U.S. Department of the Interior
Bureau of Land Management

BLM Alaska Open File Report 123
BLM/AK/ST-09/013+3033+A010
September 2009

BLM

A Geophysical Investigation of Glacial Lake Outburst Potential of Nourse Moraine, Taiya River Watershed, Skagway, Alaska

Charles Denton, Brent Lewis, and Gary Fisk

Alaska

Mission Statement

The Bureau of Land Management (BLM) sustains the health, diversity and productivity of the public lands for the use and enjoyment of present and future generations.

Authors

Charles Denton is a hydrologist with the BLM Anchorage Field Office, Anchorage, Alaska. Brent Lewis is a geophysical survey specialist and Gary Fisk is a civil engineer, both located at the BLM's National Operations Center, Denver, Colorado.

Cover

Geophysical instruments are used to assess the static stability of Nourse Moraine and Lake near Skagway, Alaska.

Open File Reports

Open file reports present the results of inventories or other investigations published outside the formal BLM-Alaska technical publication series. These reports can include preliminary or incomplete data and are not published and distributed in quantity.

Reports are available while supplies last from Office of Communications, Bureau of Land Management, 222 West 7th Avenue, #13, Anchorage, AK 99513 (907) 271-5555. Copies are also available for inspection at the Alaska Resource Library and Information Service (Anchorage), the United States Department of the Interior Resources Library in Washington D.C., various libraries of the University of Alaska, and other selected locations.

A complete bibliography of BLM-Alaska scientific reports is on the Internet at:
http://www.blm.gov/ak/st/en/info/gen_pubs.html.

A Geophysical Investigation of Glacial Lake Outburst Potential of Nourse Moraine, Taiya River Watershed, Skagway, Alaska

Chuck Denton, Brent Lewis, and Gary Fisk

BLM Open File Report 123
September 2009

U.S. Department of the Interior
Bureau of Land Management
Alaska State Office
222 W. 7th Avenue, #13
Anchorage, Alaska 99513
http://www.blm.gov/ak/

Contents

Introduction

At the request of the National Park Service (NPS), the Bureau of Land Management (BLM) performed a preliminary geophysical assessment of the Nourse Moraine. The specific objective of this study was to assess the moraine's static stability, e.g., its ability to perform as an earthen dam. The moraine's physical properties were acquired through visual observations and data collected by a geophysical survey. The geophysical survey assessed the moraine's thickness and internal structure, specifically for the presence of an ice-core, which upon melting would weaken the moraine.

Background Information

Climate change and global warming have increased the rate of melting and receding of glaciers, and subsequently has caused an increase in the size of glacial lakes and the weakening of the glacial moraines that typically impound these lakes to a point of failure. These failures are often catastrophic and are known as Glacial Lake Outburst Flood (GLOF). The process of weakening is not solely based upon the increasing lake size, but also the melting of the moraine's ice-core, i.e., ice contained within the sediments of some glacial moraines. On July 23, 2002, a lateral moraine of the West Creek Glacier failed, causing such a flood. Though the mechanics of this flood are unknown, it raised concerns about the potential for additional floods in the area of the Klondike Gold Rush National Historic Park (KLGO).

In a previous study by Capps (2004), the NPS identified the Nourse Moraine as having a potential to cause a GLOF. Currently, the Nourse Moraine is on lands administered by the BLM and selected by the State of Alaska for conveyance under Section 6 of the Alaska Statehood Act PL85-508 (72 STAT 339) as amended (Denton, 2005). The BLM initiated its first study later that year (Denton, 2005). Due to equipment failure, this initial investigation fell short of its primary objective to determine the presence of an ice-core within the moraine that may lead to structural failure if degraded.

On April 5, 2005, BLM State Director Henri Bisson received a letter from Superintendent James Corless, KLGO, requesting an additional investigation of the potential for a GLOF of Nourse Lake. Chuck Denton, hydrologist with the BLM Anchorage Field Office, assembled a team for the reassessment. This team consisted of Brent Lewis (geologist, geophysical survey specialist) of the BLM National Science and Technology Center (NSTC), who was familiar with the project from the initial assessment; Gary Fisk (Professional Engineer), who is the BLM's structural dam engineer at the NSTC; and Meg Hahr (natural resources specialist) from the KLGO, who participated in the reassessment of Nourse Moraine and assisted with logistical support, local environmental interpretation, and liaison between the assessment team and KLGO management.

