University of Alberta

A Framework for Cold Weather Construction Simulation

By

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This thesis is dedicated with love and respect to my mother, late father and sister,
to my beloved family, my wife and son;
the people who taught me what life is all about.

ABSTRACT

In cold regions, weather poses a great deal of uncertainty to construction projects carried out in the open. Actual project schedules could significantly deviate from the original plans. Management requires reliable plans and schedules to set project activity times and baseline schedules against which the project performance will be measured. Faced with winter weather uncertainty in cold regions, this task becomes quite challenging. Planners often depend on their personal experience and judgement to assess for cold weather effects in their estimates; these speculations often differ from one planner to the other. There is a need for a well-structured and consistent approach to account for the impact of cold weather on construction projects. In this thesis, a structured approach to quantify and include the weather impact on construction processes is presented, which takes into consideration the location and time of year the project is scheduled to take place. The approach depends on developing and testing a good weather generator capable of generating the weather parameters affecting the construction industry. The generated weather should be similar to the historical weather of the location in which the project is taking place, then quantifying their effect on the process productivity. A framework is proposed for developing the integrated process simulation models to account for the interaction between the weather and the construction process. To ensure the ability of the framework to model the impact of cold weather on different construction processes, the framework is tested by systematically applying it to two construction processes: High Density Poly-Ethylene (HDPE) pipeline installation and the tunnelling construction process. The framework proved successful in modelling the

impact of cold weather on the tested construction processes, and has the potential to be applied to a variety of construction processes. To promote reusability and interoperability of the framework in future applications, the weather generator was redeveloped using High Level Architecture (HLA), which showed great potential and suitability for this work.

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CHAPTER 1. INTRODUCTION

1.1. Introduction

A considerable segment of Canada's heavy construction takes place in cold weather. Construction projects are generally subject to several factors leading to uncertainty during the planning stage. Planning for cold weather construction in particular is characterized by a great deal of uncertainty in estimating activity durations and in determining the logic of performing the tasks. Cold weather can severely impact construction projects carried out in an open environment, leading to significant deviations from the scheduled finish dates. Planners often depend on personal judgment to estimate the potential impact of cold weather on a construction project. A more rigorous analysis is needed to provide for better project plans.

1.2. Background

Many researchers cite weather as an influential factor in causing construction project delays (Koehn and Meilhede 1981; Laufer and Cohenca 1990). In fact, Benjamin and Greenwald (1973) suggest that approximately 50% of construction activities are affected by weather. The impacts vary from reduced productivity to complete work stoppage (Moselhi et al. 1997). Management needs reliable plans and project schedules to set project activity times and baseline schedules against which the project performance will be measured. Variability and uncertainty in the project schedule make achieving this a difficult task.

Quantification of uncertain activity durations could be dealt with using the Program Evaluation and Review Technique (PERT), however, PERT assumes that activities durations are independent from each other, leading to unrealistic schedules.

Planners have accounted for the weather impact on a construction project using different methods (Smith and Hancher 1989), of which the most common are:

1. Add a certain percentage of time to each activity, based on the type of activity, the time of year in which the activity is to be executed, and experience.
2. Add a time allowance to the entire project based on the time of year and previous experience.
3. Reduce the number of working days for the duration in which the project is expected to take place based on experience or standard tables.

Figure 1-1 shows a simplified example of the first two approaches in the previous list.

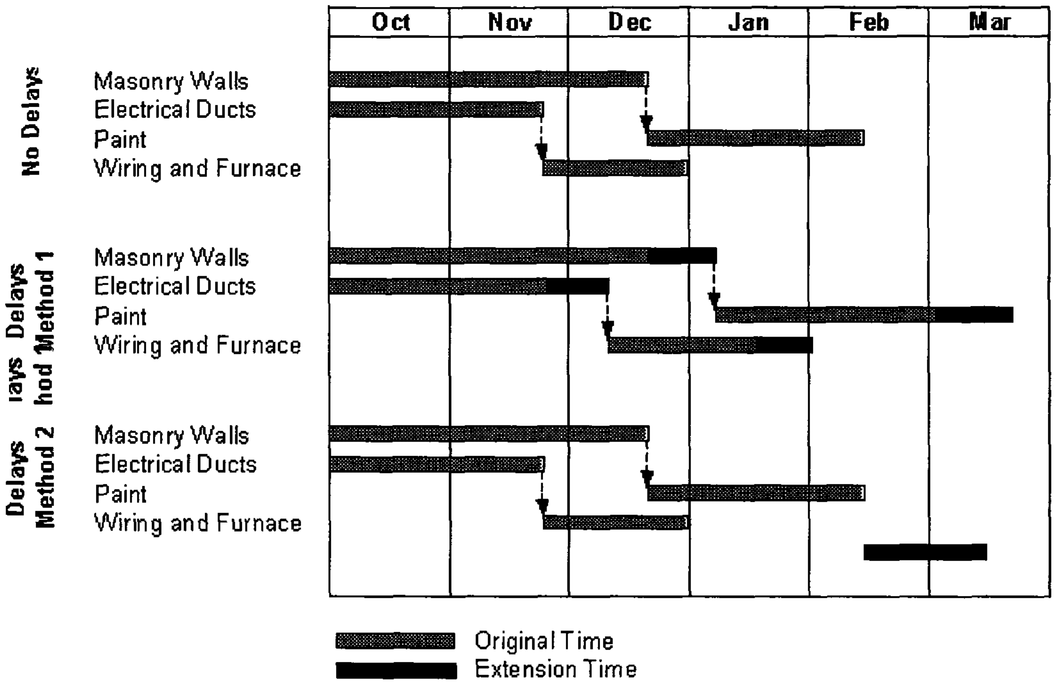

Figure 1-1. Simplified Example of Common Approaches to Include the Weather Impact on Construction Project Duration

Other trials to account for the weather impact on construction exist in the literature. Benjamin and Greenwald (1973) worked with a simulation model that simulates the construction duration by making daily work / no-work decisions based on historical weather data and the sensitivity of the construction activity to the different weather factors. Moselhi and Nicholas (1990) proposed a hybrid expert system that takes into account the impact of weather on construction planning and scheduling due to reduced labour productivity. Moselhi et al. (1995) developed a decision support system, *Weather*, to estimate the weather impact on activities productivities and durations. Moselhi et al. (1997) expanded the applications of *Weather* to include a function to account for interrupted duration due to precipitation and / or wind, the combined impact of weather on labour productivity and other interruptions.

1.3. Problem Statement

After reviewing the literature, it was evident that the previous research did not cover the topic in sufficient detail. Furthermore, it did not provide enough information to facilitate the task of planning for cold regions construction projects.

For example, in the literature reviewed, construction labour efficiency was modeled a number of times, showing its relation to the temperature and relative humidity (Koehn and Brown 1985; Thomas and Yiakoumis 1987), nevertheless, the weather generators used to simulate the weather effects on construction projects were only able to generate the maximum and minimum temperatures and the amount of precipitation.

