University of Alberta

Frozen Oil Sands Lumps – Effects of Climate, Geology and Shovels

By

Derek James Cyr ©

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BCM	Bank Cubic Meter	=	m^3
ρ	Density	=	kg/m^3
Z_o	Depth	=	m
k_f	Frozen Thermal Conductivity	=	W/m°C
L	Latent Heat	=	J/m^3
mc	Moisture Content	=	%
n	Porosity	=	%
T	Temperature	=	°C
t	Time	=	

DRC	Double-Roll Crusher
GPS	Global Positioning System
NEFB	North-East Feeder Breaker
NMET	North Mine Event Tracking
NMFB	North Mine Feeder Breaker
NWFB	North-West Feeder Breaker
PI	Plant Information
PSV	Primary Settling Vessel
QPD	Quality Production Database
SIO	Serial Input/Output

1 INTRODUCTION

1.1 Thesis Objectives

Syncrude Canada Limited currently produces approximately 85 million barrels of synthetic crude oil annually, generating approximately 13% of Canada's total oil production. In this market, productivity and lower unit costs are the basis for the success of such a venture. With a barrel of oil valued at around $40US, even minor drops in production add up to large sums of lost revenue.

This thesis is a continuation of work started by Fowler et al. (2000) in attempting to determine and explain the causes of lump jams experienced at Syncrude's North Mine near Fort McMurray, Canada. A related problem is the issue of significant rehandling of oil sands that is delivered to a lump dump in the winter months. Oil sands lump jams in the crushers are a major source of downtime occurrences that need to be minimized. Since the start-up of Syncrude's North Mine in 1997, there have been over 1,650 hours of lost production in two crushers, NMFB6 and NMFB7. Presently, no quantifiable information exists as to the causes of these lumps, but using available information one should be able to develop a relationship between the numerous factors. As such, the objectives of this thesis are:

1. Collect and integrate available climatic, geologic and production data from Syncrude's database systems.

2. Create a relational database between the various factors to be used for a correlative analysis.

3. Quantify the effects that climate, geology, equipment and other operational factors have on lump generation as well as provide possible explanations for the results.

4. Suggest methods to minimize the occurrences/effects of frozen lumps and improve overall mining efficiency during winter months.

5. Provide recommendations for better data collection as well as areas of future work.

Completion of these objectives should provide sufficient information to reduce the occurrences of frozen oil sands lumps that cause significant losses of productivity for Syncrude.

1.2 Scope of Work

Climatic and production data is needed for the analysis of lump dump activity and lump jam events. Accordingly, data from July 2001 to June 2003 was collected from Syncrude databases and summarized into tables that will allow for analysis and further compilations. This two-year period provided the best quality data and was deemed a reasonable time frame to make valid conclusions from. This information used in conjunction with site visits, established theory and internal reports to provide the basis for the research presented in this thesis. Field or laboratory testing is beyond the scope of the thesis.

Using heat flow theory and daily temperature data from the North Mine, the depth and rate of frost penetration was modeled to provide a correlation with lump generation. Unfortunately, as very little research has been conducted on the mechanical and thermal properties of frozen oil sands, a number of values used in the thesis were extrapolations of work on unfrozen oil sands.

Investigations into the cause of lumps, whether those dumped into the lump dump or the crushers, were conducted using the production reference tables. Composited shovel types, origin locations and facies groups were created to facilitate easier correlational studies to lump generation. Volume normalized comparisons were made within each factor as well as any relational effects that may have existed between these factors. Possible explanations were also provided to explain some of the discovered trends.

Recommendations are proposed to reduce the negative effects of cold temperature on the oil sands as well as operational improvements, both proactive and reactive, to reduce/eliminate the lump generation and/or its effects on the productivity of the North Mine.

1.3 Thesis Organization

Data was collected and filtered from Syncrude databases to enable quantification and discussion of the effects of climate, shovel type, geology, and mine planning on lump generation. Recommendations and improvements are suggested to minimize/eliminate the effects of these factors as well as provide some areas of potential future work.

Background information regarding Syncrude site location and mining activity is discussed in Chapter 2. Additional information regarding the purpose of the thesis is also further elaborated on, such as descriptions of the lump dump and lump jams, as well as the magnitude of the problem.

In Chapter 3, issues with the collection and organization of the data from the multiple databases are discussed. Methods used in merging and filtering the data are mentioned along with the methodology used in the analysis in subsequent chapters.

Chapter 4 addresses the effect that the winter climate has on the mining operation. The mechanical and thermal properties of frozen ground are discussed as well as the freezing process. An explanation of the frost model and how it applies to the problem of lump generation is presented. Suggested remedial measures, both proactive and reactive, are presented to reduce the rate and/or depth of frost penetration and its role in frozen lump generation.

Chapter 5 investigates lump dump activity and lump jam events comparing hydraulic and cable-electric shovels. The effects that shovel type has on lump jam events at NMFB6 and NMFB7 is also examined. In addition, a case study of shovel types and lump dump activity is provided based on a site visit during a week of winter operations. Remedial measures are also discussed.

In Chapter 6, the geology of the Athabasca oil sands is discussed as well as how Syncrude organizes and models the geology. The effects that geology, as well as geology and shovel type, have on lump generation is examined as well as the effect of geology on crusher performance during lump jam events.

Chapter 7 address the operational effects that cause lump generation. Lump origin locations are examined for their relationship with lump generation, as well as any correlations with shovel type, crushers and geology. Sequencing of the mine and its role in lump generation is discussed in addition to a study showing the efficiency of the lump dump in reducing lump jams. The effects of downstream demand on mine production and visibility within the mine are also quantified for lump dump activity and lump jam events.

Chapter 8 contains some concluding remarks, and recommendations for future work and possible improvements that could reduce lump generation as well as their associated effects.

2 SYNCRUDE CANADA LTD.

2.1 Introduction

Syncrude operates the largest oil sands crude oil production facility in the world and produce over 13% of Canada's total oil requirements at approximately 225,000 barrels per day of Syncrude Sweet Blend. Statistics Canada (1997) quoted Canada's annual oil demand at 570 million barrels. Syncrude is a joint venture between eight companies (Figure 2-1): Canadian Oil Sands Limited Partnership, Canadian Oil Sands Limited, Conoco Phillips Oilsands Partnership II, Imperial Oil Resources, Mocal Energy Limited, Murphy Oil Company Ltd., Nexen Inc., and Petro-Canada Oil and Gas. It is operated and administered under Syncrude Canada Limited, which is responsible for the mining, extraction and upgrading facilities at the Mildred Lake site, the mining, primary extraction and slurry transportation at the Aurora site, and the Research Center in Edmonton. Within Syncrude's mandate is the task of identifying and developing potential future expansion opportunities as well as obtaining and maintaining all the necessary regulatory permits, licences and permits (Syncrude, 2004).

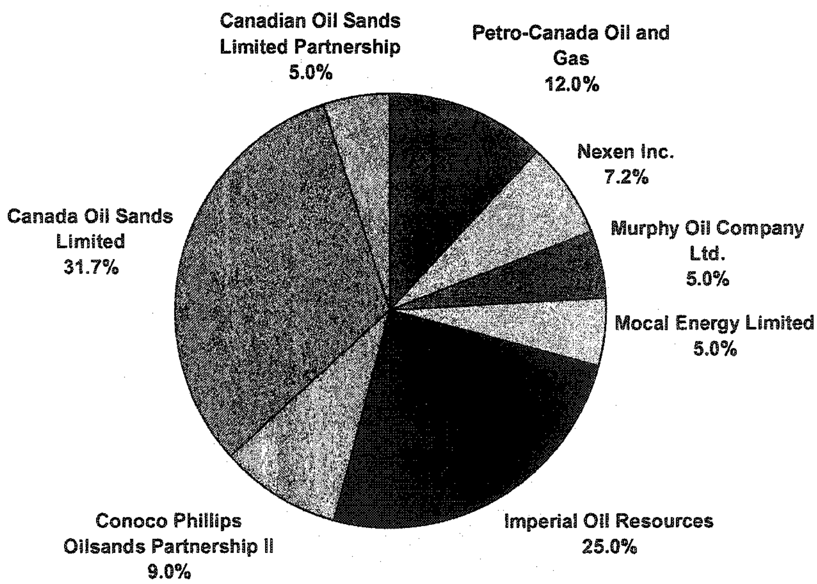


Figure 2-1- Syncrude Ownership Distribution (after Syncrude Canada Ltd., 2004)

2.2 Location and Topography

Syncrude is located approximately 38 km north of the city of Fort McMurray along highway 63, or 475 km north by northeast of Edmonton, at about 56°39'N, 111°13'W and at an elevation of 369 m above mean sea level (Environment Canada, 1984). The map in Figure 2-2 depicts the location of Syncrude's base mine in relation to Edmonton and Fort McMurray as well as its approximate size in relation to the Athabasca oil sands deposit.

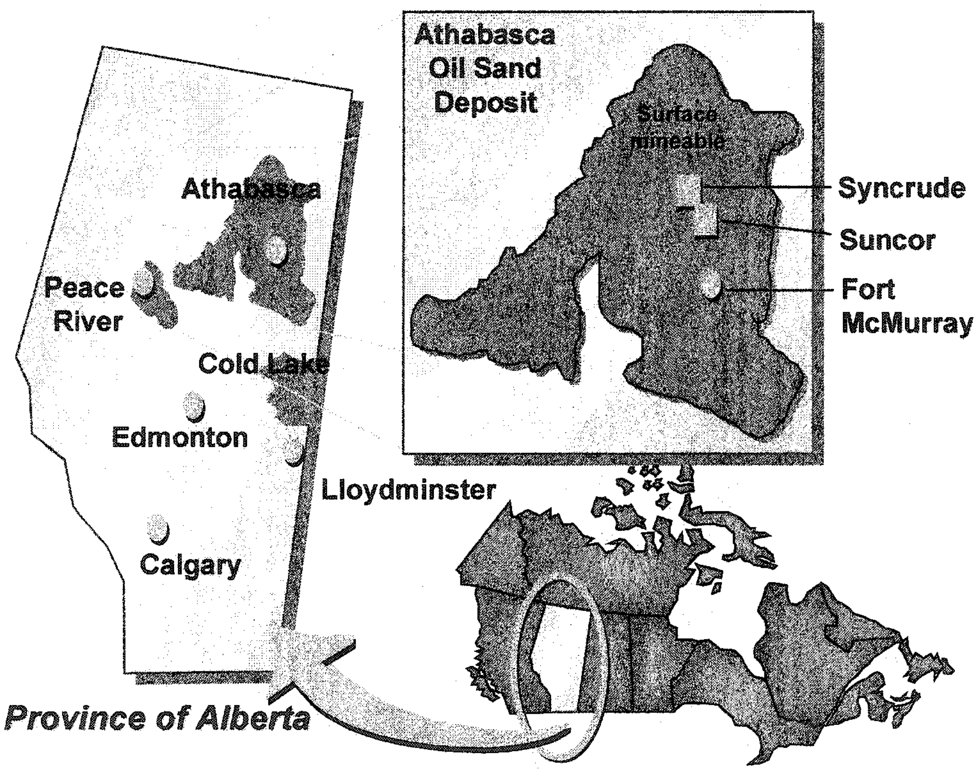


Figure 2-2 - Location of Syncrude Canada Limited (Syncrude Canada Ltd., 2003b)

2.3 Syncrude's Mining Pits

Syncrude owns and operates three mines north of Fort McMurray, Alberta. The Base mine was the original mine that opened in 1978 and is reaching the end of its mineable life, scheduled for decommissioning in 2005. The North Mine is located northwest of the Base plant and began production in 1997 with a scheduled mineable life until 2032. Lastly, the Aurora mine that opened in 2000 is meant to replace the production loss due to the closure of the Base mine. Aurora is located approximately 45 km north of the Base plant on the right bank of the Athabasca River. Figure 2-3 shows the relative locations of these mines in the regional setting. The focus of this thesis will be on the North Mine, yet the findings are hoped to provide guidance for similar problems at the Aurora mine and other oil sands mines in the area.

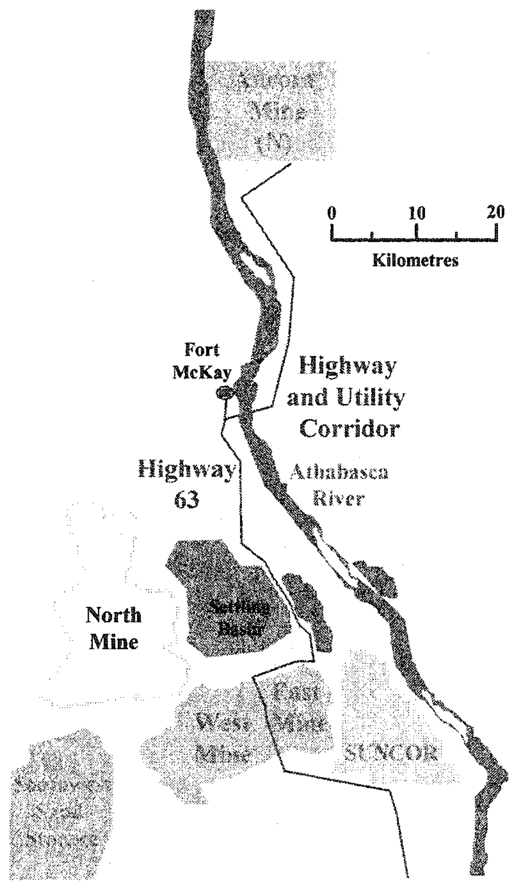


Figure 2-3 - Syncrude Mine Locations (modified from Syncrude Canada Ltd., 2003b)

2.4 Surface Mining Methods

Prior to the mining of the oil sands, the overburden must be removed. A layer up to 3 m thick of muskeg is dewatered over a 2-year period by vacuum trucks and ditches before it is removed, stockpiled and used for future or current reclamation activities. Beneath the muskeg is the overburden layer that ranges between 0 and 45 m thick. Overburden consists of unconsolidated glacial till that is excavated using trucks and shovels. It can be utilized as suitable dyke construction material, road grade and/or surface material, or placed in dumps located both external and internal to the pits. Once the oil sands formation is exposed, it is excavated using two methods. The original dry method used in the Base mine relied upon draglines windrowing the oil sands onto the bench where the bucketwheel reclaimers reclaimed the oil sands and placing it on conveyors. The conveyed oil sands was then stockpiled at the mine tower and drawn down as needed. This method is being phased out and will be retired when the Base mine is exhausted in 2005. The wet method being utilized in the North and Aurora mines is a truck and shovel mining method where the excavated oil sands is delivered by large haul trucks to crushers that size the feed using double roll crushers to a 100 mm to 150 mm size (Syncrude Canada Ltd., 2003b). The oil sands is then conveyed to a mixing operation that combines the oil sands with hot or warm water to create a slurry that is pumped via pipeline to the extraction plant. This hydrotransportation begins the extraction process causing the bitumen and sand to separate as it is pumped to primary extraction. Figure 2-4 is an artistic rendition of the North Mine operation showing the (1) mining, (2) crushing, (3) stockpiling, (4) slurrifiying and (5) piping of the oil sands to extraction. Figure 2-5 shows the mining, extraction and tailings processes in relation to each other.

Total annual North Mine production ranges between 70 and 100 million tonnes (Mt) of excavated oil sands. The average oil sands grade is approximately 11% with a stripping ratio between 1.1 and 1.6 (Syncrude Canada Ltd., 2003).

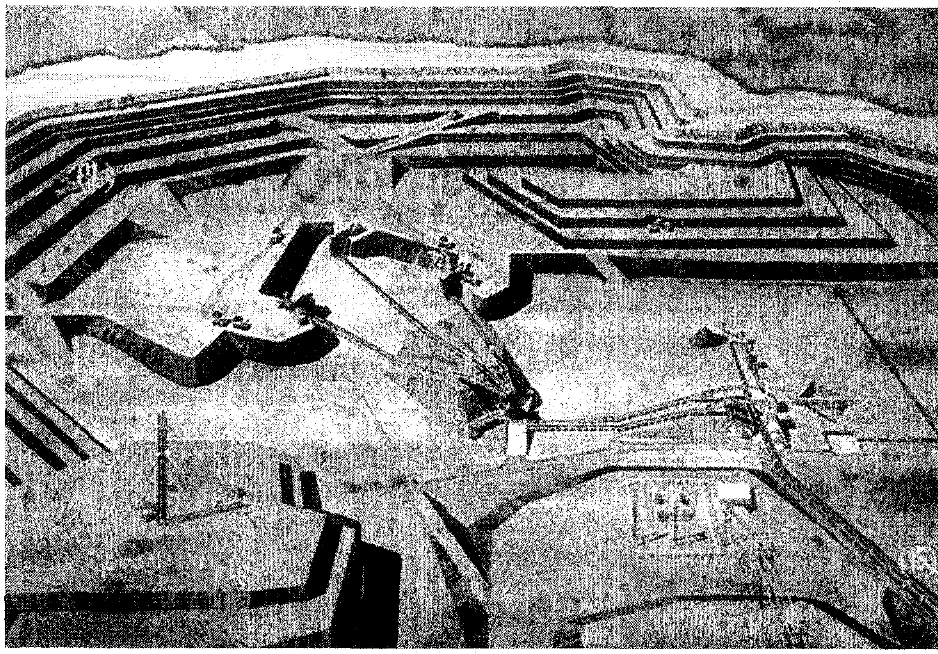


Figure 2-4 – Artistic rendition of the North Mine (modified from Syncrude Canada Ltd., 2003b)

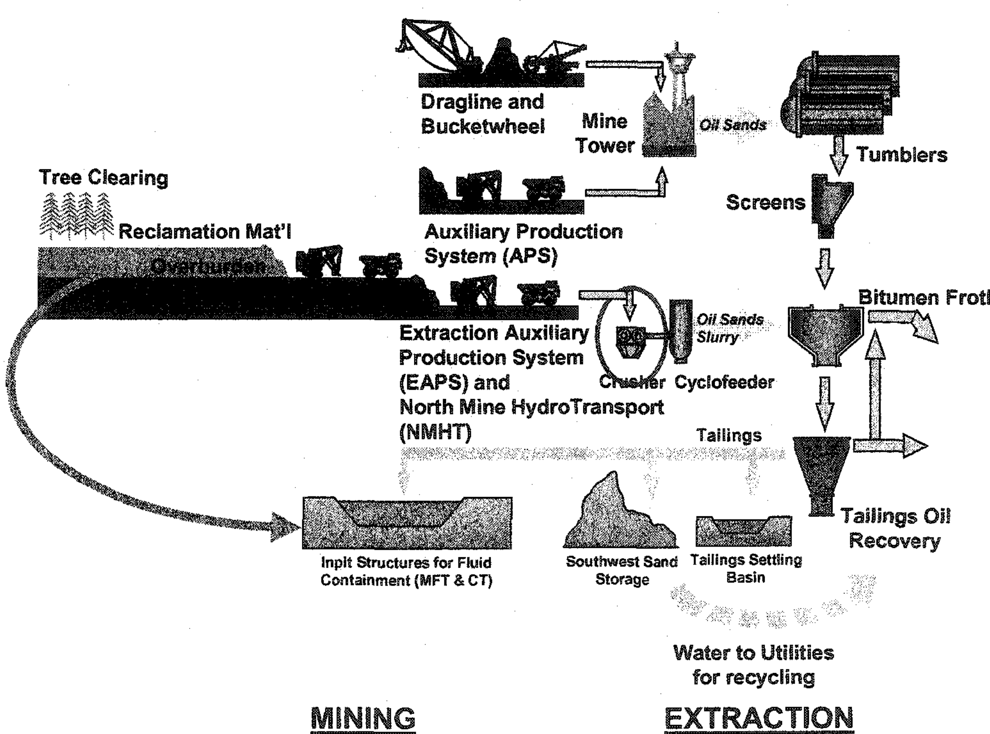


Figure 2-5 - Mining and Extraction Processes (modified from Syncrude Canada Ltd., 2003b)

There are two main crushers in the North Mine: North Mine Feeder Breaker 6 (NMFB6) and North Mine Feeder Breaker 7 (NMFB7). These crushers handle over 90% of the mined volume from the North Mine, with the remaining volume being delivered to the Northwest Feeder Breakers 2 and 5 (NWFB2 and NWFB5), which comprise the auxiliary production system (APS), and the Northeast Feeder Breaker (NEFB3). NMFB6 and NMFB7 are major components that have a large impact on the generation of lump jams. Each of these crushers are composed of two counter-rotating cylinders with 18 crushing plates attached to the hexagonal bore of each roll. Six crusher tooth caps are fixed to each crusher plate for a total of 216 teeth (Syncrude Canada Ltd., 2003b). Figure 2-6 and Figure 2-7 show the double-roll crushers and the tooth caps used in the North Mine.

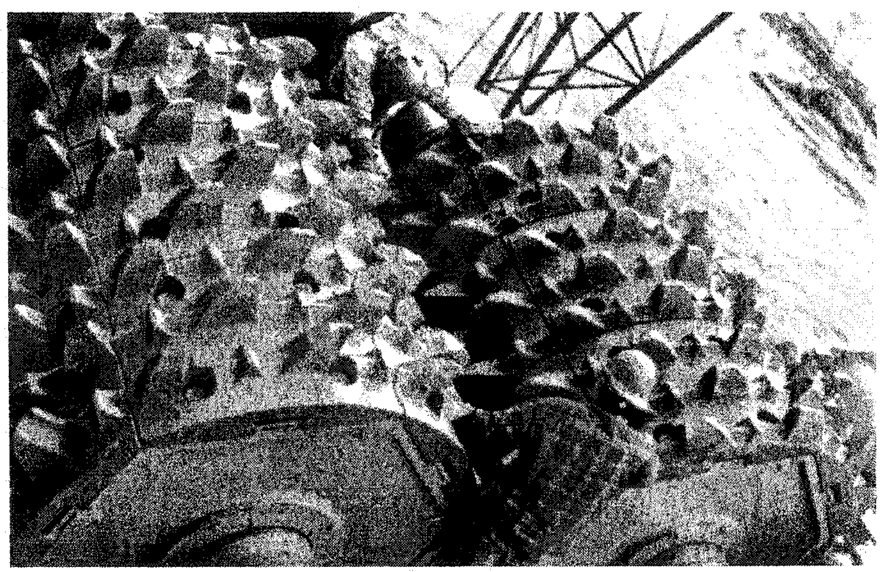


Figure 2-6 - Double-Roll Crushers being installed in NMFB6 (Syncrude Canada Ltd., 2003b)

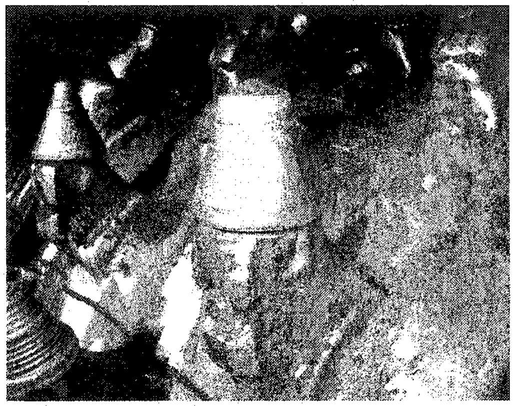


Figure 2-7 - Tooth Caps on Crushers Plate (Syncrude Canada Ltd., 2003b)

Haul trucks dump the oil sands into the dump pocket, or hopper, which has a maximum capacity of 700 t. The oil sands is then fed to the crusher by an apron feeder where the material is crushed to a size no larger than 150 mm. The apron feeder is approximately 3.3 m in width delivering the oil sands to the crushers at a maximum speed of 0.385 m/s at an angle of 15° to the horizontal (Wooley, 1998). Bed thickness ranges between 0 m when the hopper is empty to as much as 1.7 m with low grade, high fines oil sands. Each crusher has a maximum sustained throughput of 7,500 t/hr for all ore grades with a maximum design output of 9,250 t/hr under ideal operating conditions. Tests on DRC6 in July 1998, however, show that under ideal operating conditions, the peak capacity at 100% apron feeder speed exceeds design rate and can be as much as 12,000 t/hr (Wooley, 1998). Average operating conditions in the winter months will be lower than in the summer due to more frequent planned and unplanned stoppages, thus a nominal throughput of 6,000 t/hr will be assigned for winter operation.

2.5 Frozen Lumps

Frozen oil sands lumps have a real and detrimental effect on the mining operation. Lumps are created at the face by hydraulic and cable-electric shovels excavating material in the winter months. When the shovel operator identifies a lump inside a truck box, the truck dumps it at a lump dump, but if it is not identified, the truck dumps at a crusher and can potentially cause a lump jam.

2.5.1 Lump Dumps

The lump dump is a special dumping location created in the winter months where lumpy loads of oil sands are dumped. Lump jams are a serious problem in the North Mine, thus the lump dump is created to eliminate or reduce the likelihood of any large lumps jamming the crushers. Figure 2-8 shows an example of the size of lumps that can be found in the lump dump. There is no design or plan as to when the lump dump is created, but rather it initiates after the first occurrences of severe lump jams at the North Mine crushers. Its location is often along main haulage routes to minimize the rehandle hauls. Mining of the lump dumps generally occur in the spring allowing time for the large lumps to thaw and fracture, and removing the probability of creating a lump jams. This proactive measure is undoubtedly saving hundreds of hours of productivity each year.

Figure 2-8 - Large Lump in North Mine Lump Dump with Hard Hat for Scale

Starting in November and ending in May, the lump dump at the North Mine receives between 4,500 and 7,000 dumps each winter creating on average 800,000 BCM of rehandle work each year. Figure 2-9a shows the volume of material that is dumped at the North Mine lump dump each month over a two-year period from July 2001 to June 2003. Comparing these volumes to the total quantities mined each month provides a better appreciation to the size and significance of the lump dump. Figure 2-9b shows the volume dumped at the lump dump as a percentage of the total volume mined in the respective month. The percentages are not trivial ranging from 0% in the summer months to as high as 8.3% in the winter.

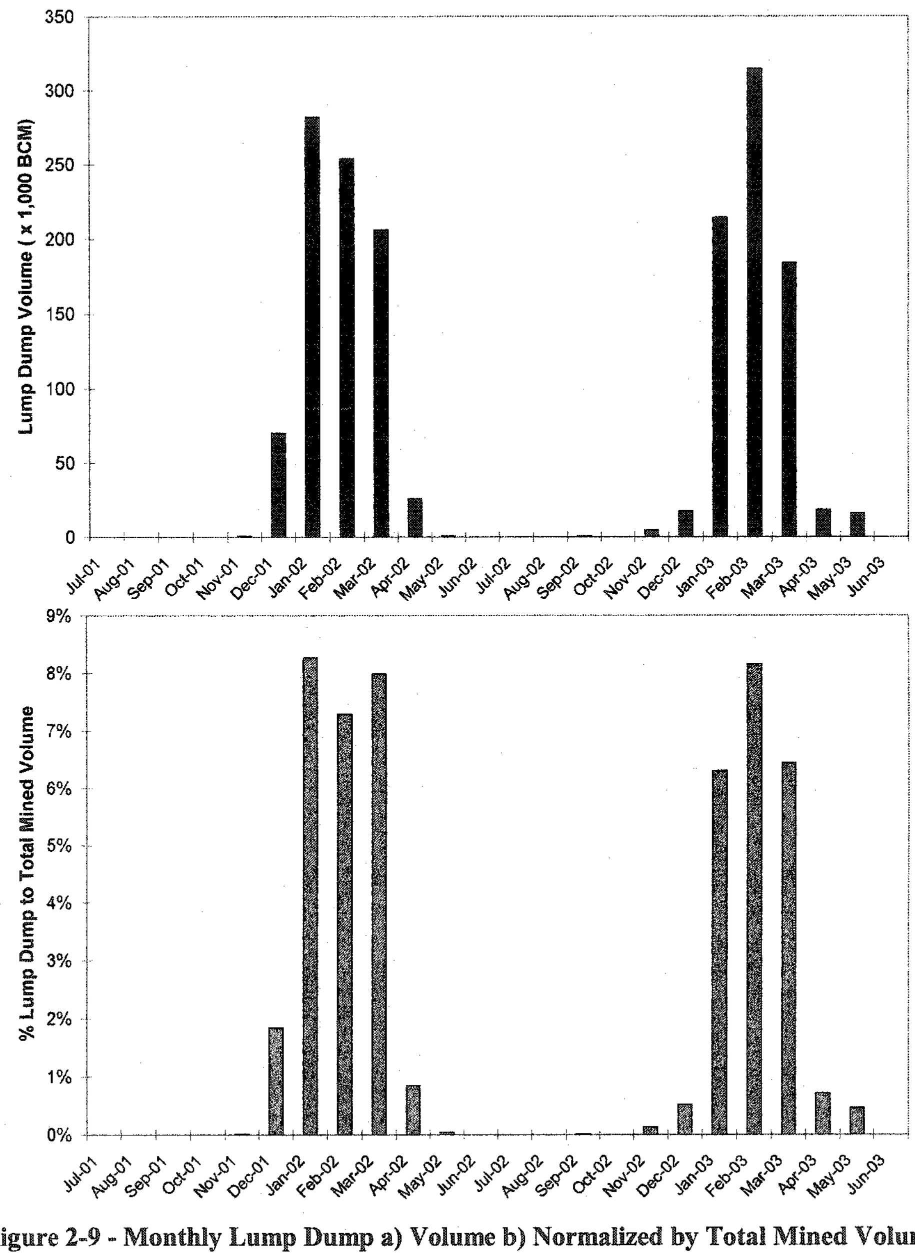


Figure 2-9 - Monthly Lump Dump a) Volume b) Normalized by Total Mined Volume

Activity of the lump dump is essentially operator dependent with the shovel operators relying on judgment and experience. According to discussions with Noble of Mine Planning (2004), if a load is deemed non-lumpy, then a single honk signals to the truck driver to proceed to the crusher, but if a load is lumpy, two honks are made, which tells the truck driver to proceed to the lump dump instead. This system, however, has proven to be unreliable and a new policy that is under consideration is for the shovel operator to verbally communicate with the truck driver over open radio to assign the truck's destination.

When investigating the amount of material dumped versus the amount mined from the lump dump, the two volumes do not match. The volume removed from the lump is approximately 100,000 BCM more than dumped volume each year. Upon consulting with Mine Planning, this discrepancy is most likely due to mining of the in situ oil sands beneath the lump dump in combination with the rehandled oil sands. The Wenco dispatch system simply codes the entire truck volume as lump dump in origin, thus leading to the discrepancy. Figure 2-10 compares when and how much volume was dumped and excavated at the lump dump during the two-year period studied. Moreover, there are months when simultaneous dumping and excavating of the lump dump occurs. This is not good practice as the material in the lump dump is not being allowed to thaw, which could potentially lead to lump jams.

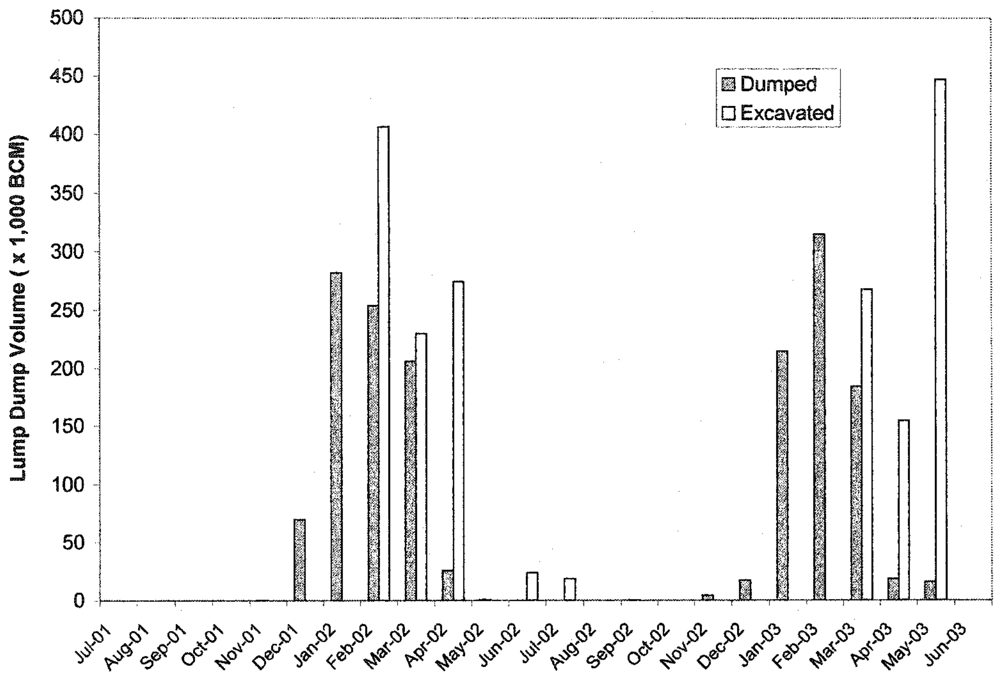


Figure 2-10 - Monthly Lump Dump Volume: Dumped and Rehandled

While the use of lump dumps does assist in reducing lump jam events, they do nonetheless create their own set of problems. Due to the lack of management of the lump dumps, oil sands grade and geology cannot be accurately determined, thus the properties of the lump dump can only be averaged over its sources. This assumption may be considered an advantage as it aids in blending, yet preferential source geology and geo-chemistry can create significant problems. Lump dumps are preferentially loaded from certain benches more than others, thus the blend quality may suffer (this will be discussed further in *Chapter 7 – Mine Planning and Other Effects)*. A problem associated with the geo-chemistry is one of sludging of the primary settling vessels (PSVs). Mixing marine ore and high fines material causes the clay particles to surround the bitumen, thereby inhibiting separation and flocculation. Recovery can drop by up to 50% with as little as 5% clay content mixed with marine ore (Wright, 2004).

2.5.2 Lump Jams

Lump jams are a serious source of downtime for the North Mine crushers and related to lump dump activity. Lump jams are created when the shovel operator does not notice or perceive a lump as being hazardous and the truck dumps into the crushers. Essentially, lump jams are lump dump loads that did not make it to the dump. These lumps can range in size up to 15 m^3 and weigh in excess of 25 t (Bell, 2000). In Figure 2-11 is an example of a large lump that caused a jam and had to be removed by using a crane. Although this is an extreme case, lumps of this magnitude can be encountered.

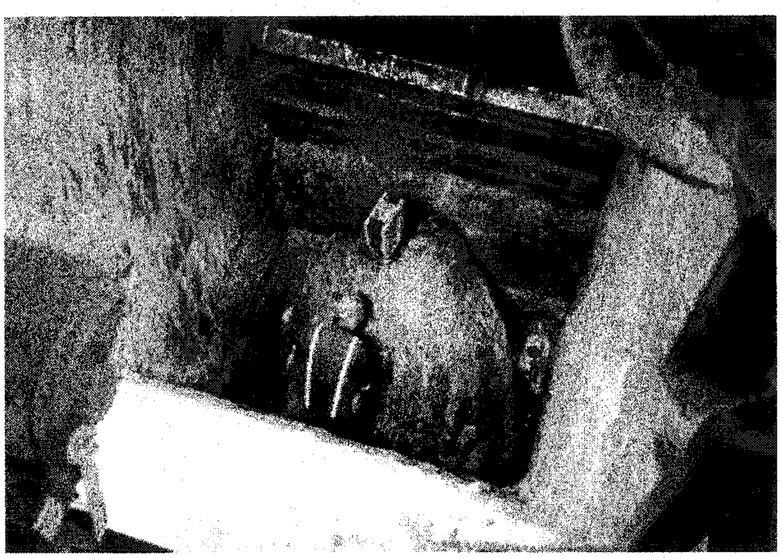


Figure 2-11 - Large Lump in Double-Roll Crusher (Syncrude Canada Ltd., 2003b)

There are three types of lump jams encountered at the North Mine depending on the geometry and size of the lump. One type occurs due to extremely large lumps that cannot even pass through the neck of the apron feeder. If the lump cannot pass through the neck, a backhoe must be piloted into the hopper to slowly excavate the lump to a smaller passing size. Occasionally the flow of material can orient the lump to pass through the neck, but in doing so can create the second type of lump jam. The second type occurs when the lump is lodged in the chute between the apron feeder and the double-roll crushers. Likewise, the flow of material can sometimes push the lump down into the double-roll crushers, but often a backhoe must be driven into the hopper to slowly break the lump to a passing size. The last type of lump jam occurs when the lump physically cannot pass the double-roll crushers and becomes lodged between them, as seen in Figure 2-11. In this circumstance, the rolls are reversed to loosen the lump and then forward rotation occurs again in an attempt to pass the lump. If the lump is persistent, the roll gaps can be varied to achieve the same goal, but if this action still does not work, then as a last resort a backhoe or crane can attempt to remove the lump.

Another type of jam that can occur more frequently in the summer months is due to the processing of high-grade (>12% bitumen) oil sands. Instead of crushing, the oil sands deform like a thick fluid and absorb the crushing energy stalling the crushers; however, this form of jam is far less common and will not be discussed further in this thesis.

Lumps of various sizes can cause stoppages of production that can range from minutes to hours of lost productivity several times a month. Figure 2-12a shows the frequency of recorded lump jam events from September 1999 to December 2003. This cyclic trend is similar to lump dump activity peaking in the winter months, but a small percentage of lump jams still occur throughout the year. The maximum monthly frequency of lump jams greater than 5 minutes in duration occurred in January 2000 at 537. Annual frequency ranges from approximately 270 to 1,520 with an average of approximately 730. Nonetheless, one can notice the decreasing trend in frequency of lump jam events over the past number of years. Upon discussion with site, it was learned that exposed inventory has decreased in the past number of years, which probably reduced exposure time of the benches. Additionally, improvements to the crushers, operator experience and effective lump dump use may also be attributing factors in this decreasing trend. Figure 2-12b shows the duration of lump jams with the maximum downtime month occurred in December 2000 at approximately 98 hours of downtime. Annual downtime ranges from approximately 60 to 320 hours with an average of approximately 213 hours.

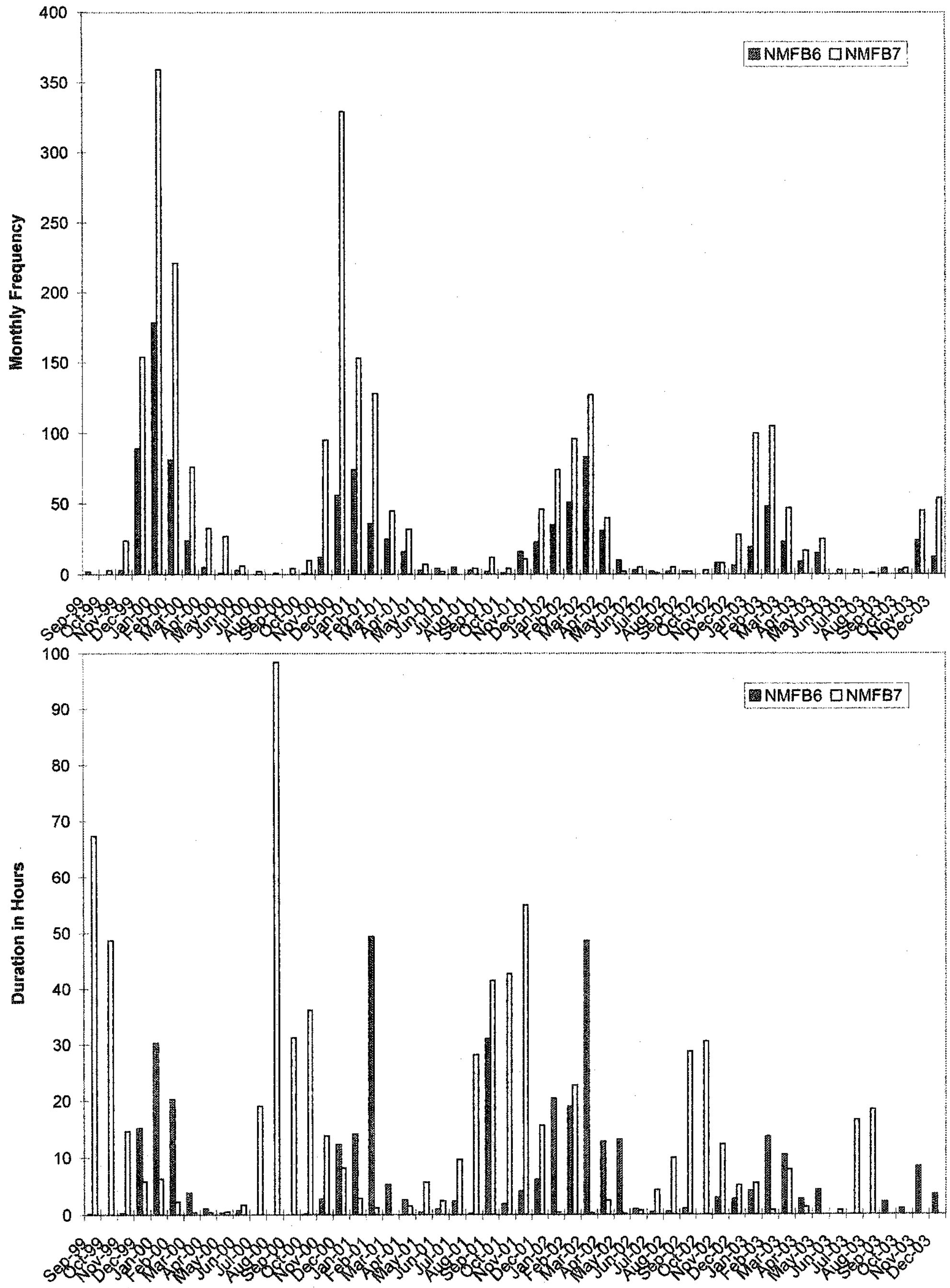


Figure 2-12 – Monthly a) Frequency b) Duration of Lump Jam Events in the North Mine

There is a noticeable difference between the number and duration of lump jam events between the two North Mine crushers. Each crusher has the same ratio of duration-to-frequency of approximately 17.5 minutes of downtime for every lump jam event. This suggests that the manner and efficiency in which a lump is managed at each crusher is the approximately same. Nevertheless, NMFB7 consistently experiences more lump jams than NMFB6 each winter. Although the number of occurrences for NMFB7 is decreasing each year, NMFB6 is relatively constant. A difference exists between these two crushers, but whether the difference is mechanical, operational, or due to preferential feed from a particular bench, geology or shovel is what will be examined in subsequent chapters.

2.5.3 Current Remedial Measures

Syncrude's proactive activity of using the lump dump to minimize the occurrence of lump jams is working quite well, yet a better understanding of the factors leading to lump generation is needed. Shovel type, geology, operators, origin location of oil sands and climate will all be discussed with additional suggestions to reduce lump generation. Ripping is the preferred reactive measure to reduce lump generation while a backhoe is used when a lump jam has occurred. Currently a backhoe is required to fragment large lumps by driving down into the hopper and use the hoe to break the lump. This activity is not very efficient and can consume a great amount of time. Depending on the persistence of the lump, this activity can take 15 minutes to in excess of 2 hours. Other options discussed have been the use of high-pressure water jets, jackhammers or clamshells to remove the lumps.

2.6 Summary

Syncrude Canada Ltd. owns and operates three open pit mines north of Fort McMurray, Canada. Using a truck-and-shovel method, the oil sands is excavated and dumped into double-roll crushers that size the ore before becoming a slurry and proceeding to primary extraction. Due to the location of the mining operation in Northern Alberta, frozen lumps are often formed and pose a challenge in maintaining productivity.

When a large lump is created at the face there are two options that can occur. It can be identified as a hazard and dumped at a lump dump thus eliminating the potential for a lump jam from occurring. Material at the lump dump is left to thaw and fragment before being rehandled in the spring or summer. This proactive measure can divert up to 8% of the total monthly mined volume to the lump dump; this translates to approximately 800,000 BCM annually of rehandle. However, if a dangerous lump is not identified, it is dumped into the crusher where it can create a lump jam. Lump jams are a much more severe problem as they impede production as opposed to increasing rehandle volume. Lump jam events can cause between 60 and 320 hours of lost productivity each year. Fortunately, in recent years the frequency of these events appears to be decreasing.

3 COMPILATION OF PRODUCTION DATA

3.1 Introduction

A number of data sources are being used in the analysis of the frozen lump problem occurring at Syncrude's North Mine crushers. The North Mine Event Tracking System, weather, Quality Production Database, Wenco and Plant Information databases are being utilized for the collection of all production and weather related data. Each database contains information that can be used to generate correlations to lump dump activity and lump jam events.

Challenges, however, are present within and external to each database making correct amalgamation difficult. Inconsistent time stamping, missing and/or duplicate entries, poor resolution and GPS error are some of the problems that had to be overcome. Nevertheless, the completion of an accurate production list provides a sound basis for future analysis of lump dumps and lump jams.

3.2 Data Sources

3.2.1 North Mine Event Tracking (NMET)

The North Mine Event Tracking (NMET) database collects occurrences of lump jams dating back to the start-up of the North Mine in August 1997. NMET can be accessed through the Syncrude PROD family of databases under NMET_EVENTS_VIEW or a union between NMET_CAUSE and NMET_EVENTS. A number of fields are contained within this database, but the fields that are most important for this project are: START_DATE_TIME, STOP_DATE_TIME, EQUIPMENT_NUMBER, CLASS_CODE, CAUSE_CODE and OPERATOR_COMMENTS. With these fields, the duration of each lump event can be calculated and filtered for each crusher.

Most lump jam events occur at either NMFB6 or NMFB7 with secondary systems, such as conveyors, occasionally failing due to lump jams as well. Figure 3-1 shows the number of raw entries recorded per location from September 1997 to June 2003. Since the start-up of the North Mine in 1997, 75-T-6 (NMFB6) and 75-T-7 (NMFB7) each recorded in excess of 1,000 entries while secondary systems recorded only 100 entries at most. Due to the much higher number of entries found at the crushers in comparison to other equipment, only these entries will be considered in the thesis.

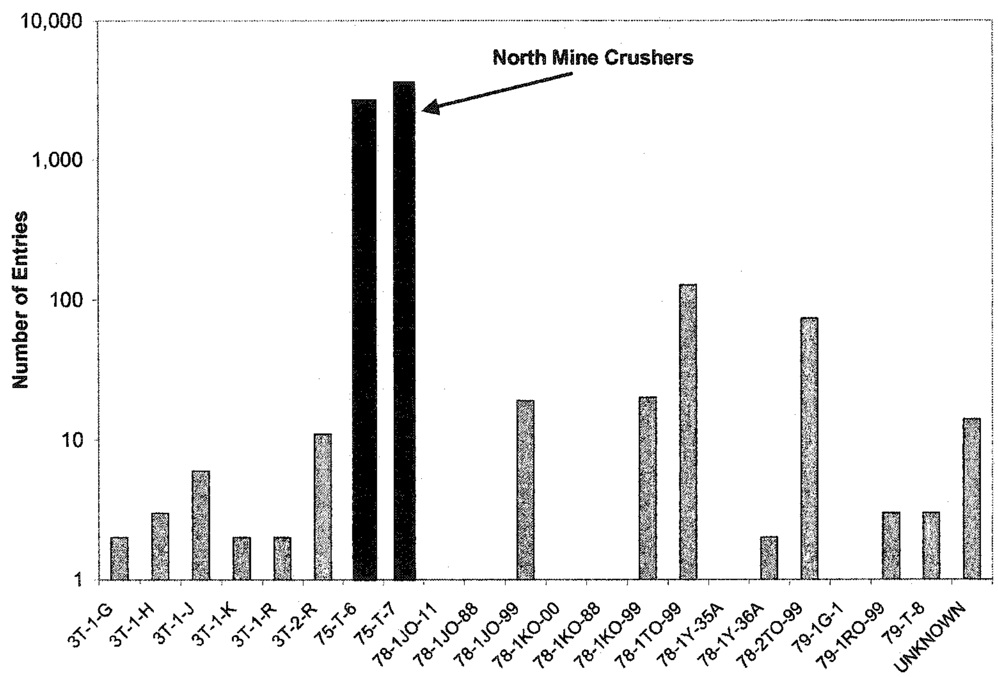


Figure 3-1 – Number of Lump Jam Entries by Component from September 1997 to June 2003 in the North Mine

The main challenge with the NMET system is the manner in which it classifies the start and stop times of entries as well as how it classifies the entries themselves. Algorithms are used to classify entries based on inputs from various sensors, but while the logic of these codes is based on simple sensor readings, dispatch operators can manipulate the equipment when dealing with lump jams that can trigger the sensors and lead to incorrect time stamping and classification.

The CLASS_CODE is used to differentiate between the four different types of entries: Downgrading (D), Opportune (O), Restrictive (R) and Lump Jam (L). Lump jams are generally recorded as either a Downgrading (D) and/or Lump Jam (L) entry. Although each code has its own unique logic, the circumstances due to an event can be such that the logic is triggered for multiple codes. A class L entry is recorded depending on the crusher roll speeds. The start time of the entry is when the roll speed goes below 25% (of its maximum velocity) and the end time corresponds to when the roll speed goes above 25%. Class D entries are dependent on a Plant Information (PI) tag that takes into account the entire primary extraction system as running or down. When the system is down the entry's start time is recorded and when it is running the entry's stop time is recorded. While these logic statements seem simple, the cause of the change in the sensors may not be.

Dispatch operators can manually control virtually any component of the system, although the majority of the time the system is automatic. The manner in which the dispatchers deal with events create changes in the sensor readings that get interpreted by the NMET system and hence what CLASS_CODE(s) gets attributed to the entry. Operators often manually control the rollers and apron feeder speed in a lump jam event and their actions can be misinterpreted by the logic. The numerous actions taken by dispatch operators to relieve lump jams is discussed below in section *3.2.4 Plant Information*. The roller speed may drop to below 25% and then increase back above 25% and create an end to the class L entry, but the lump can still be inhibiting production and the class D entry remains until production is restored. Furthermore, the roll speed can change a number of times during a single event as the operator attempts to pass the lump through the rollers. This can create multiple class L entry that are sourced from the same lump (Corcoran, 2004). In the period from July 2001 to June 2003 there have been 2,733 lump jam entries recorded in NMET for both the NMFB6 and NMFB7, yet 466 (17%) are either duplicates or entries within entries caused by this multiple coding of the same event.

Cliff Corcoran, the database administrator for the NMET system, recommends using only Downgrading entries as the true number of lump jams (2004). As this code takes into account the overall production from the system and not simply the speed of the rollers, this assumption seems reasonable. Using this filter on the data generates the total number of downgrading lump jams to 1,264.

Another concern with the NMET database is the high occurrence of entries less than 5 minutes in duration that are coded as lump jams. Of the 2,733 recorded entries during the two-year study period, 1,217 (45%) are less than five minutes in duration. These small entries are considered lump jams in as much as their presence is due to execution of the logic defining a lump jam in NMET; however, for the course of this thesis, only entries greater than 5 minutes will be considered as significant losses to productivity. Therefore, the total number of significant lump jam entries for the NMFB6 and NMFB7 from July 2001 to June 2003 is 1,162. These entries are class D lump jams greater than 5 minutes in duration. Figure 3-2 shows the breakdown of the raw data from the NMET system for the two-year time period.

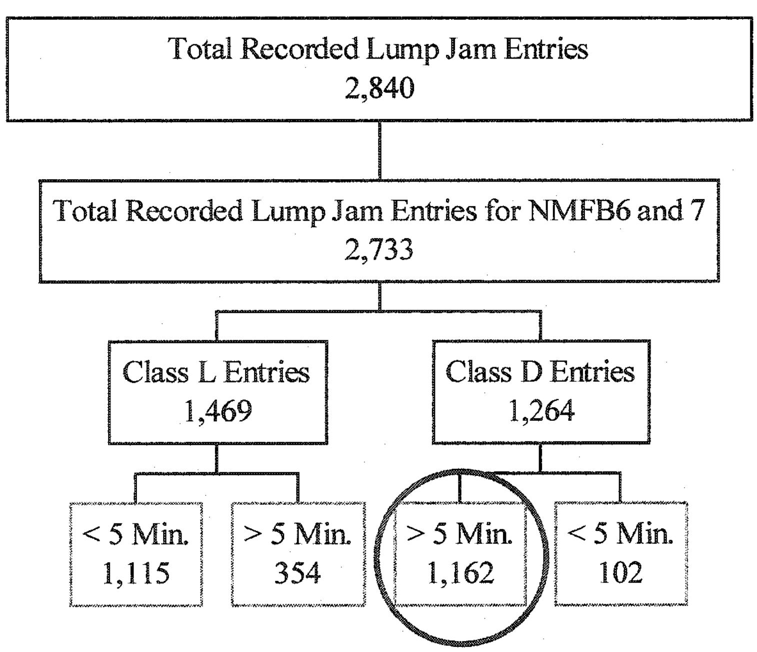


Figure 3-2 - NMET Data Breakdown for Lump Jam Events, July 2001 to June 2003

Upon more careful examination of the filtered data, it appears a number of the larger lump entries (>100 min) cannot be confirmed by other data sources. When taking some of the larger entries and cross-referencing them to the activity of the crusher in the Plant Information (PI) and Quality Production Databases (QPD), there is no indication of a lump jam event in progress. In Appendix 1, the QPD and PI databases do not show a stoppage or slow down of trucks dumping to the NMFB7 during the time frame which the NMET entry claims a lump jam has occurred. One can use data from QPD or PI databases, or video recordings, to assist in validating NMET lump jam entries, but a lack of confidence will remain. The presence of these problems makes validation of the true number and duration of lump jam occurrences difficult.