All Nourse team members met in Skagway, Alaska, on August 1, 2005, for a project briefing with KLGO Superintendent James Corless and Resources Supervisor Theresa Thibault. The objective of the meeting was to introduce the team members to the KLGO management, understand KLGO concerns, describe techniques to be used, and identify project goals.

Three days were allocated for data collection, from August 2 to 4, 2005.

Physiography

The Nourse Moraine (lat -135.4250, long l59.5693) impounds a large icy-blue proglacial lake known as Nourse Lake. The lake is estimated to occupy a surface area of 200 acres (80.94 ha) with a depth of 95 feet (28.956m) and spills over the moraine at two primary locations (Figure 1). With an estimated gradient of 14.5% (Capps, 2004), the outlets form high-gradient glacial streams that flow to a smaller unnamed proglacial lake. Eventually this watershed enters the Taiya River at a confluence approximately 8 miles (12.88 km) downstream. Located approximately 22 river miles (35.4 km) farther downstream is Dyea, Alaska. The broad, U-shaped Nourse and Taiya River valleys were carved out by past glacial events. Though the glaciers remain, they have significantly receded and mainly reside high in the mountains. The surface of Nourse Moraine is composed of multiple-size class sediments, including large boulders, cobbles, gravel and sand with clusters of dense vegetative growth, primarily common alder (*Alnus glutinosa*) (Figure 2). The Nourse Moraine has a measured length of 2640 ft (804 m), an average slope of 15%, and a calculated height of 396 ft (120 m) (Denton, 2005). The estimated width of the moraine is 2296 ft (700 m).

Methods

Three geophysical methods were used to assess the presence of an ice-core within the moraine. Each of these methods relies upon a different geophysical property on which to base an interpretation and conclusion, and when used collectively, these methods greatly increase the confidence in the conclusions. Moreover, because unforeseen site conditions might hinder or even prohibit the use of any one method, having multiple methods available provided a backup approach to the field effort. The specific methods used for this geophysical survey were direct current (dc) resistivity, electromagnetic (EM), and gravity.

Unfortunately, due to poor helicopter landing conditions on the eastern half of the moraine, the swift current of the outlets, and time restrictions, only the west half of the moraine was assessed. It is assumed that the study area is representative of the entire moraine, and conclusions based on the data are applicable to the moraine as a whole.

A static stability assessment was performed using the visual information collected in 2004 and 2005, and the geophysical results (Appendix A).

Findings

On August 5, 2005, a project debriefing meeting was attended by BLM team members Chuck Denton, Theresa Thibault, Brent Lewis, Meg Hahr, and KLGO Head Ranger Reed McClusky. The Nourse Team discussed the complicated logistics, adverse weather conditions, and difficult terrain that resulted in slower-than-expected data acquisition, but preliminary observations indicated that acceptable information was collected. BLM representatives expressed the need to further analyze the data before conclusions about moraine stability could be discussed with confidence. Nonetheless, preliminary data suggest no ice-core, but rather a layer of moraine sediment consisting of large boulder and gravel atop a competent bedrock foundation.

Geophysical Survey

Preliminary findings of each of the geophysical methods suggest there is no ice-core within the Nourse Moraine; however, the data were only collected on the western half of the moraine as access to the eastern half was too hazardous for helicopter landings or for crossing the moraine's outlets. To date, the dc resistivity results provide the best insight to the internal structure of the moraine (Figure 3). The 500m long (546.8 yd) resistivity profile indicates a thick layer (30m to 80m) (32.8yd to 87.48yd) of unconsolidated gravels and boulders atop a competent bedrock surface. The GEM survey (EM) acquired 20km (12.4274 miles) of data that shows spatial changes related to the various sediment deposits of the moraine (Figure 4). Simultaneous to the acquisition of the EM data, detailed topographic information (X, Y, Z) was collected with decimeter or better accuracies to produce a topographic map of the study area (available on request).