This deficiency identifies the need for a universal construction weather generator, which could be used in generating the various weather parameters that impact construction activities. In cold regions construction, activities are affected by various weather parameters. The universal weather generator would be used to account for the uncertain weather parameters by attempting to quantify their impact on construction projects. In addition to the weather parameters that were covered in the literature, stochastic generation of relative humidity, wind speed, and frost penetration in the ground is needed to produce a universal construction weather generator that would enable modellers to simulate the impact of weather on construction projects in cold regions.

Previously, weather generators were rarely used in construction research. Shahbodaghlou (1987) and Wales (1994) have taken advantage of the weather generator developed by Richardson (1981), however, the industry did not make use of such techniques. A possible explanation could be the fact that this technique would require redeveloping and coding the weather generator for each application. This task can be time-consuming and inconvenient for the industry to apply. This deficiency demonstrates that the weather generator would need to be amenable to ready use with those parties that need only to simulate the weather effect without needing to redevelop a weather generator.

Previous construction models that targeted the relation between weather parameters and construction productivity studied the impact on electrical work (National Electrical Contractors Association 1974), labour efficiency (Koehn and Brown 1985; Thomas and Yiakoumis 1987), and masonry construction (Grimm and Wagner 1974). These studies targeted the impact of weather parameters on human activities. The existing literature does not facilitate planning for more complicated construction processes executed in cold regions.

In addition to the labour segment of the construction industry, the production process is also affected by weather. This deficiency identified the need to explore and model the effects of weather on different construction processes and to show their impact on process productivity, which includes the impacts on both the process itself as well as on construction labour.

Planning for construction projects particularly during winter construction depends largely on the experience of the planner. Different planners have different experiences and their estimation of the required time allowance, which would account for the impact of cold weather on the schedule, suffers from a lack of consistency among them.

This deficiency illustrates the need for a structured and consistent approach to documenting and accounting for the impact of weather on the different construction processes. Furthermore, this approach must involve an eventual implementation of knowledge within the context of the project schedule.

1.4. Research Objectives

In a cold region construction project, a wide range of weather parameters may affect construction activities. The impact of weather on construction activities has not been sufficiently assessed in the literature to furnish the needs of the construction field. Many deficiencies have since been identified that hinder the use of the developed models. The general objective of this research is to develop tools that would facilitate planning for cold regions construction. The tools must be developed in a way that enables the transference of technology to interested parties for the purposes of research and industry practices enhancement.

The first objective is to develop a practical, well-structured, and consistent framework that researchers can follow to study and model the impact of cold weather on the different construction processes and which the construction industry can use in their projects planning. The proposed framework attempts to structure the approach to include the impact of winter conditions on a construction process, thus trying to reduce the inconsistencies experienced at the planning stage.

The second objective of this research is to develop a universal construction weather generator. Different weather parameters can affect different construction activities, for example, according to the literature, if human labour is being utilized in an open cold region, both the effective temperatures and the relative humidity can impact productivity. Effective temperatures are a combination of ambient temperatures and wind speed. In addition to those parameters, precipitation and frost penetration through the ground can affect many construction earthwork activities.

There is an immense need for a weather generator capable of successfully generating the following parameters affecting construction activities:

- Maximum, minimum temperatures,
- Precipitation occurrence and amounts,
- Maximum, minimum relative humidities,

- Wind speed, and
- Frost penetration through the ground.

The third objective of this research is to develop the weather generator in a manner that facilitates the transfer of the weather generation technology to the other parties in need of such a tool. Such a development would enable the reuse of the weather model by parties for academic and industrial use without having to redevelop the weather generator itself. The interested parties would therefore be able to focus the bulk of their efforts on documenting and modelling the impact of weather on the different construction processes.

The fourth and final objective of this research is to start building information and simulation libraries to chronicle the impacts of weather in cold regions on the different construction processes. This objective comprises a two-fold approach:

- Firstly, different construction processes should be visited and investigated to develop a better understanding and documentation of the process. Achieving this would facilitate further investigation into the different effects of weather that impact the various stages of the process. Generally, a construction process will have many stages and activities; the weather impact on each might vary considerably. So far, two construction processes have been recognized as being sensitive to cold weather and have been targeted for further study: high density poly-ethylene (HDPE) pipeline installation and tunnelling construction. The weather impact on each stage of the targeted processes will also be explored and documented.

- Secondly, to facilitate planning for cold regions construction projects, integrated simulation models for the previous processes should be developed, detailed, and tested. Those models will take advantage of the developed weather generator as well as the knowledge gained about the impact of cold regions weather on the targeted processes. These models should give construction planners a good idea about the impact of cold weather on the project's performance and the overall productivity by taking into account the location and the time of year in which the project should start.

1.5. Construction Processes Simulation

Scheduling methods like the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) were criticized for not being true representations of the construction process. The complexity of construction processes cannot be adequately modeled by these methods (Koskela 2000)

Simulation presents a cheap and reliable approach to experiment, evaluate, and quantify the performance of a system subject to a different set of conditions (Mohamed 2002). Construction operations have been simulated using general-purpose simulation languages, such as VISUAL SLAM (Pritsker et al. 1997) and SIMSCRIPT (Russell

1993). These languages are capable of modelling different domains including construction and manufacturing.

Other simulation languages were developed primarily for the construction domain. Examples include CYCLONE (Halpin 1976), STROBOSCOPE (Martinez and Ioannou 1994), and RESQUE (Chang 1987). These languages can be used to develop simulation models for different construction domains.

Special purpose simulation (SPS) tools were introduced that generally focus on a certain construction domain, and through which the task of modelling projects for that domain was significantly facilitated. Examples of models developed using SPS tools include: Ap2Earth (Hajjar and AbouRizk 1996) and CRUISER (Hajjar and AbouRizk 1998). A unified modelling methodology was then introduced that takes advantage of the SPS approach. This resulted in the development of the Simphony simulation environment, which significantly reduced the time needed to develop construction SPS tools (Hajjar 1999).

Currently, simulation is recognized as a powerful tool for modelling and analyzing construction operations. Nevertheless, despite the numerous developments in the simulation tools that have been developed for construction, the use of simulation by industry practitioners is still limited (Hajjar 1999).

1.6. Methodology

A summary of the proposed methodology is shown in Figure 1-2. This research begins with a literature review. The literature review covers areas such as weather generation, simulation modelling, High-level Architecture (HLA) for distributed simulation, and the impact of cold weather on construction.

Attention was given to developing a framework for cold weather construction simulation. Clearly defining the steps required in applying the framework to simulate and account for the cold weather impacts on a construction process is important to ensure the generality, simplicity, and consistency in applying the framework.

Following the conceptual development of the framework, two parallel branches of work will be carried out simultaneously:

- Development of a universal weather generator, and
- Applications of the framework on different construction processes to test its ability to account for the impact of cold weather on those processes.

For the first branch, work began by developing and testing a universal weather generator for construction purposes. The existing weather generator's functionality was extended to add particular weather parameters that impact construction activities. So far, maximum temperature, minimum temperature, precipitation, relative humidity, and frost penetration in the soil have been included for generation.

Next, the weather generator was developed for more than one location in Canada using data available from Environment Canada's climate database. This development should increase the utility of this weather generator in the future.

