Maintaining Stability Beneath Cold Region Transportation Infrastructure

With Special Emphasis on Railroads

By

SHANE M. FERRELL

A REPORT

Submitted in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

MICHIGAN TECHNOLOGICAL UNIVERSITY

2009

This report, "Maintaining Stability Beneath Cold Region Transportation Infrastructure With Special Emphasis on Railroads," is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN CIVIL ENGINEERING.

DEPARTMENT of Civil and Environmental Engineering

Faculty Advisor ______________________________________
Dr. Pasi T. Lautala

Department Chair ______________________________________
Dr. William M. Bulleit

Date ______________________________________

Abstract

Spurred by recent concerns over rising transportation costs, increased accessability and the desire for natural resource development, several cold climate railroad projects are currently under development around the globe. As the demand for new rail infrastructure grows and the possibility of global climate change becomes more apparent, stabilization of cold region rail transportation structures becomes an important challenge.

This report is a comprehensive effort to better understand the difficulties and challenges associated with construction of rail embankments across permafrost. Analysis of costs, performance and constructability of engineered solutions and a site specific case study for a selected section of the Alaska Railroad have been performed.

The first objective of the report is to identify some of the problems occurring in the soils beneath rail embankments and the most promising engineered solutions to stabilize these issues. Methods investigated include: thermosyphon tubes, air cooled stone embankments, ventiduct embankments, shading boards and awnings, convection sheds, insulating methods such as foam boards, peat, wood chips or tire shreds and embankment modifications such as widened shoulders and berms. Analysis and comparisons utilize available data and include selected decision criteria, such as perceived advantages and disadvantages, engineering considerations and economic costs.

Research conclusions indicate that each location has a unique set of conditions. Differences in soil type, temperature, precipitation and vegetation all contribute to the

individuality of the site. There is no single engineered solution that can be applied to all sites and each location should be evaluated on an individual basis. Additionally, in many cases, the best cooling option appears to be a combination of solutions. Each method has a distinct set of advantages and disadvantages which can be used in combination with other alternatives to exploit the benefits of each.

The second objective of the report is to reevaluate a site specific case study which was conducted for the Alaska Railroad's Ester siding near Fairbanks, Alaska. This involves reviewing a geotechnical study conducted by Shannon & Wilson, Inc. Knowledge gained through the literature review and research findings are applied to recommend the best course of action to improve conditions at the site.

Data gathered during the Ester Siding design and construction phases was examined and it was concluded that the "do nothing" method appears to be the most cost effective solution. Continued maintenance and the addition of ballast in regular intervals seem to be the least expensive method to address the continued settlement issues at this location. However, from the viewpoint of ensuring site stability, a combination of thermosyphons and polystyrene insulation would offer a long term solution worth consideration. Findings regarding anticipated costs and engineering considerations have been included.

Acknowledgements

Many individuals deserve recognition and gratitude for their efforts on my report. Several helped by providing their time and expertise while others offered encouragement and moral support during the many long hours and stressful days. While not everyone can be mentioned specifically, there are several individuals who merit special recognition for their amazing help and contributions.

I would like to sincerely thank my advisor, Dr. Pasi T. Lautala for his encouragement, expertise, patience and guidance during the course of my graduate studies. Without your vision and willingness to help, my report would not be in the condition that it is today. Thanks as well to my committee members Dr. Bernie Alkire and Brian Lindamood for their knowledge and time in reviewing my project. Your contributions were well received.

Also thank you to the University of Alaska Fairbanks and the Michigan Tech University Transportation Center for their financial support of my education and research efforts. This report would not have been possible without it.

Finally, a special thank you to my mother Brenda Mikula for the many encouraging words and editing which helped to shape my report into a more complete document. Through the many complaints, rough drafts and long hours, she was always there as my biggest supporter.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

The construction of transportation infrastructure in cold climates has always been a challenging task. Projects such as the Trans-Siberian Railroad, Alaska Pipeline and ALCAN Highway portray images of extreme conditions and rugged individuals building across wide expanses of frozen ground.

Remote locations which have been thermally stable for centuries undergo a very rapid and abrupt change with the construction of transportation infrastructure. Disruptions to the natural energy balance of the soil from construction and surface modifications can lead to serious degradation of the subgrade soils. Permafrost degrades, soils compress and drainage patterns are altered. Further aggravated by climate change, permafrost and deep seasonal frost areas are expected to experience increased deterioration due to human interaction. Effective countermeasures must be developed to counteract this soil degradation and help to stabilize these sites to continue successful operations of vital transportation connections.

Recent developments such as the demand for natural resource development, increasing accessibility, and rising energy costs have spurred planning and construction of cold climate rail projects worldwide. Locations such as Alaska, Scandinavia, China, Russia and Canada are planning or already constructing cold climate railways to efficiently move freight in these unique environments. One of the planned railroad projects is the Alaska Canada Rail Link (ACRL) which will connect the Alaska Railroad to the current

Canadian rail network (Figure 1) (ALCAN RaiLink Inc. 2007). As planning for the ACRL progresses project leaders have recognized the importance of better understanding issues pertaining to cold climate railroads.

Figure 1: ACRL Route Alternatives

As part of this effort, Michigan Technological University was requested to address this issue by synthesizing the best railroading practices in areas of deep seasonal frost and permafrost. One of the key challenges identified in the project has been stabilization of the railway embankment. As the frost levels and permafrost soils change and degrade, the track structure is altered. The result of these track changes can be significant frost heaves or settlement areas which may interrupt rail operations. This report will identify and investigate engineering solutions which have been developed to minimize the settlements occurring in such locations.

Statement of the Problem

The disturbance to the natural soil from activities associated with the construction of railway embankment is perhaps one root cause to many of the future problems with the embankment. Areas that have for centuries been undisturbed have reached a state of thermal equilibrium. For the most part, the thermal forces affecting the soils have been balanced over time, allowing the state of the soil to remain constant.

Construction activity causes many unnatural forces acting upon the soil and environment. Vegetation is altered or removed which changes precipitation and solar absorption factors. Soils and surface conditions are disturbed allowing previously frozen ground to thaw and consolidate upon exposure to increased external energy and loading factors. With the placement of a heavy soil embankment instead of the natural surface cover, a significantly different thermal profile is developed. The result is thawing, settlements and increased stress on the subgrade soils which previously withstood natural forces in a state of equilibrium.

With the new development and construction of cold climate rail lines, many of these geotechnical issues are expected to become significant concerns. As a result, embankment stabilization is emerging as a critical issue for many of these projects. Further agitated by changing global climates, the ground conditions beneath many of these rail lines and their infrastructure also change. Historically, embankments constructed across permafrost have depended upon the frozen ground to provide bearing capacity for the infrastructure. This permafrost ground performs well in carrying the loads imparted by the infrastructure and railroad traffic. However, as these soils begin to thaw and degrade, the bearing capacity of the subgrade is reduced, leading to embankment settlements and distortions (Figure 2).

Figure 2: Track Deformations Due to Frost Heave

Ultimately, maintenance resources, track time and financial capital must be diverted from other projects to address these failures. As embankments and ballast sections deform, they can bring the tracks out of the tolerance for their operational speed, leading to possible slow orders and delays. Trains must also be slowed or stopped while maintenance crews repair and adjust the track back into an acceptable range. If solutions can be identified to minimize or eliminate these embankment variations, a more uniform rail network will develop. This will allow the railroad to operate at higher speeds and with more capacity resulting in a lower annual cost.

Research Objectives

This project is divided into two main sections. The first section consists of a literature review focusing on the isothermal reactions occurring in the permafrost soils and the engineered stabilization solutions to address these issues. The second portion is a case study identifying potential engineering solutions for a problematic location along the Alaska Railroad.

The literature review provides an overview of journal articles, conference proceedings, government documents and engineering consultant reports. Problems and solutions associated with embankment construction across permafrost were reviewed to identify various types of engineered solutions and their adaptability to railroads. Primary objectives for the literature review were:

- Introduce the reactions and thermal changes occurring in subgrade soils beneath railroad embankments across permafrost
- Identify stabilization methods applicable for use by railroad engineers to address these problems
- Define advantages and disadvantages of each method

The objective of the case study was to highlight the challenges faced by the Alaska Railroad at their Ester Siding location near Fairbanks. This siding has experienced extensive settlement since its construction in 2005 and currently requires frequent maintenance. This study was in response to a direct request from railroad representatives to reexamine stabilization alternatives in this location. The specific aim of the case study was to:

- Review geotechnical report and conclusions provided by Shannon & Wilson in 2003
- Develop recommendations for cost effective passive cooling solutions that can be implemented after construction on this site, or other similar locations along the Alaska Railroad

Representatives indicated that their ideal solution should be a mechanically passive (maintenance free) cooling method that can be installed on short sections of “at risk” track. The solution could be implemented on sections that otherwise may be susceptible to frost heaving and settlement due to an unstable ground state.

Definitions and Limitations of the Study

Cooling methods are often divided into two types: active and passive. Methods are sometimes defined by their mechanical properties and characteristics. In this case, active methods are those which use anthropogenic energy sources or moving parts, while passive methods require no power and use no mechanical parts (Long and Zarling 2004). For the purpose of this research project, cooling methods are defined by their thermal characteristics, not their mechanical ones.

From a thermal perspective, active cooling is defined as techniques which *freeze or refreeze soil using no external energy*, while the passive cooling methods' main function is to *delay thawing or otherwise slow permafrost degradation with no heat removal*. As a result, all methods included in this report are considered mechanically passive cooling methods.

Additionally, many innovative and unique engineered solutions may exist in locations around the globe. However, this study focuses primarily on the most documented methods used or adapted by railroads for permafrost stabilization. When available, resources from other sectors such as highway and pipeline cooling solutions were utilized, although applicability of some may be called into question due to the unique loading conditions of railroads.

While deep seasonal frost areas present numerous challenges and affect significant portions of many rail lines, they were not considered during this report. Instead, focus was given to addressing issues with rail embankments constructed across permafrost soils.

Chapter 2: Literature Review

Thermal Regime of the Soil

There are several geophysical properties involved in the thermal energy balance of a location. The construction and placement of rail embankments can have wide ranging effects on many of the natural processes present at a location, sometimes with detrimental consequences. The more prominent geophysical properties as well as a brief description of each are listed in Table 1, and Figure 3 gives a simple graphic representation of many of the energy sources affecting the thermal regime of the soil.

Table 1: Soil Balance Energy Factors

Geophysical Property	Description
Surface Radiation	Short wave solar radiation and the long wave atmospheric radiation. Typically is the leading energy source in permafrost regions
Atmospheric Convection	Heat transferred between the air and the surface layer
Moisture Flow	Energy transferred through evaporation, condensation and the movement of moisture in the soil
Phase Change	Caused by the physical change of the moisture such as ice to water or vice versa
Conduction & Convection	Energy transfer between soil layers such as geothermal energy

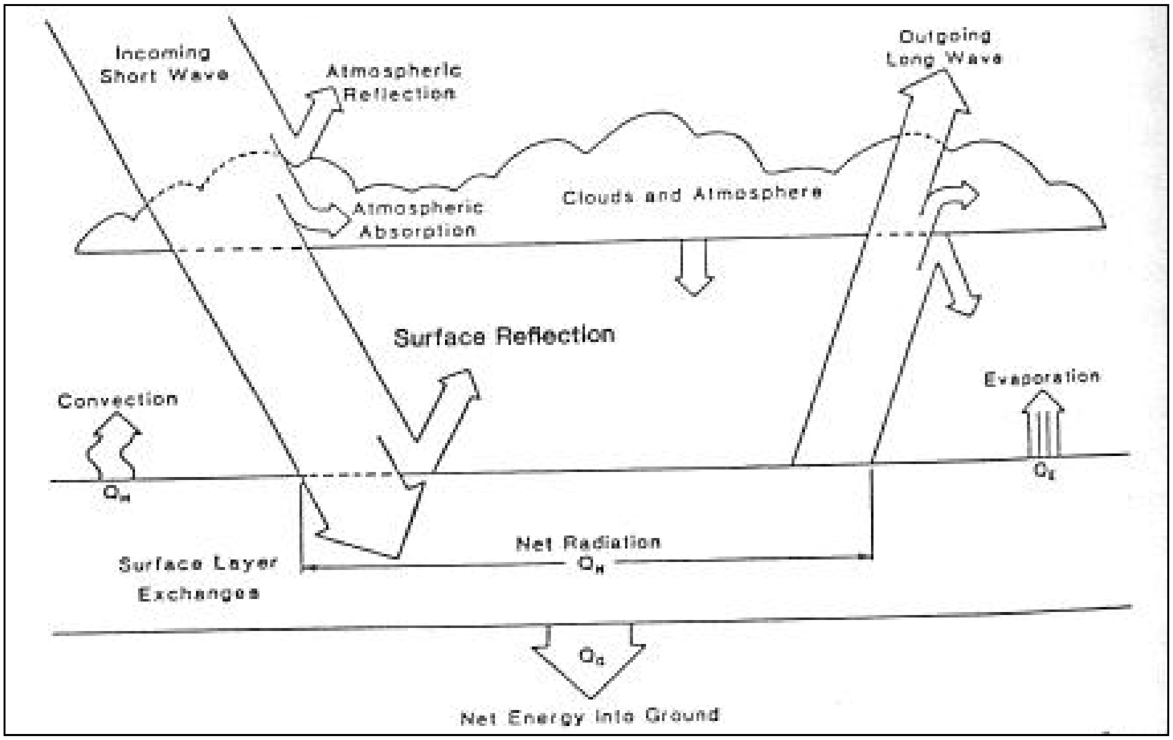


Figure 3: Soil Energy Balance- Without Vegetation (Esch 2004)

Environmental features of a location have a notable influence on the mostly unseen energy transfers which occur in the soils beneath the surface layer. Main components and some of their most observable roles are listed in Table 2, with a brief discussion on each presented afterward. Features examined include vegetation, precipitation and water formations, soil type, solar influence and wind currents.

Table 2: Surface Features and Their Role in Energy Transfer

Environmental Feature	Site Function
Vegetation	Protection from surface radiation, influences convection currents and moisture flow.
Precipitation/ Water & Ice	Directly related to site drainage and moisture flow. Phase change energy is generated through this feature as well. Soil freezing also alters soil matrix structure.
Soil Type	Fine grained soils can retain or absorb water, creating saturated soil pockets and reducing bearing capacity. Coarse grained soils freely drain water and change little in volumetric size when frozen.
Solar Influence	Impacts the amount of radiation present at a given site. High altitudes and low latitudes result in more exposure to solar radiation.
Wind Currents	Influences convective cooling of the surface. Can provide cooling or warming influence depending on the temperature of the current.

Vegetation is an important factor of the energy transfer, as in plays a major role in maintaining the thermal balance of the soils. The cover provided by trees and shrubs minimizes the solar radiation directly reaching the soil. In addition, they play a role on the natural convective heat transfer between the air and the soil. For example, dry moss and lichens have been found to have an insulating value roughly comparable to fiberglass insulation. (Gavriliev 2004)

The removal of the vegetation in particular can have significant consequences to the thermal regime of the soil. In a road project near Barrow, Alaska, a layer of tundra was removed and replaced with a 2 foot (.6 meters) thick roadway embankment made of silty sand. (Farouki 2004) Consequently, the insulating value of the newly placed embankment soils was not thermally equivalent to the natural ground soils. The result is subgrade soils which display colder than normal temperatures during cooling months and warmer than normal temperatures during warming months.

Construction activities can severely alter water infiltration and change drainage patterns which may lead to significant subsurface soil changes. As water freezes, its volume expands by roughly 9%. As a result, soils with at least 90% saturation will expand in size when frozen. The freezing expands the volume of the soil matrix and breaks it apart to make room for the ice. With exposure to an external source of water and under slow freezing conditions, silts in particular can expand several times the anticipated 9-10% volume change due to the increasing presence of ice in its soil matrix.

Another characteristic of slow freezing is the development of ice lenses and inclusions. As freezing occurs, the water is drawn to the freezing surface and the result is layers and lenses which form parallel to the freezing surface. These lenses are found only in fine grained soils and can range from centimeters thick in the active layer, to several meters thick in permafrost soils. (Andersland and Ladanyi 1994)

During thawing, the soil matrix remains basically intact and voids formed by ice, such as cracks and lenses, may remain even after the ice has melted. Some of these voids break down after the application of external loading, resulting in significant settlement and consolidation of the soil. This is the source of many problems both during construction and operation of railroads in the cold climate regions.

Thawing rates and settlements can also be significantly impacted by the size and orientation of ice pockets within the soils. Smaller ice pockets have a larger specific surface area leading to greater heat input and faster thawing rates. Thawing of frost heaves may result in pockets of supersaturated soil which have a mushy consistency. These pockets of soft soil can lead to settlements and consolidation, as they retain no bearing capacity to resist external loading.

As soils continue to thaw, unfrozen water begins to displace and redistribute throughout the soil. This process also is largely dependent upon the soil type in which thawing and drainage is occurring. Coarse grained soils are typically considered well drained as the excess water is dissipated quickly under hydrostatic pressure and gravitational forces. However, excess water in fine grained soils may result in the oversaturation, as roughly 15% of the water may be absorbed by the clay minerals present in the soil. The remaining water is dispersed by gravitational forces. Water moved by these gravitational forces tends to move down and to the sides, however in the case of permafrost soils, the bottom is a frozen and impermeable layer. The result is a significant amount of water moving outward through the sides and can lead to considerable erosion or settlement.

Permafrost degradation can often be reduced to manageable levels, or by using cooling solutions can be maintained in a frozen state. If no stabilization methods are utilized, thawing and soil degradation can be expected beneath many of the new cold climate railroads constructed in permafrost regions. Before it is built the designers and engineers must decide what the best course of action will be for each site. Thermal balance must be considered and the appropriate response will depend largely upon the local conditions and the desires of the engineer. The next sections present a review of the most commonly used engineered stabilization solutions to stabilize areas of permafrost construction.

Engineered Solutions

The majority of the literature review consisted of investigation of most common and best documented embankment stabilization methods. The solutions have been classified using a descending order of perceived thermal effects from "active cooling" to "passive cooling" (Figure 4). Methods which are perceived to have the greatest ability to actively remove heat from the embankment are listed near the top of the list (active cooling section). These solutions include thermosyphon cooling and ventiduct embankments. Methods which do not remove heat from the embankment, but function to reduce heat absorption, are placed in the passive cooling category. Examples include insulation and shading boards.

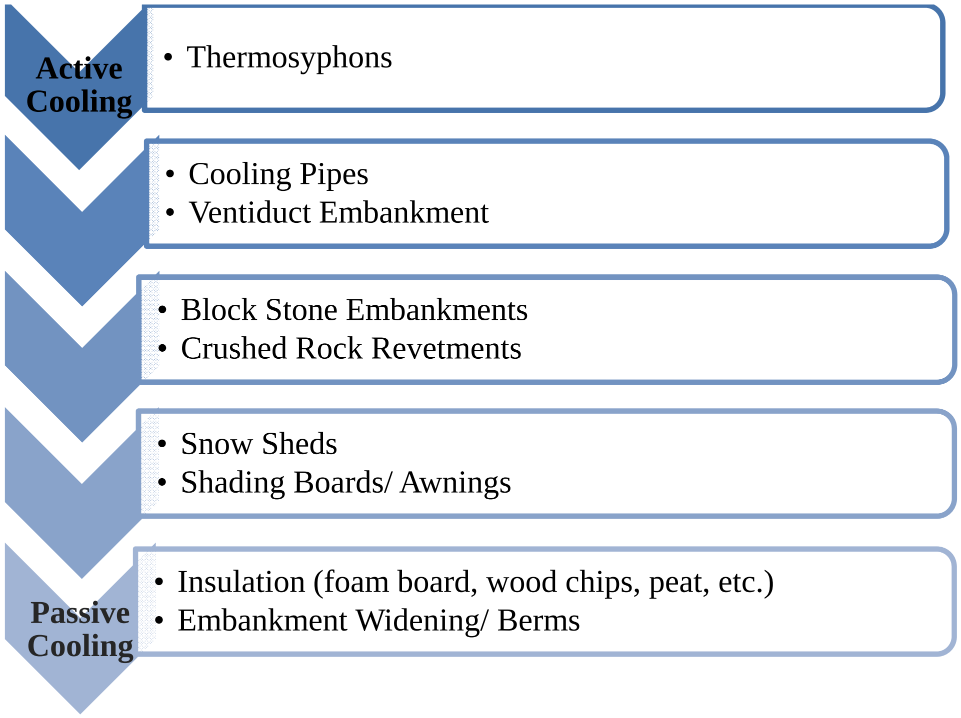


Figure 4: Active Cooling vs. Passive Cooling

Table 3 provides a brief summary of the engineered solutions investigated during the project, including some of the key considerations or issues associated with each solution. The solutions and related literature review findings are introduced in more detail in the following sections of this report.

Table 3: Engineered Solutions

Engineered Solution	Special Considerations
Thermosyphons	Transportation to site, field charge vs. factory charge, potential for damage or maintenance
Ventiducts	Placement depth and spacing, potential for blockage
Block Stone Embankments	Availability of large aggregates, plugging potential
Crushed Rock Embankments	Availability of medium sized aggregates, plugging potential
Convection Sheds	Snowfall and wind potential, Deterioration over time
Awning/ Shading Board	Snow accumulation and drifting, solar radiation intensity
Extruded Polystyrene	Water absorption potential, possibility of mechanical damage
Peat	Locally available peat, potential for settlements
Wood Chips	Potential for decay, availability of local timber
Tire Shreds	Environmental concerns, settlement potential
Embankment Widening/ Berms	Available aggregates/soils and obtainable land adjacent to embankment for additional required width

Thermosyphons

Thermosyphons are used where the frozen state of the soil must be maintained. A thermosyphon is a sealed tube which is pressurized and filled with a low boiling point liquid such as Freon, ammonia or carbon dioxide (Zhi, Yu et al. 2005). As air temperature drops below that of the embankment, the tube uses evaporation and condensation of the liquid to remove heat from the embankment and dissipate it into the atmosphere.

Heat from the embankment boils the liquid inside the thermosyphon tube and the vapor rises. When the vapor reaches the upper sections of the apparatus, cold air temperatures cool and condense the vapor back into liquid form, thus removing heat. The liquid then returns to the buried portions and completes another cycle.

In many thermosyphon applications, the air-heat exchanger is placed vertically with respect to the embankment to optimize air flow and cooling (Figure 5). In a study done along the Baikal Amur Railway in Russia, the air-heat exchangers were placed vertically while the soil-heat exchanger was inserted at an angle between 95°-100° with the condensers placed along the shaded side of the embankment (Kondratiev 2002). Thermosyphons have been used to effectively increase the depth of permafrost beneath transportation embankments and to counter the warming effects of construction and operation of these structures.

Thermosyphons are also very effective in utilizing the cold temperatures of winter to cool the embankments while guarding against the warming effect of the summer months. When the air temperature rises above the temperature of the embankment, heat transfer is essentially stopped. The liquid present in the tube will only boil if the soil is warmer than the air (Esch 1988; Goering 2003).

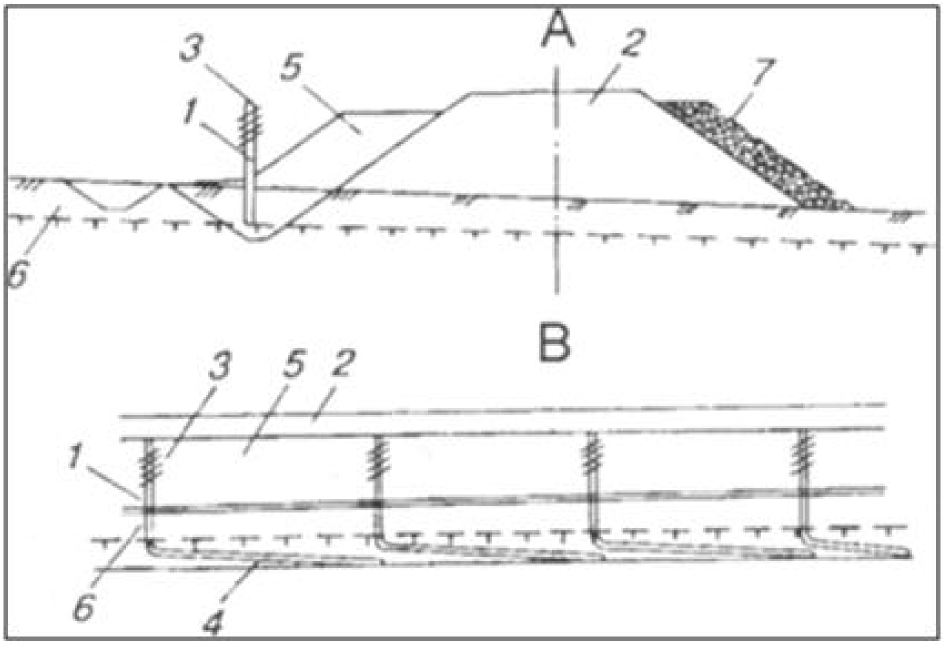


Figure 5: Thermosyphon Placement (Kondratiev 2002)

Experiments conducted along the Qinghai-Tibet Railway have found that the radius of influence around thermosyphons can extend to approximately 1.8 meters/5.8 feet (Figure 6). Based on these findings, the recommended spacing of these cooling tubes is 3 meters/9.7 feet center to center(Cheng, Sun et al. 2007). This spacing will ensure that the radii overlap, and cooling is consistent along the embankment.

Locations which may see the greatest benefit from these devices include areas of high-ice permafrost (Qingbai, Shiyun et al. 2007) and transitional areas between permafrost and non-frozen ground (Hayley 1988). The Hudson Bay Railway in Canada has successfully demonstrated the advantages of embankment stabilization using these tubes. Permafrost transition zones were first identified using ground penetrating radar and then stabilized using four thermosyphons spaced four meters apart (two on each side). Thermosyphon installation at these sites ranged from 1-6 tubes per hour, with an average of 3.3 per hour during the project duration (Hayley 1988). A project in Fairbanks constructed near the University of Alaska- Fairbanks utilized hairpin thermosyphons placed beneath the road surface to cool the subgrade and to prevent damage due to thermal degradation. Thermosyphons were chosen for this site due to the high capital cost of the project and the desire to prevent expensive future maintenance from settlements and distortions (Goering 1998).

Figure 6: Thermosyphons Along the Qinghai-Tibet Railway (Cheng, Sun et al. 2007)

Ventiduct Embankments

Ventiduct embankments typically utilize a traditional soil embankment with the inclusion of pipes placed widthwise across the embankment. These pipes serve as “air culverts” allowing air to pass effectively through the embankment and draw heat out from the interior portions of the soil embankment (Figure 7).

Pipes not equipped with blowers or air-gas mixtures use only the outside air as the cooling mechanism so as air temperatures increase, the effectiveness of the embankment cooling is reduced (Zarling, Connor et al. 1983). As the temperatures rise in summer months, the warm air flowing through the pipes can actually increase heat absorption within the embankment (Cheng, Sun et al. 2007). Due to this effect, many ventiduct systems have been equipped with shutter systems which allow the pipes to be sealed during warm periods in order to minimize air flow (Figure 7).

Figure 7: Ventiduct Embankment with Shutters (Cheng, 2007)

One system in Alaska utilized shutters which are manually opened during winter and closed during summer (Esch 1988) while other applications use automatic shutter systems which close automatically in warm weather (Cheng, Sun et al. 2007; Qihao, Fujun et al. 2007). A system equipped with an automated shutter system produced temperatures 1.13°C (2°F) cooler than a standard pipe embankment constructed nearby, although these shutters increased the overall cost of the pipes by roughly 10% (Qihao, Fujun et al. 2007).

In situ tests showed that the heat release period for the shuttered ventiduct was 40 days longer when compared to a standard ventiduct system. This longer cooling cycle allows more heat to be removed from the embankment soils and increases stability. Although the design life for the automated shutters is only five to ten years, for high risk stabilization areas they may prove to be a justified investment (Qihao, Fujun et al. 2007).

Experiments show that embankment temperatures follow an asymmetrical pattern with respect to the wind direction (Yu, Lai et al. 2005). Wind strength is important because as Esch noted, the temperature within the ventiduct increases as the air approaches the exit. Because of this effect, the cooling effect is reduced on the exit side of the embankment (Zarling, Connor et al. 1983; Esch 1988).

During a five year test period along the Qinghai-Tibet Railway, snow blockage within the pipes proved not to be an issue (Fujun, Xingfu et al. 2007). This is because of the limited snowfalls and relatively open terrain found along the Tibet Plateau. Hoar frost may also prove to be a challenge as it has contributed to diminished ventiduct performance due to its buildup on the pipe walls (Buchko, Kuznetsov et al. 1978).

Pipe placement with respect to the embankment height was found to have an effect on the cooling ability of the pipes. Pipes placed closer to the natural ground level provided a more significant cooling influence. In a field study it was found that pipes placed .7 meters (2.3 feet) above the original ground surface demonstrated the best cooling effect (Cheng, Sun et al. 2007).

Air Cooled Stone Embankments

Air cooled stone embankments, for the purpose of this report, have been divided into two categories. These are the block stone embankments and crushed rock embankments. Both embankment types have been used in several areas of warm permafrost where the long term stability of the embankment is in danger (Yu, Lai et al. 2003; Yuanming, Luxin et al. 2003; Qingbai, Shiyun et al. 2007). These embankments use poorly graded aggregates used to create pore space within the embankment. This porosity allows air to penetrate into the structure and by means of natural convection remove heat from the subgrade (Qingbai, Cheng et al. 2007; Cheng, Qingbai et al. 2008).

Several varieties of rock embankments have been developed to cool and remove energy from the embankment soils (Cheng, Qingbai et al. 2008). These include: a) embankment made completely of stone, b) a layer of rock placed directly on the native surface and used as a base for the soil embankment (interlayer embankment), c) rock placed along the side slopes of a traditional embankment (revetment embankment) and d) a combination of the two which uses aggregate along the bottom and sides of the embankment (U-shape embankment) (Figure 8).

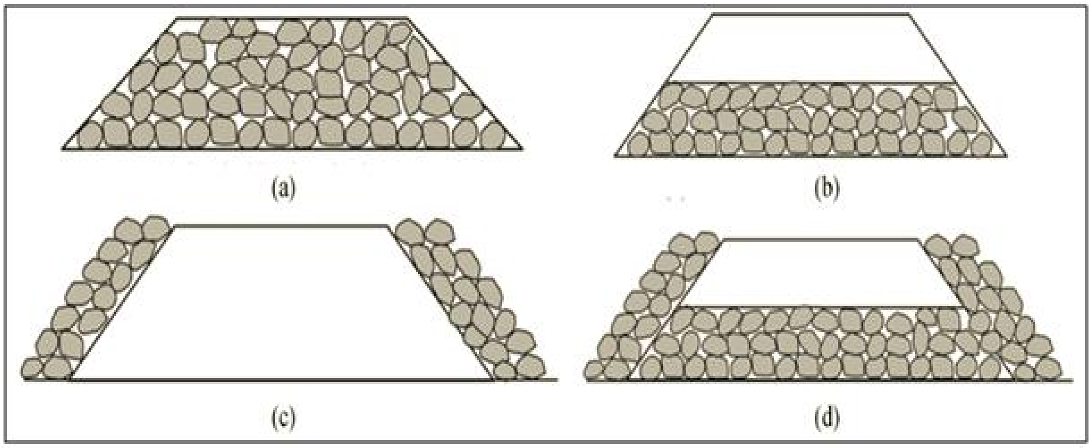


Figure 8: Rock Embankment Configurations (Cheng, Sun et al. 2007)

Air cooled embankments have demonstrated excellent cooling abilities in several field tests. A study conducted by in Alaska found that an air cooled roadway embankment lowered the ground temperature 6.9°F (3.8°C) compared to .2°F (.1°C) for a standard insulated embankment (Saboundjian and Goering 2002). The embankment was constructed across silty ice-rich soil near Fairbanks and the air cooled embankment helped to stabilize the roadway by cooling the embankment well below freezing. The control section showed a minimum subgrade temp of 31.5°F (-.3°C) while the cooled section showed a temperature of 15°F (-9.4°C).

Due to the low thermal conductivity of the air and the relatively small contact area of the stones, the rock layers begin to function as a thermal insulating barrier, limiting heat flow into the embankment. This insulating effect causes a large heat loss in the winter with limited heat gain during the summer. The resulting net heat loss improves embankment stability when compared to a traditional embankment (Goering 1998; Qingbai, Shiyun et al. 2007).

Interlayer embankments use wind and convection to move air through the embankment core while the revetment layer creates a natural chimney effect which draws heat out of the embankment and subgrade (Cheng, Qingbai et al. 2008).