Although more time is needed to invert the EM information and obtain depth information, the preliminary data suggest the lack of an ice-core. The gravity meter rented from Scintrex is the best available gravity technology, but its battery problems significantly reduced the amount of gravity data collected. Though only 13 stations were acquired out of the 50 planned, the preliminary gravity data collected also suggest the lack of an ice-core.

Static Stability Assessment

Based on the results of the geophysical data and the basic dimensions of the moraine, the BLM performed a static stability assessment of the moraine as an earthen dam. The static stability assessment is presented in Appendix A. The conclusion of this assessment is that the moraine is stable; however, environmental hazards other than a melting ice-core could have adverse effects on the moraine and flood potential.

Conclusions and Recommendations

The primary objective of this geophysical survey was to assess the Nourse Moraine for the presence of an ice-core that upon its deterioration may lead to structural failure of the moraine. In addition, the geophysical survey obtained information regarding the thickness of the moraine sediment and the overall geometry of the moraine. While the presence of an ice-core is important, these additional attributes (sediment thickness and type; the moraine height, length, slope, etc.) collectively establish the moraine's ability to function as an earthen dam. These characteristics were assessed by a BLM Professional Engineer specializing in dam assessments (Gary Fisk, P.E.). According to Fisk (see report in Appendix A), the Nourse Moraine appears to be a stable structure, but other possible catastrophic sources could have adverse effects on the moraine and the potential to cause additional flooding. Though remotely possible, these other mechanisms include liquefaction of earthen material due to violent shaking induced by earthquake events, overtopping of the moraine as proglacial lake water is displaced by a large mass, and wasting events such as catastrophic glacial calving or ice falls of upstream glaciers.

Although Fisk recommended it in his preliminary report (Appendix A), according to the following documents the Nourse Moraine does not require federal regulation as it is a natural structure. Per the National Dam Inspection Act of 1972 P.L. 92-367 (33 U.S.C 467) and as written in the National Inventory of Dams (version 3.0, 2005) and the National Dam Safety Program P.L. 104-303, a dam is an "artificial barrier" that has the ability to impound water. BLM Manual Sec. 9177 defines a dam as a "man-made structure."

Geophysical data verified by Fisk indicate a stable natural structure exists in the Nourse Moraine. Structural stability may be degraded or excessive water displacement may occur in the unlikely event of an outstanding natural anomaly. These events cannot be predicted, implying that scheduled inspections will not mitigate results. Public awareness may be the best mitigation at this time.

The authors wish to thank Jared Abraham, currently with the U.S. Geological Service, for his assistance with data collection and processing.

Figure 1. Two high-energy streams flow across the surface of Nourse Moraine to a downstream glacial lake. These streams initiate from a proglacial lake created by the retreat of the Nourse Glacier ***(background)*****.**

Figure 2. Nourse assessment team carries equipment across moraine composed of multiple-size class sediments, including large boulders, cobbles, gravel and sand.