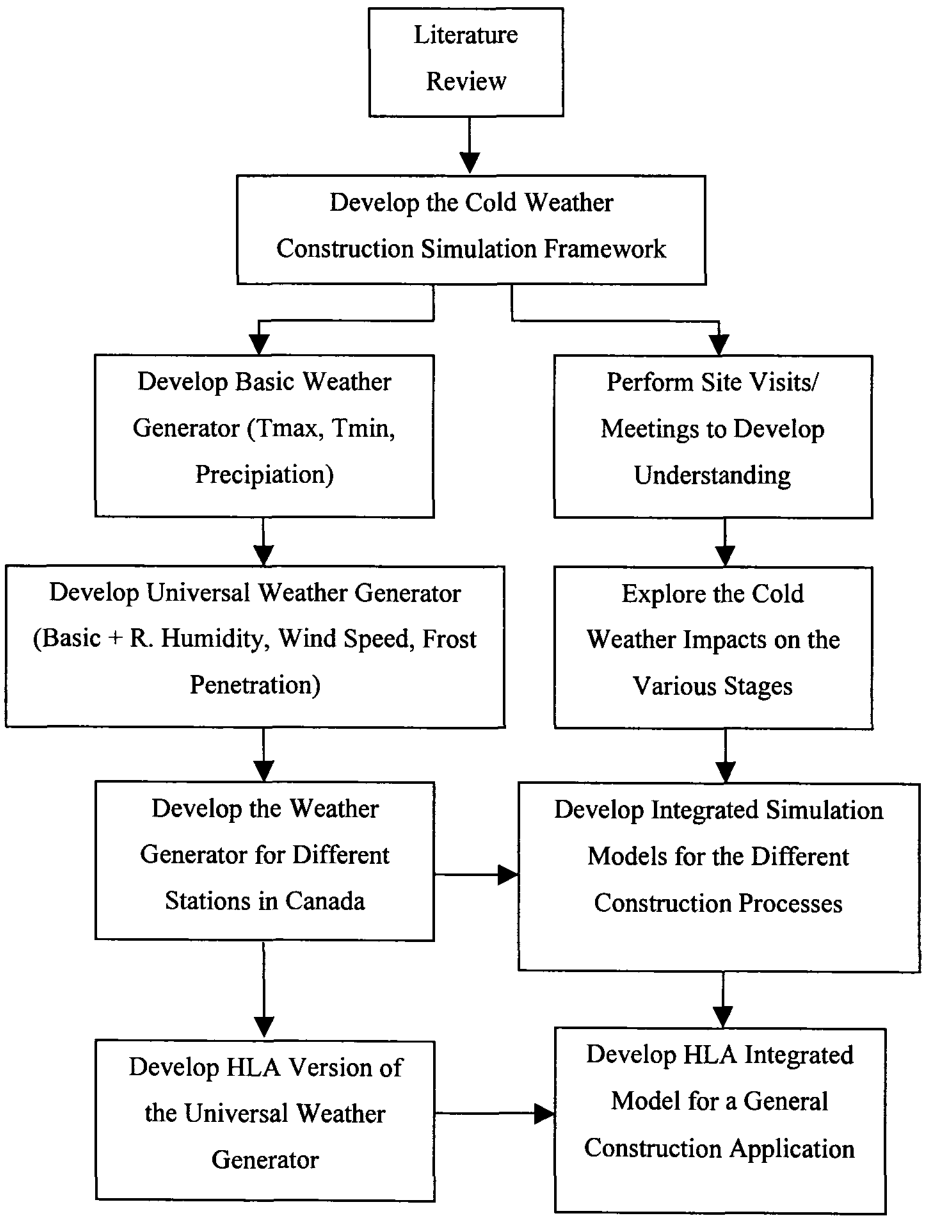

Figure 1-2. Overall Research Methodology

The weather generator was then redeveloped using High Level Architecture (HLA) to enable its use as part of distributed simulation models that can model different construction processes.

In the second branch of Figure 1-2, several visits to construction sites were scheduled to be carried out in order to test the effectiveness of the framework. The targeted processes were studied in detail. For the tunnelling process, interviews with City of Edmonton personnel and tunnelling supervisors, as well as site visits were scheduled. For the pipeline installation process, collaborations took place with a major construction company, North American Construction Group (NACG). Interviews with site engineers and with the project superintendent as well as personal monitoring was carried out to collect data and to develop an understanding about the construction process's work sequence, activity times, delays, and constraints.

The effect of cold weather on the targeted construction processes was explored. What stages or activities of work are affected by cold weather? For those activities, to which weather parameters are they most sensitive? How severely do those parameters affect the activity and the process as a whole?

The aim of construction simulation modelling is to represent construction systems in a manner that captures reality in a cost effective way. To achieve this, the weather parameters affecting construction activities' durations were targeted for simulation. The uncertain weather parameters were stochastically generated and their impact on the activities' durations was quantified.

Finally, integrated simulation models for the above-mentioned construction processes were developed, which integrated the developed universal weather generator with available documentation concerning the impact of weather on the different stages of the construction process. These models were developed in the *Simphony* simulation environment. To explore the potential benefits of using the HLA framework, a prototype of a general construction application was developed, which was integrated with the HLA version of the weather generator.

The research methodology makes use of the developed cold weather construction framework as guidance in modelling the different construction processes that are executed in cold regions.

1.7. Thesis Organization

Chapter 2 lays the foundation on which this research is based. It proposes and explains in detail a framework that simplifies the simulation and representation of the impact of cold weather on a construction process. The chapter introduces the framework in sequential steps.

Chapter 3 expands on the first element of the framework, the universal weather generator. It studies the different weather parameters to be generated and proposes the methodology for successfully addressing and generating each of them.

Chapter 4 validates the proposed weather generator developed in Chapter 3. It statistically validates and tests the output series of weather parameters by generating 40 years of weather data and comparing them statistically to the available historical weather data.

Chapter 5 is an application of the proposed framework. It involves the systematic analysis and evaluation of cold weather impacts on the construction process. This chapter applies the framework to two different construction processes: tunnelling construction and High Density Poly Ethylene (HDPE) pipeline construction. The benefits and lessons learned from applying the framework are discussed at the end of each application.

Chapter 6 introduces and explains the High Level Architecture (HLA) approach in simulation. Within this context, it also demonstrates the weather generator federate, which was developed using the HLA. Chapter 6 then integrates the weather generator federate into a general construction federation. It then explores and discusses the benefits of using such a technique in the proposed cold weather framework.

Chapter 7 presents the final discussion of this research, describing the findings, conclusions, contributions, and recommendations for future research.

CHAPTER 2. A FRAMEWORK FOR COLD WEATHER CONSTRUCTION SIMULATION

In this chapter, a framework is proposed for simulating construction projects that take place in cold regions. The uncertainties caused by weather can significantly affect a project's schedule, resulting in significant variations as compared to the baseline schedule. The proposed framework represents an attempt to structure the way an engineer would approach the project and its work breakdown structure of activities in order to develop an understanding that would enable the quantification of weather effects and account for their impact on the project baseline.

2.1. Overview of the Framework

The framework is composed of a collection of components, which help in understanding and simulating construction projects that are subject to the uncertain effects of weather. The framework also details the steps needed to model successfully the weather-sensitive activities. This model will allow the researcher to quantify the weather impact on the project schedule. Figure 2-1 shows the proposed cold weather simulation framework. The components of the framework will be handled in the following sections.