U-Shaped embankments are a combination of a rock interlayer and a revetment embankment. They use coarse aggregates to create an air cooled envelope around the standard embankment section. With the advantage of cooling both the embankment center and the sides, this configuration may have a greater overall cooling effect than either of the other methods used individually. (Cheng, Qingbai et al. 2008)

Block Stone Embankments

Block stone embankments use large aggregates typically ranging between 20-30 centimeters / 7.9-11.8 inches in diameter (Figure 9). These large rocks provide large pore spaces for air circulation throughout the embankment and can significantly lower the ground temperatures of the subgrade when compared to traditional embankments. When block stone interlayers are used, the typical depth of the rock layer ranges between 1-1.2 meters/3.2-3.9 feet (Qingbai, Cheng et al. 2007) .

Figure 9: Block Stone Embankment (Qingbai, Shiyun et al. 2007)

Over 130 kilometers (81 miles) of the Qinghai-Tibet railway is constructed of coarse rock embankments and it has been a very successful method of stabilization. Test sites along the railway have shown that coarse rock embankments such as block stone embankments can raise the permafrost depth by as much as 1.8-2.6 meters (5.8-8.3 feet) in some areas (Goudong, Qingbai et al. 2008). However, there are two locations with a ground temperature above -.5° C (31.1°F) which have not demonstrated cooling with the coarse rock layer. This suggests that coarse rock embankments may not be suitable for extremely warm permafrost.

Crushed Rock Embankments

Crushed rock embankments utilize smaller aggregate, typically between 8-10 centimeters/ 3.1- 3.9 inches in diameter (Figure 10). Although the pore spaces are smaller than in block stone embankments, they function basically in the same way by circulating air to cool the embankment. A study done in 2003 found that although convection forces are stronger in the coarse rock layers, a fine rock layer can provide a more significant cooling effect. The results showed that the average embankment bottom temperature of the fine rock layer was 1.3°C (2.3°F) cooler than the coarse rock layer (Wenbing, Yuanming et al. 2003). The difference is caused by the positive heating effect of the coarse rock and is further increased by higher wind velocities.

Figure 10: Crushed Rock Embankment (Wei, Jilin et al. 2008)

Convection Sheds

A convection shed is a structure which is constructed on top of the side slope of the embankment and is used to enhance the stability of the slope and embankment (Figure 11). The sheds serve two very important functions which allow for embankment cooling. The first function is to limit the effects of solar radiation into the soil. In some cases, the sheds have been painted white which helps reflect light away from the embankment and reduces the overall warming effect of the embankment. A second function the sheds provide is to prevent snow accumulation from insulating the soil and limiting the cooling effect of the cold winter air (Esch 1988).

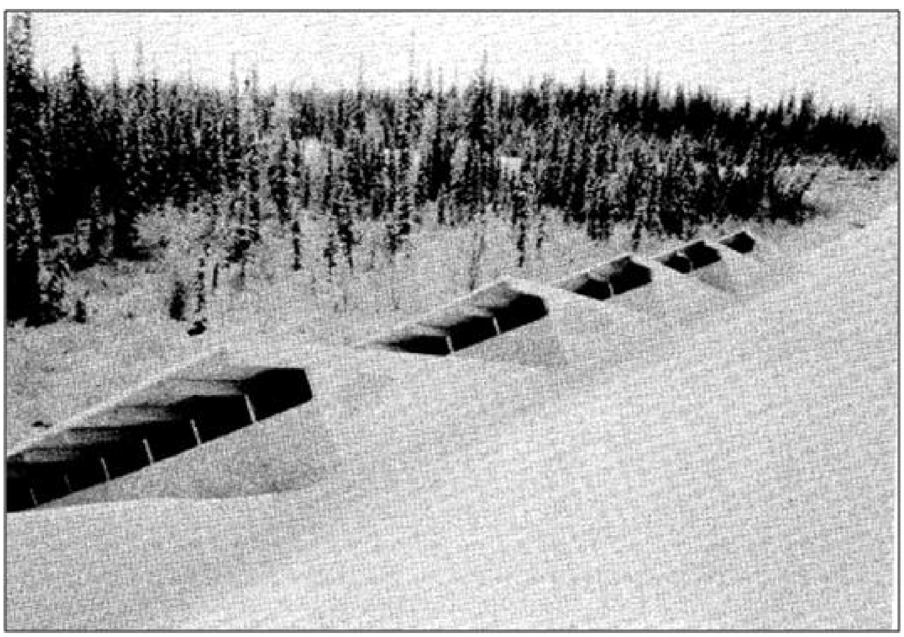


Figure 11: Convection Sheds Located Adjacent to Highway (Zarling and Braley 1986)

The literature review revealed only a handful of documented convection sheds, all of which were located in Alaska and adjacent to highways. A test section along Bonanza Creek utilized seven sheds built next to each other while the Farmer’s Loop test site used only a single convection shed. Despite the limited data available for these structures, they offer an interesting combination of cooling strategies such as air convection, snow protection and solar radiation reduction.

Side slopes are often warmer than the roadway surface or adjacent areas of undisturbed soil so they may benefit more from stabilization measures (Esch 1988). The convection sheds at Bonanza Creek examined were wooden structures measuring 32 feet long by 12 feet wide (9.8 x 3.7 meters) and equipped with a two foot (.6 meter) overhang above the opening (Figure 12). Total area covered by the sheds was 84 feet by 32 feet (25.6 x 9.8 meters) with a total unit cost of $1.50 per square foot of protected surface area (Zarling and Braley 1986). Shed openings were also oriented away from the direction of traffic to prevent snow plows and vehicles from directing snow into the structure.

Overall the sheds proved to be very effective in lowering the ground temperature. Results showed that while the average ground temperature outside of the shed was 3.9°C/39°F, the temperature of the soil beneath the shed was -2.3°C/27.9°F (Esch 1988; Zarling, Braley et al. 1988). This demonstrates cooling effect of 6.2°C/11.1°F during the course of the investigation. Additionally, the sheds doubled the freezing factor of the soil while cutting the thawing factor in half, resulting in a decrease of the thaw depth by two meters beneath the shed when compared to soil outside of the structure (Zarling, Braley et al. 1988).

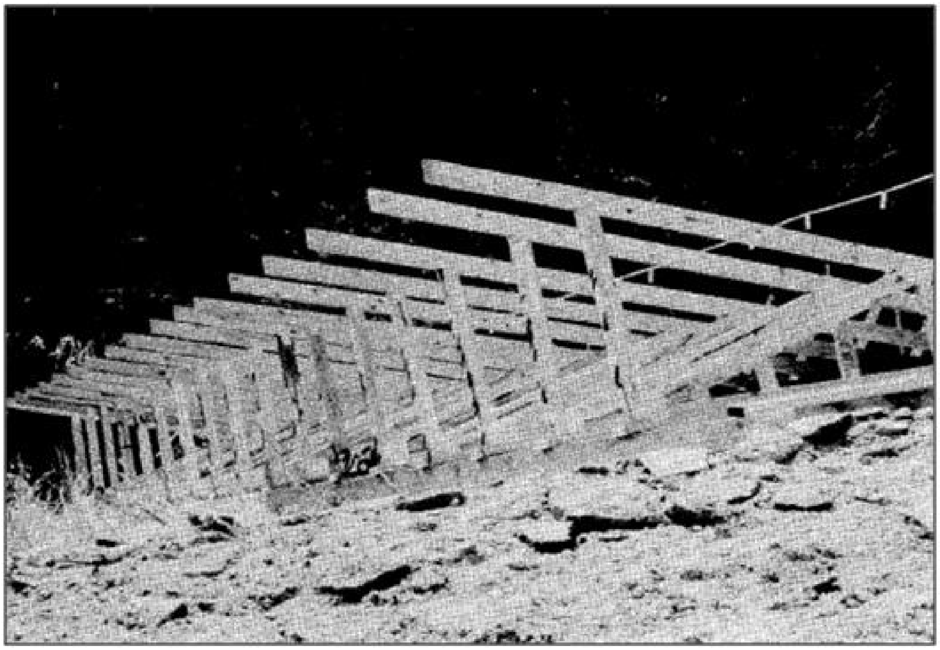


Figure 12: Wooden Frame of Convection Shed (Zarling and Braley 1986)

Zarling also forecasted that with the combined effects of increased cooling and decreased thawing that occurred beneath the sheds, unfrozen taliks beneath the structure would return to permafrost in six to eight years. Soils adjacent to the sheds would also see decreased settlement and increased stability (Zarling, Braley et al. 1988).

Awning/Shading Boards

This cooling method functions by reducing the influence of solar radiation on the embankment soils. The shading boards and awnings create a barrier above the embankment to prevent the most intense radiation from reaching the ground surface. This allows the warming influence to be minimized and can help to maintain the natural stability of the soils. These structures can also help to increase convection cooling of the embankment by utilizing wind currents help to remove heat by circulating in the space between the awning surface and the embankment.

The awnings can be constructed of several types of material, such as a rigid structure of wood, metal, or a canvas type fabric with soft sides that can be stretched over a rigid frame. Embankment awnings can also be constructed as standalone structures or used in areas of deep cuts or recesses as a canopy type structure above the track (Kondratiev 2002). As Kondratiev demonstrated standalone awnings can take several shapes such as an (A) arched roof, (B) ridge roof, or (C) simple roof (Figure 13).

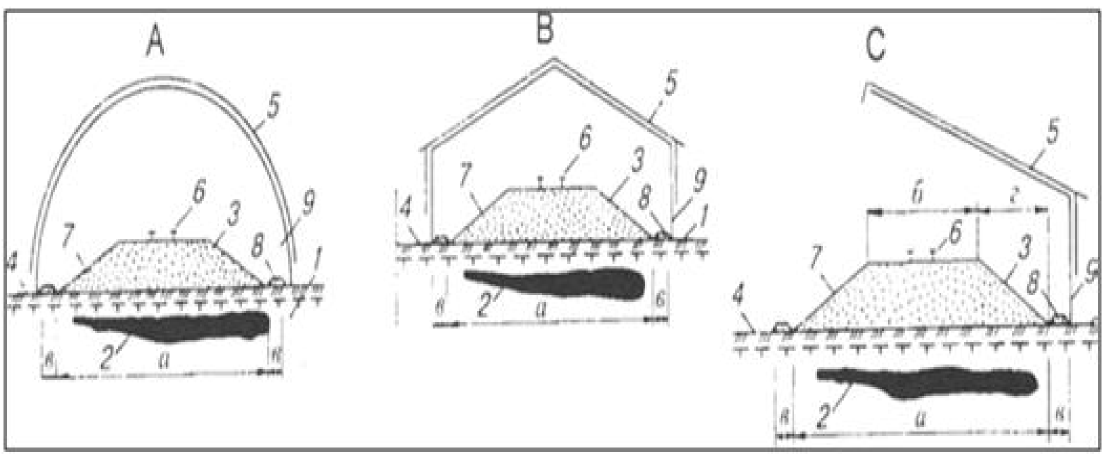


Figure 13: Railway Embankment Awnings (Kondratiev 2002)

In addition to reducing water infiltration and minimizing the insulating effect of wintertime snow accumulation, the awning structures help to stabilize the embankment by reflecting solar radiation (Kondratiev 1996; Wenjie, Wei et al. 2006). Embankment awnings are typically wide enough to cover the entire embankment which provides stability for both side slopes as well as the top of the embankment structure (Kondratiev 2002; Wenjie, Wei et al. 2006).

The awnings can be equipped with an opening or series of holes near the ground surface which allow for cross wind flow and to help remove snow accumulation within the structure (Kondratiev 1996; Kondratiev 2002). The holes allow natural wind and wind generated by passing trains to clear snow beyond the embankment and increase cooling by limiting the insulating effect of the snow accumulation. An awning test site constructed on the Qinghai-Tibet plateau found that the interior of the awning was 8-20° C (14.4-36° F) cooler than the exterior of the awning and found that after one, two and five years the permafrost table was raised by 150 centimeters (5.9 inches), 158 centimeters (6.2 inches) and 180 centimeters (7.1 inches) respectively (Wenjie, Wei et al. 2006).

An awning constructed along the railway also noted similar results. After one season of operation, the embankment beneath the awning was 3-5°C (5.4-9°F) cooler than a standard embankment constructed nearby and the permafrost table was raised between 1-1.7 meters (3.2-5.5 feet), with an average of 1.1 meters (3.6 feet) (Wenjie and Wei 2006).

High wind conditions found in the test section resulted in damage to the awning (Wenjie, Wei et al. 2006; Cheng, Sun et al. 2007; Goudong, Qingbai et al. 2008). These damaged sections may reduce the overall effectiveness of the awning as well as possibly slowing train operations. At the site, the effect of the wind damage was so severe, that a modified system of solar shades was introduced which lowered the exposure to potentially harmful wind gusts (Goudong, Qingbai et al. 2008).

Shading boards are smaller structures which are placed on the side slopes of the embankment. The shades serve a similar purpose as the awnings, to reduce solar radiation, water infiltration and snow accumulation, but they only stabilize the slopes, instead of the entire embankment as the awnings do (Figure 14) (Li, Li et al. 2008).

In a laboratory test, results indicated embankment sections with shading boards saw solar radiation intensity reduced by 85.5% (Yu, Pan et al. 2008). In addition to reduced solar radiation, sheds also help to reduce the detrimental effects of wind and water erosion to the embankment side slopes (Cheng, Qingbai et al. 2008).

Figure 14: Solar Shades (Cheng, Sun et al. 2007; Yu, Pan et al. 2008)

Because the embankment is protected from solar radiation, the shades help create a more uniform temperature distribution relative to the ambient air temperature. This limits the frequency and severity of the freeze thaw cycles and as a result should increase its stability over time (Cheng, Qingbai et al. 2008).

A test section along the Qinghai-Tibet railway showed temperatures under the shading board to be 3.2°C (5.8°F) cooler than an unprotected embankment section nearby and 1.5°C (2.7°F) cooler than an undisturbed natural soil section (Cheng, Qingbai et al. 2008). Another important function the shades provide is to use the natural temperature gradient for developing a chimney effect under the board. This effect allows the warmer, lighter air under the board to rise to the top and escape. The convective airflow helps to remove heat trapped behind the board as well as heat generated by the soil (Cheng, Sun et al. 2007; Yu, Pan et al. 2008).

A laboratory experiment found sections equipped with shading boards have over twice the airflow velocity of natural embankment sections (Yu, Pan et al. 2008). This is due to the convective forces chimney effect drawing air behind the board and increasing overall airflow near the embankment surface.

An important consideration for the creation of the chimney effect is the spacing of the shading board from the embankment slope. In the previous experiment it was found that a spacing of 15 centimeters (5.9 inches) generated the best airflow velocity. A smaller spacing limits airflow and promotes conductive heat transfer between the shading board and the embankment. A larger spacing reduced the conductive heat flow effect, but the air convection was also reduced due to the larger volume of air to be moved (Yu, Pan et al. 2008).

Despite their reduced wind profile, solar shades may be susceptible to wind damage. In a field test, the shades were placed 70 centimeters (27.6 inches) above the embankment side slope. This resulted in a significant wind profile and within two years over 50% of the shading board sections were destroyed by wind (Yu, Pan et al. 2008).

Insulation

Subgrade and embankment insulation layers are typically used as an alternative solution or in conjunction with stabilization methods introduced in the previous sections. The objective is to increase the thermal resistance of the embankment through the use of insulation. As a result, during winter months when the embankment is warmer than the air, the insulating layer provides a “heat preservation” effect which decreases heat release. In the summer months when the embankment is colder than the ambient air, the insulation provides a “cold preservation” effect which limits heat absorption into the soil (Cheng, Zhang et al. 2004).

In addition to reducing the temperature changes in the embankment, incorporating an insulating layer may allow the use of lower embankment heights than a traditional soil embankment (Railways; 1978). This is due to the insulating layer’s capability to provide an equivalent heat resistance when compared to a much larger soil embankment section.

This reduction in embankment height may result in significant soil weight reductions to the subgrade surface and lessen settlement over time (McHattie and Esch 1988).

There are many types of commercial insulation available today. In addition to the widely used polystyrene boards, other types of insulation include polyurethane, foamed sulfur, lightweight clay aggregate, peat, wood chips and tire shreds. This section will focus on the most common types, such as polyurethane, organics (including peat and wood chips) and tire shreds.

Extruded Polystyrene

Extruded polystyrene (XPS) is the most widely used embankment insulation material. This insulation has been used in a variety of transportation structures in several regions including roadways, railways and airports ranging from Maine and Alaska to Finland and Russia. The insulation is typically placed in segments as a board and may be used with a separating fabric to isolate it from the subgrade soils (Figure 15).

A key design aspect to polystyrene boards is their water absorption properties. Thermal resistance values of polystyrene decreases as the amount of water absorbed by the insulation board increases. Eventually this water absorption leads to inferior insulating properties. A field test conducted by Nurmikolu and Kolisoja in Finland found that by the end of the 40 year service life of the polystyrene board, an expected moisture content of 10-12% would be reached (Nurmikolu and Kolisoja 2005). This fact indicates that 40 years is roughly the maximum service life which could be expected from these boards.

Further moisture absorption would negate any benefit to overall embankment thermal stability and the insulation would no longer be effective.

Figure 15: Placing Polystyrene Boards
(Nurmikolu and Kolisoja 2005; Oiseth, Aaboe et al. 2006)

Tests conducted along the Qinghai-Tibet Railway in China and also on roadways in Sweden indicate the maximum thawing depth of insulated embankment sections is smaller than standard embankment sections (Gandahl 1978; Zhi, Yu et al. 2005). Frost penetration was also reduced in these insulated sections and it was observed that due to this effect, areas in which thawing occurs may not refreeze due to the heat preservation function of the polystyrene board (Zhi, Yu et al. 2005).

The placement of the insulation layer appears to play an important part on the effectiveness of its thermal protection properties. Gandahl and Zhi both noted that the closer to the embankment surface the polystyrene was placed; the more pronounced the insulation properties were. In other words, the insulating effect is greater, if the polystyrene is placed close to the surface (Gandahl 1978; Zhi, Yu et al. 2007).

Another example of the use of polystyrene is the Nunapitchuk airport. Polystyrene was chosen for use at the airport due to its ability to minimize settlement depths. The designers recognized that over the 20 year design life of the runway settlement was inevitable. A .24 meter (9.6 inch) settlement was estimated with a .1 meter (3.6 inch) thick insulating layer while a .15 meter (5.8 inch) thick insulation layer could expect to see .15 meters (5.8 inches) of settlement. These values were compared to the expected settlement of 3.7 meters (12 feet) for an unprotected embankment (Johnson and Bradley 1988).

Overall, even with the use of polystyrene insulation, settlement still occurred. However, it happened in a more controlled manner. This controlled subsidence was preferred to the anticipated large settlements which would have occurred with an unprotected embankment. Periodic releveling and maintenance of the runway was ultimately needed to maintain operations although much less than that would have been required had insulation not been employed.

In general, polystyrene provides good strength properties, resists water absorption and can survive mechanical damage such as cracks and indentations which may occur due to ballast and train loadings (Nurmikolu and Kolisoja 2005). However, tests suggest that during the 50 year life cycle of an insulated embankment, the thermal protection alone may not be sufficient. As an example, Zhi estimates that given climate warming models, permafrost thaw will still occur beneath insulated embankments along the Qinghai-Tibet Railway (Zhi, Yu et al. 2005).

Organics

Organics are natural versions of insulating materials. They include peat, moss and wood chips. They are commonly used due to their availability close to the construction site and their natural insulating abilities when compared against soil and gravel.

Peat

Peat has long been used by engineers and builders for its insulating properties due partially to its prevalence and abundance in northern regions, particularly near swamps and marshland. Peat is a dense organic material which can typically be cut from the ground in sections and placed beneath an embankment in similar manner to insulation boards (Figure 16). Peat has been found to have a relatively low thermal conductivity, roughly 50% that of natural soil. Additionally, its frozen conductivity is twice that of its thawed conductivity (Gandahl 1978; Esch and McHattie 1983; Esch 1988).

As a result, peat will increase heat flow out of the embankment when frozen and when thawed, the peat layer will act to reduce heat flow into the embankment. These combined effects lead to reduced thawing depths (Railways; 1978), as well as the prevention of talik formation beneath the embankment (Esch 1988).

Figure 16: Peat Formation and Cut Sections (University of Wyoming 2002)

A test conducted along a railway in China found that when peat was used as a backfill material, the seasonal depth of thaw was reduced by 14%, or roughly .3-.4 meters (11.7-15.6 inches) when compared to a mixture of sandy clay and crushed stone used on an adjacent section. In addition to backfill, peat was also placed as a vegetative mat on the side slopes. The side slopes consequently saw the maximum depth of thaw reduced by 20-30% and after two years, the peat was rooted to the embankment. As the root system became interwoven, slope stability increased and erosion was minimized (Railways; 1978).

Overall, Esch has noted that the benefits of placing peat insulation rarely outweigh the costs associated with this practice. The thermal benefits are considered minor when compared to the costs of time and equipment to place the peat layer. Instead, if peat is encountered, Esch recommends preserving the peat as a subgrade layer. The peat should be thawed and consolidated using a thin gravel layer for one summer season before construction. In this way the peat can be preserved as an insulation layer without the excessive costs of excavation and placement (Esch 1988).

Wood Chips

Brush and tree removal can be a problem on even the simplest types of construction projects. Road, railway and airport builders alike have all experimented with inclusion of the unwanted wood into their embankment designs. This practice has the benefit of reducing construction waste, as well as lightening the embankment load onto the ground surface. Wood chips have a wet unit weight of approximately 25% that of soil (Schrader, Lukanen et al. 1998) and can significantly reduce ground pressure found with traditional soil embankments. On a roadway section near Fairbanks, placement of wood chips reduced the embankment load by 20% (McHattie and Esch 1988).

A road section on TH 53 in northern Minnesota has also benefited greatly from the use of wood chip fill. The roadway was constructed through several peat swamps and was prone to periodic settlements. A decision was made to widen the embankments with wood chips which were placed at the bottom of the embankment and covered with clay and soil (Figure 17).

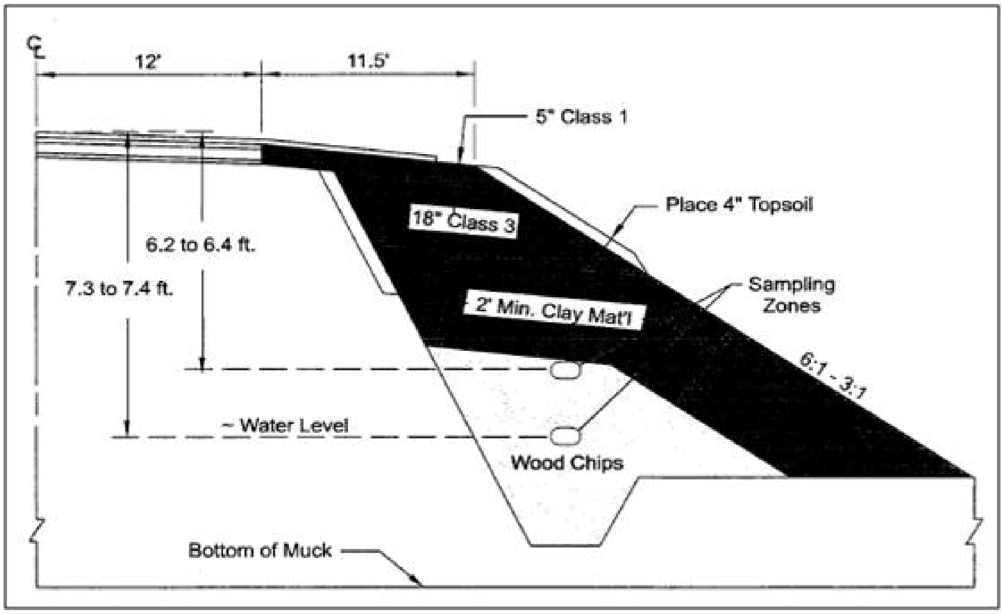


Figure 17: Wood Chip Embankment (Braun Intertec 1996)

Follow up testing concluded that after 19 years of service, no noticeable settlement had occurred in the embankment. The chips showed that very little volumetric change had occurred since placement and the used chips were virtually indistinguishable from fresh wood chips (Braun Intertec 1996). Despite the fact that wood chips placed closest to the natural soil displayed some signs of bacterial degradation, it was still estimated that the embankment could provide a useful design life of up to 35 years. After this period, natural chip decay may require resurfacing and backfilling to adjust settlements that have occurred (Schrader, Lukanen et al. 1998).

Tire Shreds

The use of waste tires in embankments is still a fairly new practice, although it is gaining popularity. Research and field tests are currently being conducted in a wide range of climates and under different loading conditions which may lead to increased usage of this method in the future. Shredded tires have a high thermal resistivity combined with durability and free draining properties which make them desirable for cold climate embankment fill (Humphrey and Eaton 1995). The tires can be shredded at a designated facility and hauled to the site or on site using portable shredders. The shreds care then end dumped and leveled with excavators and bulldozers, before they are covered with soil for final compaction (Figure 18).

The thermal resistance of shredded tires is up to eight times greater than gravel. A roadway test site in Maine found that a 1 foot (.3 meters) tire layer can reduce frost depth by 40% compared to a standard gravel embankment (Han 1998). Another test found that a 6 inch (15.2 centimeter) tire layer combined with 18 inches (45 centimeters) of gravel fill reduced frost penetration 22-28% (Humphrey and Eaton 1995).

Tire shreds can also be beneficial environmentally, as they reduce waste tire inflow into dumps. A cubic meter of tire chip fill can contain nearly 100 used tires. This means that for a mile of 2 lane roadway with a 12 inch (30.5 centimeters) tire layer, roughly 300,000 tires will be consumed (Khan and Shalaby 2001). An environmental disadvantage is the leachate which may leak from the embankment. Both wood chip and tire chip leachate can produce toxic effects on native species. Tire chips were also found to contribute to elevated levels of aluminum, iron, and manganese (Khan and Shalaby 2001). Testing performed in Wisconsin indicated most leachates were within acceptable limits and tests in Maine determined metal levels did not exceed drinking water standards (Han 1998).

Figure 18: Placing and Compacting Shredded Tires (Khan and Shalaby 2001)

Shredded tires appear to offer an interesting opportunity for using waste materials to enhance cold climate embankment stabilization. Premixing of soil and tire shreds is recommended by Han to increase workability and compaction. The cost of tire shreds ranges between \$1.50-\$10.00 per cubic yard (\$1.96-\$13.08 2009 Dollars) (Han 1998). Proper planning is important as transportation limitations may limit the use of this technology in remote locations due to the availability of shredded tires.

Embankment Widening/ Berms

Embankment widening and the placement of berms are common methods used by engineers to enhance stability of the rail embankments. These structures utilize excess soil or rocks placed along the shoulders or at the toe of the embankment (Figure 19). These oversized shoulders and berms do not bear the load of the soil, or train impact, and function more as a sacrificial structure. The goal is to allow the widened shoulders (or berms) to settle or crack, instead of the load bearing embankment (Rooney and Johnson 1988), thus saving in required maintenance costs.

Berms are typically made of silty soil, which have a reduced seasonal thaw depth when compared to gravel soils (Esch 1988). A test site along the Parks Highway near Fairbanks, Alaska monitored berms for 12 years after construction. It was found that although the berms slowed the formation of grabens for the first two years, it did not prevent the failure of the embankment (Esch 1983; Esch and McHattie 1983; Rooney and Johnson 1988). The berms were also found to settle between 40-60% of their original height and slumped outward from the embankment 2-3.5 feet/.61- 1.1 meters (Esch 1988).

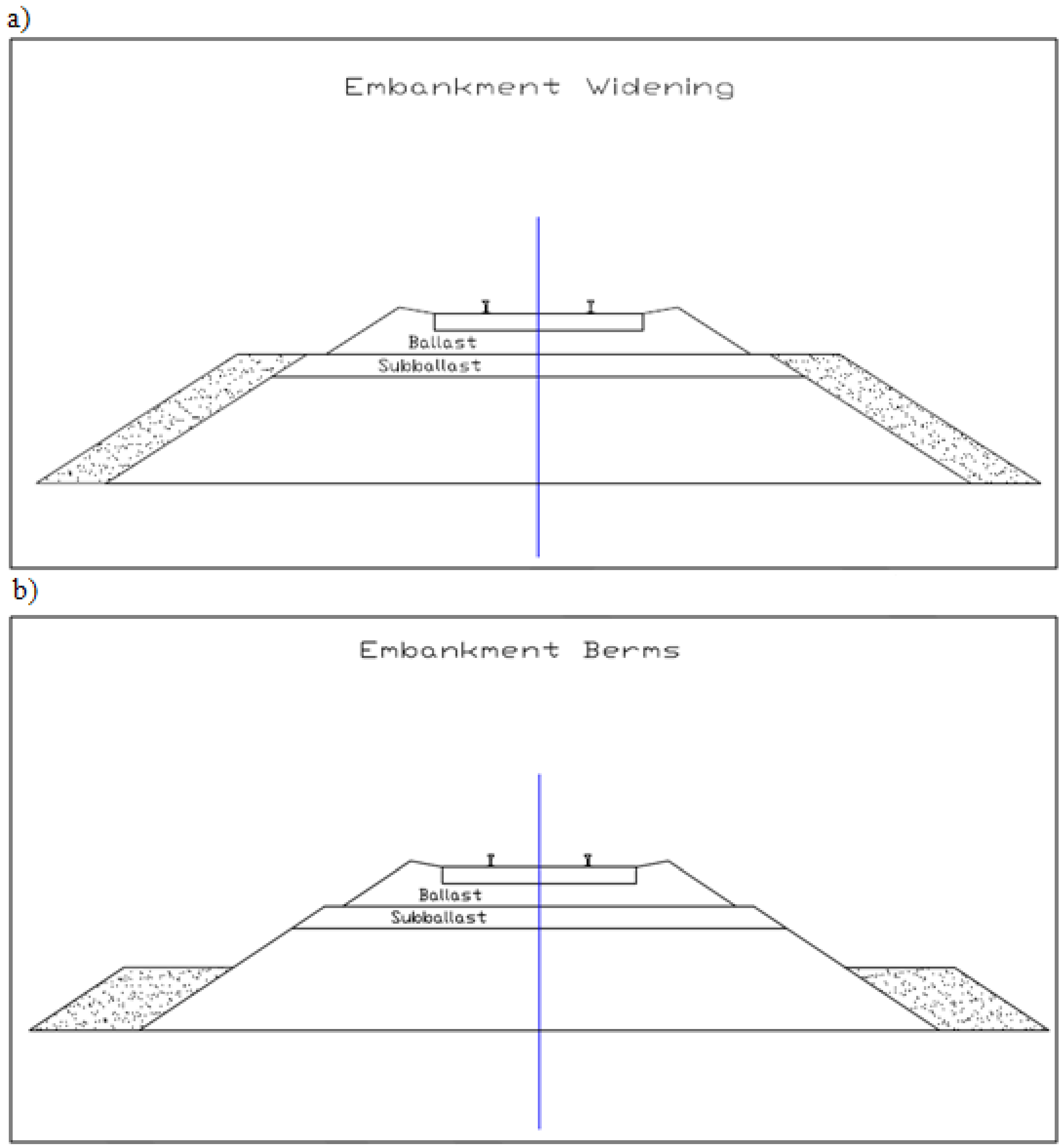


Figure 19: Embankment Widening (a) & Embankment Berms (b)

In addition to the settlements and cracking, it was found that the increased shoulder dimensions and the placement of berms resulted in a greater width of terrain disturbance for the site (Esch 1983). The increased soil disturbances lead to a greater thawing area and rapid settlement beneath the embankment (Esch 1988). Based on the results, embankment widening was determined by Rooney in 1988 to be cost prohibitive for highways and railways, due to the large amounts of soil required and the minimal thermal benefit offered by this method. Berms were recommended to be used only as a method to dispose of waste material, not as a thermal solution (Rooney and Johnson 1988).

Recent tests conducted along the Qinghai-Tibet railway also seem to confirm these earlier findings. Using a two dimensional finite element analysis, it was found that the increased dimensions of the berm have only a minor influence on the overall embankment temperatures. Berms were found to have an asymmetrical heat distribution between the north and south embankment slopes, with the southern berm developing a larger thaw zone. Overall, Yue concluded that the berm structure was not an efficient method of permafrost protection. Figure 20 shows the thaw zone progression of a bermed embankment and traditional embankment over a 50 year lifespan (Yue 2008). As the photo demonstrates, the two embankments are almost thermally identically, although the thaw zone beneath the embankment with berms is noticeably larger than the traditional embankment. The left side of each embankment represents the south facing exposure while the right side is the north facing exposure.