3.2.2 Weather

Data on weather is important in this project due to the strong correlation between it and lump jam/lump dump events. Weather data is recorded hourly on site and filed in a database that can be accessed through the Syncrude internal portal at **http://intranet.syncrude.com/atmosdata**. Minimum and maximum hourly temperatures, wind velocity and direction, precipitation, humidity, snowfall and snow on the ground measurements are some of the values that can be retrieved.

Using the information in this database, temperature profiles can be created showing the average daily temperature over the July 2001 to June 2003 period. The cyclic nature of the temperature pattern, as shown in Figure 3-3, lends itself easily to simple modeling and prediction, which is used in subsequent calculations of frost penetration depth.

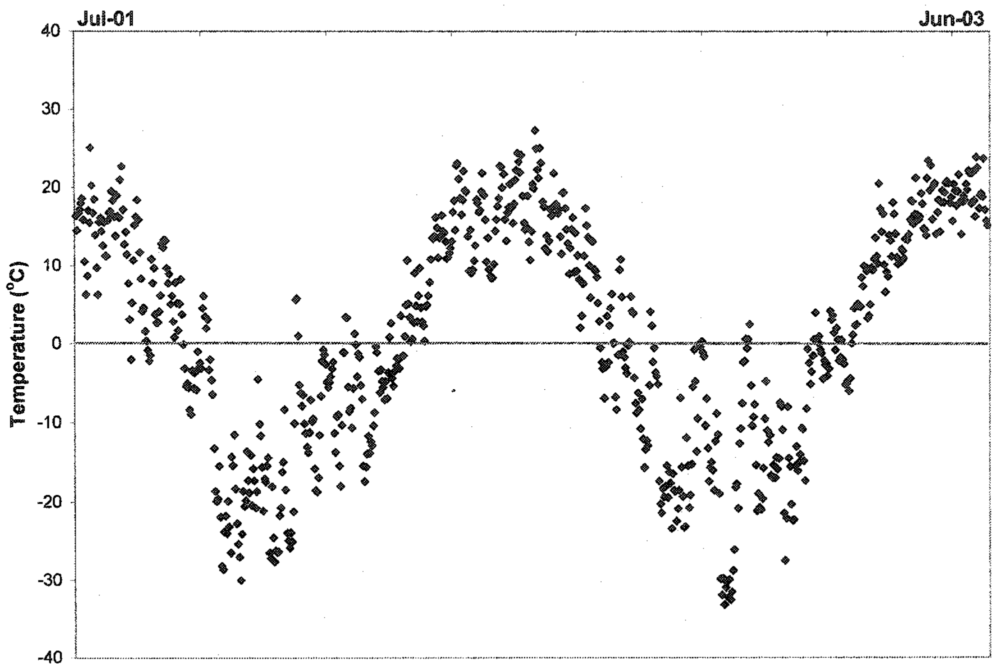


Figure 3-3 - Syncrude Site Annual Temperature Cycle using Mean Daily Temperatures

Upon analyzing the occurrences of lump jams on a yearly basis for NMFB6 and NMFB7, one can notice that during the months of December to March, approximately 80% of all lump entries are recorded. Viewing this data in conjunction with mean monthly temperature taken on site, as displayed in Figure 3-4, a strong negative correlation exists between these two variables. This relationship will be analyzed in subsequent chapters in conjunction with shovel type, geology and operational parameters.

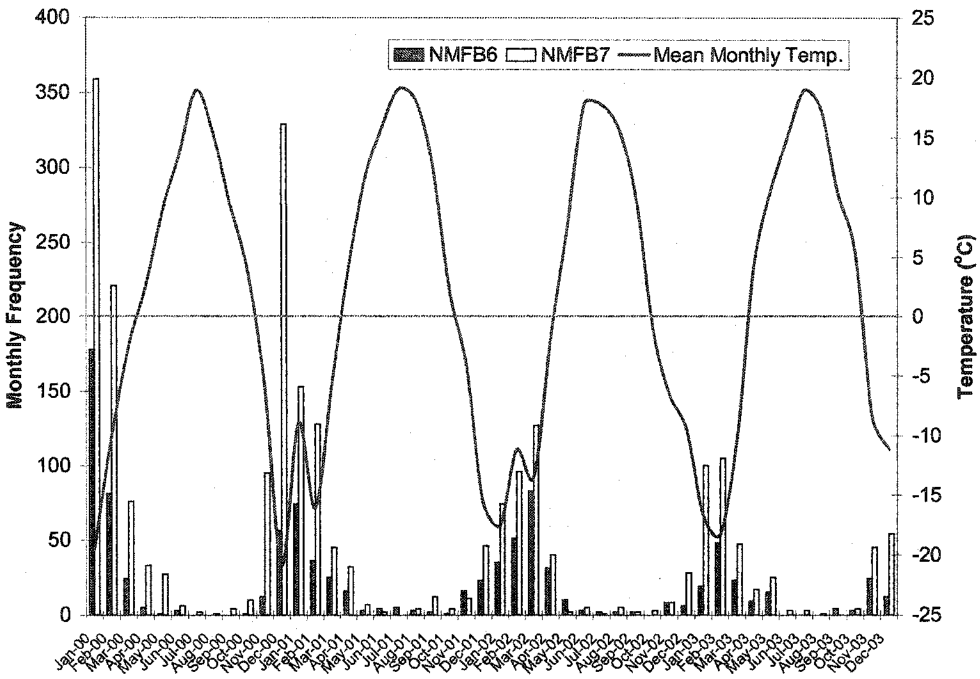


Figure 3-4 - Lump Jam Frequency versus Mean Monthly Temperature

3.2.3 Wenco and Quality Production Database (QPD)

The Wenco and QPD databases are contained within the same family of tables, thus draw on similar data sources. Data is compiled on a truck-by-truck basis according to the Wenco truck dispatch system in conjunction with the Surpac block model that provides geologic information for each truck payload. Time stamping in the QPD/Wenco system is based on the dumping time of the truck when the box has reached full dumping height (Hachey, 2004). Data on equipment, origin and destinations of material, and geology are the primary fields of interest within these databases. Shovel location is acquired through high-precision GPS in accordance with bench designation allocated by the Mine Planning department. The Surpac geologic block model used in this reporting is based on Mine Planning's 25 m x 25 m x 0.5 m block size that reflects a composite of values from borehole logs (Wright, 2004). Geology is assigned to a truck based on an intersection through the block model made according to the digging height of a shovel and its elevation. A more detailed explanation of the construction of the block model is found in *Chapter 6 - Geology*.

Wenco does not suffer from human interference with data collection, yet the QPD data can be manually overridden, hence one must still be cautious in using the data unquestionably. A great deal of data is compiled and assigned to each truck, with geology being assigned by connecting the block model to the GPS trace of the shovel where the truck is loaded. GPS accuracy and the presence of the unusually large amount of UNKNOWN and WASTE coded facies is cause for some concern as only loads to the crushers are being used as the basis for this work.

Hantelmann (2004) of Mine Planning has cautioned about using data from Wenco if the validity code for the GPS is greater than 2; the validity code is used to quantify the accuracy of the GPS. Tolson (2004) of Tridon Communications provided a break down of the meanings of each value coded in the Validation Code field as seen in Table 3-1.

Table 3-1- Validation Code Explanations (after Tolson, 2004)

Validation Code	Explanation of Validation Code
1	Reading is of sub-meter accuracy (<0.1m - usually in the centimetre range).
2	Reading is a floating solution (~>1.5m).
3	Reading is an autonomous solution (10-100m accuracy).
4	Reading is between value 1 and 2 > "> fix float> "> (+/- ~0.2m).
5	No high precision GPS Rx on shovel.
6	No high precision GPS Rx on shovel.
7	Error in Serial Input/Output device (SIO) signal.
8	Error in Serial Input/Output device (SIO) signal.
9	Error in Serial Input/Output device (SIO) signal.

Generally, a value of less than 3 corresponds to a good GPS signal, whereas a value greater than 5 corresponds to a bad GPS signal. For validity codes greater than 7, the GPS simply reports the last good signal's northing and easting, and uses the bench name as the elevation. Upon examining this field in the database, it appears a great number of GPS traces are greater than 3.

However, randomly checking a shovel location and comparing the precision from a validity code of 1 (excellent) and 9 (poor), it appears that the accuracy is rarely more than ±50 m horizontally and ±5 m vertically. This translates to an average error of no more than a couple blocks in the block model. This magnitude in error, in conjunction with truck time and compositing of the geology, is not deemed significant, thus will be neglected for the purpose of this thesis. Furthermore, whenever a GPS signal becomes poor with a validation code greater than 5, the geology of the truck being loaded becomes coded as UNKNOWN.

Other causes of UNKNOWN coded facies could be due to the limits of the block model and weekly surveyed surfaces. The actual top and bottom of the minable oil sands is an undulating surface that cannot be accurately capturing using blocks. Whenever a block is found either below the top or above the bottom minable oil sands surfaces that is not oil sands the database cannot determine how to code the material, thus it is coded as UNKNOWN. Another possible explanation for UNKNOWN facies is that the surveyed pits do not match the actual pit condition (Wright, 2004). Each week the pits are surveyed using GPS to update the mine map for planning and geology purposes; however, errors can occur with GPS accuracy and people. Discrepancies between the actual and surveyed pits can create circumstances whereby block values become UNKNOWN. For example, if one week the surveyed surface has a block as being mined out, but the next week it shows as being there, this block would have an UNKNOWN facies coded to it the 'second' time it is mined. To create a better reference list, these UNKNOWN facies are altered using shovel digging time and known facies information. The search routine used to modify the records is explained in more detail later on in section *3.3.2 Challenges*.

According to the QPD/Wenco database, occasionally waste is dumped into the crushers or the lump dump. This is almost always a system error in load assignment. One probable source of this error is that the truck was hauling waste, but was reassigned during the course of the shift to haul ore without its code being updated in the database (Hachey, 2004). Conversely, the truck could be hauling ore, but when linking information from the block model to the truck, the latest update shows the block as waste, thus assigning the load a waste code. Another possible explanation is construction around the crushers or lump dumps. If a truck is loaded with gravel being used for maintenance, when the truck dumps, its proximity to the crusher/lump dump triggers the dispatch system into believing the gravel is being dumped into one of the crushers/lump dumps instead and codes the dump as such. The last possible explanation is that a truck of waste material is actually dumped into the hopper. During summer operation, waste is sometimes dumped into the hopper to clean the hopper and crushers after a load of rich oil sands is dumped. This can prevent jams from occurring to subsequent loads (Parsons, 2003). While the number of waste coded loads that dump into the hoppers is relatively small, they should be brought to the attention of Syncrude.

Recorded payloads, however, do have a great deal of error and complexity when entered into the dispatch system. Of concern is a problem that exists in Wenco when the default settings are exercised whenever a truck is filled to less than 80% or over 150% of its designed payload. These half or over loads are recorded at the truck's 100% loaded capacity, which does not reflect the true weight of oil sands in the truck. Furthermore, the accuracy of the truck weightometers are also suspect, thus often truck payloads are manually altered in Wenco to the default maximum payload. Although payloads recorded in either the Wenco or QPD databases may not be entirely accurate for a particular truck, monthly reconciliations are not effected due to averaging. Table 3-2 shows the number of default entries recorded each month for the study period.

Another issue is that of the manner in which the on-board weightometers record the payload on the trucks. Currently readings are taken every few seconds with the recorded payload being an average of a smaller sample set, thus this value may again not be the true payload if consistent high and low values are used. According to Joseph's (2002; 2003) research on soft ground conditions in oil sands, the road conditions that the haul trucks travel on can have a large effect on the recorded payload due to the dynamic motion they experience. Traveling over bands of softened and hardened ground causes a bouncing motion that can either increase or decrease the weightometer reading. Consequently, the dynamics of the truck while it is in motion can skew the recorded payload values by as much as 30%.

Table 3-2 - Default Payloads in Wenco

	PAYLOADS		
MONTH	DEFAULT	TOTAL	%
JUN 03	11,633	28,604	40.7
MAY 03	13,769	29,075	47.4
APR 03	10,038	21,956	45.7
MAR 03	9,728	22,947	42.4
FEB 03	12,013	32,104	37.4
JAN 03	10,691	27,344	39.1
DEC 02	11,173	27,916	40.0
NOV 02	10,719	26,845	39.9
OCT 02	10,895	31,510	34.6
SEP 02	13,094	31,290	41.8
AUG 02	11,964	31,353	38.2
JUL 02	11,081	24,268	45.7
JUN 02	10,328	20,885	49.5
MAY 02	4,480	11,453	39.1
APR 02	12,071	24,295	49.7
MAR 02	10,261	19,799	51.8
FEB 02	12,354	27,181	45.5
JAN 02	12,818	26,389	48.6
DEC 01	12,477	29,405	42.4
NOV 01	13,982	23,999	58.3
OCT 01	11,141	19,069	58.4
SEP 01	10,271	27,546	37.3
AUG 01	13,032	37,559	34.7
JUL 01	12,606	34,821	36.2

3.2.4 Plant Information (PI)

The PI database contains data for plant operations recorded by various sensors located throughout the site starting at crushing and continuing until the bitumen has been fully upgraded. For this project, Plant 75 information pertaining to hopper level (75XLI16C/75XLI16D), apron feeder speed (75XS11), roll crusher speed (75XS8B/75XS9B) and crusher chute level (75XLI16E) are considered; tags IDs correspond to each sensor with the 'X' being a variable for the crusher with '6' referring to NMFB6 and '7' referring to NMFB7. Plant 78 data is also used with the tags monitoring the demand (78DEMAND) and actual (78WX1) rates on the North Mine oil sands feed in tonnes/hr.

During a lump jam event numerous actions taken by the crusher operator can be captured by the PI sensors. Regardless of the type of lump jam, it is practice to stop the apron feeder to minimize the amount of build-up once a lump has jammed the feed. This is registered as a drop in apron feeder speed. However, the operator may perceive the lump as small and pile material on top to push the lump through the crusher, thus not registering a drop in apron feeder speed. Likewise, the lump may not be large enough to impede all throughput of the crusher, thus the apron feeder continues to supply material until enough material has accumulated to create a jam whereby the apron is then stopped. Roll speed of the crusher can also be a good indicator of a lump event, yet this indicator can be misleading at times as well. Once a lump has landed on the crusher, the operator may continue to run the crusher in an attempt to grind the lump down to a passing size; if the lump passes, little or no indication on PI will be recorded, but if the lump is persistent and does not reduce in size, the rolls must be stopped and the lump removed mechanically. Conditions as described above could explain some of the inconsistencies and time lags between entries recorded in PI and coding of lump jam entries, thus making reconciliation a challenge.

An additional challenge present with this database is one of resolution. When accessing data back to June 2001 its resolution is compressed to no less than one-minute intervals, therefore, making any matching with other, more precise, data streams difficult. Up to three trucks can dump in a one-minute gap, thus making correct determination of the effects of the dumped loads on the system difficult.

3.3 Combining and Filtering of Data

A number of files are created before the compilation of information can be done into a complete reference list. In generating the files for all the material sent to the crushers, raw queries for each month and each crusher are made from the Wenco and QPD truck dispatch databases. Although records from the Wenco and QPD systems are similar, each database is missing key fields that would be necessary to make the analysis complete. Wenco contains no information on geology or GPS traces while QPD does not contain the names of the source locations. Therefore, it is necessary to merge the monthly queried files from each database to generate a complete list of available information on each truck load, including where it is loaded, where it is going, what shovel loaded it and what the facies geology is within the truck. Using this reference list, tables are made that summarize the available information by crusher, shovel, bench and geology for every month over the two-year study period from July 2001 to June 2003.

3.3.1 Merging Data

The raw production data contained in the reference list is organized into tables on a month-by-month basis. Each month has a breakdown of its production by shovel and dump location as well as origin location and facies member. Table 3-3 shows the table arrangement for oil sands volume being dumped into NMFB6 for a particular month divided up according to shovel and origin location. A similar table exists for facies instead of origin location as well as for frequency instead of volume for every dump location.

Table 3-3 - Typical Monthly Production (BCM) Table for Shovel ID, Bench ID and Crusher

		SHOVEL ID										
	BENCH ID	0034	0035	0036	0076	0077	0078	0079	0080	R110	R685	Grand Total
NM Feeder Breaker #6	NM 252E Ore Bench Panel 5									91		91
	NM 264E Ore Bench Panel 5				450,004						50,150	500,155
	NM 264W Ore Bench Panel 10 N										40,670	40,670
	NM 264W Ore Bench Panel 10 S		12,785									12,785
	NM 276E Ore Bench Panel 5				92,109						110,107	202,215
	NM 276W Ore Bench Panel 10 N		134,017	1,742		113,693						249,452
	NM 276W Ore Bench Panel 10 S		22,358									22,358
	NM 284W Ore Panel 10 S			98			8,685				5,846	14,629
	NM 288W Ore Bench Panel 10 N										745	745
	NM 288W Ore Bench Panel 10 S			8,704			217,112					225,816
	NM 288W Ore Bench Panel 11 N				103		92,447					92,550
	NM KCA South Panel 6				137				107			244
	NM KCA West Panel 10 S											0
	NM KCW West Panel 10 S		484	112								596
	NM NT1 325	7,409										7,409
	NM OB1 South Panel 6											0
	North Mine N. Ore Lump Dump					87,571					32,463	120,034
	Sand Stockpile											0
NM Feeder Breaker #6 Total		7,409	169,643	10,657	542,353	201,263	318,244	0	107	91	239,982	1,489,748

Throughout the two-year study period, the raw data contained 130 origin locations, 7 dump locations, 57 facies and 14 shovels. The extent of this data would make any correlations or analysis extremely difficult, thus the data was composited to reduce the number of fields and making conclusions possible. Origin locations were reduced from 130 to 20 and facies were reduced from 57 to 25. Unfortunately, this still provided too many sources of oil sands, thus these lists were further filtered based on the criterion that an origin location or facies group must produce more than or equal to 3% of the total annual mined volume. Using this criterion, the origin list decreased to nine sources, but since benches NM252, NM254 and NM256 are essentially the same, they were grouped together as NM25X. The remaining seven origin locations being: NM245, NM25X, NM264, NM276, NM284, NM288 and Lump Dump. The geologic facies groups based on this last criterion reduced to seven: 95/15, 96/16, 12/13, 10/9, 7/8/11, 6/26 and UNKNOWN. Shovels were grouped based on their classification as either cable-electric or hydraulic. Shovels 0076, 0077, 0078, 0079 and 0080 are cable-electric and all other shovels are hydraulic. Appendix 2 contains how the origin locations and were grouped. Table 3-4 contains the composited list of facies groups, origin locations, shovels and dump locations, with the highlighted names being those that produced more than or equal to 3% of the total annual mined volume, which were used in subsequent analysis.

Table 3-4 - Composited List of Facies, Origin Locations, Shovels, and Dump Locations

Facies	Origin Locations	Shovels	Dump Locations
99	Coke Cell	0034	NMFB6
27	Inpit Ramps	0035	NMFB7
23,26,18	N/A	0036	NWFB2
95,15	NE Ext.	0037	NWFB5
96,16	NM 245	0039	NEFB
19,17,14	NM 252	0076	N Lump Dump
50	NM 254	0077	W Lump Dump
22,21	NM 256	0078	
12,13	NM 264	0079	
10,9	NM 276	0080	
7,8,11	NM 284	R92	
6,25	NM 288	R93	
78,4	KCA	R110	
74,70,71	KCW	R685	
77,3,2	OB		
75,61,63	Lump Dumps		
1	NW Quad		
COKECELL	SW Quad		
LUMP DUMP	W Quad		
N/A	Other		
NE EXT.			
ROADS			
WASTE			
UNKNOWN			
OTHER			

3.3.2 Challenges

The databases used in this thesis are generally well organized, but during the course of the research, a number of challenges arose. During the initial querying within the QPD database some months reported duplicate entries. The Wenco database did not report these duplicates, thus it was concluded that this was a database management error. As information was nearly identical for the paired entries, one of the paired entries was ignored when generating the fully matched dataset.

Minor discrepancies between the databases were also discovered during the task of combining their respective data. One was in the manner that the databases report the amount of material that each truck carries. Wenco reports quantity in metric tonnes and QPD reports volume in bank cubic metres (BCMs).

Upon discussions with Parsons (2003) of Syncrude Research, he suggests using the QPD Quantity field as it does not undergo any human modification, therefore, for the scope of the thesis, all quantities will be reported as volume in BCMs. Moreover, time stamping between the databases is not identical, thus further complicating record matching. The largest challenge when merging the two databases is the occurrence of incomplete records between the Wenco and QPD databases. Often truckloads were missing in either the QPD or Wenco databases making matching of geology and source location difficult. In order to generate a viable and complete list, no partial record was ignored in either database, but this left a number of gaps throughout the list where only one database's information was present. To fill these gaps some reasonable assumptions were made based on the available information. Within each database, some fields are identical, such as truck number, shovel number and dump location, which are used to partially fill in the missing information. From these partially filled records, it is possible to infer either the origin of the material, quantity or geology. Using a one-hour maximum period from the record's time stamp, a search is conducted where the missing information could be reasonably relied upon to be accurate. When the origin of a truck is unknown, a previous occurrence is found where the origin of the same shovel loading a truck is known and that origin name is copied over into the gap in the partial record. When the QPD quantity is not available, the Wenco tonnage is converted to BCMs and used. Lastly, when geology records are not available or when an UNKNOWN geology is encountered for a record, known information from trucks loaded from the same location and by the same shovel are searched, and if a match exists, the facies information is copied over. If no match can be found within an hour of the partial record in either database, any missing geologic information is recorded as UNKNOWN. This problem is persistent with GPS interruptions and poor resolution during the download time, as mentioned previously. Any records that have undergone any modifications have been tagged as such in the modified data field within the compiled reference list. For the scope of this thesis, allowing a discrepancy of up to 50 m laterally and/or 60 minutes lag time when filling in partial records should be an acceptable tolerance in relation to the geology and mining operation.

Once all of the previous challenges were overcome and concerns addressed, the complete production list from July 2001 to June 2003 was ready for analysis. This data will be used to compare lump dump activity and lump jam events to the overall production scheme. Correlations to climate, origin location, shovel type, and geologic facies code as well as other possible indicators, such as time of day and plant demand, will all be investigated. It is believed that some or all of these factors contribute in some way to the formation of frozen lumps that burden the mining operation at the North Mine.

3.4 Methodology of Analysis

The tabulated information can be used to compare production across months and identify trends in either lump dump and/or lump jam activity. The major performance indicators that will be examined in accordance with the objectives of this thesis are shovel type, origin location and facies. In addition to determining the amount of lump dump/lump jam activity that is attributed to each of the indicators, these compiled production lists can be used to cross correlate between these indicators. It will be possible to determine, for example, if a certain crusher is preferentially fed by oil sands from a particular shovel type or origin location. Likewise, crushers' performance in lump jam situations can be compared if their feed is from the same shovel type and/or origin location or geology.

3.4.1 Lump Dump

Comparing the raw volume or frequency of lump dump activity can be informative as to which shovel type, origin location or facies is the worst contributor. Knowledge about which indicator produces the most lump dump activity is important in determining where the greatest improvement can be realized in the mining operation. However, as not all shovels, origin locations or facies are mined equally, normalization will be done to determine which indicator is more probable in generating a lumpy load. The normalization will be done against the lump dump volume/frequency and the total oil sands volume/frequency originating from the each shovel type, origin location or facies. Both the raw lump dump volume/frequency as well as the normalized percentages are useful in determining if there exists certain shovel types, origin locations or facies that contribute more to lump generation than others.

3.4.2 Lump Jams

Quantifying the frequency of lump jams is important in determining which shovel type, origin location or facies is the worst generator of lump jams. Much like lump dump activity, the greatest improvement can be realized when concentrating on those factors that generate the most lump jams, yet normalization is still required as each shovel type, origin location and facies does not produce equal volumes. Normalization to determine the more probable shovel type, origin location or facies is done by taking a ratio of the lump jams to how many million BCMs of material came from that shovel type, origin location or facies. Comparing these ratios between the different indicators will provide some insight into which shovel type, origin location and facies is the more probable in generating a lump jam. In addition, comparisons between NMFB6 and NMFB7 can be made to determine if one crusher's performance differs from the other as well as attempt some possible explanations based on feed by shovel type, origin location or facies. Furthermore, for the scope of this thesis, it is assumed that the duration of lump jams is independent of shovel type, origin location and facies, thus only the frequency of lump jam events will be considered.

Determining the shovel type, origin location and facies that causes a lump jam requires correctly matching the source truck and the downgrading lump. This task is not trivial. As multiple trucks can dump into a hopper during a short time, mixing of their payloads decreases the confidence that can be placed on the lump originating from a particular truck. Changes in apron feeder speed, bed height, oil sands fragmentation, angle of repose, bitumen content, and temperature are all additional factors that can effect the mixing and flow of the oil sands in the hopper as well as the production rate of the crushers. Furthermore, a lump can be dumped into a hopper without severely impeding throughput for minutes after it has been dumped, thus further creating ambiguity as to the true source of the lump.

The search routine that has been selected to match a lump jam to a truck relies upon basic statistics. As it is nearly impossible to determine the exact truck that delivered the lump that caused the jam, a weighting system is used based on the payload in the trucks to the total volume capacity of the hopper (700 t). The hopper will always be assumed to be at capacity to increase the likelihood of capturing the origin and shovel of the truck that delivered the lump. These weighting are then summed based on whichever parameter is being investigated and compared to determine the greatest generator as well as most probable to create a lump jam. As 1,162 events will be considered in the analysis, it is believed that any abnormalities will be removed and any visible trends will be evident and valid due to the population of the data set. Other assumptions are that the time stamping in the NMET, PI and QPD systems are all accurate and can be used relative to each other as well as on the reliance that lump jam entries are accurate and real.

The algorithm will proceed starting from the lump jam entry time in NMET. The previous four trucks that dumped previous to the jam are queried with their weighting established based on their volume payload to hopper volume ratio. In the example, illustrated in Figure 3-5, the first truck prior to the lump jam is given a weighting of 0.46 (325 t / 700 t), the second truck is given a weighting of 0.35 (240 t / 700 t) and the third truck is given a weighting of 0.19 (1.0 - (0.46 + 0.35)). Usually only three trucks are weighted for each lump jam entry, but occasionally if truck capacities are smaller, a fourth truck can be considered in the weighting.

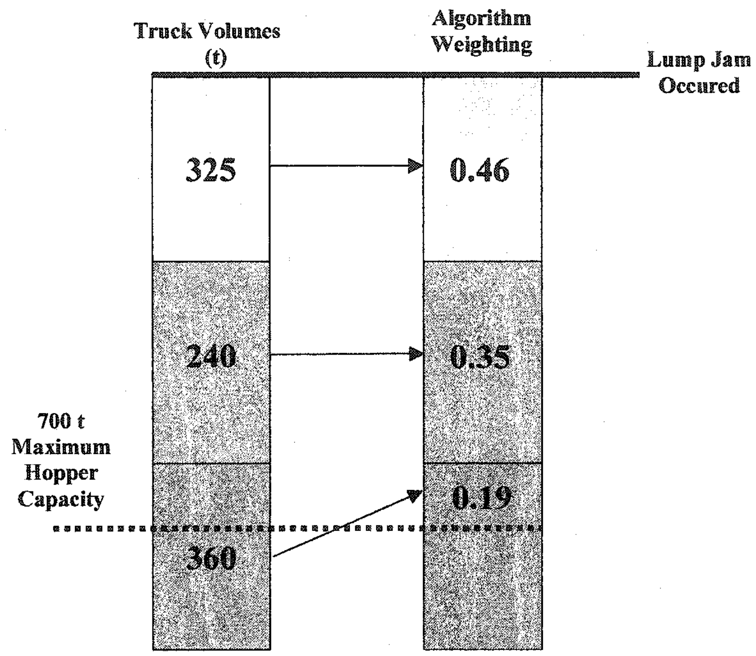


Figure 3-5 - Example Truck Weighting for Lump Jam Matching

Challenges are still present with this search routine when accounting for the resolution of the NMET system. One-minute resolution is as small as is recorded in the NMET system, yet in this time frame multiple trucks can dump in the hopper. The average operating throughput for each of the crushers in the North Mine is approximately 6,000 t/hr, although the maximum operating throughput can be as high as 12,000 t/hr (Wooley, 1999). Using these values to account for nominal and maximum production rates, a 360 t haul truck's payload can be processed in the order of 1.8 to 3.6 min. Furthermore, since an event is rounded to the nearest minute, the error of the event can be out by as much as ±30 seconds. Cumulatively these effects, due simply to resolution, can lead to uncertainty in any analysis.

3.5 Summary

In the process of analyzing the causes of lump dump activity and lump jams, a number of Syncrude databases are used in linking production to climate to equipment performance: NMET, weather, QPD/Wenco and PI. The NMET database contains all the occurrences of lump jams at the North Mine. Using the criteria of only downgrading entries greater than 5 minutes in duration from July 2001 to June 2003, 1,162 lump jams have occurred at the NMFB6 and NMFB7. Comparing these occurrences to the temperatures recorded in the weather database from the Mildred Lake weather station shows a high negative correlation between these two variables. The Wenco and QPD databases were merged to create a production reference list that contains the shovel, origin location, dump location, payload, and geology of every truck of oil sands during the two-year period. PI tags provide feedback from sensors used by NMET in classification of downtime entries as well as in capturing plant demand and actual production through the North Mine.

Using the production reference list, tables were generated on a month-by-month basis summarizing the relationship between shovel, origin location, dump location and facies group. Through additional compositing and filtering based on minimum production requirement, the number of origin locations and facies groups reduced down to seven each with two shovel types and six dump locations. This will allow for easier correlations and analysis to be done in subsequent chapters. Although there were a number of challenges faced in the retrieval and organization of the data, such as inconsistent time stamping, gaps in the databases, and inaccurate GPS, they were all dealt with in a logical manner that provided tables that will be used in the analysis of lump dump activity and lump jam events.

4 CLIMATE AND FROST PENETRATION

4.1 Climate

4.1.1 Climate of Fort McMurray and Syncrude

The climate in Fort McMurray, Canada is indicative of a sub-arctic environment characterized by short, hot summers and long, cold, dry winters. Based on Environment Canada's station at the Fort McMurray airport, the mean annual temperature is approximately –0.2 °C with extremes of up to 36.1°C and –50.6°C. Table 4-1 shows the monthly temperature, precipitation and wind values collected over a 30-year period from 1953-1983.

Table 4-1 - Fort McMurray Monthly Climatic Means (after Environment Canada, 1984)

Hourly	1953-1983	Fort McMurray	Elevation	369m
Extreme	1944-1980		Lat./Long.	56°39' N 111°13' W

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temperature (°C)													
Maximum	-16.5	-9.0	-2.2	8.7	16.9	21.0	23.1	21.4	14.8	8.6	-3.5	-12.2	5.9
Minimum	-27.1	-21.8	-16.1	-4.5	2.4	7.0	9.5	8.0	3.1	-2.0	-12.7	-21.7	-6.3
Average	-21.8	-15.4	-9.2	2.1	9.7	14.0	16.3	14.7	9.0	3.3	-8.1	-17.0	-0.2
Extreme Maximum	10.6	15.0	18.9	30.2	32.8	36.1	35.6	33.3	30.6	28.4	18.9	10.0	36.1
Extreme Minimum	-50.0	-50.6	-44.4	-35.0	-13.3	-4.4	-3.3	-2.8	-15.6	-22.8	-37.8	-47.2	-50.6
Precipitation													
Rainfall (mm)	0.5	0.6	0.9	7.3	33.4	64.1	75.4	76.6	54.4	16.2	2.5	0.9	332.8
Extreme in 24hrs.	6.4	4.8	6.1	11.7	38.4	46.0	51.6	94.5	60.5	21.8	13.0	5.8	94.5
Snowfall (cm)	26.4	21.9	24.2	13.5	2.7	0.0	0.0	0.0	4.0	12.7	29.1	29.3	163.8
Extreme in 24hrs.	16.3	13.2	29.7	20.8	15.2	0.3	0.0	0.0	27.9	16.5	16.3	22.6	29.7
Total (mm)	22.7	18.8	20.7	20.5	36.3	64.1	75.4	76.6	58.5	28.1	25.2	25.0	471.9
Extreme in 24hrs.	16.0	13.2	29.7	20.8	39.4	46.0	51.6	94.5	60.5	22.9	15.7	22.6	94.5
Wind													
Prevailing Direciton	E	E	E	ESE	E	E	W	SW	W	E	E	E	E
Speed (kph)	8.6	9.1	9.9	11.2	11.4	9.8	9.2	8.9	9.6	10.6	9.3	8.4	9.7
Peak Wind (kph)	79	72	64	79	80	97	105	77	84	97	97	80	105

These data are typical of the Athabasca oil sands region, however, microclimates in the area can vary the values. Syncrude is located approximately 45 km north and at a lower elevation than the Environment Canada station, thus its climate is slightly different. Comparing Syncrude's Mildred Lake weather station to Environment Canada's located at the Fort McMurray airport from July 2001 to June 2002, shows that while minor, the annual mean temperature at

Syncrude is 1.0°C warmer than at the Fort McMurray airport. As the thesis is being conducted at the North Mine and due to the available climatic data, Syncrude's weather database will be used for all subsequent modeling of frost penetration and temperature correlations.

4.1.2 Climate Related Effects on Mining Activities

The wide range of temperatures experienced at Syncrude in conjunction with the mining activities causes a wide range for problems, both in the summer and winter months. Equipment-oil sands interaction is a major driver in reliability and one that is being continually studied and researched.

In the summer, oil sands soften rapidly under cyclic loading creating soft underfoot conditions that can no longer support the weight of trucks and shovels. Trucks experience increased rolling resistance up to the point where they may no longer generate sufficient power to move, thus requiring the load to be dumped or for support equipment to push/pull the truck out of the area. Furthermore, the excessive rack, pitch and rolling that the equipment is subjected to increases maintenance costs, decreases productivity and creates excessive operator vibration.

Shovels can simply sink into the bench if the oil sands grade is high enough and/or the temperature is high enough. While digging, the rocking motion of the shovel preferentially softens the underfoot near the ends of the track-ground contact. As the digging cycles increase, this softened zone progresses toward the mid-point of the track creating a crowning effect. Given sufficient cycles, this softened zone encompasses the entire shovel footprint, which causes the oil sands to fail in shear giving the appearance of sinking. The increased extent of the cyclic motion is more damaging for the shovel on side frames and the carbody with cracks being more frequent and pronounced.

In the winter months oil sands is stiffer, thus underfoot conditions are less of a concern, but other issues arise that cause concern for equipment reliability, productivity and cost. The ease with which oil sands is processed is largely inversely proportional to the temperature, thus the winter causes the greatest challenges. Long, cold winters result in frozen oil sands that cause increased abrasiveness, greater penetration resistance for the excavation equipment and a reduction in overall machinery efficiency. Frost penetration can be measured in metres with large lumps being generated that cause rehandling and/or jams at the crushers. Plotting the mean monthly temperature against the volume delivered to the lump dump shows a high negative correlation between these two variables. In Figure 4-1 the increase in lump dump volume as the temperature drops can be easily seen, especially during the months of January to March with the summer months showing no lump dump activity whatsoever. A similar trend can be seen when plotting lump jam events from the North Mine versus mean monthly temperature in Figure 4-2.

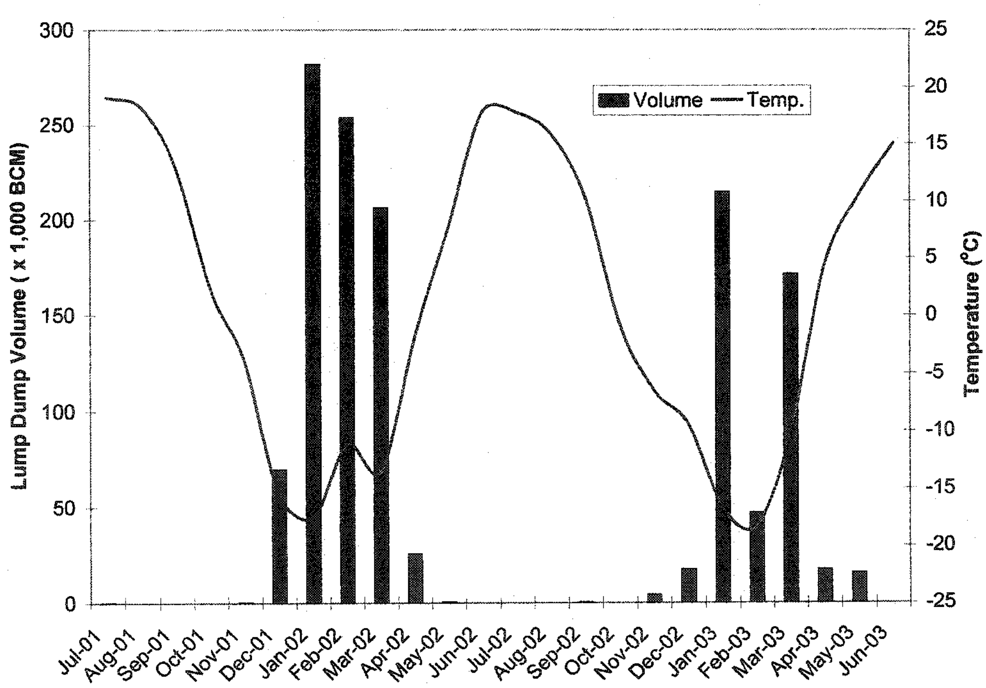


Figure 4-1 - Lump Dump Volume versus Mean Monthly Temperature

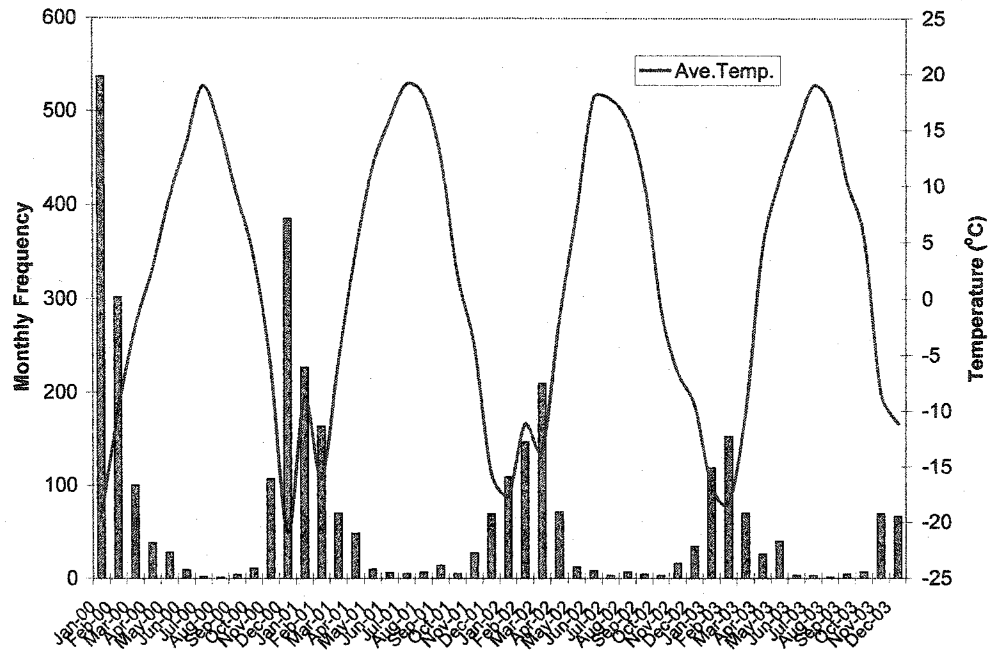


Figure 4-2 - Lump Jam Events versus Mean Monthly Temperature

4.2 Frozen Ground

4.2.1 Freezing Process

Frozen oil sands is a five-component matrix consisting of a soil skeleton, water/ice, bitumen, dissolved gasses and clay. The oil sands grains have a thin film of water coating them, thus the bitumen is not directly in contact with the grains. Voids are filled with ice and/or unfrozen water, gasses, bitumen and clay. The ice may be distributed uniformly throughout the soil mass or accumulated in irregular or stratified ice inclusions. Upon freezing, the water within the material solidifies and fuses the soil skeleton together increasing the compressive strength and decreasing the hydraulic conductivity. The oil sands behaviour can range from brittle to plastic depending on the unfrozen water content and temperature. Seasonal fluctuations in temperature create frost action that can be predicted upon determination of the thermal properties.

The process of freezing in a soil matrix involves temperature effects, phase change and volume expansion of water. As cool air moves over the surface, the temperature at depth decreases due to heat flow from the warm to cold soil surface until the surface reaches 0°C. When the soil temperature reaches 0°C, the water in the voids liberate 334 kJ/m^3 of heat as it undergoes phase change. This liberated heat is conducted to the surface and the frost front progresses into the soil. At the surface, the frost front propagates quickly due to the high temperature gradients, but slows down considerable as it goes deeper as the gradient decreases with depth. As the frost front slows, thermodynamic conditions are established such that it is possible to have migration of water to the frost front. This occurs due to surface tension effects between the ice crystals that form and the water that is in contact with the ice in the void spaces. Water flowing towards the frost front brings energy in the form of latent heat that is released as the water undergoes a phase change to form an ice lens. During this phase change at the frost front, continuity of energy flow is fulfilled without the need for the frost front to advance deeper into the unfrozen soil. Under these conditions, ice lenses form just on the cold side of the frost front nucleating slightly below 0°C. These ice lenses form normal to the direction of heat flow and the heave that takes place occurs in the direction of heat flow. Changes in the surface temperature disrupt the heat flow balance causing the frost front to advance at a rate that disturbs the growth of an individual ice lens. When the heat flow re-establishes its continuity under the new set of environmental conditions, ice lenses will begin to form again. Figure 4-3 depicts the freezing process and its effects on temperature, pressure, and soil condition.

A soil that meets the requirements for ice lens growth under certain thermal conditions is known as a frost susceptible soil. Generally, a grain size distribution can be used to indicate if a soil is frost susceptible, yet this property alone does not capture mineral type or climatic conditions. The most reliable method is to measure the thermal gradient of the soil and determine if ice lenses can grow.

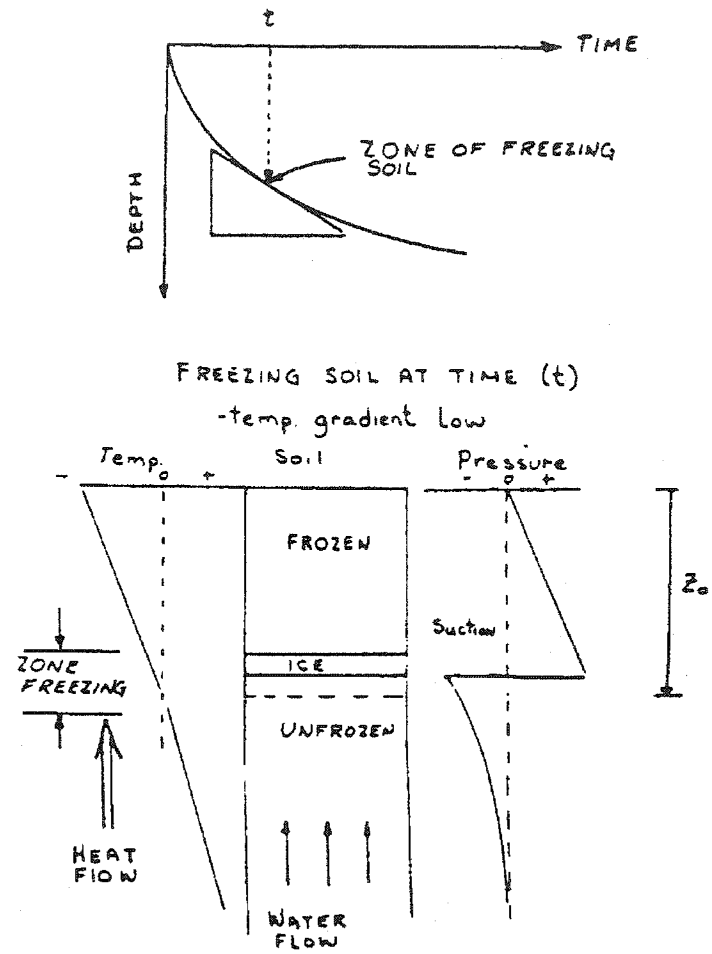


Figure 4-3 - Model of Freezing Process (Sego, 2004b)

Fort McMurray is located in an area of isolated patches of permafrost (<10% area). Figure 4-4 shows the regional permafrost lines ranging from none in the south to extensive in the northeast. The star is the location of the Syncrude North Mine. While permafrost related problems are rare in this region, the freezing and thawing processes are important, especially the thermal and physical properties that accompany frozen ground.

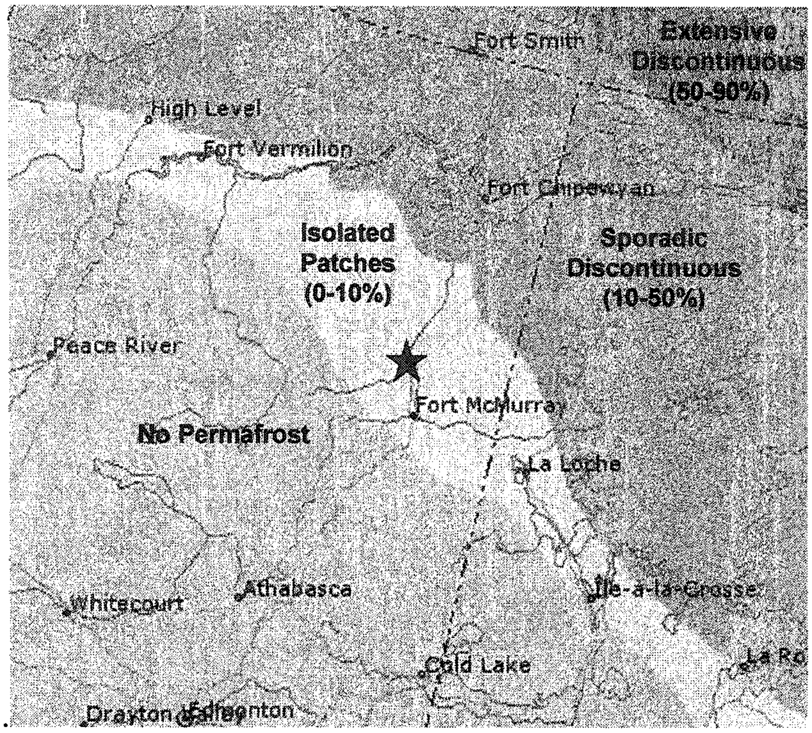


Figure 4-4 - Regional Permafrost Cover (modified from Canadian Natural Resources, 2003)

4.2.2 Physical Properties of Frozen Ground

Physical properties of frozen ground are highly dependent upon the freezing and thawing processes as well as the long-term temperature fluctuations in the area. Once soil is in its frozen state it becomes relatively impervious and develops high strength. These changes in property are important and must be considered in engineering design, mine planning and mine operation. While these conditions may seem more favourable for mining oil sands considering better quality underfoot conditions, it does create a great deal of mechanical problems such as higher breakout forces, greater wear and larger lumps.

<u>Strength</u>

Increased strength of frozen ground results from a combination of frictional resistance, dilatancy and interaction between the soil skeleton and the ice matrix. A comparison was made (Andersland and Ladanyi, 1994) between the strength of Ottawa sand under frozen and unfrozen conditions. Under confinement of 0.62 MPa, with no cohesion and a friction angle of 30°, the frozen sand had a compressive strength of about 11.5 MPa; approximately 8.5 times higher than the strength of unfrozen Ottawa sand (Andersland and Ladanyi, 1994). A similar comparison was made for Sault Ste. Marie clay in the reference, but the difference in strength, although less dramatic, was comparable. This substantial increase in strength of frozen soil has implications for higher bearing capacity as well, and can be observed by the haul road conditions in the North Mine during the winter months.

Permeability

The permeability of any soil in its frozen state approaches zero as the pore fluid solidifies and can no longer flow. As a soil undergoes freezing, its volume expands due to the presence of water. Water in the voids move to the frost front and form ice lenses that culminate to represent total frost heave in the soil. When a sand or gravel undergoes freezing in situ, water contained in the voids expands by about 9% by volume; however, this does not necessarily generate a 9% increase in void space as a portion of the water may be expelled during the freezing process or confinement may not allow expansion. Unlike a coarse-grained soil, freezing in a saturated silt or silty-sand is dependent on the rate of temperature decline. Rapid freezing causes the water to freeze in situ, yet gradual cooling causes ice lenses to be generated in the deposit since water cannot be easily expelled due to these soils' relatively low hydraulic conductivity. These ice lenses form a series of layers of frozen soil separated by layers of clear ice that act as an impermeable barrier to water movement, thus dropping the hydraulic conductivity of the soil even further. Small amounts of water are still allowed to move via thin films making up the unfrozen water content in frozen soil.

Unfrozen oil sands has a hydraulic conductivity that can range from 1×10^{-3} to 3.2×10^{-6} cm/s (Hackbarth and Nastasa, 1979). The presence of bitumen makes the oil sands behave more like a silt when considering the flow of water. The amount of bitumen present does exert a strong influence on hydraulic conductivity, but since the degree of bitumen saturation widely varies, both laterally and vertically, so does the hydraulic conductivity. The presence of bitumen acts to retard the flow of water as the water must follow a more torturous flow path, thus as the bitumen content increases, the hydraulic conductivity decreases. Water flows through the intergranular pores not filled completely with bitumen and is not thought to flow in the water film surrounding the individual sand particles. As the oil sands freeze, its hydraulic conductivity decreases even further and become essentially impermeable.

Thermal Expansion

Thermal expansion of a soil mass is an important parameter to fully understand thermally induced stress changes and ground deformations. In porous, multi-phase materials, such as oil sands, thermal expansion of both soil and fluid phases contribute to these changes. Furthermore, with different thermal expansion coefficients of the solid and fluid components, further complications of their effects are introduced. Figure 4-5 compares the coefficient of thermal expansion for the different constituents of oil sands at 50°C (Butler, 1986). Bitumen has a coefficient thermal expansion of 6.4×10^{-4}/°C compared with 4.5×10^{-4}/°C for water and only 0.4×10^{-4}/°C for quartz sand.

Tests conducted by Agar et al. (1986) on undisturbed Athabasca oil sands for drained and undrained conditions to study the effects that temperature has on volumetric expansion and pore pressure generation. These samples were tested using a temperature consolidometer over the temperature range 20°C to 300°C. During drained testing the samples were heated at a constant vertical effective confining stress of 6.0 and 0.05 MPa while pore pressure was maintained constant at 5 MPa up to 200°C and 15 MPa to 300°C. These tested oil sands samples were undisturbed with porosities of about 38% and bitumen/water saturations of 89%/11%. Undrained testing required that pore pressure and vertical effective confining stress was held constant during heating. The experiment held pore pressures constants between 0.05 and 15 MPa with a nominal effective confining stress of 0.05 MPa. Findings show that undrained samples undergo far greater volumetric expansion than drained samples. Figure 4-6 depicts the volumetric expansion of Athabasca oil sands using undrained and drained testing over a range of temperatures. While this information is not directly useful for the purpose of this thesis as the temperature range for this thesis is primarily below 0°C, it does show a trend that cannot be ignored. No published values of volumetric expansion or coefficients of thermal expansion for oil sands below 20°C have been found, but would be useful in attempting to understand the relationship between temperature and thermal conductivity of oil sands.

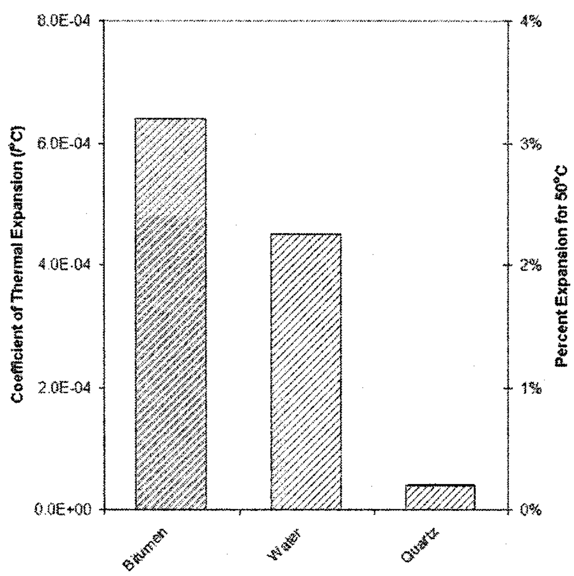


Figure 4-5 - Coefficient of Thermal Expansion for Oil Sands' Constituents (after Butler, 1986)

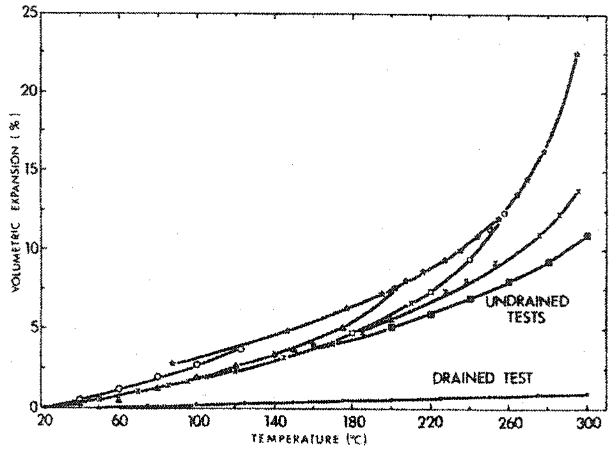


Figure 4-6 - Undrained and Drained Tests for Volumetric Expansion (modified from Agar et al., 1986)

4.2.3 Thermal Properties of Frozen Ground

Thermal Conductivity

Thermal conductivity is defined as the quantity of heat flow through a unit area of substance of unit thickness in unit time under a unit temperature gradient. Mineral composition, grain size, structure, temperature, density, moisture content and degree of saturation all significantly impact thermal conductivity values.

