Glacier Creek debris avalanche suggests a large rotational bedrock slide not previously identified by other workers (Figure 2.9). Failure or rotation of the slide block could have occurred along the fault contact between the Nooksack Group rocks and the Chuckanut Formation or along weak interbeds. Differential rotation of the slide block in the downstream direction may have created the confined reach of the Glacier Creek channel below the upper alluvial compartment (Figure 2.3) or perhaps be related to the landslide deposit studied by Van Siclen (1994) and Carpenter (1993). The valley confinement below the upper alluvial reach is puzzling as the glacially carved upper valley ends abruptly here without terminal ice features such as a hanging valley or moraine remnants. This interpretation suggests a post-glacial failure



where is this?

Figure 2.8 Boundary of Glacier Creek debris avalanche and proposed slide scarp (from Carpenter, 1993).

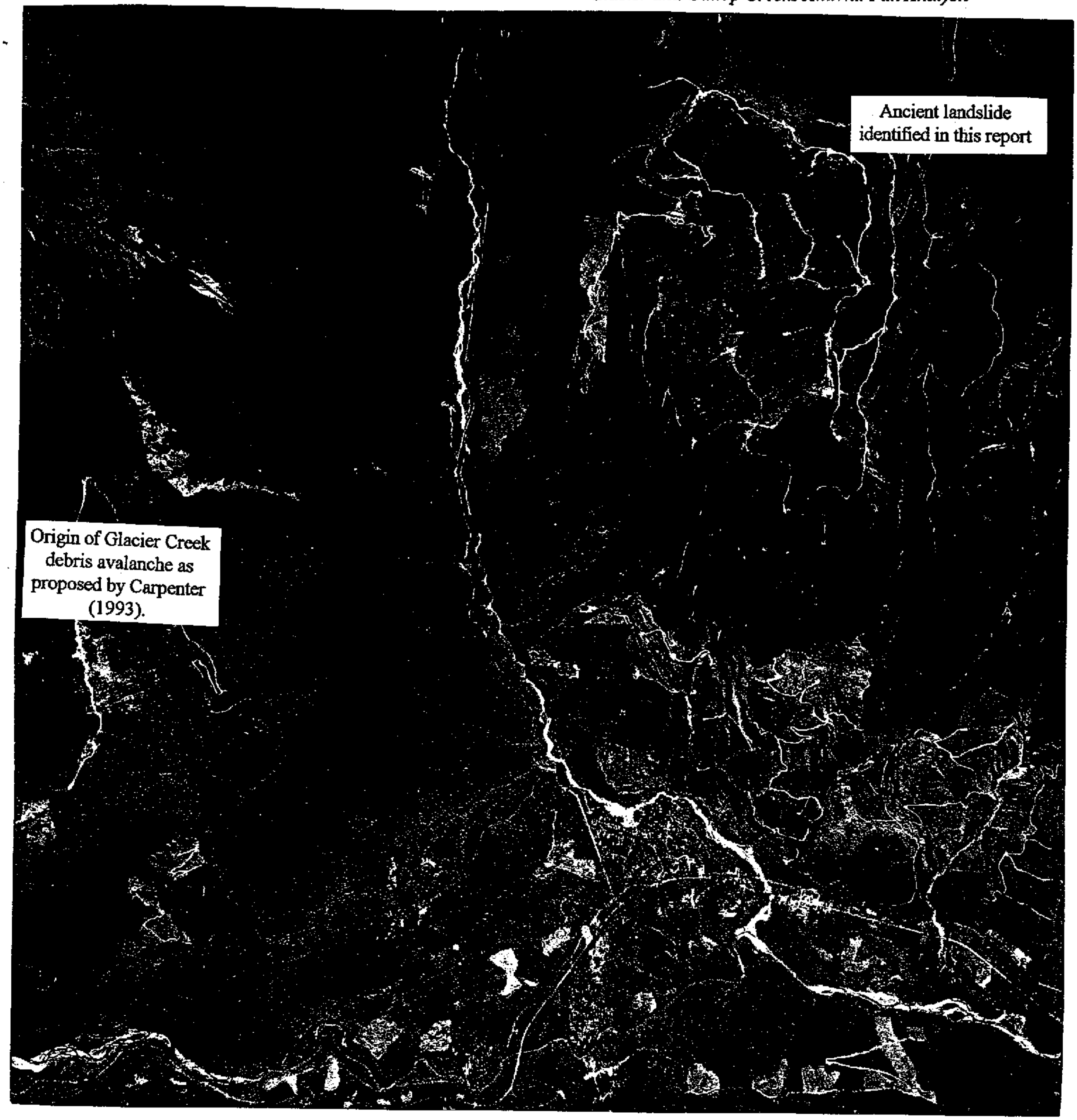


Figure 2.9 Aerial Photograph of Glacier Creek and ancient landslide in the Deep Creek drainage. USDA Forest Service photo 616050B 389-160, 9-6-89.