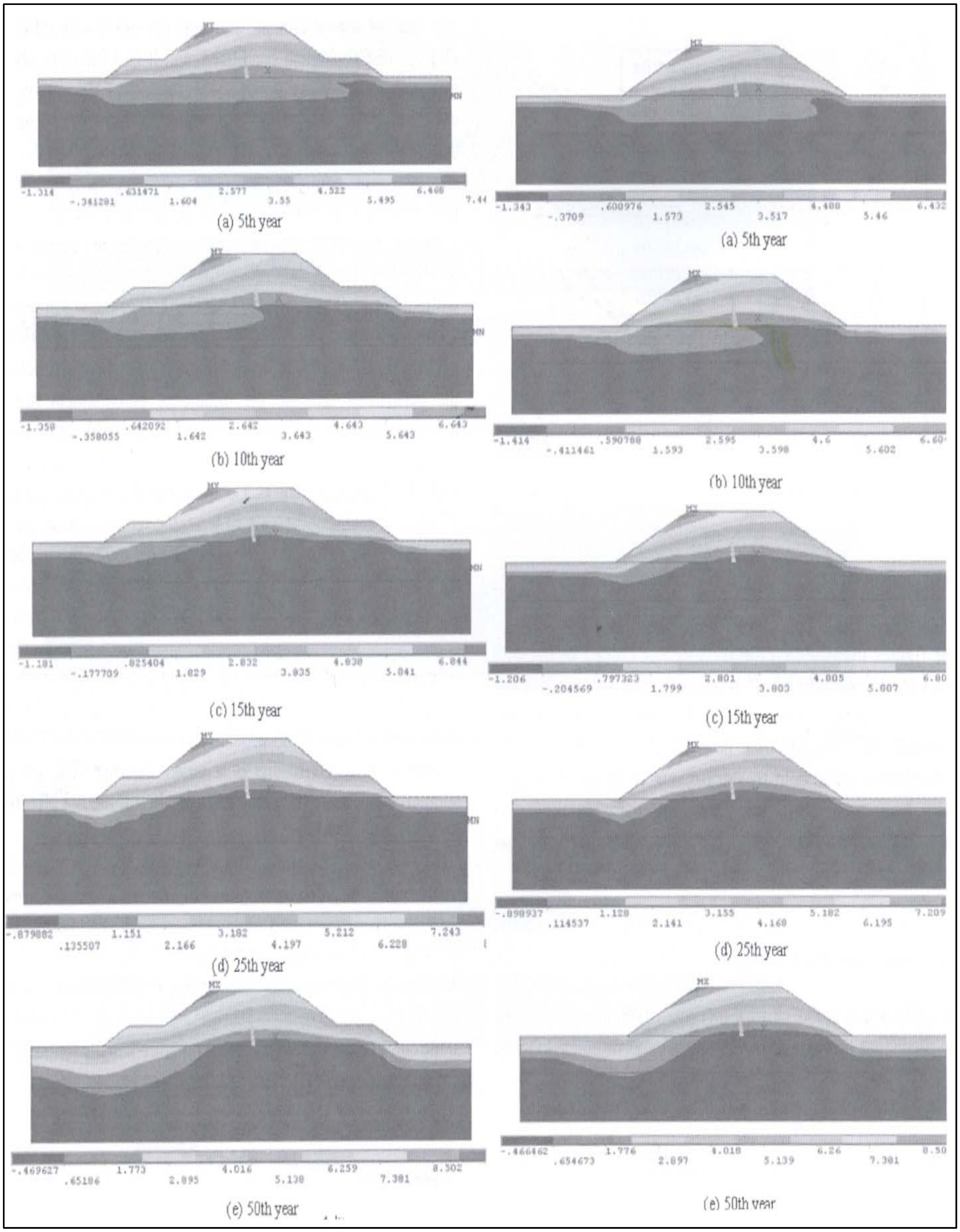


Figure 20: Embankment Thaw Zone Progression (Yue 2008)

Bermed Embankment (left side) Traditional Embankment (right side)

Chapter 3: Summary and Analysis of Stabilization Methods

Global climate change is proving to be an increasing concern for permafrost construction in cold climates worldwide. Research conducted along the Qinghai-Tibet railways shows with increasing confidence that temperatures are indeed rising and that actions should be taken to address this concern (Zhi, Yu et al. 2005; Cheng, Sun et al. 2007). Although climate change will not be consistent in all locations around the globe, its effect on the infrastructure should be a consideration at the sites of future cold climate construction projects.

Nearly all of the methods investigated in this report have been previously utilized in railroad applications. The few exceptions to this appear to be convection sheds, wood chips and shredded tire insulation layers. It could be speculated that wood chips and possibly tire shreds have been used in railroad applications, although the literature review did not find any instances of this.

Each type of engineered solution has its own unique set of advantages and disadvantages for stabilizing cold climate rail embankments. Some methods such as air cooled rock embankments or awnings, are effective in particular climates or locations like those with limited snowfall or without significant wind forces, respectively. Others, such as insulation layers, appear to be most effective when used in combination with other more thermally active cooling methods like ventiducts or thermosyphons.

The limiting factor doesn't appear to be the technologies themselves, but rather the climates and locations in which they are used. Snowfall, average annual air temperature, soil conditions, wind speed and solar radiation intensity all influence the effectiveness of the engineered solutions. Each site must be evaluated individually to find the best overall cooling solution for the climate and conditions found at that specific location.

Table 4 summarizes all of the engineered cooling solutions investigated during the project. In addition to a brief listing of some key site selection criteria for each solution, the expected outcome, potential risks and implementation/ construction methods are noted. The following sections provide discussion and comments regarding the contents of the table. In addition, a rough cost estimate has been created for each solution to compare the capital costs of the solutions. Detailed calculations are provided in Appendix A.

It should be noted that limited data was available to produce these estimates. Sources included available product catalogs, personal communications with industry representatives and data from literature sources. Necessary engineering assumptions to complete these estimates were made based on available data from reviewed literature sources. It should be recognized that the actual cost to implement a solution may differ significantly from those listed here, as material costs and labor, as well as production or logistics expenses can vary significantly between areas.

Table 4: Summary of Engineered Solutions

Engineered Solution	Site Selection	Expected Outcome	Potential Risks/ Drawbacks	Implementation / Construction Methods	Cost ($/100 track feet) ($/ 30.5 meters)
Thermosyphons	High risk sites, unstable permafrost, useful for transitional zones	Stabilization of thaw-unstable soils, refreezing of thawed soils	Damage during transport or installation, obstruction of fins during operation, maintenance potential	Can be constructed after embankment placement using track mounted auger	$27,500-$30,800
Ventiducts	Natural wind convection, ample drainage and lack of hoar frost, no problematic soils beneath pipes, low snow accumulation	Minimize differential settlements, reduce internal temperature of embankment	Blockage due to snow or debris, minimized performance due to settlements, water ponding, maintenance potential	Placed during construction of embankment or possibly after using jack and bore drilling. Recommended placement on NFS soil	$9,804- PVC $16,512- Concrete $23,756- Metal
Block Stone Embankments	Natural wind convection, nearby large aggregate sources (8-12 inch/ 20.3-30.5 centimeters diameter)	Increase convection cooling of entire embankment, increased full width embankment stability	Plugging due to snow or fines, settlement risk	Placed during construction of embankment	$44,800
Crushed Rock Revetment	Natural wind convection, nearby aggregate sources	Remove heat by convection cooling of shoulders, stability of shoulder sections	Warming in center of embankment with cooling of the shoulders (differential	Placed during construction or afterward (using side dump cars)	$12,000

	(3-4 inch / 7.6-10.2 centimeter diameter)		settlement), plugging due to snow or fines		
Convection Sheds	Natural wind convection, area not prone to excessive decay, problem zones may be targeted specifically	Facilitate wind convection while keeping shoulder free of snow accumulation, reduce solar radiation	Damage due to natural or manmade occurrences, decay of wood construction, maintenance requirement	Constructed after embankment, can be placed directly adjacent to problem locations	$27,448
Awning/ Shading Board	Susceptible to solar radiation, avoid excessive wind areas	Reduce solar radiation influence on embankment and improve convection cooling	Damage due to natural or manmade occurrences, maintenance potential	Constructed after embankment, can be placed across deep cut sections to reduce solar influence	No Data
Extruded Polystyrene	Area with moderate to high external heat influence, useful to minimize construction depth	Minimize heat influx into the soil, reduce frost penetration depths	Water absorption , mechanical damage or decreased insulating performance	Place during application of ballast or during ballast cleaning operations	$2,291.50
Peat	Natural sources of peat nearby, ability to cut and place peat sections	Minimize heat influx into the soil, reduce frost penetration depths, use naturally available materials	Decay potential, settlements due to decay, settlements due train loading or overburden load	Place during construction of embankment	No Data

Wood Chips	Availability of acceptable nearby timber, area not prone to excessive decay	Minimize heat influx into the soil, reduce frost penetration depths, use naturally available materials	Decay potential, settlements due to decay, settlements due train loading or overburden load. Potential for leachate contamination	Place after clearing and grubbing or during construction of embankment	$1,089
Tire Shreds	Deep water table preferred, desire to reduce embankment load, availability of waste tires	Minimize heat influx into the soil, reduce frost penetration depths, increase sustainable practices for transportation	Settlements due to train loading or overburden load. Potential for leachate contamination	Place during embankment construction	$444
Dry Bridge	Extremely high risk sites, poor soil conditions, stable track structure required	Ensures stability even during permafrost or soil degradation, eliminates settlements due to thaw or consolidation	Differential settlements of columns, damage due to natural occurrences (earthquakes, landslides, etc)	Constructed before placement of track	$1,040,000
Embankment Widening/ Berms	Areas where significant shoulder settlement is expected	Minimize settlement in structural portions of embankment by sacrificing non-load bearing shoulders or berms	Increased thawing zone, eventual settlement of the embankment core, maintenance required to correct settlements or cracks	Place during or after embankment construction	No Data

Thermosyphons

Locations which will see the most benefit from thermosyphon cooling are “high risk” locations. Examples include areas with relatively warm (< -1°C /30.2°F) and unstable permafrost, soils with high ice content or transitional zones. These units will serve to keep thaw-unstable soils frozen and to refreeze previously thawed soils.

Due to the fact that the tubes are metal and function only when maintaining a pressurized seal, thermosyphons may be susceptible to damage or leaking during their service life. If a puncture of the tube occurs, the pressurization is lost and the tube will no longer function correctly. Potential for damage in rail applications appears significantly lower than similar applications in highway or airport projects due to the limited mobility of rail vehicles.

There was a noticed lack of any sort of discussion of future maintenance costs or lifespan for thermosyphons in the reviewed literature. It can be assumed that maintenance of these units will be required in the future although the extent and costs associated with this remain unknown. An appropriate lifespan for design purposes was also notably absent. These items are important considerations for selection of cooling solutions and may result in significant future costs for this method.

Ventiducts

Ventiducts require the availability of natural wind convection. Without this convective cooling, ventiduct embankments rely on conduction cooling to remove heat. This is a much less efficient method and will not properly cool the embankment. Due to the need for a steady wind current, obstructions in the pipe reduce cooling efficiency. This means that debris such as accumulated ice, hoar frost, vegetation, tree branches or snow will reduce the overall effectiveness of this solution by restricting airflow. There is also the potential for maintenance to remove any debris that may obstruct the pipes and also to ensure that cracks and ponding water are addressed to keep the pipes working efficiently.

Pipes are recommended to be placed during construction so that they can be positioned on top of NFS soils to minimize settlement and heaving problems beneath the pipes. Soils or other locations with high moisture may be unsuitable for ventiducts, unless other counter measures are taken to minimize blockages due to frost and snow. Ventiducts do have the advantage of being able to be placed post construction using jack and bore tunneling. Jack and bore tunneling is less than ideal, especially in areas of poor soils, as the pipes cannot be placed on freely draining soils to reduce water related issues.

Given the heavy soil loading found in railroads, settlements and heaves in the pipe may cause significant damage to the pipe itself. If the cover height of soil above the pipe is no longer sufficient to protect the structure, cracks or deterioration may occur. As rail axle loads increase, ventiduct sections could see similar damage that current culvert and bridge sections are undergoing now due to heavier train loads.

Rock Embankments

Block stone and crushed rock embankments also require wind convection. A block stone interlayer is useful for cooling the embankment core while crushed rock revetments are more suitable for stabilizing shoulder sections. Due to the requirement for wind convection, permeable rock embankments are susceptible to plugging from snow or dust accumulation. Risks for these methods include potential settlements within the rock layer or increased thawing due to water infiltration through the void spaces.

These permeable embankments may also help to reduce some of the embankment load on the subgrade soils. By using these highly permeable layers, the embankment will not be as densely compacted as a traditional embankment. This would allow significant weight savings and in some field tests rock have been found to weigh up to 30% less than a traditional soil embankment. A separating layer of geosynthetics placed above the coarse layer may also be required when utilizing rock embankments. Without preventative measures like geosynthetics, soil mixing could result in altered freeze-thaw characteristics of the cooling layer, as well as reducing or eliminating the convective cooling effect.

Rock embankments seem particularly well suited for many of the conditions found in railroad applications such as heavy loads and the desire for minimal maintenance. Assuming the availability and reasonable costs of large aggregate, they appear to offer a reliable and cost effective stabilization method. They should remain maintenance free during their lifespan and provide good cooling of the embankment soils. Several configurations are available based on the perceived needs of the site. These embankments should be evaluated in locations which have the appropriate material availability.

Studies conducted along the Qinghai-Tibet railway by Wei and Jilin in 2008 observed settlements in rock embankments. Over a three year observation period, a standard embankment settled 89 millimeters (3.5 inches) compared to settlements of 220 millimeters (8.7 inches) in a coarse rock embankment and 140 millimeters (5.5 inches) in a crushed rock revetment. It is important to note however that after three years of monitoring, the rock embankments were observed to stabilize, while the conventional embankment continued to deform linearly with time (Wei, Jilin et al. 2008). This suggests that during the initial years of operation, even rock embankments are susceptible to settlement, although for very different reasons than the thaw settlements occurring in permafrost soils.

Convection Sheds

The sheds examined were of wood construction and excessive environmental decay could shorten the lifespan of the structure by eroding the wooden frames. Future sheds may be built of other materials, such as metal or plastic, to minimize decay potential although this may significantly impact their cost. Due to their small size and significant construction costs, sheds are not suited for large scale stabilization projects, but may instead be more appropriate for small trouble zones.

Damage to the shed due to events such as tree falls, vehicle impacts, vandalism or other similar events may result in reduced performance due to poor air circulation or increased snow accumulation. Convection sheds should also be periodically observed and maintained to ensure their integrity and operational efficiency.

Convection sheds may be more suited to the railway than their original application along highways. Given the smaller cross sections and limited freedom of railroad vehicles, the sheds can be located closer to the centerline of the railway. This means that the cooling effects provided by the shed may be more pronounced because they can penetrate more of the embankment width.

Awnings/Shading Boards

Awnings and shading boards are best used in areas prone to significant solar radiation. Locations such as low latitudes, high altitude, south facing exposures, or deep cut sections are good candidates for stabilization using this method. Excessive wind should be avoided due to the ground profile of these structures and the possibility of wind damage. However, mild to moderate wind is desirable due to the increased convective cooling ability of the embankment.

Shading boards may present a better alternative to railroads than awnings, especially if high profile cars such as double stack container cars or auto racks are forecasted. With an awning placed over the railway, design height would need to include sufficient clear space for these large cars. Shading boards present a low ground profile and would not obstruct or limit the types of traffic that could operate on the line even if the car sizes increase over the lifespan of the structure.

Insulation

Insulation layers such as polystyrene, peat, wood chips and tire shreds are all used to decrease heat infiltration into the embankment and also can help to limit frost penetration and thawing.

As a standalone engineered solution, insulation may not offer many advantages for permafrost construction. The insulation, although limiting the depth of thaw, also reduces the natural ability of the embankment soils to refreeze. This means that once a soil becomes thawed beneath insulation layers, it will likely not refreeze. This is not necessarily a detrimental effect, but it must be accounted for in the design and long term operation of the embankment.

Polystyrene insulation in particular appears to be very susceptible to mechanical damage due to contact with the ballast layer. Repeated train loading and the sharp angular surfaces of the ballast rock can create indentations or fractures in the insulation board, which may reduce its effectiveness. Placing the boards beneath a geotextile fabric or intermediate soil layer above the boards is recommended to reduce damage from ballast contact.

Dry Bridge

The dry bridge method is the most drastic stabilization method and has been used previously in locations in which settlement and thaw were considered unavoidable. Extremely thaw unstable soils, poor soil conditions and areas where extremely stable track are required are likely candidates for this method. Bridges utilize piles driven deep into the soils so stability and settlements are not anticipated. Due to placement above the surface, thawing, soil degradation or poor drainage will not limit the effectiveness of this solution.

Damages due to earthquakes, landslides, or differential pile settlement should be considered but are no more a severe risk than the risks to traditional bridges. Design enhancements can be made to address these issues and reduce exposure to these failure modes. Construction of the dry bridge must be completed prior to the placement of the rail, the same as a traditional bridge.

Embankment Widening/ Berms

One of the main advantages of using widened embankments or berms seems to be the fact that these structures are non-load bearing. Settlements and cracks that occur in these portions of the embankment do not directly affect the strength of functionality of the core embankment. The failures can be addressed and corrected as time and resources allow without major disruptions to the operation of the railway.

Berms in particular also seem well suited as a disposal area for waste soils and aggregates. During the course of construction, excavation and earthwork create soils and aggregates which are otherwise unsuitable to be reused in the embankment and subgrade. These soils which would normally have to be removed or disposed of could be used instead to build berms at the toe of the newly built embankment. Materials of this type have minimal costs other than the resources to move and place them and should help to stabilize the core embankment, if only for the first few years.

From a thermal perspective, widened embankments and berms offer little advantage over traditional designs. Results of the literature review indicate that although they may limit core embankment cracking and settlements, in the long term they do not prevent these from forming. Widened embankments and berms should be examined more closely for each site to better anticipate potential settlements and the advantages offered by these structures.

Chapter 4: Ester Siding Case Study

In 2003, a geotechnical study was commissioned by the Alaska Railroad to prepare a site analysis and construction plans for the proposed Ester (Goldstream) siding near Fairbanks, Alaska (Figure 21). The siding was to be 6,400 feet (1950 meters) long and would serve mainly as a passing siding for trains entering and leaving the Fairbanks area. Investigations were conducted by Shannon & Wilson, Inc. and included soil borings, materials sampling and recommendations for the construction of this siding.

Figure 21: Goldstream/Ester Siding Location

Conclusions of the geotechnical study indicated that nearly 3,100 feet (945 meters) of this site was located on peat underlain by relic ice and permafrost. These conditions present great challenges for construction, as they are prone to settlement and thaw degradation. Final construction recommendations made by Shannon & Wilson were for a combination of insulation soil replacement (mass exchange) to be used in conjunction with continued long term maintenance. Figure 22 shows the typical section for the recommended solution. It was noted during the study that to construct an embankment with the least possible settlement potential, it would have to be constructed outside of the thawed areas of the mainline track and should employ passive cooling using either thermosyphons or a permeable rock layer.

Ultimately, the siding was constructed using a standard embankment design, with no insulation or other cooling methods included. It was determined that continued long term maintenance was the preferred and most cost effective method for the site. Since construction, it is estimated that several feet of ballast has been added over the last four years to some locations along the mainline and siding to bring the tracks back to the proper elevation.

A request was made by representatives from the Alaska Railroad to review the data presented by Shannon & Wilson and to reanalyze the project conclusions. The desired outcome of this review was to identify potential cost effective engineered solutions that can be installed to the current, post construction situation. It was indicated that the ideal solution should be a mechanically passive system (maintenance free) to prevent future costs. The following sections review the analysis and recommendations made by Shannon & Wilson, Inc.

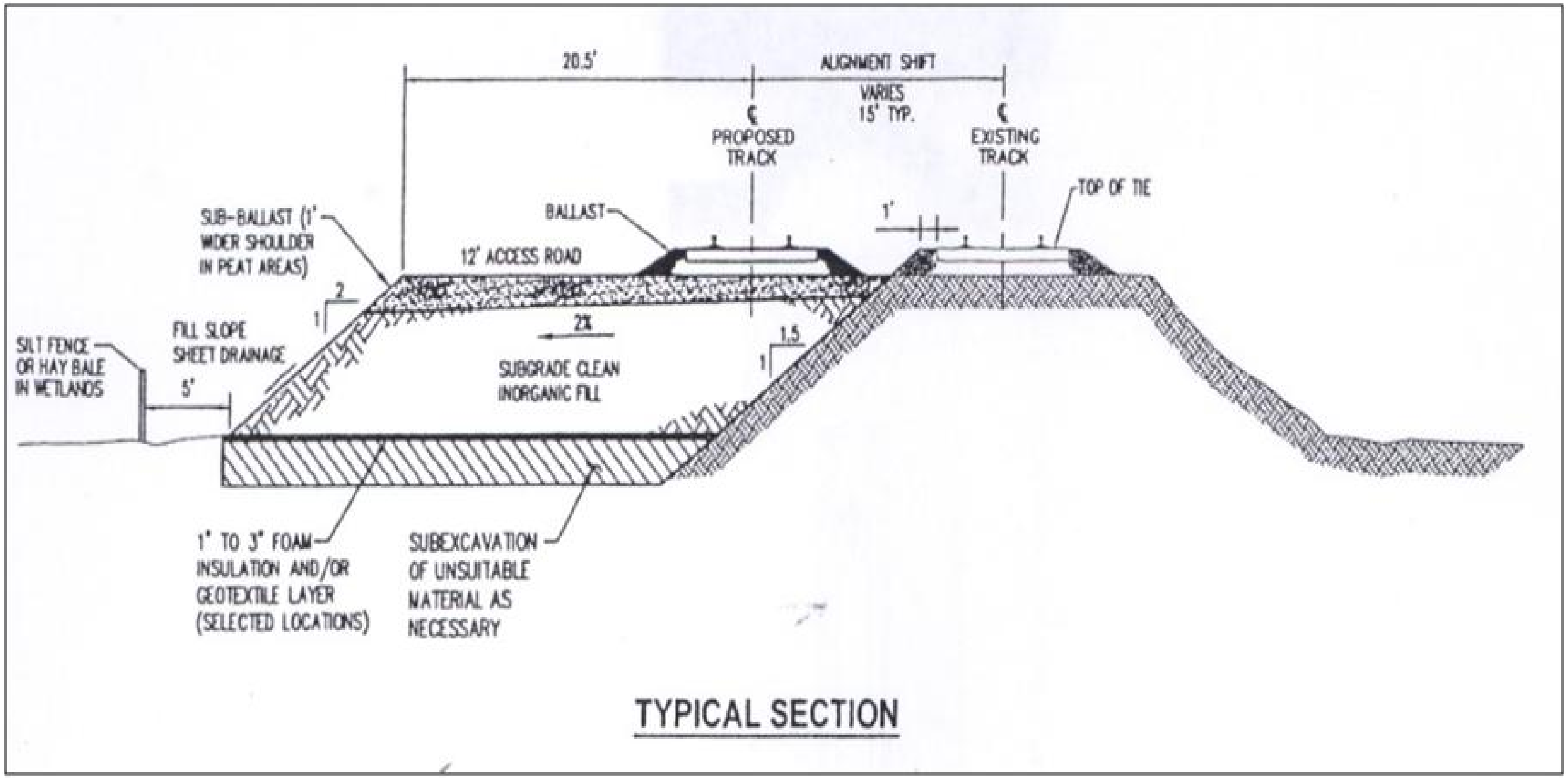


Figure 22: Typical Section- Goldstream/Ester Siding

(Shannon & Wilson 2003)

Site Conditions

Assuming that the climatic differences between Fairbanks and the Goldstream Valley will be minor due to their close proximity, data obtained from the National Weather Service for Fairbanks was used to summarize conditions for the site of the siding. Snowfall totals for the area average nearly 70 inches (178 centimeters) annually, with the maximum accumulated snow depth of 23 inches (58.4 centimeters) occurring in mid February (NOAA 2009). Temperatures for the area range between normal highs of near 70°F (21.1°C) with a record high of 99°F (37.2°C) in the summer and winter can see normal lows of -20°F (-28.9°C) with a record low of -66°F (-54.4°C).

Using available data, Shannon & Wilson concluded that the mean annual air temperature at the Goldstream site was 27° F (-2.8°C) with a mean annual surface temperature for the site of 37°F (2.8°C). These values showed that while the average air temperature remained below freezing, the ground temperature was roughly 10°F (5.6°C) warmer than the air.

Geotechnical Study

Shannon & Wilson stated in their report that the construction activities and the placement of a rail embankment above the unstable soils found was expected to increase the average soil temperature. This change would result in warming of the underlying permafrost and lead to thaw and consolidation settlements. Without insulation, maximum settlement of the thawed areas was estimated at nearly 7 feet (2.1 meters) over the next 50 years (Figure 23). An additional 2 feet (.61 meters) of consolidation settlement due to consolidation was forecasted in the peat sections beneath the existing track sections over the next 50 years (Figure 24). As a result of these large settlements, extensive maintenance and alignment issues were expected to arise with traditional construction.

Shannon & Wilson's investigation noted that the top of an existing 72 inch (182.9 centimeter) steel culvert near MP 458.4 was found to be 1 foot (.3 meters) above the existing ground surface. The report suggested the cause of this movement is due to significant ground heaving from the soils beneath the pipe. Another 36 inch (91.4 centimeters) concrete culvert at MP 459.2 was found to be collapsed and the drainage that normally moved through this pipe was instead flowing through the embankment. These preexisting drainage heaving issues further complicate conditions at this site and limit some of the corrective options available for site stabilization.

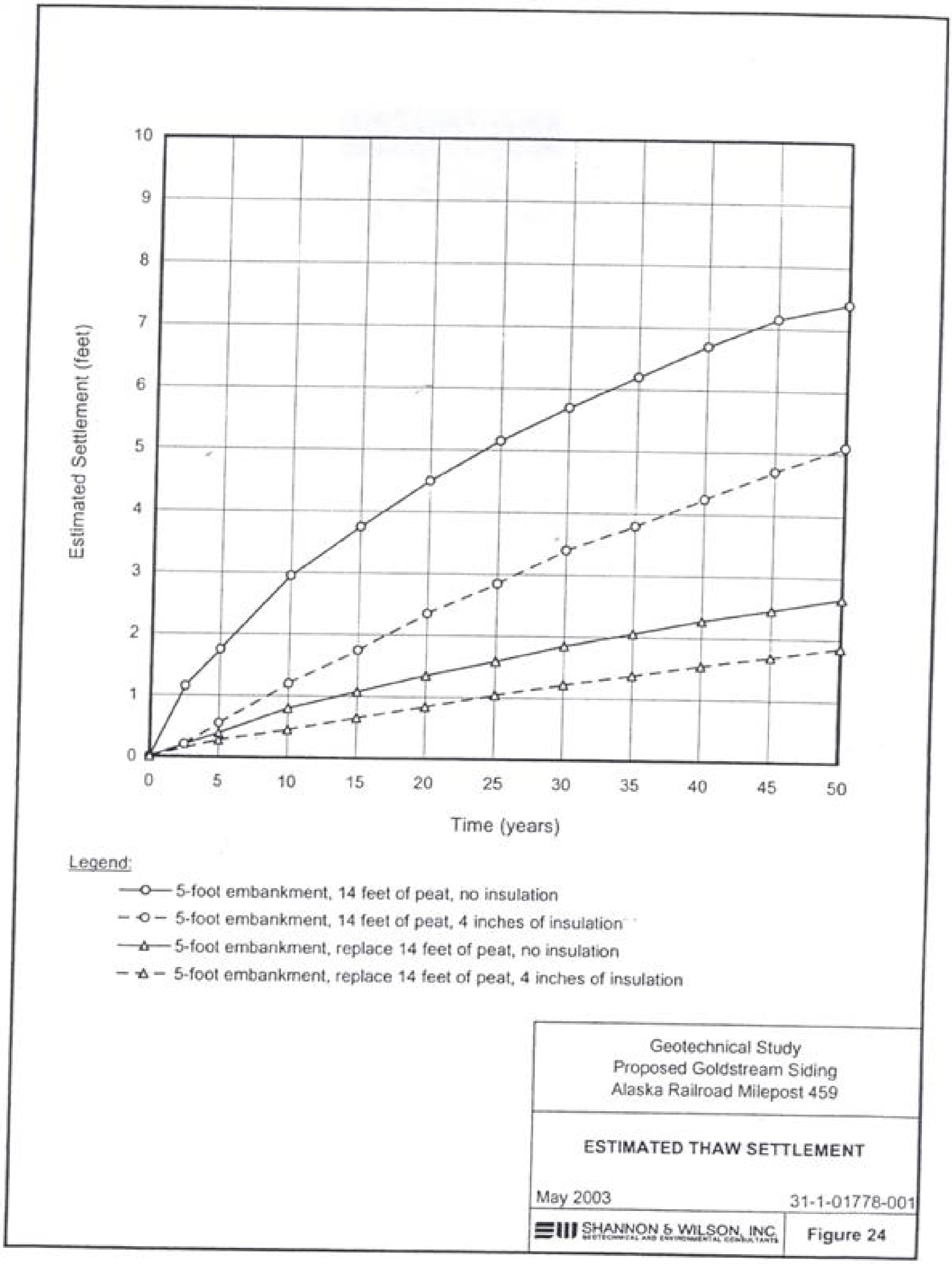


Figure 23: Estimated Thaw Settlement (Shannon & Wilson 2003)

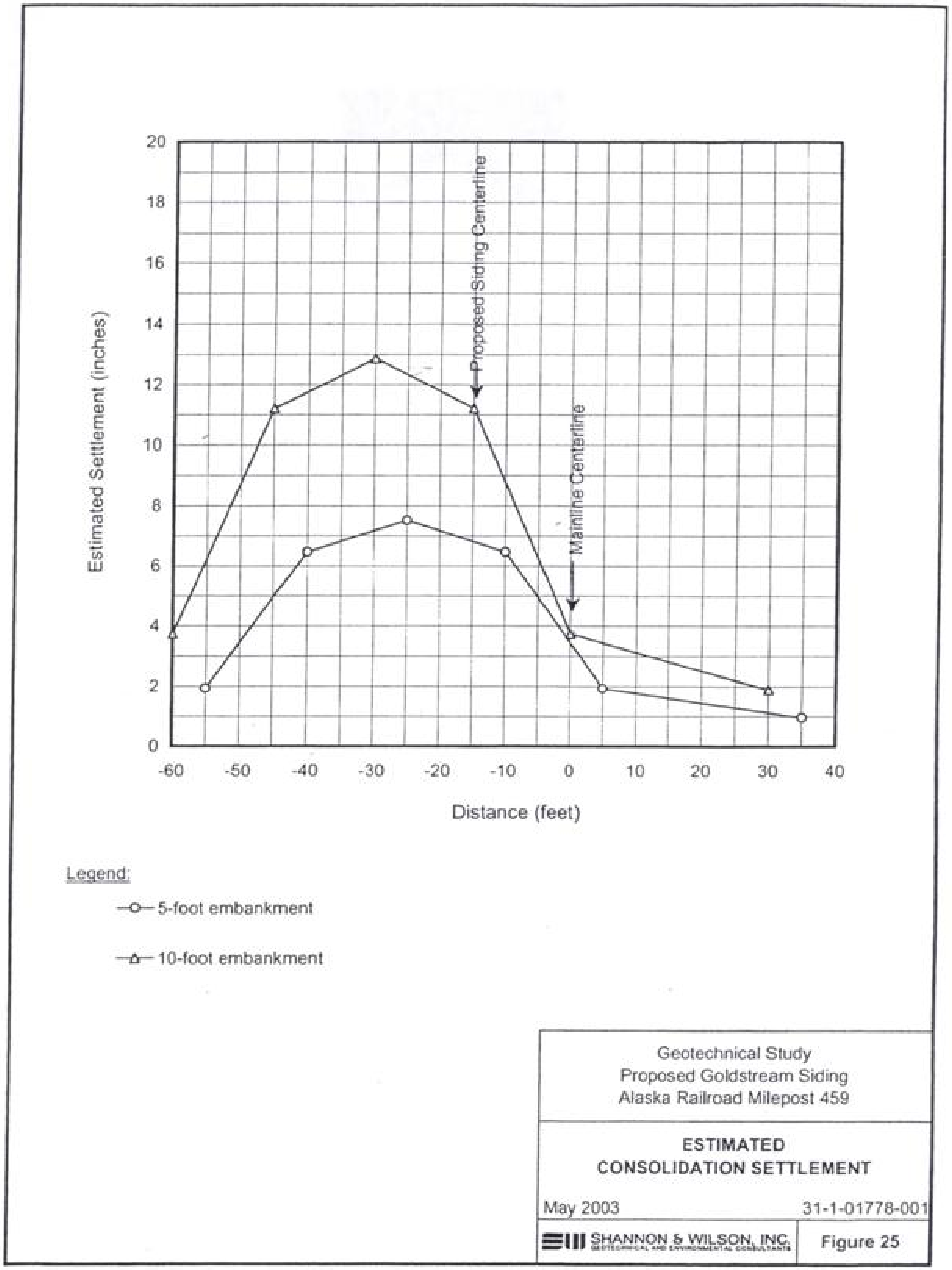


Figure 24: Estimated Consolidation Settlement (Shannon & Wilson 2003)

Reevaluation of Stabilization Methods

The foundation for much of the analysis is based solely upon the results of the literature review, the geotechnical study done by Shannon & Wilson and limited discussion with railroad representatives. Any stabilization recommendation should be verified by railroad representatives and combined with field experience as well as a more detailed investigation on the problem.