Many studies have been previously conducted to determine the thermal conductivity of oil sands and bitumen for temperatures at and greater than room temperature, but for the purpose of this thesis, values of thermal conductivity at temperatures below 0°C are needed. As no value has been documented for the frozen thermal conductivity of oil sands, it was necessary to calculate its property as a function of temperature over the typical operating range in Fort McMurray from –40°C to 30°C.

Calculating thermal conductivity can be accomplished using various methods, but according to Farouki (1981), Johansen's method provides the best results for the conditions and grain size under consideration. Johansen's method (1975) is equally applicable to frozen or unfrozen soils, and can be used for saturated or unsaturated conditions. He noted that the microstructure of the soil mass (dry density or porosity) are major factors in the dry thermal conductivity of the soil, but not as important when saturated. In the case of saturated soils, Johansen proposed using a geometric mean equation based on the thermal conductivities of the constituent parts and their respective volume fractions. Johansen's equation used in the analysis is:

$$k_{sat} = k_s^{(1-n)} k_w^n$$

Where k_{sat} is the saturated thermal conductivity [W/m°C], k_s is the solid thermal conductivity [W/m°C], k_w is the fluid thermal conductivity [W/m°C] and n is the porosity [%]. This method further describes methods of calculating the thermal conductivity according for unfrozen water content and unsaturated conditions, but for the purpose of this study oil sands is assumed to be a saturated soil with no unfrozen water content.

Johansen's method relies upon knowing the thermal conductivities of the solid and liquid components of the soil. In oil sands, the solid is predominantly quartz sand, yet the liquid is not simply water, but a mixture of bitumen and water. Therefore, to facilitate this method, a weighted average using the volume fraction of bitumen and water was used in generating a fluid thermal conductivity that could be used.

The thermal conductivity for water at room temperature decreases as the temperature approaches 0°C, but due to the phase change that occurs when ice is formed, the thermal conductivity of ice is much larger than that for water at 0°C. As the temperature continues to drop, the thermal conductivity for ice actually begins to rise. Figure 4-7 shows the response of water's thermal conductivity to temperature.

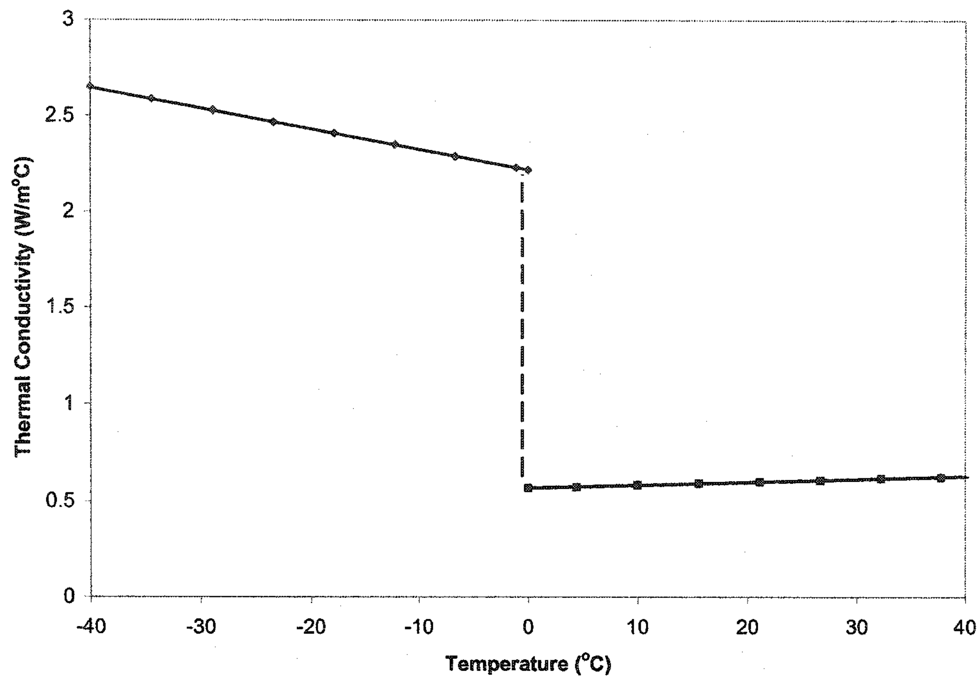


Figure 4-7 - Thermal Conductivity for Water/Ice
(after CRC Handbook for Chemistry and Physics, 2003)

Studies conducted by Hall (2001) from Syncrude Research on UNITAR bitumen provided thermal conductivity values valid for temperatures ranging from 20°C to 100°C. While the majority of this temperature range is not of use in this project, a trend has been proposed and hypothesized values for temperature to -40°C are made based on these findings. Figure 4-8 shows the trend of decreasing thermal conductivity as the temperature is lowered. Unlike water, bitumen does not undergo a phase change, but simply continues to increase in viscosity as temperature drops, thus exhibiting a pseudo-solid like response. Data points from Hall's research are shown along with the proposed trend as temperature drops to -40°C.

Hall's published trend is based on testing performed by Mathis Instruments of Fredericton, New Brunswick, Canada using a HOT Disk™ Thermal Constants Analyzer. Specified precision for this instrument is stated to be within 2% with an accuracy of ±5% (Hall, 2001).

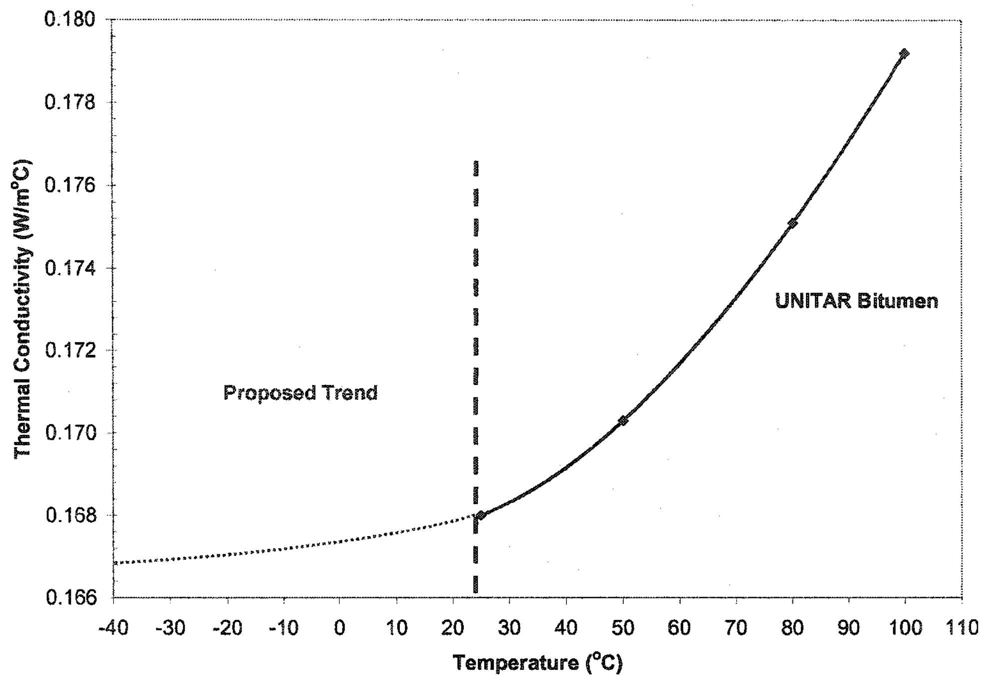


Figure 4-8 - Thermal Conductivity of Bitumen (modified from Hall, 2001)

In determining the value of thermal conductivity to be used for the sand fraction of oil sands, a comparative study was done against values of thermal conductivity of oil sands done by Scott and Seto (1986). In their work, thermal property measurements of oil sands were conducted on undisturbed samples over a range of bitumen contents using a transient state testing technique. Transient state methods were used due to inherit problems of steady state methods when considering fluid redistribution and their associated thermal conductivity values. Furthermore, transient state testing techniques only take approximately 10 minutes, thus minimizing any thermal disturbance to the sample and removing the need for a guarded heater and insulation system. Results from their study showed that oil sands with the properties in Table 4-2 at 20°C had a thermal conductivity value of 2.0 W/m°C. The sample density was 2,073 kg/m^3 at a porosity of 35%. These samples were saturated with bitumen and water under the assumption that any air was displaced by water. Using the same porosity, density and volume fraction of the constituents, in conjunction with the thermal conductivities of UNITAR bitumen and water, the thermal conductivity of sand within the Athabasca oil sands is approximately 5.7 W/m°C. This value is slightly higher than values obtained for saturated quartz sand by Scott and Seto (1986) of 4.0 W/m°C.

Table 4-2 - Physical Properties of Athabasca Oil Sands (after Scott and Seto, 1986)

Constituents	% Mass	Pore Saturation (%)
Sands	80.7	
Fines	2.5	
Bitumen	12.3	73
Water	4.5	27
Oil Sands	100.0	100

Unfortunately, when extending the temperature range from -40°C to 50°C, the trend of thermal conductivity does not match Scott and Seto's (1986) as well as others done on oil sands in the past (Hanafi and Karim, 1981; 1986). As temperature rises from 0°C to 50°C, the thermal conductivity of oil sands based on Johansen's method shows an increase due to the increasing thermal conductivities of both bitumen and water with the quartz sand's thermal conductivity being constant; however, published trends show the opposite trend to be occurring with oil sands' thermal conductivity decreasing as temperature increases. Upon further discussion with Scott (2003), a suggested possible reason for the trend is the dependence of thermal conductivity on density. As oil sands is heated, the constituents undergo thermal expansion causing a decrease in the density. Bitumen and water expand more than the quartz sand, thus the percentage of sand-to-sand contacts is presumed to decrease within the oil sands matrix. Since quartz is the dominant medium for heat flow, the retardation of heat flow by the interruption of sand-to-sand contact by the expanding fluids is hypothesized to generate the decreasing thermal conductivity as temperature increases.

When investigating thermal expansion of oil sands, the tested temperature range by Agar et al. (1986) does not apply to the operating temperatures in the mining process, typically between -40°C and 30°C. Nevertheless, a trend can be seen in Figure 4-6 with increasing volumetric expansion as temperature increases, which could potentially explain the deviation in Johansens' thermal conductivity values from tested values. Extrapolating this trend to -40°C was accomplished by taking the slope of the line back to -40°C while accounting for the volumetric expansion of water upon freezing. Figure 4-9 shows the experimental data at temperatures greater than 20°C along with the extrapolated curve.

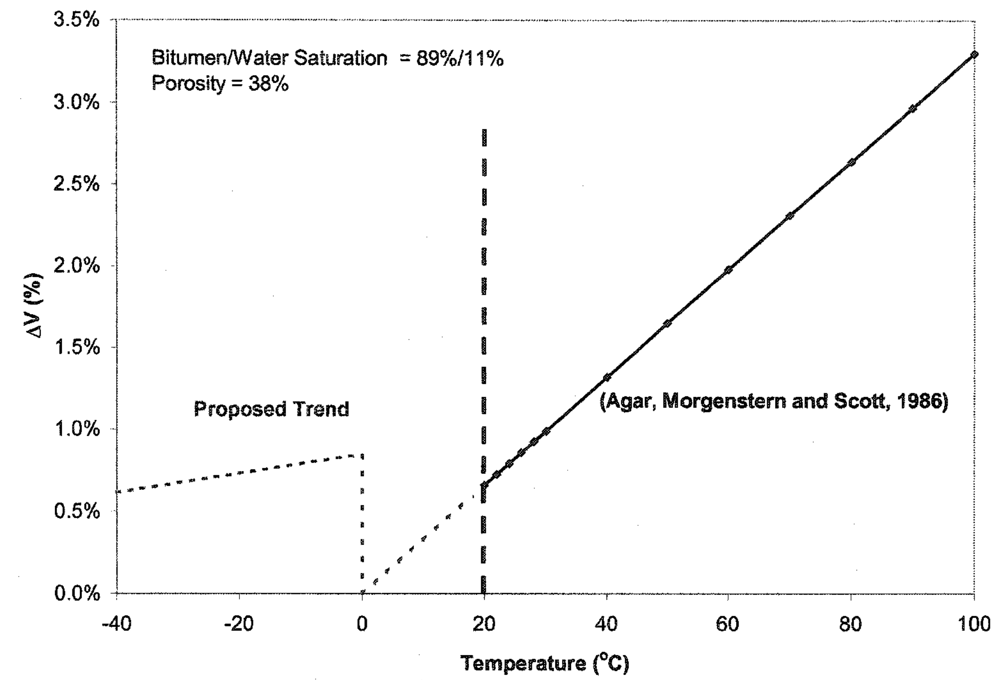


Figure 4-9 - Undrained Thermal Expansion of Oil Sands (modified from Agar et al., 1986)

Coupling the trend found for thermal expansion for undrained oil sands with that of Johansen's oil sands thermal conductivity, a reasonable trend has been established for the temperature range -40°C to 30°C. This trend, while consistent with results and trends for oil sands at and above room temperature, should not be heavily relied upon until accurately measured. Figure 4-10 shows the proposed thermal conductivity of oil sands given the properties stated in Table 4-2 with the error bars accounting for variations in bitumen content, water content, solids content and degree of saturation.

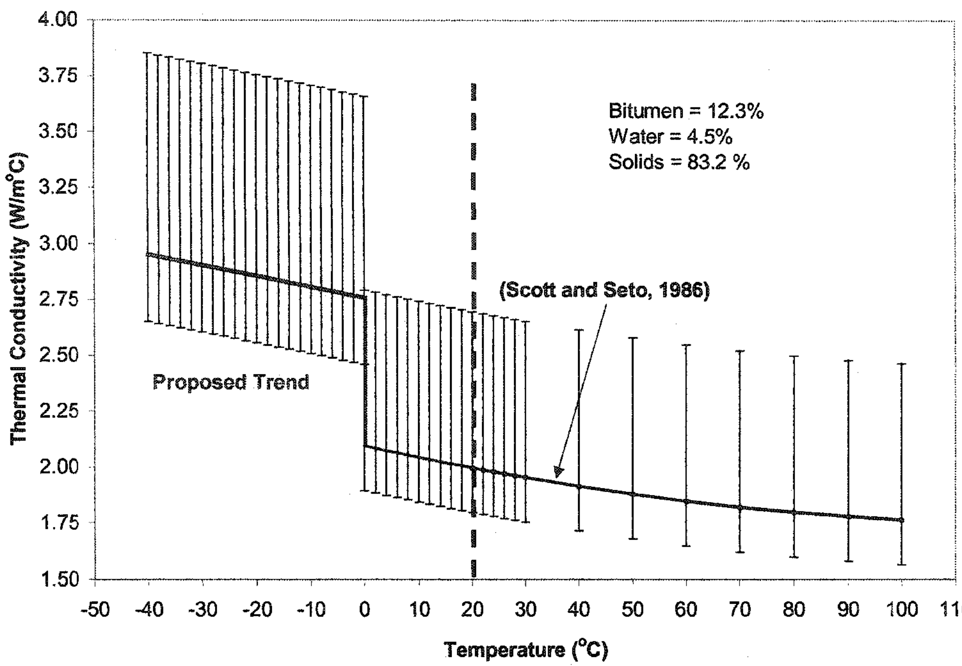


Figure 4-10 - Proposed Thermal Conductivity of Athabasca Oil Sands (modified from Scott and Seto, 1986)

The thermal conductivity for oil sands is highly dependent on the value of the thermal conductivity of quartz sand as its value is an order of magnitude larger than any other fluid. However, when ice is formed, its thermal conductivity is larger than water, thus the dependence on the thermal conductivity of quartz sand decreases.

Further factors that affect the thermal conductivity of oil sands are bitumen content, degree of saturation, and mineral grains/soil structure. The following trends are made based on testing of undisturbed oil sands samples done by Scott (1989).

- Bitumen Content: As the percent bitumen increases, the thermal conductivity decreases. Rich oil sands' thermal conductivity at 20°C is approximately 1.8 /m°C while lean oil sands' at the same temperature has a value of approximately 2.7 /m°C.

- Degree of Saturation: As the bitumen saturation increases, the thermal conductivity decreases. Thermal conductivity values appear to drop quite sharply for bitumen saturations from 0 to 20%, but decrease at a slower rate after 20%. As the overall degree of saturation increases, the thermal conductivity likewise increases.

- Mineral Grains and Soil Structure: Upon comparing two grades of oil sands under similar conditions, the lean oil sands' thermal conductivity is higher than the rich oil sands'. With more fines in the void space, greater contact areas between the mineral fraction are created in the lean oil sands, thus facilitating a more conductive heat flow.

Heat Capacity

Heat capacity is defined as the amount of heat required to raise the temperature of a given mass of material one degree. A material's specific heat capacity is the ratio of its heat capacity to that of water. It can be calculated by adding the heat capacities of the different constituents for a unit mass of soil. Oil sands' specific heat capacity ranges between 0.85 and 1.23 kJ/kg °C (Cervenan et al., 1981).

Latent Heat of Fusion

Latent heat of fusion is the amount of heat energy absorbed when a phase change occurs between solid and liquid phases without a change of temperature. For soils, the total energy involved in the phase change process will depend on the amount of water in a given soil volume as well as the fraction of this water that changes phase. The density of the soil also has an impact on the heat energy required for phase change to occur. In a soil, the latent heat of fusion can be calculated by:

$$L = \rho_d L' \left(\frac{\omega - \omega_u}{100} \right)$$

Where L is the volumetric latent heat of fusion for the soil [kJ/m^3], L' is the latent heat of fusion of water [333.7 kJ/kg], ρ_d is the soil's dry density [kg/m^3] and ω is the total water content and ω_u unfrozen water content [%]. Oil sands has little or no unfrozen water, thus its ω_u term can be neglected.

4.3 Frost Penetration Model

4.3.1 Theory

It is believed that frost and its effect on the properties of in situ oil sands are a determining factor in the generation of frozen lumps. Determining the depth of frost penetration can be modeled using Stefan's equation in a simplified, linear one-dimensional condition (Aldrich and Paynter, 1966). Inherent in the derivation of this equation are the assumptions that only the latent heat of water must be removed when freezing the soil and that volumetric specific heat of the soil is neglected. Stefan's equation for the prediction of frost penetration, Z_o, measured in metres is:

$$Z_o = \sqrt{\left(\frac{2k_f\left(N_f * AFI\right)}{L}\right)}$$

Where k_f is the frozen thermal conductivity of the soil [W/m°C], N_f is a ground cover factor, AFI is the Air Freezing Index [°C-Seconds] and L is the soil's latent heat [J/m ^{3}]. Difficulty in determining the frozen thermal conductivity of oil sands has been discussed in the previous section, thus a range from 2.0 W/m°C to 3.0 W/m°C will be assumed depending on temperature.

Ground surface temperature is typically measured at 1 cm below the ground surface and is typically warmer than the air temperature in the winter due to the influences of surface effects and boundary layers. Often very little information is available for ground temperature, but studies conducted in Alaska and Canada established an N_f-factor that relates the Air Freezing Index to the ground surface freezing index for various ground conditions. Table 4-3 shows typical values of the N_f-factor for a number of ground covers to best capture the ground temperature - air temperature relationship for freezing. Oil sands can be considered close to asphalt due to its colour and thermal properties, thus its N_f-factor probably ranges between 0.3 and 1.0.

Table 4-3 - Typical Values of N_f-Factor (after Andersland and Ladanyi, 1994)

Ground Surface Cover	N_f
Asphalt	0.3 – 1.0
Concrete	0.7 – 0.9
Gravel	0.6 – 1.0
Snow	1.0
Turf (Below Snow)	0.5

These N_f-factors can be further verified by analyzing work done by Sego (2004) in the winter of 1996/97 at Suncor Energy Inc.'s mine near Fort McMurray. Temperature measurements were made on the oil sands surface under varying surface conditions. Using the measured ambient air and ground temperatures under different depths of snow, ranging from 0.2 m to 1.8 m, N_f-factor values ranged from 0.2 to 0.7. Table 4-4 shows the range of N_f-factor values for each scenario and Figure 4-11 shows the relationship between snow cover and values of N_f-factor for the oil sands. The relationship is assumed to be linear based on the findings of this study.

The air freezing index (*AFI*) is a cumulative summation of days where the mean daily temperature is below 0°C multiplied by how long it was below 0°C. The *AFI* was initiated on the first day that recorded a mean daily temperature below 0°C. Any days following the initiation date that recorded a mean daily temperature above 0°C are neglected along with any thawing that may occur, thus Stefan's equation can overestimate the depth of frost. Based on data from the Mildred Lake weather station, the degree-days for the 2001/2002 and 2002/2003 winters were approximately 2,070 and 1,960. Figure 4-12 and Figure 4-13 show the plots of cumulative degree-days and temperature as a function of time for the two winters. When the *AFI* is used in Stefan's equation, it must be converted from degree-days to degree-seconds.

Table 4-4 - Snow Cover versus N_f Values for Oil Sands (modified from Sego, 2004)

Snow Cover		Ambient Temp.		N_f values	
Jan.28	Feb.16	Jan.28	Feb.16	Jan.28	Feb.16
(m)	(m)	(°C)	(°C)		
0.3	0.2	-27.5	-12.6	0.5	0.7
0.2	0.2	-27.5	-12.6	0.4	0.6
0.9	0.9	-27.5	-12.6	0.4	0.5
1.5	1.2	-27.5	-12.6	0.2	0.4
1.8	1.5	-27.5	-12.6	0.2	0.4

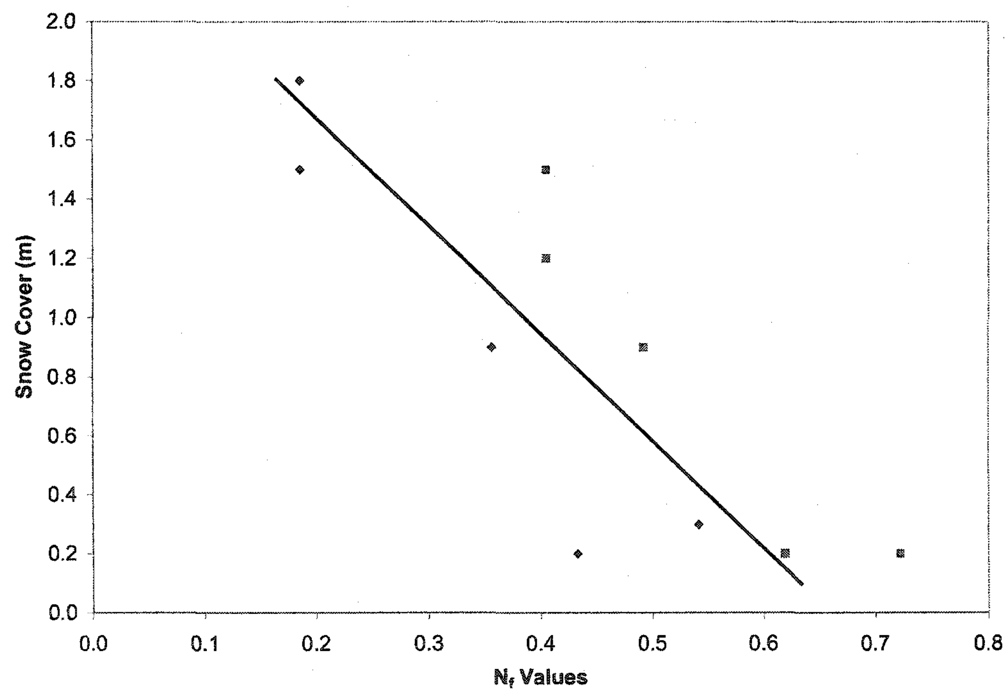


Figure 4-11 - Snow Cover versus N_f Values for Oil Sands

Latent heat of fusion (*L*) was discussed in the previous section and defined as the quantity of heat liberated when a unit volume of soil undergoes phase change without a temperature change. For oil sands, its in situ dry density is approximately 1,750 ±150 kg/m^3 (Lord and Cameron, 1985) with typical moisture content ranging from 4% to 15% by weight (Lord and Cameron, 1985), thus the latent heat of fusion for oil sands is between 21.3 MJ and 95.1 MJ.

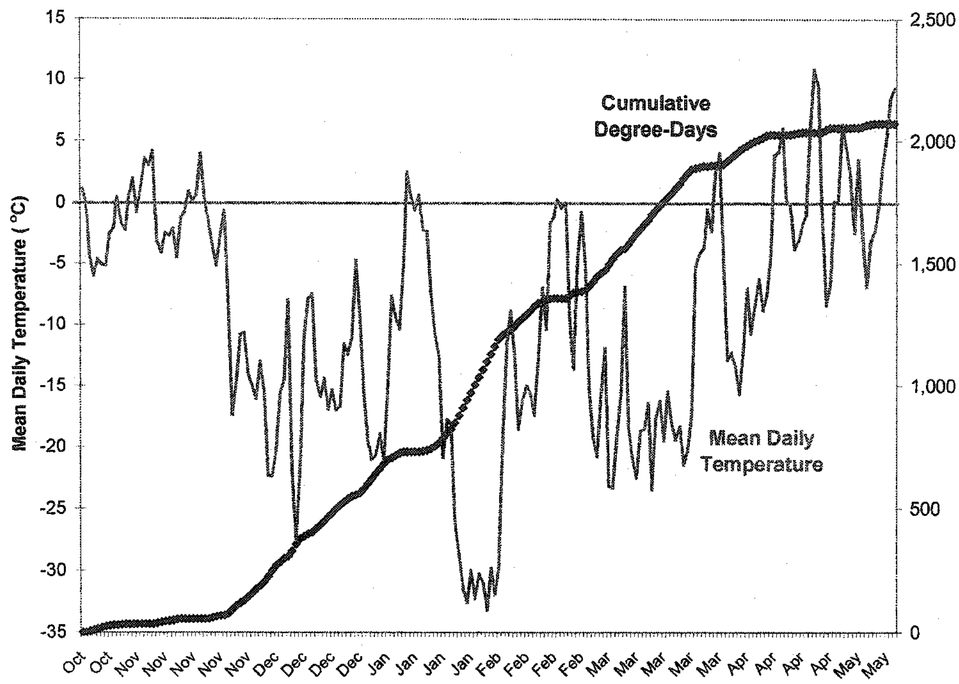


Figure 4-12 - Degree Days for Winter 2001/02

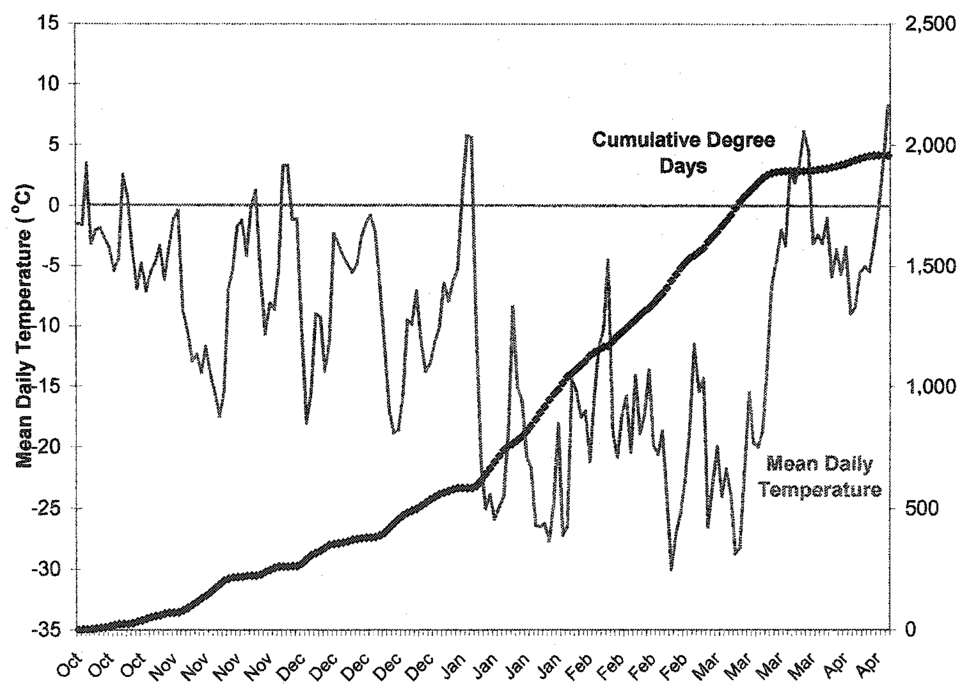


Figure 4-13 - Degree-Days for Winter 2002/03

Imperial Oil tested frost penetration of in situ oil sands in 1962 (Hodgetts) and some of their values can be used in preliminary calculations, yet the environment has changed since their testing was completed. Their experiment was based on an electric analyzer with a thermal conductivity value of 1.5 W/m°C; this value is almost 1/2 the value being used in this thesis, unfortunately no information was provided as to how this value was determined. Results showed that for 400 degree Fahrenheit-days, the frost front penetrated approximately 0.9 m. Mining activities, stress relief, bench exposure time, snow cover and even global warming are all factors that have changed the testing environment in the last 40 years.

4.3.2 Frost Model Applied to Syncrude's North Mine

The depth of frost penetration according to Stefan's equation is dependent on the input values for the typical ranges found in oil sands. Table 4-5 summarizes the range of values for the input parameters that were considered for the model as well as those values that are believed to best categorize the oil sands. The frost model is initiated in tandum with the *AFI* or degree-days calculation, thus it is initiated on the first day that records a mean daily temperature below 0°C. Due to the assumption in the *AFI* calculation that ignores days with a mean daily temperature above 0°C, the initial and final days of the model can be in error, yet it is still relatively accurate for the interim period.

Table 4-5 - Range of Input Parameters for Frost Model

Factors	Range	Typical
Density (kg/m^3)	2,050 – 2,150	2,073
Bitumen (%m)	0.0 – 18.0	12.3
Moisture Content (%m)	4.0 – 15.0	4.5
N_f	0.3 – 1.0	0.5
Thermal Conductivity (W/m°C)	2.7 – 3.2	2.9

Using the typical values matching medium grade oil sands, frost penetration depth was modeled for both the winters of 2001/2002 and 2002/2003. The respective final frost depths were 2.9 m and 2.8 m with Figure 4-14 and Figure 4-15 showing the trends of depth as a function of time.

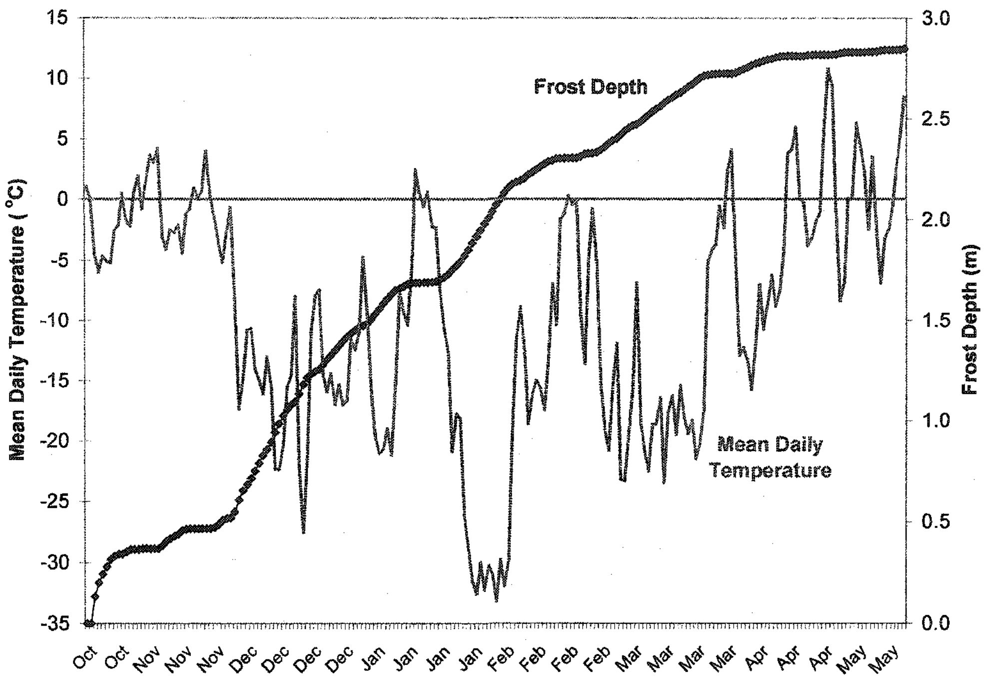


Figure 4-14 - Estimated Frost Depth for Winter 2001/02

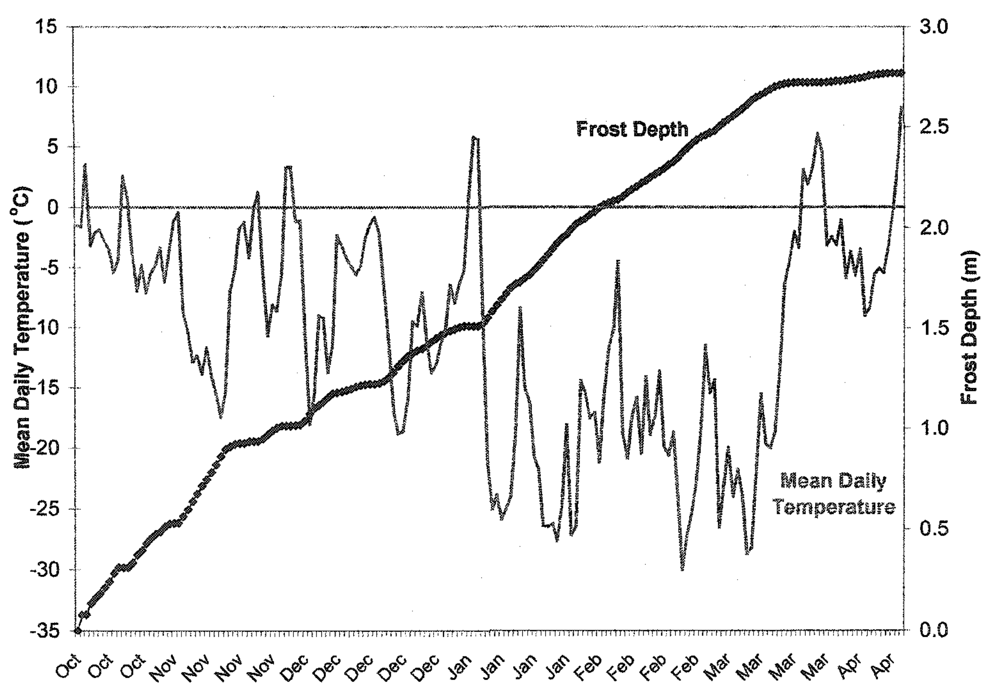


Figure 4-15 - Estimated Frost Depth for Winter 2002/03

This represents the worst-case scenario for lump generation as the frost front would have penetrated the deepest; however, due to the nature of the mining operation, the frost depth is rarely related to the cumulative degree-days for the entire winter. The benching scheme exposes and then excavates the oil sands in a relatively short period of time. While some areas may be left exposed and untouched for weeks or months, the majority of activity focuses on particular areas for prolonged periods thus reducing the actual degree-days the bench is exposed to cold weather.

Frost depth studies on varying bench exposure times were done to determine the amount of time that best matched the occurrences of lump activity. Seven day, 14-day, and 21-day exposures were investigated with Figure 4-16 showing the variability in frost depth as a function of bench exposure time for the winter of 2001/02. The trends show that as the exposure time increases, the frost depth increases, but with a longer lag before reaching maximum depth in comparison to shorter exposure times. Using these three exposure durations, a study was done to determine which exposure duration best matches the available data. Comparisons where done on the activity of the lump dump and the frequency of lump jams to these exposure durations. Correlation coefficients are calculated for each scenario and summarized in Table 4-6. The lump dump has a stronger correlation to the bench exposure times than the lump jams, yet for both, the 14-day exposure time shows that highest correlation. Correlation coefficients for the lump dump at 14-day exposure time for the winters of 2001/02 and 2002/03 are 0.65 and 0.62, respectively. Lump jam correlation coefficients for winters of 2001/02 and 2002/03 are lower at 0.35 and 0.48, respectively. Based on these findings, the 14-day exposure duration will be used as an overall average bench exposure time to determine frost depth on the benches.

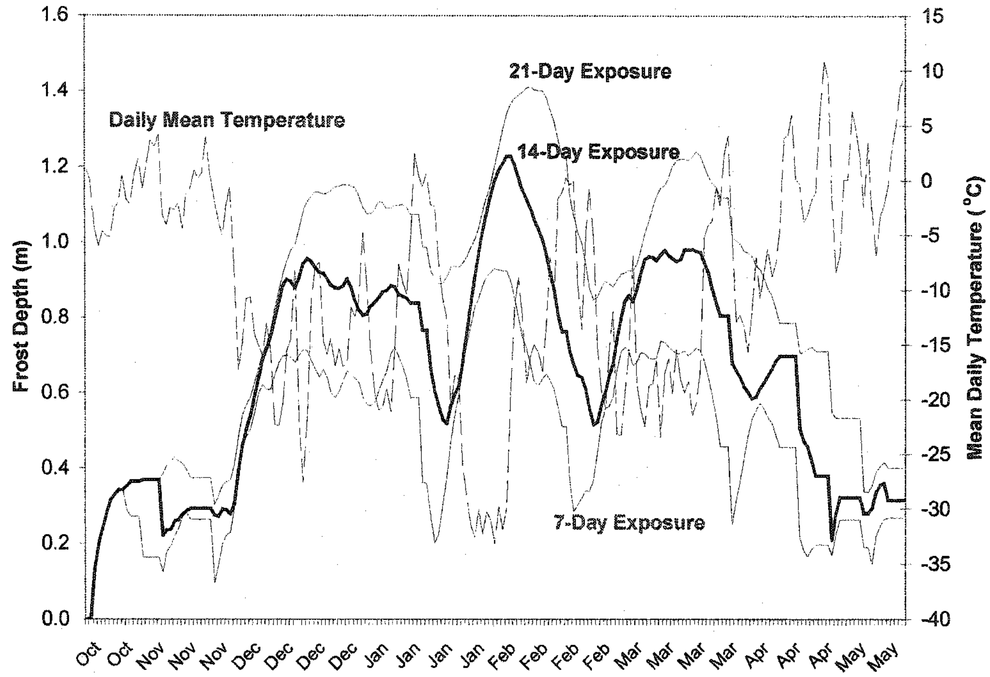


Figure 4-16 - Effect of Bench Exposure Time on Frost Depth

Table 4-6 - Correlation Coefficients for Bench Exposure Time

	7 Days	14 Days	21 Days
Lump Dump			
Winter 2001/02	0.59	0.65	0.57
Winter 2002/03	0.62	0.62	0.63
Lump Jams			
Winter 2001/02	0.31	0.35	0.36
Winter 2002/03	0.46	0.48	0.47

Using the assumed 14-day exposure time, Figure 4-17 and Figure 4-18 shows the frost depth and temperature profiles for the winters of 2001/02 and 2002/03. The maximum frost depth based on this exposure time is approximately 1.2 m compared to approximately 2.8 m for the cumulative winter model. This maximum 14-day frost depth occurred for both winter period at nearly the same time, the end of January, while the cumulative winter model is based on a date near the end of April for both winter periods.

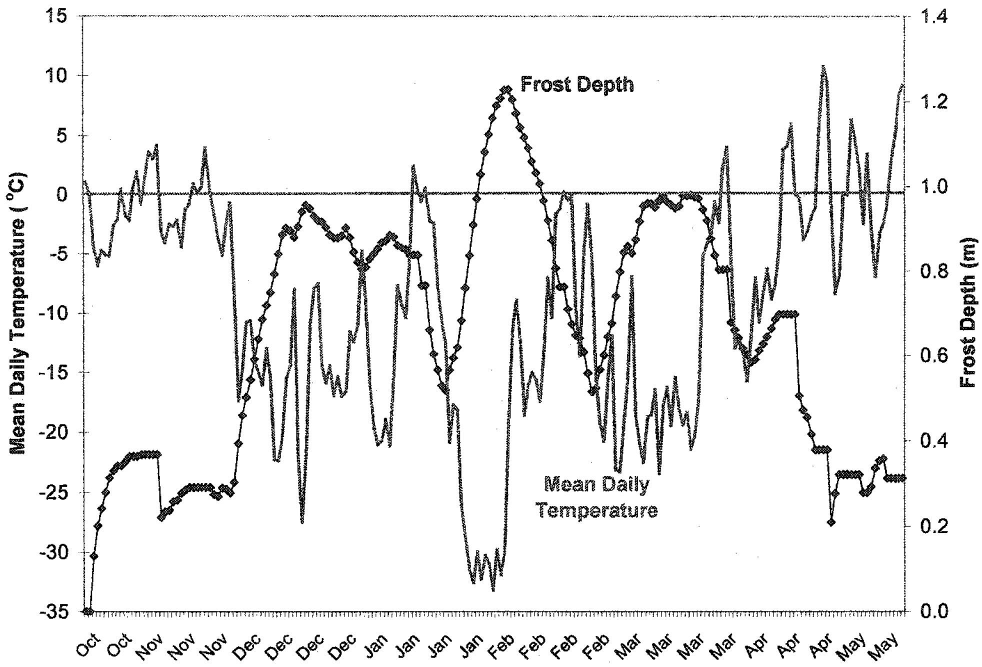


Figure 4-17 – 14-Day Exposure for Winter 2001/02

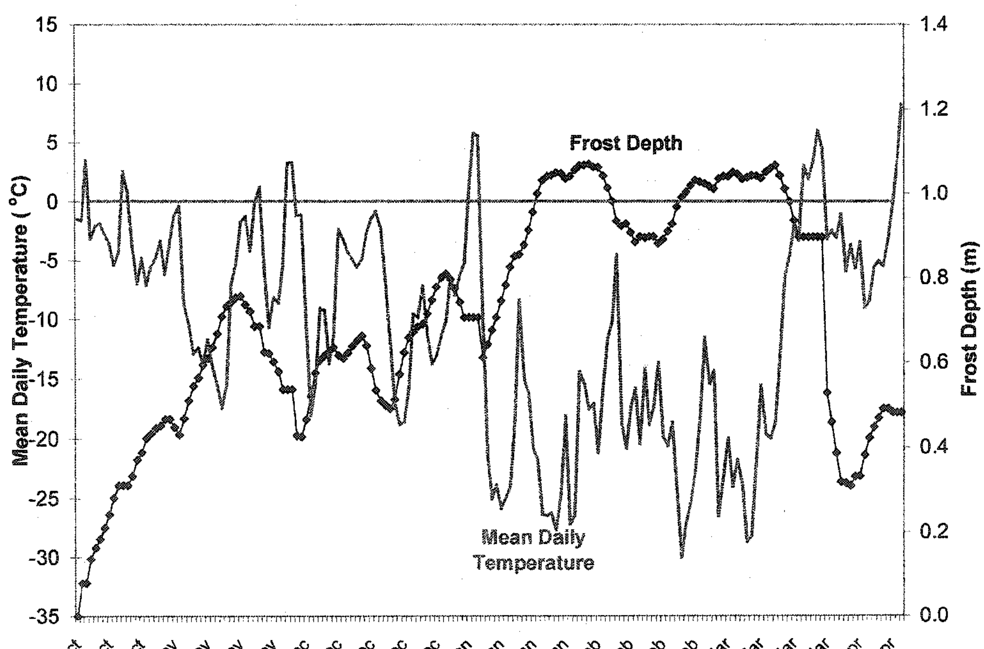


Figure 4-18 – 14-Day Exposure for Winter 2003/03

The actual frost depth is likely somewhere between the two extremes of the 14-day exposure and the cumulative winter exposure with their difference generally increasing as the winter prolongs. As the exposure duration of each bench is variable and changes depending on the mine plan, the 14-day exposure can only be used as a representative bench exposure time. Typically the lower elevation benches are exposed for a relatively short period of time while the top oil sands benches are exposed for the greatest amount of time (Wright, 2004). This disparity occurs due to the overburden benches above the oil sands and their use.

Certain restrictions, regulatory, engineered, and production-based, create a large area of exposed oil sands at the end of the summer going into the winter months, which usually expose the top oil sands bench. Overburden is not simply a waste material, but is a major component in earth structures. Depending on the type and quality of the material it can be used in dyke construction, road construction, or placed in dumps. The removed muskeg above the overburden is either stockpiled or directly placed onto reclamation areas elsewhere on the property. The majority of the overburden material is Clearwater clay with pockets of gravel and sands. Due to the specifications of geotechnical construction of earth structures, soil should not be placed under freezing conditions, thus any material used in these structures should be excavated and placed in the spring to fall period. Similarly, the muskeg can only be removed and placed during the same period. This requirement often leads to large exposed oil sands areas, typically on the top oil sands bench, heading into the winter.

The effect of snow on the bench can also alter the depth of frost. The N_f -factor in Stefan's equation is the relationship between the air and ground temperatures, and a manner in which to quantify the effectiveness of snow on frost depth. Taking the 14-day exposure time and varying the N_f -factor between 0.3 and 1.0 can model the effect of snow on frost depth. As shown in Figure 4-19, the range in frost depth as a function of the N_f -factor for the winter of 2001/02 can be as much as 0.5 m. Unfortunately, due to difficulties in accurately capturing the variability in snow depth across the mine, the N_f -factor has been assumed at 0.5. This N_f -factor value corresponds to a snow depth of about 0.6 m (see Figure 4-11) according to the study performed by Sego (2004).

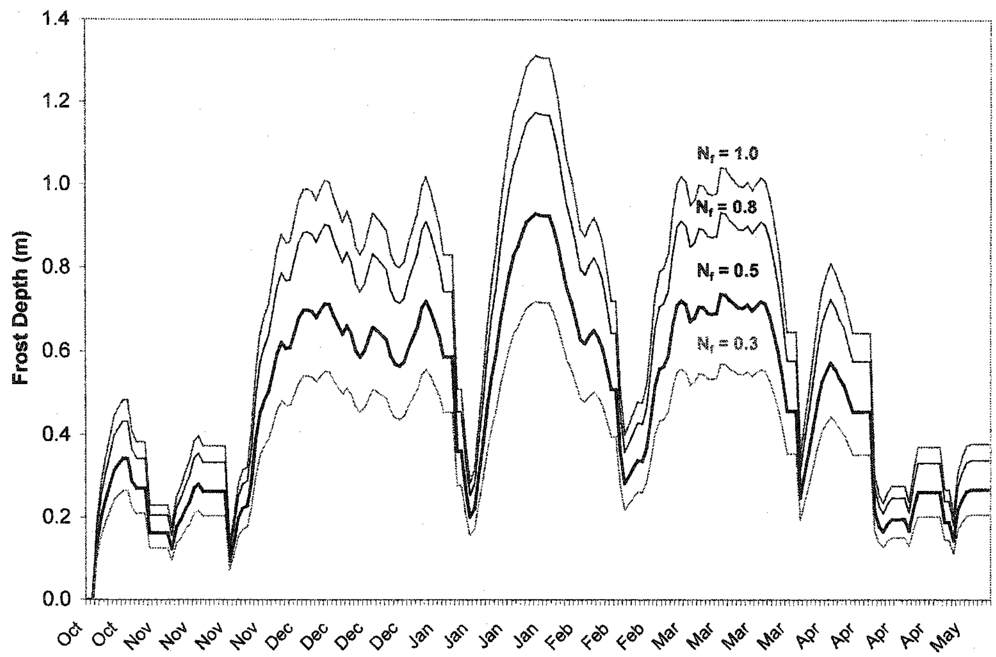


Figure 4-19 - Effect of N_f-factor on Frost Depth for 14-Day Exposure Time

4.3.3 Sensitivity Study

Taking the winter of 2001/2002 as a typical winter, sensitivity studies were done varying the parameters to quantify their effects on depth of frost penetration. The minimum and maximum frost depths were determined to be 1.6 m and 5.5 m by varying the parameters to the extremes as shown in Table 4-5; Figure 4-20 shows the range over the entire winter. One can see the trends are similar with only exaggerated vertical extent for the extreme cases. This large range of predicted frost penetration is a direct result of lack of knowledge and/or confidence in the input parameter values.

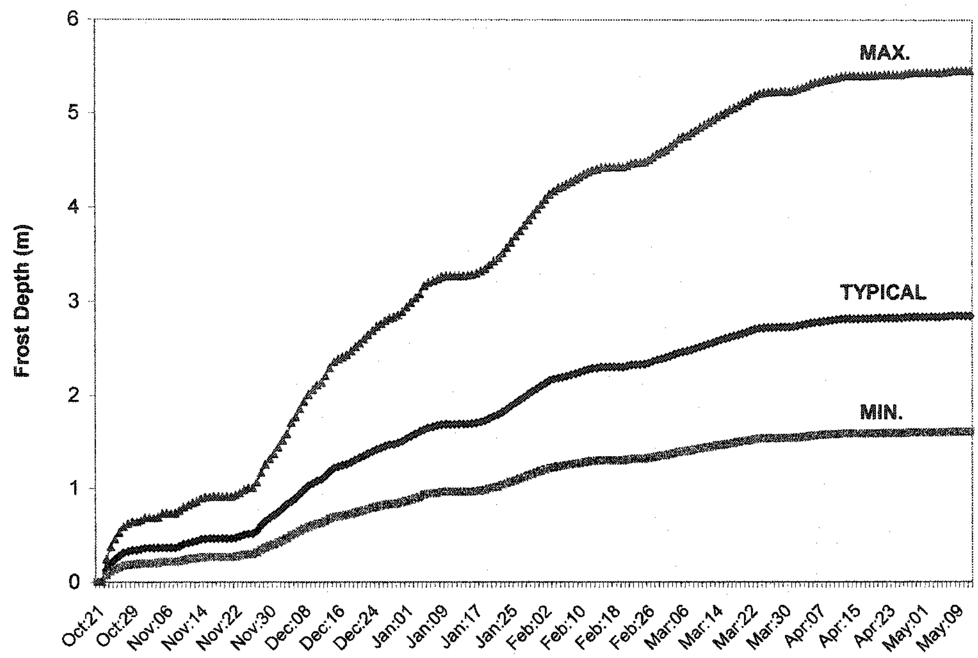


Figure 4-20 - Range of Estimated Frost Depth for the Entire of Winter 2001/02

Upon analyzing the sensitivity of each parameter separately, the N_f-factor and moisture content were discovered to be the most critical parameters. Table 4-7 shows the deviation from the typical frost depth for each parameter. Moisture content is a value that should be well known and could be inferred from the core samples, but upon discussions with Syncrude geologists Finnson (2004) and Wright (2004), they indicated that moisture contents derived from assayed core are not very reliable. The N_f-factor is based on the relationship between the air the ground temperature and any insulating layer between these two mediums. Since the N_f-factor is affected by the insulating layer as well as such factors as sunlight exposure, wind speed and direction, and temperature its true value can be subject to variability. The work done by Sego (2004) has been used as a good first-approximation in this regard. Furthermore, the frozen thermal conductivity had only a minimal effects, thus possible errors in the assumptions that were required to determine its values do not have a large effect on the final frost penetration prediction.

Table 4-7 - Deviation of Frost Depth from Typical Model

Factors	Deviation from Typical Frost Penetration Depth (m)
Density (kg/m^3)	0.2
Bitumen (%v)	----
Moisture Content (%v)	1.4
N_f	1.8
Thermal Conductivity (W/m°C)	0.2

4.3.4 Summary

To test the validity of this model, it is proposed that frost depth be measured for varying surface conditions and exposure times in the North Mine. Different areas of the mine that are exposed when frost first begins its ingress can be targeted and systematically checked for frost depth. The measurement could be quantitative using a frost depth gauge or simply by asking shovel operators what his or her "feeling" was of the depth of frost. If the frost depth for the entire winter is within error to the model's prediction, then subsequent estimates for smaller exposure periods can be assumed to be accurate as well. Using forecasts for the area in conjunction with mine planning, frost depth can be predicted in advance, thus providing a warning when frozen lumps would be encountered more frequently.