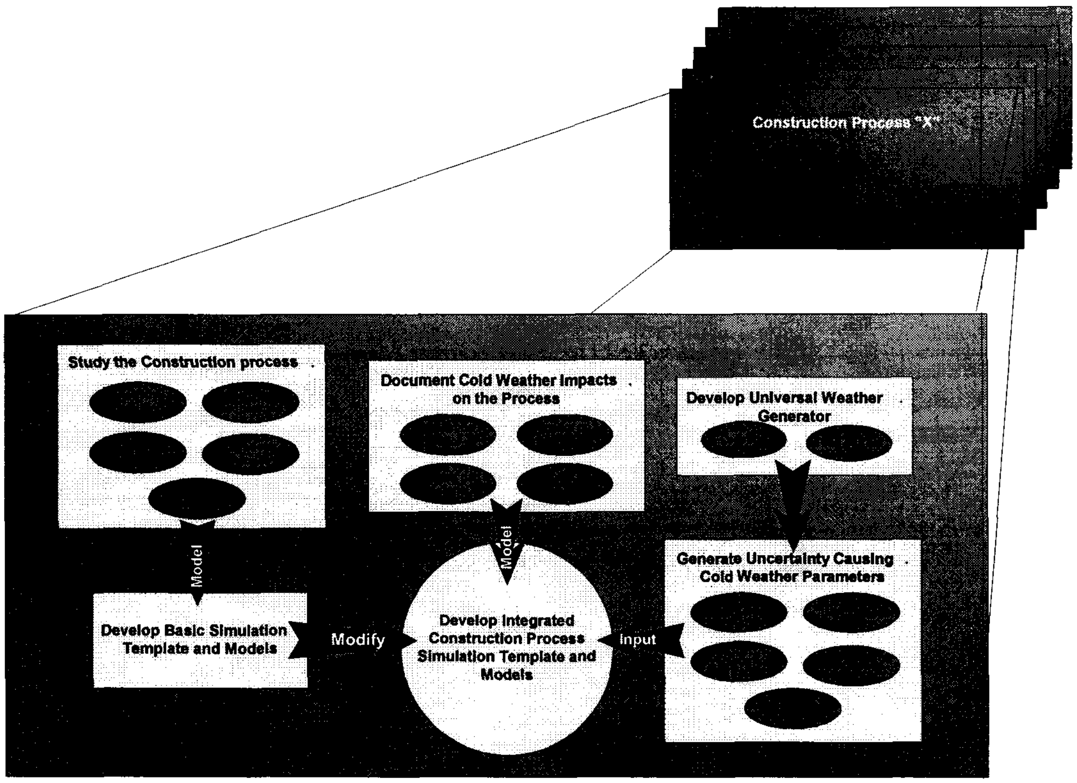

Figure 2-1. Proposed Cold Weather Construction Framework

The goal of the proposed framework is to produce a library of simulation models that are representative of the various weather-sensitive construction processes requiring execution. The library is in fact a collection of work pieces, the seed for which is being implanted in this research.

In Figure 2-1, the construction process that is under focus is referred to as construction process "X", and is representative of any construction process under consideration (e.g. tunnelling, pipeline construction, or building construction). The following sections will be a description of the steps needed for the successful modelling of process "X." It should be noted that the goal library is simply the collection of the different construction processes' simulation models, which are themselves the aggregate of sequential steps that are proposed by the framework.

2.2. Components of the Framework

The proposed cold weather construction framework is composed of a number of components that will be integrated together. This integration will facilitate the inclusion of the weather effects, and will improve the evaluation of their impacts on the project schedule in the planning stage of the project.

The components of the framework help to develop a good understanding of the construction process under consideration, which entails studying the process at the activity level and documenting the impact of weather on the process and its activities. The weather-generating component, which is another integral part of the framework, is responsible for generating stochastically the uncertain weather parameters for the project. Details of the suggested components are presented in the following sub-sections of this chapter.

2.2.1. Detailed Process Study

The first step of applying the framework to account for the impacts of cold weather on a particular construction process is to analyze the process in order to develop a better understanding of its details. At this stage, the impact of weather uncertainty on the construction process will be overlooked.

Site visits should be scheduled, and the process should be watched and documented by the engineer. This entails documenting many aspects of the process:

- The work breakdown structure of the process activities,
- The logic of performing the tasks and the activity sequencing,
- Any process constraints or dependence on external factors (e.g. material delivery) should be noted,
- The resource requirements of each activity of the process should be studied: the types or resources needed, the required level of resource, and the priorities of the different activities sharing the same resource should be determined, and
- Data about the average productivity rates for each activity should be collected. For example, in the case of labour productivity, the average level of labour productivity at the crew level could be measured using Equation 2-1.

$$\text{Average Labour Productivity} = \frac{man-hours\ \ used}{quantity\ \ produced} \qquad \text{Equation 2-1}$$

The average productivity value could be documented based on historical data, expert opinion, or standard estimating manuals. In commercial construction, it could be the estimated or budgeted productivity at completion, which is normally treated as a constant parameter (Thomas and Yiakoumis 1987). In many cases, the engineer might choose to study the effect of weather uncertainty on activity durations, in which case activity durations data should be collected.

2.2.2. Developing the Basic Process Simulation Model

After gathering all the required information about the process under consideration, the next step is to develop a basic simulation model for the process while disregarding the impact of cold weather.

At this stage, the engineer has the option to develop the simulation model for the process using discrete event simulation or using combined discrete-continuous event simulation. Both approaches will be sufficient for this step; however, it is important to note that developing a discrete event model will most likely require more modifications in order for the basic model to be adapted to include the weather impacts on the process. This adaptation will be handled in Section 2.2.5.

The combined discrete-continuous event simulation model details the construction process at the operation level, which requires detailed information and a better understanding of the construction process under consideration (Shi and Abourizk 1998). For that reason, the previous step, handled in Section 2.2.1, is crucial for the success of the final model. Also, developing the basic simulation model serves to promote a better understanding of the details of the process, which in turn facilitates the integration of the weather impacts in the final model.

The main target of this step is to make sure that the model is an acceptable abstraction of the construction process. For that reason, the basic simulation model should be validated and tested to ensure that it is capable of simulating in sufficient detail the construction process and is an acceptable abstraction of it.

2.2.3. Documenting the Impact of Weather on the Process

Weather can impact a construction process in various ways (Moselhi et al. 1997). In severe conditions, certain activities and sometimes the whole project can be halted. Bad weather conditions can slow down a construction process by lowering the productivity of the construction crews and equipment. Additional activities can also be added to the construction process to counteract the negative impact of the cold weather. An example is the excavation activities for pipeline construction in which the soil is frozen, thereby severely impacting the productivity of excavators. In such cases, an additional ripping activity is added to the process to counteract the impact of the frozen ground on the excavation activity productivity.

To facilitate the task of documenting the required information about a process, Figure 2-2 can be used to guide the procedure of documenting the impact of weather on a construction process. First, the process stoppage conditions should be investigated. These conditions affect the entire process; and when triggered, the conditions bring the entire process to a halt. An example of this is the need to stop all the tunnelling projects activities whenever the ambient temperature is less than -40^{o}c.