Several options were presented by Shannon & Wilson to address the permafrost thaw and settlement issues expected at the Ester siding including: thermosyphons, a rock embankment, polystyrene insulation, dry bridge, mass exchange and the “do nothing” approach. Table 5 summarizes the solutions investigated by Shannon & Wilson with the addition of ventiduct cooling, crushed rock revetment embankment and embankment widening/ berms for additional comparisons. A brief summary of options, their implementation requirements and a rough cost estimate are provided.

Table 5: Stabilization Alternatives for Ester Siding Location

Engineered Solution	Implementation Method	Cost ($/100 track feet) ($/ 30.5 meters)
Thermosyphons	Can be constructed after embankment is placed using track mounted auger	$27,500- $30,800
Ventiduct Embankment	Placed during construction or embankment or possible afterwards using jack & bore drilling, place on NFS material	$9,804- $23,736
Block Stone Embankment	Placed during construction of embankment	$44,800
Crushed Rock Revetment	Placed during or after construction of embankment	$12,000
Extruded Polystyrene Insulation	Placed during application of ballast or during ballast cleaning operations	$2,291.50
Dry Bridge	Must be constructed prior to operation of the railway	$1,040,000
Mass Exchange	Must be completed prior to embankment construction	$67,550
Embankment Widening/ Berms	Placed during or after construction of the embankment	No Data
"Do Nothing" Approach	Utilize regular maintenance and track lifts to correct settlements	$2,255/ year

Due to the fact that the siding has already been constructed, the options available for stabilization are limited. Of the engineered solutions listed in Table 5, thermosyphons, ventiducts, crushed rock revetments, polystyrene insulation, and embankment berms represent the only realistic cooling alternatives. These methods can be employed after construction and are therefore most suitable to the current site conditions. A more in depth discussion follows to weigh the advantages and disadvantages associated with each.

Thermosyphons

Thermosyphon cooling solution appears viable, as the mean annual air temperature is below freezing. They would allow the cooling influence of the air to be used for removing heat from the embankment. In locations where air temperatures average above freezing, thermosyphons will be a less attractive option, as circulation of the coolant inside the tube can only occur when the air temperatures drop below freezing.

Shannon & Wilson stated that the thermosyphon units would have to be balanced properly to prevent refreezing of the thawed soils beneath the existing mainline. However, it can be speculated that even though heaving of the mainline track may occur in the short term, the long term stability of both siding and mainline track will increase with this method. The severity of the short term heaving problems should be less significant than the maintenance currently required in addressing continued settlements at this location.

Ventiduct Embankment

Ventiduct pipes could be installed after construction utilizing jack and bore drilling which allows the tracks to remain active. However, several factors at this site minimize many of the benefits from this method. For jack and bore drilling, a hole must be excavated adjacent to the tracks to place the drilling equipment in. The water table at this site was found to be only 3 feet (.91 meters) below the track surface and this could cause problems for the excavation and drilling (Figure 25).

Additionally, the presence of water or ice in the ventiducts limits convective cooling and may lead to potential settlements or heaves which could damage the pipes. As noted by Shannon & Wilson, existing culverts appear to be experiencing significant heaving problems which are anticipated to affect the ventiducts in a similar manner.

With the potential for plugging due to snow and debris, water issues and the possible settlement of the embankment, these pipes may prove to be more of a maintenance problem than a reliable cooling solution. This method is not recommended for the Ester siding.

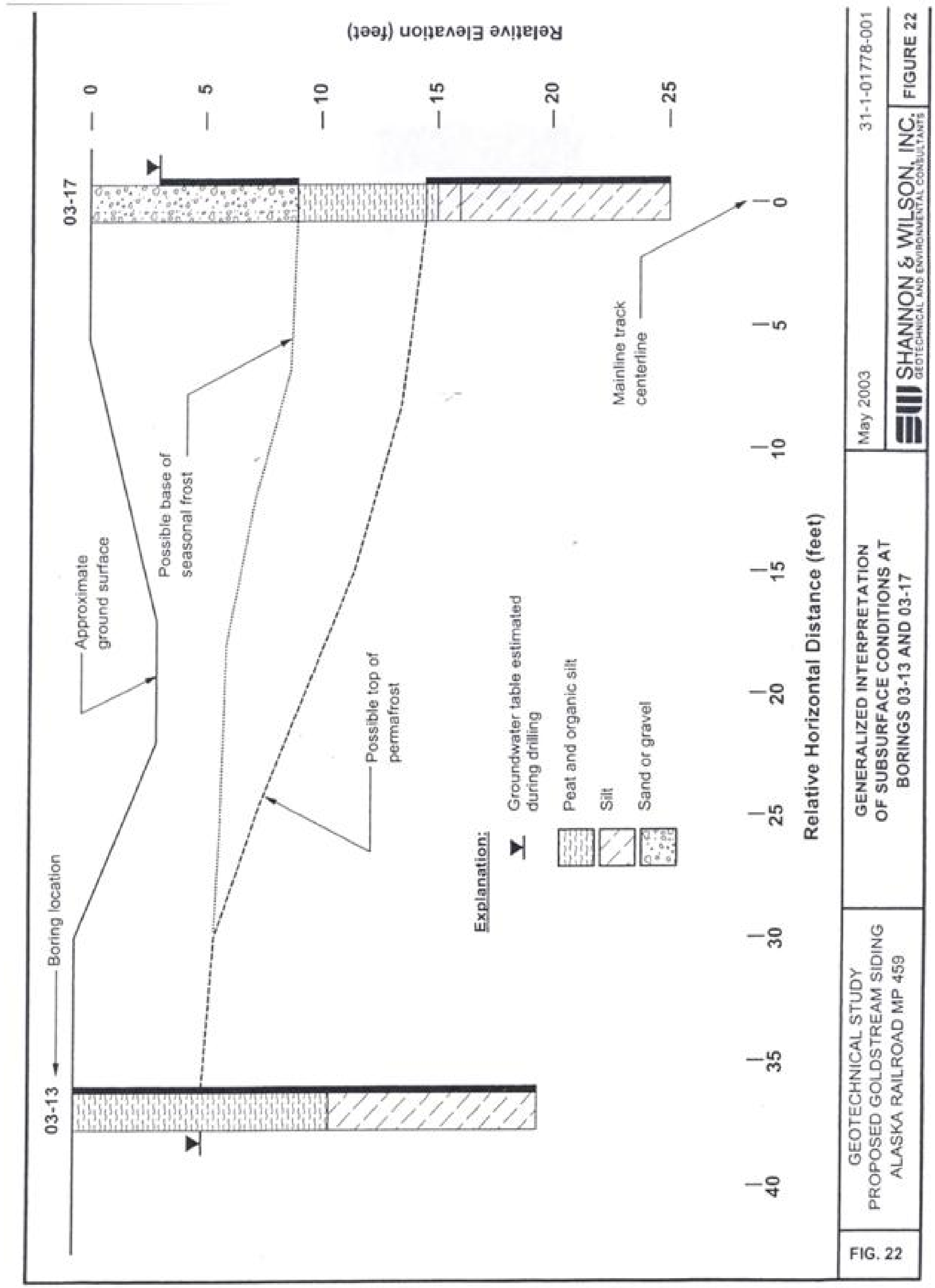


Figure 25: Soil Boring & Subsurface Interpretation

Crushed Rock Revetment

The revetment layer uses void spaces created by the aggregates to utilize natural air convection and remove heat from the embankment soils. Given the scarce aggregate supplies present in Alaska, permeable rock layers may present a difficulty to construct due to the shortage of available large aggregate. Shannon & Wilson specified that rocks be 2 inches (5 centimeters) or larger in diameter, although results from the Qinghai-Tibet Railway indicate a diameter of 3-4 inches (8-10 centimeters) may perform better. These aggregates can be obtained locally for $50/ton and could be transported and placed on site using side dump rail cars. A limiting factor in the application of this method is the significant annual snowfall combined with snow removal operations of both the mainline and siding. This is expected to contribute significant snow accumulation along the embankment slopes which reduced the cooling effect of the rock embankment.

Polystyrene Insulation

Inclusion of a 4 inch (10.2 centimeter) insulation layer into the embankment was estimated by Shannon & Wilson to result in total embankment settlement of roughly 5 feet (1.5 meters) over the next 50 years (Figure 23). This is in comparison to the more than 7 feet (2.1 meters) of settlement that was forecasted for an unprotected embankment and demonstrates a significant advantage.

Insulation can be placed beneath the ballast layer of the track, although the costs and resources required for this limit its application. Even though insulation could reduce the severity of settlement, it is not recommended for use due to economic considerations unless maintenance or cleaning of the ballast is scheduled. During such activities, insulation could be placed beneath these sections as a supplemental construction activity. This would limit the cost of insulation to only the materials and labor required for installation of the boards.

Embankment Widening/ Berms

Alaska Railroad representatives suggested that this was one available option for the site. Given the limited availability of data regarding this option, the only resources available to study the effectiveness of this solution were a handful of published articles and the geotechnical report conducted by Shannon & Wilson. More data combined with field experience and knowledge is needed to more effectively weigh this option.

Based on the literature review, it was found that widening the embankment or placing berms alongside the existing railroad siding will increase the thermal profile of the embankment. Due to the fact that thermal degradation and settlements are already occurring at this site, literature suggests these additional structures would do little to stabilize the size. Subgrade soils beneath the embankment are already warming and thawing, so the increased weight of this soil may only serve to further consolidate thaw weakened soils.

"Do Nothing" Method

The “do nothing” method involves using no stabilization methods for the siding, and instead, correcting settlements and heaves as they occur. This is the alternative that was initially chosen by the Alaska Railroad due to the high costs associated with the alternatives proposed by Shannon & Wilson.

In conversations with railroad representatives, it has been noted that several feet of settlement have occurred at the site since its construction in 2005. This indicates settlement is occurring at an even more significant rate than was predicted during the geotechnical report. However, the conversations also stated that settlements along the adjacent mainline are not as severe as in previous years. This may suggest that the sites will begin to naturally stabilize over time, even without the use of engineered stabilization solutions. If that is the case, the annual cost of the “do nothing” method alternative would also reduce, as settlements are less severe and require less frequent maintenance actions.

Recommended Method(s)

For site stability and settlement reduction, thermosyphon tubes combined with an insulation layer represent the most appropriate solutions. Economically, the “do nothing” approach is the most appropriate. To compare the costs of each method, several assumptions were made.

- Maintenance costs were neglected for the thermosyphon and insulation method based on lack of reliable data regarding these potential future costs. This is considered the best case scenario for these stabilization solutions.
- “Do nothing” approach assumes a worst case scenario based on the fact that observed settlements have exceeded the forecasted settlements over the last four years.
- Annual settlement and track lifting of 6 inches (15.2 centimeters) were anticipated for the next 30 years, representing 15 feet (4.6 meters) of total lift.

Table 6 summarizes the economic costs of each of the proposed solutions. More detailed calculations and values can be found in Appendix B. Cost comparisons utilized average annual cost (AAC) and net present value (NPV) calculations to compare the solution methods. The annual cost of the solution is essentially a payment made each year, or a negative cash flow. To simplify this, the AAC of the method has been stated as an equivalent positive payment, made annually for the life of the project. This signifies how much a project is worth for each year. Net present value indicates the value of the project in today’s terms (Year 0).This represents a single value which is equivalent to the lifecycle cash flows. Because the cash flows each year represent a negative balance to the owner, the NPV’s are displayed as negative values. The closer to zero the net present value is, the better the economic value for the owner.

Table 6: Economic Comparisons of Proposed Solutions

Solution	Average Annual Cost- 100 track feet (30.5 meters) (30 year)	Net Present Value- 100 track feet (30.5 meters) (30 year)
Thermosyphon	$ 2,756.62	$ -18,099.96
Polystyrene Insulation	$ 344.53	$ -2,262.17
Thermosyphon & Insulation	$ 3,101.15	$ -20,362.13
Do Nothing	$ 2,254.55	$ -14,803.34

Overall, the “do nothing” method appears to be the least expensive alternative. The assumption of a 30 year project lifespan was made based on two factors. The first is the anticipated life cycle of polystyrene insulation noted by Nurmikolu and Kolisoja in 2005 and the other is that thermosyphons installed in conjunction with the Alaska Pipeline in 1977 appear to remain fully functional.

Two values of the minimally acceptable rate of return (MARR) were used. An 8% MARR value represents the rate utilized in FY 1998 by the Alaska Railroad for asset costs (Alaska Railroad Corporation 1997). A MARR value of 15% represents a more typical value used by corporations for project evaluation. Using an 8% MARR, the breakeven point for the best case thermosyphon/ insulation method versus the worst case “do nothing” is 14 years (Figure 26). With the inclusion of maintenance costs into the thermosyphon method or reduction of the total “do nothing” costs, the payback period will extend even further. The use of a 15% MARR does not have a breakeven point during the 30 year lifespan (Figure 27).

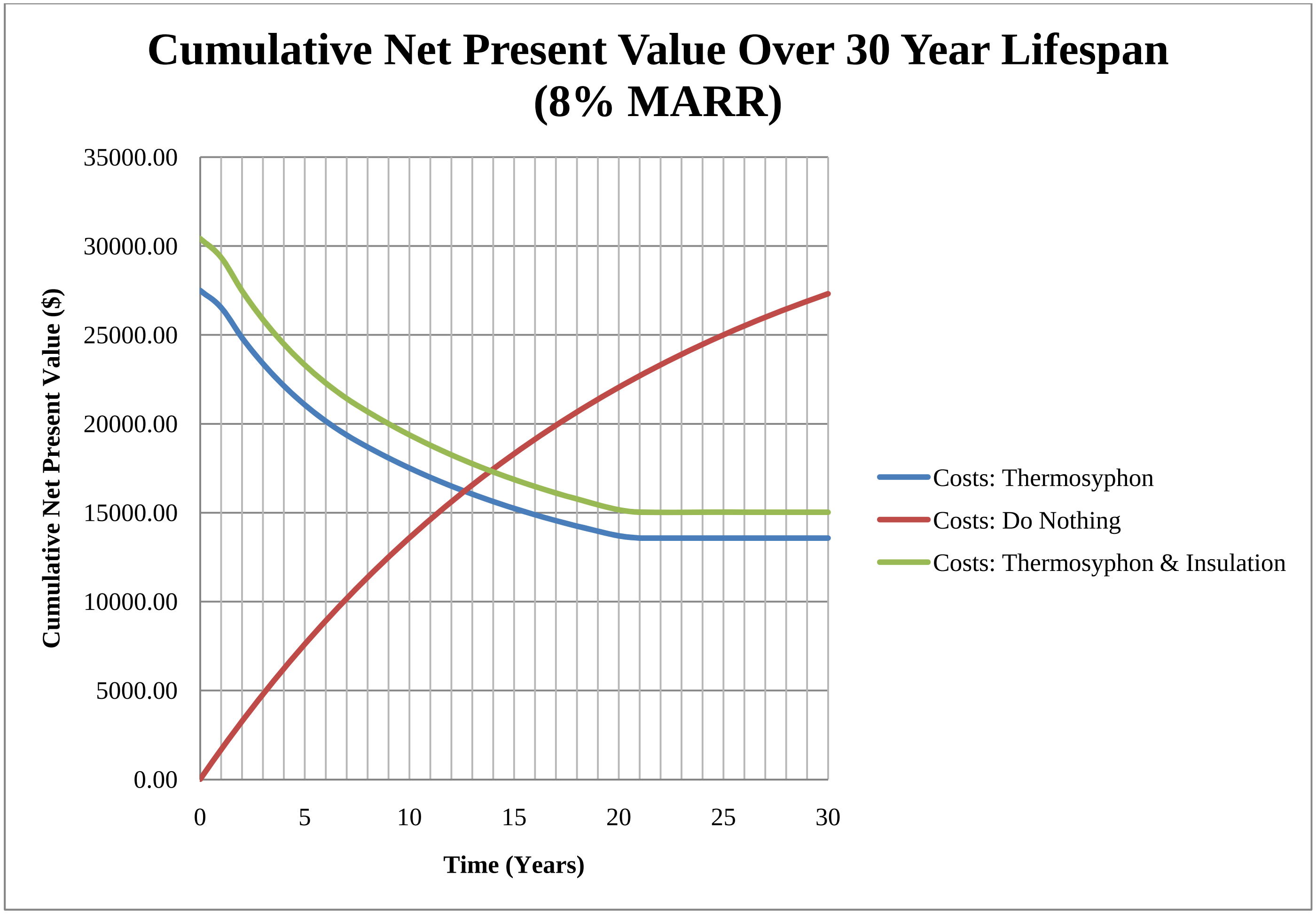


Figure 26: Cumulative Net Present Value (30 years, 8% MARR)

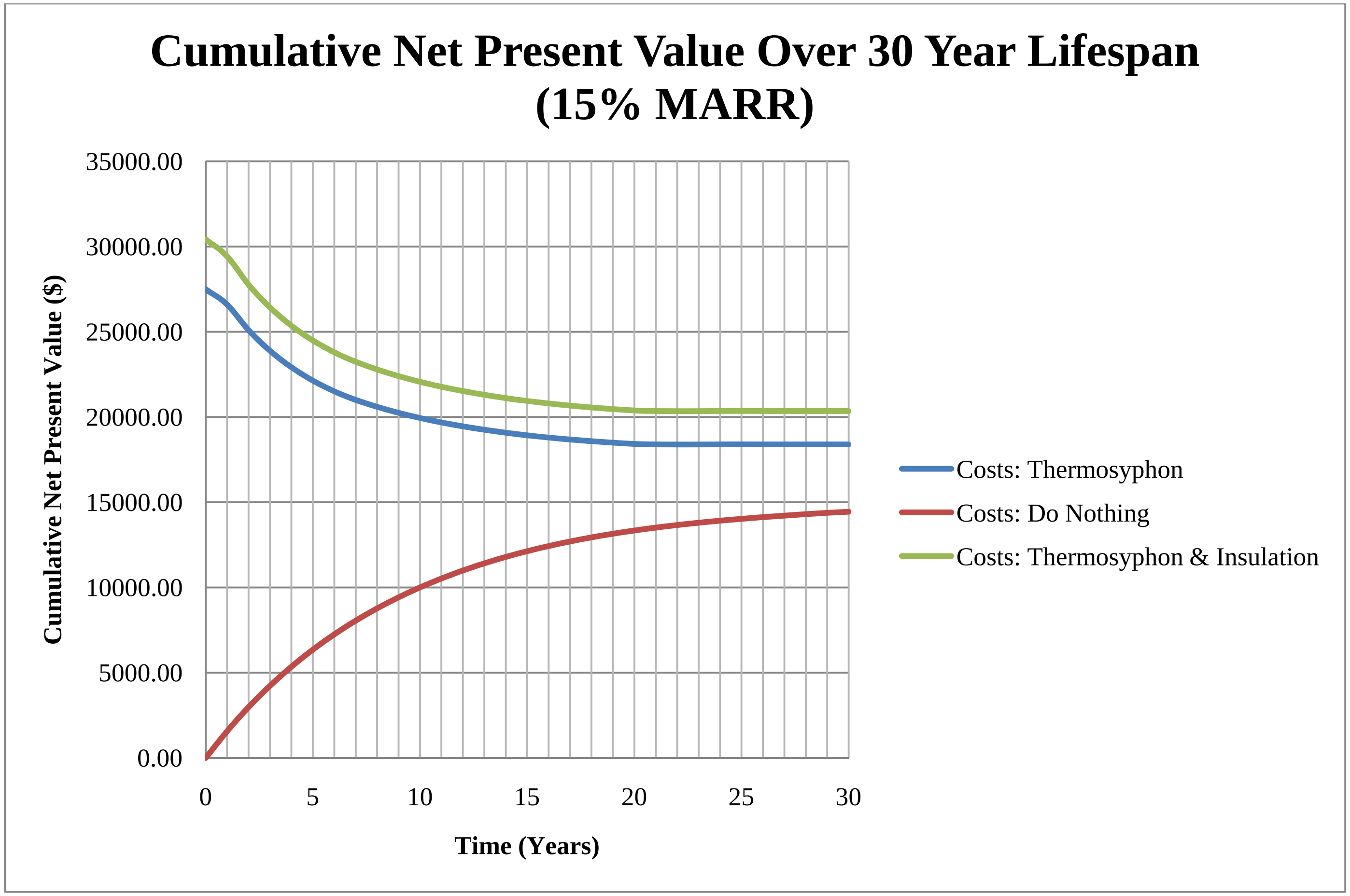


Figure 27: Cumulative Net Present Value (30 years, 15% MARR)

Despite the fact that the "do nothing" method appears to be the lowest cost option for the site, if stabilization is desired by the railroad, engineered solutions may still offer an attractive option. In an effort to reduce the high capital costs required, Ester siding could be stabilized using strategically placed thermosyphon tubes placed at high risk zones along the embankment. These zones should be carefully selected using further site exploration such as ground penetrating radar and soil borings, combined with settlement experiences of railroad representatives to maximize effectiveness.

Areas with high ice content, large ice inclusions and with fine subgrade soils like peat or silt are likely candidate areas for thermosyphon stabilization. Based on the data from Shannon & Wilson, the most critical locations for thermosyphon treatment were identified. Table 7 presents a brief summary of critical information from the soil borings and Figure 28 shows a schematic layout of the siding and the boring locations. Soil boring data from the geotechnical study have been included in Appendix C.

Table 7: Soil Boring Analysis

Soil Boring Number	MP	STA	Stabilize (Y/N)	Notes
3-09	458.42	04+18	**Y**	Fine grained silt with 35% ice 2.2-4 feet. Water table and thawed layer at 4.5 feet. Ice lenses and inclusions present
3-10	458.52	09+46	N	
3-08	458.61	14+21	N	
3-11	458.71	19+49	N	
3-07	458.80	24+24	N	
3-18	458.80	24+24	N	
3-12	458.90	29+52	N	
3-06	459.00	34+80	**Y**	Peat and silt frozen to depth of 20 feet. < 5% visible ice above 5 feet but up to 30% ice 5-6 feet and 20% ice 6-8 feet

3-13	459.09	39+55	**Y**	Frozen peat with ½ inch (1.3 centimeter) ice inclusions and 35% ice content 5.5-11 feet. Water table and thawed layer at 5.5 feet.
3-17	459.09	39+55	N	
3-05	459.20	45+36	**Y**	Ice rich silt and peat, frozen to 20 feet. 50% visible ice up to 13.5 feet
3-14	459.28	49+59	**Y**	Frozen silt and organics. Peat layer with 35% ice content to 11feet. Thawed zone at 5.5 feet
3-16	459.28	49+59	N	
3-04	459.37	54+34	N	
3-03	459.47	59+62	N	
3-02	459.56	64+37	N	
3-01	459.66	69+65	N	
3-15	459.75	74+40	N	

Based on analysis of the soil boring data, locations 3-05, 3-06, 3-09, 3-13 and 3-14 appear the be the most likely candidates for selective thermosyphon stabilization. With the exception of boring 3-09, all candidate sites are located in a continuous section which suggests a potential stabilization length of roughly 1,500 feet (457.2 meters). Boring 3-09 is located near the turnout and represents a single problem site.

These locations should be compared with actual settlement history at the siding to verify correlation between boring data and the occurrence actual settlements. If significant settlement has been observed at these locations, the problems may be directly related to the degradation of frozen soils beneath them.

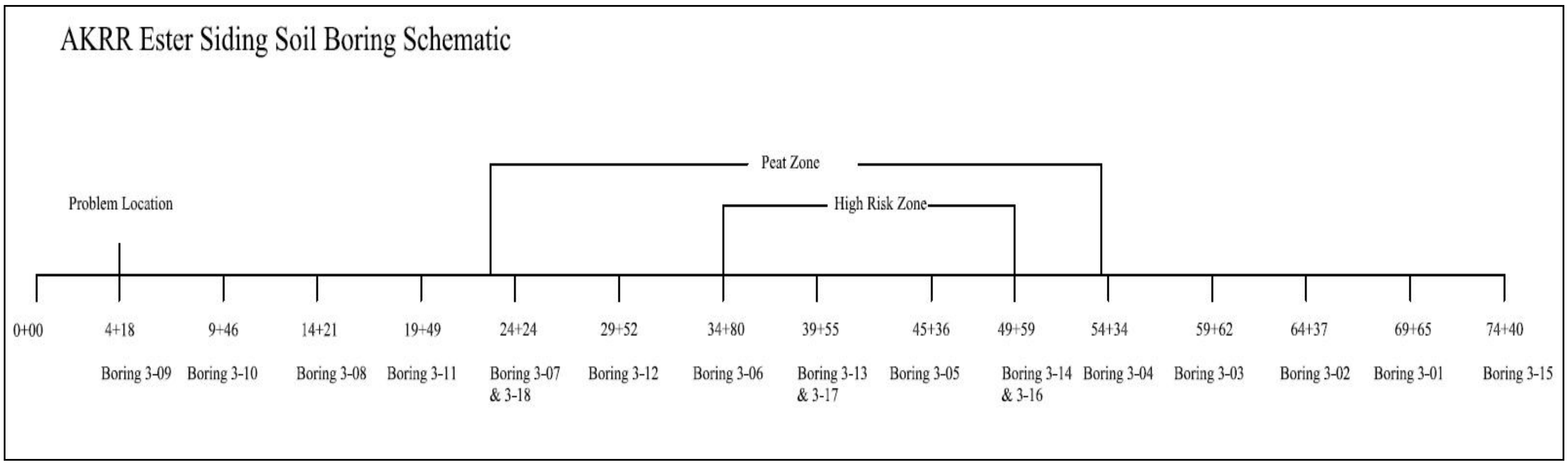


Figure 28: Soil Boring Schematic (based on Shannon & Wilson data)

Boring 3-05

This boring was consistently frozen for the entire 20 foot (6.1 meters) boring depth, a trait that should be maintained with the inclusion of thermosyphon cooling. The high ice content (50%) to a depth of 13.5 feet (4.1 meters) also indicates that should the soils melt, significant settlements could result from the thawing and consolidation of the peat layer. Small ice veins were noted from13.5-20 feet (4.1-6.1 meters), but these are beyond the designed 9 foot (2.7 meters) cooling range of the thermosyphon tube and will not be affected.

Boring 3-06

This boring was also frozen for the 20 foot (6.1 meters) boring depth. Soils include peat and organic silt with an ice content of 5% above 5 feet (1.5 meters). High ice content (30%) was noted in the silt between 5–6 feet (1.5-1.8 meters) with 20% ice content and ice lenses between 6-8 feet (1.8-2.4 meters). These high ice soils are in the effective cooling range and will be stabilized with a thermosyphon.

Boring 3-09

Analysis revealed a site consisting primarily of silt frozen to a depth of 20 feet (6.1 meters), with the exception of a thawed zone between 4.5-5 feet (1.4-1.5 meters). The water table is high at this site (4.5 feet/ 1.4 meters) and appears to correspond to a thawed zone in the soil boring. This may indicate thawing due to insufficient drainage and water ponding. Ice veins and 35% ice content from 2.2-4 feet (.7-1.2 meters) and additional ice lenses to 9.5 feet (2.9 meters) indicate high settlement risk.

Boring 3-13

Frozen peat to a depth of 14.5 feet (4.4 meters) was noted at this location. A high water table (5.5 feet/ 1.7 meters) appears to pose a risk for soil thawing and ½ inch (1.3 centimeters) ice inclusions with 35% ice content between 5.5-11 feet (1.7-3.4 meters) suggest a very significant risk for settlement. Should these large ice inclusions melt, large settlements could occur in a very short period of time as the soil settles into the void created by the melted ice. Stabilization is recommended to reduce this possibility.

Boring 3-14

Full depth frozen silt and peat was encountered to a depth of 20 feet (6.1 meters) with a small thawed zone between 5-5.5 feet (1.5-1.7 meters). High ice content (35%) from 4.5-11 feet (1.4- 3.4 meters) presents risk for thaw and consolidation settlement. Ice lenses and 15% ice content were noted beyond a depth of 11 feet (3.4 meters) although they are out of the cooling range of the thermosyphon and will not be affected.

Remaining Borings

Remaining soil borings were not identified for stabilization based upon the soil conditions in each. Many of these borings showed the soils at these locations were unfrozen and are not considered at risk for thaw settlement which was estimated by Shannon & Wilson as the main failure mode (Figure 23). The three borings (3-15, 3-16, 3-17) did indicate frozen soils were located along the mainline track and thermosyphons are not expected to significantly impact the stability of the siding.

Implementation & Concluding Remarks

Installation of thermosyphons could be accomplished using a track mounted auger to place the tubes into the existing embankment. This technology would allow installation during time blocks with light revenue train service. Should ballast cleaning be required in the future, placement of insulation boards should be considered if settlement continues to be an issue for the siding.

The justification for using polystyrene insulation would be to reduce heat influx into the embankment, especially for the 1,500 feet (457 meter) continuous high risk section as seen in Figure 28. This reduction in heat inflow should increase the effectiveness of the thermosyphon tubes and minimize the frost penetration depth. The outcomes include reduced settlement and heave issues associated with permafrost degradation and seasonal frost action on the embankment.

Even though a solution utilizing thermosyphons would provide a more stable track, the “do nothing” method seems to be the most cost effective long term solution. It should be noted that other factors such as the availability of work crews, importance of the siding, sensitivity of revenue trains to temporary slow orders, and the value of resources currently being devoted to correct settlements at this site must be considered when selecting the preferred solution.

If increased stability is desired at Ester siding, railroad representatives must decide between the tradeoff of capital costs and annual maintenance expenses. If sufficient operations can be maintained with the current site conditions, the “do nothing” approach appears to be the best overall method.

On the other hand, if more consistent operating conditions and stable track are a priority, strategically placed thermosyphons together with annual maintenance and potential future installation of insulation boards would be recommended. In any case, a more in depth analysis of actual conditions and costs are needed to decide upon the best method.

Chapter 5: Summary and Recommendations for Additional Research

Recent demand for resource development and exploration has been the driving force behind the planning and construction of many new cold climate railroad projects Governments and companies in locations such as Alaska, Scandinavia, China, Russia and Canada are all developing rail connections in their extreme and often remote cold climate areas. This project was selected partially in response to this demand and aimed to compile research results, data and experiences with engineered stabilization solutions and apply them to a specific site in Alaska.

An extensive literature review was performed to reveal and examine engineered solutions which could be utilized by railroad engineers and designers to increase embankment stability in permafrost regions. Primary goals of the literature review were to identify applicable stabilization solutions and to define the advantages and disadvantages of each solution.

The case study was performed to highlight the challenges faced by the Alaska Railroad in their Ester siding location near Fairbanks, Alaska. Objectives for the case study were to review a geotechnical report conducted in 2003 by Shannon & Wilson and to develop recommendations for a cost effective cooling solution for this site. Following are the conclusions of the literature research and case study.

Literature Review Conclusions

- Recent construction of the Qinghai-Tibet railway and the inclusion of two embankment test sections along the line has generated much of the most current research and findings.
- As a whole, engineered solutions appear to be very expensive to install and may require inspection or maintenance over time.
- Each location has unique conditions. Climatic differences, varying soil types and vegetation all contribute to the unique features of the site and all must be evaluated before the ideal solution is revealed. There is no single method that can be used with success at all locations.
- Global climate change is posing new risks and challenges for cold climate rail construction and is changing the design and construction practices of several agencies.
- Best cooling results appear to be achieved using a combination of cooling methods. Each solution has a distinct set of advantages and disadvantages and by combining methods, these strengths and weaknesses can be used most beneficially.