Some simplifications used in this analysis are that this model is derived from Stefan's equation, which accounts for one-dimensional heat flow only. Although heat flow is a three dimensional problem, it is assumed that the major cause of lumps is heat loss in the vertical direction from the top of the bench. Frost can penetrate into the face of a bench as well, but it is believed to be less of a problem as once mining begins on a face there is little or no time for frost to have an effect. In contrast, the bench itself can be exposed for a greater amount of time allowing vertical heat flow and frost to penetrate deeper, thus being a more persistent problem.

Discussions with operators validate this claim that the top portion of the bench is harder digging than the rest of the bench. The crust that is formed by the frost at the top of the bench breaks in a brittle manner when being excavated by the shovels, which the operators can see and feel when making a cut. Currently, dozers attempt to rip this crust ahead of the shovel advance and create smaller lumps, but the occurrences of lump jams and the frequency of the lump dump loads indicate the problem is not completely solved. Moreover, when a shovel begins digging in a face that has been left exposed for a long time, some, if not all, of the trucks loaded during the initial cut are sent to the lump dump. This fact should not be ignored, thus minimizing both bench and bench face exposure time in the winter months should be practiced.

4.3.5 Traffic Issues

A topic of some discussion is the effect that driving has on frost penetration depth. Many operators and engineers claim that traffic "drives" the frost down, yet according to theory this is not possible. The presence of haul trucks on the road, given that no snow cover is between the oil sands and the tires, should have no direct effect on frost penetration. Frost penetration is governed by heat flow. There is no correlation between applying load and heat flow equations. Compaction of unfrozen soil does increase the density of the soil and can decrease the moisture content. An increase in the strength and thermal conductivity of the soil are a result, but as shown previously, thermal conductivity is not a dominant parameter in Stefan's frost penetration calculation. A decrease in the moisture content, however, could decrease the soil's latent heat. As Stefan's equation only considers latent heat when calculating frost penetration, any decrease in latent heat would increase the frost depth. As frost depth is sensitive to moisture content, this could explain the claims by operators and engineers. Nevertheless, this change in density and moisture can only occur prior to the ground freezing. Once the ground has been allowed to freeze, the effect of traffic has little or no impact on the soil's physical properties or frost penetration.

The amount of snow cover can also have a large impact due to its role in affecting the N_f -factor value. The presence of snow acts as an insulator and minimizes the rate of frost ingress into the ground, thus the more snow present the better. However, snow on a bench is compacted due to traffic, which causes the frost front to penetrate to a greater depth in this area than in areas of uncompacted snow. Additionally, snow on roads usually melts from traffic or is cleared away, thus exposing the bench to the full amount of frost susceptibility with no snow cover at all. This loss of snow insulation could explain the greater depth of frost present beneath trafficked areas, and not the loads exerted on the bench.

There is a slight discrepancy between what theory suggests and what people believe to be fact when dealing with the effect that traffic has on frost penetration. There is only one right answer, but one should not ignore years of experience. The simplest solution would be to conduct a test to determine if cyclic loading has any bearing on frost depth. A field test could be arranged to have an area instrumented under natural snow conditions and under a haul road. If the test reveals that traffic does not affect frost depth, mine planning will benefit by not having to continually alter haul routes to minimize frost depth on the bench. However, if the test reveals that the trafficked area has greater frost depth than the natural area, then this must be explained and the theory expanded to account for this effect. Regardless, some verification needs to be conducted to settle this point.

4.4 Effect of Climate on Lump Dump Activity

Plotting the various bench exposure times versus the occurrence of lump dump activity for both winters show that a 14-day period provides the highest correlation. Figure 4-21 and Figure 4-22 compares the estimated 14-day bench exposure for frost depth versus lump dump occurrences. These figures show that for both the winters of 2001/02 and 2002/03, the 14-day bench exposure provides a good correlation between frost depth and lump dump activity with correlation coefficient of 0.62 and 0.65, respectively. The effect of temperature, and hence frost, is a crucial factor in the activity of the lump dump.

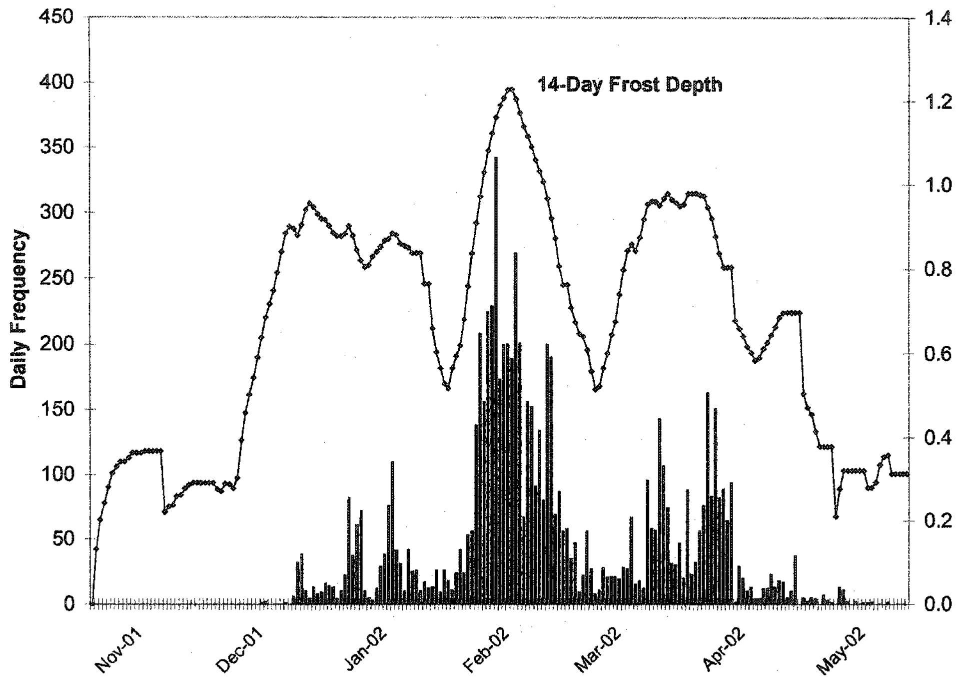


Figure 4-21 - 14-Day Frost Depth versus Lump Dump for Winter 2001/02

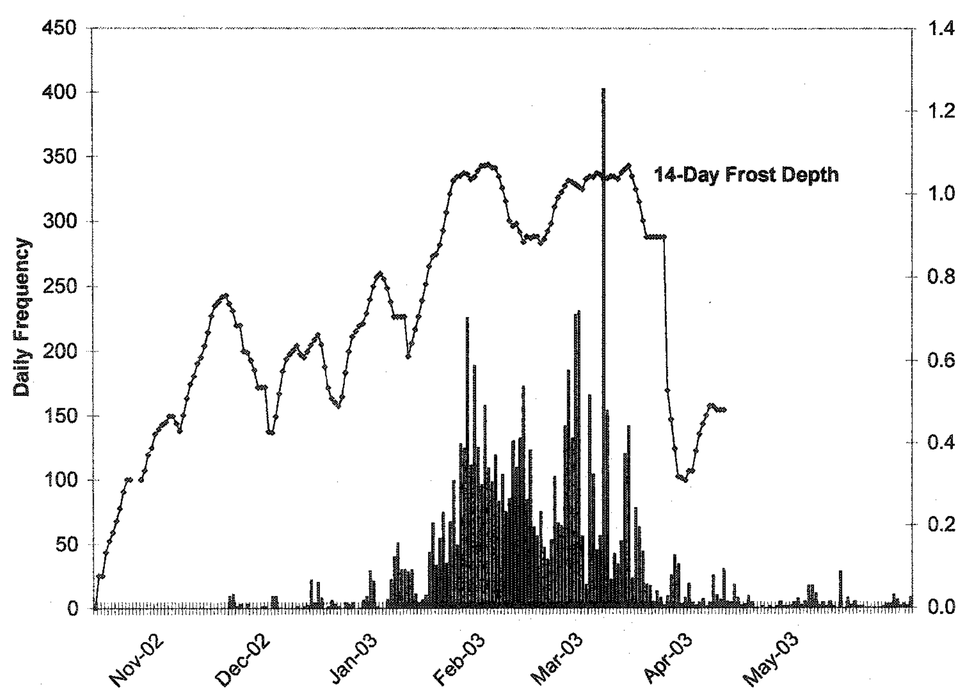


Figure 4-22 - 14-Day Frost Depth versus Lump Dump for Winter 2002/03

4.5 Effects of Climate on Lump Jam Events

Unlike lump dump activity, lump jam events show a lower correlation to temperature and frost depth on a daily basis. While the frequency is significantly higher in the winter months, jams do occur in the summer (Figure 2-12) with as many as nine jam events per month can be recorded in any particular summer month in the North Mine. It can be reasonably assumed that jams in the summer are caused by geology and/or equipment and not to freezing temperatures.

Plotting the frequency of lump jam events for the winters of 2001/02 and 2002/03 against a 14-day exposure period for frost penetration does not provide a good correlation. Correlation coefficients for these winters are only 0.35 and 0.48, respectively, with Figure 4-23 and Figure 4-24 showing the comparisons for the two winters. Unlike the lump dump whose activity is highly correlated to daily temperature and frost depth, lump jams do not show the same direct correlation.

While climate does have an effect on the generation of frozen lumps, its effects are not a major factor responsible for lump jams. Operators, equipment performance, changes in material properties with temperature and changes in geology or active benches between seasons are among some of the proposed factors that contribute more to lump jam occurrences. In the winter, the number of problem lumps increases thus the probability of a jam occurring increases proportionally. Essentially, most lump jams are lump dumps that were not identified. If there was no lump dump, the number of lump jams would be expected to be at higher levels.

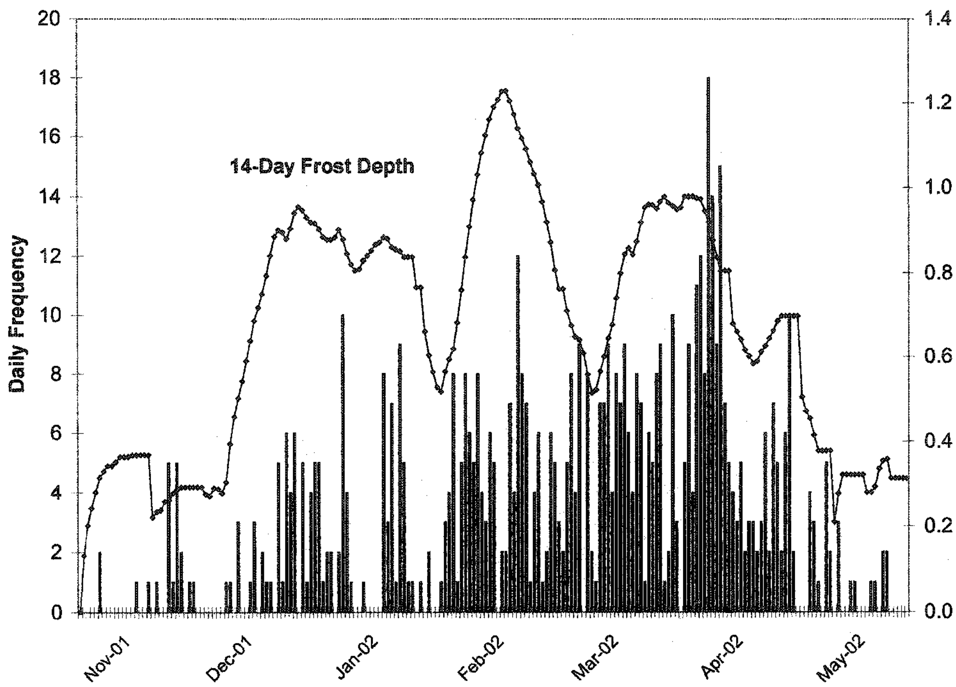


Figure 4-23 - 14-Day Frost Depth versus Lump Jams for Winter 2001/02

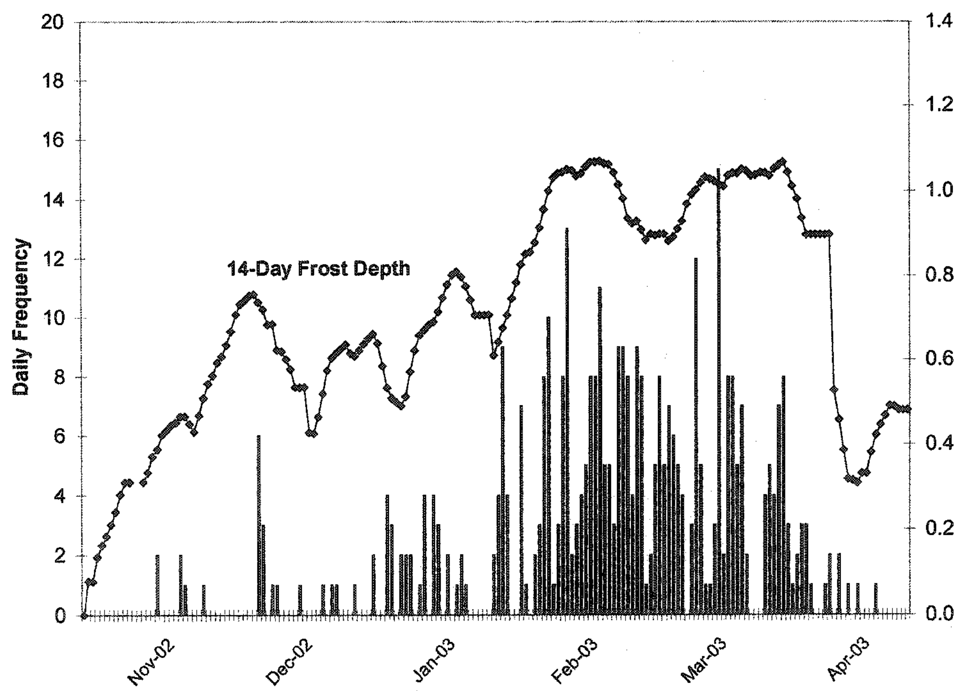


Figure 4-24 - 14-Day Frost Depth versus Lump Jams for Winter 2002/03

4.6 Methods of Reducing Frost Penetration

Climatic variation is a variable that cannot be controlled, but there are methods that can be exercised to control the climate's effects on the mining operation. Frost penetration is highly dependent on the ground temperature, but there are techniques that can be implemented to reduce the air temperature's effect on ground temperature. This proactive measure is accomplished by insulating the ground with snow, water/ice or a combination to maintain higher ground temperatures and reduce frost penetration. A more reactive approach is to blast or rip the frost-affected ground prior to mining to facilitate easier digging and smaller lumps. To date, the latter solution has been the favoured alternative due to its flexibility in mine planning.

4.6.1 Snowmaking

At Suncor's Fort McMurray operation during the winter of 1996/1997, a study was done to determine the effects that varying snow cover depth has on winter mining (Sego, 2004). Temperatures were measured at and beneath the surface of the covered oil sands in conjunction with shovel productivity of the varying test plots to determine the optimal snow cover depth. Based on the study, it was recommended that at least 0.6 m of snow be placed on top of ore benches by early winter to reduce frost penetration, thus facilitating easier mining of these benches in late winter. Table 4-8 shows the snow cover when placed and the temperature profile for each test plot when mining began. Table 4-9 provides information on long-term seasonal averages for monthly temperature and snowfall in comparison to the winter of 1995-1996.

Table 4-8 - Snow Cover versus Temperature Profiles in Oil Sands (Sego, 2004)

Snow Cover Dec. 11-15, 1996	Snow Cover Jan.28	Snow Cover Feb.16	Ore Surface Temp. Jan.28	Ore Surface Temp. Feb.16	5ft Depth Temp. Jan.28	5ft Depth Temp. Feb.16
	(m)	(m)	(°C)	(°C)	(°C)	(°C)
Natural	0.3	0.2	-14.9	-9.1	-5.1	-5.1
Cleared	0.2	0.2	-11.9	-7.8	-4.1	-4.1
0.6 m	0.9	0.9	-9.8	-6.2	-2.8	-2.8
1.2 m	1.5	1.2	-5.1	-5.1	-1.8	-1.8
1.8 m	1.8	1.5	-5.1	-5.1	-2.0	-2.0

Table 4-9 - Temperature and Snowfall Seasonal Averages (Sego, 2004)

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1951-1980 Snowfall (cm)	12.7	29.1	29.3	26.4	21.9	24.2	13.5
1995-1996 Snowfall (cm)	13.7	29.8	30.4	40.4	31.8	22.0	5.8
1951-1980 Mean Temp. (°C)	3.3	-8.2	-17.0	-21.8	-15.4	-9.2	2.1
1995-1996 Mean Temp. (°C)	3.2	-12.2	-16.1	-25.7	-13.7	-12.4	2.0

Observations and shovel productivity were made on test plots for snow depths of 0.6 m, 1.2 m, and 1.8 m as well as the cleared and natural snow covered test plots. The areas that reported easier excavation had ground temperatures warmer than –6.2°C at the surface and –2.8°C at 1.5 m depth whereas areas with more difficult excavation had temperatures colder than –9.1°C and –4.1°C, respectively. Based on the observations, at least 0.6 m of snow cover is needed to maintain the ore surface temperature warmer than -5°C for ease of late winter mining. As all plots had frozen oil sands, cutting force and strength must be highly dependent on temperature.

These findings concerning cutting force and temperature agree with tests conducted by Syncrude Research (Kershaw and Maciejewski, 1981) in determining the cutting forces present when excavating oil sands with a bucketwheel reclaimer. The O&K wedge test was modified to determine the dynamic cutting forces present when excavating oil sands at different bitumen and water contents from -40°C to 20°C. A test rig was constructed with a 65 mm wide cutting wedge that was dropped onto cylindrical samples at a load rate mimicking the bucketwheel cutting speed of 2.6 m/s. Samples sizes were 150 mm in diameter and 150 mm in height, and included a rich oil sands (10-12% bitumen) and lean oil sands (6-9%). These samples were remoulded under a pressure of 1 MPa to better represent the pressure generated by a windrow of 44.5 m high, as well as to represent the operating conditions of the bucketwheel.

Results shown in Figure 4-25 indicate that oil sands exhibit a dependence on temperature with a sharp increase in cutting force between -5°C and -15°C. This correlates well with the findings of Sego (2004), whereby operators and observations concluded excavation was more difficult if the oil sands temperature was less than -4°C. No explanation was given for the sharp increase in cutting force as temperature dropped below –5°C, nor was an explanation given as to the reason a peak value was measured at -18°C. The rich oil sands is also shown to be more difficult to cut than the lean oil sands with a peak cutting force of about 38 kN compared to 30 kN. While the trends concerning temperature effects on cutting forces are assumed to be correct, due to the loss of structure upon remoulding, these values are less than what would be expected upon excavation of in situ oil sands.

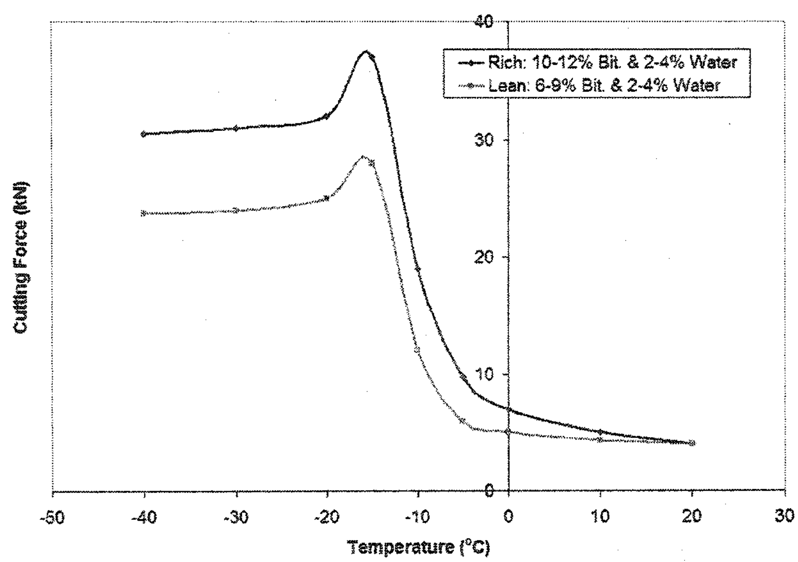


Figure 4-25 - Oil Sands Cutting Force versus Temperature (after Kershaw and Maciejewski, 1981)

An additional benefit to easier mining of the oil sands, and perhaps the reduction of lump generation, is processibilty of the ore. Oil sands at or warmer than -5°C will produce a lower frequency of large lumps that will reduce rehandle volume as well as reduce the frequency of lump jams at the crushers. If the frequency of lump generation is not significantly reduced, it may be necessary to increase the snow cover to achieve more efficient mining and processibility. Increased efficiency in hydrotransportation of this warmer oil sands may also be another benefit as less energy will be needed to heat up the oil sands and melt any ice as less of the bench will be frozen.

The goal of snowmaking is in preventing the early winter downward freezing before an insulating cover of snow can be placed or falls naturally, but there are operational challenges that exist. One of them being that the equipment used in the process of snowmaking operates less efficiently at or near 0°C air temperature, which is approximately when snowmaking would be needed to commence. As the waterlines may not continually be in operation, they need to be protected from freezing by either insulation or allowing free drainage. Protection from equipment damage is another aspect that would need to be addressed.

4.6.2 Ice Ponds

A method similar to snowmaking, and one that can be implemented in tandum, is to construct shallow dykes that would be filled with process water creating shallow ponds above the exposed ore. Dyke construction would have to be done in fall while the oil sands is not frozen and then fill the pond with a one-time water transfer before winter arrives, thus negating the need for winterization of the pipeline. With the onset of freezing temperatures, the pond water insulates the underlying ore and begins to freeze top-down. As the air temperature becomes cold enough for snowmaking, the water beneath the ice can be used to make snow and placed on top of the ice to provide further insulation.

Additionally, the dykes can be used to capture natural and artificial drifting snow on top of the ice and prevent it from leaving the protected area. This approach has the potential of being more robust and efficient than snowmaking alone while still reducing the winter operational challenges of lump generation, maintenance and wear.

Depth of water required for each pond will vary depending on when in the winter the bench is planned to be excavated. Using the average temperature conditions from Table 4-9, it would take 1 m of water to prevent freezing of the underlying ore through the winter period without any snow cover. Ore that would be mined in December would only require a water/ice depth of 0.5 m to prevent freezing of the ore. Figure 4-26 shows the development of ice thickness during a typical winter period in Fort McMurray without a snow cover with the arrows indicating month-end ice thickness. Although more current temperature profiles can be used in the ice thickness approximation, the overall magnitude will not vary greatly. Furthermore, water depths in the pond would be reduced by up to half with the addition of a 1 m thick snow cover.

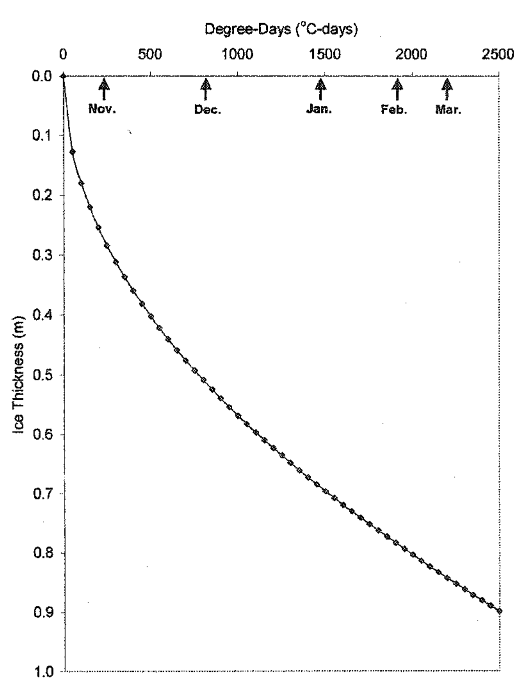


Figure 4-26 - Development of Ice Thickness During Winter (Sego, 2004)

Mining of areas where these dykes exist can be done in a progressive nature with shallower ponds being mined early and deeper ponds being mined later. Mine operation can clear the bench prior to mining by removing the build-up of snow and ice using dozers. The accumulated snow and ice need not be loaded and hauled to the crusher. This method does provide an easier and more robust system of frost penetration than snowmaking, but does require more effort in short and medium range mine planning and mine operations.

4.6.3 Trapping Natural Snow

Natural snow can be used as an insulator by trapping the drifting snow using ridges of oil sands on top of the ore benches oriented normal to the prevailing wind direction. The ridges can be pushed up prior to the onset of winter much like the dykes in the ice ponds method. Minimizing deep penetration of the frost depends on early snowfall. According to the records in Table 4-9, the onset of freezing temperatures are accompanied by snowfall, that if trapped into an insulating cover, should minimize frost penetration into the oil sands. Snowfall records indicate that long-term accumulation of 0.9 m to 1.2 m is possible by late winter.

4.6.4 Blasting

Ice-saturated and frozen soil behaves similarly to rock, thus similar excavations practices can be followed. At most quarries or rock mines, drilling and blasting are the first processes in sizing and excavating the rock. Baker and Johnston (1981) stated that "drilling and blasting is the most economical method for dealing with the large quantities of frozen material involved in a mining operation".

The effectiveness of any drilling and blasting operation is a function of the precision of the drilling and placement of the explosives. Powder factor for frozen material can be high, ranging from 0.6 to 1.2 kg/m due to the fact that the ice absorbs a large portion of the energy created from the blast. Spacing of the drill pattern is usually extended to be as large as possible, typically up to 3 m due to the high cost of drilling, thus large lumps are often a result.

Improper frost blasting in open pits can introduce a variety of problems due to excessive back breaking. As seen in Figure 4-27, the pit floor rises with each successive blast increasing the backbreak and removal of unbroken toe material, which may require secondary blasting and incur even higher costs. The first scenario provides an ideal case where the burden, 'a', and toe distance, 'b', are critical distances from the charge, 'c', and the mining face. The second scenario portrays a moderately successful blast with the third scenario leaving too much material unblasted in sector 'y'. A shovel cannot easily excavate material in sector 'y' due to the lack of approach from the poor toe condition at 'x'. The last scenario shows a situation where serious production time would be lost due to the need for secondary drilling and blasting or cleanup work of the extended toe. Secondary blasting may also be needed to fragment large blocks of material created by large burden and spacing, or otherwise lead to lump jams. Alternatively, the large blocks may be left to thaw naturally. This last solution is one that has been adopted by Syncrude with the generation of the North Mine lump dump.

Winter conditions create a harsh and difficult environment for the mining of the Athabasca oil sands. Blasting oil sands prior to digging to improve productivity has been practiced for decades, yet to a lesser extend in the last number of years with the switch to truck and shovel mining methods.

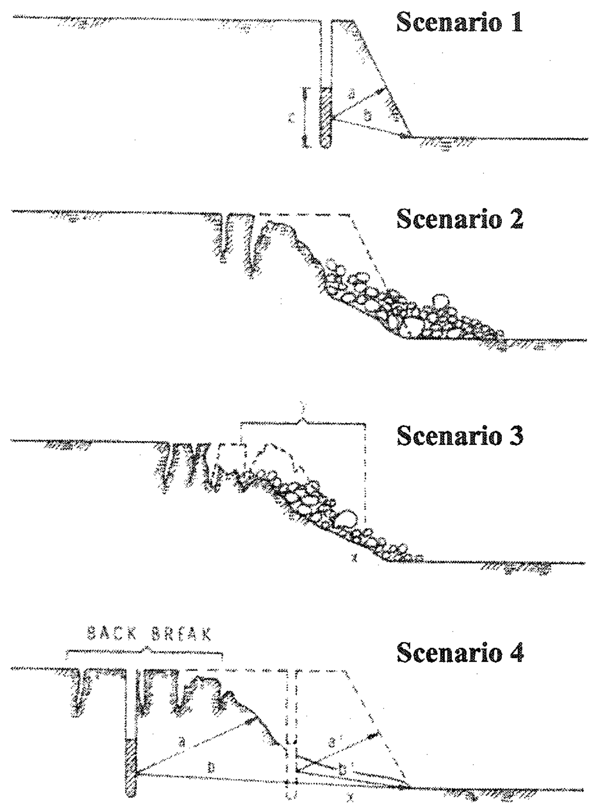


Figure 4-27 - Possible Outcomes due to Blasting (modified from Andersland and Ladanyi, 1994)

In 1989, Syncrude embarked on a frost blasting program to improve mine production and reduce maintenance costs on shovels by blasting frost ahead of active faces (Graf et al., 1993). Drilling was done with a 114 mm diameter hole on 4 m x 4 m pattern with hole depths from 1.5 m to 2.1 m. ANFO was the explosive of choice with a powder factor ranging between 0.33 – 0.50 kg/m depending on the material being blasted. For example, frost holes in oil sands required improved breakage for the feeder breakers, thus a powder factor of 0.5 kg/m was used in comparison to 0.33 kg/m for overburden. A typical frost blast involved over 1000 holes with 30-50 rows of holes and 20-30 holes per row; optimum results are achieved when 100 ms delays are placed between blast holes. Initially, 10,000 holes were blasted in the winter of 1988/1989, but this number had increased to 60,000 holes by the winter of 1991/1992. Syncrude's experience agreed with Suncor's that oil sands will not freeze as hard and inhibit digging if it is heaved. Early results from Syncrude's frost program showed promise as summer digging rates were achieved during the winter months. This improved cycle time during mining, reduced maintenance costs and less downtime more than justified the cost of blasting in their opinion.

In February 2001, another study was conducted at Syncrude's North Mine comparing blasting and ripping of the oil sands on the 288 ore bench (McAdam and Holte, 2001). Results indicated the cycle time of the P&H 4100 T/S decreased by 3 seconds when the shovel moved from ripped material to blasted material; this decrease is equivalent to a 34% increase in shovel productivity. Consequently, this ease of excavating blasted material translates to less maintenance and wear on the equipment leading to longer equipment life. Blasted material had a 12% less frequency of lump dump loads than ripped material, yet neither method seemed to have any effect on reducing lump jams from occurring. A sensitivity study was conducted to ascertain relative operating costs of ripping versus blasting. One scenario requires 40% of a dozer's operating hours for ripping, which equates to blasting costs of $0.10/BCM more than ripping. Another scenario required 150% of a dozer's time for ripping above the shovel, which showed that ripping was $0.15/BCM more than blasting. The breakeven scenario was that the cost of 83% of a dozer's operating hours is equally comparable to blasting. Blasting, however, does require more planning, greater lead-time and exposed inventory than ripping. Currently, ripping is being practiced at the North Mine due to its flexibility.

4.6.5 Ripping

Breaking up frozen soil by ripping is discussed in *Earthwork in Cold Regions* by Andersland and Ladanyi (1994). Using the principle of shear or drag-bit cutting with single or multiple-toothed rippers, large areas of frozen soil can be fractured in an economical manner. Ripper shanks come in two types: adjustable parallelogram rippers and radial; however, adjustable parallelogram rippers are the more common. A cross-ripping grid pattern on 1.5 m centers was found to provide the best results as reported by Andersland and Ladanyi. The paths of the ripping should not be parallel to the face otherwise large slabs of frozen material can be generated when excavated. Ultimately, tooth penetration is the key to successful ripping.

The strength of frozen soil is highly dependent on the loading rate of the equipment. For practical speeds of tractor-mounted rippers (approximately 4 kph), the loading rate is sufficient to produce brittle failure in most frozen soils. At these speeds, the frozen soil strength is almost independent of the speed of ripping (Andersland and Ladanyi, 1994). Properties of frozen soil that determine its susceptibility to ripping are soil type, density, gradation, degree of saturation and temperature. Generally fine-grained soils are easier to rip than coarse-grained soils. In any homogeneous type of soil, the denser the soil the more difficult to rip; however, in a stratified soil, frozen soil tends to break along thin seams of sand or gravel. As water is drawn from these coarse-grained layers to the fine-grained layers, a reduced degree of saturation and lower strength is expected in the sand or gravel, which would provide natural breaking planes for the rippers. As the temperature drops, all soils get stronger and their susceptibility to ripping decreases. However, frozen soils at low water content's, usually sands or gravels, can be easily ripped even at very low temperatures.

Oil sands can be classified as a fine-grained sand with a locked structure hence it has a reasonably high density in comparison to similar sand sized particles. Geology of the oil sands is variable with many lenses of hard sediments laid down in a horizontally deposited fashion. This stratification does cause failures along these weak zones as evident in the large tabular lumps present when mining in the winter at the North Mine. Figure 4-28 shows one of these types of large frozen lumps. While the overall water content of the oil sands is about 4% by weight, certain facies can have water contents up to 15% and create large lumps when frozen.

Figure 4-28 - Tabular Lump in the Lump Dump

Determining the rippability of a soil is accomplished by measuring its seismic velocity (Tart, 1983). Charts have been developed based on field tests in accordance with measured seismic velocities for a variety of materials and found in the Caterpillar Performance Handbook (Caterpillar, 2002). For a D11 dozer in a sedimentary deposit, ripping is possible if the seismic velocity is below 2,900 m/s and marginal if between 2,900 m/s and 3,500 m/s. Measurements of p-wave velocity by Pullin et al. (1987) using seismic surveys at Gregoire Lake indicate that the McMurray formation has a seismic velocity of about 2,400 m/s at in situ conditions. P-wave measurements of core from the oil sands show that at a ground temperature of 25°C, the seismic velocity is approximately 2,800 m/s (Lines et al., 1990). These values generate an average value of 2,600 m/s. Using this information in conjunction with recommended ripping practices from Caterpillar, it appears ripping is effective. However, as ripping is mainly done in the winter when the ground is harder and thus generate even higher p-wave velocities, the rippability of the oil sands could become classified as marginal at best. Figure 4-29 shows the rippability chart for a D11 with the measured range of seismic velocity for unfrozen oil sands.

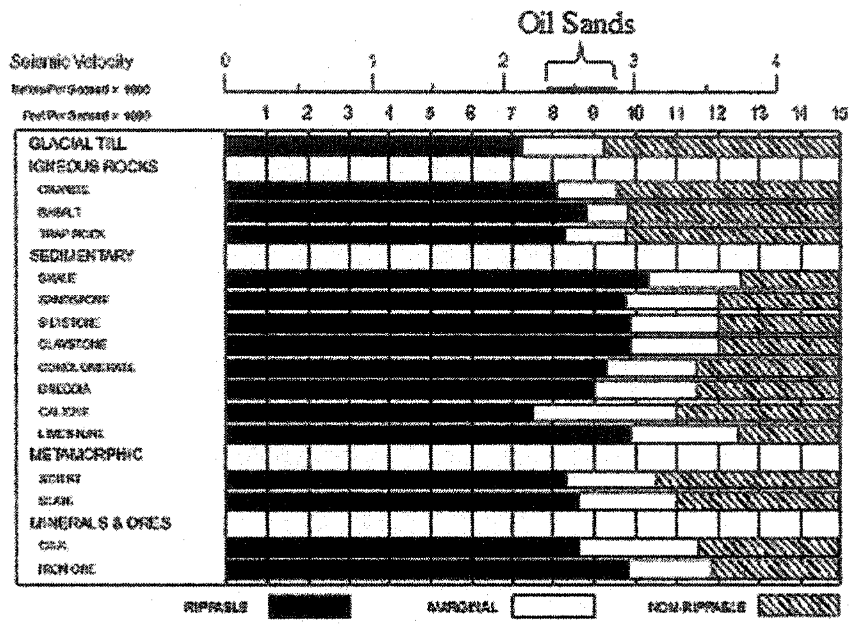


Figure 4-29 - D11R Rippability Chart (modified from Caterpillar, 2002)

The D10 dozers can have single or multiple shank rippers with maximum penetration depths of 1.4 m and 0.9 m, respectively, while D11 dozers have a single shank ripper with a maximum penetration depth of 1.6 m (Caterpillar, 2002). Penetration forces for a D11 are about 280 kN compared to about 205 kN for a D10. Likewise, pryout forces for a D11 and D10 are 658 kN and 429 kN, respectively (Caterpillar, 2002). These forces are defined as the maximum sustained upward (pryout) or downward (penetration) force generated by the hydraulic cylinders measured at the tip of the ripper. Both the penetration and pryout forces vary with dozer type and are important when assessing their efficiency in ripping activities.

Syncrude operates approximately 15 dozers in the North mine as support equipment for a variety of tasks. Generally, Syncrude uses D11 and D10 dozers for support work around shovel pits. One of their main tasks in the winter months is ripping the bench face in front of the shovels. This activity is believed to help in reducing lump jams and decrease the number of loads that are reassigned for dumping into the lump dump. No engineering is relied upon during ripping, but according to Noble (2004) of Mine Planning there is a design that is used.

Ripping is done in a diamond pattern with the dozer ripping at ±45° to the bench face with a spacing of about half the dozer width, approximately 2.5-3 m. The dozer rips in one direction for a length of bench face and then cross rips the same area; generally ripping is done 6-12 hours in advance of the shovel. Poor traction on frozen ground can further reduces the penetration of the ripper, thus either subsequent passes are made or lugs are placed on the tracks of the dozer to attain the shank's full penetration depth. While these practices are the recommended state, field observations during site visits have shown that actual ripping is operator dependent, thus a range of ripping quality and fragmentation can be expected.

Comparing Syncrude's ripping conditions and practices to theory outlined by Andersland and Landanyi (1994) suggests that ripping may be the most efficient manner to break the frozen ground. Rippability of the oil sands is possible according to the Caterpillar Performance Handbook, yet the lack of engineered control on ripping practices may negate its maximum possible effectiveness. Syncrude's spacing is double what Ladanyi recommends coupled with operator inconsistency in following the ripping pattern may be areas of improvement that could prove beneficial.

4.7 Summary

The climate in Fort McMurray is sub-arctic with temperature ranges from 36°C to -51°C and a mean yearly temperature of –0.2°C. These harsh conditions cause problems, such as increased maintenance costs and decreased productivity, for the mines in the area. Syncrude experiences increased rehandle with the generation of the lump dump as well as crusher downtime caused by lump jams. The generation of frozen lumps by the penetration of frost into the exposed oil sands is a major problem that should be better understood.

Using Stefan's equation for modeling frost penetration, maximum frost depths over the course of a winter are estimated to be approximately 2.9 m.

However, due to the practiced benching sequence, a 14-day exposure time generates the best correlation between frost depth and lump dump activity providing a frost depth ranging from 0 to 2.1 m. Actual bench exposure times can be quite variable, ranging from a week to the whole winter, but minimizing the exposure time will reduce the depth of frost and hence lump dump and lump jam occurrences. Examination of lump jams show that factors other than climate are major contributors.

Although the climate cannot be controlled, there are methods of minimizing its effect on the ground. Artificial snow making, ponding of water, and trapping of natural snow are all potential proactive measures to reduce frost ingress by creating an insulating layer over the oil sands. Blasting and/or ripping can be used as reactive measures to reduce the rehandle volumes and the potential for frozen lump jams from occurring by decreasing the probability of creating large lumps.

5 EQUIPMENT

5.1 Introduction

Syncrude operates one of the largest mining operations in the world. In the North Mine, Syncrude operates as many as 9 shovels and 40 haul trucks at one time, not including all the support and contractor equipment. The emphasis of their mining operation is bigger is better with increasing shovel bucket size and increasing haul truck payload. As production targets are set to increase in the future, the number of shovels is expected to increase to match these heightened levels, thus the reliability, productivity and effectiveness of these shovels must be well understood. As each piece of equipment costs millions of dollars, one cannot ignore the importance in understanding to the best available measure how these pieces of equipment operate. Shovel type is hypothesized to be a major cause of the frozen lumps, thus a comparison is made between the cable-electric and hydraulic shovels.

5.2 Shovel Types

There are two main types of shovels being used at the Syncrude North Mine: hydraulic and cable-electric. These shovel types vary in a number of ways that make their operation unique. Digging trajectory, mobility, reliability, breakout force, and bucket capacity are a few of the ways that these shovels differ. While this diversity can be advantageous at time, they nevertheless create challenges in mine planning, maintenance and productivity.

During the study period from July 2001 to June 2003, Syncrude operated a total of 14 shovels in oil sands mining. Five were cable-electric shovels and nine were hydraulics shovels, yet of these hydraulic shovels, four were contractor shovels. While Syncrude does own the majority of the shovels and prefers to use their equipment and personnel, contractor shovels are used to meet production quotas. These rental shovels are from local contractors with their own operators that are paid on an hourly basis, but their rates can vary with volume (Klemke, 2004). The normal operating procedure is to have contractor shovels in overburden benches and Syncrude shovels in oil sands benches, yet occasionally contractor shovels are used to mine oil sands to meet plant demand. Table 5-1 summarizes the shovel types, model numbers, IDs and how many were used in the North Mine during the two-year period.

Table 5-1 - Summary of Shovels in North Mine from July 2001 to June 2003

Equipment	Model	Number	ID
Hydraulic			
	O&K RH200	1	0034
	O&K RH400	3	0035 – 0037
	O&K RH120E	1	0039
Electric			
	B.E. 395B	2	0076 – 0077
	P&H 4100 TS	3	0078 – 0080
Rental			
	Demag/Komatsu H685	1	R685
	N/A	1	R110
	N/A	2	R092, R093
TOTAL		14	

5.2.1 Cable-Electric Shovels

Cable-electric shoves evolved out of the larger stripping shovels, but were adapted for more mobility by employing a singe pair of tracks. The digging element is a bucket, or dipper, with a cutting edge equipped with replaceable teeth. The bucket is attached to a handle, or stick, with a latched door that allows the material in the bucket to be dumped. When excavating material, the bucket is pulled through the oil sands by hoist cables, which pass over a boom, and held against the face by the crowd motion that extends or retracts the handle lengthwise. The handle pivots on the shipper shaft allowing the bucket to be pulled through the face in a flat arc while being loaded. When the bucket is full, it is retracted from the face and swung to the dumping location. Figure 5-1 shows the powered functions for a cable-electric shovel.

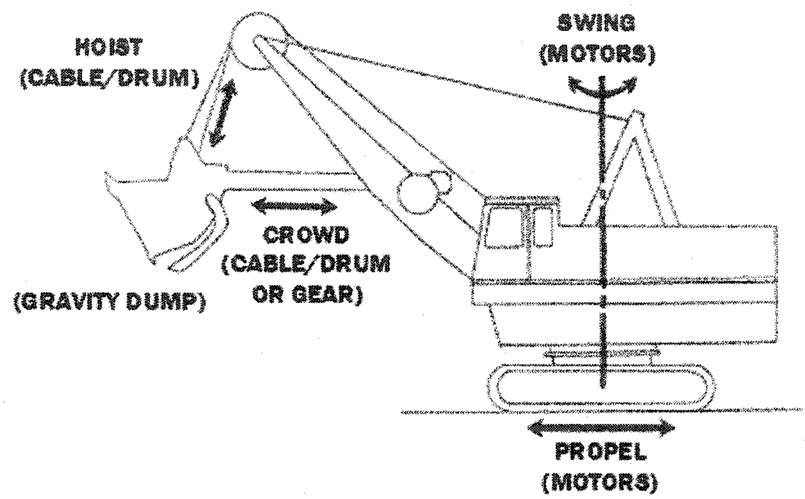


Figure 5-1 - Powered Functions for a Cable-Electric Shovel (modified from Frimpong, 2002)

Syncrude uses two types of cable-electric shovels in its operation: 2-Bucyrus-Erie (BE) 395B and 3 - P&H 4100 TS. Bucket sizes vary depending on the model and digging material, but are typically between 30 and 40 m^3. Maximum digging heights of these machines is approximately 17 m with dumping heights of up to 10 m. Due to the rigid digging motion of this shovel type, bench heights generally do not vary greatly or else the shovel productivity quickly diminishes, thus benches are typically 14 m in height (Wright, 2004). Additionally, the breakout force of cable-electric shovels is generally higher than that of hydraulic shovels.

5.2.2 Hydraulic Shovels

Adapted from the construction industry, hydraulic shovels are becoming very common in surface mining operations across the globe. They are essentially a typical backhoe excavator with a face shovel arrangement. All of the digging operations are controlled by hydraulic motors and cylinders powered by diesel engines. The digging motion is much more flexible, due to the hydraulic cylinders, than the cable-electric shovels who rely upon cables to generate their motion. This increase in selectivity is the major difference between the two shovel types. The buckets, or clamshell, of hydraulic shovels consists of a lip and a door. In a digging motion, the teeth on the lip penetrate the material until the bucket is full. Upon dumping, the door is opened using hydraulic cylinders allowing the material to drop into the truck gently, instead of the more sudden loafing that occurs when cable-electric shovels dump. The attitude of the bucket is also controlled by hydraulic cylinders, which provide more degrees of freedom than cable-electric shovels. As hydraulic shovels' mobility is not restricted due to electric cables, they are more mobile and can be quickly transported to different areas of the mine with ease. Figure 5-2 shows the powered function for a hydraulic shovel.

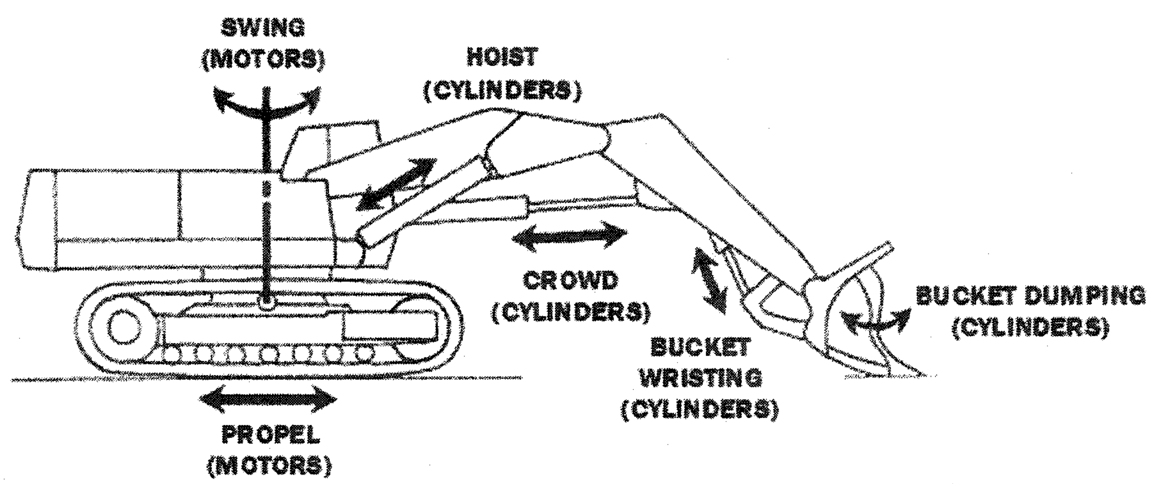


Figure 5-2 - Powered Functions for a Hydraulic Shovel (modified from Frimpong, 2002)

The variety of hydraulic shovels being used in the North Mine is much greater than cable-electric shovels. Syncrude utilizes 1 - O&K RH200 and 3 – O&K RH400s while occasionally an O&K RH120E backhoe may assist in stockpiled oil sands. The O&K RH200 shovel has a 23 m^3 bucket and is well matched for loading a 240 t capacity haul truck with a typical four-pass loading scheme. The larger O&K RH400s have bucket capacities of about 43 m^3 and better suited for loading the larger 360 t+ haul trucks in four-passes. The main contractor shovel is a Demag/Komatsu H685, although smaller backhoes are used in stockpiled oil sands as well. The bucket size of the Demag/Komatsu H685 is 36 m^3 and can adequately four or five-pass load most trucks (Klemke, 2004).

Digging heights of these shovels vary due to their selectivity and can mine benches as little as 8 m in height to 15 m for the O&K RH200 and Demag H685 to 20 m for the O&K RH400; typical bench heights for hydraulic shovels are between 10 – 12 m. Likewise, the dumping height for the O&K RH200 is smaller at 11 m compared to the O&K RH400 with a maximum dumping height of 15 m. It is this difference in dumping height that reduces the flexibility of the O&K RH200, as it cannot properly load the larger 360 t+ haul trucks.

The reach of the O&K RH200 shovel does not allow the load to be dumped into the middle of the truck box, thus leading to off-centered loading or reduced fill factors. Furthermore, the O&K RH200 must 5 or 6 pass-load, whereas the O&K RH 400 4 or 5 pass-loads, the larger 360 t+ trucks. This increase in loading time reduces the productivity when handling the larger haul trucks, coupled with the increasing number of 360 t+ haul trucks being used at the North Mine, makes planning with these shovels challenging.

5.3 Shovel Type and Lump Generation

5.3.1 Effects of Shovel Type on Lump Dump Activity

Upon analyzing the lump dump loads for the period from July 2001 to June 2003, there is evidence to suggest that there is a difference between the shovel types. Lump dump activity generally begins in December with the months of January to March being the greatest and then drastically decreasing in April. Figure 5-3a shows the monthly volume delivered to the lump dumps by each type of shovel. From this graph, neither shovel type appears more of a contributor to lump dump volume than the other in the winter of 2001/02, but in the winter of 2002/03, the hydraulic shovels consistently delivered more volume to the lump dump. Monthly volumes range from 0 BCM in the summer to 187,000 BCM in the winter. A more meaningful comparison, however, is to normalize the volume delivered to the lump dump by the total volume mined by each particular shovel type (Figure 5-3b). The percentages are not trivial ranging from 0% in the summer months to as high as 18% in the winter. A trend can be easily seen showing a difference among the shovel types where the hydraulic shovels are clearly producing more lumps than the cable-electric shovels on an equivalent basis. In the 2002 winter months, the hydraulic shovels were up to three times more likely to send a load to the lump dump than the cable-electric shovels; however, in the winter of 2003, data shows this difference decreased. A potential reason for this discrepancy is that the operators are getting experience in the hydraulic shovels and better managing the creation of lumps at the face. Cable-electric shovels, however, show that while they produce lumps, the normalized lump production has not changed over the two years.

From these plots of shovel type against lump dump activity, it appears that shovel type does show some differences in the generation of lumps. However, lump dump activity is not solely affected by shovel, but also by a shovel operator's judgment and experience. It is this factor that may explain the trend of lump dump loads from hydraulic shovels being more probable than from cable-electric shovels. Based on discussions with some operators, their perception that hydraulic shovels generate more lump jams may cause the operator to be more discriminating when determining if a truck load looks lumpy, hence creating a greater probability of sending a truck to the lump dump. But the reality, as presented in *Section 5.3.2 Effects of Shovel Type on Lump Jam Events,* shows that each shovel type is equally as probable to generate a lump jam. Therefore, a discrepancy exists between the perception and the reality of lump generation that could explain the elevated lump dump activity of hydraulic shovels.

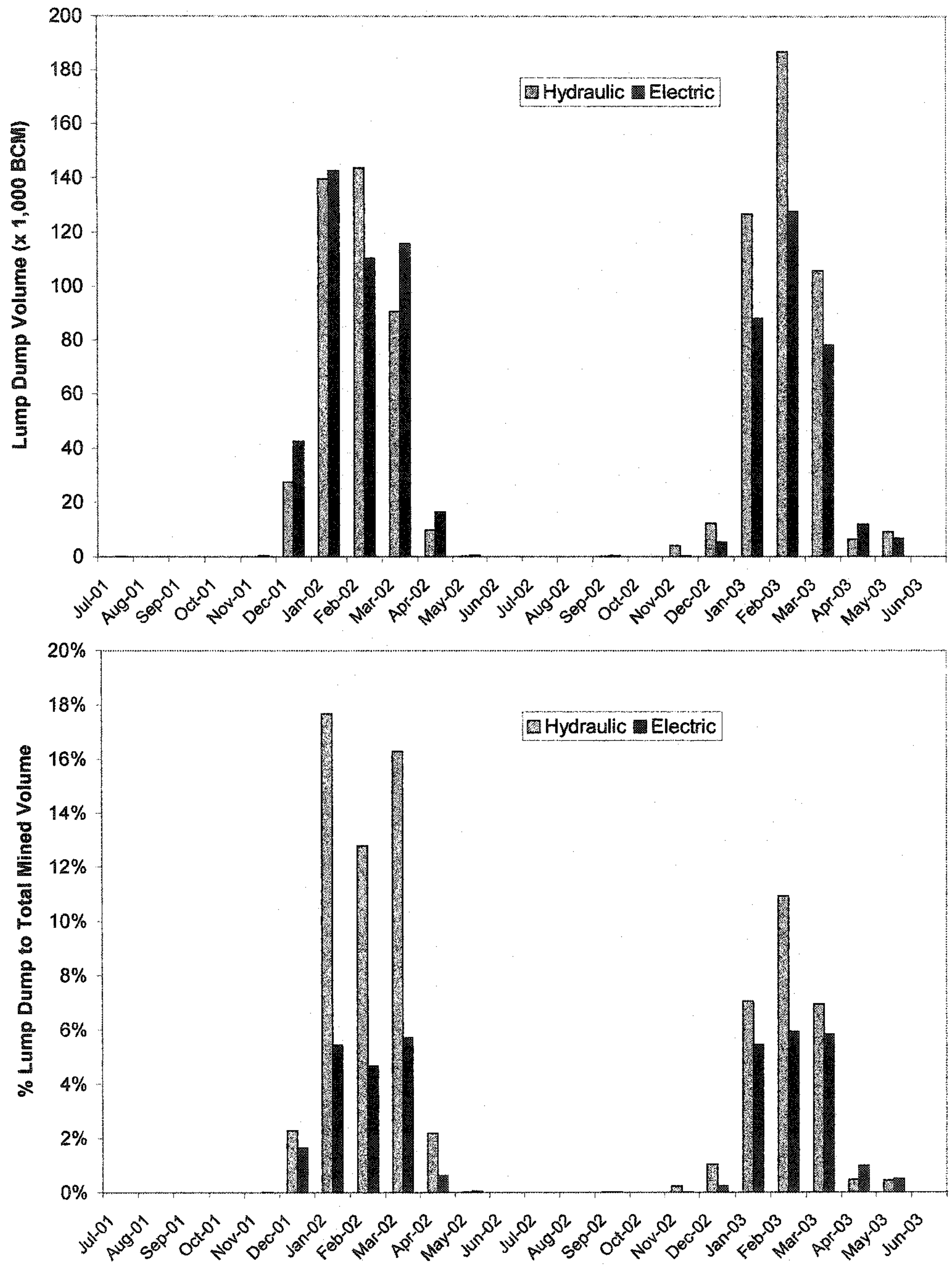


Figure 5-3 - Shovel Type a) Lump Dump Volume b) Normalized Lump Dump Activity

Determining if certain shovel types were preferentially digging on certain benches or in certain facies during times of lump dump activity, mainly from November to May, could possible explain the greater likelihood of hydraulic shovels sending loads to the lump dump. Comparing the volume from a bench to the total volume mined by a particular shovel is shown in Figure 5-4. Based on this graph, hydraulic shovels predominantly excavate on benches NM245, 264 and 276 and the cable-electric shovels predominantly excavate on the NM25X and 288 benches as well as the lump dump. In subsequent chapters, origin locations will be analyzed for their likelihood of generating lumps, which when used in conjunction with the findings concerning shovel type, a relationship may be established.