Benjamin and Greenwald (1973) suggest that approximately 50% of construction activities are affected by weather. The second step, therefore, in collecting data about the effect of cold weather on construction activities, is to go over the work breakdown structure (WBS) of the process activities and investigate which of the activities are sensitive to weather effects and which are not. The following is a summary of the data that must be documented for each weather-sensitive activity:

- Influencing weather parameters;
- Stopping conditions; and
- Model describing the relation between the weather-sensitive activity and the influencing weather parameters.

For the identified weather-sensitive activities, the influencing weather parameter should first be identified. For example, crane operations are sensitive to the wind speed, whereas labour dependent activities are generally influenced by the effective temperature and relative humidity (Thomas and Yiakoumis 1987, Koehn and Brown 1985).

Following the identification of the weather-sensitive activities and their influencing weather parameters, the weather-sensitive activity stoppage conditions should be identified. These conditions will be based on the range of the influencing weather parameter within which the weather-sensitive construction activity is forced to be halted. In the tunnelling process, for example, the crane is supposed to stop working whenever the wind speed is more than 50 km/hr.

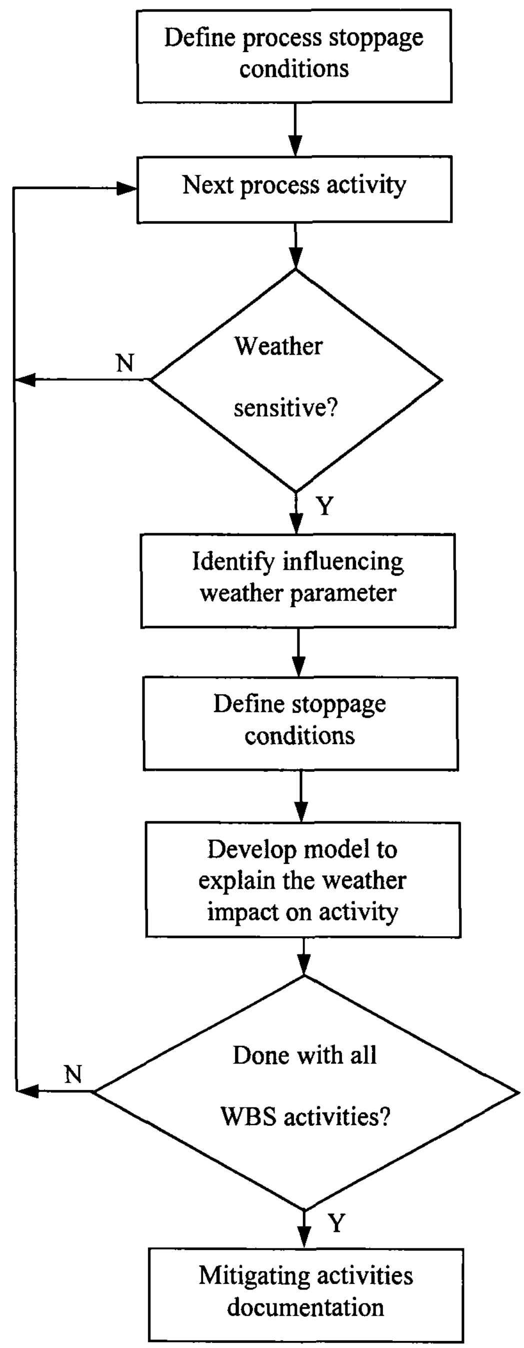

Figure 2-2. Impact on Construction Process Documentation Flow Chart

Next, the extent of the influence of the weather parameters on the weather-sensitive activities should be investigated. This is generally achieved by assessing the impact on task duration. To carry out the calculations, a selection between either the impact directly on the task duration or on the task productivity, under varying weather conditions should be made. General guidelines for this selection are given in Section 2.2.5.

If task productivity is chosen, daily productivity factors (PF) can be used to assess the weather impact on the activity. The objective of this step is to quantify the effect of the weather parameters on the weather-sensitive activities' performances. This could be done using regression analysis (Thomas and Yiakoumis 1987, Koehn and Brown 1985). In previous cases, neural networks have been used (Wales and AbouRizk 1996). Another alternative is to use expert judgement and translate the experts' knowledge into a collection of if-then rules through which the effect of uncertainty weather parameters on the sensitive activities could be identified.

If regression or neural networks are chosen for the analysis, site data collection or historical records, if available, will be needed. For example, if task productivity is chosen for the analysis, the daily productivity factors (PF) can be calculated using Equation 2-2. On the other hand, if task duration is chosen, the total task duration or the duration required to produce a certain number of units can be targeted for data collection. Please refer to Section 2.2.5 for further guidelines on this issue.

$$\text{Productivity Factor (PF)} = \frac{average \quad productivity}{actual \quad productivity} \qquad \text{Equation 2-2}$$

Productivity factors less than 1 mean that the actual productivity is worse than average. It should also be noted that Equation 2-2 is compatible with this convention for labour activities, where the average productivity values are measured using Equation 2-1. However, for other activities, in which the average productivity values, measured, for example in units produced per unit time, increase with the improvement in productivity, the reciprocal of Equation 2-2 should be used to measure the PF.

Along with the productivity factors and task durations, the values of the influencing weather parameters (i.e. temperature, relative humidity, wind speed, etc.) should also be collected. After the data have been collected, a mathematical relation should be established between the influencing weather parameters and the productivity factors or task durations achieved in the field. This is established as the statistical or neural network model is developed.

Another aspect of the impact of weather on the construction process that needs to be investigated and documented involves those incidents in which certain activities, which were not present in the original process, are added to ease the impact on the process. These are called mitigating activities. They are normally triggered when a weather parameter reaches a certain level. For example, in the pipeline installation process, if the frost depth exceeds one ft, then the trenching productivity of backhoes is severely affected. In such cases, a ripping activity, which is not normally conducted in the typical construction process, can be added to ease the impact on productivity.

Several factors related to these mitigating activities should be identified, including their triggering condition, their role in the construction process, and their relation to the process logic. In addition, their productivity values should be documented for inclusion in the integrated simulation model.

2.2.4. Stochastic Weather Generation

PERT or Monte Carlo simulation can be used to quantify the impact of uncertainty variables on different construction processes; however, these techniques assume that the project tasks' durations are independent random variables. The methods are unable to establish the cause of uncertainty, making them unsuitable for modelling the impact of weather on construction processes (Wales and AbouRizk 1996).

To better model the impacts of weather on construction processes, the task should be broken down into two steps. The uncertainty variables should first be quantified through stochastic generation of the influencing weather parameters. Secondly, their impact on the activities' productivity or duration should be simulated.

In this research, a very important requirement of the framework is to build a good stochastic weather generator that can generate series of weather sequences of the most influential weather parameters affecting construction. The weather sequences must keep the historical serial correlation of the weather parameter values and keep the historical cross correlations between the different generated weather parameters. Statistical tests are recommended to verify the developed model and to confirm its conformance with these requirements.

Attention should be given to the weather variables that affect productivity and, in particular, those that could lead to activity or entire process stoppage. The following list of such weather variables were targeted for inclusion in a stochastic weather generator.