Summary of Case Study

- Traditional embankment design methods were used to build the siding and severe settlements have occurred during the first four years of operation. Only stabilization solutions which can be implemented after construction can be considered because the siding has already been built.

- Settlements appear to be following a trend similar to the one forecasted by Shannon & Wilson. However, they have occurred faster than originally anticipated.
- From a stabilization standpoint, thermosyphons with an insulation layer offer the greatest benefit to reduce settlements and minimize track distortion at the site.
- Given the high costs of implementing the thermosyphons and insulation boards, the "do nothing" approach appears to be the most cost-effective option. Continuing maintenance and the inclusion of ballast to address settlements as they occur seems to be the cost efficient course of action for this specific location.

Recommendations for Further Study

- Cooperation between other applicable fields such as mechanical, electrical, materials and geotechnical engineering and economics should be increased. A wide range of skills and expertise are required to develop a better understanding of the unique conditions and techniques for engineered solutions in cold climates.
- Further efforts need to be directed toward developing a full scale test site in North America, similar to the sites that currently exist along the Qinghai-Tibet Railway. A large portion of recent research has come from China, although its applicability to sites in North America could be drawn into question as climatic conditions differ severely.

- Efforts should be made to gather and translate experience and research from Russian experts. There is a noticed lack of available research and publications on solutions developed in Russia. Given the vast amount of permafrost and experiences from this region, this project revealed few resources for review.
- A database or index should be developed to aid in future projects. Information such as locations of test sites, dates of study, reports or papers created using the site or test results could be included. This information will be useful for future research to easier identify relevant experiences and data for particular kinds of engineered solutions or climate conditions.

References

Alaska Railroad Corporation (1997). 1997 Annual Report. Anchorage, Alaska**:** 24.

ALCAN RaiLink Inc. (2007). Research Report: Rails to Resources to Ports: The Alaska Canada Rail Link Project Phase 1 Feasibility Study. Whitehorse, YK, Yukon Government/State of Alaska.

Andersland, O. and B. Ladanyi (1994). An Introduction to Frozen Ground Engineering. New York, New York, Chapman & Hall.

Braun Intertec (1996). Wood chips as a lightweight fill (MN/RC- 1998/05U), Minnesota Department of Transportation**:** 9.

Buchko, N. A., A. L. Kuznetsov, et al. (1978). Seasonally Operating Units and Their Use in Northern Construction. Third International Conference on Permafrost. Edmonton, Canada**:** 227-239.

Cheng, G., W. Qingbai, et al. (2008). "Innovative design of permafrost roadbed for the Qinghai-Tibet railway." Science in China Series E: Technological Sciences **52**(2): 630-638.

Cheng, G., Z. Sun, et al. (2007). "Application of the roadbed cooling approach in Qinghai–Tibet railway engineering." Cold Regions Science and Technology **53**(3): 241-258.

Cheng, G., J. Zhang, et al. (2004). "Principle of thermal insulation for permafrost protection." Cold Regions Science and Technology **40**(1-2): 71-79.

Esch, D. (1988). Roadway Embankments on Warm Permafrost Problems and Remedial Treatments. Fifth International Conference on Permafrost. Trondheim, Norway**:** 1223-1228.

Esch, D. C. (1983). Design and Performance of Road and Railway Embankments on Permafrost. Fourth International Conference on Permafrost. Fairbanks, Alaska**:** 25-30.

Esch, D. C. (1988). Embankment Case Histories on Permafrost. Embankment Design and Construction in Cold Regions. A. Phukan and W. H. Haas, American Society of Civil Engineers**:** 127-159.

Esch, D. C. (2004). Thawing Techniques for Frozen Ground. Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground. E. D.C., ASCE.

Esch, D. C. and R. L. McHattie (1983). Benefits of a Peat Underlay Used in Road Construction on Permafrost. Fourth International Conference on Permafrost. Fairbanks, Alaska**:** 826-831.

Farouki, O. (2004). Ground Thermal Properties. Analysis, Construction, and Monitoring Methods for Frozen Ground. D. C. Esch, ASCE.

Fujun, N., L. Xingfu, et al. (2007). "Monitoring study on the boundary thermal conditions of duct-ventilated embankment in permafrost regions." Cold Regions Science and Technology(July 2007).

Gandahl, R. (1978). Some Aspects on the Design of Roads With Boards of Plastic Foam. Third International Conference on Permafrost. Edmonton, Canada**:** 791-797.

Gavriliev, R. I. (2004). Thermal Properties of Soils and Surface Covers. Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground. D. C. Esch, ASCE.

Goering, D. J. (1998). Experimental Investigation of Air Convection Embankments for Permafrost-Resistant Roadway Design. Seventh International Conference on Permafrost. Yellowknife, Canada**:** 319-326.

Goering, D. J. (2003). "Passively Cooled Railway Embankments For Use in Permafrost Areas." Journal of Cold Regions Engineering **17**(3).

Goudong, C., W. Qingbai, et al. (2008). "Innovative designs of permafrost roadbed for the Qingha-Tibet Railway." Science in China Series E: Technological Sciences **52**(2): 530-538.

Han, C. (1998). Use of shredded tires as lightweight fill in roadway construction. St. Paul, Minnesota, Minnesota Local Road Research Board.

Hayley, D. W. (1988). Maintenance of a Railway Grade Over Permafrost in Canada. Fifth International Conference on Permafrost. Trondheim, Norway**:** 43-48.

Humphrey, D. N. and R. A. Eaton (1995). Field performance of tire chips as subgrade insulation for rural roads. Sixth International Conference on Low Volume Roads. Minneapolis, Minnesota**:** 77-86.

Johnson, E. G. and G. P. Bradley (1988). Protection of Warm Permafrost Using Controlled Subsidence at Nunapitchuk Airport. Fifth International Conference on Permafrost. Trondheim, Norway**:** 1256-1261.

Khan, R. and A. Shalaby (2001). Recycling of shredded rubber tires as road base in Manitoba: A case study. Canadian Geotechnical Conference. Calagary, Alberta.

Kondratiev, V. G. (1996). Strengthening railroad roadbed bases constructed on icy permafrost soils. Eighth International Conference on Cold Regions Engineering. Fairbanks, AK.

Kondratiev, V. G. (2002). Design and Experience--Controlling Railroad Embankment Deformation on Ice-Rich Permafrost. 11th International Conference on Cold Regions Engineering. K. S. Merrill. Anchorage, Alaska**:** 16.

Li, G., N. Li, et al. (2008). "Study on design optimization of a crushed stone layer with shading board placed on a railway embankment on warm permafrost." Cold Regions Science and Technology **54**(1): 36-43.

Long, E. L. and J. P. Zarling (2004). Passive Techniques for Ground Temperature Control. Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground. D. C. Esch, ASCE.

McHattie, R. and D. Esch (1988). Embankment Failure from Creep of Permafrost Foundation Soils. Fifth International Conference on Permafrost. Trondheim, Norway**:** 1292-1297.

NOAA. (2009). "Average Weather for Fairbanks, AK." Retrieved 6/30/2009, 2009, from http://www.weather.com/outlook/recreation/ski/wxclimatology/monthly/graph/99701?from=yest_bottomnav_ski.

Nurmikolu, A. and P. Kolisoja (2005). Extruded Polystyrene (XPS) Foam Frost Insulation Boards in Railway Structures. Osaka**:** 4.

Oiseth, E., R. Aaboe, et al. (2006). Field test comparing frost insulation materials in road construction. 13th International Conference on Cold Regions Engineering. J. E. Z. Michael Davies. Orono, Maine**:** 11.

Qihao, Y., N. Fujun, et al. (2007). "Investigation of Embankment with Temperature-Controlled Ventilation Along the Qinghai-Tibet Railway." Cold Regions Science and Technology(53): 193-199.

Qingbai, W., H. Cheng, et al. (2007). "Cooling mechanism of embankment with block stone interlayer in Qinghai-Tibet railway." Science in China Series E: Technological Sciences **50**(3): 319-328.

Qingbai, W., Z. Shiyun, et al. (2007). "Qinghai-Xizang Railroad Construction in Permafrost Regions." Journal of Cold Regions Engineering(June 2007).

Railways;, I. o. M. o. (1978). Experimental Roadbed in an Area With A Thick Layer of Ground Ice. Third International Conference on Permafrost. Edmonton, Canada**:** 187-194.

Rooney, J. W. and E. C. Johnson (1988). Embankment Stabilization Techniques. Embankment Design and Construction in Cold Regions. W. H. H. Arvind Phukan, American Society of Civil Engineers**:** 13-34.

Saboundjian, S. and D. J. Goering (2002). Air Convection Embankment for Roadways: A field experimental study in Alaska. TRB 2003 Annual Meeting. Washington D.C., Transportation Research Board.

Schrader, C., E. Lukanen, et al. (1998). Evaluation of wood chip fill on MN TH 53. Ninth International Conference on Cold Regions Engineering. Duluth, Minnesota**:** 512-523.

Shannon & Wilson, I. (2003). Development of Alternative Concepts for a New Main Track at Alaska Railroad MP 459 in the Goldstream Area. Anchorage, AK.

University of Wyoming. (2002). "What is Peat?" 2009, from http://www.wsgs.uwyo.edu/coalweb/swamp/peat.aspx.

Wei, M., Q. Jilin, et al. (2008). "Analysis of the Deformation of Embankments on the Qinghai-Tibet Railway." Journal of Geotechnical and Geoenvironmental Engineering(November).

Wenbing, Y., L. Yuanming, et al. (2003). "Laboratory investigation on cooling effect of coarse rock layer and fine rock layer in permafrost region." Cold Regions Science and Technology(June 2003).

Wenjie, F., M. Wei, et al. (2006). "Application investigation of awning to roadway engineering on the Qinghai-Tibet Plateau." Cold Regions Science and Technology **45**(1): 51-58.

Yu, Q., X. Pan, et al. (2008). "An experimental study on the cooling mechanism of a shading board in permafrost engineering." Cold Regions Science and Technology **58**: 298-304.

Yu, W., Y. Lai, et al. (2005). "Experimental Study on the Ventiduct Embankment in Permafrost Regions of the Qinghai-Tibet Railroad." Journal of Cold Regions Engineering **19**(No. 2 (June 2005)).

Yu, W., Y. Lai, et al. (2003). "Laboratory investigation on cooling effect of coarse rock layer and fine rock layer in permafrost region." Cold Regions Science and Technology(June 2003).

Yuanming, L., Z. Luxin, et al. (2003). "Cooling effect of ripped-stone embankments on Qing-Tibet railway under climatic warming." Chinese Science Bulletin **48**(6): 598-604.

Yue, Z. (2008). "Thermal Regime Simulation of Embankment and Berm in Permafrost." Geomechanics and Geoengineering **3**(2): 97-105.

Zarling, J., B. Connor, et al. (1983). Air Duct Systems for Roadway Stabilization Over Permafrost Areas. Fourth International Conference on Permafrost
Fairbanks, Alaska**:** 1463-1468.

Zarling, J. P. and W. A. Braley (1986). Thaw Stabilization of Roadway Embankments Constructed Over Permafrost, Federal Highway Administration: FHWA_AK_RD_87_20.

Zarling, J. P., W. A. Braley, et al. (1988). Thaw Stabilization of Roadway Embankments. Fifth International Conference on Permafrost. Trondheim, Norway**:** 1352-1357.

Zhi, W., S. Yu, et al. (2007). "Numerical Evaluation of Insulation Application to Embankment of Qinghai–Tibetan Highway." Journal of Cold Regions Engineering **Vol. 21**(Issue 2 (June 2007)): 47-59.

Zhi, W., S. Yu, et al. (2005). "Analysis on effect of permafrost protection by two-phase closed thermosyphon and insulation jointly in permafrost regions." Cold Regions Science and Technology(April 2005).

Appendix A: Cost Estimates

Thermosyphons

Base Unit Price: $2,800 each (installation included)

*Personal communication with Arctic Foundations, Inc.

Assume Unit Price of $2,500 each for large quantity orders

*Personal communication with Arctic Foundations, Inc.

Use 9 foot (2.7 meters) spacing

*Based on recommendations presented in (Shannon & Wilson 2003)

$$100ft \div 9ft\ thermosyhon\ spacing = 11.1\,\frac{thermosyphons}{100\ ft}$$

$$11\ thermosyphons\ \times \$2{,}500 = \$27{,}500$$

$$11\ thermosyphons\ \times \$2{,}800 = \$30{,}800$$

Ventiducts

Use 14 inch (35.6 centimeter) pipe diameter

Use 28 inch (71.1 centimeter) spacing

*Based on recommendation presented in (Yu, Lai et al. 2005)

Assume 16 foot (4.9 meter) pipe length

*based on embankment width

Assume 2x multiplier of materials for installation/transportation costs

*Personal communication with Branden Strayer, Davies Water Equipment

Base Unit Price (Concrete Pipe): $ 8/foot

*Personal communication with Branden Strayer, Davies Water Equipment

Base Unit Price (PVC Pipe): $ 4.75/foot

*Personal communication with Branden Strayer, Davies Water Equipment

Base Unit Price (Corrugated Metal Pipe): $ 11.50/foot

*Personal communication with Branden Strayer, Davies Water Equipment

$$100ft \div 28\ in\ pipe\ spacing = 43\,\frac{pipes}{100\ ft}$$

$$43\ concrete\ pipes\ \times (\frac{\$8.00}{ft} \times 16\ ft + \frac{\$16.00}{ft} \times 16ft) = \$16{,}512$$

$$43\ PVC\ pipes\ \times (\frac{\$4.75}{ft} \times 16ft + \frac{\$9.50}{ft} \times 16\ ft) = \$9{,}804$$

$$43\ metal\ pipes\ \times (\frac{\$11.50}{ft} \times 16ft + \frac{\$23.00}{ft}\ \times 16\ ft) = \$23{,}736$$

Block Stone Embankment

Base Unit Price 8-12 inch (20.3-20.5 centimeter) diameter aggregate: $100/ton (placement included)

*Personal communication with Brian Lindamood, Alaska Railroad

Assumed rock layer depth of 3.5 feet (1.1 meters)

*Based on recommendation presented in (Qingbai, Cheng et al. 2007)

Assumed rock layer width of 16 (4.9 meters)

*Personal judgment of author based on embankment design width

$$Unit\ Weight = \frac{160lb}{ft3}$$

Unit weight comes from assumed density of granite aggregates

$$1ton = 12.5\ ft3$$

$$100ft\ \times 3.5ft \times 16ft = 5600ft3$$

$$\frac{5600ft3}{12.5ft3/ton} = 448\ tons$$

$$448tons \times \frac{\$100}{ton} = \$44{,}800$$

Crushed Rock Revetment

Base Unit Price 3-4 inch (7.6-10.2 centimeter) diameter aggregate: $50/ton (placement included)

*Personal communication with Brian Lindamood, Alaska Railroad

Assumed rock layer depth of 3 feet (.91 meters)

*1.5 feet crushed rock revetment on both embankment slopes

Assumed slope width of 10 foot (3 meters)

*Personal judgment of author based on embankment height and slope of shoulder section

$$Unit\ Weight = \frac{160lb}{ft3}$$

Unit weight comes from assumed density of granite aggregates

$$1ton = 12.5\ ft3$$

$$100ft\ \times 3ft \times 10ft = 3000ft3$$

$$\frac{3000ft3}{12.5ft3/ton} = 240\ tons$$

$$240tons \times \frac{\$50}{ton} = \$12{,}000$$

Convection Sheds

Base Unit Price 2 inch x 4 inch (5.1 x 10.2 centimeter) lumber: $3.30/each

*Alaska Economic Trends- September 2006

*Assumed quantity of 50 per shed

*Personal judgment of author based on basic calculations derived from photos in (Zarling and Braley 1986)

Base Unit Price 4’x 8’ plywood sheet: $51.77/each

*Alaska Economic Trends- September 2006

*Assumed quantity of 18 per shed

*Personal judgment of author based on basic calculations derived from photos in (Zarling and Braley 1986)

Base Unit Price screws/ fasteners: $28/box

*Online quote, www.Lowes.com

*Assumed quantity of .5 per shed

*Personal judgment of author based on basic calculations derived from photos in (Zarling and Braley 1986)

$$Lumber\ Cost: \$3.30\ \times 50 = \$165$$

$$Plywood\ Cost: \$51.77\ \times 18 = \$931.86$$

$$Fastener\ Cost: \$14\ \times 1 = \$14$$

$$Total\ Materials\ Cost = \$1112.18/shed$$

Assume 2x multiplier of materials for installation/transportation costs

*Personal communication with Branden Strayer, Davies Water Equipment

$$Installation\ Costs: \$1112.18\ \times 2.2 = \$2{,}224.36$$

$$Total\ Shed\ Cost: \$1{,}112.18 + \$2{,}224.36 = \$3{,}336.54$$

Assume total cost of $3,300/ shed for simplification

Constructed sheds will be 12 feet long by 32 feet wide (3.7 x 9.8 meters)

$$Cost\ per\ square\ foot: \frac{\$3{,}300}{32ft\ \times 12\ ft} = \$8.59/ft2$$

$$100\ ft\ \times 32\ ft = 3{,}200\ ft2$$

$$3{,}200\ ft2 \times \frac{8.59}{ft2} = \$27{,}448$$

Expanded Polystyrene

Base Unit Price 4 foot x 8 foot x 2 inch (1.2 meter x 2.4 meter x 5.1 centimeter) XPS Board: $40.83/board

*Online quote from Universal Foam Products

Assume placement and transportation costs of $5/ board

*Personal judgment of author based on assumed ease of transportation and installation (light weight material and close proximity to Fairbanks metropolitan area)

Assume insulated layer of 8 foot (2.4 meters) wide based on embankment width based on width of 2 insulating boards

*Personal judgment of author based on simplification of design

$$100ft \times 8ft \times 2\ layers\ thick = 1{,}600ft\hat{}2$$

$$4ft \times 8ft = \frac{32ft^2}{board}$$

$$\frac{1600ft^2}{32ft^2/board} = 50\ boards$$

$$50\ boards \times \frac{\$45.83}{board} = \$2{,}291.50$$

Wood Chips

Assume market value of $91/ odmt

*North American Wood Fiber Review- June 2007

*1 odmt= 1 Oven Dried Metric Ton = 2204lb

Assume insulated layer of 12 feet (3.7 meters) wide

*Personal judgment of author based on desired insulated area and simplification of design

Assume insulation depth of 12 inches (30.5 centimeters)

*Personal judgment of author based on literature results presented in (Humphrey and Eaton 1995) and simplification of design

$$Unit\ Weight = \frac{22lb}{ft3}$$

Unit weight comes from assumed density of wood chips

$$1\ ODMT = 100.2ft3$$

$$100ft \times 12ft \times 1ft = 1{,}200ft^3$$

$$\frac{1{,}200ft3}{100.2\ ft3/ODMT} = 11.97\ ODMT$$

$$11.97\ odmt \times \frac{\$91}{odmt} = \$1{,}089.27$$

Peat

No data available

Tire Shreds

Assume transportation and placement costs of \$10.00/ yd^3 based on values presented in (Han 1998)

Assume insulated layer of 12 feet (3.6 meters) wide

> *Personal judgment of author based on desired insulated area and simplification of design

Assume insulation depth of 12 inches (30.5 centimeters)

> *Personal judgment of author based on literature results presented in (Humphrey and Eaton 1995) and simplification of design

$$100ft \times 12ft \times 1ft = 1{,}200ft^3$$

$$\frac{1200ft3}{27ft3/yd3} = 44.4yd3$$

$$44.4yd3 \times \frac{\$10.00}{yd3} = \$444$$

Mass Exchange

Base Unit Price 2-3 inch aggregate: \$50/ton (placement included)

*Personal communication with Brian Lindamood, Alaska Railroad

Assumed layer depth 10 feet (3 meters)

*Personal judgment of author based on literature results presented in (Shannon & Wilson 2003) and simplification of design

Assumed layer width 20 feet (6.1 meters)

*Personal judgment of author based on literature results presented in (Shannon & Wilson 2003) and simplification of design

$$Unit\ Weight = \frac{135lb}{ft3}$$

$$1ton = 14.8\ ft3$$

$$100ft\ \times 10ft \times 20ft = 20000ft3$$

$$\frac{20000ft3}{14.8ft3/ton} = 1351\ tons$$

$$1351tons \times \frac{\$50}{ton} = \$67{,}550$$

Do Nothing Approach

Base Unit Price 3 inch (7.6 centimeters) lift: \$9/TF

*Personal communication with Brian Lindamood, Alaska Railroad

Base Unit Price 6 inch (15.2 centimeters) lift: \$18/TF

*Personal communication with Brian Lindamood, Alaska Railroad

$$\frac{\$18}{TF} \times 100\ TF = \frac{\$1{,}800}{100\ ft}$$

Dry Bridge

Base Unit Price: $10,400/TF

*Personal communication with Mat Fletcher, Hanson Professional Services

*Multiply by 1.5x based on personal communication with Brian Lindamood, Alaska Railroad

Adjusted Base unit Price: $15,600/ TF

Assumed cost savings of 10% due to ease of mobility for cranes & equipment compared to standard construction over water

*Personal communication with Mat Fletcher, Hanson Professional Services

$$Unit\ Cost = \$15{,}600/TF$$

$$Assumed\ Actual\ Cost = \$14{,}040/TF$$

$$100ft\ \times \$14{,}040 = \$1{,}404{,}000$$

Embankment Widening/ Berms

No data available

Appendix B: Net Present Value Spreadsheets

A 20 year Modified Accelerated Cost Recovery System (MACRS) property class was used based on the expected lifespan of over 20 years. The depreciation schedule can be seen in Table 8.

Table 8: Accelerated Depreciation Schedule for Personal Property (Declining-Balance Method)

20 Year Property Class			
Year	Depreciation	**Year**	Depreciation
0	0.0000	**11**	0.0446
1	0.0375	**12**	0.0446
2	0.0722	**13**	0.0446
3	0.0668	**14**	0.0446
4	0.0618	**15**	0.0446
5	0.0571	**16**	0.0446
6	0.0528	**17**	0.0446
7	0.0489	**18**	0.0446
8	0.0446	**19**	0.0446
9	0.0446	**20**	0.0446
10	0.0446	**21**	0.0225

Net present values were converted to average annual worth for easier comparison using a multiplying value based on the 30 year service life and the MARR percentage, (A/P, 30 yr, %). The values used are listed in Table 9.

Table 9: NPV to Annual Worth Conversion Factors

Present Worth Conversion Factors	
(A/P, 30 yr, 8%)	.08883
(A/P, 30 yr, 15%)	.1523

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Costs: Thermosyphon																
Cash Operating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-Cash Costs																
Depreciation	0	1031.25	1985.5	1837	1699.5	1570.25	1452	1344.75	1243	1226.5	1226.5	1226.5	1226.5	1226.5	1226.5	1226.5
Total Costs	0	1031.25	1985.5	1837	1699.5	1570.25	1452	1344.75	1243	1226.5	1226.5	1226.5	1226.5	1226.5	1226.5	1226.5
Non-Cash Charges	0	1031.25	1985.50	1837.00	1699.50	1570.25	1452.00	1344.75	1243.00	1226.50	1226.50	1226.50	1226.50	1226.50	1226.50	1226.50
Capital Expenditures	-27500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	27500	1031.25	1985.50	1837.00	1699.50	1570.25	1452.00	1344.75	1243.00	1226.50	1226.50	1226.50	1226.50	1226.50	1226.50	1226.50
Net Present Value=	27500.00	-896.74	-1501.32	-1207.86	-971.69	-780.69	-627.74	-505.54	-406.34	-348.65	-303.17	-263.63	-229.24	-199.34	-173.34	-150.73
Cumulative Net Present Value=	27500.00	26603.26	25101.94	23894.08	22922.39	22141.69	21513.95	21008.41	20602.07	20253.43	19950.25	19686.63	19457.38	19258.04	19084.70	18933.97
Total NPV=	**18395.83**															
Annual Worth=	**2801.68**			MARR=	**15%**											
				Inflation=	3%											

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Costs: Thermosyphon															
Cash Operating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-Cash Costs															
Depreciation	1226.5	1226.5	1226.5	1226.5	1226.5	618.75	0	0	0	0	0	0	0	0	0
Total Costs	1226.5	1226.5	1226.5	1226.5	1226.5	618.75	0	0	0	0	0	0	0	0	0
Non-Cash Charges	1226.50	1226.50	1226.50	1226.50	1226.50	618.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	1226.50	1226.50	1226.50	1226.50	1226.50	618.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Present Value=	-131.07	-113.97	-99.11	-86.18	-74.94	-32.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Net Present Value=	18802.90	18688.93	18589.82	18503.64	18428.70	18395.83	18395.83	18395.83	18395.83	18395.83	18395.83	18395.83	18395.83	18395.83	18395.83

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Costs: Thermosyphon																
Cash Operating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-Cash Costs																
Depreciation	0	1031.25	1985.5	1837	1699.5	1570.25	1452	1344.75	1243	1226.5	1226.5	1226.5	1226.5	1226.5	1226.5	1226.5
Total Costs	0	1031.25	1985.5	1837	1699.5	1570.25	1452	1344.75	1243	1226.5	1226.5	1226.5	1226.5	1226.5	1226.5	1226.5
Non-Cash Charges	0	1031.25	1985.50	1837.00	1699.50	1570.25	1452.00	1344.75	1243.00	1226.50	1226.50	1226.50	1226.50	1226.50	1226.50	1226.50
Capital Expenditures	-27500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	-27500	1031.25	1985.50	1837.00	1699.50	1570.25	1452.00	1344.75	1243.00	1226.50	1226.50	1226.50	1226.50	1226.50	1226.50	1226.50
Net Present Value=	27500.00	-954.86	-1702.25	-1458.27	-1249.18	-1068.69	-915.01	-784.65	-671.55	-613.56	-568.11	-526.02	-487.06	-450.98	-417.58	-386.64
Cumulative Net Present Value=	27500.00	26545.14	24842.89	23384.62	22135.44	21066.75	20151.75	19367.10	18695.54	18081.99	17513.88	16987.86	16500.80	16049.82	15632.24	15245.60
Total NPV=	**-13578.92**															
Annual Worth=	**1206.22**			MARR=	**8%**											
				Inflation=	3%											

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Costs: Thermosyphon															
Cash Operating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-Cash Costs															
Depreciation	1226.5	1226.5	1226.5	1226.5	1226.5	618.75	0	0	0	0	0	0	0	0	0
Total Costs	1226.5	1226.5	1226.5	1226.5	1226.5	618.75	0	0	0	0	0	0	0	0	0
Non-Cash Charges	1226.50	1226.50	1226.50	1226.50	1226.50	618.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	1226.50	1226.50	1226.50	1226.50	1226.50	618.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Present Value=	-358.00	-331.48	-306.93	-284.19	-263.14	-122.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Net Present Value=	14887.59	14556.11	14249.18	13964.98	13701.84	13578.92	13578.92	13578.92	13578.92	13578.92	13578.92	13578.92	13578.92	13578.92	13578.92

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Costs: Do Nothing																
Cash Operating	0	-1800	-1854.00	-1909.62	-1966.91	-2025.92	-2086.69	-2149.29	-2213.77	-2280.19	-2348.59	-2419.05	-2491.62	-2566.37	-2643.36	-2722.66
Non-Cash Costs																
Depreciation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Costs	0	-1800	-1854	-1909.62	-1966.91	-2025.92	-2086.69	-2149.29	-2213.77	-2280.19	-2348.59	-2419.05	-2491.62	-2566.37	-2643.36	-2722.66
Non-Cash Charges	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	0	-1800.00	-1854.00	-1909.62	-1966.91	-2025.92	-2086.69	-2149.29	-2213.77	-2280.19	-2348.59	-2419.05	-2491.62	-2566.37	-2643.36	-2722.66
Net Present Value=	0.00	-1565.22	-1401.89	-1255.61	-1124.59	-1007.24	-902.14	-808.00	-723.69	-648.17	-580.54	-519.96	-465.70	-417.11	-373.58	-334.60
Cumulative Net Present Value=	0.00	1565.22	2967.11	4222.71	5347.30	6354.54	7256.67	8064.67	8788.36	9436.53	10017.07	10537.02	11002.73	11419.83	11793.42	12128.02
Total NPV=	**-14450.11**															
Annual Worth=	**2200.75**			MARR=	**15%**											
				Inflation=	3%											

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Costs: Do Nothing															
Cash Operating	-2804.34	-2888.47	-2975.13	-3064.38	-3156.31	-3251.00	-3348.53	-3448.99	-3552.46	-3659.03	-3768.80	-3881.86	-3998.32	-4118.27	-4241.82
Non-Cash Costs															
Depreciation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Costs	-2804.34	-2888.47	-2975.13	-3064.38	-3156.31	-3251.00	-3348.53	-3448.99	-3552.46	-3659.03	-3768.80	-3881.86	-3998.32	-4118.27	-4241.82
Non-Cash Charges	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	-2804.34	-2888.47	-2975.13	-3064.38	-3156.31	-3251.00	-3348.53	-3448.99	-3552.46	-3659.03	-3768.80	-3881.86	-3998.32	-4118.27	-4241.82
Net Present Value=	-299.69	-268.41	-240.41	-215.32	-192.85	-172.73	-154.70	-138.56	-124.10	-111.15	-99.55	-89.17	-79.86	-71.53	-64.06
Cumulative Net Present Value=	12427.70	12696.12	12936.52	13151.84	13344.69	13517.42	13672.12	13810.68	13934.79	14045.94	14145.49	14234.66	14314.52	14386.05	14450.11

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Costs: Do Nothing																
Cash Operating	0	-1800	-1854.00	-1909.62	-1966.91	-2025.92	-2086.69	-2149.29	-2213.77	-2280.19	-2348.59	-2419.05	-2491.62	-2566.37	-2643.36	-2722.66
Non-Cash Costs																
Depreciation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Costs	0	-1800	-1854	-1909.62	-1966.91	-2025.92	-2086.69	-2149.29	-2213.77	-2280.19	-2348.59	-2419.05	-2491.62	-2566.37	-2643.36	-2722.66
Non-Cash Charges	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	0	-1800.00	-1854.00	-1909.62	-1966.91	-2025.92	-2086.69	-2149.29	-2213.77	-2280.19	-2348.59	-2419.05	-2491.62	-2566.37	-2643.36	-2722.66
Net Present Value=	0.00	-1666.67	-1589.51	-1515.92	-1445.74	-1378.80	-1314.97	-1254.09	-1196.03	-1140.66	-1087.85	-1037.49	-989.46	-943.65	-899.96	-858.30
Cumulative Net Present Value=	0.00	1666.67	3256.17	4772.09	6217.83	7596.63	8911.60	10165.69	11361.73	12502.39	13590.24	14627.73	15617.19	16560.84	17460.80	18319.09
Total NPV=	**-27316.26**															
Annual Worth=	**2426.50**			MARR=	**8%**											
				Inflation=	3%											

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Costs: Do Nothing															
Cash Operating	-2804.34	-2888.47	-2975.13	-3064.38	-3156.31	-3251.00	-3348.53	-3448.99	-3552.46	-3659.03	-3768.80	-3881.86	-3998.32	-4118.27	-4241.82
Non-Cash Costs															
Depreciation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Costs	-2804.34	-2888.47	-2975.13	-3064.38	-3156.31	-3251.00	-3348.53	-3448.99	-3552.46	-3659.03	-3768.80	-3881.86	-3998.32	-4118.27	-4241.82
Non-Cash Charges	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	-2804.34	-2888.47	-2975.13	-3064.38	-3156.31	-3251.00	-3348.53	-3448.99	-3552.46	-3659.03	-3768.80	-3881.86	-3998.32	-4118.27	-4241.82
Net Present Value=	-818.56	-780.66	-744.52	-710.05	-677.18	-645.83	-615.93	-587.42	-560.22	-534.28	-509.55	-485.96	-463.46	-442.00	-421.54
Cumulative Net Present Value=	19137.65	19918.32	20662.84	21372.89	22050.07	22695.90	23311.83	23899.25	24459.47	24993.75	25503.30	25989.26	26452.72	26894.72	27316.26