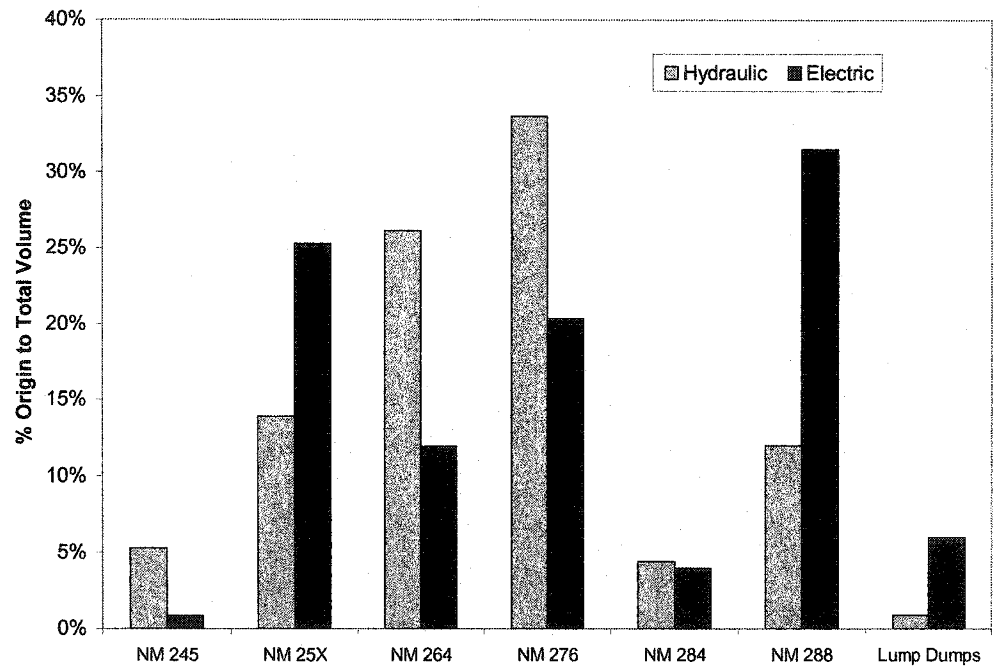


Figure 5-4 – Percentage Bench to Total Volume by Shovel Type

Figure 5-5 examines the volume mined from a particular facies group to the total volume mined by a shovel type. The cable-electric shovels mine more in facies groups 95/15 and 96/16 (Upper McMurray) and 6/25 (Lower McMurray) while the hydraulic shovels mine more in facies group 7/8/11 (Middle McMurray). These trends coincide with those depicted in Figure 5-4 with the top elevation benches being Upper McMurray and the lower elevation benches being Lower McMurray.

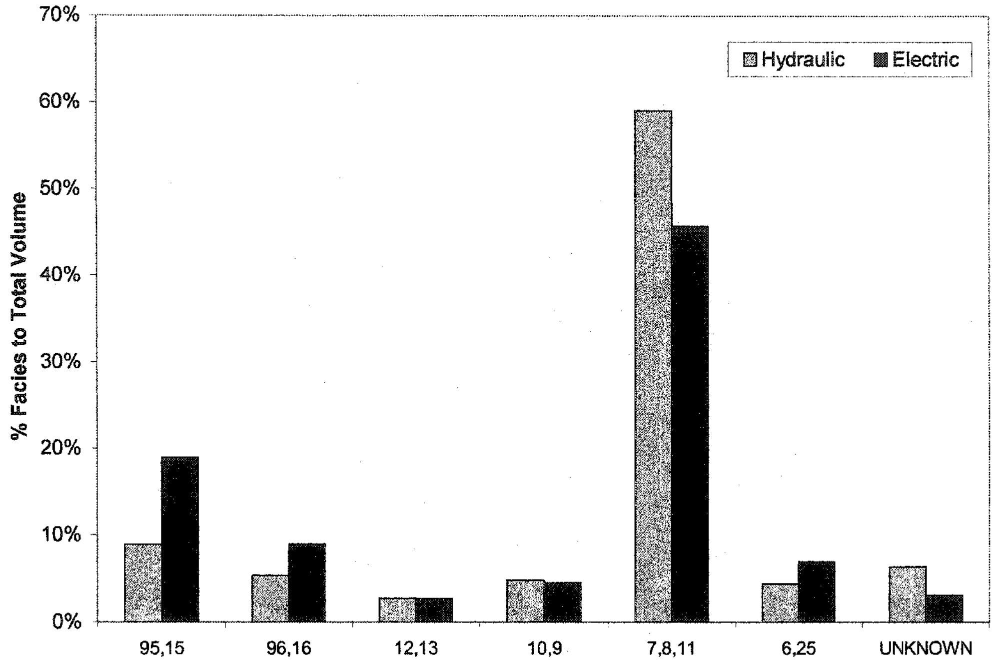


Figure 5-5 - Percentage Facies to Total Volume by Shovel Type

Spatially the distribution among the shovel types could have an effect, but upon plotting GPS coordinates for every truckload based on shovel type for each bench, there is little bias in planning that could be observed (See *Chapter 7 Mine Planning and Other Effects*). Taking the NM288 as a typical bench, the distribution of the shovel types can be seen in Figure 5-6a with the blue points as cable-electric and the pink points as hydraulic shovels. The majority of points are cable-electric, as would be expected as they mine more volume than hydraulic shovels, with localizations of hydraulic shovels where they were mining for a time before being moved elsewhere. In Figure 5-6b, the points show those trucks that dumped into the lump dump. Once again the majority of these traces originated from cable-electric shovels, yet on a total volume mined equivalence, the hydraulic shovels create more lump dump loads. Similar findings are found for all benches, which can be viewed Appendix 3. This is clearly demonstrated on the NM276 bench where the northern extent is divided into two regions, one mined by cable-electric and the other by hydraulics shovels. When overlying the bench activity by the lump dump origins, there is a drastic difference in concentrations between hydraulic and cable-electric mined areas. It is not very probable that the digging becomes harder only for the area mined by the hydraulic shovels, thus adding to the validation that there is an influence in shovel type on lump generation.

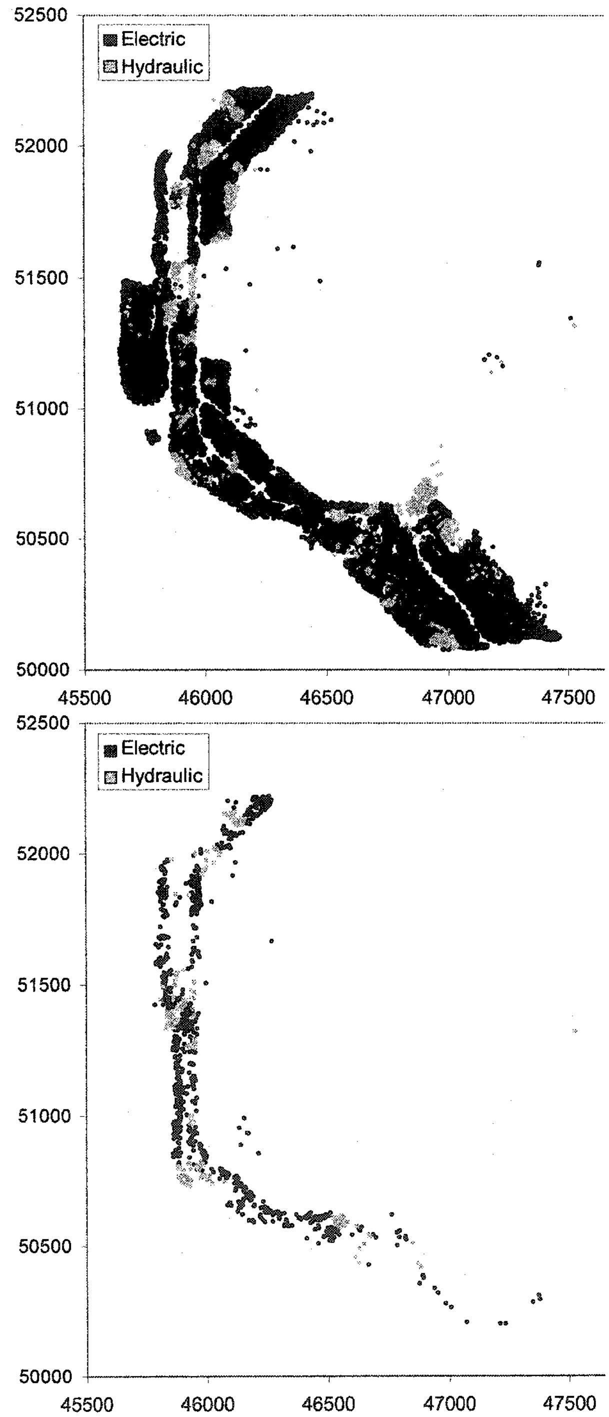


Figure 5-6 - NM288 bench a) Shovel Allocation b) Lump Dump Loads for July 2001 to June 2002

5.3.2 Effects of Shovel Type on Lump Jam Events

Analyzing lump jam events for the same time period, however, does not show as clear a distinction between shovel types as lump dump activity. Lump jams are more frequent during the winter months, much like lump dump activity, yet some jams do occur throughout the year. During the summer, no more than nine jams occur per month, but in the winter, up to 200 jams can occur in a single month. In Figure 5-7a, the number of lump jam events originating from each shovel type is shown with cable-electric shovels generating significantly more lumps jams in the winter of 2001/02 while there appears to be little difference in the winter of 2002/03. After normalizing the number of lump jams from each shovel type by the amount of million bank cubic metres (MBCM) of produced oil sands shows little discernable difference between the two shovel types over the two years (Figure 5-7b). A decrease in the total number of lump jams, however, is apparent between the 2001/02 and 2002/03 winters from 659 to 478.

Investigating the lump jams attributed to each crusher revealed that there is a difference between them. In Figure 5-8a and Figure 5-8b, the number of lump jams per month at each crusher is graphed for hydraulic and cable-electric shovels, respectively. In the winter of 2001/02, hydraulic shovels generated far less lump jams than the cable-electric shovels, but in the following winter the number of lump jams was nearly equal for the two shovel types. Once again to normalize the data, the number of lump jams was divided by the monthly volume of material dumped into each crusher from respective shovel types. Figure 5-9 shows the normalized data for lump jams by crusher and shovel type. The general trend shows that NMFB7 generated more lump jams per MBCM delivered than NMFB6 for each shovel type. On the normalized data, shovel type does not have an appreciable effect on the number of lump jams per MBCM mined, regardless of crusher. However, the results show that the NMFB7 does differ from NMFB6 as it generates more lump jams per MBCM delivered.

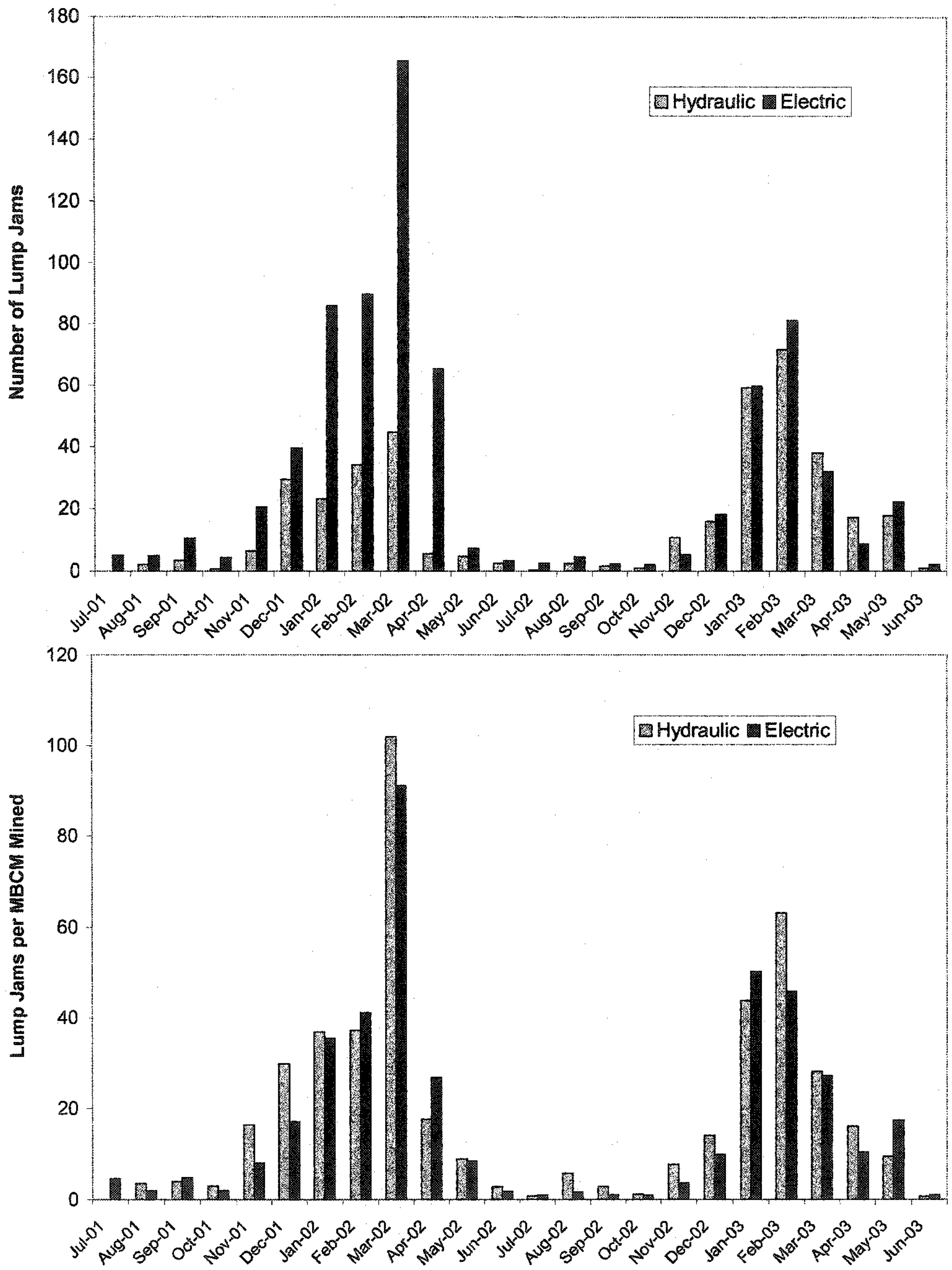
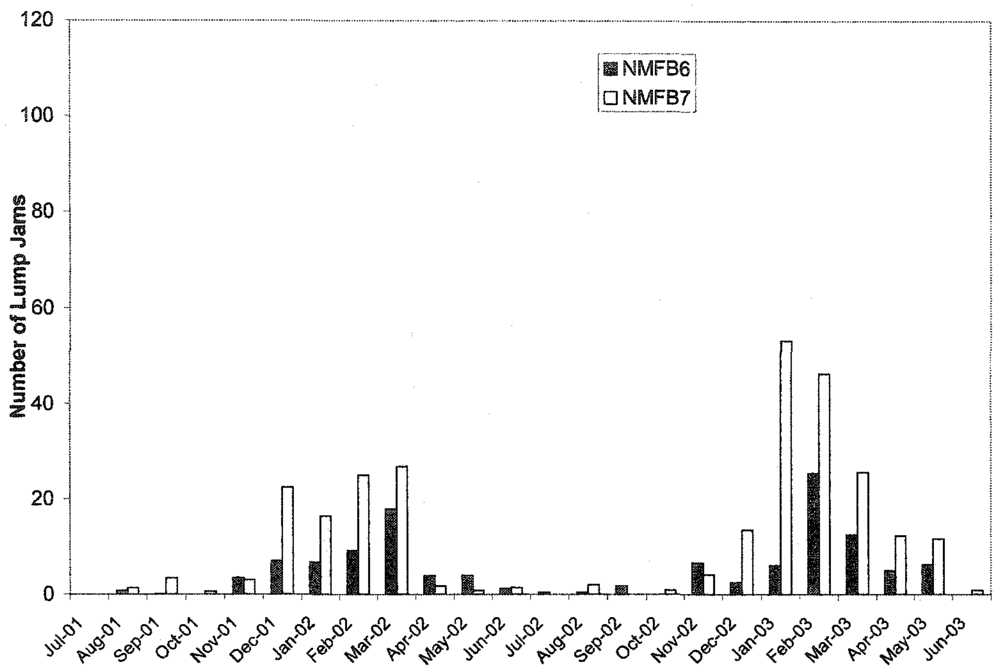


Figure 5-7 – Shovel Type a) Number of Lump Jams b) Lump Jams per MBCM Mined



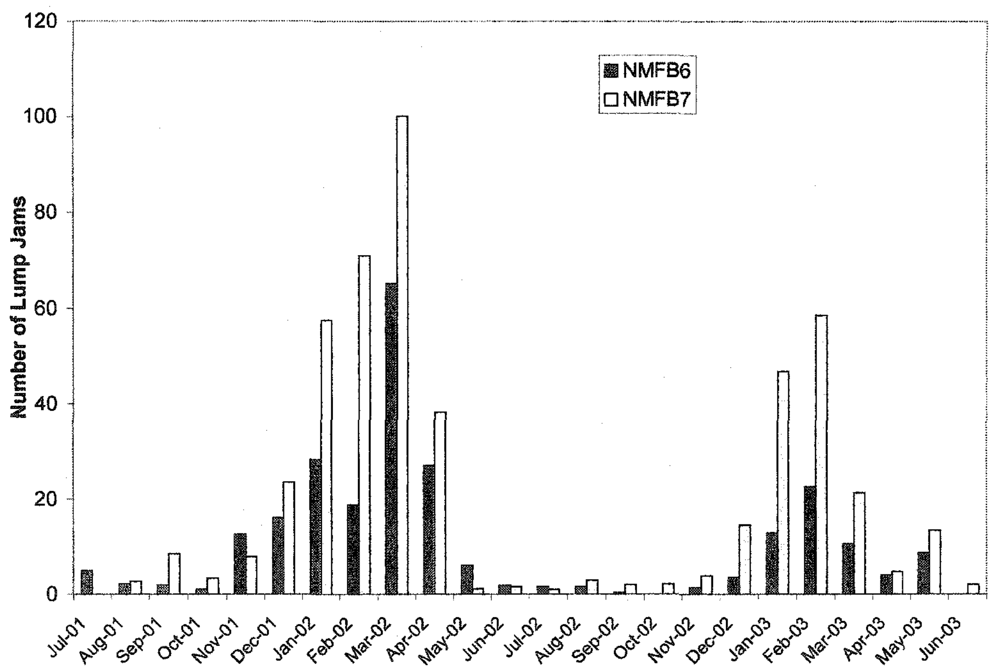


Figure 5-8 - Number of Lump Jams by Crusher for a) Hydraulic b) Cable-Electric Shovels

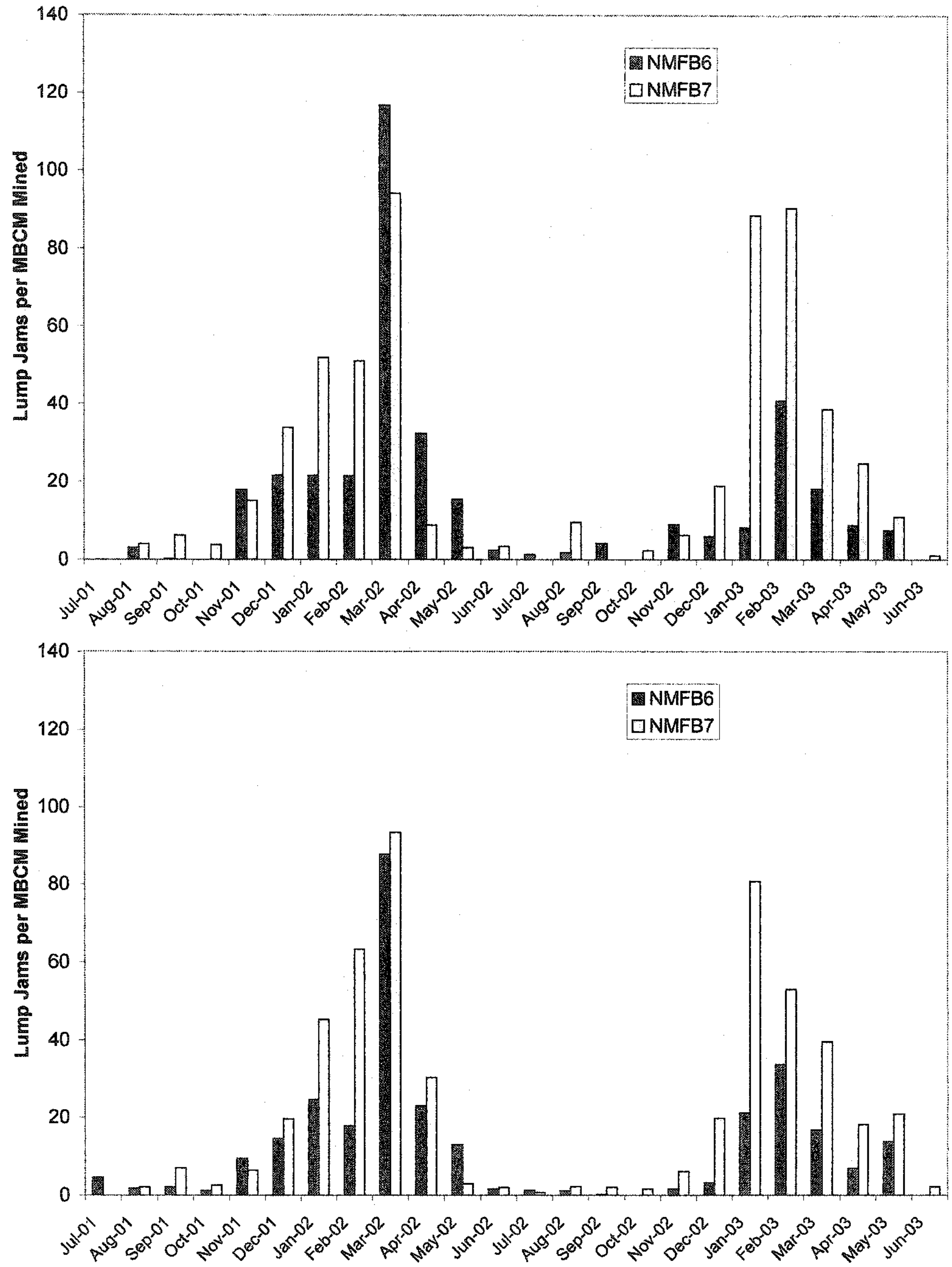


Figure 5-9 - Normalized Lump Jams by Crusher for a) Hydraulic b) Cable-Electric Shovels

A determination if certain shovel types were preferentially delivering to a particular crusher from particular benches was conducted. The volume excavated by a shovel type on a bench was normalized by the total volume of material excavated by that shovel type, which was then compared across shovel types and crushers. Figure 5-10a and Figure 5-10b show the percentage of shovel volume excavated from each bench that was delivered to the NMFB6 and NMFB7, respectively. Although there are some variations between the crushers as to the percentage of a particular origin that dumps into a particular crusher, there is no significant difference between the two crushers. Each crusher gets proportionally the same amount of material from each shovel type and origin.

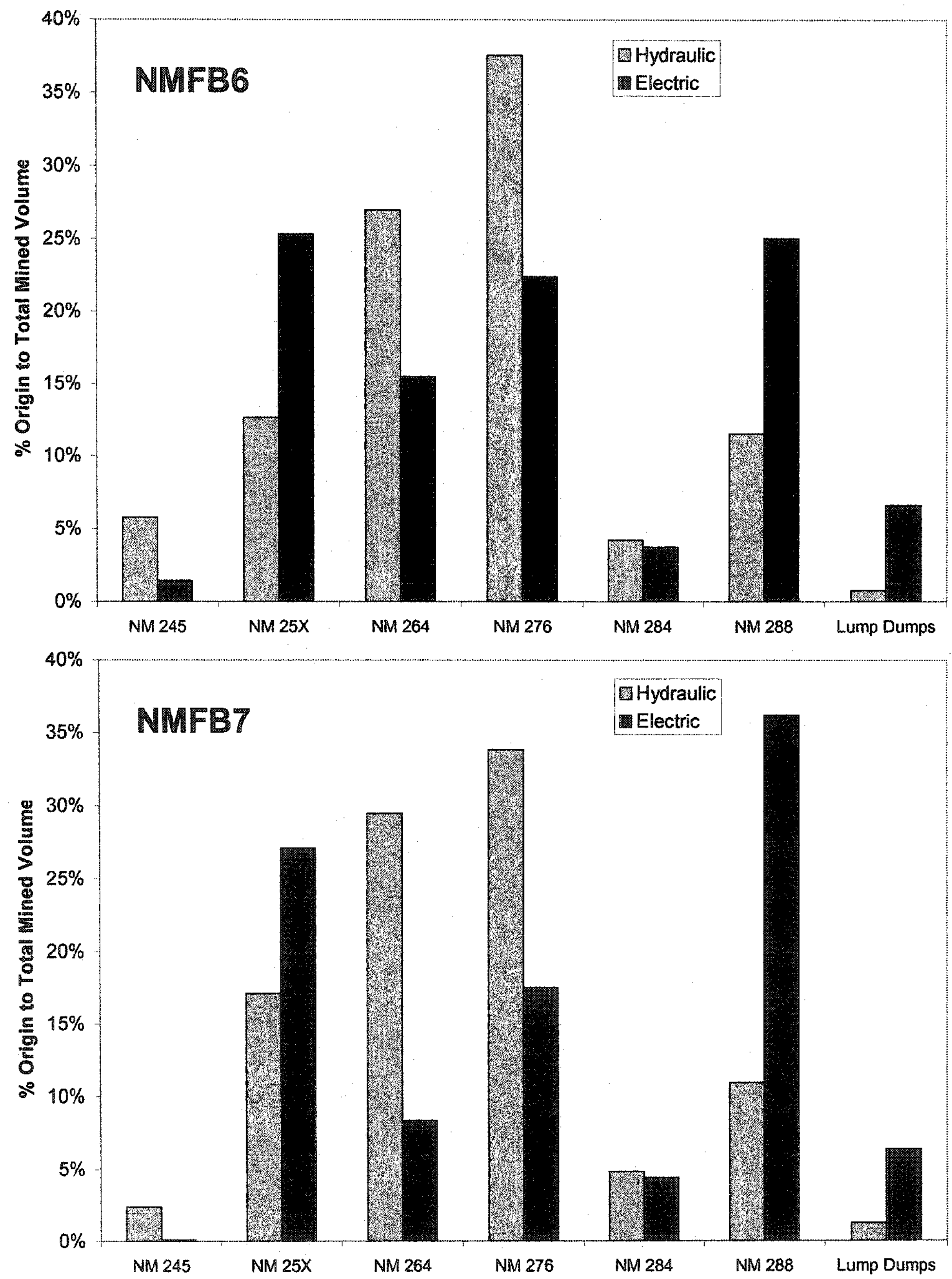


Figure 5-10 - Percentage Volume Excavated by Shovel Type from each Bench delivered to a) NMFB6 and b) NMFB7

Investigating the role that shovel type might have on lump jam events due to mining of the lump dump is inconclusive. Figure 5-11a shows that the cable-electric shovels generate most of the lump jams originating from the lump dump, while Figure 5-11b shows that the hydraulic shovels are more probable to generate a lump jam. Nevertheless, as both shovel types are mining the lump dump simultaneously in only two months, any comparison or trend would be pointless.

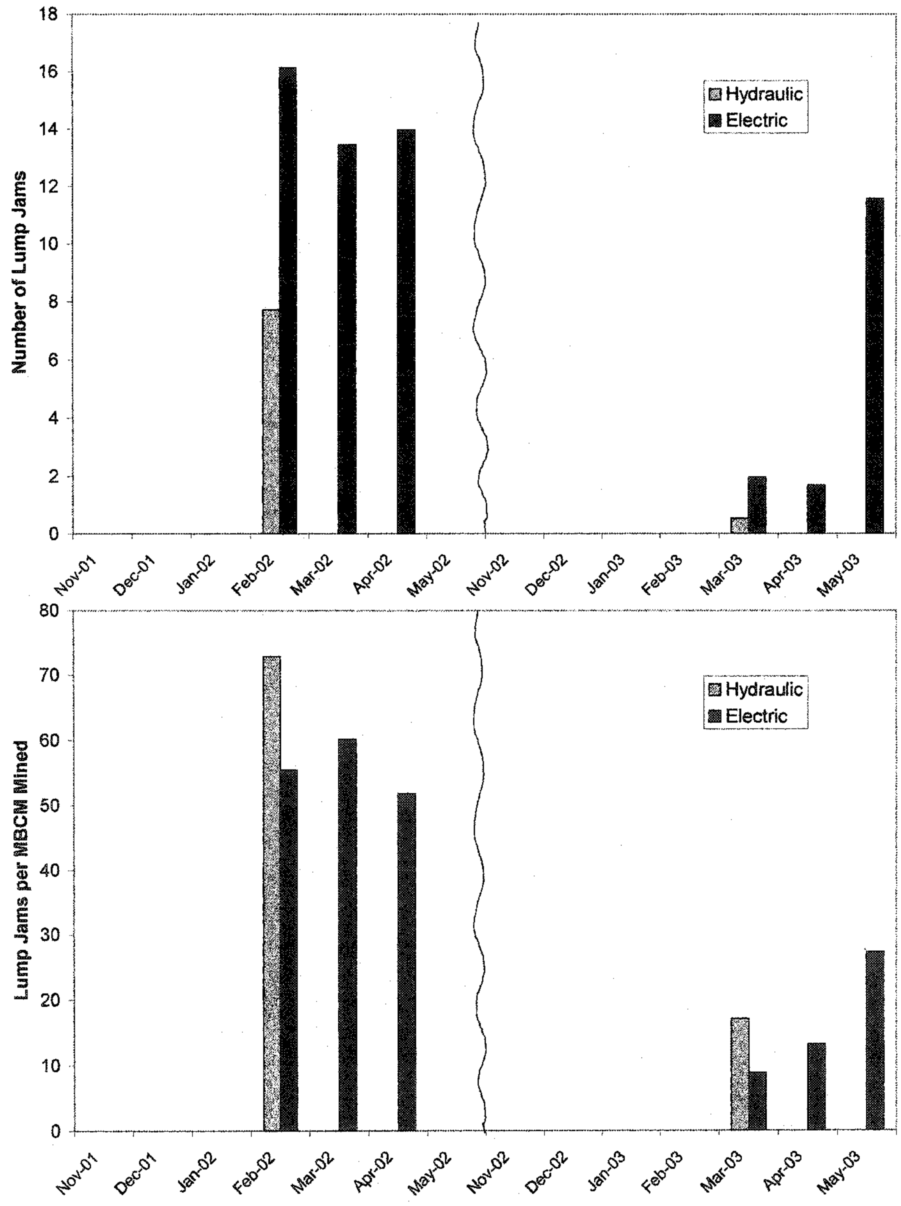


Figure 5-11 - Monthly a) Number of Lump Jams b) Normalized Lump Jams by Shovel Type Originating from the Lump Dump

5.4 Case Study Comparing Shovel Types

A site visit during the week of January 26-30, 2004 provided an ideal scenario for a case study comparing the performance of shovel type in frozen lump generation. From approximately 23:00 on January 26th to 09:00 on January 29th, an O&K RH400 (hydraulic) and a P&H 4100 (cable-electric) were both actively mining in the same shovel pit on the top oil sands bench designated NM288 Ore Panel 13W B 821. They were digging side-by-side for the duration of the time until the O&K RH400 had to be taken down for maintenance on the morning of January 29th. As location can be considered reasonably identical for both shovels, the impacts of origin location and geology can be neglected.

The mean daily temperature for the weeks preceding the study is shown in Figure 5-12 with a steadily decreasing trend in the week prior. The two full days during the test were the two coldest days of the year.

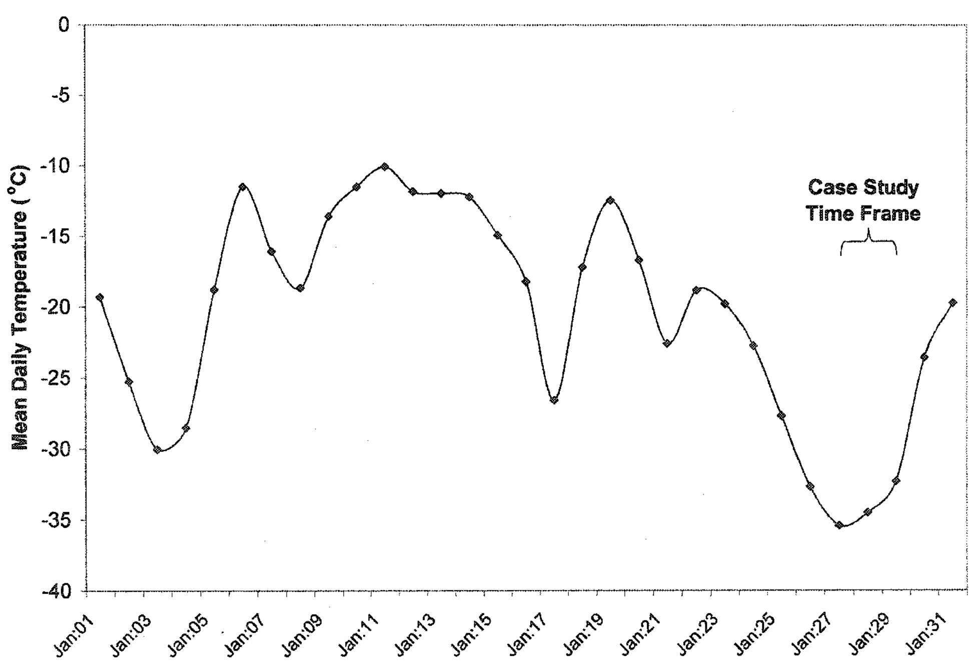


Figure 5-12 - Mean Daily Temperature, January 2004

During the 58-hours, the cable-electric shovel nearly doubled the production of the hydraulic shovel. The P&H 4100 excavated over 100,000 BCM of material with 11,000 BCM being delivered to the lump dump while the O&K RH400 only excavated 57,000 BCM, but send 14,000 BCM to the lump dump. Furthermore, the hydraulic shovel's productivity showed that nearly 25% of its volume went to the lump dump in comparison to only 10% of the cable-electric's productivity. This means that the hydraulic shovel was 2.5x more probable in generating a lumpy load than the cable-electric shovel. These findings agree with trends reported earlier in this chapter regarding shovel type and lump generation. Unfortunately, an insufficient number of lump jams occurred to properly draw any valid conclusions as to which of these shovel produce, or is more likely to produce, lump jams.

5.5 Remedial Measures

5.5.1 Operator Training

The hydraulic shovels are more prone to generate lump dump activity than the cable-electric shovels, yet their operation during the two-years have shown improvement. Whether this improvement is from experience or modifications to the shovels and/or mining practice is not known, but these efforts should continue. Due to the lack of improvement in cable-electric shovels, perhaps the practices can be applied, or new ones introduced, that may lead to a reduction in lump dump activity for this shovel type as well. Nevertheless, any reduction in lump dump activity is a savings in rehandle cost, but should not be practiced at the expense in an increase in lump jam events.

5.5.2 Lump Fracturing

It is unlikely that the presence of lumps in the hoppers can be completely eliminated, thus a manner should be considered in reducing the downtime incurred by jamming the crushers. Currently a backhoe is placed near the crushers in the event that a lump cannot be crushed and blocks the neck or chute of the hopper. The time required for the backhoe to remove the lump can range from approximately 15 min to 2+ hours. An alternative approach would be to fix a device on a boom that could be swung into position as needed at a crusher. If applicable, this device could save valuable time and money. Due to the non-violent fragmentation and minimal impact on the surrounding structure, these techniques for fracturing lumps are safe and easily adaptable to the present crusher geometry and operation at the North Mine.

Lump Breaker

The general theory behind the lump breaker is to create a fracture that will propagate through the lump and cause fragmentation. A utensil would be fixed to an impact hammer that would hit the lump until it fragmented. The number of impacts required would depend on the energy of the impact and on the strength and/or energy absorption of the lump.

Another mechanical fragmentation method is the use of high-pressure water to fracture the lump. This technique requires drilling of a hole in the lump and propelling water into the hole at a pressure of approximately 40 MPa. The liquid hits the bottom of the hole at such a velocity that a shockwave is produced that travels back through the water creating a radial high pressure. Radial and axial fractures are produced and water pressure forces them to the surface leading to fragmentation of the lump (Figure 5-13).

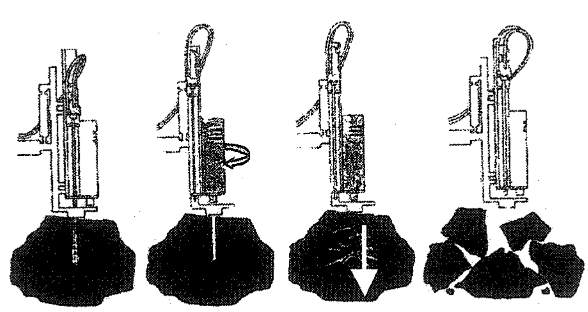


Figure 5-13 - Using a High Pressure Water Cannon to Fracture Rock (modified from Jimeno et al., 1995)

Lump Cutting

This technique would use high-pressure water jets to cut the lump into pieces while in the crusher. Tests by Gilpin and Gates (1981) were conducted using a water jet traversing a freshly exposed oil sands face with different combination of nozzle diameter and water pressure. Their results indicated that a penetration of 1 m could be achieved in less than 30 seconds using a nozzle 6.35 mm in diameter at a constant water pressure of approximately 10 MPa. Pulsating the water jets further increases both the rate and depth measured in comparison to the constant jet source. An increased cutting depth was directly related to increased jet pressure and nozzle diameter. Unfortunately these test were conducted on unfrozen oil sands, but the results do show promise.

5.6 Summary

From July 2001 to June 2003, Syncrude operated a total of 14 shovels in the North Mine: five were cable-electric and nine were hydraulic. Based on GPS coordinates during a one-year period, no significant spatial bias could be found to suggest that particular shovel type dug in certain areas than others.

Analysis of lump dump activity illustrates that the hydraulic shovels are more probable to generate a lumpy load than the cable-electric shovels on a normalized basis by volume mined. However, while the cable-electric shovel's probability of sending a load to the lump dump has remained relatively constant in both years, the hydraulic shovel's probability has been decreasing. While other factors, such as a reduction in exposure time, improvements to shovel and/or crusher operation or warmer winters, can be effecting this trend, perhaps operator experience and being less discriminating in lump identification could be playing a role as well. Furthermore, trends for lump jam events for both shovel types are rather similar and have not changed in spite of the reduction in lump dump activity of the hydraulic shovels. The reasons why a greater probability exists for lump dump activity of hydraulic than cable-electric shovels is not fully understood, but differences in digging/dumping motion, bucket sizes, breakout forces and mobility could be a factors.

A comparison was made for lump jam events for NMFB6 and NMFB7, and a difference was found to exist between the two crushers. Regardless of shovel type, NMFB7 does produce more lump jams than NMFB6 on a volume normalization of feed. In addition, as little difference existed in the origin of the feed, no preferential origin could be attributed for the noticed difference between the crushers.

Some of the remedial measures that could be untaken would be to continue to train operators on the correct manner to manage lumps depending on the shovel type. A more reactive approach would be to use lump breakers or jet cutters located at the crushers to size large lumps while in the crusher.

6 GEOLOGY

6.1 Introduction

There are four major reserves of oil sands in Alberta: Peace River, Athabasca, Wabasca and Cold Lake. These oil sands deposits contain 1,800 billion barrels of bitumen with 300 billion recoverable barrels using current technology (Syncrude, 2003b). Figure 6-1 shows the relative outlines of the four Alberta oil sands deposits. This represents the largest oil reserve in the world with Saudi Arabia second at 259 billion barrels. Of the 300 billion recoverable barrels of bitumen, about 10% can be mined using surface mining methods with the remainder accessible through in situ techniques. Surface methods are limited to the Athabasca oil sands deposit with Figure 6-2 comparing the regions that can be accessed through surface or in situ methods. Syncrude's leases in the Athabasca deposit contain approximately 8 billion barrels of reserves (Syncrude, 2004).

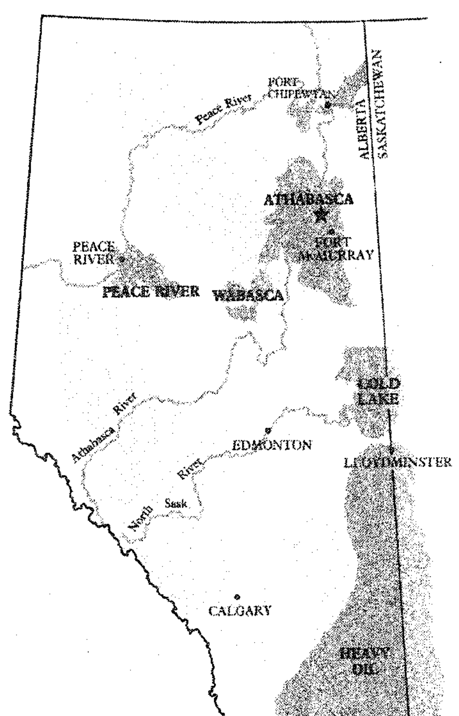


Figure 6-1 - Alberta Oil Sands Deposits (modified from McRoy, 1982)

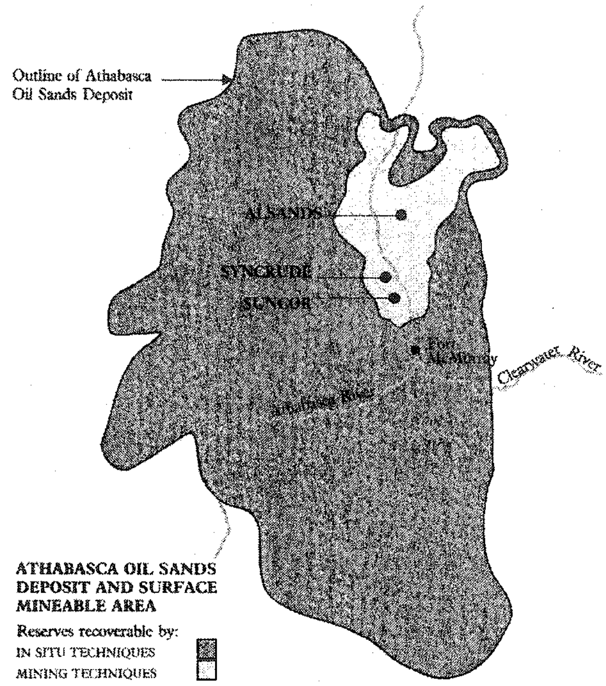


Figure 6-2 - Athabasca Oil Sands Surface versus In Situ Extraction Areas (modified from McRoy, 1982)

6.2 Athabasca Oil Sands Deposit

6.2.1 Origin of the Oil Sands

The true source of the heavy oil that is found in the McMurray formation is a point of much debate. Some believe that the oil was formed in situ from humic acids of plants, yet tests have shown that this is not the case. The unaltered nature of organic material and the lack of clay diagenetic features are typical of sediment that was not subject to the temperatures and pressures associated with deep burial. Furthermore, hydrocarbons require minimum depths of 1,000 to 3,000 m to form, thus the bitumen in the Athabasca deposit must have migrated from greater depths (Hitchon, 1963).

The heavy oil most likely migrated up dip along the pre-Cretaceous unconformity from either Cretaceous or Paleozoic rocks, or alternatively from several sources in both Cretaceous and Paleozoic rocks mixing as it flowed along the unconformity. Figure 6-3 portrays the flow scheme that may have taken place along the unconformity.

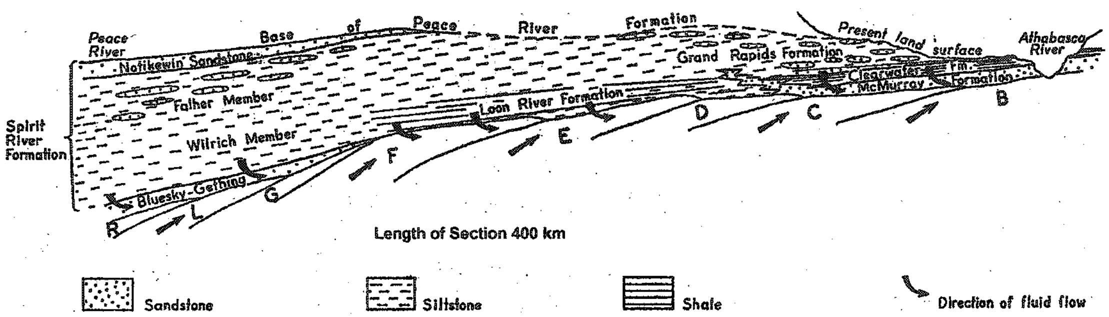


Figure 6-3 - Lithological Section from the Peace River to the Athabasca River Showing the Migration Path of the Heavy Oil in the Athabasca Oil Sands (modified from Hitchon, 1963)

In early Cretaceous time, the majority of Alberta existed in a submerged marine environment. The deposition of lower Cretaceous sediments created an environment conducive to the development of heavy crude oils and explains the presence of these heavy oils in lower Cretaceous reservoirs at many locations across Alberta. The cross section in Figure 6-3 show the gradual westward increase in thickness of the Lower Cretaceous strata from Fort McMurray towards the Rocky Mountains. In early Cretaceous times this shallow depositional basin was probably asymmetrical with its western margin within the present Rocky Mountains. Various Lower Cretaceous age oil sands deposits exist on the eastern side of the structural basin, which is better known as the Western Canadian Sedimentary Basin, with the Athabasca oil sands deposit at the eastern extreme (Carrigy and Kramers, 1973).

6.2.2 Characteristics of Oil Sands

Oil sands may be considered as a five-phase system – a dense interlocked skeleton of predominantly quartz sand grains with pore spaces occupied by bitumen, water, gasses and minor amounts of clay. The quartz grains are hydrophyllic, and are surrounded by a thin film of water, thus the bitumen is not directly in contact with the quartz grains. This water-wet feature is what ultimately allows the bitumen to be extracted from the Athabasca oil sands with ease using the Clark Hot Water process. Bitumen and water occupy the fluid portion of the pore space with varying degrees of saturation. Additionally, appreciable quantities of methane and nitrogen are dissolved in both bitumen and water phases. The fine-grained mineral fraction consists of clay minerals, predominantly kaolinite and illite (Carrigy and Kramers, 1973). Figure 6-4 depicts the in situ structure of Athabasca oil sands. The mean bitumen content is approximately 10% by total weight, but varies from 0 to 18%. Typically the bitumen content varies inversely with the clay content (Carrigy and Kramers, 1973) with the richer, cleaner oil sands being found in the lower portion of the McMurray formation and the leaner, siltier oil sands in the upper portion. The sum of the bitumen and water contents is roughly constant at 12 – 18% of total weight. Figure 6-5 shows the relationship between fines and bitumen content, as well as the linearly decreasing trend of bitumen and water content with decreasing particle size.

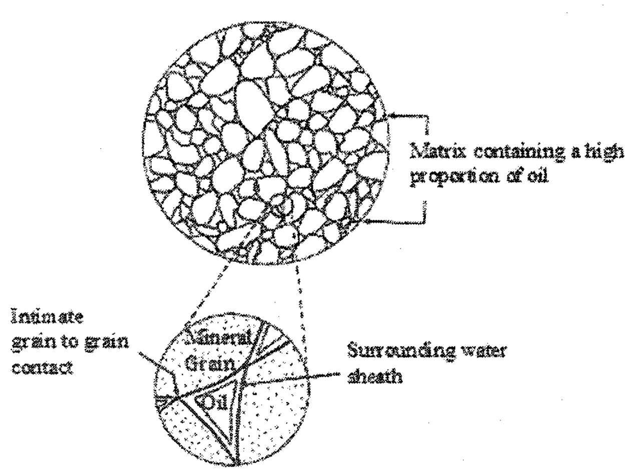


Figure 6-4 – In Situ Structure of Athabasca Oil Sands (modified from McRoy, 1982)

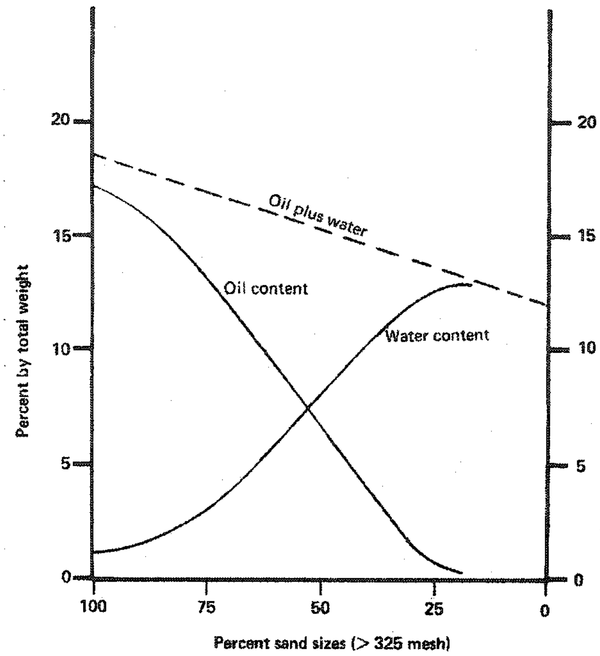


Figure 6-5 - Schematic Representation of the Bitumen Content-Grain Size Relationship (Dusseault, 1977)

6.2.3 Regional Geology

The stratigraphy of the Fort McMurray region is comprised of Paleozoic strata overlying the Precambrian basement complex that dips gently to the southwest. The Paleozoic sequence in turn is overlain by Cretaceous, Pleistocene and Holocene age sediments. Figure 6-6 depicts a typical cross-section through the Athabasca river valley near the Fort McMurray area and summarizes the major units with the formation, age, period and rock type. Figure 6-7 provides a more detailed look at geology found at Syncrude's North Mine.