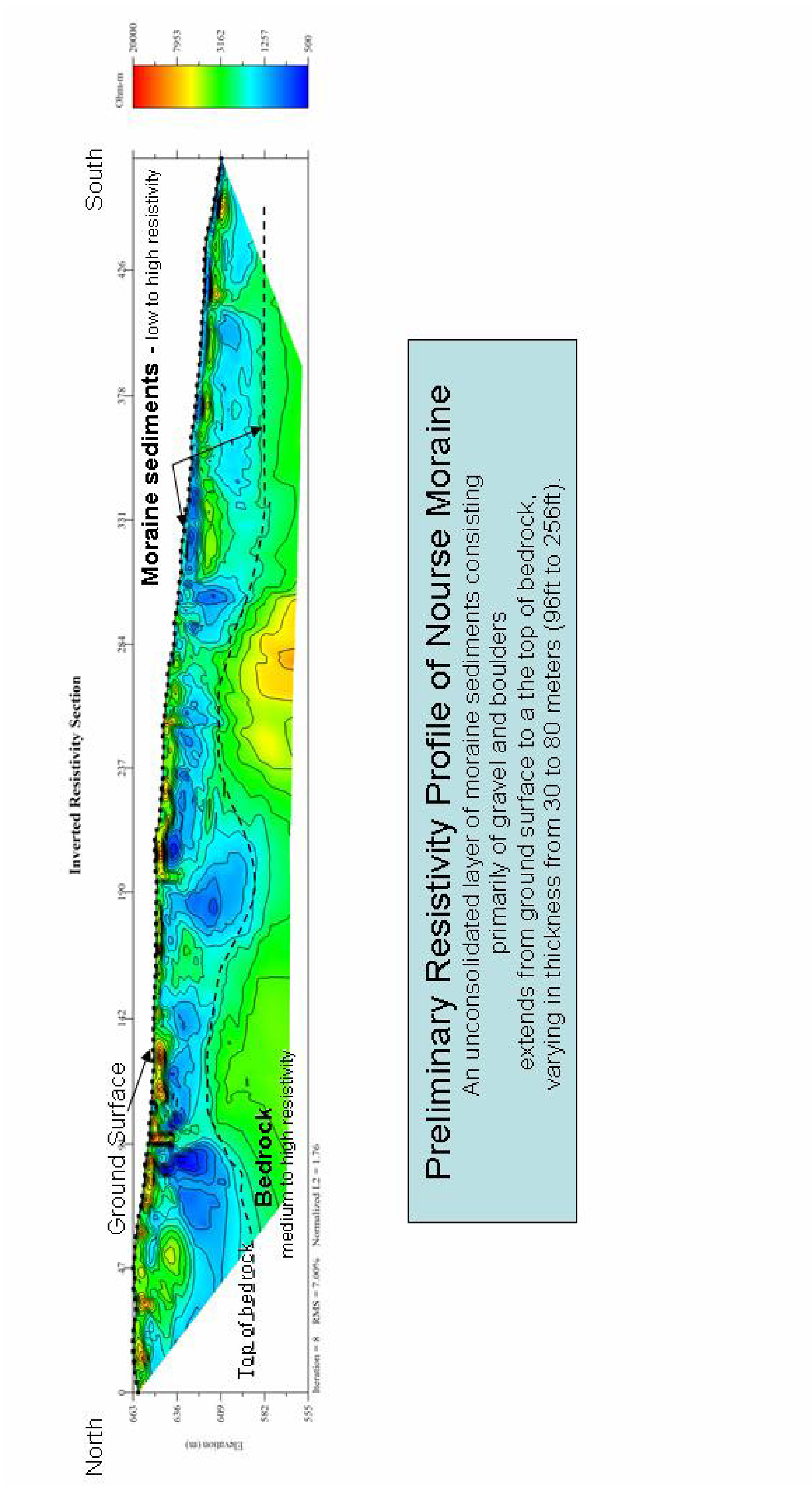

Figure 3. Resistivity profile of Nourse Moraine

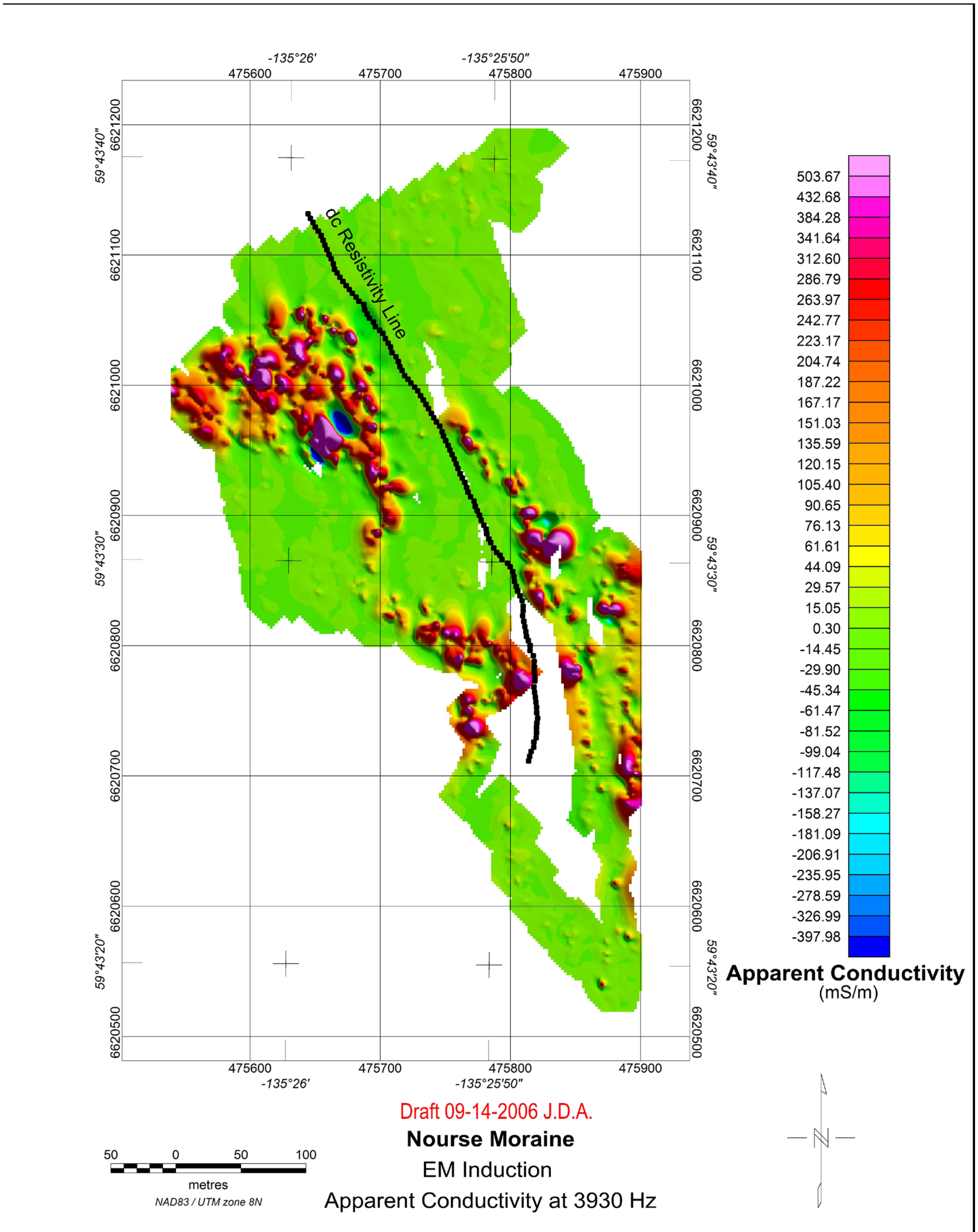

Figure 4. Map of EM Induction analysis and apparent conductivity at Nourse Moraine.

APPENDIX A

Static Stability Considerations, Nourse Moraine, Dyea, Alaska

Preliminary Evaluation by Gary Fisk, Civil Engineer, P.E.
Bureau of Land Management, U.S. Department of the Interior, ST-110
August 29, 2005

Reference:

Denton, Standley, and Lewis. "A Field Investigation of Glacial Lake Outburst Potential in the Taiya River Watershed, Skagway, Alaska." Bureau of Land Management-Alaska, U.S. Department of the Interior, June 2005.

Background:

The Nourse Moraine, upriver from the Klondike Gold Rush National Historic Park and upriver from Dyea, Alaska, impounds a natural reservoir fed by a receding glacier. Because of the flooding caused by failure of the nearby West Creek Glacier Moraine, park managers have requested BLM to evaluate the static stability of the Nourse Moraine.

A cross-section of the moraine showing geophysical resistivity values was furnished by BLM ST-180, based on work done in the summer of 2005. The Nourse Moraine is a 2640ft-long glacial deposit between two lakes. The moraine has a ground surface slope of approximately 15% (1V:6.7H, or 8.59º). Approximately 130ft of boulders, cobbles, gravel and sand overlies undulating bedrock. Several large seasonal streams, fed by the receding glacier, flow over the moraine. The streambed is composed of large boulders and cobbles with little potential for erosion. At least one spring was noticed in the moraine.