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Costs: Insulation																
Cash Operating	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Cash Costs																
Depreciation	0	109.56	210.93	195.16	180.55	166.82	154.26	142.86	132.05	130.30	130.30	130.30	130.30	130.30	130.30	130.30
Total Costs	0	109.56	210.93	195.16	180.55	166.82	154.26	142.86	132.05	130.30	130.30	130.30	130.30	130.30	130.30	130.30
Non-Cash Charges	0	109.56	210.93	195.16	180.55	166.82	154.26	142.86	132.05	130.30	130.30	130.30	130.30	130.30	130.30	130.30
Capital Expenditures	-2921.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	-2921.5	109.56	210.93	195.16	180.55	166.82	154.26	142.86	132.05	130.30	130.30	130.30	130.30	130.30	130.30	130.30
Net Present Value=	-2921.50	95.27	159.50	128.32	103.23	82.94	66.69	53.71	43.17	37.04	32.21	28.01	24.35	21.18	18.41	16.01
Cumulative Net Present Value=	2921.50	2826.23	2666.74	2538.42	2435.19	2352.25	2285.56	2231.86	2188.69	2151.65	2119.44	2091.44	2067.08	2045.90	2027.49	2011.48
Total NPV=	**-1954.31**															
Annual Worth=	**297.64**			MARR=	**15%**											
				Inflation=	3%											

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Costs: Insulation															
Cash Operating	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Cash Costs															
Depreciation	130.30	130.30	130.30	130.30	130.30	65.73	0	0	0	0	0	0	0	0	0
Total Costs	130.30	130.30	130.30	130.30	130.30	65.73	0	0	0	0	0	0	0	0	0
Non-Cash Charges	130.30	130.30	130.30	130.30	130.30	65.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	130.30	130.30	130.30	130.30	130.30	65.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Present Value=	13.92	12.11	10.53	9.16	7.96	3.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Net Present Value=	1997.55	1985.44	1974.92	1965.76	1957.80	1954.31	1954.31	1954.31	1954.31	1954.31	1954.31	1954.31	1954.31	1954.31	1954.31

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Costs: Insulation																
Cash Operating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-Cash Costs																
Depreciation	0	109.56	210.93	195.16	180.55	166.82	154.26	142.86	132.05	130.30	130.30	130.30	130.30	130.30	130.30	130.30
Total Costs	0	109.56	210.93	195.16	180.55	166.82	154.26	142.86	132.05	130.30	130.30	130.30	130.30	130.30	130.30	130.30
Non-Cash Charges	0	109.56	210.93	195.16	180.55	166.82	154.26	142.86	132.05	130.30	130.30	130.30	130.30	130.30	130.30	130.30
Capital Expenditures	-2921.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	-2921.5	109.56	210.93	195.16	180.55	166.82	154.26	142.86	132.05	130.30	130.30	130.30	130.30	130.30	130.30	130.30
Net Present Value=	-2921.50	101.44	180.84	154.92	132.71	113.53	97.21	83.36	71.34	65.18	60.35	55.88	51.74	47.91	44.36	41.08
Cumulative Net Present Value=	2921.50	2820.06	2639.22	2484.30	2351.59	2238.06	2140.85	2057.49	1986.15	1920.96	1860.61	1804.73	1752.98	1705.07	1660.71	1619.64
Total NPV=	**-1562.47**															
Annual Worth=	**138.79**			MARR=	**8%**											
				Inflation=	3%											

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Costs: Insulation															
Cash Operating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-Cash Costs															
Depreciation	130.30	130.30	130.30	130.30	130.30	65.73	0	0	0	0	0	0	0	0	0
Total Costs	130.30	130.30	130.30	130.30	130.30	65.73	0	0	0	0	0	0	0	0	0
Non-Cash Charges	130.30	130.30	130.30	130.30	130.30	65.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	130.30	130.30	130.30	130.30	130.30	65.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Present Value=	13.92	12.11	10.53	9.16	7.96	3.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Net Present Value=	1605.71	1593.60	1583.08	1573.92	1565.96	1562.47	1562.47	1562.47	1562.47	1562.47	1562.47	1562.47	1562.47	1562.47	1562.47

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Costs: Thermosyphon & Insulation																
Cash Operating	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Cash Costs																
Depreciation	0	1140.81	2196.43	2032.16	1880.05	1737.07	1606.26	1487.61	1375.05	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80
Total Costs	0	1140.81	2196.43	2032.16	1880.05	1737.07	1606.26	1487.61	1375.05	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80
Non-Cash Charges	0	1140.81	2196.43	2032.16	1880.05	1737.07	1606.26	1487.61	1375.05	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80
Capital Expenditures	-30421.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	-30421.5	1140.81	2196.43	2032.16	1880.05	1737.07	1606.26	1487.61	1375.05	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80
Net Present Value=	-30421.50	992.01	1660.82	1336.18	1074.92	863.63	694.43	559.25	449.51	385.69	335.38	291.63	253.60	220.52	191.75	166.74
Cumulative Net Present Value=	30421.50	29429.49	27768.68	26432.50	25357.58	24493.95	23799.52	23240.27	22790.76	22405.08	22069.70	21778.06	21524.47	21303.95	21112.19	20945.45
Total NPV=	**-20350.14**															
Annual Worth=	**3099.33**			MARR=	**15%**											
				Inflation=	3%											

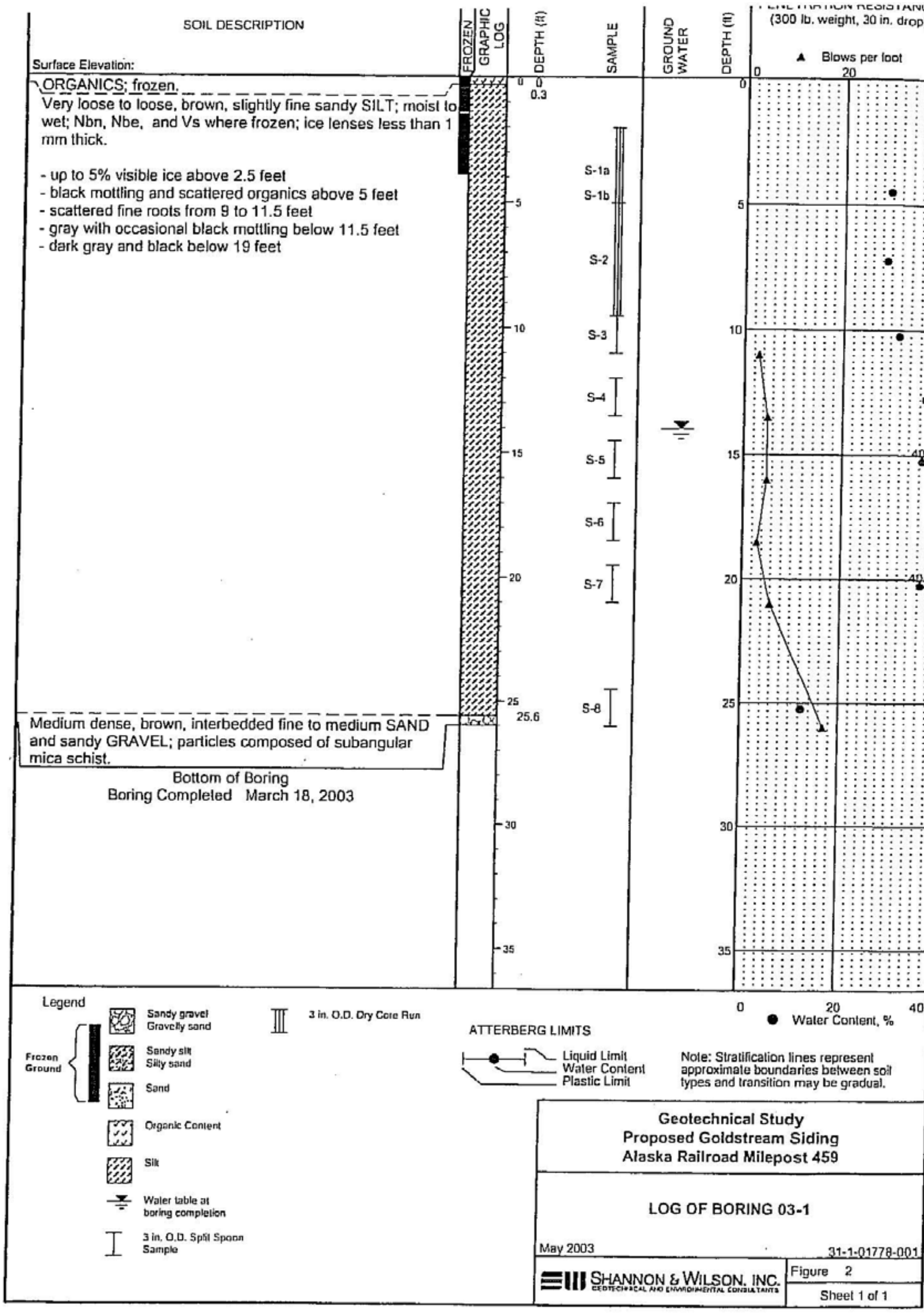
Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Costs: Thermosyphon & Insulation															
Cash Operating	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Cash Costs															
Depreciation	1356.80	1356.80	1356.80	1356.80	1356.80	684.48	0	0	0	0	0	0	0	0	0
Total Costs	1356.80	1356.80	1356.80	1356.80	1356.80	684.48	0	0	0	0	0	0	0	0	0
Non-Cash Charges	1356.80	1356.80	1356.80	1356.80	1356.80	684.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	1356.80	1356.80	1356.80	1356.80	1356.80	684.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Present Value=	144.99	126.08	109.64	95.34	82.90	36.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Net Present Value=	20800.46	20674.38	20564.74	20469.40	20386.50	20350.14	20350.14	20350.14	20350.14	20350.14	20350.14	20350.14	20350.14	20350.14	20350.14

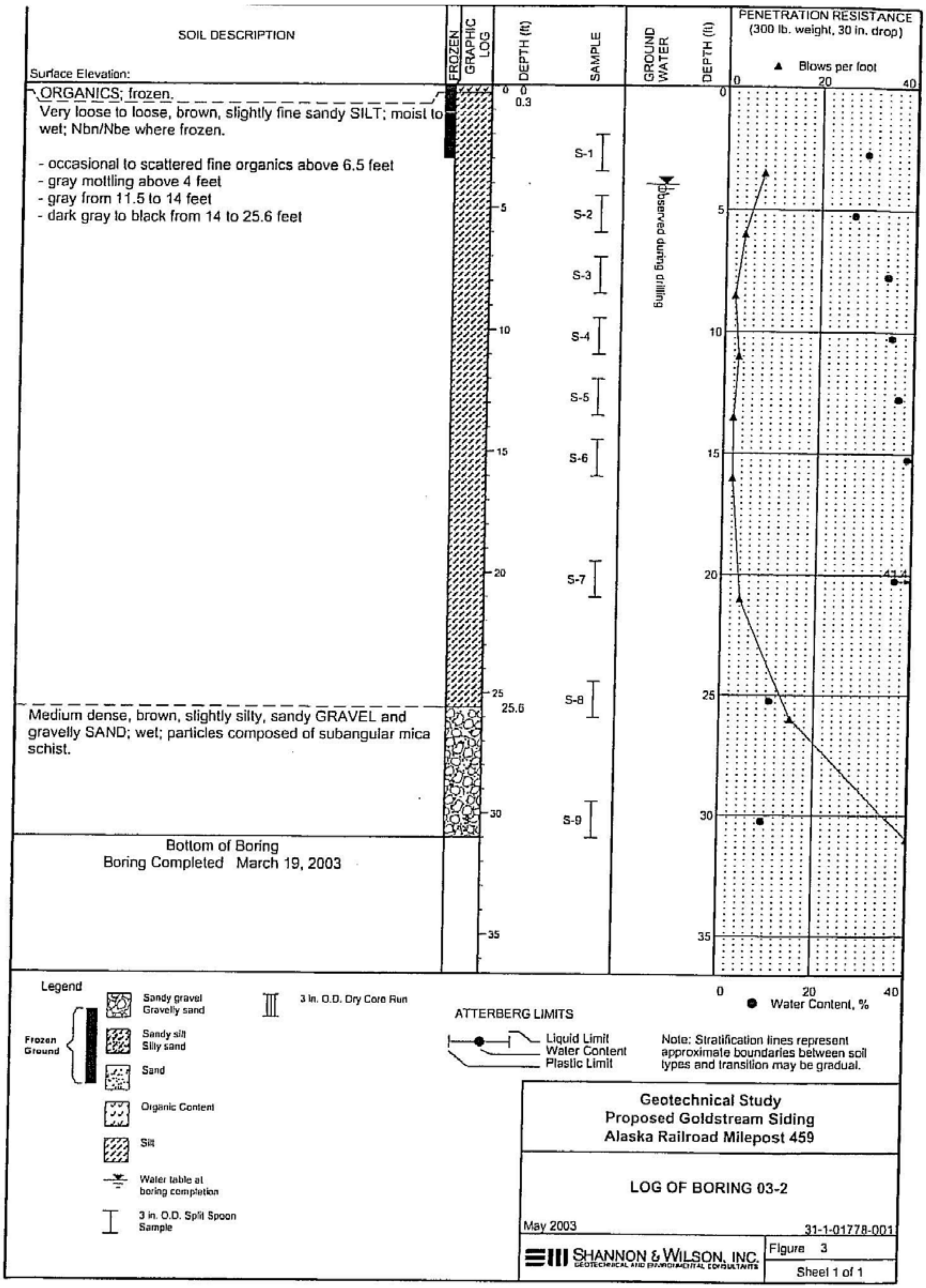
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Costs: Thermosyphon & Insulation																
Cash Operating	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Cash Costs																
Depreciation	0	1140.81	2196.43	2032.16	1880.05	1737.07	1606.26	1487.61	1375.05	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80
Total Costs	0	1140.81	2196.43	2032.16	1880.05	1737.07	1606.26	1487.61	1375.05	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80
Non-Cash Charges	0	1140.81	2196.43	2032.16	1880.05	1737.07	1606.26	1487.61	1375.05	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80
Capital Expenditures	-30421.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	-30421.5	1140.81	2196.43	2032.16	1880.05	1737.07	1606.26	1487.61	1375.05	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80	1356.80
Net Present Value=	-30421.50	1056.30	1883.09	1613.19	1381.89	1182.22	1012.21	868.01	742.90	678.74	628.46	581.91	538.80	498.89	461.94	427.72
Cumulative Net Present Value=	30421.50	29365.20	27482.11	25868.92	24487.03	23304.81	22292.60	21424.59	20681.69	20002.95	19374.49	18792.59	18253.78	17754.89	17292.95	16865.23
Total NPV=	**-15021.50**															
Annual Worth=	**1334.36**			MARR=	**8%**											
				Inflation=	3%											

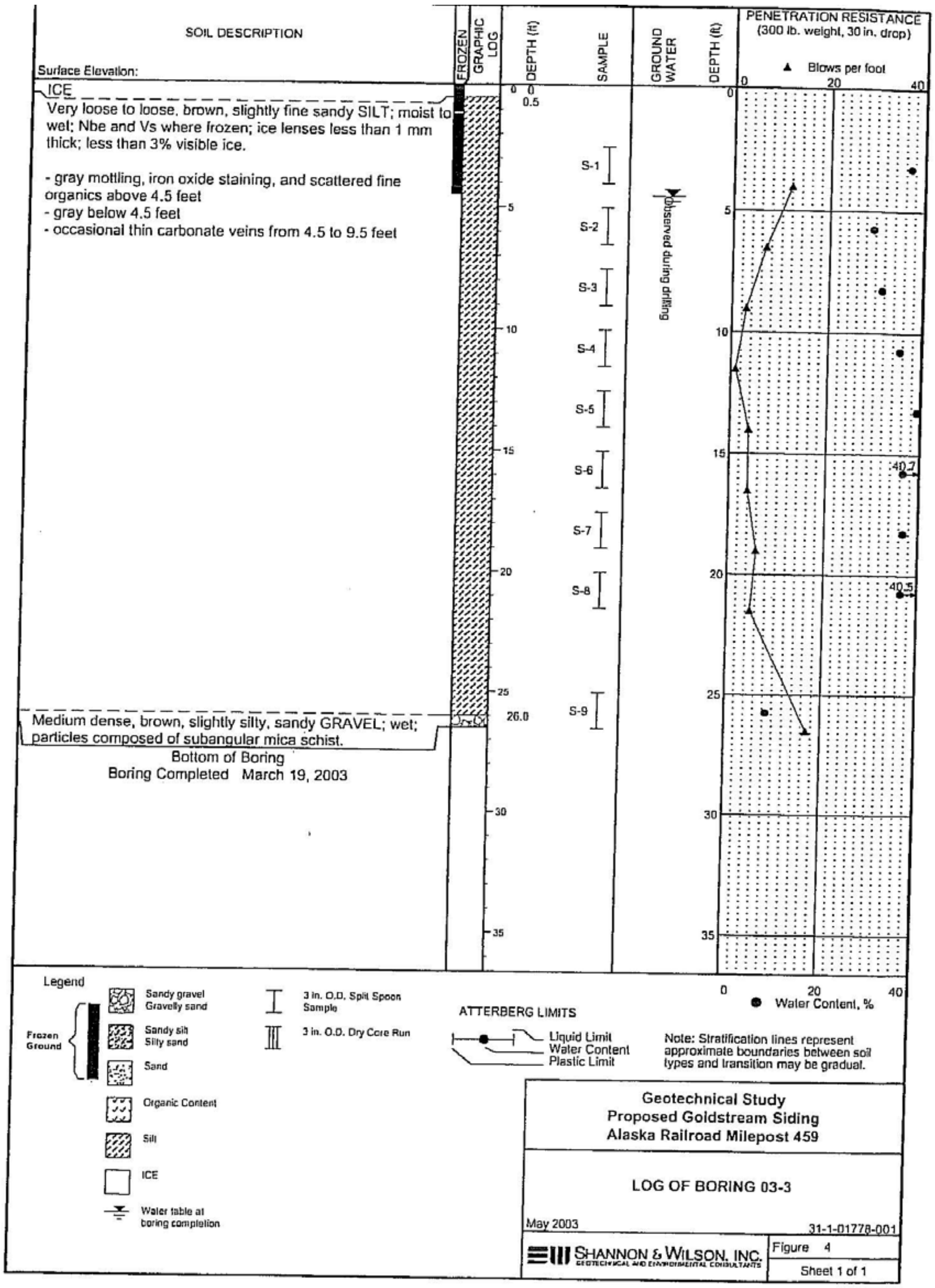
Costs: Thermosyphon & Insulation															
Cash Operating	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Cash Costs															
Depreciation	1356.80	1356.80	1356.80	1356.80	1356.80	684.48	0	0	0	0	0	0	0	0	0
Total Costs	1356.80	1356.80	1356.80	1356.80	1356.80	684.48	0	0	0	0	0	0	0	0	0
Non-Cash Charges	1356.80	1356.80	1356.80	1356.80	1356.80	684.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capital Expenditures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Cash Flow	1356.80	1356.80	1356.80	1356.80	1356.80	684.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Present Value=	396.04	366.70	339.54	314.39	291.10	135.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative Net Present Value=	16469.20	16102.50	15762.96	15448.57	15157.47	15021.50	15021.50	15021.50	15021.50	15021.50	15021.50	15021.50	15021.50	15021.50	15021.50

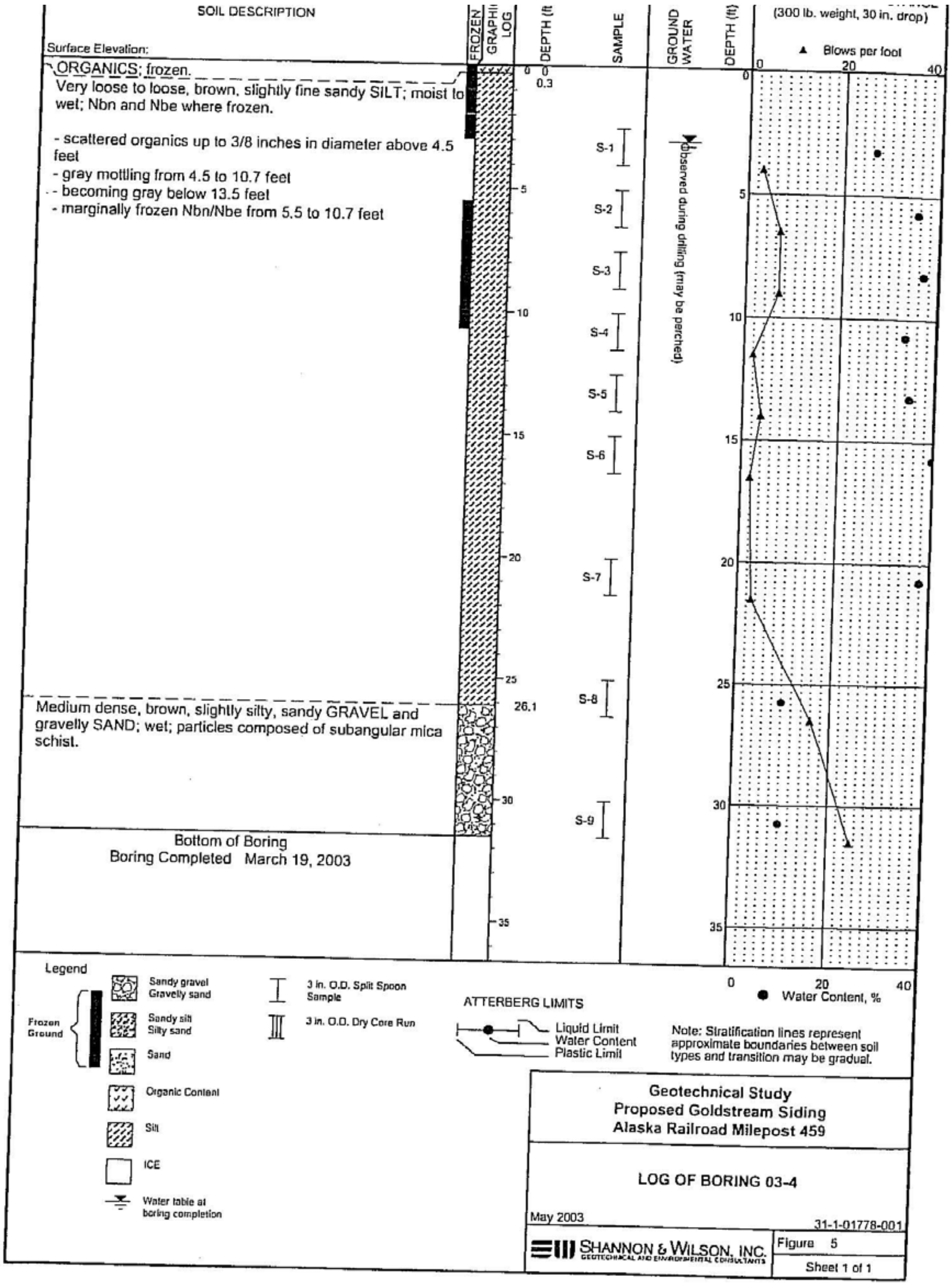
Appendix C: Soil Boring Data

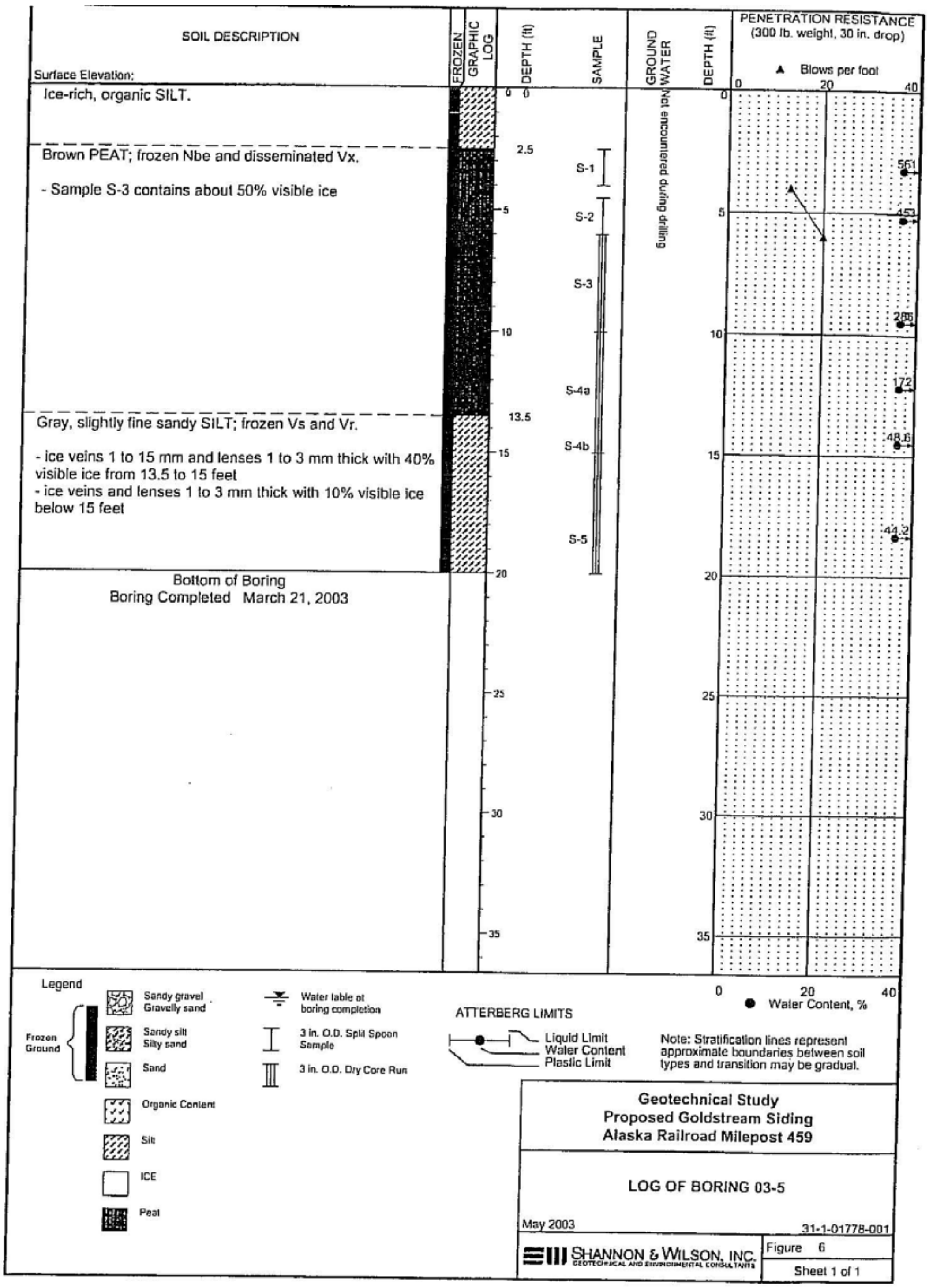
These are soil borings which were conducted by Shannon & Wilson during their geotechnical study in 2003.

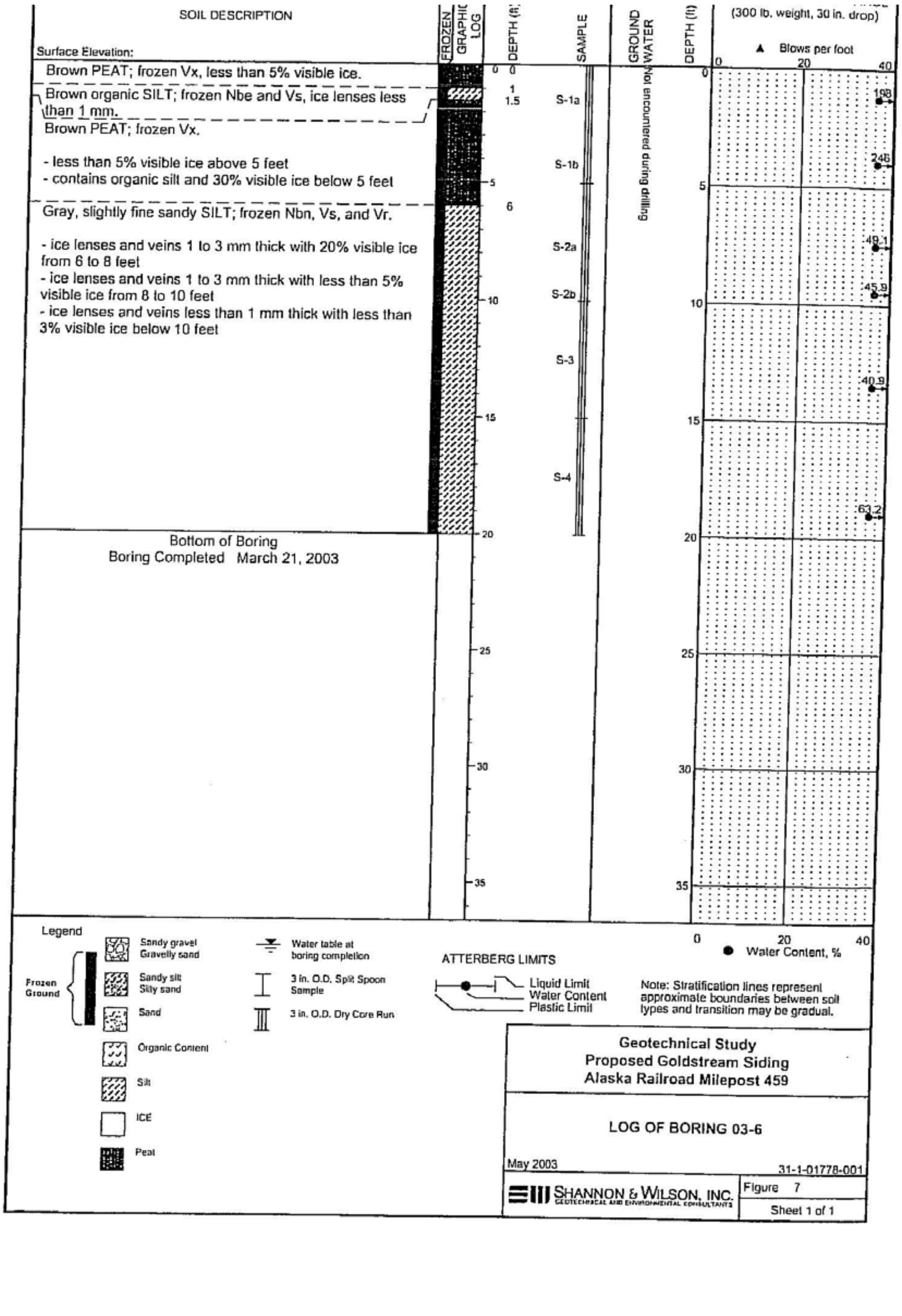

SOIL DESCRIPTION
Surface Elevation:
ORGANICS; frozen.
Very loose to loose, brown, slightly fine sandy SILT; moist to wet; Nbn, Nbe, and Vs where frozen; ice lenses less than 1 mm thick.
- up to 5% visible ice above 2.5 feet
- black mottling and scattered organics above 5 feet
- scattered fine roots from 9 to 11.5 feet
- gray with occasional black mottling below 11.5 feet
- dark gray and black below 19 feet
Medium dense, brown, interbedded fine to medium SAND and sandy GRAVEL; particles composed of subangular mica schist.
Bottom of Boring
Boring Completed March 18, 2003
FROZEN
GRAPHIC LOG
DEPTH (ft)
0.3
25.6
SAMPLE
S-1a
S-1b
S-2
S-3
S-4
S-5
S-6
S-7
S-8
GROUND WATER
DEPTH (ft)
(300 lb. weight, 30 in. drop)
▲ Blows per foot
40.2
40.8
Legend
Sandy gravel
Gravelly sand
Frozen Ground
Sandy silt
Silty sand
Sand
Organic Content
Silt
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
● Water Content, %
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-1
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 2
Sheet 1 of 1