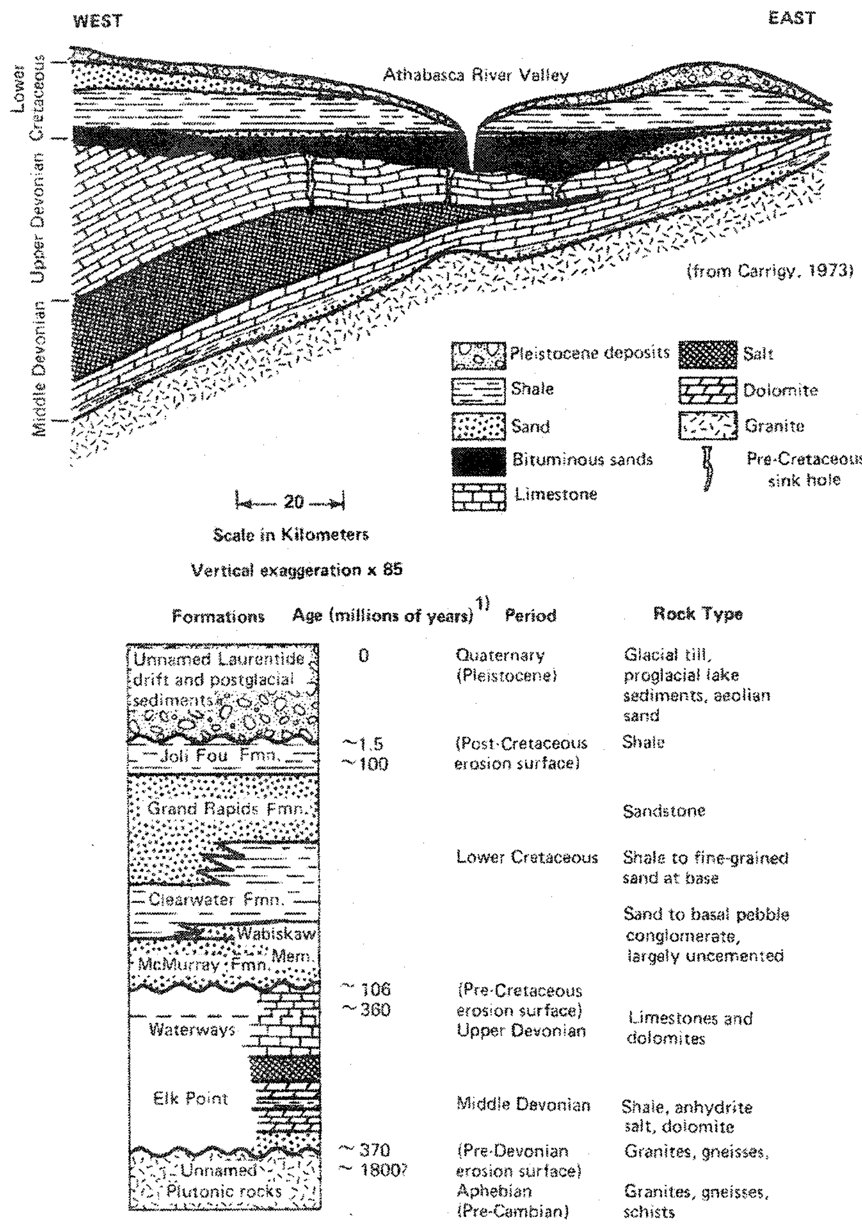


Figure 6-6 - Regional Geology Cross-Section near Fort McMurray (Dusseault, 1977)

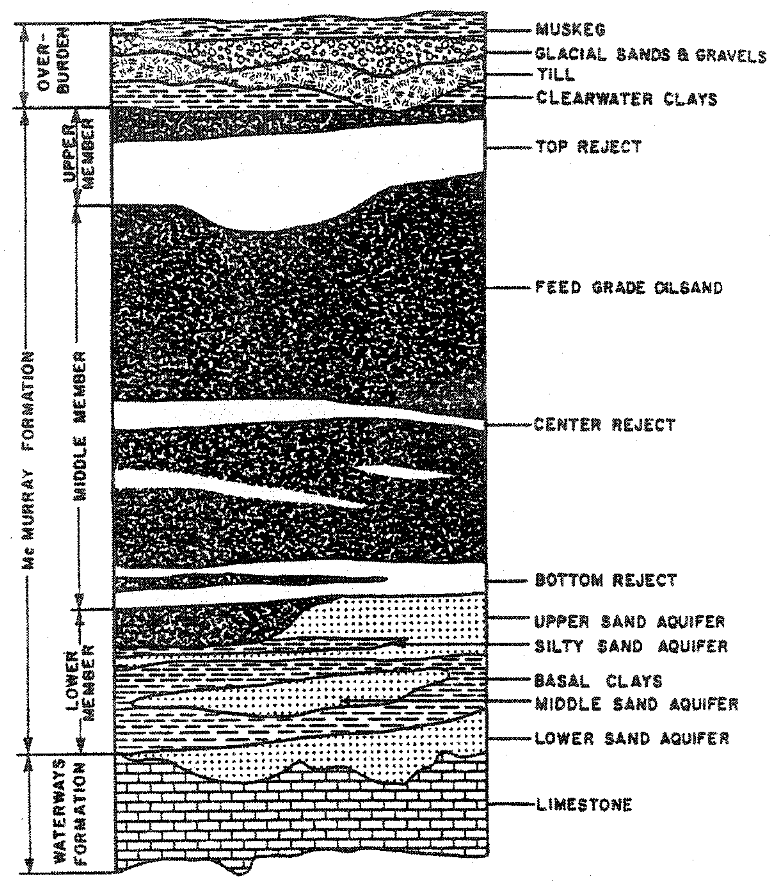


Figure 6-7 - Syncrude Geologic Cross-Section (modified from Cuddy and Muwais, 1989)

6.2.4 *Local* Geology

Surficial Geology

Surficial features are those that were deposited during or after the last glaciation, approximately 20,000 years ago. This relatively recent geology is divided into the Pleistocene and the more recent Holocene epochs.

Holocene age deposits are those that were deposited after the glaciers had retreated. These lacustrine clays, sand and gravels are saturated with poor drainage thus form the base for the organic muskeg overlying the majority of the region. These deposits can range in thickness up to 3 m thick with a highly variable moisture content and slightly acidic pH.

Pleistocene age deposits are those that were formed by the advance and/or retreat of the ice sheet, erosion and/or deposition of discharging meltwater channels and/or settlement within glacial lakes. These glacial deposits infilled the erosional surface of the underlying Cretaceous age rocks. Due to this irregular and extremely undulating contact, estimation of the thickness of the Pleistocene units vary considerably. The thickness, however, of this glacial till does decrease as it approaches the Athabasca River valley, making surface mining economically feasible. This regional erosional feature is evidence of the large amounts of water that drained along this spillway from glacial lakes that were present at the end of the Pleistocene epoch. Concurrently, the smaller tributaries of the Athabasca once also contained much larger flows as evident by the erosion through the glacial tills even down into the Paleozoic limestone in some cases.

The Clearwater clay in the Cretaceous formation is a marine deposit of uncemented clay shales, clays, silts and fine-grained sands. In general, the bedding is gently dipping, but at a local scale can be dipping as much as 10° to 15° due to glacial scours or thrusting. Within the Clearwater are numerous stratified, highly cemented, fine-grained siltstones layers that can be laterally continuous or lenslike in structure conforming to the bedding direction. The thickness of these siltstones layers range from 0.1 to 0.9 m with joint spacing normal to the bedding of 0.3 to 1.0 m. When excavated, the siltstone fractures forming rectangular slabs. Due to the relatively impermeable clays and bituminous sands of the Cretaceous surface, any overlying depressions are often saturated. Combined with glaciofluvial deposits and thrust features of the area, unpredictable perched water tables are also found throughout the area (O'Donnell and Jodrey, 1992).

In the mining operation, all the material in these formations is regarded as overburden. The total thickness of the overburden typically ranges from 2 to 50 m with increasing thickness away from the Athabasca River. Muskeg is stockpiled for future reclamation activities while the overburden is either used in dyke and road construction or placed in dumps.

Oil Sands Geology

The regional geologic model for the McMurray Formation is described by Carrigy (1959) as a tripartite layered sequence of fluvial, estuarine and marine deposits with internal lateral complexities and disconformities ranging in thickness up to 90 m. The distribution of oil within the Athabasca oil sands is controlled by the petrographic properties of the reservoir rocks. The porosity is intergranular and was established by the sorting action of the traction currents and the winnowing action of oscillatory currents at the time of deposition; it has been modified only locally by compaction and cementation. Where the sands are clean, porosity is high, as much as 35%, and bitumen saturation of 10-18% (by weight) is common (O'Donnell, 1988).

The marine, Upper McMurray, formation is not clearly differentiated from the Middle McMurray formation with its upward-coarsening sequences from clayer-silts in the lower part to fine-grained sand in the upper part. Although the lithology is similar to the Middle McMurray, the Upper McMurray is mostly horizontally bedded and identified by the presence of brackish-water fauna. Grain size curves fall largely within Group III in Figure 6-8. The thickness of the Upper McMurray is usually no larger than 30 m (Dusseault, 1977). A problem with some of the marine ore is of iron and calcium oxidizing causing cementation of the mineral grains causing an increase in strength (Wright, 2004).

The estuarine, Middle McMurray, formation contains the majority of the oil sands and consists of upward-fining tidal flat sediments. The high degree of sorting found in the fine and medium-grained sands is indicative of a fluviodeltaic environment, thus falling within Group II of Figure 6-8. Two sediments types are contained within this formation: muddy and sandy estuarine facies. Muddy estuarine facies are considered waste and sandy estuarine facies are considered ore. The oil sands is very uniform in mineralogy, but contains interbedded lenticular beds of silts, shales and clays. Thicknesses have been reported up to 40 m for the Middle McMurray member (Dusseault, 1977).

The fluvial, Lower McMurray, formation consists of lenticular beds of conglomerate, sand, shale and silt with a basal strata comprised of residual clay sediments overlying an eroded Devonian limestone. These sediments are confined to depressions of restricted drainage paths on the underlying erosional limestone. Channel sands can occur in the Lower McMurray as infillings of drainage channels, but where they occur below the oil-water contact, aquifers can be created; these aquifers need to be depressurized in advance of mining. The general characteristic of these sediments has been controlled by the topography on which they were originally deposited. In some areas, thick deposits of coarse sand are found where they were probably laid down in a valley on a pre-Cretaceous erosional surface. Whereas in other areas in the formation, boulders of Athabasca sandstone, angular vein-quartz and some white quartzite grains are found. The grain size curve for the Lower McMurray sands and pebble conglomerates fall within the region of Group I in Figure 6-8. The Lower McMurray is absent over large areas of the McMurray formation with its thickness rarely being exceeding 25 m (Dusseault, 1977).

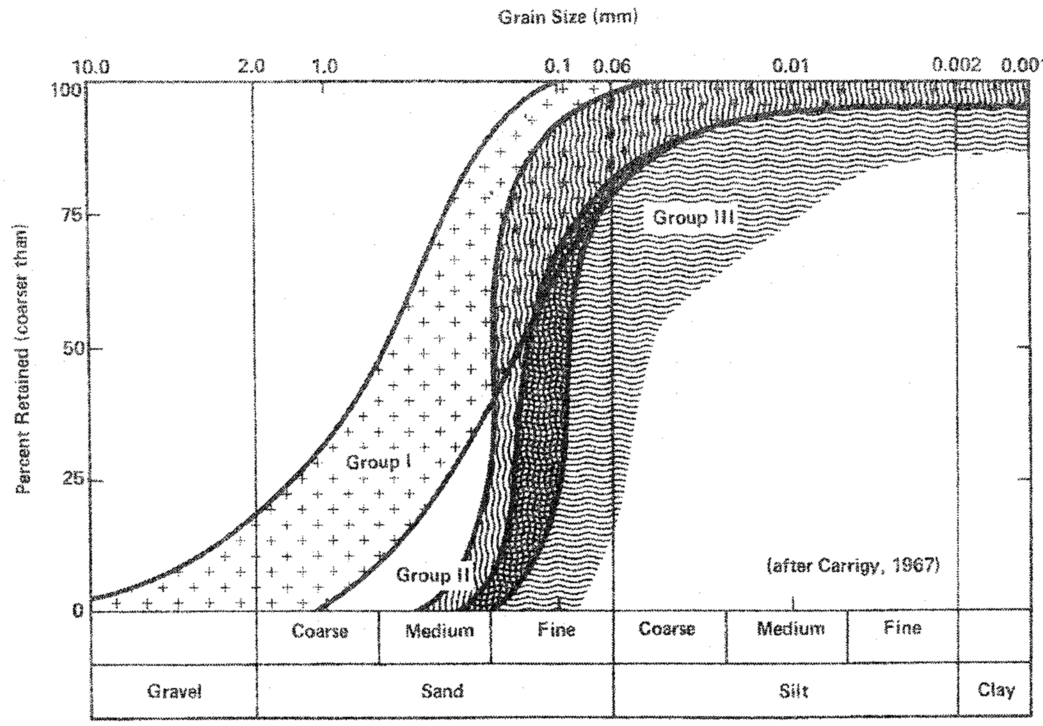


Figure 6-8 - Grain Size Groups for Oil Sands (Dusseault, 1977)

Bedrock Geology

The McMurray formation rests unconformably on an extensive erosional surface of argillaceous limestone, calcareous shale and limestone of Upper Devonian age (Norris, 1973). The basal unconformity represents about 250 million years of subaerial erosion alternating with minor depositional periods producing gentle overall relief of about 50 m. The presence of these erodible limestones in conjunction with the underlying Prairie Evaporites has resulted in a series of structural domes and basins whose effects can be seen at surface with relief of up to 100 m. These formations have influenced the paleodrainage patterns and paleotopography with visible drainage channels cutting through the sedimentary structure (Carrigy, 1959).

6.3 Syncrude's Geology and Block Model

6.3.1 Geology

Geology at Syncrude is very typical of the regional geology, but has been further classified using facies codes that describe precise changes in the mineralogy, texture and deposition. These codes are how each facies is tracked within the block model and subsequently linked to each truck via GPS. When a shovel is excavating a bench, its elevation is used in conjunction with the elevation of the top of the mined bench to assign blocks to a truck. As each block contains information regarding volume and geology, the total volume and geology contained in each truck can be easily tracked and calculated based on the blocks dumped into it.

6.3.2 Block Model

Syncrude has had a method of ore reserve estimation in one form or another since start-up in 1978. Early techniques followed a conventional petroleum reservoir analysis format, with relatively widely spaced drill holes and semi-quantitative grade data. Experience has developed a more standard mining approach, including classification of geological materials by lithology and sedimentary origin, timely and multi-purpose drill holes, precise analytical data, empirical recovery factors, a computerized geological database and an ore body block model.

A geologic block model is a common tool used to summarize known information about the geology. It is used in resource estimation, mine planning and engineering. The basis for the block model is the drilling program and its associated assayed values. Exploratory drilling done up to 25 years in advance has a spacing of about 300 m and provides approximate information. Production drilling, which is used for the Five Year Mine Plan, has a much denser drill hole spacing to provide more confidence in the geology. While the actual spacing is a function of geologic complexity, typically spacing follows a 100 m by 150 m grid (O'Donnell and Ostrowski, 1992). All cores are sent to the Syncrude laboratory on site where they are frozen and slabbed in half. Half of the core is used for description while the other is used for analysis. Geologists describe the core and record all pertinent geologic information as well as select appropriate sample intervals used for analysis. Weight percentages of bitumen, water and solids are done during analysis with any material passing a 44-micron sieve classified as fines. Once all the drill holes have been assayed and reported, the construction of the block model can begin from the geologic database.

The basic concept in constructing a block model is to divide the entire ore body into smaller blocks containing an average value for all the properties pertinent to that volume of material (Stanley, 1978). Syncrude's block model is based on four sub-horizontal surfaces used to define the economical minable region of the deposit. Zone surfaces are generated corresponding to the top of 6% bitumen (T-6), top of minable oil sands (TMOS), bottom of minable oil sands (BMOS) and bottom of 6% bitumen (B-6). A grid is superimposed on the mine area with a 30 m by 30 m spacing with varying thickness. Each block is divided into sub-zones with the values of each sub-zone being assigned from the calculated assay or the oil/water/solids analysis file. Defining the attributes for a particular block is accomplished by using geostatistics whereby a weighted average from surrounding drill holes are taken and a value is assigned for the block. This method is used for defining each attribute of each block in the model.

Improvements are continually being made for enhancement of existing techniques for block model construction by using complex geostatistical algorithms, quantification of confidence limits, and improved control of the ore model by geological parameters. Syncrude currently uses a mine planning software package (Surpac) that addresses the following issues: change of technology to shovel/truck mining, very large mining models, planning for future mines and existing software was no longer the best tool for the job. Application of

Surpac for mine modeling, reduction and dilution of ore and waste, bitumen calculation, economic criteria, bench design, pit design, volumetrics, and dump design has been used to date (Beers, 1997).

6.4 Geology and Lump Generation

6.4.1 Background

During the study period from July 2001 to June 2003, 57 individual facies were encountered. This large number makes any correlations or analysis difficult, thus a composite of facies was done according to geological descriptions reducing the number of facies groups to 25. In addition, any facies groups that did not produce at least 3% of the total annual volume were neglected. This criterion further decreased the number of facies groups to 7: 95/15, 96/16, 12/13, 10/9, 7/8/11, 6/26 and UNKNOWN.

Using the volume of material originating from each of these facies groups, a geological cross-section was produced showing the relative amount of mined material processed from each group. Figure 6-9 shows this cross-section as well as which formation these facies belong to. It can be seen that the majority of the oil sands is derived from the Middle McMurray with facies group 7/8/11 as the predominant contributor. While the geological sequencing may not be exactly as depicted with bands of interburden found throughout the formations, the general depositional environment is consistent with Syncrude's Lithofacies chart. The UNKNOWN unit below the Lower McMurray is geologically not present, but is displayed as a reference of the quantity of material that was derived from that facies.

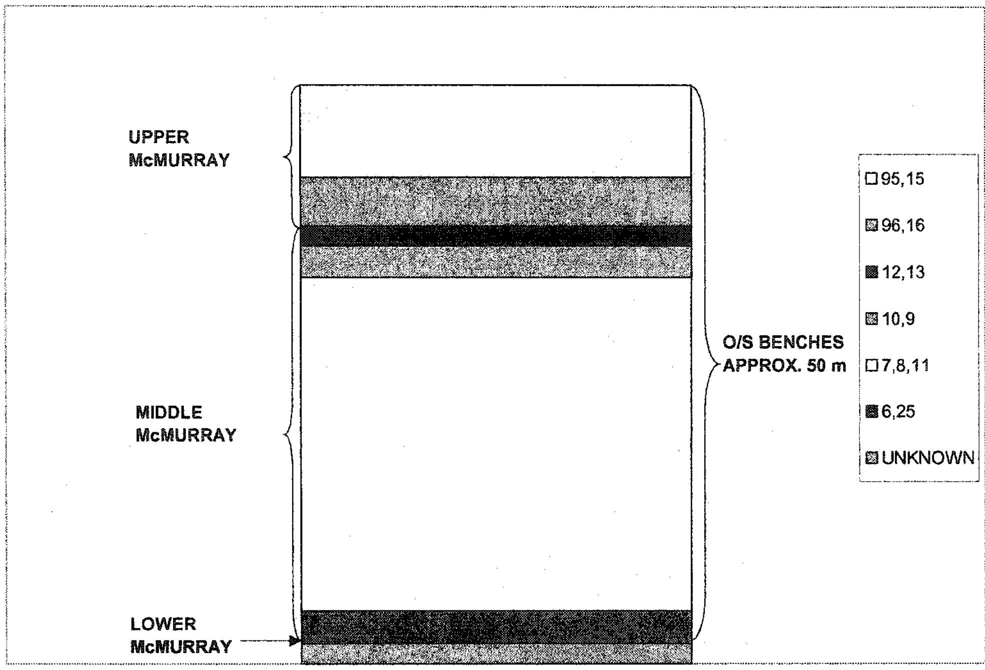


Figure 6-9 - Syncrude Facies Cross-Section based on Volume Mined

6.4.2 Effects of Geology on Lump Dump Activity

The effects that geology has on lump dumps are first investigated by comparing the volume contribution of each facies group. Figure 6-10a shows that facies 7/8/11 is the largest lump dump contributor at almost 700,000 BCM while another 500,000 BCM is from facies 95/15 and 96/16 with facies group 12/13 as the lowest at 21,000 BCM. Facies groups 7/8/11, 95/15 and 96/16 also produce the majority of the production for the North Mine with facies 7/8/11 being Middle McMurray, and facies 95/15 and 96/16 Upper McMurray. To provide a more meaningful comparison between facies groups, lump dump volumes will be normalized by the total volume mined from each respective facies group. As the lump dump's activity is localized between November and May, these volumes will be normalized by the total quantity mined during this period. Figure 6-10b shows the UNKNOWN facies is a relatively high contributor at 5% of its volume being send to the lump dump; however, since the true geology of this facies is indeterminable, little improvements could be made except to reduce the amount of UNKNOWN coded material in the QPD. Facies 95/15 and 96/16 stand out as the worse at over 5% of their volume being assigned to the lump dump. These figures indicate that the Upper McMurray formation is the most likely generator of lump dump loads.

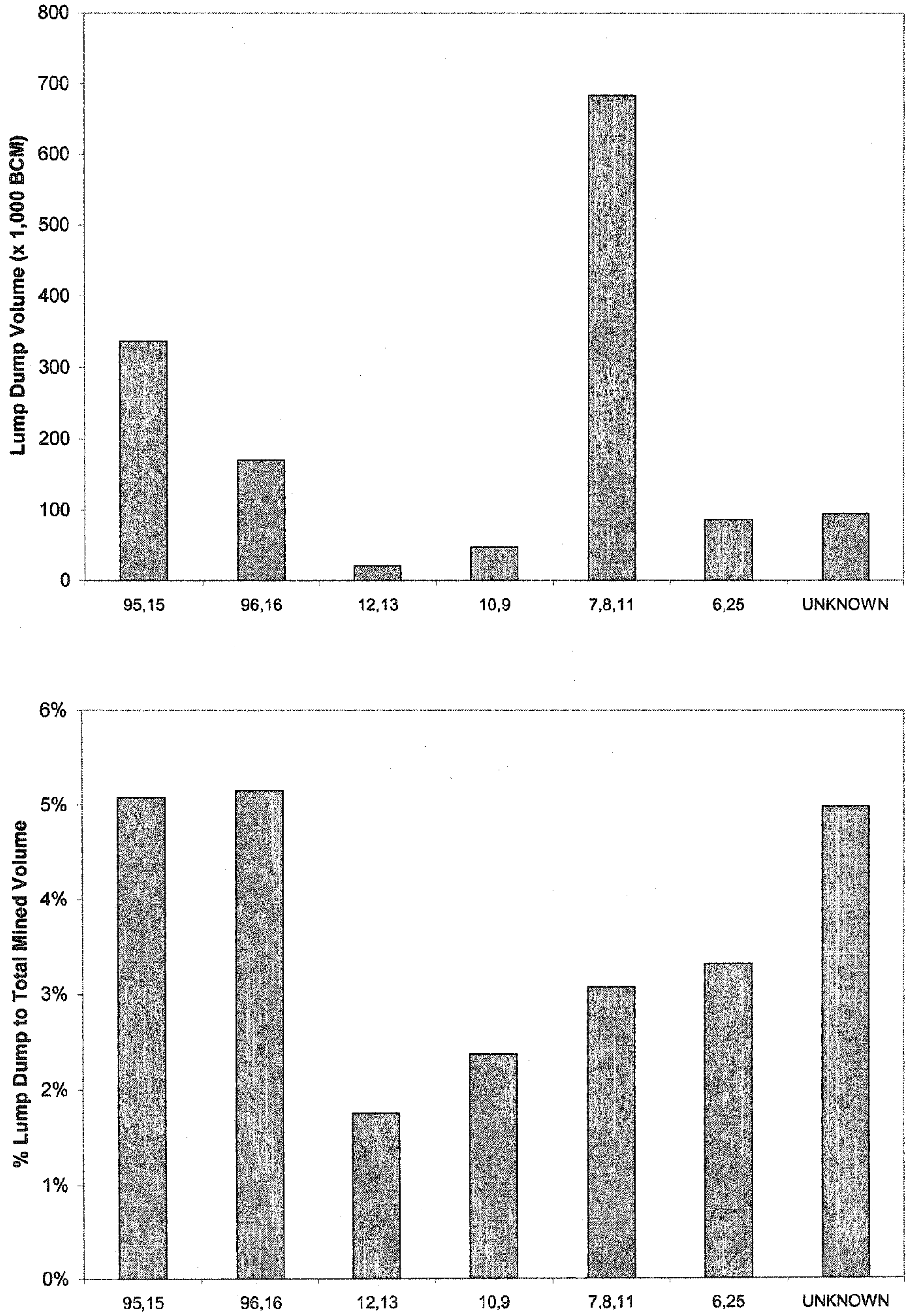


Figure 6-10 - Facies a) Lump Dump Volume b) Normalized Lump Dump Activity

The effect that shovel type might have on the excavation of these facies is also analyzed. Figure 6-11 shows the normalized lump dump activity for each facies group subdivided into shovel type. The hydraulic shovels show more variability among the facies groups than the cable-electric shovels, yet consistently more likely to send a load to the lump dump; as much as 8% of a facies group' excavated volume can end up delivered to the lump dump. However, regardless of shovel type, facies groups 95/15 and 96/16 are among the higher percentage facies contributors to the lump dump. This trend suggests that shovel type, while maintaining a difference between the two types, is not the major factor in the high lump dump activity of the Upper McMurray facies groups. Geology, specifically the Upper McMurray facies groups, remains a highly probable lump dump contributor.

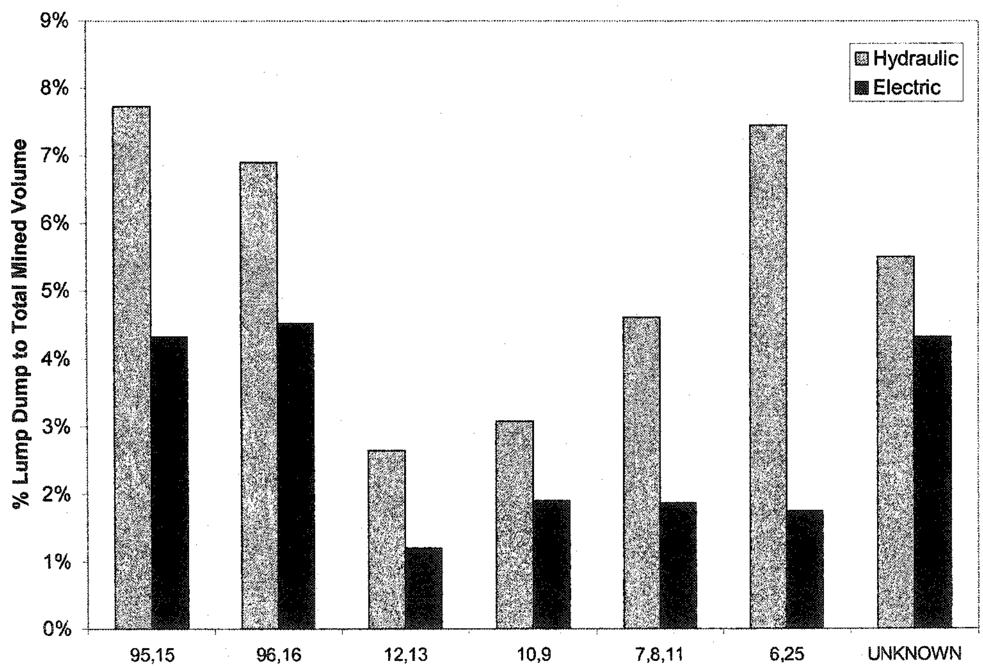


Figure 6-11 - Normalized Lump Dump Activity by Facies and Shovel Type

6.4.3 Effects of Geology on Lump Jam Events

Determining the effects that geology has on lump jams show that the Upper McMurray facies groups have the highest likelihood of lump jams. Using the same 7 facies groups analyzed during the same periods from November to May as in lump dump analysis, Figure 6-12 was generated. The raw number of lump jams is similar to the distribution among the facies groups found in lump dump activity with facies 7/8/11 as the highest with over 500 and facies groups 95/15 and 96/16 as the next highest with over 300 cumulative lump jams. Normalizing these occurrences by the quantity of million bank cubic metres (MBCM) mined from each respective facies group shows that facies groups 95/15 and 96/16 are the most likely to generate a lump jam at approximately 35 lump jams per MBCM while facies group 7/8/11 shows 26 lump jams per MBCM. These figures have similar trends to those of lump dump activity, and thus similar conclusions can be made regarding the effects of geology on lump jams: the Upper McMurray is the most likely member to generate a lump jam.

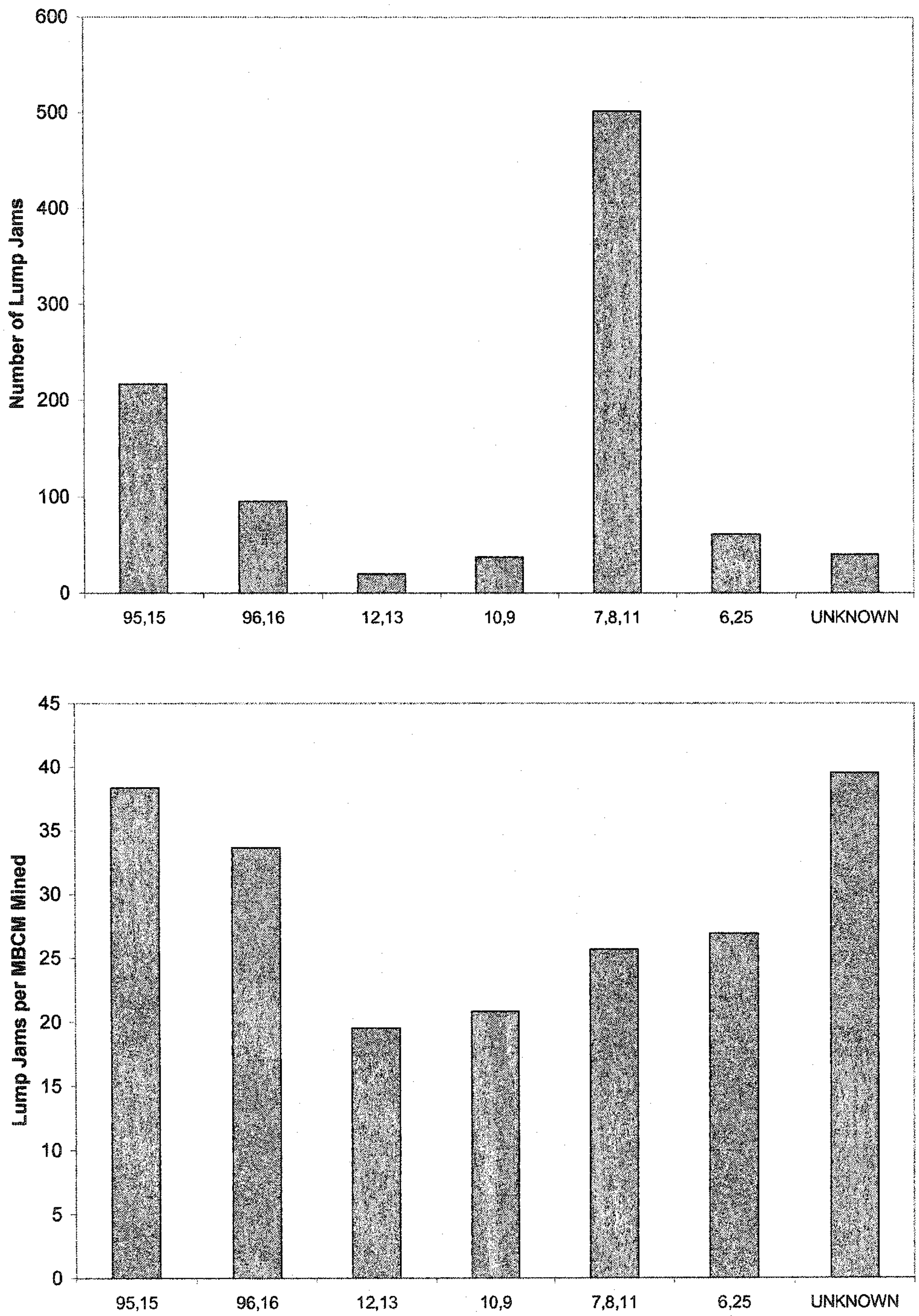


Figure 6-12 - Facies Group a) Number of Lump Jams b) Lump Jams per MBCM Mined

Upon examining shovel type and facies group relationships for lump jam events, results were consistent with findings thus far. Figure 6-13 indicates that neither hydraulic nor cable-electric shovels are more prone to generate a lump jam in any facies group. This differs from findings presented in the effects that geology and shovel types have on lump dump activity where hydraulic shovels were more likely than cable-electric shovels, yet consistent with those findings presented in *Chapter 5 – Equipment*, where no shovel type was more prone to generate a lump jam than another. Nevertheless, for each shovel type, facies groups 95/15 and 96/16 where among the more probable to generate a lump jam. These findings further reinforce that while geology has an impact on lump generation, shovel type may not. Other factors are creating the discrepancy noticed between the shovel types for lump dump activity in Figure 6-11.

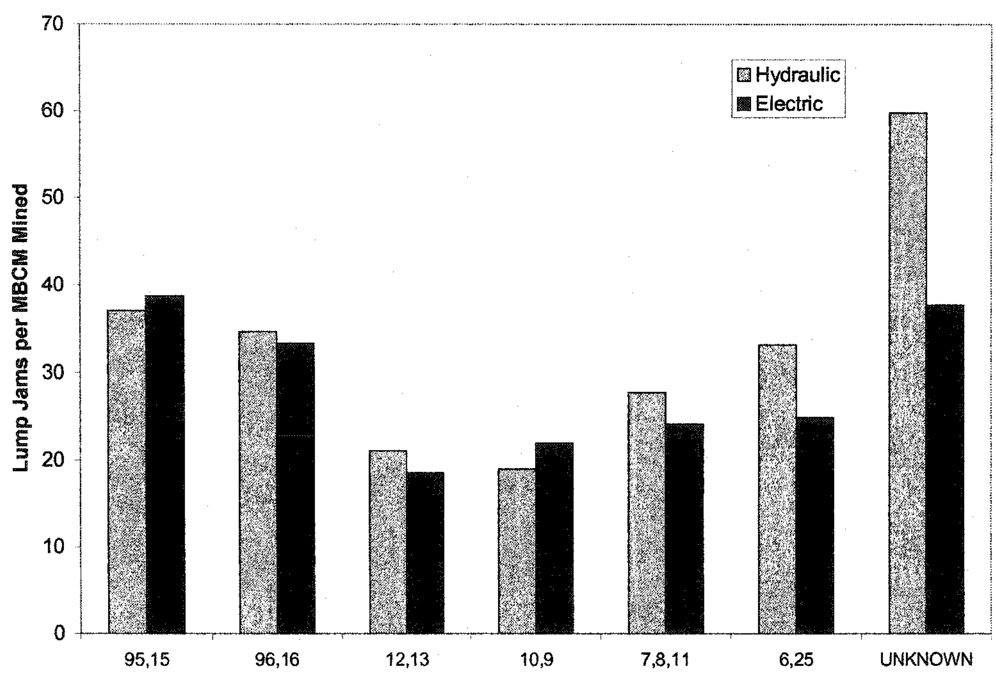


Figure 6-13 - Normalized Lump Jam Events by Facies and Shovel Type

Further analysis of lump jam events by separating the lump jam occurrences by crusher yielded a discrepancy between NMFB6 and NMFB7. The number of lump jams from each facies is subdivided by crusher in Figure 6-14a and shows that NMFB7 creates more jams than NMFB6 regardless of facies group. Normalizing the lump jams by the number of million bank cubic metres (MBCM) delivered to each crusher is done in Figure 6-14b. This plot shows the consistency of NMFB7 in generating as much as twice as many lump jams than NMFB6 ranging from 28 to 48 lump jams per MBCM depending on the facies group. Additionally, facies group 95/15 and 96/16 (Upper McMurray) are the most prone, albeit much more likely for NMFB7.

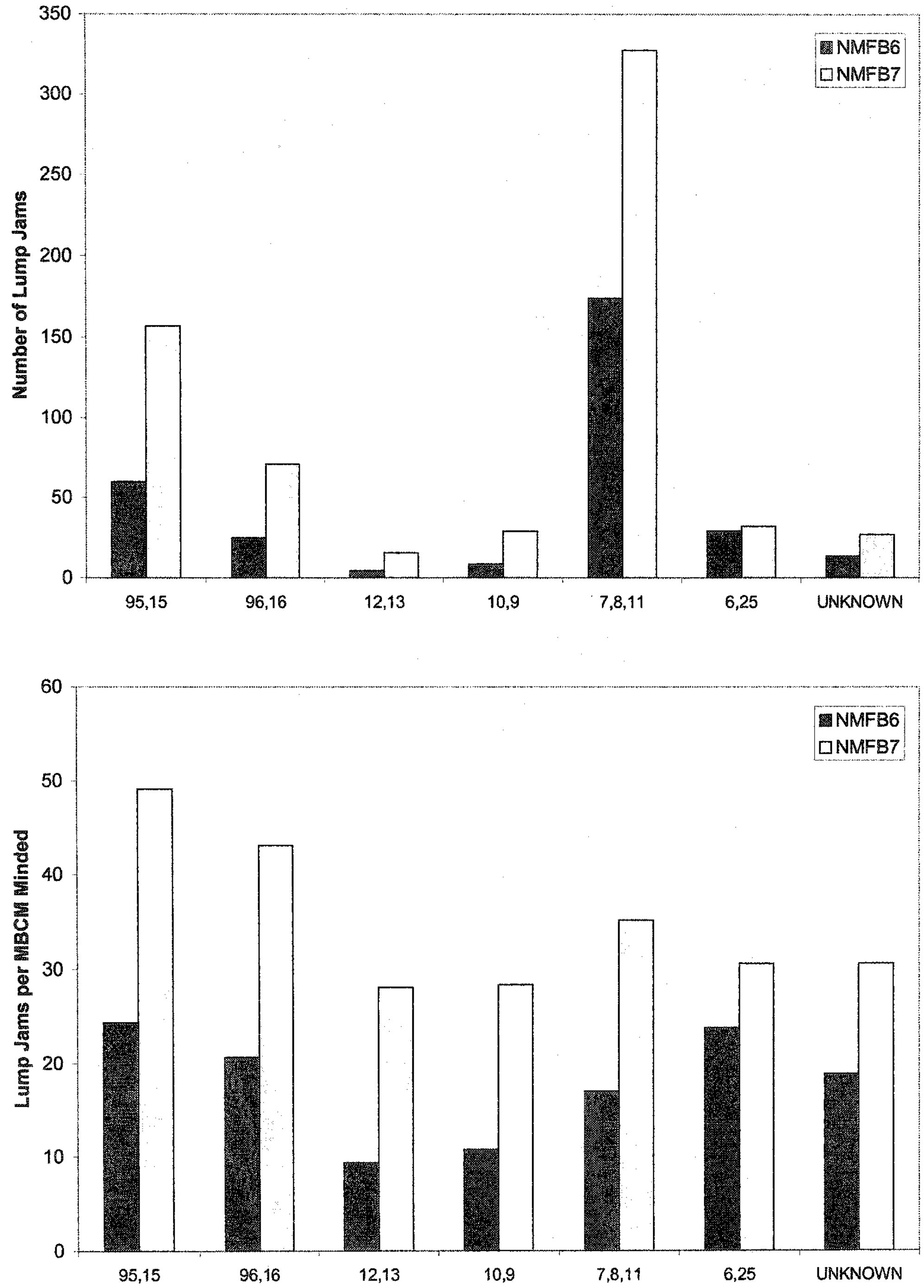


Figure 6-14 – Facies Group and Crusher a) Number of Lump Jams b) Lump Jams per MBCM Mined

6.5 Summary

The Athabasca oil sands is a tripartite layered sequence of marine (Upper McMurray), estuarine (Middle McMurray) and fluvial (Lower McMurray) deposits overlain with glacial deposits and underlain by Devonian limestone. Syncrude geologists have further subdivided the oil bearing McMurray formation into over 100 individual facies each with a unique lithology, texture and structure. Through the study period of this thesis from July 2001 to June 2003, 57 individual facies were encountered. Compositing of these facies was done based on similar geologic descriptions and contributions to a minimum of 3% total annual mined volume. The reduction to seven facies groups facilitated easier analysis and correlation.

When investigating the effect that geology has on lump generation, a number of interesting trends were discovered. The Upper McMurray facies groups 95/15 and 96/16 are more likely to generate lump dump loads as well as lump jams than any other facies groups. Up to 5% by volume mined during the winter can be delivered to the lump dump and approximately 35 lump jams per MBCM mined can be expected. Examining the relationship between geology and shovel type revealed that, although hydraulic shovels are more likely to produce lump dump activity than cable-electric shovels, the Upper McMurray facies was a highly probable unit for both shovel types. However, the number of lump jams per MBCM mined was approximately the same for each shovel type, regardless of facies group. These findings suggest that geology has an effect on lump dump activity and lump jam events, but shovel type only has an effect on lump dump activity. In addtion, NMFB7 generates more lump jams per MBCM delivered than NMFB6 regardless of feed, further indicating some difference exists between the two crushers.

The lithology of Upper McMurray is characterized by clayey-silts to fine-grain sands with an average moisture content approximately 2% higher than the Middle McMurray. Perhaps this slight difference in moisture and/or the presence of finer grained soils, as seen in Figure 6-8, can account for the Upper McMurray being more prone to lump dump activity and lump jam events. The added moisture when frozen would strengthen the oil sands creating a structure more difficult to excavate. Interestingly, this formation coincides with the top oil sands benches in the mine. Results from *Chapter 7 - Mine Planning and Other Effects*, show that the top benches are also among the more likely to generate lump dump loads. This makes the conclusion that geology alone may not be generating lumps, but its contribution to lump generation cannot be neglected.

7 MINE PLANNING AND OTHER EFFECTS

7.1 Introduction

Through the course of this thesis, equipment, geology and climate were investigated as to potential sources of the occurrences of lump dump activity and lump jam events. However, another major factor to consider is the operational conditions within the mine, such as the benching scheme, the downstream demand for oil sands, the time of day and the operators. Planning of the mine sequence, both long and short range, has an impact on lump generation through its ties with the other factors. Plant demand and daytime versus nighttime operating conditions are other suggested factors that may prove detrimental in the generation of lumps. Operator experience is another factor that effects lump generation as well as the manner in which frozen lumps are managed.

7.2 Mine Planning and Lump Generation

7.2.1 Background

In situ oil sands in the North Mine is excavated using a benching scheme found in many open pit mines. Shovels on the bench excavate material from the face and load haul trucks that deliver the oil sands to the crushers and waste material to dumps, dykes or other structures. Figure 7-1 shows a schematic of the mining process used in the North Mine.

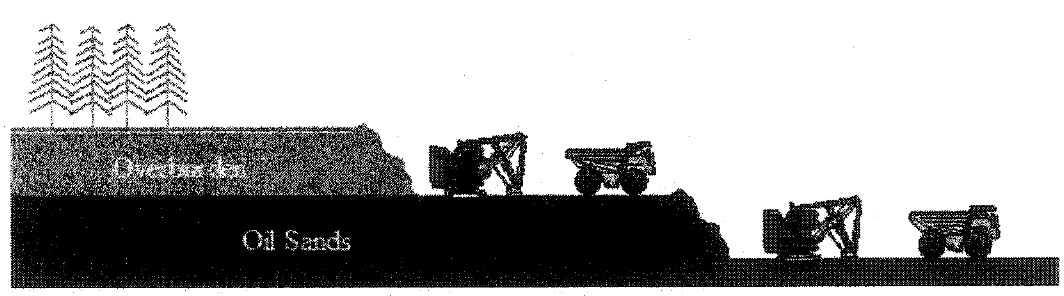


Figure 7-1 - Schematic of Benching Scheme in an Open Pit

At Syncrude, each bench elevation is based on a mine-specific coordinate system. Typically the top oil sands bench is referred to as the NM (North Mine) 288 with the bottom bench varying depending on location from NM256 to NM245. The true elevation is seldom exactly these elevations, but for planning and database purposes, these are examples of some of the common names used when referencing benches. The name is based on the elevation that the shovel sits on, but the mining face extends up to 18 m higher than the bench name. For example, a shovel mining the NM288 bench can be excavating a 17 m face from elevation 288 to 305.

The height and elevation of a bench is a function of a shovel's maximum digging height and/or the location of specific geologic facies. Generally the cable-electric shovels have higher digging faces than the hydraulic shovels, but the hydraulic shovels are more efficient over a wider range of bench face heights due to their flexible digging trajectories. Bench faces can range from 8 m to 18 m in height, which explain the varying bench elevation names from NM245 to NM288. Usually only the top and bottom oil sands bench correspond to change in a major geologic unit, such as between the Clearwater clay (overburden) and the top of the minable oil sands (NM288) and the bottom minable oil sands bench and the Devonian limestone. Although the other benches can be designed to strip to an interburden band, it is often not done (Wright, 2004).

The origin of oil sands used in the production of bitumen comes from a variety of sources both from the dragline/bucketwheel and the truck - shovel methods. As this thesis considers only oil sands delivered within the North Mine, the total number of tagged sources of oil sands within the Quality Production Database (QPD) from July 2001 to June 2003 is 130. As was done with geologic facies, the origin locations are composited for simplicity. Origin locations were reduced to bench elevations with any distinctions due to lateral location neglected. Furthermore, their contribution to the total annual mined volume must have been at least 3%. The remaining origin locations were reduced to 7, which are based on bench elevation, such as NM288 or NM245, or uniquely identified sources, such as the Lump Dump.

The sequencing of the mine benches is referred to as planning, and relies upon taking into account a number of factors. As mining is the start of the process, it must adapt to the demands of the downstream processes. This translates to a dynamic environment that must juggle a great many priorities as best as possible. Geologic variations in bitumen and fines, downstream demands on blended oil sands, and volume requirements of overburden and tailings for structures are all priorities that are met on a daily basis. In addition, long-range objectives must be considered with maximum utilization of equipment in the most cost effective manner possible while minimizing maintenance costs. This is not an easy task. It requires many engineers, geologists, planners and operators to work in collaboration. As a result, mine plans remain relatively simple with as little variations as possible.

7.2.2 Effects of Bench Design on Lump Dump Activity

When investigating a relationship between lump dump activity and origin location, Figure 7-2a identifies the volume delivered to the lump dump versus origin location. The lowest elevation bench (NM245) produces less than 100,000 BCM of lump dump volume while the highest elevation bench (NM288) produces more than 500,000 BCM. Normalization of the lump dump volume is necessary to gauge the potential for a particular origin to generate a lump. However, since lump dump activity is localized to the months of November to May, only the volume produced during these months will be considered for normalization. Upon normalizing (Figure 7-2b), the percentages vary by origin between 1% and 7%. The top NM284 bench is the most probable to generate a lump with nearly 7% of its volume being assigned to the lump dump, while the bottom NM245 bench becomes the second most probable at 6% of its volume being assigned to the lump dump. The lump dump, as an origin, does not appear to be a major contributor in generating additional rehandle volume, moreover, mining of the lump dump only incurs secondary rehandle of 2%.

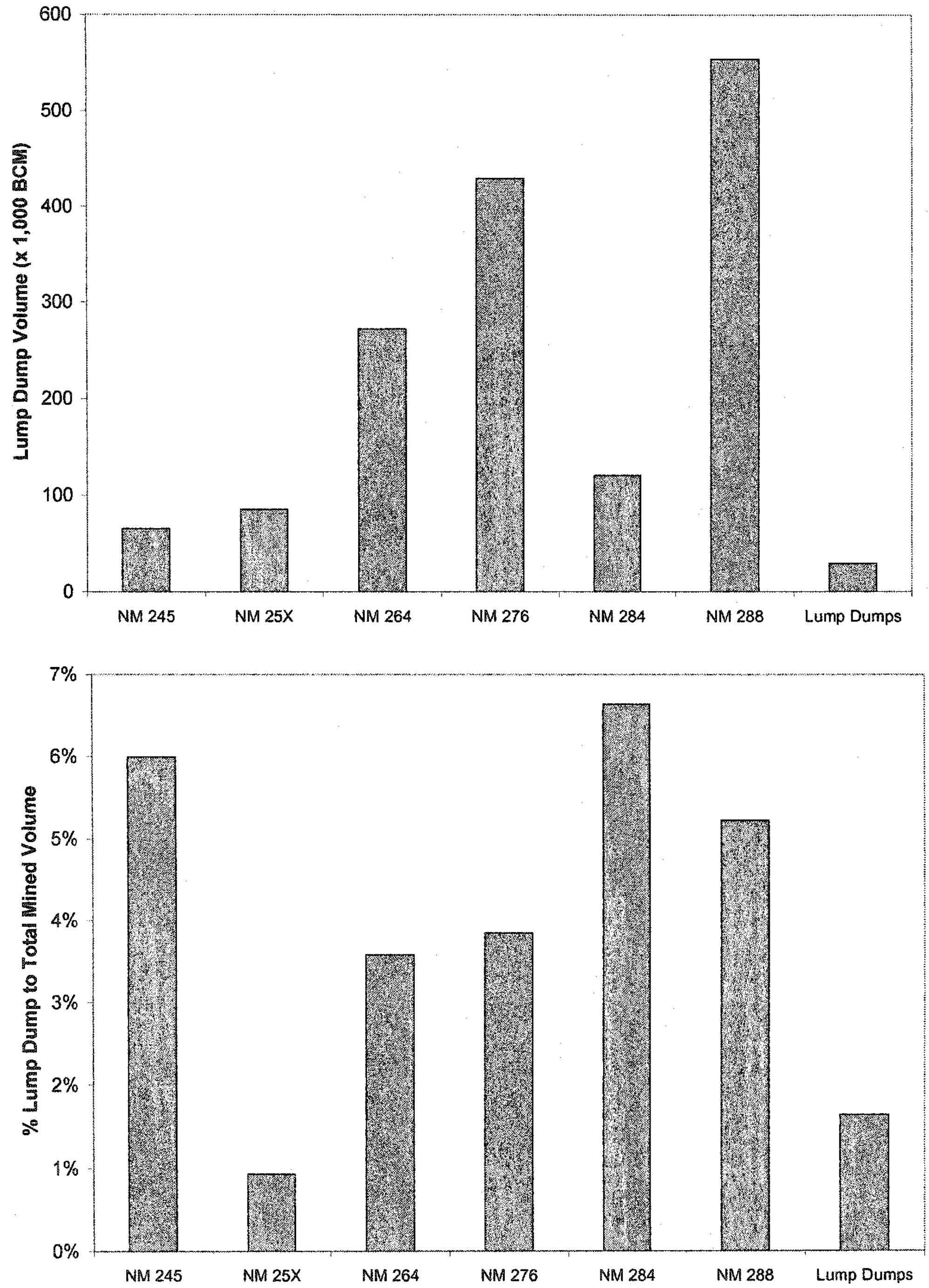


Figure 7-2– Origin Location a) Lump Dump Volume b) Normalized Lump Dump Activity

These figures indicate that the lump dump follows a weak relationship whereby the higher elevation benches generate more lump dump volume than the lower elevation benches. On a normalized comparison, when accounting for the small absolute volume mined from the NM245 bench, the higher elevation benches are slightly more probable than the lower elevation benches to generate a lump dump load. Operationally, the most improvement in reducing rehandle can be made by focusing on the higher elevation benches; however, lump jam events should not be neglected. As the lump dump is a means of reducing lump jam events, a more serious operational concern, priority should be given to reducing lump jams. The reduction of lump dump volume should not result in an increase in lump jam events.

Relating shovel type to origin location is useful in determining if any correlations may exist. A plot of the normalized lump dump activity for each origin location and subdivided into shovel type is done in Figure 7-3. This graph reveals that regardless of origin, much like facies, the hydraulic shovels are more likely to generate a lump dump load than the cable-electric shovels. These findings agree with those presented in the *Chapter 5 - Equipment* regarding the increased likelihood of hydraulic shovels generating lumpy loads compared with cable-electric shovels. Moreover, while each shovel type shows similar trends of likelihood of lump dump activity from the various origin locations, there does exist a great deal of variance between the shovel types for each respective origin location. The higher elevation benches show increased likelihood, regardless of shovel type as well. This leads to the conclusion that although origin location does effect the probability of a lump dump load, shovel type in combination with origin location does have an impact on lump dump activity.

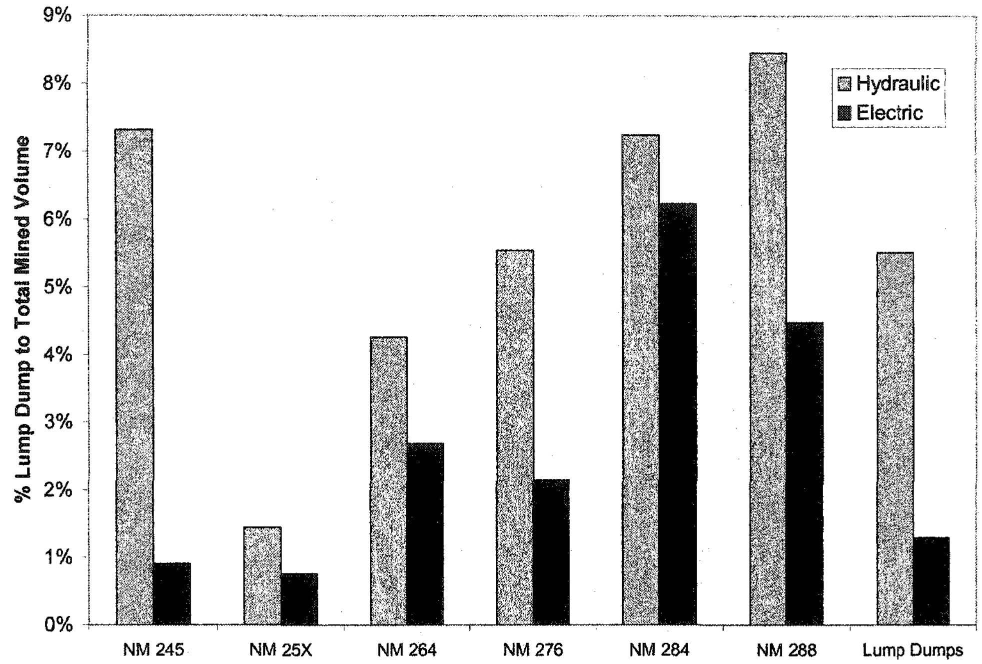


Figure 7-3 - Normalized Lump Dump Activity by Origin Location and Shovel Type

7.2.3 Effects of Bench Design on Lump Jam Events

Analyzing the number of lump jams for the 7 origin locations is plotted in Figure 7-4a. The range in the number of lump jams originating from a particular origin location is from approximately 50 to 320 with a general trend of increasing occurrences as the bench elevation increases. The number of lump jams from an origin location normalized by the total million bank cubic metres (MBCM) mined from that location during the same period as lump dump activity (November to May) is shown in Figure 7-4b.