- Precipitation,
- Maximum and minimum temperatures,
- Average daily wind speed,
- Maximum and minimum relative humidity, and
- Frost penetration in the ground.

Although frost penetration is not a weather parameter by itself, it is closely related to temperature; it has a significant effect on many construction activities. It was therefore logical to include it in the stochastic weather generation model. Details of the weather generator and how each of these parameters is generated will be described in the next chapter.

2.2.5. Developing the Integrated Process Simulation Model

The final step in modelling the impact of cold weather on a construction process is to integrate the process simulation model with the stochastic weather generator. To achieve this, the basic process simulation model should be extended to reflect its relation to the uncertainty weather parameters. Furthermore, the simulation logical clock should be integrated with a calendar. Each day, both the logical time clock and the calendar advance one day. The weather for that day is then generated. Next, the progress of the weather-sensitive activities can be advanced using the PF model or the task duration model developed in Section 2.2.3. When using the PF model, predictions of the actual productivity for that day can be made using Equation 2-2. That way, the activity progress can be assessed based on the generated weather for that day. After updating all the process activities' progress, the logical time and calendar advance one day and the procedure repeats.

It is preferable that the engineer makes any decisions regarding the simulation model type (i.e. whether discrete or combined discrete-continuous simulation model) and the data to be collected (i.e. duration to accomplish a task or PF data) before developing the basic simulation model in order to minimize the amount of modifications in the integration stage. To help answer those questions, the flowchart in Figure 2-3 can be used. It should be noted that activities that are not weather-sensitive should not require any modification to extend the basic simulation model to the final integrated model. The engineer's prior choice for modelling those activities, whether discrete or combined discrete-continuous event simulation, should not require any further modifications at this stage.

To extend successfully the basic process simulation model, it is important to answer and decide a number of issues for each weather-sensitive activity in the process.

Questions designed to prompt answers to each issue are illustrated in Figure 2-3. Those issues are listed below:

- Will the activity be modeled using discrete event or combined discrete-continuous event simulation?
- Will task progress be assessed using PF or task duration will be calculated directly?
- What is the time interval between data collections or task progress updates?

Referring to Figure 2-3, for each weather-sensitive activity in the process, the first question is whether this is a mitigating activity. If it is, then a conditional node should be created in the simulation model. The mitigating activity progress or duration will only be valid if a certain triggering condition regarding the influencing weather parameter is present; otherwise, the node should be treated as a dummy node.

The next question is whether the quantity to be executed is a continuous quantity (e.g. excavation or masonry) or discrete (e.g. pipe welds or crane lifts). In continuous quantities, assessing task progress using productivity factors is recommended. If the entire task is expected to be executed in multiple days then discrete-continuous event simulation in recommended to model the activity, the time interval between successive progress updates must be less than or equal to one day due to the weather parameters' daily updates. At the end of every update cycle, partial completion of the activity should be allowed.

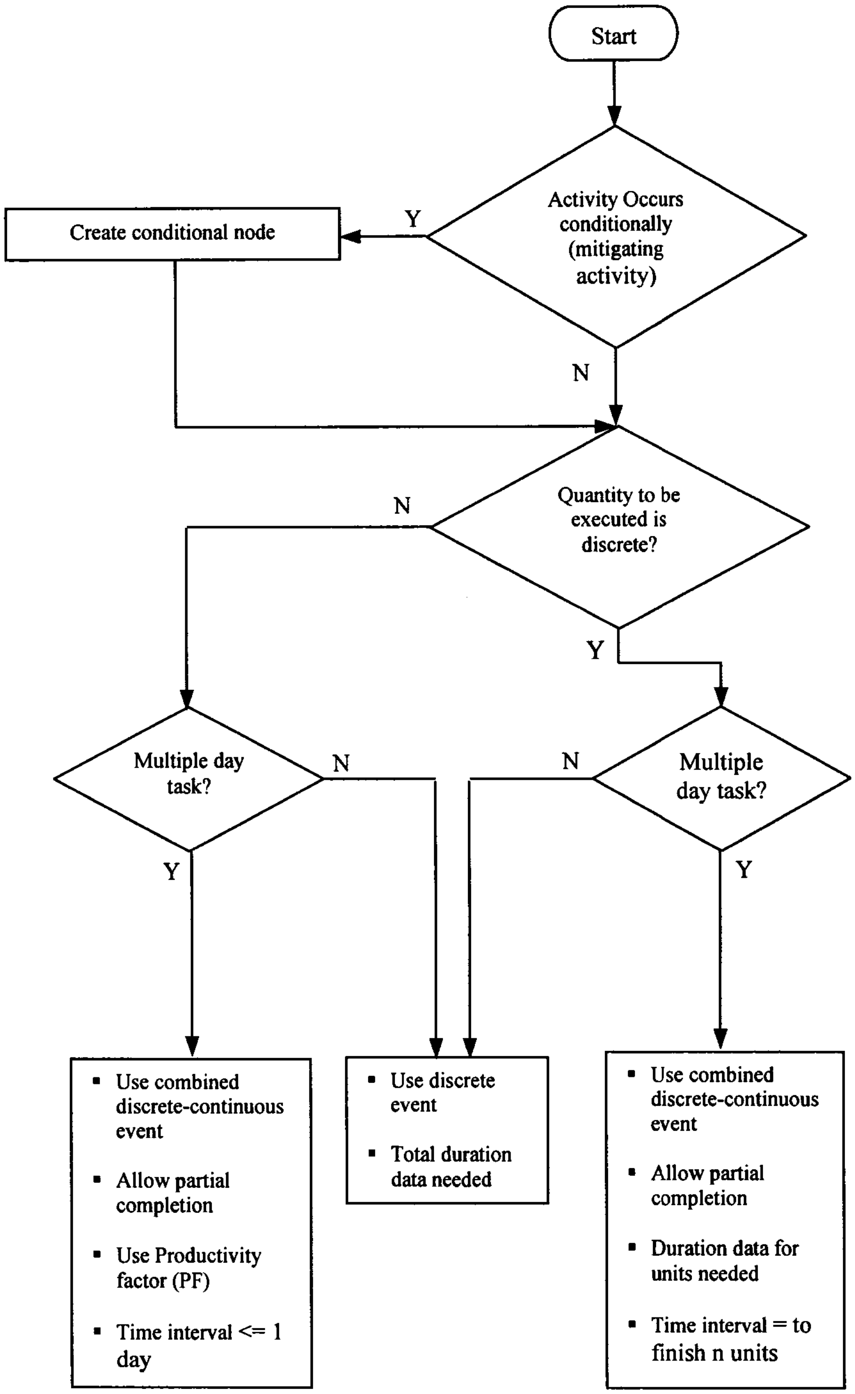

Figure 2-3. Flow Chart to Facilitate the Integrated Simulation Model Choices

For discrete quantity tasks, activity progress is assessed based on the number of discrete units completed and the duration needed to execute them. For multiple day tasks, using combined discrete-continuous event simulation is recommended in that case. The time interval between successive progress updates should be based on the time to finish *n* number of units, which will require data collection related to the duration required to execute the n discrete units. At the end of every update cycle, partial completion of the activity should be allowed.