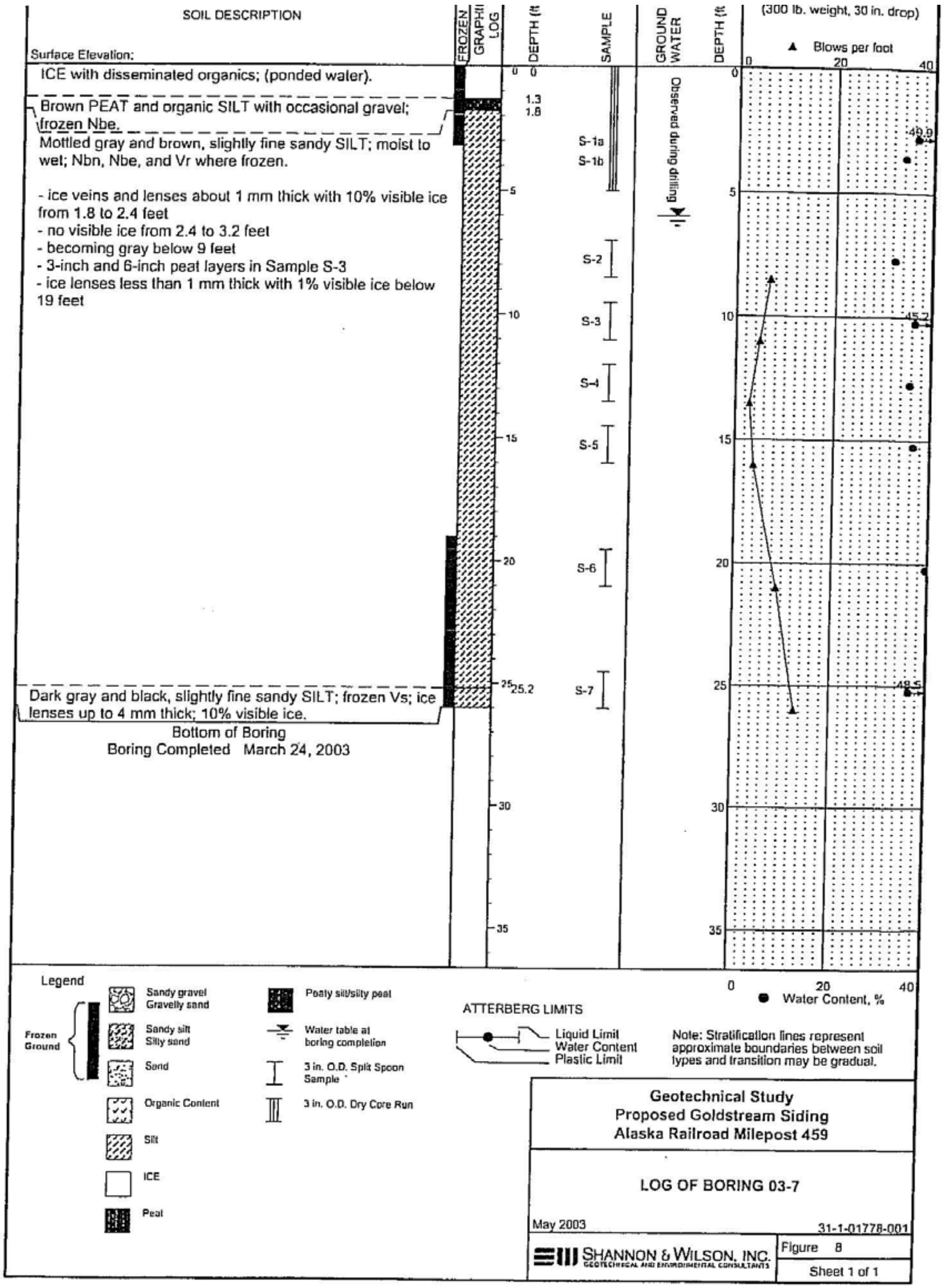

SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
PENETRATION RESISTANCE
(300 lb. weight, 30 in. drop)
▲ Blows per foot
ORGANICS; frozen.
Very loose to loose, brown, slightly fine sandy SILT; moist to wet; Nbn/Nbe where frozen.
- occasional to scattered fine organics above 6.5 feet
- gray mottling above 4 feet
- gray from 11.5 to 14 feet
- dark gray to black from 14 to 25.6 feet
Medium dense, brown, slightly silty, sandy GRAVEL and gravelly SAND; wet; particles composed of subangular mica schist.
Bottom of Boring
Boring Completed March 19, 2003
0.3
25.6
S-1
S-2
S-3
S-4
S-5
S-6
S-7
S-8
S-9
Observed during drilling
0
5
10
15
20
25
30
35
20
40
41.4
● Water Content, %
Legend
Sandy gravel
Gravelly sand
Frozen Ground
Sandy silt
Silty sand
Sand
Organic Content
Silt
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-2
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 3
Sheet 1 of 1

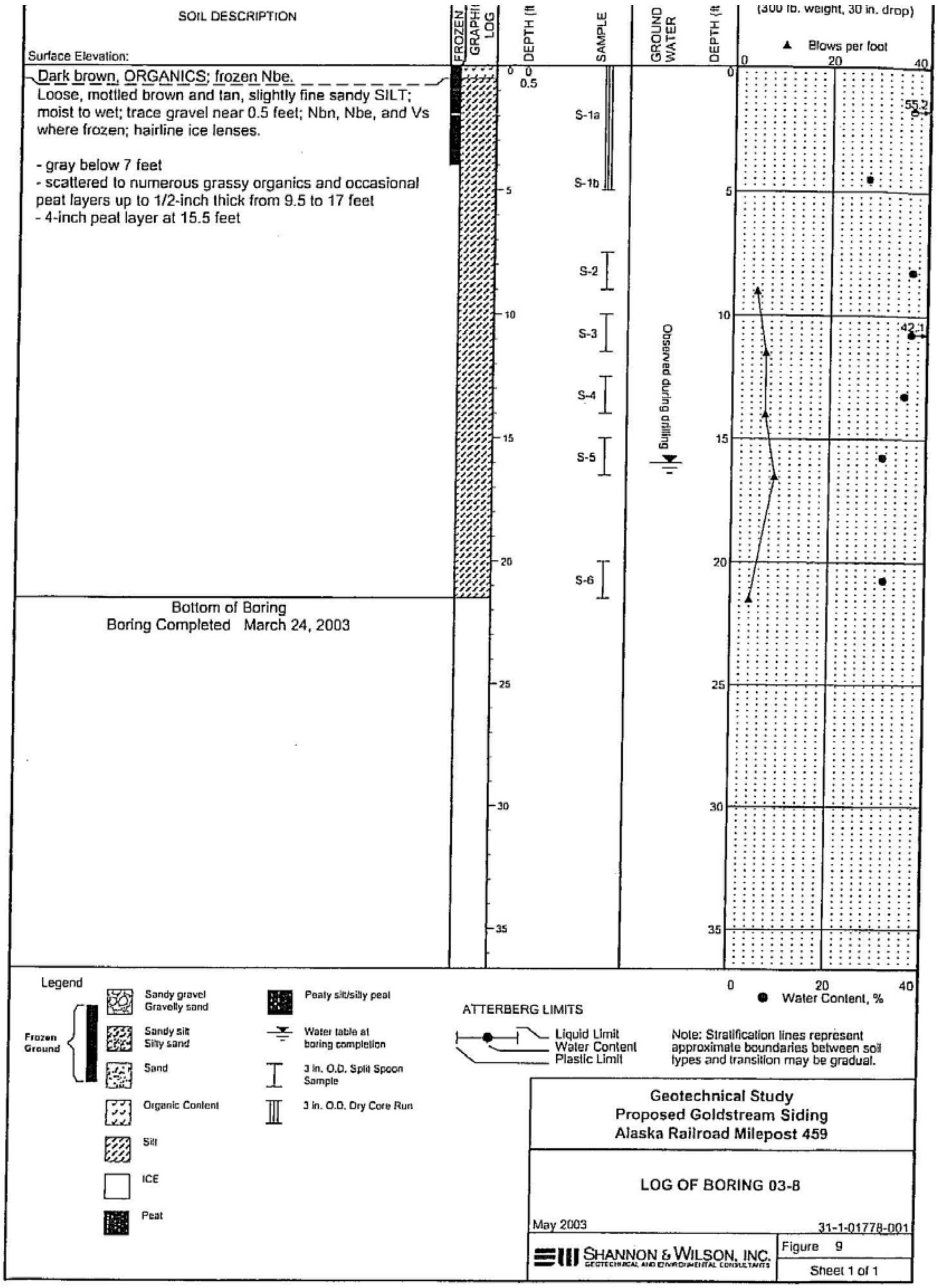

SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
PENETRATION RESISTANCE
(300 lb. weight, 30 in. drop)
▲ Blows per foot
ICE
Very loose to loose, brown, slightly fine sandy SILT; moist to wet; Nbe and Vs where frozen; ice lenses less than 1 mm thick; less than 3% visible ice.
- gray mottling, iron oxide staining, and scattered fine organics above 4.5 feet
- gray below 4.5 feet
- occasional thin carbonate veins from 4.5 to 9.5 feet
Medium dense, brown, slightly silty, sandy GRAVEL; wet; particles composed of subangular mica schist.
Bottom of Boring
Boring Completed March 19, 2003
0.5
26.0
S-1
S-2
S-3
S-4
S-5
S-6
S-7
S-8
S-9
Observed during drilling
40.7
40.5
Legend
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Frozen Ground
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
● Water Content, %
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-3
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 4
Sheet 1 of 1

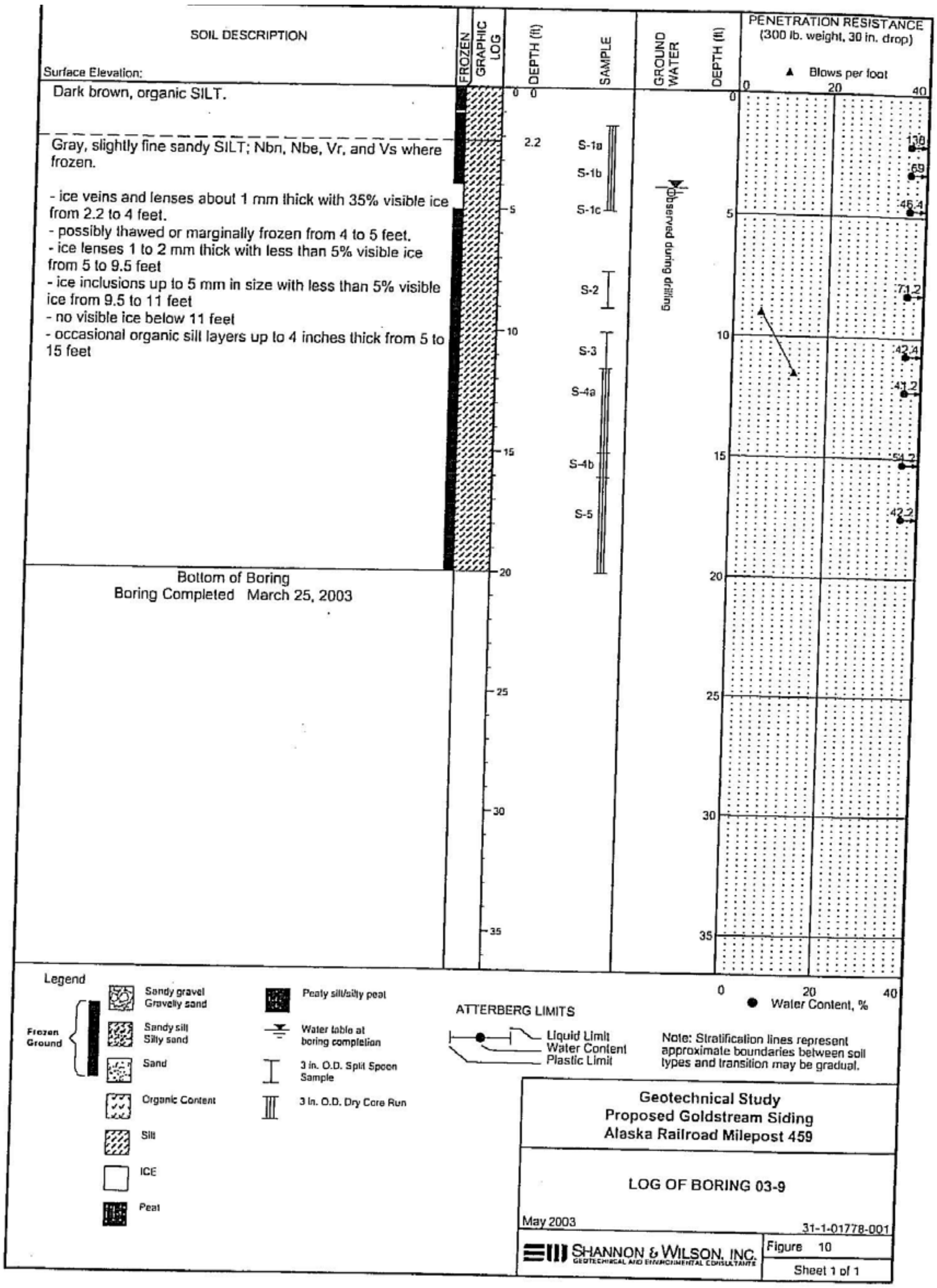

SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
(300 lb. weight, 30 in. drop)
▲ Blows per foot
ORGANICS; frozen.
Very loose to loose, brown, slightly fine sandy SILT; moist to wet; Nbn and Nbe where frozen.
- scattered organics up to 3/8 inches in diameter above 4.5 feet
- gray mottling from 4.5 to 10.7 feet
- becoming gray below 13.5 feet
- marginally frozen Nbn/Nbe from 5.5 to 10.7 feet
Medium dense, brown, slightly silty, sandy GRAVEL and gravelly SAND; wet; particles composed of subangular mica schist.
0.3
26.1
S-1
S-2
S-3
S-4
S-5
S-6
S-7
S-8
S-9
Observed during drilling (may be perched)
Bottom of Boring
Boring Completed March 19, 2003
Legend
Frozen Ground
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
● Water Content, %
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-4
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 5
Sheet 1 of 1

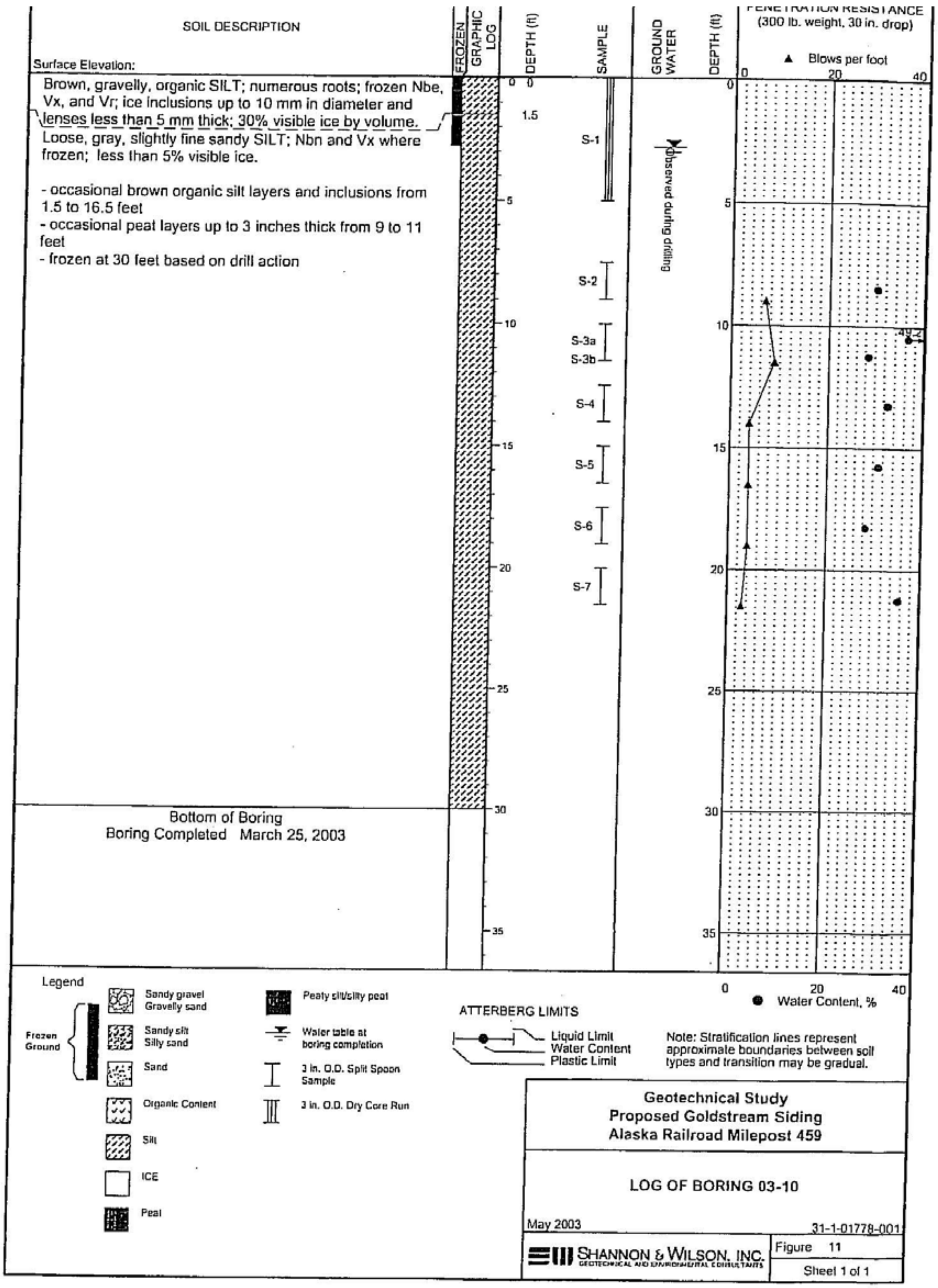

SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
PENETRATION RESISTANCE (300 lb. weight, 30 in. drop)
▲ Blows per foot
Ice-rich, organic SILT.
Brown PEAT; frozen Nbe and disseminated Vx.
- Sample S-3 contains about 50% visible ice
Gray, slightly fine sandy SILT; frozen Vs and Vr.
- ice veins 1 to 15 mm and lenses 1 to 3 mm thick with 40% visible ice from 13.5 to 15 feet
- ice veins and lenses 1 to 3 mm thick with 10% visible ice below 15 feet
Bottom of Boring
Boring Completed March 21, 2003
2.5
13.5
S-1
S-2
S-3
S-4a
S-4b
S-5
Not encountered during drilling
561
453
286
172
48.6
44.2
● Water Content, %
Legend
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Frozen Ground
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-5
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 6
Sheet 1 of 1


SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
(300 lb. weight, 30 in. drop)
▲ Blows per foot
Brown PEAT; frozen Vx, less than 5% visible ice.
Brown organic SILT; frozen Nbe and Vs, ice lenses less than 1 mm.
Brown PEAT; frozen Vx.
- less than 5% visible ice above 5 feet
- contains organic silt and 30% visible ice below 5 feet
Gray, slightly fine sandy SILT; frozen Nbn, Vs, and Vr.
- ice lenses and veins 1 to 3 mm thick with 20% visible ice from 6 to 8 feet
- ice lenses and veins 1 to 3 mm thick with less than 5% visible ice from 8 to 10 feet
- ice lenses and veins less than 1 mm thick with less than 3% visible ice below 10 feet
S-1a
S-1b
S-2a
S-2b
S-3
S-4
Not encountered during drilling
198
246
49.1
45.9
40.9
63.2
Bottom of Boring
Boring Completed March 21, 2003
0 20 40
● Water Content, %
Legend
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Frozen Ground
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-6
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 7
Sheet 1 of 1

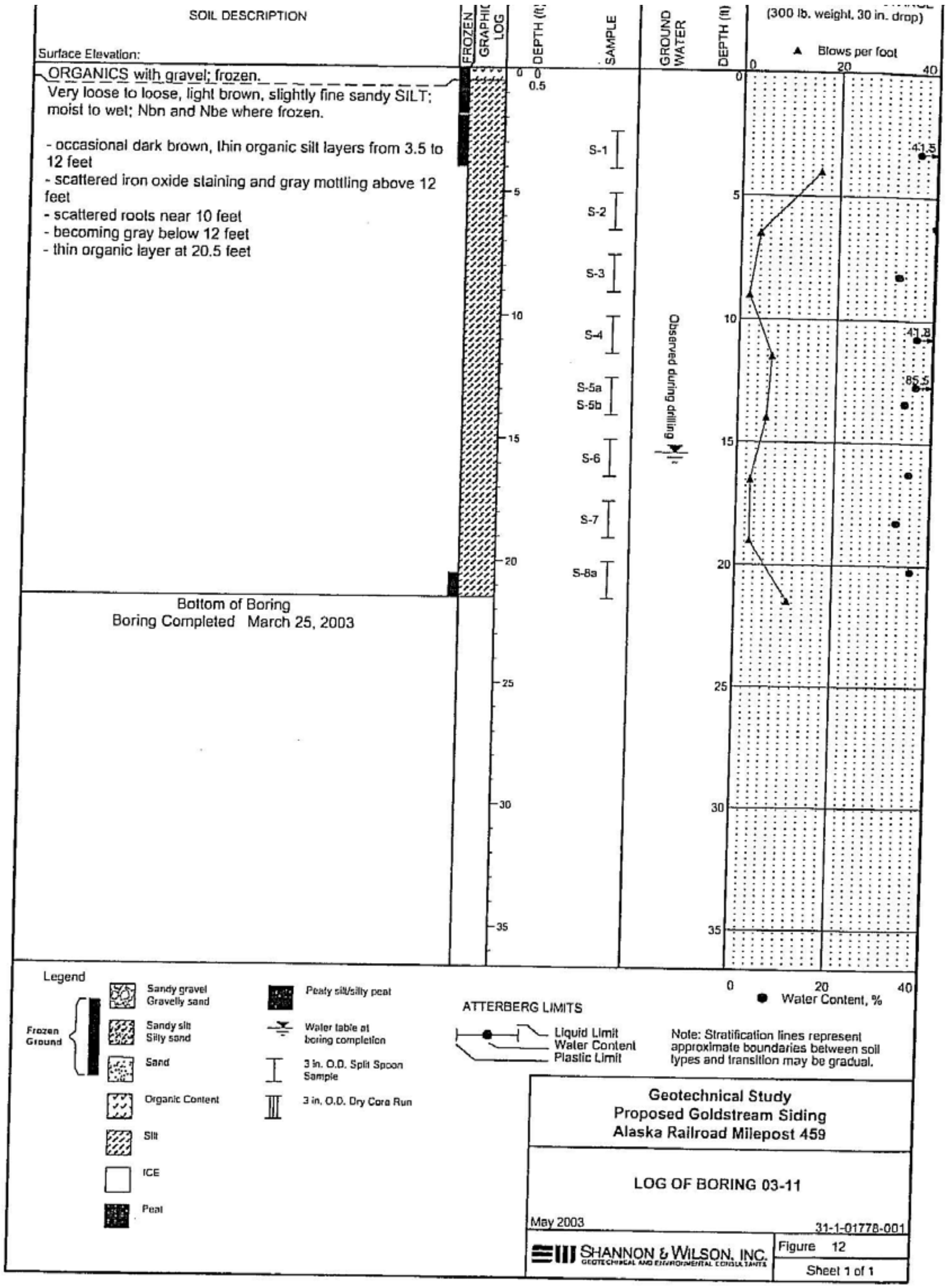

SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
(300 lb. weight, 30 in. drop)
Blows per foot
ICE with disseminated organics; (ponded water).
Brown PEAT and organic SILT with occasional gravel; frozen Nbe.
Mottled gray and brown, slightly fine sandy SILT; moist to wet; Nbn, Nbe, and Vr where frozen.
- ice veins and lenses about 1 mm thick with 10% visible ice from 1.8 to 2.4 feet
- no visible ice from 2.4 to 3.2 feet
- becoming gray below 9 feet
- 3-inch and 6-inch peat layers in Sample S-3
- ice lenses less than 1 mm thick with 1% visible ice below 19 feet
Dark gray and black, slightly fine sandy SILT; frozen Vs; ice lenses up to 4 mm thick; 10% visible ice.
Bottom of Boring
Boring Completed March 24, 2003
1.3
1.8
25.2
S-1a
S-1b
S-2
S-3
S-4
S-5
S-6
S-7
Observed during drilling
49.9
45.2
48.5
Water Content, %
Legend
Frozen Ground
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Peaty silt/silty peat
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-7
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 8
Sheet 1 of 1

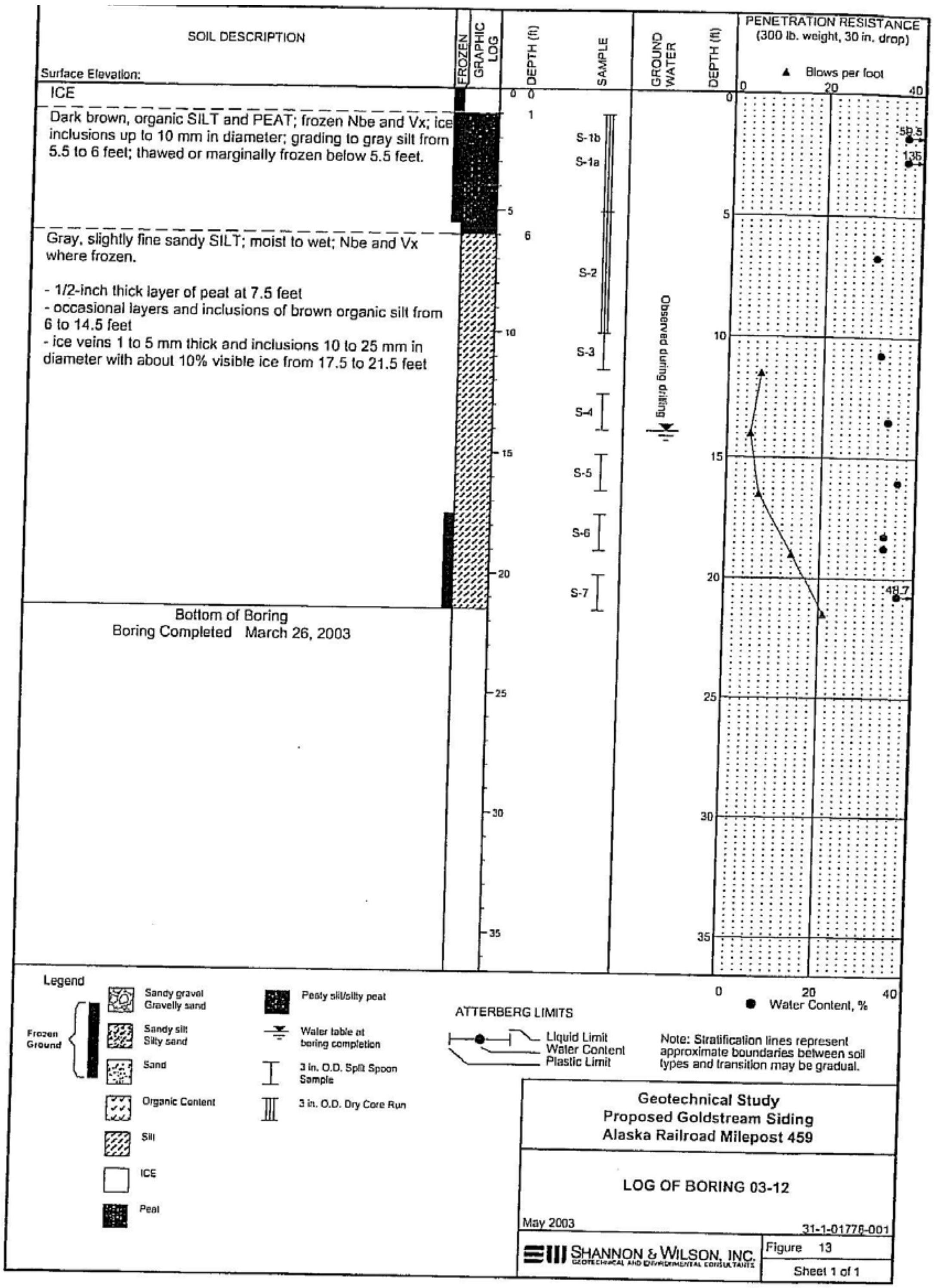

(300 lb. weight, 30 in. drop)
SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
Blows per foot
Dark brown, ORGANICS; frozen Nbe.
Loose, mottled brown and tan, slightly fine sandy SILT; moist to wet; trace gravel near 0.5 feet; Nbn, Nbe, and Vs where frozen; hairline ice lenses.
- gray below 7 feet
- scattered to numerous grassy organics and occasional peat layers up to 1/2-inch thick from 9.5 to 17 feet
- 4-inch peat layer at 15.5 feet
Bottom of Boring
Boring Completed March 24, 2003
0.5
S-1a
S-1b
S-2
S-3
S-4
S-5
S-6
Observed during drilling
55.2
42.1
Water Content, %
Legend
Sandy gravel
Gravelly sand
Frozen Ground
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Peaty silt/silty peat
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-8
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
Figure 9
Sheet 1 of 1

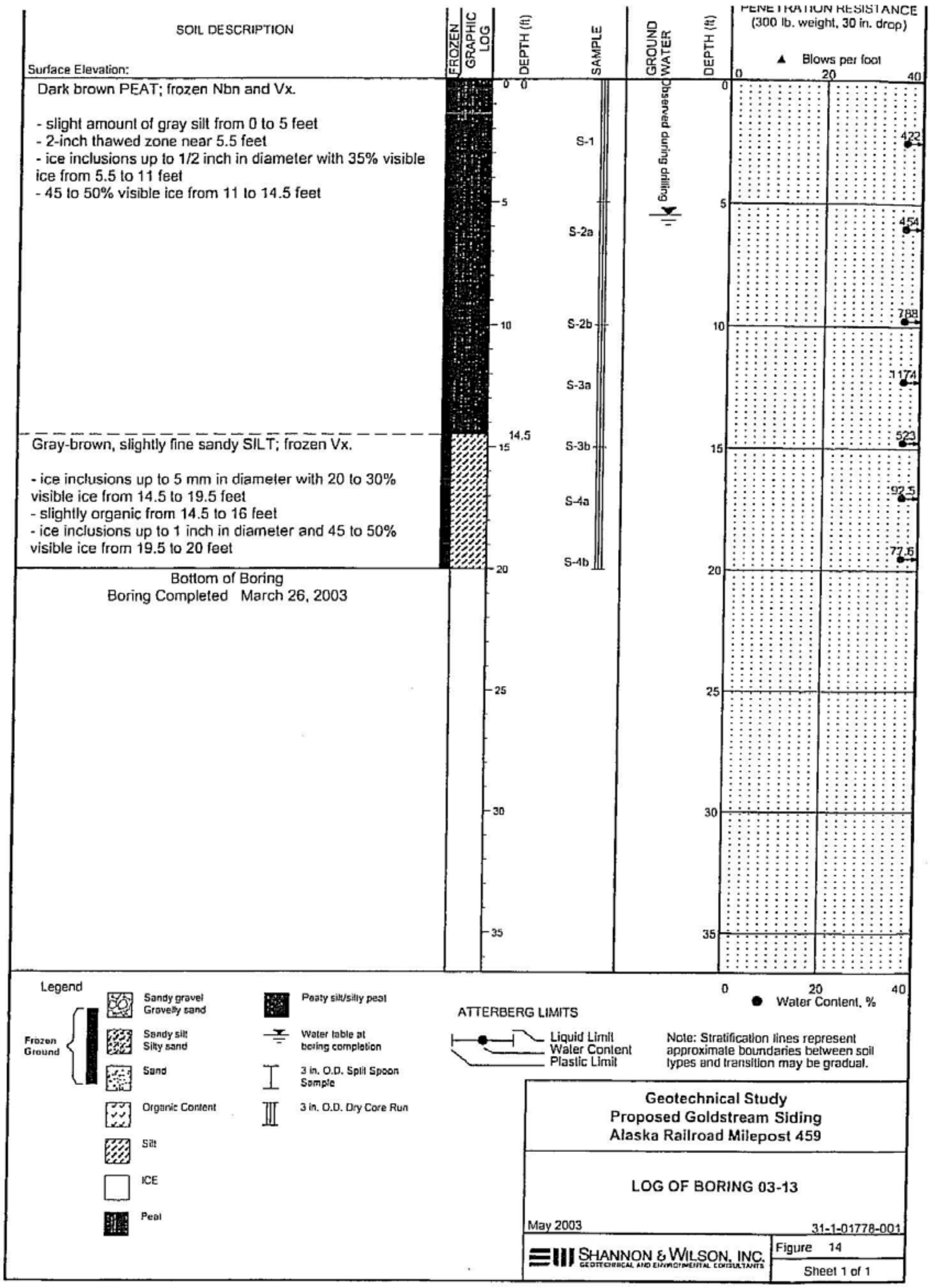

SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
PENETRATION RESISTANCE
(300 lb. weight, 30 in. drop)
▲ Blows per foot
Dark brown, organic SILT.
Gray, slightly fine sandy SILT; Nbn, Nbe, Vr, and Vs where frozen.
- ice veins and lenses about 1 mm thick with 35% visible ice from 2.2 to 4 feet.
- possibly thawed or marginally frozen from 4 to 5 feet.
- ice lenses 1 to 2 mm thick with less than 5% visible ice from 5 to 9.5 feet
- ice inclusions up to 5 mm in size with less than 5% visible ice from 9.5 to 11 feet
- no visible ice below 11 feet
- occasional organic silt layers up to 4 inches thick from 5 to 15 feet
Bottom of Boring
Boring Completed March 25, 2003
2.2
S-1a
S-1b
S-1c
S-2
S-3
S-4a
S-4b
S-5
Observed during drilling
138
69
46.4
71.2
42.4
41.2
54.2
42.2
0 20 40
● Water Content, %
Legend
Sandy gravel
Gravelly sand
Frozen Ground
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Peaty silt/silty peat
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-9
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 10
Sheet 1 of 1