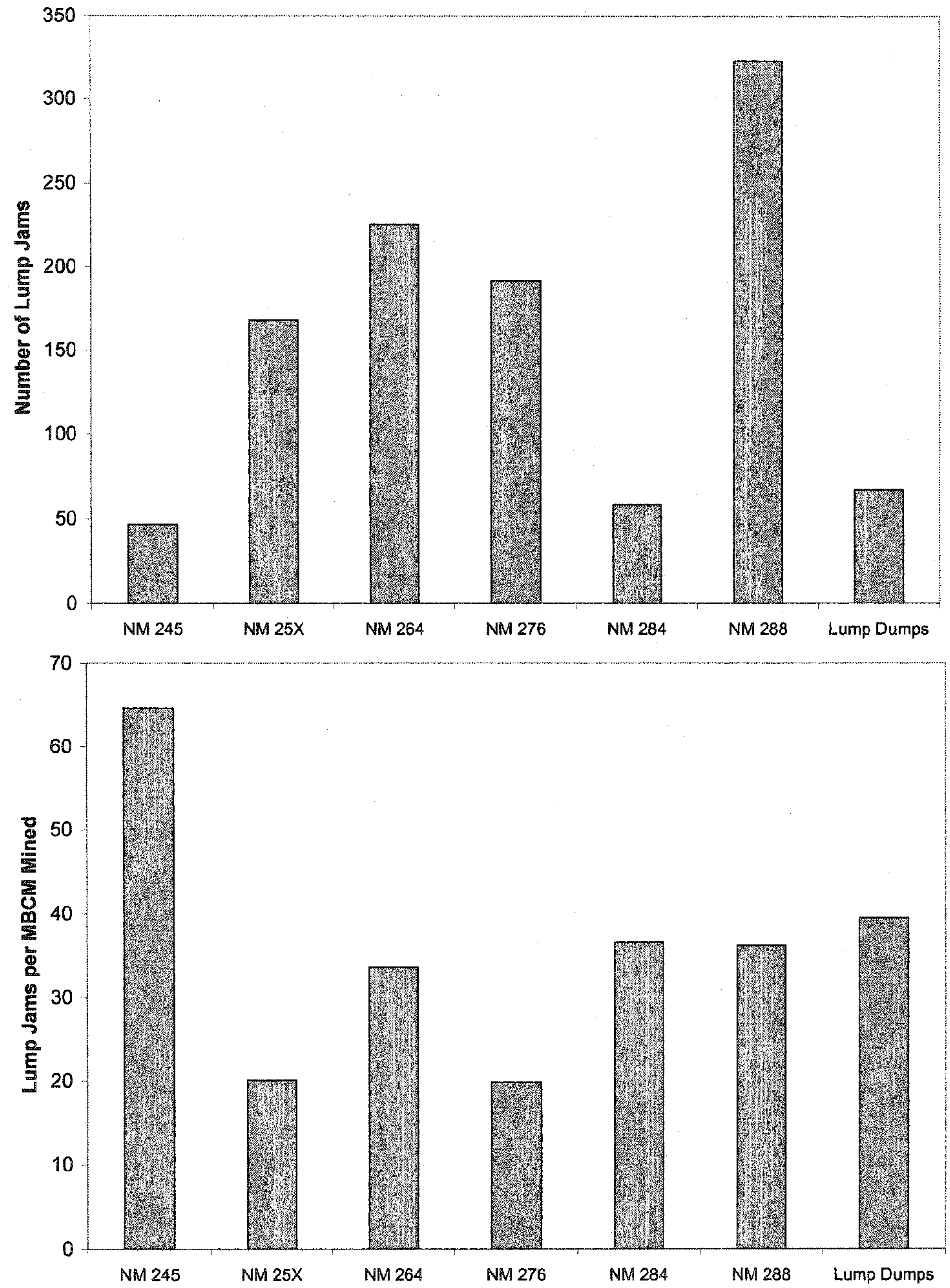


Figure 7-4 - Origin Location a) Number of Lump Jams b) Lump Jams per MBCM Mined

Unlike lump dump activity, lump jams indicate that the bottom NM245 bench is nearly twice as likely to generate lump jam than any other origin location. The NM245 bench generates lump jams at approximately 65 jams per MBCM mined, but it is important to note that this bench is not a major contributor to the total number of lump jam events given the relatively small amount mined.

All other origin locations generate from 20 to 40 lump jams per MBCM mined, thus the findings suggest that no bench is more likely than another in generating lump jams.

Investigating shovel effects on lump jams provides further insight into the differences between the two shovels types and their relationship with origin locations. Figure 7-5 contains the relationship between normalized lump jam events by origin locations and further subdivided by shovel type. Unlike lump dump activity where the hydraulic shovels produced the greatest percentage of lumpy loads based on their total volume, neither shovel type is predominantly producing lump jams from any origin locations. Again, this disconnect between shovel type and lump jam events is shown, as it was in previous chapters. There are other factors besides merely shovel type that is causing the higher percentage of lump dump activity from hydraulic as opposed to cable-electric shovels. As lump jams are quantitative, whereas lumpy loads are qualitative, the conclusion that there is little or no relationship between shovel type and origin location is valid.

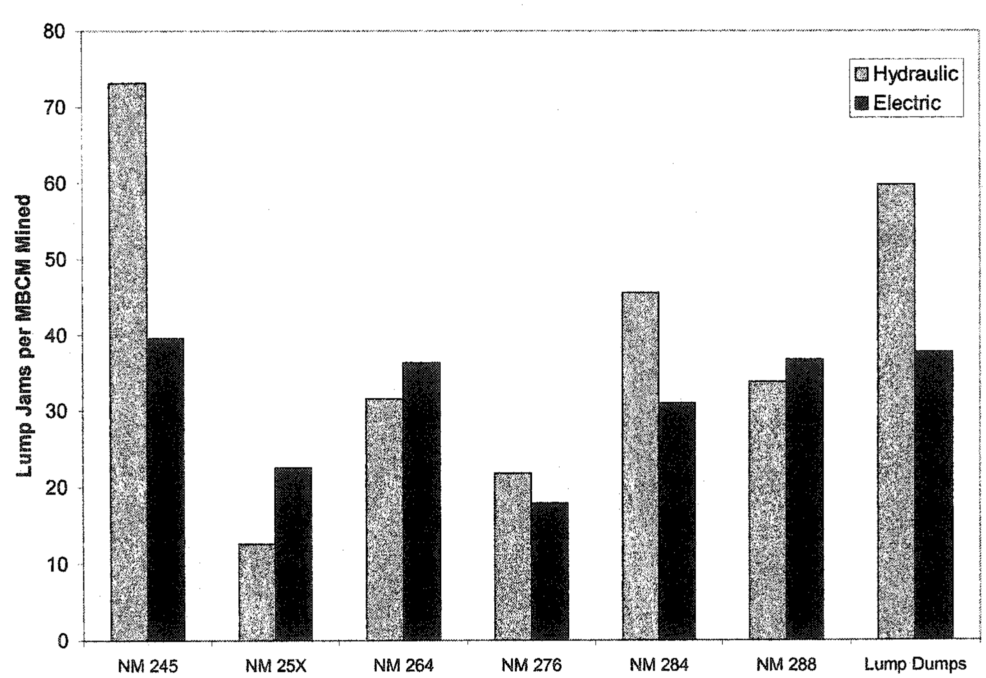


Figure 7-5 - Normalized Lump Jams Events by Origin Location and Shovel Type

Further analysis of lump jam events by dividing up the occurrences based on crusher provides additional information. In Figure 7-6a it is easy to see that NMFB7 creates more lump jams than NMFB6 regardless of which location the material originates from. Upon normalizing the number of lump jams by the total quantity of material (MBCM) delivered to each respective crusher from each origin, NMFB7 is also more probable to generate a lump jam than NMFB6 (Figure 7-6b) regardless of material origin. The NMFB6 creates lump jams uniformly from material originating from all locations while the NMFB7 is slightly more variable. Although the NM245 bench is over 3 times more probable than any other bench to generate a lump at NMFB7, due to the small amount of total material mined from this location during the time frame under study, it is difficult to conclude that this bench is the worst in generating lump jams.

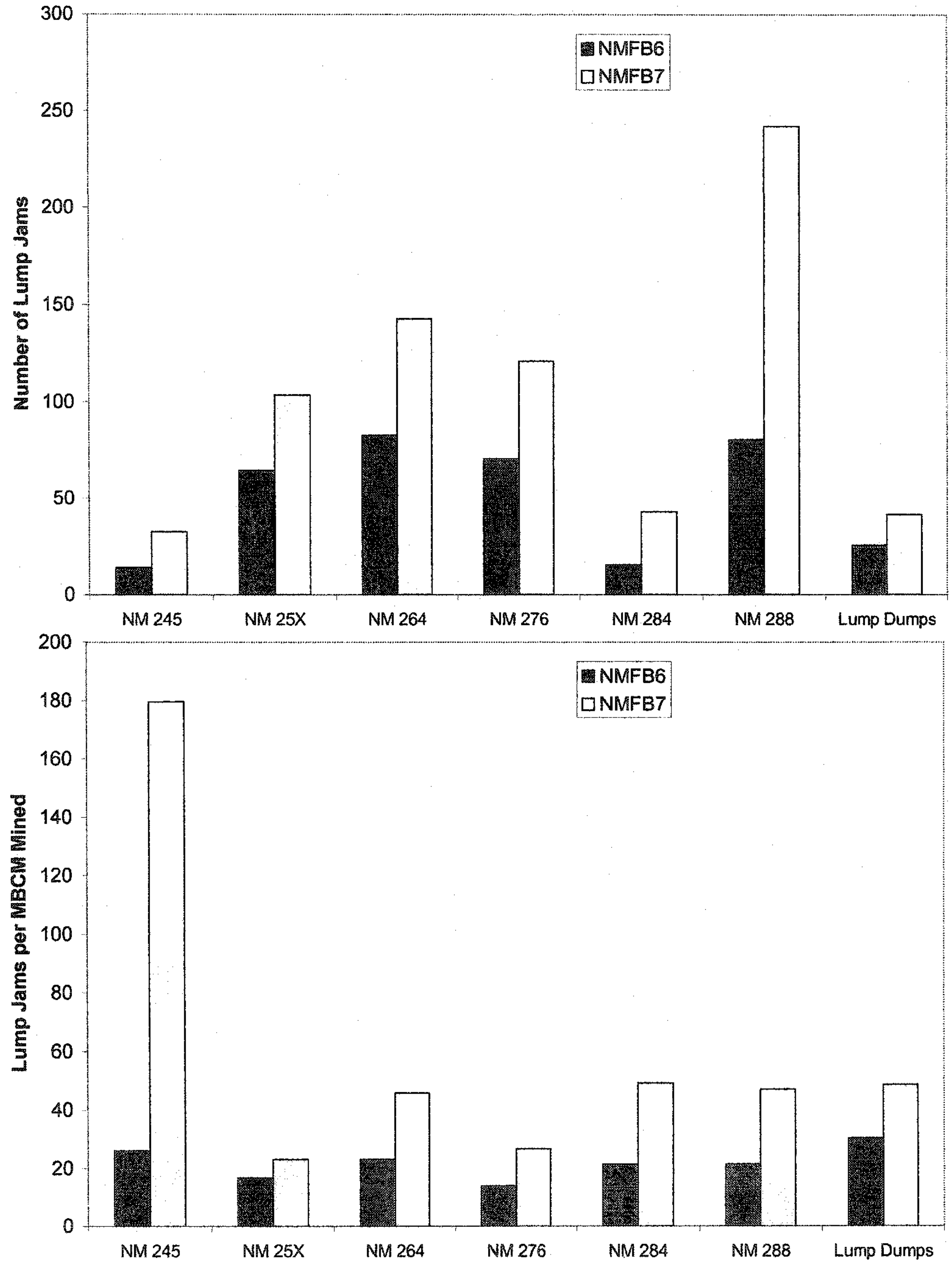


Figure 7-6 – Origin Location and Crusher a) Number of Lump Jams b) Lump Jams per MBCM Mined

Preferentially sending material from one origin to a particular crusher is possible, but in Figure 7-7, which contains the percentage of volume from each bench to the total volume mined during the two winter period (November to May), no significant claims can be substantiated. On the NM245, 264 and 276 benches, less overall material was allocated to the NMFB7 than NMFB6, and still a higher probability of lump jams occurred at the NMFB7 as seen in Figure 7-6b. The operations of these two crushers must differ in some aspect(s), otherwise nearly identical occurrences of lump jams should be found, but this is not the case. Unfortunately at this time, no differences could be identified. Future work may be conducted in this area to determine what factors are creating this discrepancy between the two North Mine crushers.

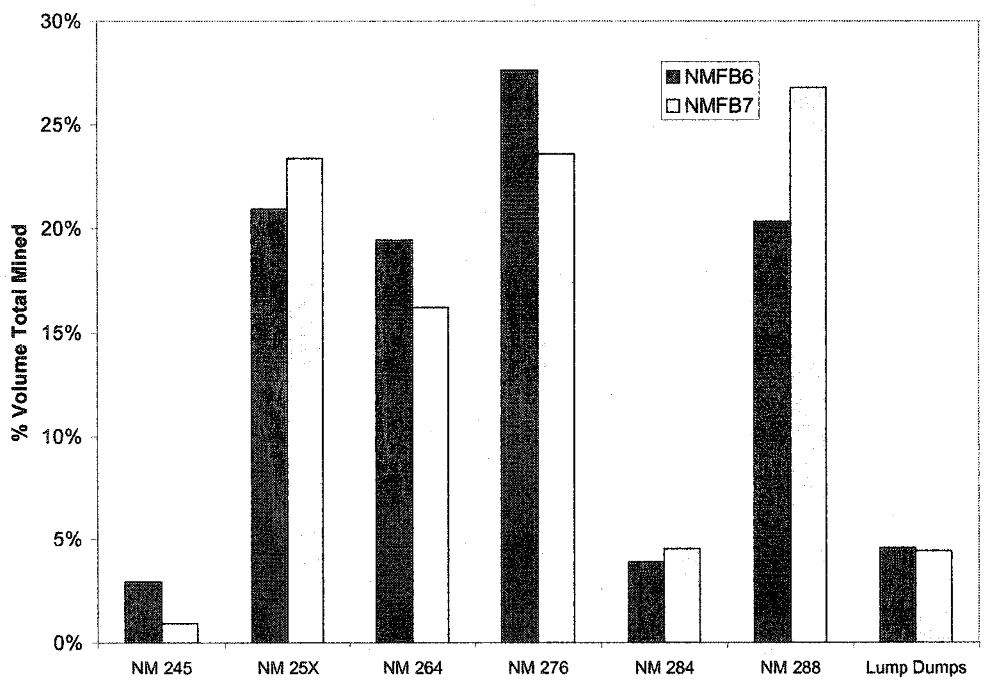


Figure 7-7 - Allocation of Feed by Bench to NMFB6 and NMFB7

7.2.4 Lump Dump Efficiency

The lump dump relies upon thawing of frozen oil sands lumps to reduce lump jam occurrences, thus it should be mined in the spring or summer. Investigation into the months that the lump dump is actually mined, however, is quite revealing. Figure 7-8 shows the amount of material mined from the lump dump with the bars indicating the total monthly volume rehandle from the lump dump along with the total number of monthly lump jams. Mining of the lump dump can start in the middle of winter and proceed until the middle of summer with monthly volumes ranging from 20 kBCM to 420 kBCM.

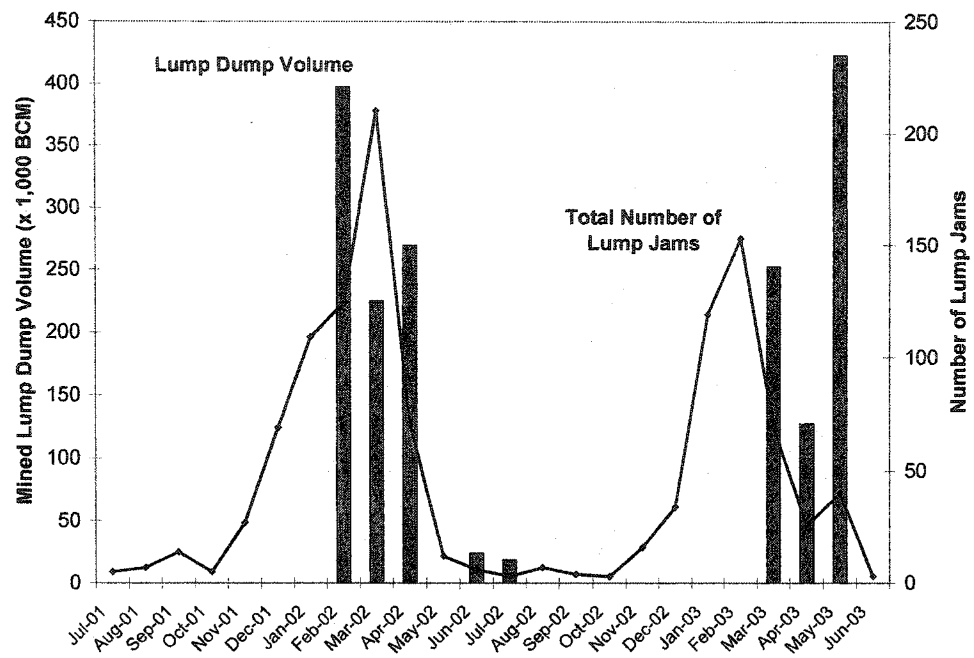


Figure 7-8 - Lump Dump Rehandle versus Lump Jam Events

To determine the impact that mining of the lump dump has on lump jam events, plots were made on a monthly basis showing the number of lump jams (Figure 7-9a) as well as the normalized number of lump jams per MBCM mined (Figure 7-9b) for three origins. Activity from the NM245 bench shows an abnormally large spike in the normalized lump jams in February 2002, which explains the high probability of this bench generating lump jams as seen in Figure 7-4b. Lump jams from the NM284 bench are those of a typical bench. The number of lump jams caused by mining the lump dump is approximately 16 for the winter of 2001/02 with a normalized value of 56 lump jams per MBCM mined. In comparison, for the winter of 2002/03 the number of lump jams was approximately 3 with a normalized value of approximately 13 lump jams per MBCM mined. Whether this difference between the two winters is due to the later mining of the lump dump in the winter of 2002/03, different shovel type or to better experience in handling lumps is difficult to determine. Nevertheless, lump jams are still occurring when mining the lump dump. Thus more time should be allowed for the material to thaw before it is rehandled and delivered to the crushers.

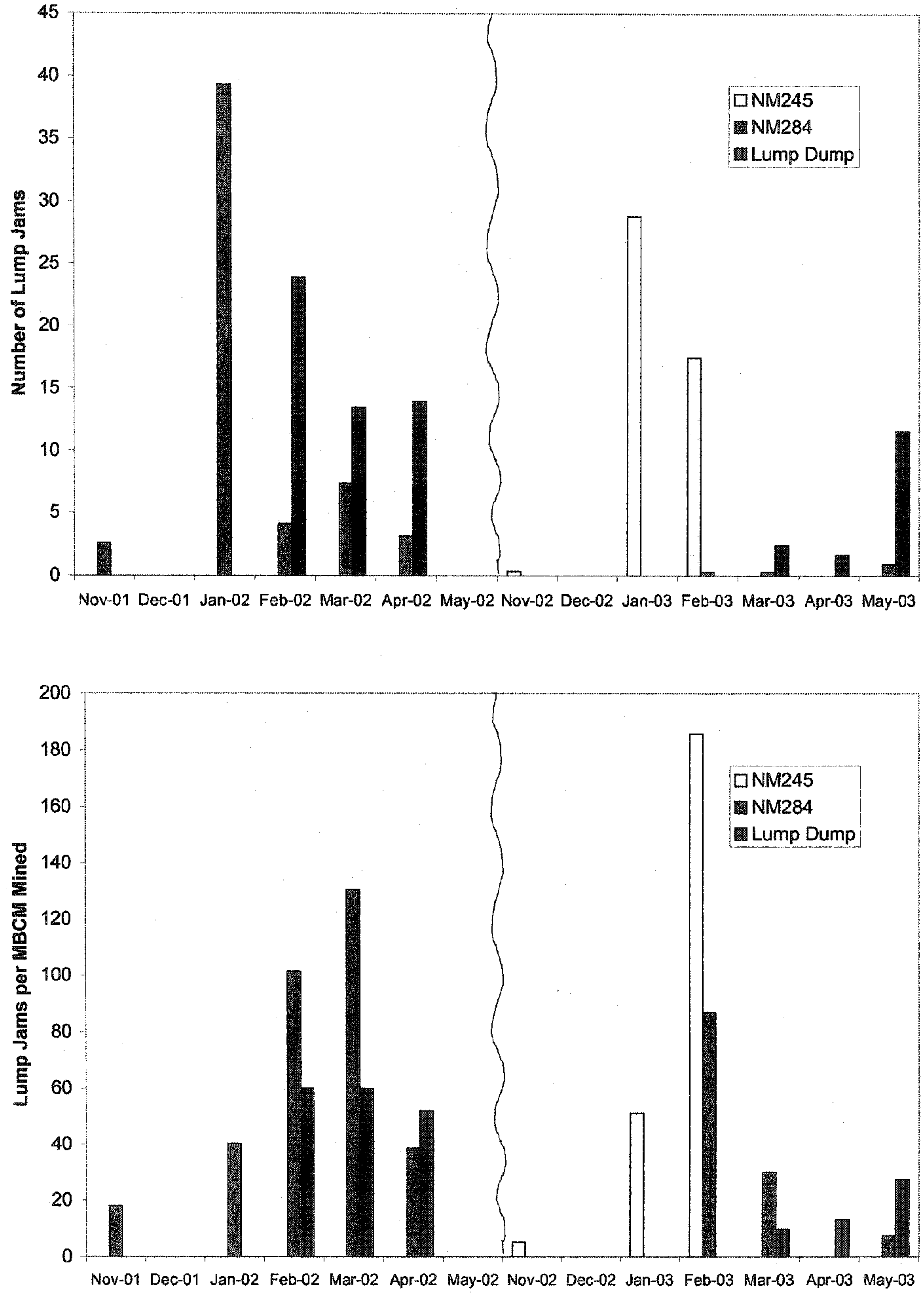


Figure 7-9 - Monthly a) Number of Lump Jams b) Normalized Lump Jams per MBCM Mined by Origin Location

7.2.5 Mine Sequencing Issues

The sequence in which mining progresses has shown a relationship with lump generation. As mentioned previously, bench exposure time is a major factor in the ingress of frost and the mine sequencing plays a critical role in the duration time the bench is exposed to the climate. In addition to exposure time, sequencing also dictates the locations where lumps can be generated, as they are more prevalent in the winter months. In Appendix 4, plots have been generated based on GPS coordinates of shovels loading haul trucks and grouped into monthly advances for each bench: NM245, NM25X, NM264, NM276, NM284 and NM288. During the period from July 2001 to June 2002, the origin location of every oil sands load has been tracked, which include all loads going to the crushers and the lump dump. Some GPS coordinates are not of good quality, thus explaining some of the outlier positions, yet the general trends and areas of active mining can still be inferred with reasonable confidence.

The effect of mine planning on lump generation can be shown using the NM288 bench as an example and comparing its advance (Figure 7-10a) with the origin locations of lump dump loads (Figure 7-10b). Lump dump activity is localized during the winter months from November to May, thus all of these GPS coordinates will be found in this time frame. The duration the bench face is exposed is important as high concentrations of lumpy loads are often found on the fringes of the advance where the bench face has been exposed to the climate. Examples of this is found during the months of February and March where bands of lump dump loads can be seen in Figure 7-10b that coincide with the excavation of the exposed bench face after being left inactive for a period of time ranging from weeks to months. Since frost penetration relies upon temperature below zero and ground cover, only a matter of weeks is all that is required for an exposed bench face in the middle of the winter to develop a frozen crust of oil sands.

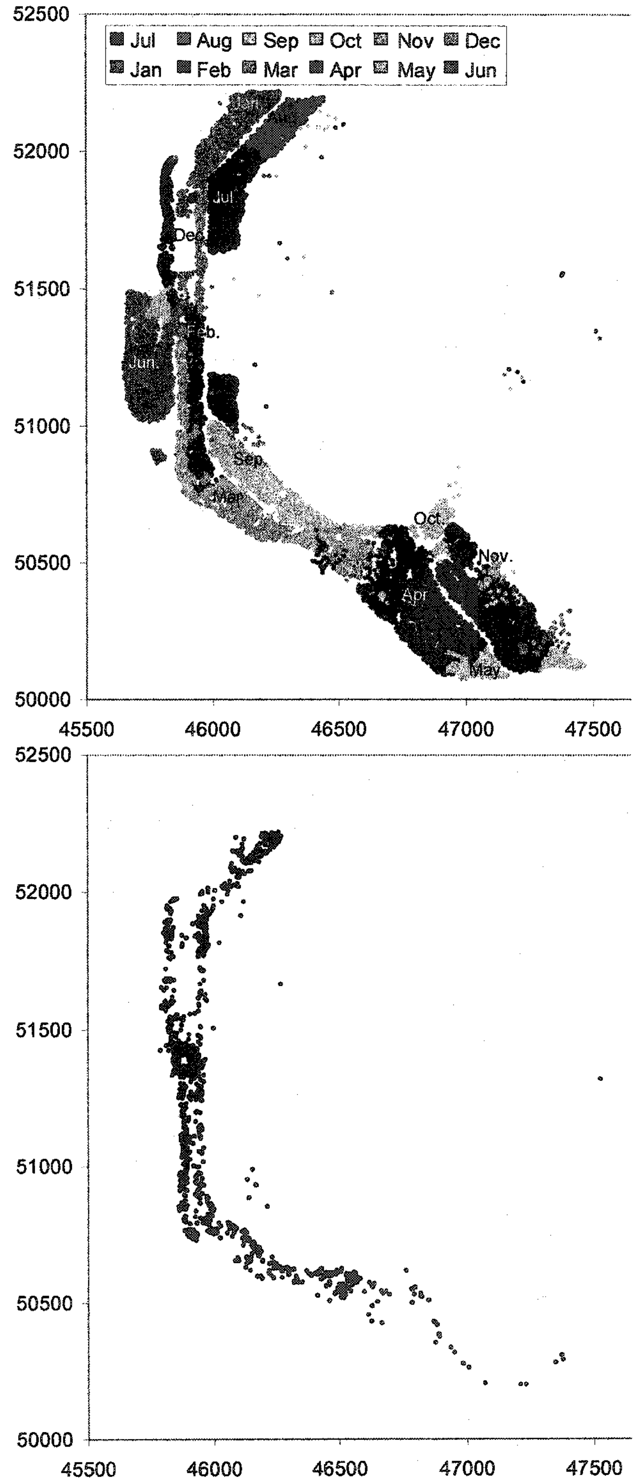


Figure 7-10 - NM 288 a) Monthly Advance b) Lump Dump Origin Locations from July 2001 to June 2002

Overlying the NM288 bench advance with the NM284 and 276 bench advances, it is possible to see the duration that benches were exposed.

Investigating areas that produced lump dump loads on the NM284 and 276 benches show that, in addition to localizations on the fringe zones where the bench face had been exposed, the bench itself was exposed for at most four weeks before mining. This trend indicates that exposed oil sands needs only a matter of weeks exposure during winter conditions to produce frozen lumps. These findings agree with the 14-day exposure time used in Stefan's frost penetration equation that best correlated with lump dump activity.

In addition, in Figure 7-10a thin bands showing no shovel GPS locations can be seen between monthly advances whenever a duration of greater than 1 month has expired between active mining. This cannot be fully explained, yet could be due to recalibration of GPS equipment or changes in digging direction.

Similar plots were generated comparing bench advance to lump jam origins and can be found in Appendix 4, but there does not appear to be any obvious trends. The number of lump jams is a small fraction of the number of lump dump loads, yet the majority of lump jams occur, much like lump dump loads, in the winter months. A more chaotic and random distribution is found for lump jam origins on all benches. Figure 7-11 shows the lump jam origins on the NM288 bench as well as the location of the crusher where the jam occurred. While the majority of the jams did occur at the NMFB7, no preferential areas or benches could be found to suggest a bias between origin location and crusher.

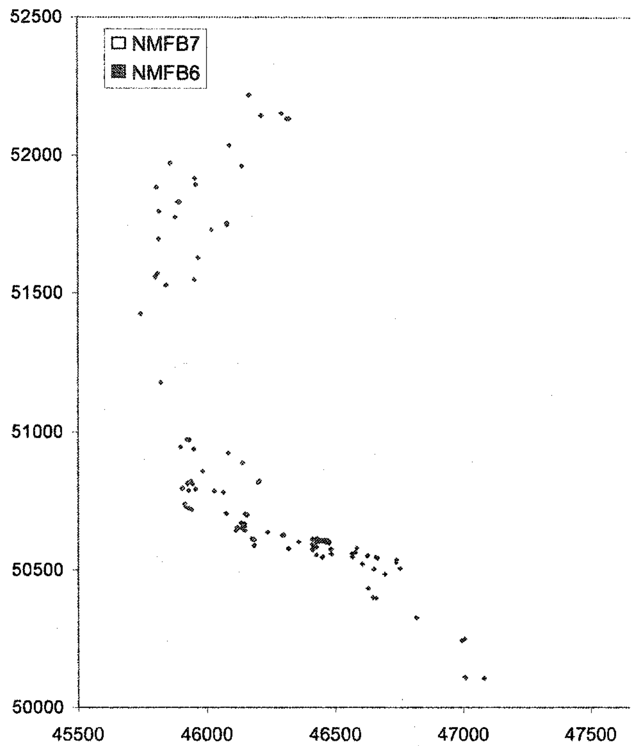


Figure 7-11 - Lump Jam Origin Locations on NM288 Bench with Crusher Allocation from July 2001 to June 2002

7.2.6 Remedial Measures

A difference between the two North Mine crushers is apparent. NMFB7 consistently generates more lump jams than NMFB6. Written correspondence with Cleminson (2004) indicate that the two crushers are operationally identical, nonetheless, there should be some explanation for the difference in lump jam activity. Investigation into the potential differences should be addressed and possible modifications of NMFB7 should be conducted.

Mine planning could adopt some new policies when considering winter excavation practices to reduce the likelihood of generating frozen lumps. Timing is the key factor that should be addressed when sequencing mine advances or mining of the lump dump. Minimizing exposure time of the bench is the best way that proper sequencing could assist in reducing the problem of frozen lumps. In the winter and in the months prior to the onset of winter, reduce the exposed inventory of oil sands benches that will be mined during the winter. Likewise inactive bench faces should be left as such until spring arrives. All that is required is no more than 4 weeks of exposure for frost to penetrate into the oil sands and generate frozen lumps. Plan the mining sequence such that a bench face remains active throughout the winter with little or no interruption in its advance while minimizing the bench's exposed inventory.

Sufficient time should be allowed for the lumps in the lump dump to thaw before mining. Premature mining of the lump dump will not help to reduce lump jams, but merely delay when they occur. In 2002 and 2003 mining of the lump dump generated 67 lump jams that should not be occurring. By waiting until late spring, the frozen lumps will be given more time to thaw and hence should reduce the chances of creating a lump jam. Planning should account for the creation of the lump dump in advance, thus having an area allocated that can be left until summer that is easily accessed to minimize rehandle hauls. How the lump dump is mined can be important, in addition to when it is mined. The frozen oil sands is placed in lifts that can raise the height of the lump dump to 15 m (Wright, 2004) by the end of winter. In spring and summer the oil sands begins to thaw from the surface down, but as the lump dump can be 15 m thick, the material at the base can still be frozen even in the summer. These frozen portions of the lump dump could be another explanation for lump jams being created upon rehandling. Mining should account for this phenomenon and either create a thin dump allowing complete thawing of all the frozen oil sands or mine the lump dump top-down in lifts. The alternative is to manage the frozen lumps being generated at the lump dump more carefully.

7.3 Other Effects

7.3.1 Plant Demand and Actual Feed Rates

The mining and extraction operations in the North Mine are closely linked systems that do not offer a great deal of independency. Previously, the dragline/bucket wheel reclaimer system could operate quite independently from the extraction of the oil sands due to the large stockpiles that were created; windrows along the benches produced by the draglines and a large surge pile at the mine tower allowed for redundancy and surge capacity of up to 36 hours (Wright, 2004). However, the present system with shovels loading trucks that dump into hoppers where the oil sands is crushed, sized, screened and slurried does not offer much flexibility. If one key component is removed from the process, the impact can be large. For example, if both crushers are down and not sending ore to the stockpile, the maximum surge time is only 17 min (Wooley, 1999).

The process requires a certain amount of bitumen per hour depending on the availability and efficiency of all the downstream components in extraction and upgrading. Mining must meet their demands for bitumen production by blending oil sands of both high and low bitumen grades, while still balancing the tasks of exposing ore and preventing downstream disruptions such as lump jams.

It is hypothesized that lump dump activity and frequency of lump jam events may increase with increased demand for oil sands. Shovel operators are aware of their need for high productivity, yet in their attempt to reach these targets, he or she may be less critical of a lumpy load and inadvertently add to the amount of rehandle and/or crusher downtime due to lumps. Comparing the frequency of loads to the lump dump and lump jams with the magnitude of plant demand, a trend is expected.

Plant Information (PI) sensors in combination with lump jam events from North Mine Event Tracking (NMET) and lump dump activity from the Quality Production Database (QPD) are utilized in the analysis. PI monitors both the demand and actual rates on the North Mine oil sands feed through Plant 78. Tags '78WX1' and '78DEMAND' were queried for hourly rates (tonnes/hr) in actual and demanded productivity, respectively, from July 2001 to June 2003. As the demand and actual feed rates fluctuates greatly, running averages were calculated for 10 hour, 5 hour and 3 hour periods to remove some of the variability. Figure 7-12 shows the effects that the running average has on the feed rates for a week in July 2001 for example. As the averaging window increases from 3 hours to 10 hours, the fluctuations in feed rate are minimized. Modified NMET data was used for both NMFB6 and NMFB7 with only class D lump jams greater than 5 minutes in duration considered. QPD data was taken from the reference list for all loads dumped at the lump dumps during the two-year period.

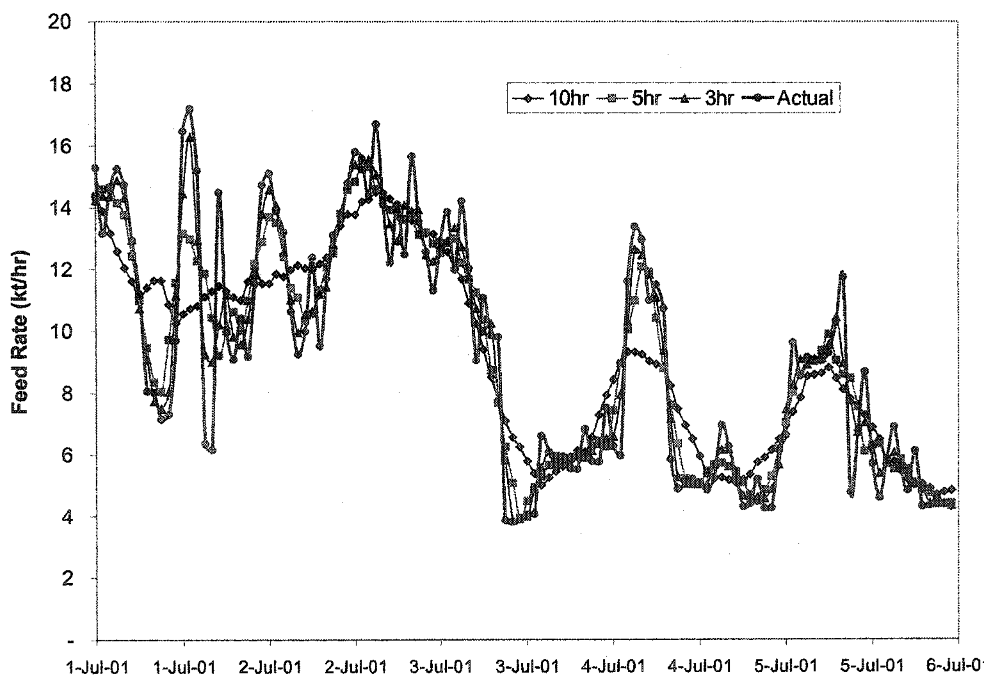


Figure 7-12 - Comparing Running Averages for Actual Feed Rate from July 1st to July 6th 2001

For the analysis, comparisons are made between the actual and demand feed rates at the time of the lump dump or lump jam to the running averages of actual and demand feed rates surrounding each event. The feed rate at the time of each event is compared to the running average and assigned a 'HIGHER' value if the event's feed rate was higher than the running average; if the event's feed rate is lower than the running average feed rate a value of 'LOWER' is assigned. The number of HIGHER and LOWER occurrences is then summed and the percentage split is determined. Table 7-1 summarizes the percentage split for the lump dump and Table 7-2 summaries the percentage split for the lump jams. Occasionally errors in the sensors for the PI tags are encountered, which account for the unequal total demand feed rates.

Table 7-1 - Feed Rate (t/hr) Distribution for Lump Dump Activity

	ACTUAL FEED RATE			DEMAND FEED RATE		
	10 Hr.	5 Hr.	3 Hr.	10 Hr.	5 Hr.	3 Hr.
Higher	7,831	7,753	7,365	7,303	6,874	6,828
Lower	6,928	7,006	7,394	6,879	7,298	7,342
TOTAL	14,759	14,759	14,759	14,182	14,172	14,170
Higher	53%	53%	50%	51%	49%	48%
Lower	47%	47%	50%	49%	51%	52%

Table 7-2 - Feed Rate (t/hr) Distribution for Lump Jam Events

	ACTUAL FEED RATE			DEMAND FEED RATE		
	10 Hr.	5 Hr.	3 Hr.	10 Hr.	5 Hr.	3 Hr.
Higher	665	646	625	620	572	562
Lower	497	516	537	541	589	599
TOTAL	1,162	1,162	1,162	1,162	1,162	1,162
Higher	57%	56%	54%	53%	49%	48%
Lower	43%	44%	46%	47%	51%	52%

The trends show that for the lump dump, neither the actual or plant demand feed rates show a strong deviation from their running averages. Comparing the actual feed rate at the time of the load to the running average of actual feed rate indicate a slight majority of lump dump loads occur during times of higher than average feed rates, however, the split between higher and lower than average feed rate is only 53%/47%. When investigating the plant demand versus lump dump activity, the split between higher and lower than demanded feed rates was nearly even. Therefore, neither of these comparisons is conclusive in determining if there exists a relationship between lump dump activity and feed rate of the operation.

When analyzing lump jam events for the percentage split between higher and lower than averaged feed rates, similar trends were found, but the magnitude of the deviation is slightly larger. The percentage of events occurring during higher than average actual feed rates for lump jam events is as much as 57%/43%, yet the split for demand feed rate is still nearly evenly split. While there is a consistently higher chance of an event occurring when the event's actual feed rate is higher than the average actual feed rate, this small difference is not significant. Furthermore, there does not appear to be any correlation between plant demand feed rates and lump jam events.

Based on these findings, there does appear to be a small correlation between the occurrence of a lump dump or lump jam event and the actual feed rate of the mine. However, the magnitude of the discrepancy is not deemed significant. As the comparison was taken over 10 hour, 5 hour and 3 hour running averages centered around the occurrence of the event, scatter within the data set could explain the slight trend to events occurring during instances of higher than average actual feed rate.

Of interest is the low percentage of the time that demand is actually met. Summing the number of occasions where actual feed met or exceeded demand feed taken on an hourly basis results in only 10% of the time. This finding leads to the possible conclusions that either the plant demand is purposely set at a nearly unreachable level or mining is a potential inhibitor for maximum production.

7.3.2 Daytime and Nighttime Productivity

The operation at the North Mine processes oil sands 24 hours a day, 365 days a year only stopping for shutdowns of major pieces of equipment. Due to this continuous operation, equipment operators are forced to deal with the many daily and seasonal fluctuations in their working environment. Changes in temperature, road conditions and visibility are but a few of the examples with which operators have to continually adjust to at Syncrude. Due to the increase in lump dump activity and lump jam frequency in the winter months, it was hypothesized that visibility may have a role in affecting the generation of lumps in the operation.

As Syncrude is located approximately 56° north of the equator, there is a large range in the hours of daylight that can be experienced. Figure 7-13 shows the yearly fluctuation in daytime versus nighttime hours in the day. One can notice the large variations from as little as 6 hours 47 minutes of daylight in December to as much as 17 hours 48 minutes in June. These values are based on astronomical indicators for Fort McMurray; therefore slight variations may exist for Syncrude's North Mine, yet they can be considered minor. Similarly, some differences may exist between the astronomical time and the time stamping that occurs in the NMET and QPD systems, yet for a comparison of daytime and nighttime operating conditions, these differences are considered minor and neglected for this work.

Adding to the problem of poor visibility in the winter months due to ambient light conditions is that of steam, fog and exhaust. During the winter months the ambient air temperature is below 0°C, but the ground temperature can be above 0°C, especially in an active mining pit. Consequently, when a fresh bench face is exposed, a large amount of steam clouds are created by the liberation of the heat in the ground. These clouds severely impair the visibility of the shovel operators and truck drivers in the vicinity. Furthermore, exhaust from the large mining equipment, such as the hydraulic shovels and haul trucks, intensify the poor visibility in the mine in much the same way. The warm exhaust gasses react with the colder air and generate even more clouds. These sources would amplify the visibility problem.

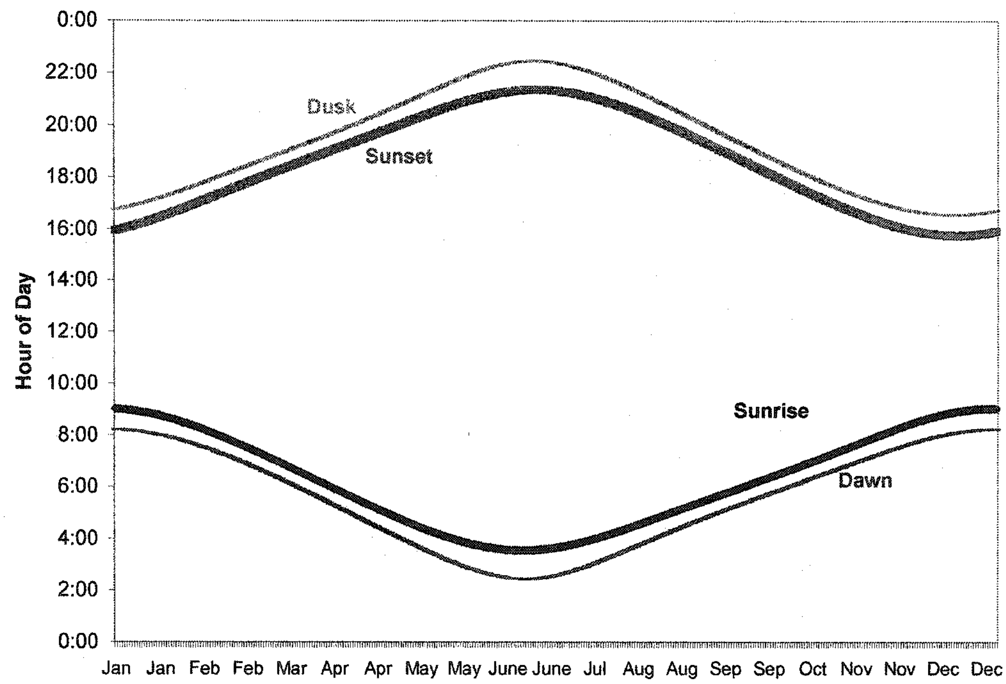


Figure 7-13 - Yearly Fluctuations in Sunlight Hours in Fort McMurray

To test the hypothesis, the number of loads to the lump dumps and the number of lump jams are categorized according to whether they occurred during the day or night on a monthly basis. These values are then normalized by the total number of loads during either the day or night for the corresponding sample set. Lump dumps are normalized by the total oil sands mined, while lump jams are normalized only by the oil sands dumped into NMFB6 and NMFB7.

Results based on this analysis show that there is little or no difference between the daytime and nighttime occurrences of lump dumps and lump jams. Over the two-year study period, 5,845 loads went to the lump dump during the daytime while 8,914 loads in the nighttime. Similarly, 490 lump jams occurred during the daytime compared to 672 at night. However, since lump activity is localized during the winter months when there are less daylight hours, the frequency of lump dump loads and lump jams should be higher at night. To perform a valid comparison, the volumes mined during each respective period, night and day, is used to normalize the occurrences.

Analyzing the frequency of loads is summarized in Table 7-3 showing that in the winter of 2001/2002 virtually no difference between the normalized daytime and nighttime lump dump occurrences exists. However, in the winter of 2002/2003, a slight contrast of 3.2% for daytime occurrences and 4.0% for nighttime occurrences exists. Plotting the normalized lump dump activity in Figure 7-14 reveals that there is little or no difference between the likelihood of a lump dump occurring during the day or night.

Table 7-3 - Daytime versus Nighttime Truck Dumps for Lump Dump Activity

	Lump Dumps		Total		% Lump Dump	
Winter	Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
2001/02	3,119	4,451	73,227	103,476	4.3 %	4.3 %
2002/03	2,721	4,463	85,741	112,957	3.2 %	4.0 %
TOTAL	5,840	8,914	158,968	216,433	3.7 %	4.1 %

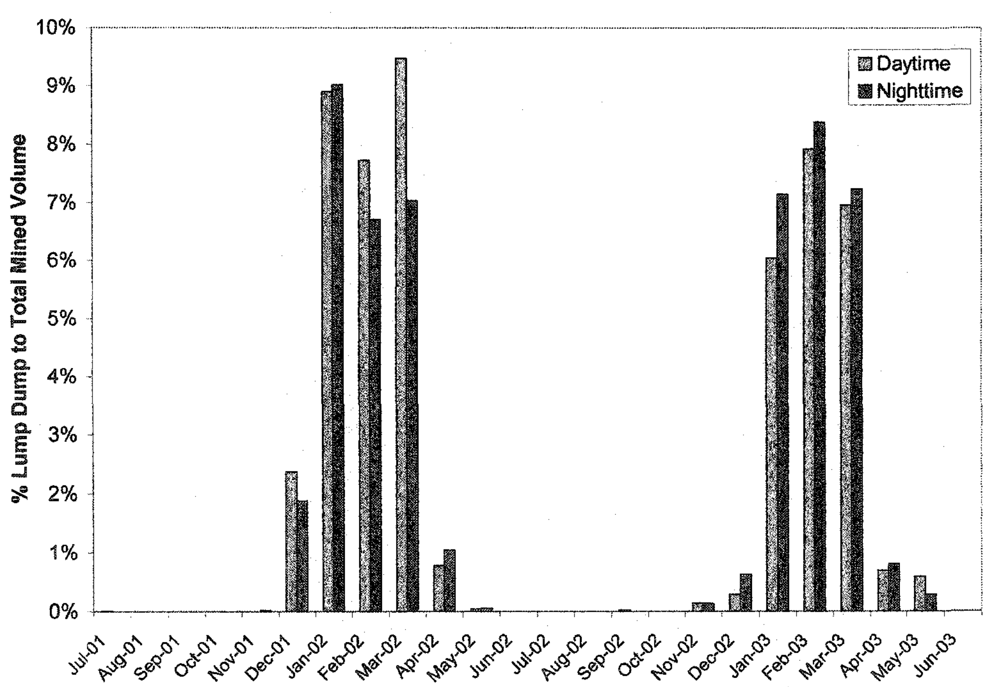


Figure 7-14 - Normalized Lump Dump Activity for Daytime/Nighttime

Findings for lump jams show a similar trend, but an even lower correlation between daytime and nighttime occurrences. Examining the number of lump jams as well as the total number of loads is in Table 7-4. The percentage of lump jams for the two winters under study is 0.34% and 0.36% for the daytime and nighttime, respectively. Figure 7-15 shows that normalized monthly lump jams for the day and night periods with little or no difference between them.

Table 7-4 - Daytime versus Nighttime Occurrences for Lump Jam Events

	Lump Jams		Total		% Lump Jams	
Winter	Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
2001/02	277	368	64,359	91,370	0.43 %	0.40 %
2002/03	174	284	69,957	90,535	0.25 %	0.31 %
TOTAL	451	652	134,316	181,905	0.34 %	0.36 %

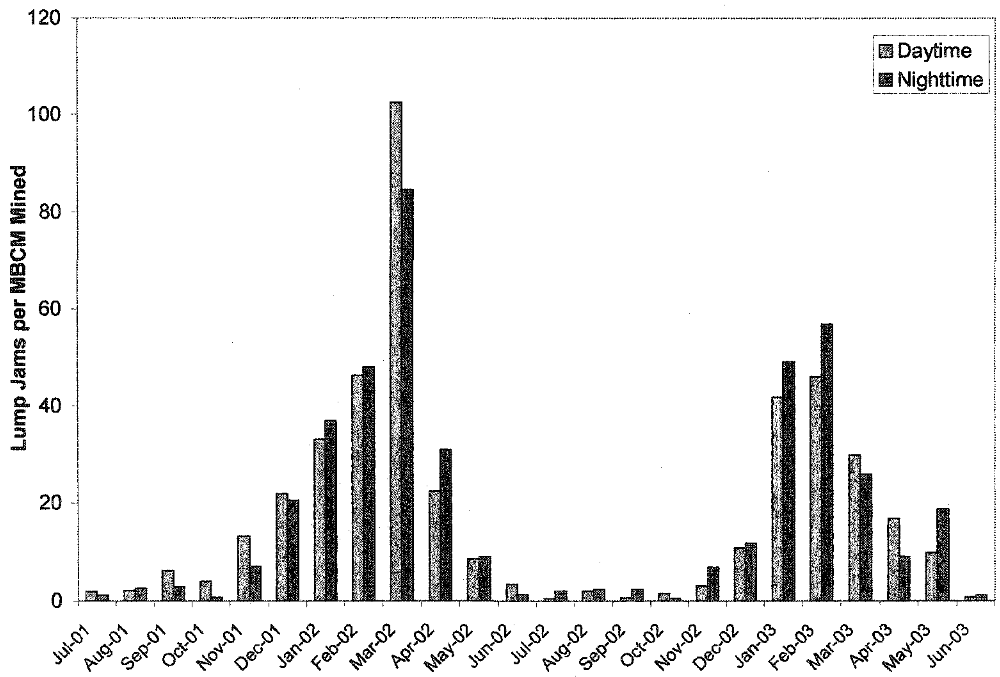


Figure 7-15 - Lump Jam Events per Load Mined for Daytime/Nighttime

Upon considering the similar results when analyzing lump dump activity and lump jams, it appears that visibility has little or no impact on lump generation.

7.4 Summary

Upon investigating lump dump activity and lump jam events based on the origin location of the oil sands, it appears that bench elevation has an effect on lump dump activity, but little or no effect on lump jam events. The higher elevation benches, regardless of shovel type, generate the most lump dump volume as well as being the most probable in generating lump dump loads. However, when normalizing the number of lump jam events, little or no effect of origin location existed.

The relationship between geology and bench elevation is a close one due to the nearly horizontal bedding of the oil sands. Bench names are assigned based on an average elevation, such as NM288 corresponds to an elevation of 288 m according to the Syncrude mine coordinate system. But the actual elevation can be up to ±3 m or more from the reference elevation as per the bench name. This discrepancy could explain the finding that while geology does show a consistent relationship with lump generation, bench elevations do not. The tracked geology in each truck load is accounted for accurately, whereas the actual elevation can be in error from its named elevation, thus causing a less than consistent relationship. When considering complexities in sequencing of facies and shovel operator experience, it is conceivable that the reference bench elevation does not always correspond to the same facies groups. It is advisable to use results in *Chapter 6 – Geology* in an attempt to limit lump generation and use the bench elevations only as a rough guide to attain any changes.

Comparing the two North Mine crushers, however, showed that NMFB7 generated the most lump jams as well as being more probable to generate a lump jam than NMFB6, regardless of origin. This independence of lump jam events by the crushers on feed by origin, compounded with findings in previous chapters showing independence from geology and shovel type, should be conclusive in stating that a difference does exist between the NMFB6 and NMFB7. This is contrary to discussions with numerous Syncrude employees that state no differences exists between the crushers that should account for different operation in handling lump jams. Either differences exists that Syncrude is unaware of or that the differences that are thought to be inconsequential are in fact important. The handling of lump jams by the dispatch operator might also account for the discrepancy, but it is reasonable to assume that since the same operator controls both crushers, that the manner in which he or she handle a lump jam should also be similar.