In either case (discrete or continuous quantities), if the entire task is expected to be executed within a single day, then discrete event simulation modelling for this task is recommended. This will need data collection related to the total task duration, which might require developing a separate regression model.

CHAPTER 3. UNIVERSAL CONSTRUCTION WEATHER GENERATOR

In this chapter, a universal weather generator for use in construction simulation purposes is proposed and developed. This chapter discusses the need for such a development, and illustrates the detailed approach for generating each of the different suggested weather parameters. The universal weather generator has been developed and given parameters for two cities in Alberta: Edmonton and Fort McMurray. The values of the model parameters for both cities will be given in this chapter in order to facilitate future utilization of the model for both academic and industrial research. The next chapter will check that the model assumptions were met as well as validate the model for both cities.

3.1. Construction Weather Generator Requirements

To successfully simulate and generate sequences of weather for a particular location, a number of requirements should first be satisfied in the weather generator:

- The stochastic processes underlying the different meteorological variables should be simulated based on an analysis of the historical weather data.
- The correlations and dependencies among the meteorological variables (cross correlations) should be preserved in the generated weather sequences. For example, in summer and on a rainy day, the temperature is more likely to be

below normal while the relative humidity is more likely to be above normal (Wales and AbouRizk 1996.)

- The time dependence within each weather variable (serial correlation) should also be preserved in the generated weather. For example, if a day has significantly higher temperature than normal, then it is more likely that the following day will be higher than normal and vice versa. This will most likely be due to the heat stored in the soil.
- The generated weather should keep the seasonal variations for each variable.

In addition to these general requirements, the weather generator should also satisfy the needs of the field in which it will be used. In the construction field, relevant weather variables are those that can affect the cost, productivity, or may cause complete work stoppage.

For the construction field, several weather variables are needed in a weather model. Precipitation can adversely impact the project schedule and cost. El-Rayes and Moselhi (2001), for example, noted that highway construction is sensitive to the impact of rainfall. Korman et al. (1992) documented a four-month delay in the completion date of a highway project due to excessive rainfall. Smith and Hancher (1989) developed a theoretical model to account for the impact of precipitation on the construction schedule.

Construction labour in an open environment is generally affected by a number of weather parameters. A number of studies modeled the impact of temperature and relative humidity on construction labour productivity. Thomas and Yiakoumis (1987) studied their impact on steel, masonry, and formwork labour activities. Grimm and Wagner (1974) studied their effect on masonry construction. Koehn and Brown (1985) showed their impact on general construction activities.

A commonly used approach is to take into consideration the effective temperature, as shown in Table 3-1, which comprises the combined effect of temperature and wind speed. Consequently, in order to be able to generate effective temperatures, the wind speed must be generated.

Table 3-1. Wind Chill Equivalence

Wind	Actual Temperature (°C)									
Speed	10	5	0	-5	-10	-15	-20	-30	-40	-50
(Kph)	Equivalent Temperature (°C)									
0	10	5	0	-5	-10	-15	-20	-30	-40	-50
10	9	3	-2	-8	-13	-18	-23	-34	-44	-54
20	4	-1	-9	-16	-22	-29	-36	-48	-60	-72
30	1	-6	-14	-22	-30	-36	-43	-56	-71	-85
40	-2	-9	-16	-23	-31	-40	-47	-61	-75	-87
50	-3	-10	-18	-26	-34	-42	-50	-64	-79	-93
60	-4	-12	-20	-28	-36	-44	-52	-66	-81	-96
70	-5	-13	-21	-29	-37	-45	-54	-68	-83	-98

Another parameter that affects construction activities is the frost penetration in the ground. This parameter severely affects excavation activities as the excavation involves cutting through frosted soil. Although frost penetration is not a weather parameter by itself, its value is highly dependent on the temperatures recorded. It could therefore be included in the weather model as a dependent variable, the value of which will be calculated from the generated temperature variables.

To summarize, the following parameters are targeted for generation by the construction weather generator:

- Precipitation,
- Maximum temperature,
- Minimum temperature,
- Maximum relative humidity,
- Minimum relative humidity,
- Average daily wind speed, and
- Frost penetration in the ground.

The following sections of this chapter detail the approach followed to generate the above-mentioned variables. The model parameter values for two Alberta weather stations, Edmonton International Airport and Fort McMurray Airport, are given in this chapter.

3.2. Overview of the Weather Generation Model

Historical weather data for the variables of interest were compiled and analyzed to determine the underlying stochastic processes of the meteorological phenomena to be simulated. This weather generation model is an extension of the work described by Richardson (1981).

Generating daily weather variables for use in a simulation model would generally follow the flow chart outlined in Figure 3-1. Details of each of the flow chart components will be given in the following sections.

3.3. Detailed Generation of the Weather Variables

To generate daily weather conditions, precipitation is treated as the primary variable in this model, and is considered an independent variable. Maximum and minimum temperatures as well as relative humidity are regulated depending on the state of precipitation for that day; that is, wet or dry. Wind speed is generated without any correlation with the other variables and is treated as an independent variable. Frost penetration in the ground is calculated as a dependent variable. Its value is dependent on the maximum and minimum temperatures, as well as the soil type. In the following sub-sections, the details of the modules to generate each of these weather variables will be presented. The model parameters values were calculated for the Edmonton International Airport weather station and for the Fort McMurray Airport weather station. 42 years of historical records (1961-2002) were used for both weather stations in order to establish their models' parameters values.