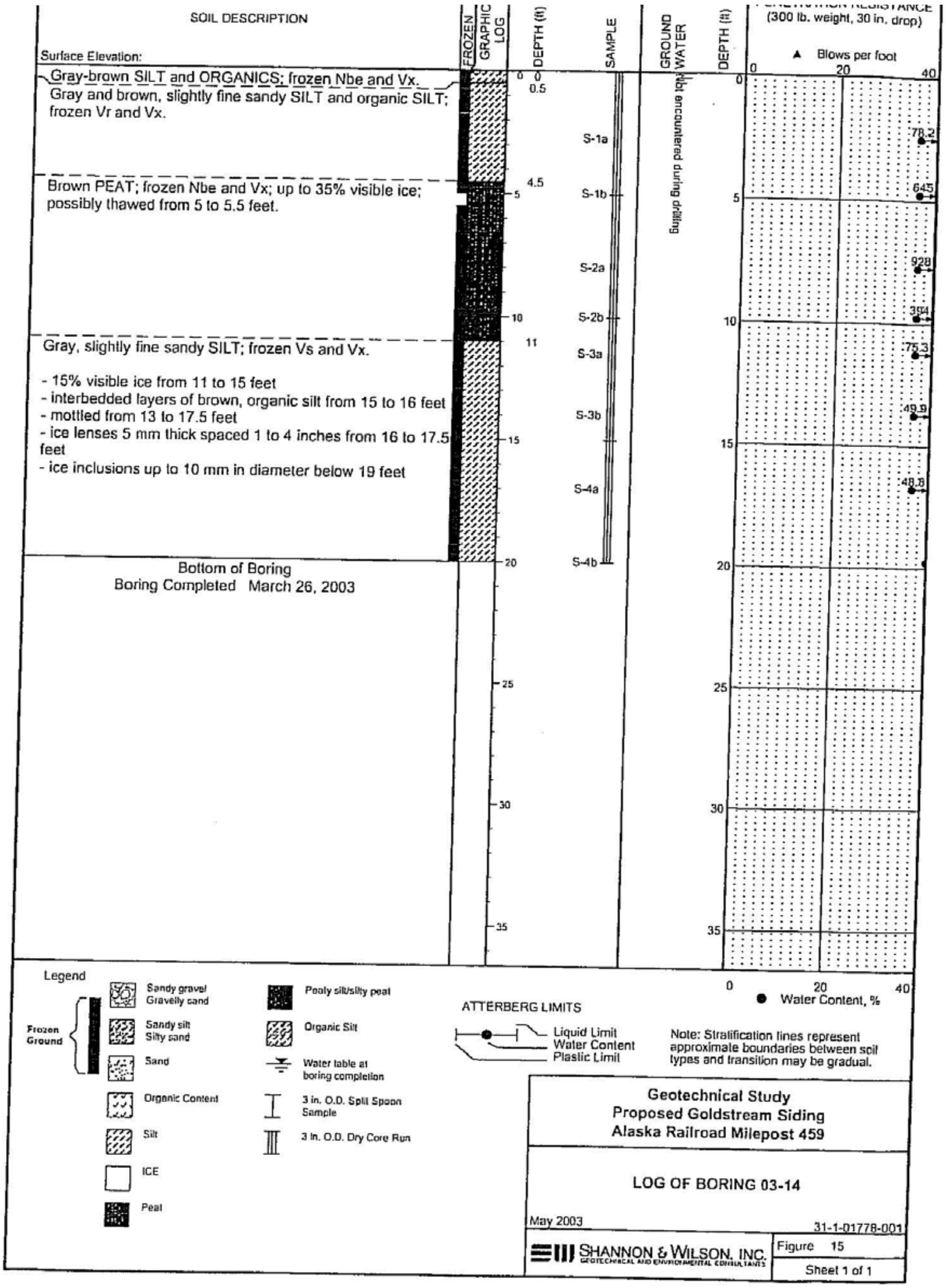


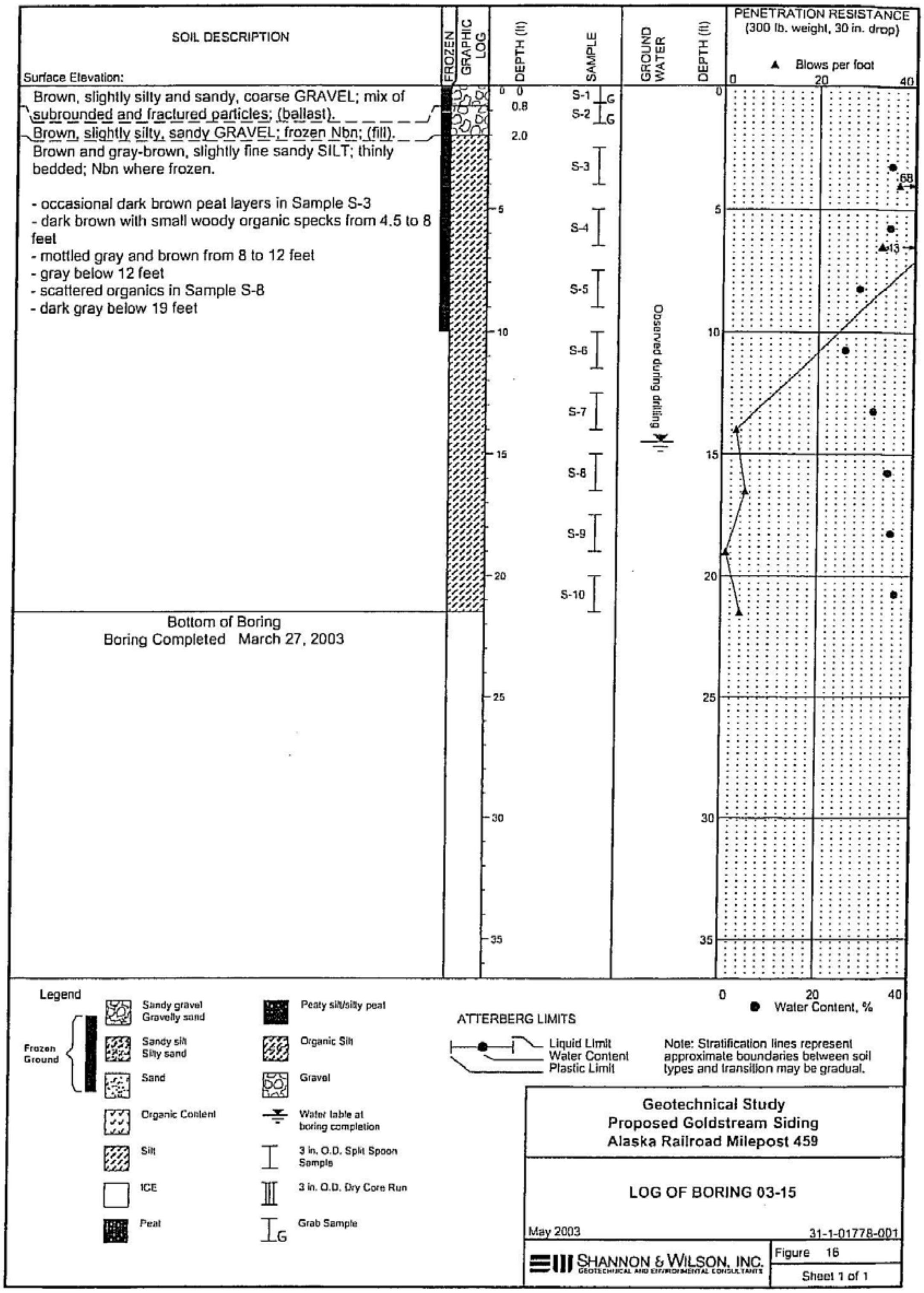
SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
PENETRATION RESISTANCE (300 lb. weight, 30 in. drop)
▲ Blows per foot
Brown, gravelly, organic SILT; numerous roots; frozen Nbe, Vx, and Vr; ice inclusions up to 10 mm in diameter and lenses less than 5 mm thick; 30% visible ice by volume.
Loose, gray, slightly fine sandy SILT; Nbn and Vx where frozen; less than 5% visible ice.
- occasional brown organic silt layers and inclusions from 1.5 to 16.5 feet
- occasional peat layers up to 3 inches thick from 9 to 11 feet
- frozen at 30 feet based on drill action
1.5
S-1
S-2
S-3a
S-3b
S-4
S-5
S-6
S-7
Not observed during drilling
Bottom of Boring
Boring Completed March 25, 2003
Legend
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Frozen Ground
Peaty silt/silty peat
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
● Water Content, %
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-10
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 11
Sheet 1 of 1

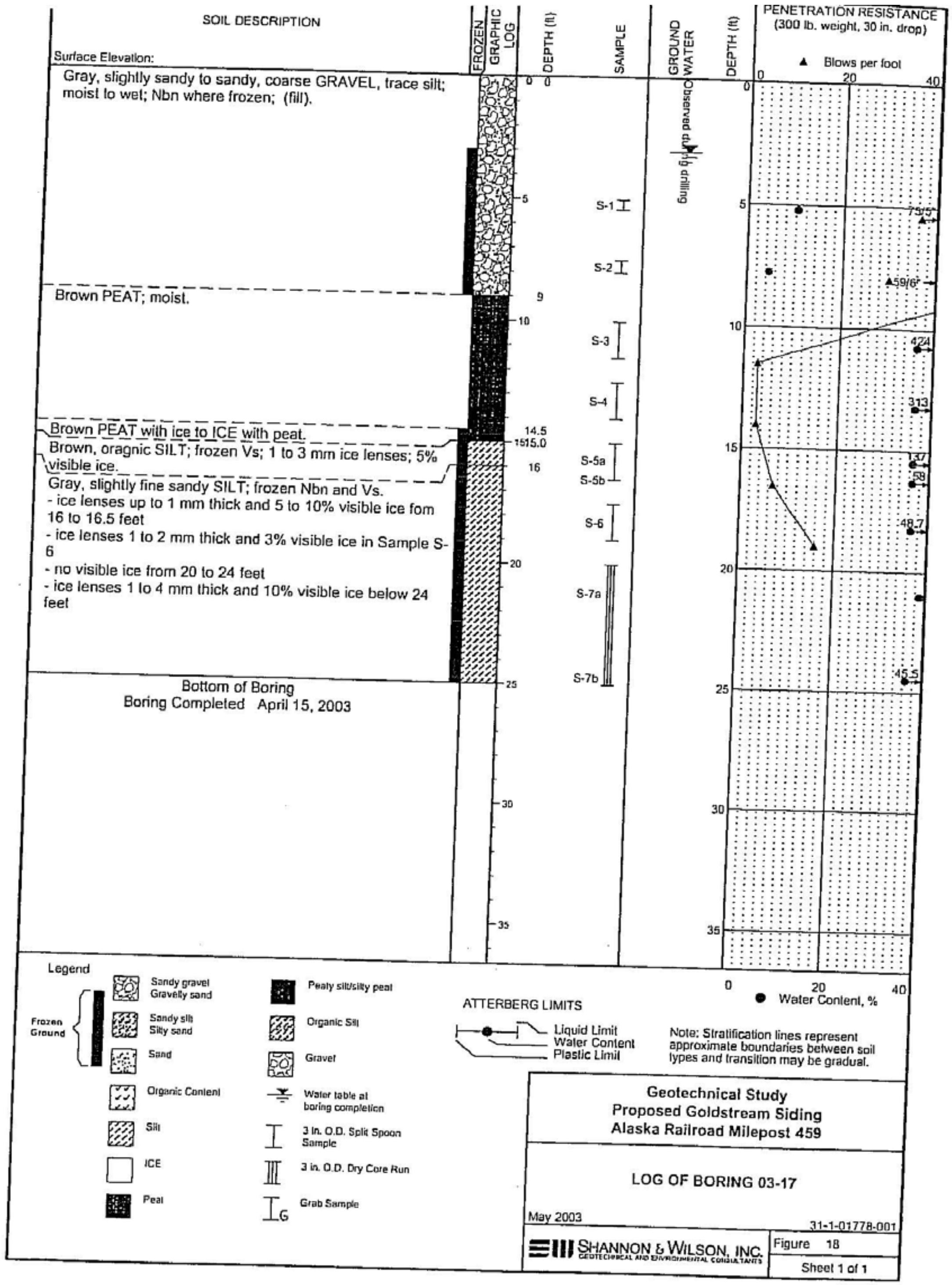

SOIL DESCRIPTION
Surface Elevation:
ORGANICS with gravel; frozen.
Very loose to loose, light brown, slightly fine sandy SILT; moist to wet; Nbn and Nbe where frozen.
- occasional dark brown, thin organic silt layers from 3.5 to 12 feet
- scattered iron oxide staining and gray mottling above 12 feet
- scattered roots near 10 feet
- becoming gray below 12 feet
- thin organic layer at 20.5 feet
Bottom of Boring
Boring Completed March 25, 2003
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
(300 lb. weight, 30 in. drop)
Blows per foot
S-1
S-2
S-3
S-4
S-5a
S-5b
S-6
S-7
S-8a
Observed during drilling
41.5
41.8
85.5
Water Content, %
Legend
Frozen Ground
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Peaty silt/silty peat
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-11
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 12
Sheet 1 of 1

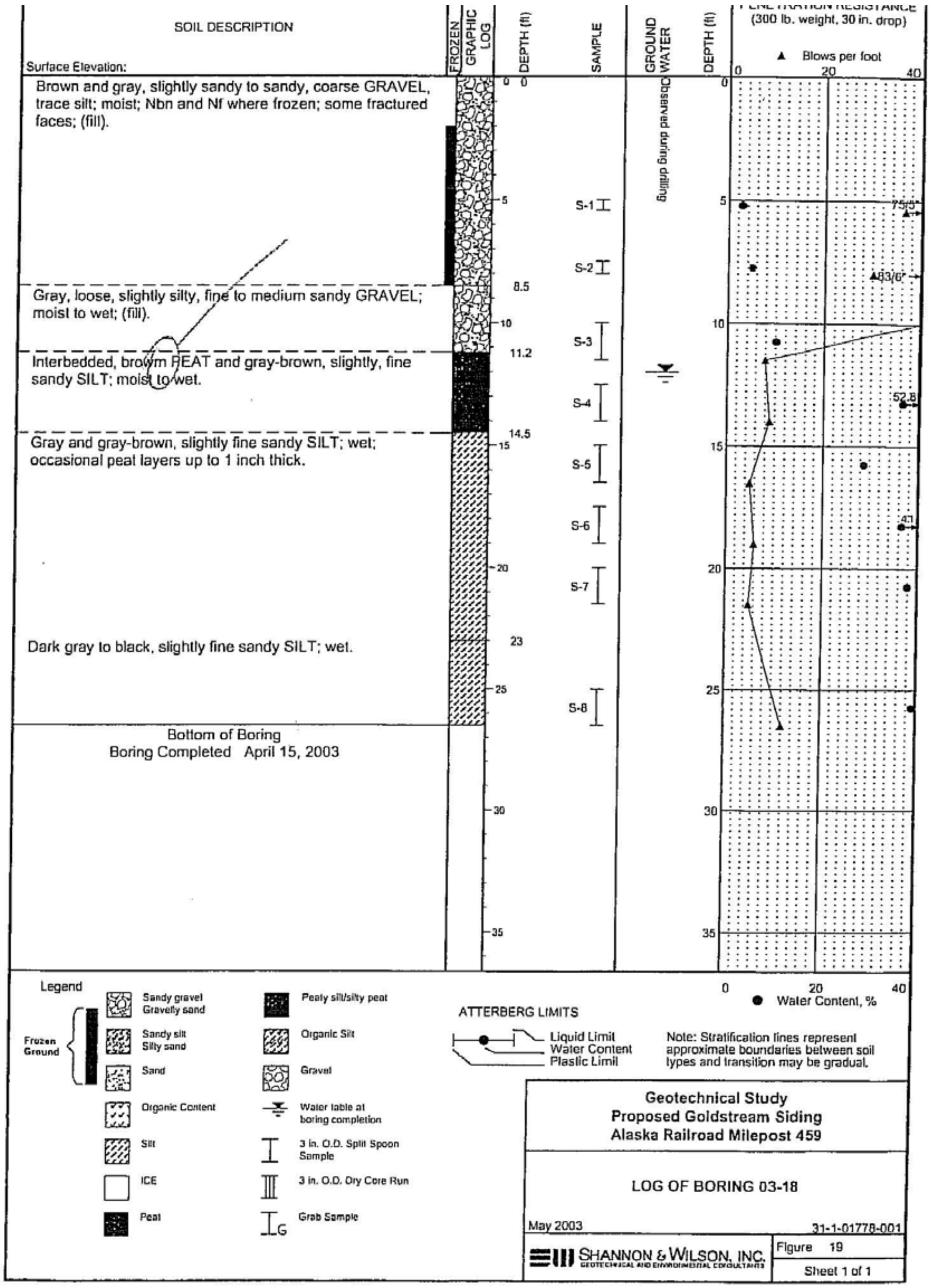

SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
PENETRATION RESISTANCE
(300 lb. weight, 30 in. drop)
▲ Blows per foot
ICE
Dark brown, organic SILT and PEAT; frozen Nbe and Vx; ice inclusions up to 10 mm in diameter; grading to gray silt from 5.5 to 6 feet; thawed or marginally frozen below 5.5 feet.
Gray, slightly fine sandy SILT; moist to wet; Nbe and Vx where frozen.
- 1/2-inch thick layer of peat at 7.5 feet
- occasional layers and inclusions of brown organic silt from 6 to 14.5 feet
- ice veins 1 to 5 mm thick and inclusions 10 to 25 mm in diameter with about 10% visible ice from 17.5 to 21.5 feet
Bottom of Boring
Boring Completed March 26, 2003
S-1b
S-1a
S-2
S-3
S-4
S-5
S-6
S-7
Observed during drilling
59.5
135
48.7
Water Content, %
Legend
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Frozen Ground
Peaty silt/silty peat
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-12
May 2003
31-1-01776-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 13
Sheet 1 of 1


SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
PENETRATION RESISTANCE
(300 lb. weight, 30 in. drop)
▲ Blows per foot
Dark brown PEAT; frozen Nbn and Vx.
- slight amount of gray silt from 0 to 5 feet
- 2-inch thawed zone near 5.5 feet
- ice inclusions up to 1/2 inch in diameter with 35% visible ice from 5.5 to 11 feet
- 45 to 50% visible ice from 11 to 14.5 feet
Gray-brown, slightly fine sandy SILT; frozen Vx.
- ice inclusions up to 5 mm in diameter with 20 to 30% visible ice from 14.5 to 19.5 feet
- slightly organic from 14.5 to 16 feet
- ice inclusions up to 1 inch in diameter and 45 to 50% visible ice from 19.5 to 20 feet
Bottom of Boring
Boring Completed March 26, 2003
14.5
S-1
S-2a
S-2b
S-3a
S-3b
S-4a
S-4b
Observed during drilling
422
454
788
1174
523
92.5
77.6
● Water Content, %
Legend
Frozen Ground
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Peaty silt/silty peat
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-13
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 14
Sheet 1 of 1


SOIL DESCRIPTION
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
(300 lb. weight, 30 in. drop)
Blows per foot
Surface Elevation:
Gray-brown SILT and ORGANICS; frozen Nbe and Vx.
Gray and brown, slightly fine sandy SILT and organic SILT; frozen Vr and Vx.
Brown PEAT; frozen Nbe and Vx; up to 35% visible ice; possibly thawed from 5 to 5.5 feet.
Gray, slightly fine sandy SILT; frozen Vs and Vx.
- 15% visible ice from 11 to 15 feet
- interbedded layers of brown, organic silt from 15 to 16 feet
- mottled from 13 to 17.5 feet
- ice lenses 5 mm thick spaced 1 to 4 inches from 16 to 17.5 feet
- ice inclusions up to 10 mm in diameter below 19 feet
Bottom of Boring
Boring Completed March 26, 2003
Not encountered during drilling
S-1a
S-1b
S-2a
S-2b
S-3a
S-3b
S-4a
S-4b
0.5
4.5
11
78.2
64.5
92.8
39.4
75.3
49.9
48.8
Legend
Frozen Ground
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Peaty silt/silty peat
Organic Silt
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Water Content, %
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-14
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 15
Sheet 1 of 1


SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
PENETRATION RESISTANCE
(300 lb. weight, 30 in. drop)
▲ Blows per foot
Brown, slightly silty and sandy, coarse GRAVEL; mix of subrounded and fractured particles; (ballast).
Brown, slightly silty, sandy GRAVEL; frozen Nbn; (fill).
Brown and gray-brown, slightly fine sandy SILT; thinly bedded; Nbn where frozen.
- occasional dark brown peat layers in Sample S-3
- dark brown with small woody organic specks from 4.5 to 8 feet
- mottled gray and brown from 8 to 12 feet
- gray below 12 feet
- scattered organics in Sample S-8
- dark gray below 19 feet
Bottom of Boring
Boring Completed March 27, 2003
0.8
2.0
S-1 G
S-2 G
S-3
S-4
S-5
S-6
S-7
S-8
S-9
S-10
Observed during drilling
68
43
0 20 40
● Water Content, %
Legend
Frozen Ground
Sandy gravel Gravelly sand
Sandy silt Silty sand
Sand
Organic Content
Silt
ICE
Peat
Peaty silt/silty peat
Organic Silt
Gravel
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
Grab Sample
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-15
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 16
Sheet 1 of 1


SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
DEPTH (ft)
PENETRATION RESISTANCE (300 lb. weight, 30 in. drop)
▲ Blows per foot
Gray, slightly sandy to sandy, coarse GRAVEL, trace silt; moist to wet; Nbn where frozen; (fill).
Observed during drilling
Brown PEAT; moist.
Brown PEAT with ice to ICE with peat.
Brown, oragnic SILT; frozen Vs; 1 to 3 mm ice lenses; 5% visible ice.
Gray, slightly fine sandy SILT; frozen Nbn and Vs.
- ice lenses up to 1 mm thick and 5 to 10% visible ice fom 16 to 16.5 feet
- ice lenses 1 to 2 mm thick and 3% visible ice in Sample S-6
- no visible ice from 20 to 24 feet
- ice lenses 1 to 4 mm thick and 10% visible ice below 24 feet
Bottom of Boring
Boring Completed April 15, 2003
S-1
S-2
S-3
S-4
S-5a
S-5b
S-6
S-7a
S-7b
75/5"
59/6"
42.4
31.3
58
48.7
45.5
Legend
Frozen Ground
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Peaty silt/silty peat
Organic Silt
Gravel
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
Grab Sample
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
● Water Content, %
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-17
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 18
Sheet 1 of 1


PENETRATION RESISTANCE
(300 lb. weight, 30 in. drop)
▲ Blows per foot
SOIL DESCRIPTION
Surface Elevation:
FROZEN
GRAPHIC LOG
DEPTH (ft)
SAMPLE
GROUND WATER
Observed during drilling
Brown and gray, slightly sandy to sandy, coarse GRAVEL, trace silt; moist; Nbn and Nf where frozen; some fractured faces; (fill).
Gray, loose, slightly silty, fine to medium sandy GRAVEL; moist to wet; (fill).
Interbedded, brown PEAT and gray-brown, slightly, fine sandy SILT; moist to wet.
Gray and gray-brown, slightly fine sandy SILT; wet; occasional peat layers up to 1 inch thick.
Dark gray to black, slightly fine sandy SILT; wet.
Bottom of Boring
Boring Completed April 15, 2003
8.5
11.2
14.5
23
S-1
S-2
S-3
S-4
S-5
S-6
S-7
S-8
75/5"
83/6"
52.8
41
● Water Content, %
Legend
Sandy gravel
Gravelly sand
Sandy silt
Silty sand
Sand
Organic Content
Silt
ICE
Peat
Peaty silt/silty peat
Organic Silt
Gravel
Water table at boring completion
3 in. O.D. Split Spoon Sample
3 in. O.D. Dry Core Run
Grab Sample
Frozen Ground
ATTERBERG LIMITS
Liquid Limit
Water Content
Plastic Limit
Note: Stratification lines represent approximate boundaries between soil types and transition may be gradual.
Geotechnical Study
Proposed Goldstream Siding
Alaska Railroad Milepost 459
LOG OF BORING 03-18
May 2003
31-1-01778-001
SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
Figure 19
Sheet 1 of 1

Appendix D: Photo Permissions

ELSEVIER LICENSE
TERMS AND CONDITIONS

Aug 07, 2009

This is a License Agreement between Shane M. Ferrell ("You") and Elsevier ("Elsevier") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by Elsevier, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

Supplier	Elsevier Limited The Boulevard,Langford Lane Kidlington,Oxford,OX5 1GB,UK
Registered Company Number	1982084
Customer name	Shane M. Ferrell
Customer address	1400 Townsend Drive Houghton, MI 49931
License Number	2240401046328
License date	Aug 01, 2009
Licensed content publisher	Elsevier
Licensed content publication	Cold Regions Science and Technology
Licensed content title	An experimental study on the cooling mechanism of a shading board in permafrost engineering
Licensed content author	Qihao Yu, Xicai Pan, Guodong Cheng and Naiwu He
Licensed content date	August 2008
Volume number	53
Issue number	3
Pages	7
Type of Use	Thesis / Dissertation
Portion	Figures/table/illustration /abstracts
Portion Quantity	3
Format	Print
You are an author of the Elsevier article	No
Are you translating?	No
Order Reference Number	

AMERICAN SOCIETY OF CIVIL ENGINEERS LICENSE TERMS AND CONDITIONS

Aug 07, 2009

This is a License Agreement between Shane M. Ferrell ("You") and American Society of Civil Engineers ("American Society of Civil Engineers") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by American Society of Civil Engineers, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

License Number	2240401210938
License date	Aug 01, 2009
Licensed content title	Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground
Licensed content author	David C. Esch
Licensed content publication	book
Licensed content publisher	American Society of Civil Engineers
Type of Use	Doctoral Thesis
Portion used	Figure
Number of figures	4
Institution	Michigan Technological University
Title of your work	Maintaining Stability Beneath Cold Regions Transportation Infrastructure with Special Emphasis on Railroads
Publisher of your work	Michigan Technological University
Publication date of your work	08/15/2009
Website	http://www.mtu.edu
Usage	print
Billing Type	Invoice
Company	Shane M. Ferrell
Billing Address	1400 Townsend Drive Dow 820 Houghton, MI 49931 United States
Customer reference info	
Total	$0.00

AMERICAN SOCIETY OF CIVIL ENGINEERS LICENSE TERMS AND CONDITIONS

Aug 07, 2009

This is a License Agreement between Shane M. Ferrell ("You") and American Society of Civil Engineers ("American Society of Civil Engineers") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by American Society of Civil Engineers, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

License Number	2240400620313
License date	Aug 01, 2009
Licensed content title	Analysis of the Deformation of Embankments on the Qinghai-Tibet Railway
Licensed content author	Wei Ma; Jilin Qi; Qingbai Wu
Licensed content publication	Journal of Geotechnical Engineering
Licensed content publisher	American Society of Civil Engineers
Type of Use	Doctoral Thesis
Portion used	Figure
Number of figures	3
Institution	Michigan Technological University
Title of your work	Maintaining Stability Beneath Cold Climate Transportation Infrastructure with Special Emphasis on Railroads
Publisher of your work	Michigan Technological University
Publication date of your work	08/15/2009
Website	http://www.mtu.edu
Usage	print
Billing Type	Invoice
Company	Shane M. Ferrell
Billing Address	1400 Townsend Drive Dow 820 Houghton, MI 49931 United States
Customer reference info	
Total	$0.00

AMERICAN SOCIETY OF CIVIL ENGINEERS LICENSE TERMS AND CONDITIONS

Aug 07, 2009

This is a License Agreement between Shane M. Ferrell ("You") and American Society of Civil Engineers ("American Society of Civil Engineers") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by American Society of Civil Engineers, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

License Number	2240400353547
License date	Aug 01, 2009
Licensed content title	Qinghai-Xizang Railroad Construction in Permafrost Regions
Licensed content author	Wu Qingbai; Zhao Shiyun; Ma Wei; Zhang Luxin
Licensed content publication	Journal of Cold Regions Engineering
Licensed content publisher	American Society of Civil Engineers
Type of Use	Doctoral Thesis
Portion used	Figure
Number of figures	3
Institution	Michigan Technological University
Title of your work	Maintaining Stability Beneath Cold Regions Transportations infrastructure With Special Emphasis on Railroads
Publisher of your work	Michigan Technological University
Publication date of your work	08/15/2009
Website	http://www.mtu.edu
Usage	print
Billing Type	Invoice
Company	Shane M. Ferrell
Billing Address	1400 Townsend Drive Dow 820 Houghton, MI 49931 United States
Customer reference info	

ELSEVIER LICENSE
TERMS AND CONDITIONS

Aug 07, 2009

This is a License Agreement between Shane M. Ferrell ("You") and Elsevier ("Elsevier") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by Elsevier, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

Supplier	Elsevier Limited The Boulevard,Langford Lane Kidlington,Oxford,OX5 1GB,UK
Registered Company Number	1982084
Customer name	Shane M. Ferrell
Customer address	1400 Townsend Drive Houghton, MI 49931
License Number	2240381103188
License date	Aug 01, 2009
Licensed content publisher	Elsevier
Licensed content publication	Cold Regions Science and Technology
Licensed content title	Application of the roadbed cooling approach in Qinghai–Tibet railway engineering
Licensed content author	Guodong Cheng, Zhizhong Sun and Fujun Niu
Licensed content date	August 2008
Volume number	53
Issue number	3
Pages	18
Type of Use	Thesis / Dissertation
Portion	Figures/table/illustration /abstracts
Portion Quantity	3
Format	Print
You are an author of the Elsevier article	Yes
Are you translating?	No
Order Reference Number	
Expected publication date	Aug 2009

AMERICAN SOCIETY OF CIVIL ENGINEERS LICENSE TERMS AND CONDITIONS

Aug 07, 2009

This is a License Agreement between Shane M. Ferrell ("You") and American Society of Civil Engineers ("American Society of Civil Engineers") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by American Society of Civil Engineers, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

License Number	2152570819505
License date	Mar 19, 2009
Licensed content title	Design and Experience Controlling Railroad Embankment Deformation on Ice-Rich Permafrost
Licensed content author	V. G. Kondratiev
Licensed content publication	Cold Regions Engineering: Cold Regions Impacts on Transportation and Infrastructure 2002
Licensed content publisher	American Society of Civil Engineers
Type of Use	Doctoral Thesis
Portion used	Figure
Number of figures	4
Institution	Michigan Technological University
Title of your work	Maintaining Stability Beneath Cold Regions Transportation Infrastructure with Special Emphasis on Railroads
Publisher of your work	Michigan Technological University
Publication date of your work	07/10/2009
Website	http://www.mtu.edu
Usage	both
Billing Type	Invoice
Company	Shane M. Ferrell
Billing Address	1400 Townsend Drive Dow 820 Houghton, MI 49931 United States

ELSEVIER LICENSE
TERMS AND CONDITIONS

Aug 07, 2009

This is a License Agreement between Shane M. Ferrell ("You") and Elsevier ("Elsevier") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by Elsevier, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

Supplier	Elsevier Limited The Boulevard,Langford Lane Kidlington,Oxford,OX5 1GB,UK
Registered Company Number	1982084
Customer name	Shane M. Ferrell
Customer address	1400 Townsend Drive Houghton, MI 49931
License Number	2152560938500
License date	Mar 19, 2009
Licensed content publisher	Elsevier
Licensed content publication	Cold Regions Science and Technology
Licensed content title	Application of the roadbed cooling approach in Qinghai–Tibet railway engineering
Licensed content author	Guodong Cheng, Zhizhong Sun and Fujun Niu
Licensed content date	August 2008
Volume number	53
Issue number	3
Pages	18
Type of Use	Thesis / Dissertation
Portion	Figures/table/illustration /abstracts
Portion Quantity	9
Format	Both print and electronic
You are an author of the Elsevier article	No
Are you translating?	No
Order Reference Number	
Expected publication date	Aug 2009

Taylor & Francis
Taylor & Francis Group

Title: Thermal regime simulation of embankment and berm in permafrost

Author: Z. R. Yue

Publication: Geomechanics and Geoengineering: An International Journal

Publisher: Taylor & Francis

Date: Jan 6, 2008

Logged in as:
Shane Ferrell
Account #:
3000171528

LOGOUT

Thesis/Dissertation Reuse Request

Taylor & Francis is pleased to offer reuses of its content for a thesis or dissertation free of charge contingent on resubmission of permission request if work is published.

BACK CLOSE WINDOW