The efficiency of the lump dump was shown as not being fully utilized. Although the occurrences of lump jams continue at the face, of more concern is material mined from the lump dump creating lump jams. Premature mining of the lump dump removes the time required for the lumps to thaw and is being considered as a possible explanation for lump jams occurring when rehandling the lump dump.

Mine planning and the exposure time of the bench and bench face are critical in the generation of frozen lumps. Both the top of the bench as well as the bench face can generate a frozen crust if left exposed for only a few weeks. Mining in the winter should be limited to active areas with as little interruptions as possible to minimize the build up of frost on the benches and bench faces.

Plant demand and time of day show very little impact on lump dump activity or lump jam events.

8 SUMMARY AND RECOMMENDATIONS

8.1 Summary

The purpose of this thesis was to use production data compiled from Syncrude Canada Ltd.'s North Mine to determine the impact of shovel type, geology, climate and origin location on the generation of frozen oil sands lumps. During the time frame from July 2001 to June 2003, all oil sands production was investigated for links between these factors. As such, the objectives of this thesis are:

1. Collect and integrate available climatic, geologic and production data from Syncrude's database systems.
2. Create a relational database between the various factors to be used for a correlative analysis.
3. Quantify the effects that climate, geology, equipment and other operational factors have on lump generation as well as provide possible explanations for the results.
4. Suggest methods to minimize the occurrences/effects of frozen lumps and improve overall mining efficiency during winter months.
5. Provide recommendations for better data collection as well as areas of future work.

When a large lump is created at the face there are two options that can occur. It can be identified as a hazard by the shovel operator, who then directs the haul truck to dump the load containing the lump(s) in a designated lump dump, thus eliminating the potential from a lump jam from occurring. Material at the lump dump is left to thaw and fragment before being rehandled in the spring or summer. This proactive measure can divert up to 8% of the total monthly mined volume in the winter months to the lump dump, which translates to approximately 800,000 BCM annually of rehandle. However, if a dangerous lump is not identified, it is dumped into the crusher where it can create a lump jam. Lump jams are a much more severe problem as they impede production as opposed to increasing rehandle volume. Lump jam events can cause between 60 and 320 hours of lost productivity each year. Fortunately, in recent years the frequency of these events appears to be decreasing.

In the process of analyzing the causes of lump dump activity and lump jams, a number of Syncrude databases were used in linking production to climate to equipment performance: NMET, weather, QPD/Wenco and PI. A production reference list was compiled from the QPD and Wenco databases, and tables were generated on a month-by-month basis summarizing the relationship between shovel, origin location, dump location and facies. Using the criteria of only class D entries greater than 5 minutes in duration within the NMET system, 1,162 lump jams have occurred at the NMFB6 and NMFB7. Comparing these occurrences to the temperatures recorded in the weather database from the Mildred Lake weather station, a strong negative correlation exists between these two variables.

The climate in Fort McMurray is sub-arctic with temperature ranges from 36°C to -51°C and a mean annual temperature of –0.2°C. These harsh conditions generate frozen lumps by the penetration of frost into the exposed oil sands, which cause increases in maintenance costs and decreases in productivity. Using Stefan's equation for modeling frost penetration, maximum frost depths over the course of a winter are estimated to be approximately 2.9 m. However, due to the practiced benching sequence, a 14-day bench exposure time is found to provide that best representation between frost depth and lump dump activity with a calculated frost depth ranging from 0 to 2.1 m. Actual bench exposure times can be quite variable, ranging from a week to a whole winter, but minimizing the exposure time will reduce the depth of frost and hence lump dump and lump jam occurrences. Specific analysis of lump jams show little correlation with frost depth, thus other factors must be major contributors, yet the effect of climate cannot be ignored.

The hydraulic shovels are more probable to generate a lumpy load than the cable-electric shovels on a normalized basis by mined volume. However, while the cable-electric shovel's probability of sending a load to the lump dump has remained relatively constant in both years, the hydraulic shovel's probability has been decreasing. Furthermore, trends for lump jam events for both shovel types are rather similar and have not changed in spite of the reduction in lump dump activity of the hydraulic shovels. No significant spatial bias could be found to suggest that hydraulic versus cable-electric shovels dug in certain areas than others.

When investigating the effects that geology has on lump generation, a number of interesting trends were discovered. The Upper McMurray facies groups 95/15 and 96/16 are more likely to generate lump dump loads as well as lump jams than any other facies groups. Up to 5% by volume mined during the winter can be delivered to the lump dump and approximately 35 lump jams per MBCM mined can be expected. Although hydraulic shovels are more likely to produce lump dump activity than cable-electric shovels, the Upper McMurray facies was a highly probable unit for both shovel types. However, the number of lump jams per MBCM mined was approximately the same for each shovel type, regardless of facies group. These findings suggest that geology has an effect on lump generation, but shovel type only has an effect on lump dump activity and not lump jam events.

It appears that bench elevation has an effect on lump dump activity, but little or no effect on lump jam events. The higher elevation benches, regardless of shovel type, generate the most lump dump volume as well as being the most probable in generating lump dump loads. However, when normalizing the number of lump jam events, little or no effect of origin location existed.

Based on the results in this thesis, a number of conclusions can be made:

1. Lump jam events appear to occur at random with little or no correlation to shovel type, origin location or geology. While results for lump dump activity do not agree, it should be reminded that lump dump activity is a qualitative measure based on shovel operator judgement and experience.

2. Lump dump activity does appear to be effected by geology and/or bench elevation, regardless of shovel type. This trend may be due to the high fines and water content of the Upper McMurray or to the larger exposure time of the top oil sands benches, or perhaps a combination of the two. However, the perception of the shovel operator can skew the results and should not be neglected as a potential cause of this trend. Believing the top oil sands benches, which coincide with the Upper McMurray, are more prone to lump jam events may cause them to be more discriminating with lumps, thus creating higher lump dump activity.

3. A difference does exist between the two shovel types when investigating lump dump activity. The reasons why there is a greater probability of lump dump activity for hydraulic shovels than cable-electric shovels is not fully understood, but differences in digging/dumping motion, bucket sizes, breakout forces and mobility could be a factors. Operator perception and being more discriminating when identifying lumps when operating hydraulic shovels is another potential factor that could explain this trend.

4. Geology, specifically the Upper McMurray unit, does effect lump generation. Although the effect of geology on lump jam events is weak, it can be noticed. Perhaps the higher fines and moisture content of the Upper McMurray is responsible for this trend.

5. The lump dump is not as efficient in reducing lump jams as it should be. The purpose of the lump dump is to reduce the likelihood of a lump jam from occurring, but studies have shown that lump jams continue to occur, even upon rehandling of the lump dump. Premature mining of the lump dump removes the time required for the lumps to thaw and is being considered as a possible explanation for lump jams occurring when rehandling the lump dump.

6. Mine planning and the exposure time of the bench and bench face during the winter are critical in the generation of frozen lumps. Both the top of the bench as well as the bench face can generate a frozen crust if left exposed for only a few weeks. Mining in the winter should be limited to active areas with as little interruptions as possible.

7. A comparison was made for lump jam events for NMFB6 and NMFB7, and a difference was found to exist between the two crushers. Regardless of the shovel type, origin location or geology of the supplied oil sands, NMFB7 consistently produces more lump jams as well as is more probable in generating a lump jam on a volume normalized basis. This finding is in contraction to discussions with numerous Syncrude employees that state no difference exists between the crushers that should account for different operation in handling lump jams. Nevertheless, differences that are either unknown, or are not thought to be of significance, do exist between these crushers when processing lump jams.

8. Plant demand and time of day showed very little impact on lump dump activity or lump jam events.

8.2 Recommendations

8.2.1 Data Collection and Processing

- A more comprehensive algorithm to define a lump jam could be implemented using more than just one input from Plant Information tags. Such an algorithm, as in Justin Gamble's M.Sc. thesis, could be developed that uses multiple inputs for the detection of lump jams at the North Mine.

- The use of video feed through the Center for Intelligent Mining Systems could be used to qualify and quantify the occurrences of lump jams at the North Mine crushers.

- Weather data, such as wind direction and speed, precipitation, snow on ground, and humidity, should be verified for quality on a regular basis. If this information was more reliable, it could be used in more sophisticated frost depth penetration models.

- Accurate weightometers should be placed on all trucks to increase the confidence of truck payloads and reduce the reliance for manual modifications in the production data.

- Filling in of missing information within the QPD and Wenco databases would provide a more complete account of the available information. Missing origin, destination and geologic data could be inferred from complete records according to a set of predefined restrictions, such as shovel number, shovel location and a time window.

- Collection of GPS data on all benches would be useful in not only tracking overburden production, but also in determining exposure time for all benches, especially the NM288 oil sands bench.

- More accurate physical properties of the different facies contained in the Syncrude Lithofacies Chart could be collected to further quantify the susceptibility of certain facies being more prone to lump generation.

8.2.2 Operational Changes to Reduce Problems Associated with Frozen Lumps

- Minimize the exposure time of benches and bench faces as well as the inventory preceding winter. Reducing the frequency of entering inactive areas in the winter will also be beneficial in minimizing problems associated with frozen lumps.

- Use snow and/or water/ice to reduce the penetration of frost into the oil sands by creating an insulating layer between the environment and the oil sands. Artificial snow, trapping natural snow and creating shallow ponds are all possible methods discussed in the thesis.

- Minimize placing roads prior to the onset of winter in areas that will be mined during the winter months. Once the ground is frozen, roads can be placed anywhere, with little or no effects of traffic on frost penetration.

- Verbal communication should be used between the shovel operators and the truck drivers when reassigning a load to the lump dump instead of the horn signals.

- The construction thickness of the lump dump is important when considering how best to mine it. A thin lift over a wider footprint would allow mining in any manner, but if the dump is constructed in lifts to a final height in excess of 5 m, the dump should be mined top-down in lifts as well. This will allow the exposed oil sands time to thaw and reduce the chances of incurring a lump jam when mining the lump dump.

- Mining of the lump dump should begin in the spring when the daily average temperature is at least 0°C, thus allowing thawing of the oil sands lump to take place.

- Ripping should continue along the planned design, but with better quality control being emphasized on the spacing and orientation of the rip patterns. A study could be done comparing variations in rip spacing, orientations and penetration with the fragmentation of the oil sands and the generation of frozen lumps.

- Continue ongoing work on adapting a lump breaker to the North Mine crushers that would fracture/cut large lumps without the need for a backhoe.

- The trend showing a reduction in lump jams indicate that the current state of practice is having a positive effect. Improvements in equipment operability, operator experience and mine planning should continue.

8.2.3 Future Work

- Validate the frost penetration model used in this thesis by setting up test plots where the actual frost depth could be measured for known bitumen, fines, and water contents, ground cover and exposure time.

- Similarly, conduct tests to qualify and quantify the effects that driving has on frost penetration and attempt to correlate back to the frost penetration model.

- Using production data, determine if certain shovels, bench elevations and locations and specific facies and not just shovel types, bench elevations and facies groups are more prone to lump generation.

- Examine whether higher fines and/or moisture content explains why the Upper McMurray and the top oil sands benches are generating more lumps than the other geologic members and benches.

- Determine why the likelihood of hydraulic shovels generating a lump dump load has decreased over the past few winter.

- Determine if the size of bucket or breakout force is an indicator of lump generation.

- Investigate why, if both North Mine crushers are supposed to be the same, does NMFB7 consistently record more lump jam events than NMFB6 regardless of material source or shovel type.

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10APPENDICES

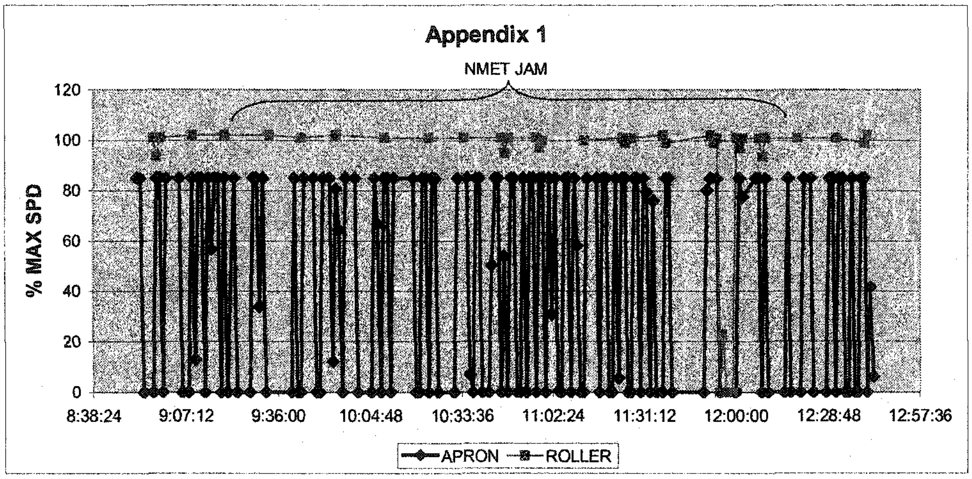
10.1 Appendix 1

North Mine Event Tracking (NMET)

START TIME	STOP TIME	EQUIP.	DURATION
2002/01/17 9:23	2002/01/17 12:20	75-T-7	177

Material Trans (MTT) and QPD

TIME STAMP	N/A	FACIES	
SHOVEL	N/A	10	N/A
ORIGIN	N/A	11	N/A
		12	N/A
MAT. CODE	N/A	15	N/A
BIT%	N/A	21	N/A
FINES%	N/A	6	N/A
		7	N/A
ESTUARINE	N/A	8	N/A
FLUVIAL	N/A	9	N/A
MARINE	N/A		



10.2 Appendix 2

Coke Cell

Coke Cell 1/2
Coke Cell 2/3

Inpit Ramps

[redacted]

N/A

N/A

NE. Ext.

NE Ext Ore 250 Bench
NE Ext Ore 260 Bench
NE Ext Ore 270 Bench
NE Ext Ore 290 Bench

NM 245

NM 245E Ore Bench Panel 5
NM 245E Ore Bench Panel 6

NM 252

NM 252E Ore Bench Panel 5

NM 254

NM 254E Ore Bench Panel 6

NM 256

NM 256S Ore Bench Panel 4
NM 256S Ore Bench Panel 5
NM 256S Ore Bench Panel 6
NM 256S Ore Bench Panel 7
NM 256W Ore Bench Panel 10 N
NM 256W Ore Bench Panel 10 S
NM 256W Ore Bench Panel 11 N
NM 256W Ore Bench Panel 11 S
NM 256W Ore Bench Panel 12 S
NM 256W Ore Bench Panel 8 S
NM 256W Ore Bench Panel 9 N
NM 256W Ore Bench Panel 9 S

NM 264

NM 264E Ore Bench Panel 5
NM 264E Ore Bench Panel 6
NM 264N Ore Bench Panel 3 W
NM 264S Ore Bench Panel 5
NM 264S Ore Bench Panel 7
NM 264W Ore Bench Panel 10 N
NM 264W Ore Bench Panel 10 S
NM 264W Ore Bench Panel 11 N
NM 264W Ore Bench Panel 11 S
NM 264W Ore Bench Panel 12 N
NM 264W Ore Bench Panel 12 S
NM 264W Ore Bench Panel 8 N
NM 264W Ore Bench Panel 8 S
NM 264W Ore Bench Panel 9 N
NM 264W Ore Bench Panel 9 S

NM 276

NM 276 Ore Eastside
NM 276 Ore Southside
NM 276E Ore Bench Panel 5
NM 276E Ore Bench Panel 6
NM 276N Ore Bench Panel 3 W
NM 276S Ore Bench Panel 5
NM 276S Ore Bench Panel 6
NM 276S Ore Bench Panel 7
NM 276W Ore Bench Panel 10 N
NM 276W Ore Bench Panel 10 S
NM 276W Ore Bench Panel 11 N
NM 276W Ore Bench Panel 11 S
NM 276W Ore Bench Panel 12 N
NM 276W Ore Bench Panel 12 S
NM 276W Ore Bench Panel 9 N
NM 276W Ore Bench Panel 9 S

NM 284

NM 284N Ore Bench Panel 3 W
NM 284S Ore Bench Panel 4
NM 284S Ore Bench Panel 5
NM 284S Ore Bench Panel 6
NM 284S Ore Bench Panel 7
NM 284W Ore Bench Panel 9 N
NM 284W Ore Bench Panel 9 S
NM 284W Ore Panel 10 N
NM 284W Ore Panel 10 S
NM 284W Ore Panel 11 N
NM 284W Ore Panel 11 S

NM 288

NM 288 Ore Stockpile
NM 288N Ore Bench Panel 3 W
NM 288S Ore Bench Panel 4
NM 288S Ore Bench Panel 5
NM 288S Ore Bench Panel 6
NM 288S Ore Bench Panel 7
NM 288W Ore Bench Panel 10 N
NM 288W Ore Bench Panel 10 S
NM 288W Ore Bench Panel 11 N
NM 288W Ore Bench Panel 11 S
NM 288W Ore Bench Panel 12 N
NM 288W Ore Bench Panel 12 S
NM 288W Ore Bench Panel 9 N
NM 288W Ore Bench Panel 9 S

KCA

NM KCA North Panel 3 W
NM KCA South Panel 5
NM KCA South Panel 6
NM KCA West Panel 10 N
NM KCA West Panel 10 S
NM KCA West Panel 11 N
NM KCA West Panel 11 S
NM KCA West Panel 12 N
NM KCA West Panel 9 S
SW KCA South Panel

KCW

NM KCW East Panel 5
NM KCW East Panel 6
NM KCW North Panel 3 W
NM KCW South Panel 5
NM KCW South Panel 6
NM KCW South Panel 7
NM KCW West Panel 10 N
NM KCW West Panel 10 S
NM KCW West Panel 11 N
NM KCW West Panel 11 S
NM KCW West Panel 12 N
NM KCW West Panel 9 S
SW KCW South Panel

OB

NM OB East Panel 5
NM OB East Panel 6
NM OB North Panel 3 W
NM OB West Panel 10 S
NM OB West Panel 11 N
NM OB West Panel 11 S
NM OB West Panel 12 N
NM OB1 East Panel 5
NM OB1 South Panel 6

Lump Dumps

North Mine N. Ore Lump Dump
North Mine W. Ore Lump Dump
NE Extension Lump Dump

NW Quad

NW Quad D/L Split
NW Quad D/L Windrow

SW Quad

SW Quad D/L Windrow
SW Structures

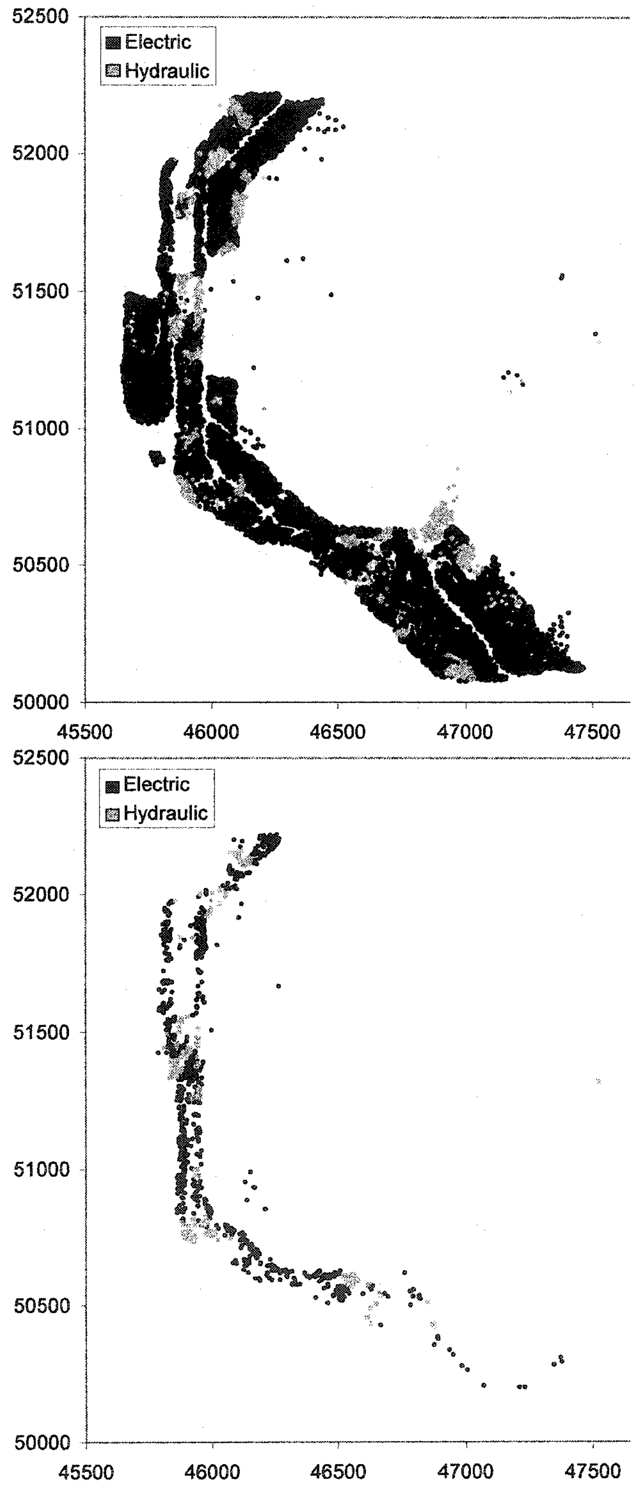
W Quad

W Quad Split Ore

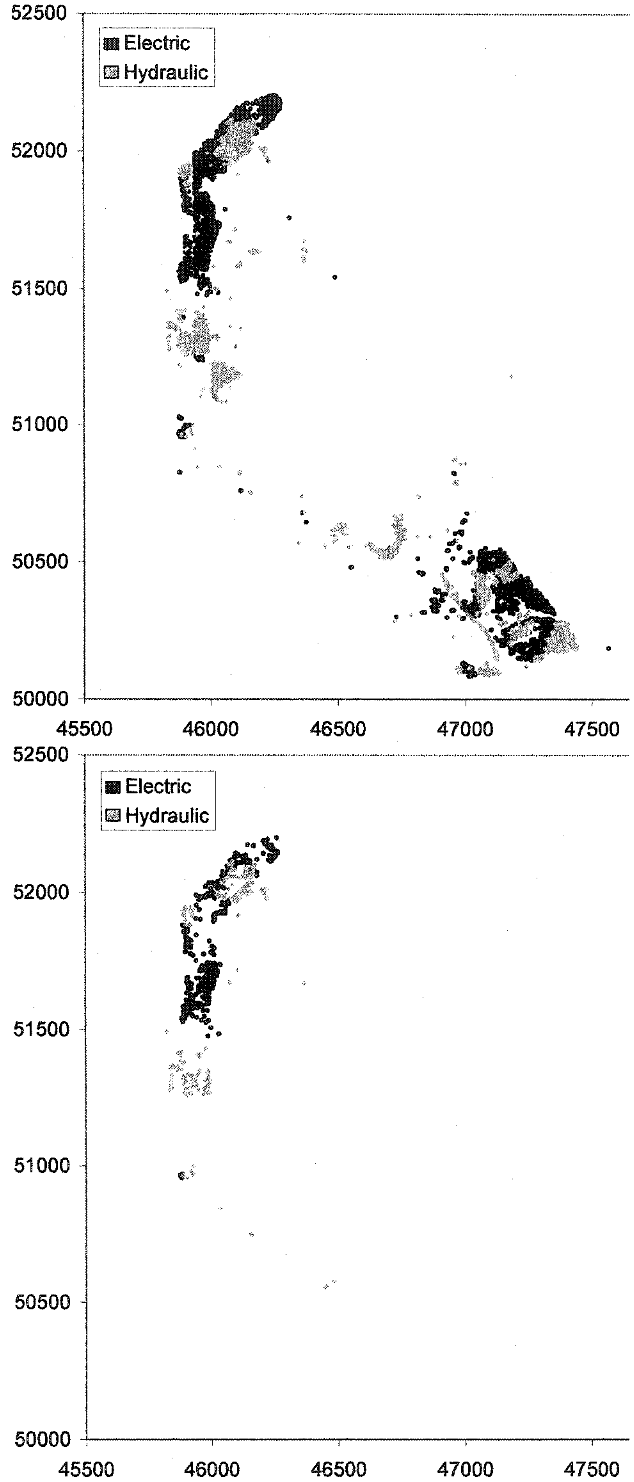
Other

NM Feeder Breaker #7
NW Feeder Breaker #2
Sand Stockpile
Sand/Gravel stkpile
G-Pit
MINE TOWER STOCKPILE
NM NT1 325

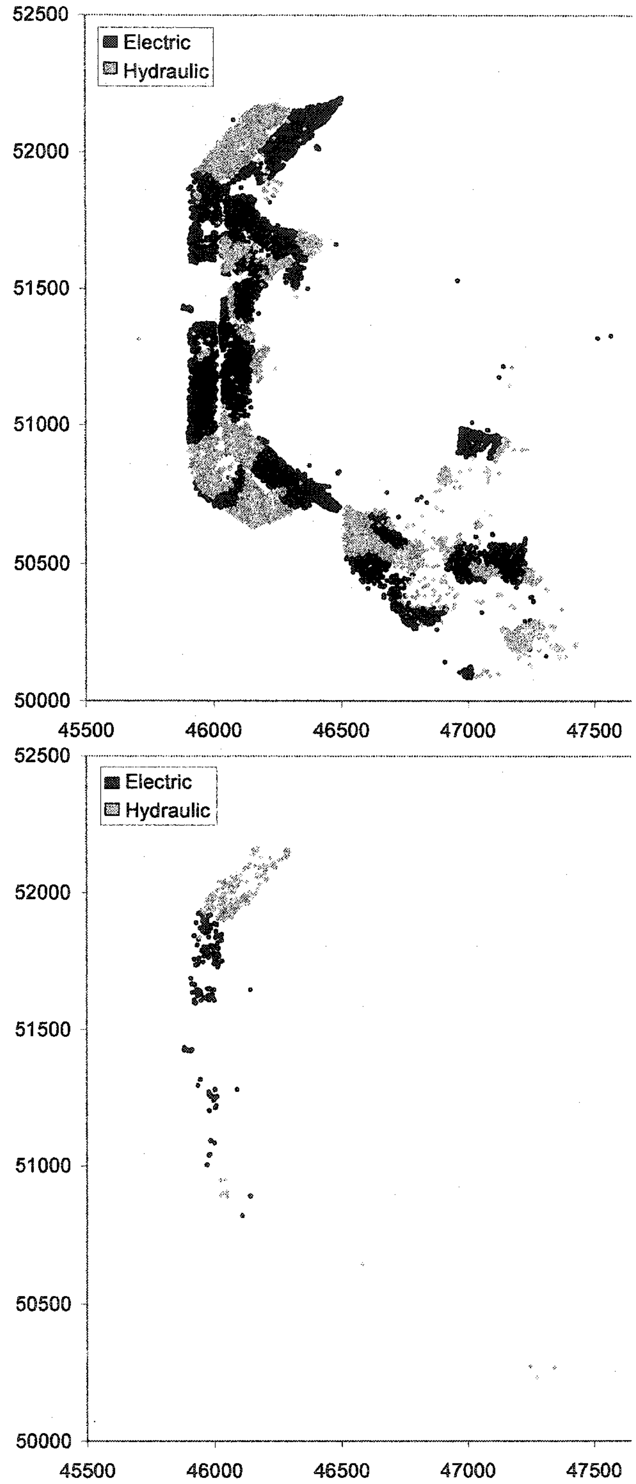
10.3 Appendix 3



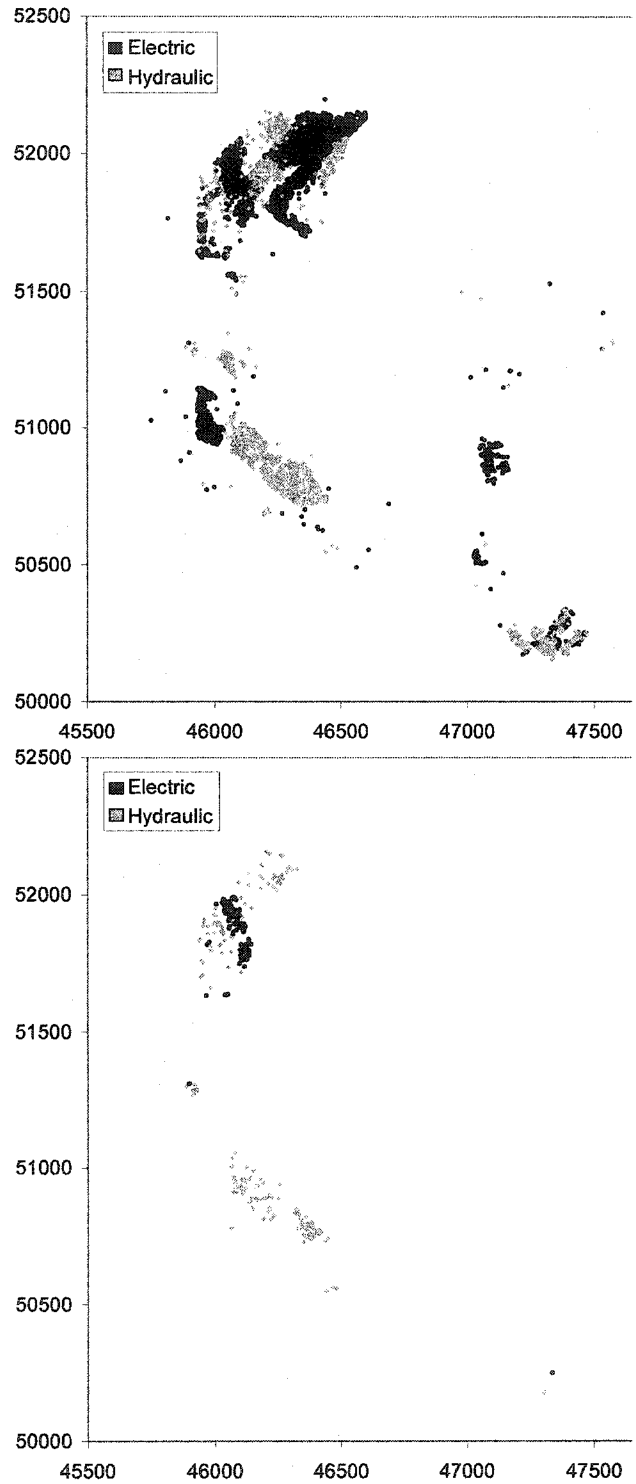
NM 288 Bench a) Shovel Type Allocation b) Lump Dump Loads July 2001 to June 2002



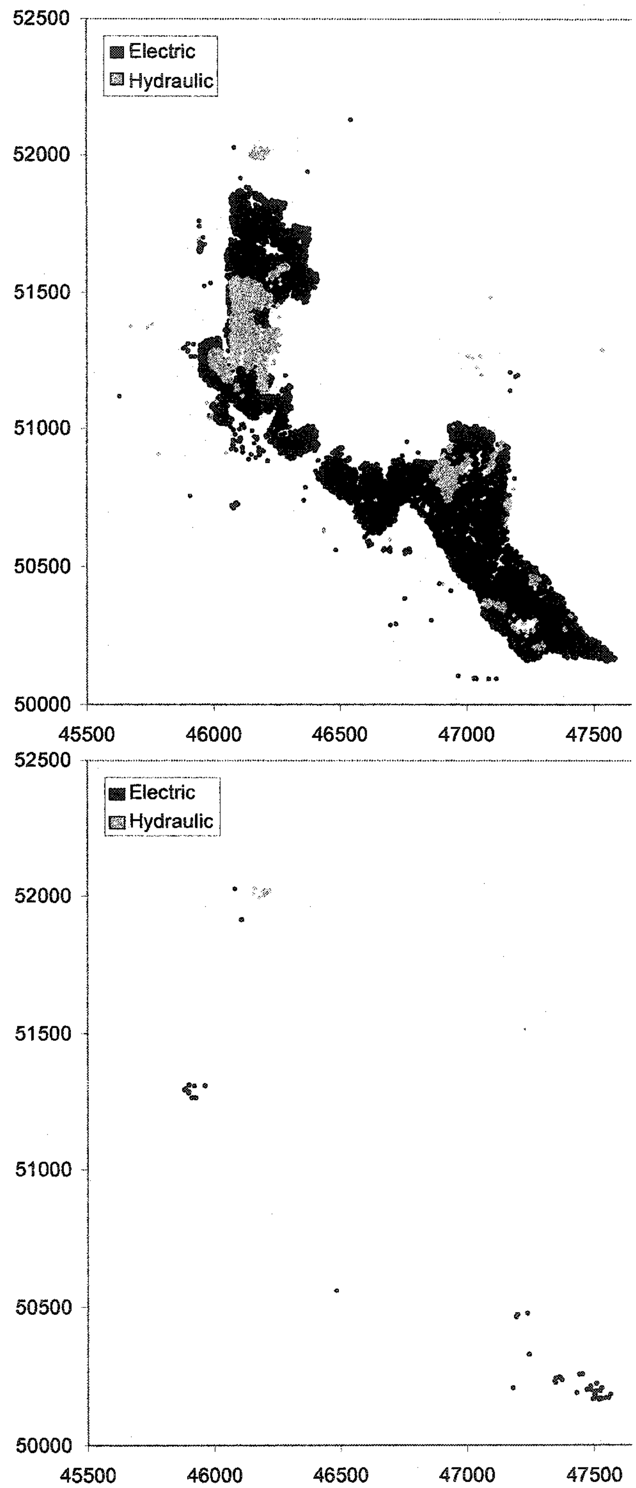
NM 284 Bench a) Shovel Type Allocation b) Lump Dump Loads July 2001 to June 2002



NM 276 Bench a) Shovel Type Allocation b) Lump Dump Loads July 2001 to June 2002

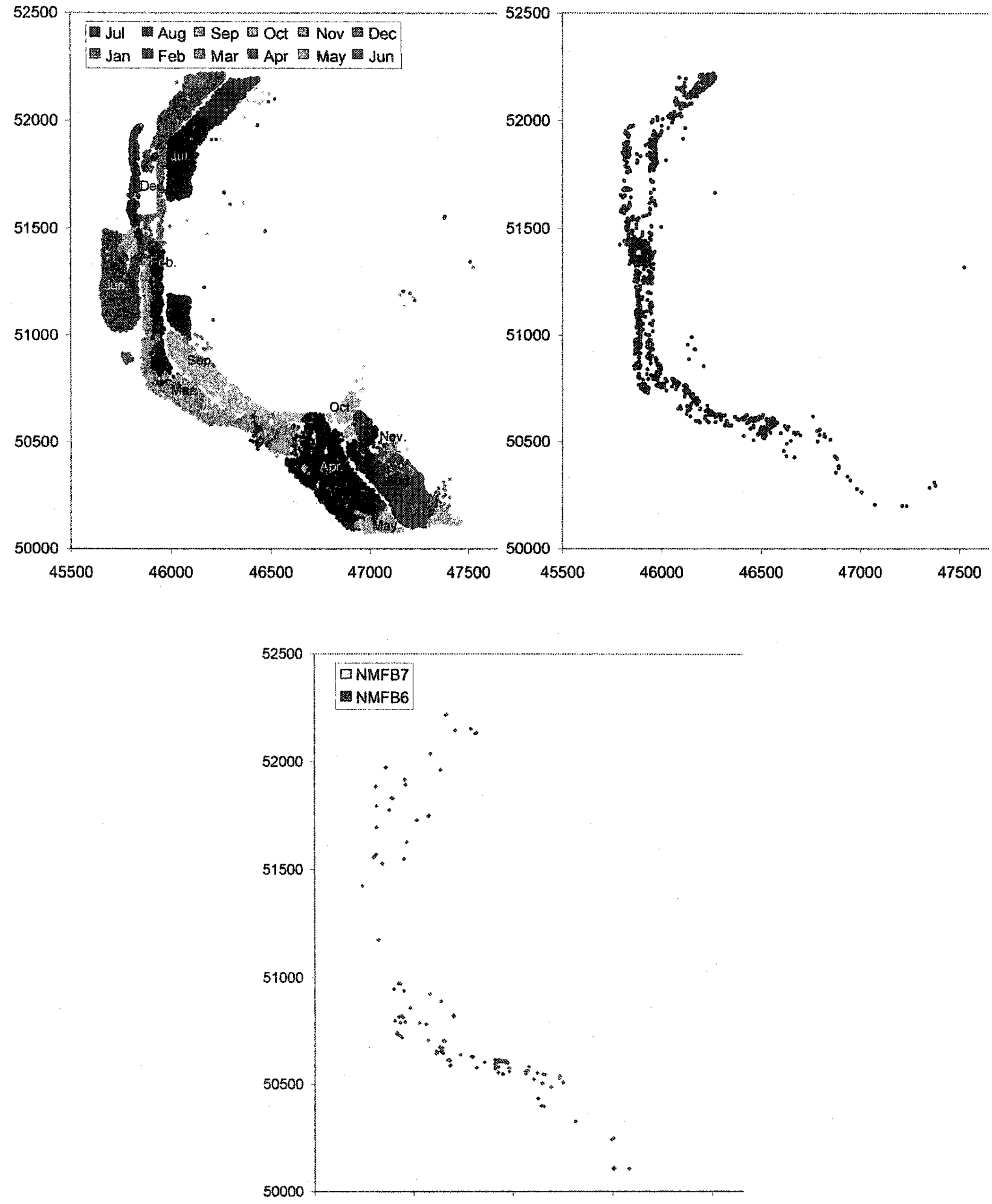


NM 264 Bench a) Shovel Type Allocation b) Lump Dump Loads July 2001 to June 2002

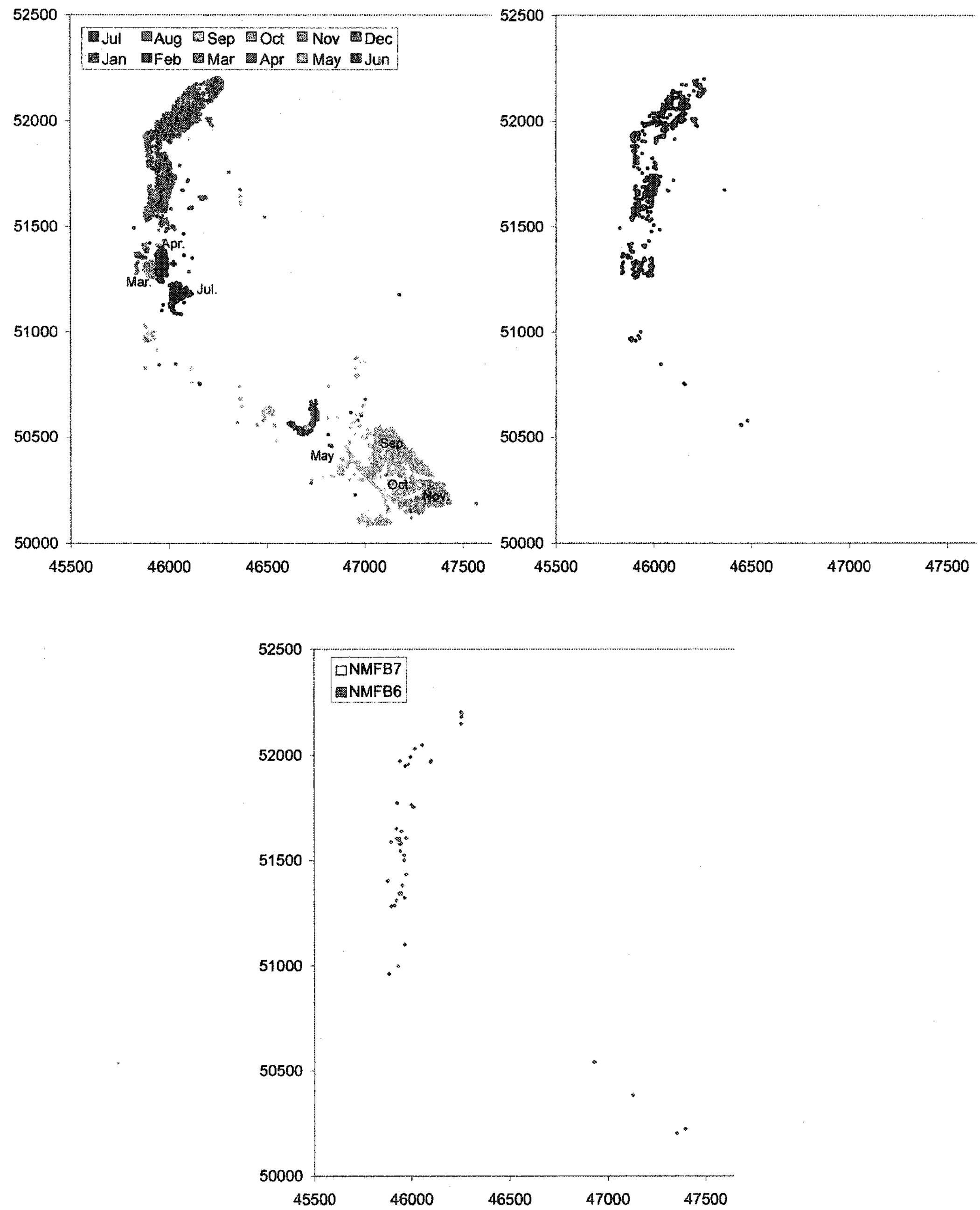


NM 25X Bench a) Shovel Type Allocation b) Lump Dump Loads July 2001 to June 2002

10.4 Appendix 4



NM 288 Bench a) Advance b) Lump Dump Loads c) Lump Jams by Crusher from July 2001 to June 2002



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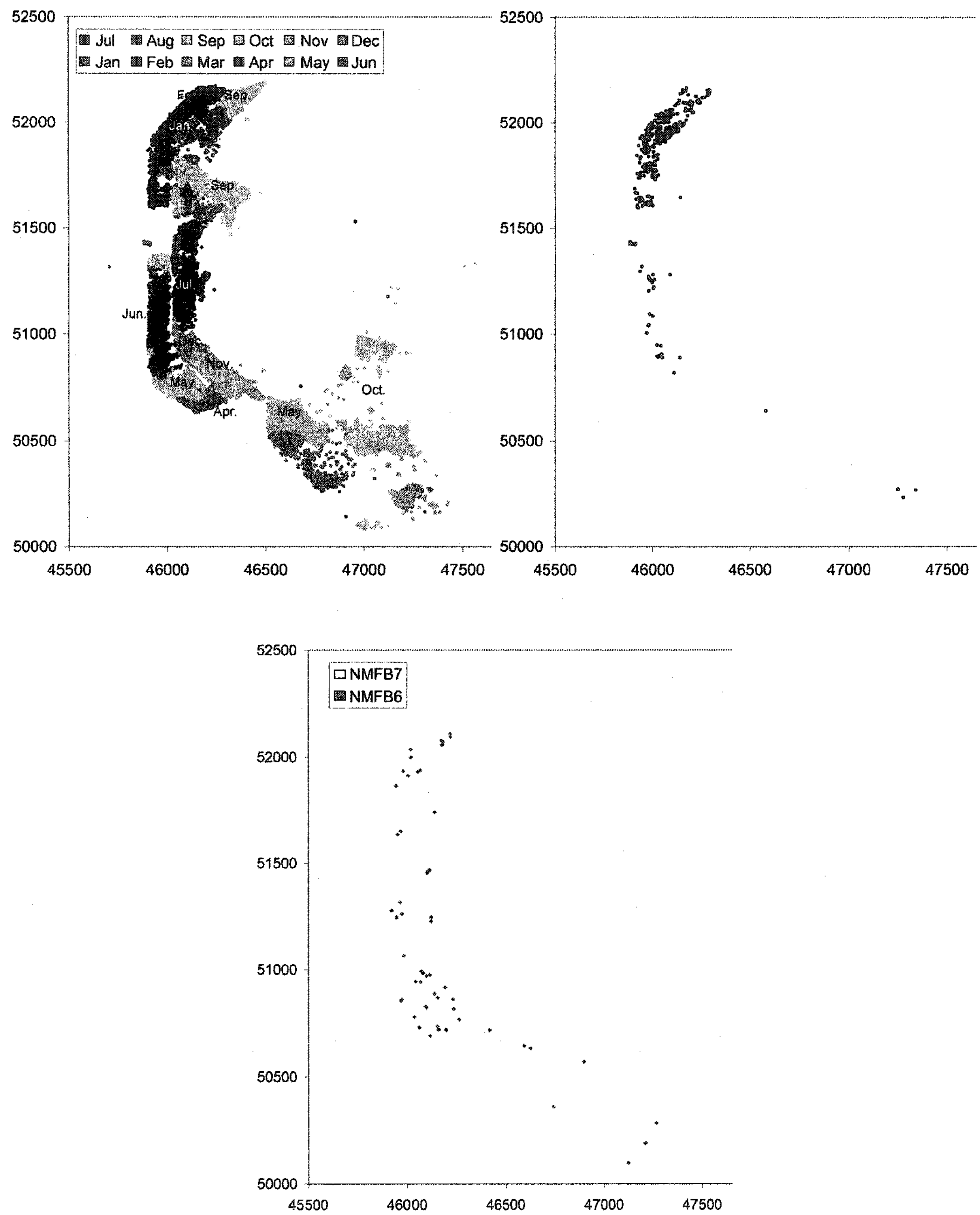

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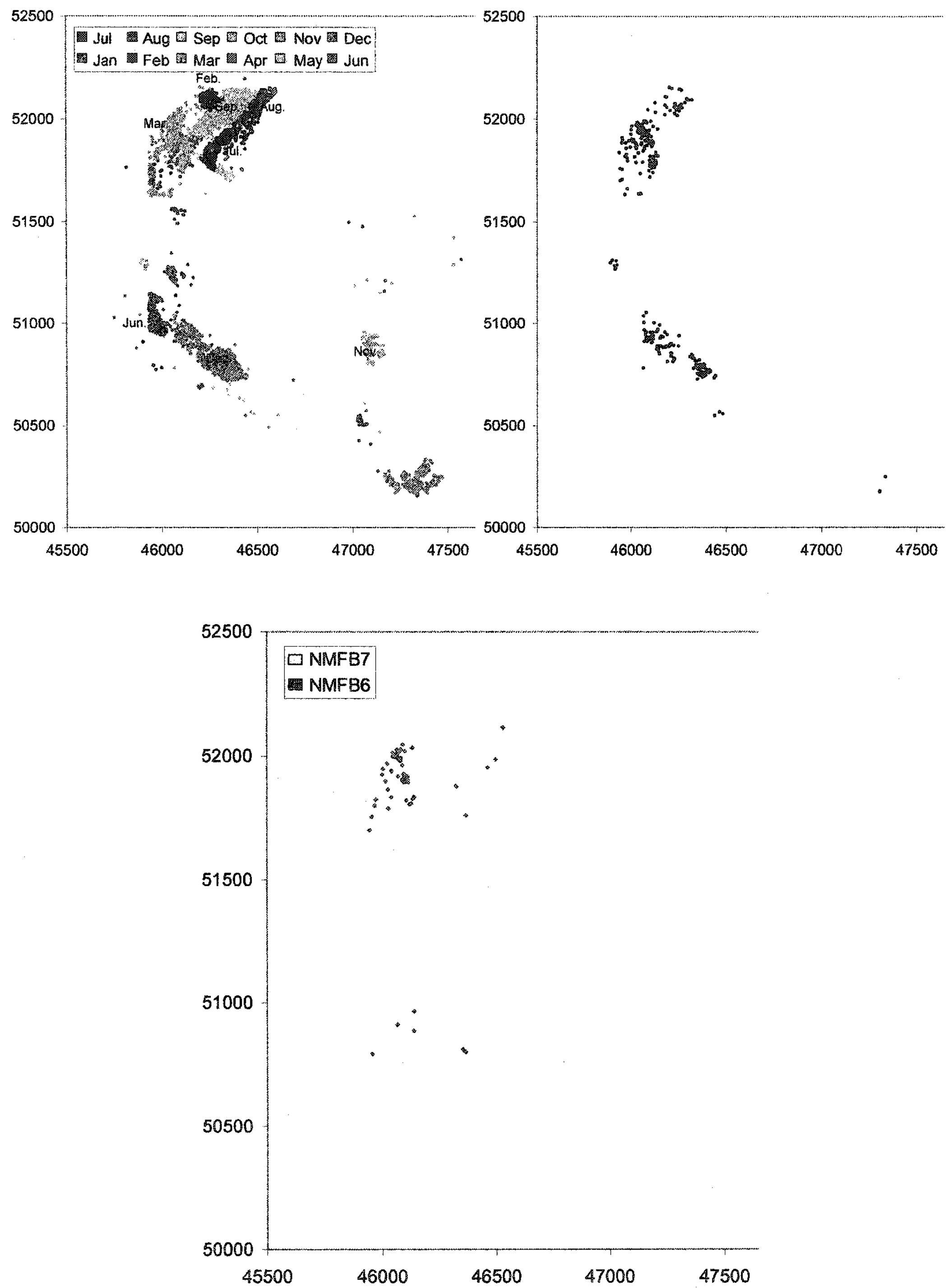

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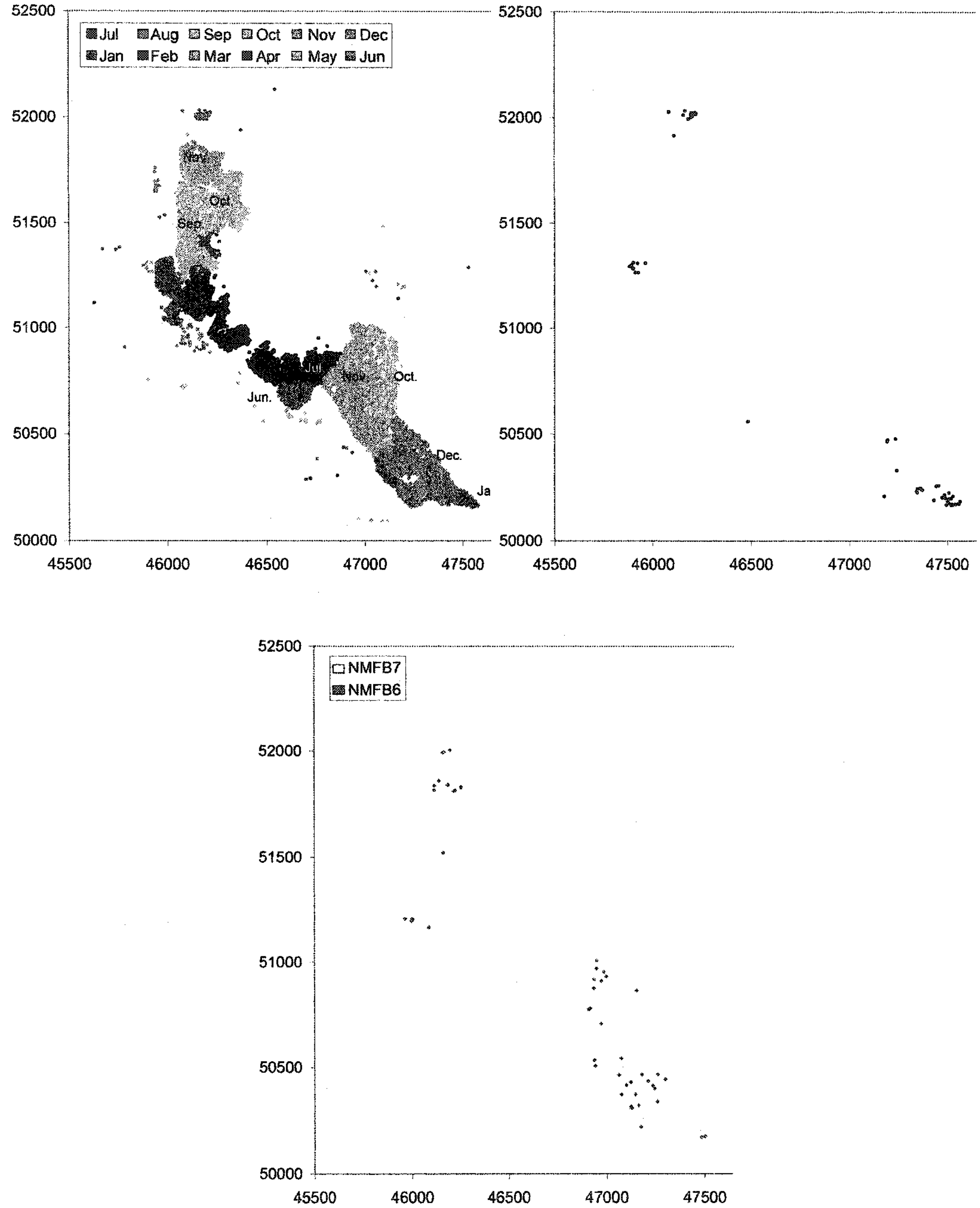

NM 25X Bench a) Advance b) Lump Dump Loads c) Lump Jams by Crusher from July 2001 to June 2002