Preliminary Evaluation:

The ground surface of the moraine is nearly flat. The presence of frozen material in the moraine is unknown, and is not indicated in the resistivity survey. The moraine is a "bull-nose" formation, pushed into place by glacial action. The pushing action probably tended to push the larger boulders together into intimate contact, forming a reworked rock mass with a high angle of internal friction. It is unknown if the boulders are well-rounded or angular. Angular boulders would have a higher angle of internal friction, hence higher stability.

Possible failure modes are: earthquake-inducted liquefaction, overtopping erosion caused by a large hydrologic event, embankment failure by static stability (a "sunny day" failure), and internal erosion (piping). Because of the nearly flat surface slope, a classic slip-circle type of embankment failure is nearly impossible. An overtopping event caused by a large hydrologic event is a very remote possibility because the moraine is a naturally armored embankment. The large boulders would move only with a catastrophic hydrologic event. Flow provided by a slowly receding glacier is not a catastrophic hydrologic event. Internal erosion (piping) is not considered likely because the embankment apparently does not contain fines, which cause the build-up of a phreatic surface in the moraine. In fact, the existing voids in the moraine allow significant quantities of seepage to proceed through the embankment, reducing pressures that would otherwise develop. There are no reports of cloudy seepage emanating from the embankment, so it would appear that no fines are piping out of the moraine.

With such a gently sloping ground surface, the most probable type of failure mode would be earthquake-induced liquefaction. But since no massive sand deposits are indicated in the resistivity survey, liquefaction would be an unlikely failure mode.

Modern zoned embankment dam design requires a static stability safety factor of 1.3. Although no static analysis has been performed with this evaluation, it is clear from inspection that the static stability factor of safety is greatly in excess of 1.3.

Recommendations:

1. Determine if the Nourse Moraine should be regulated by the Federal Guidelines for Dam Safety (FGDS), 1979. The referenced report notes that the National Park Service (geomorphologist Hal Pranger) has conducted dam break analyses showing that a catastrophic release of the reservoir behind Nourse Moraine could cause flows on the Taiya River in Dyea, Alaska, five times the estimated 500-year flood event. Perform a hazard rating analysis to determine flood depths and velocities in populated areas downstream of the Nourse Moraine. If the moraine were found to be high-hazard (i.e., failure could cause loss of life), then the following guidelines from FGDS would apply:

    - Establish an Emergency Action Plan (EAP) to notify park visitors and downstream residents if the moraine were to fail.
    - Begin annual dam safety inspections.

    It is common for low-hazard dams in good condition to become high-hazard dams as population moves into the flood plain downstream of the dam.

2. If the moraine were found to be high-hazard, a basic geologic exploration program should be considered to determine the condition of the moraine.

APPENDIX B
Literature Cited

BLM Manual Section 9177 Maintenance and safety of dams, Bureau of Land Management, U.S. Department of the Interior, Manual Transmittal Sheet.

Capps, Denny Lane, 2004. The West Creek Glacial Outburst Flood Klondike Gold Rush National Park-Skagway, Alaska. Klondike Gold Rush National Park, National Park Service, P.O. Box 517, Skagway, AK 99840.

Denton, Chuck, 2005. A field investigation of Glacial Lake Outburst Potential in the Taiya River Watershed, Skagway, Alaska. Bureau of Land Management-Alaska, U.S. Department of the Interior, Open File Report 99.

Fisk, Gary (P.E.), 2005, Static Stability Considerations, Nourse Moraine, Dyea, Alaska, Preliminary Evaluation, Bureau of Land Management, U.S. Department of the Interior, ST-110.

National Dam Inspection Act of 1972, P.L. 92-367 (33 U.S.C 467).

National Inventory of Dams, Version 3.0, 2005. Headquarters, U.S. Army Corps of Engineers, Civil Works Engineering Division.

Water Resources Development Act of 1996, National Dam Safety Program, P.L. 104-303.