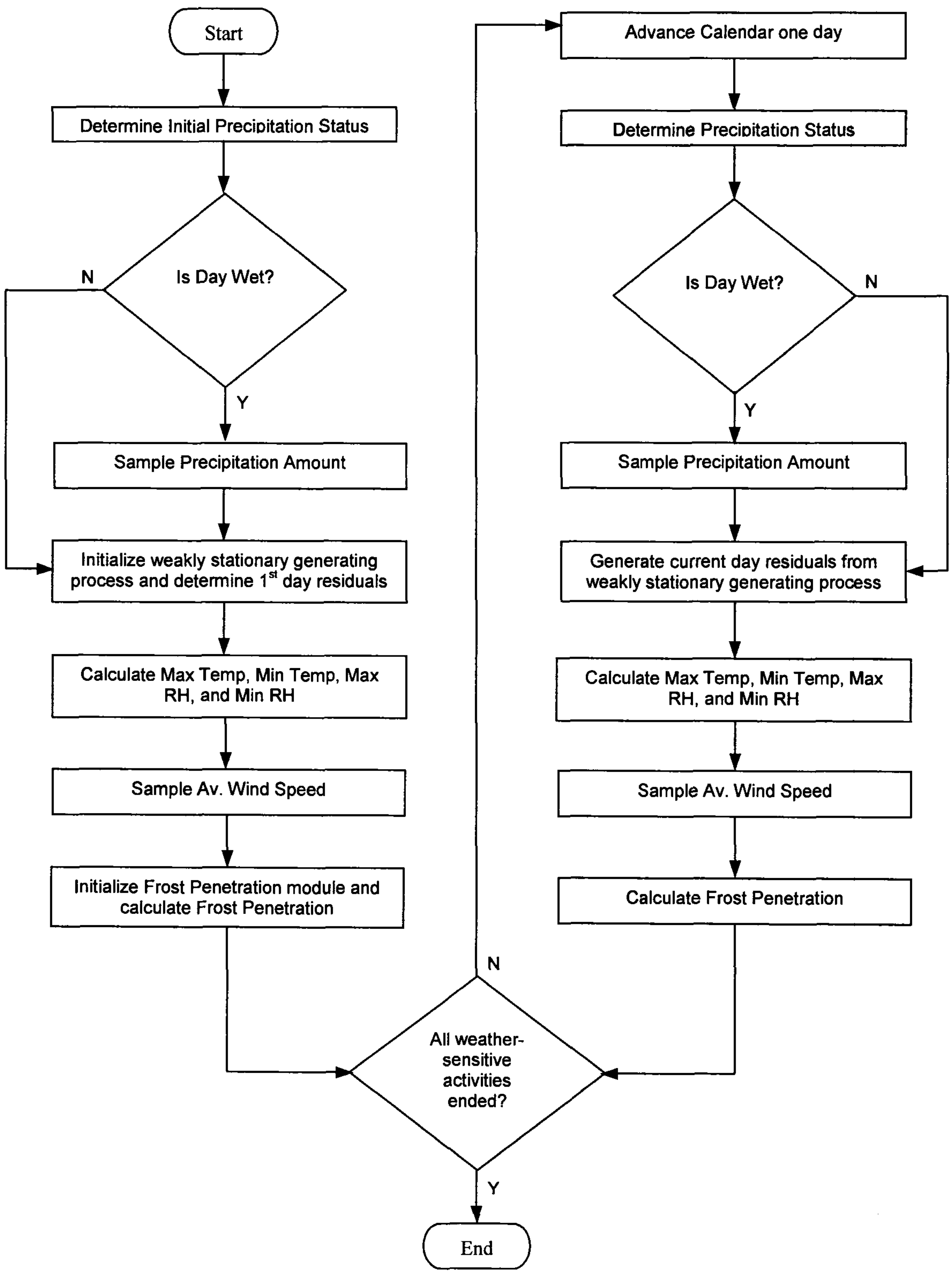

Figure 3-1. Weather Generation Flow Chart

3.3.1. Precipitation Module

For the current weather generation purposes, precipitation is considered the primary variable. Its occurrence and amount can be generated in several ways. In the literature, a number of studies reported the success of using Markov chains in modelling precipitation (Kavvas et al. 1977, Richardson 1981, Katz 1985, and Wales and AbouRizk 1996). For that reason, a first-order Markov chain was selected to model the precipitation component of the model. Precipitation is treated as an independent variable in this model, however, any other method that can model precipitation and generate its daily amount can be used as long as it has been successfully tested and accepted.

The Markov chain was modeled using the approach presented by Smith and Hancher (1989). A first-order, two-state (i.e. dry, wet) model was used to describe the precipitation state of the day. For the purposes of Markov chain transitional probabilities calculations, any day with a precipitation amount of 0.2 mm or more was considered a wet day. All other days were considered dry.

To calculate the weather model parameters values, the historical data was clustered into 12 months. To calculate the probability that a day in month *m* will be wet, Equation 3-1 can be used.

$$P_m(w) = \frac{n_m(w)}{N_m} \qquad \text{Equation 3-1}$$

Where:

$P_m(w)$ = Probability that a day in month m will be wet;

$n_m(w)$ = Number of days in the historical records in which the state of precipitation was wet and month was m; and

N_m = Number of days in the historical records in which the month was m.

For calculating transitional probabilities, Equation 3-2 can be used.

$$P_m(i/j) = \frac{n_{ji,m}}{n_{j,m}} \qquad \text{Equation 3-2}$$

Where:

$P_m(i/j)$ = Transitional probability from state j to state i for month m;

$n_{ji,m}$ = Number of transitions from state j to state i for month m in the records; and

$n_{j,m}$ = Number of transitions from state j to any other state for month m in the records.

To fully define the state probabilities for a month, only three probabilities need to be defined: $P_m(w)$, $P_m(w/d)$, and $P_m(w/w)$. The remaining transitional probabilities can be determined using Equations 3-3 and 3-4.

$$P_m(d/w) = 1 - P_m(w/w) \qquad \text{Equation 3-3}$$

$$P_m(d/d) = 1 - P_m(w/d) \qquad \text{Equation 3-4}$$

In reference to Figure 3-1, the state of precipitation for the first day (initial state of precipitation) in a simulation experiment will be determined by generating a uniform random number (R_n) between 0 and 1. If R_n is less than or equal to P_m(w), then the initial precipitation state is set to "wet." Otherwise, the first day's precipitation state is set to "dry." For all subsequent days in the simulation experiment, the precipitation state of the day will be conditioned based on the precipitation state of the previous day. For example, if the state of the previous day was dry, then the current day's precipitation state will be determined by generating a uniform random number (R_n) between 0 and 1. If R_n is less than or equal to P_m(w/d), then the current day's precipitation state is set to "wet"; otherwise, the current day's precipitation state is set to "dry." Likewise, if the state of the previous day was "wet", then the current day's precipitation state will be determined by generating a uniform random number (R_n) between 0 and 1. If R_n is less than or equal to P_m(w/w), then the current day's precipitation state is set to "wet"; otherwise, the current day's precipitation state is set to "dry."

To generate a precipitation amount for wet days, a two-parameter Gamma distribution was used. Richardson (1981) used an exponential distribution, while Wales and AbouRizk (1996) used a two-state Gamma distribution. Gamma distribution was selected due to its greater flexibility; this flexibility is due to its use of two parameters to describe the distribution. A separate Gamma distribution was defined for each month of the year to model the variation in precipitation amounts throughout a year. The Gamma distribution can be described by the formula in Equation 3-5.

$$f(x) = \frac{1}{\Gamma(\alpha)\beta^2} \exp\left[-\frac{x}{\beta}\right] x^{\alpha-1}, \quad x > 0 \qquad \text{Equation 3-5}$$

The mean (μ) and the variance (σ^2) of the Gamma distribution are related to the α and β parameters of the distribution by Equations 3-6 and 3-7. To calculate the Gamma distribution parameters values for each month, the mean and variance of the historical records are calculated for each month of the year and then matched to the Gamma distribution using Equations 3-6 and 3-7.

$$\mu = \alpha\beta \qquad \text{Equation 3-6}$$

$$\sigma^2 = \alpha\beta^2 \qquad \text{Equation 3-7}$$

For generating the precipitation amounts on wet days, it should be noted that the procedure used for sampling from a Gamma distribution depends on the value of (α). For values of (α) between 0 and 1, the procedure proposed by Ahrens and Dieter (1974) was used. For values of (α) that are more than 1, the procedure proposed by Cheng 1977, which is shown in section 3.3.3 (wind speed module) can be used.

Figure 3-2 illustrates a pseudo-code used in their acceptance-rejection procedure. To summarize, Table 3-2 lists the precipitation variables and transitional probabilities for the Edmonton International Airport weather station, calculated using the historical weather records for years from 1961 to 2002. Table 3-3 lists the same information for the Fort

McMurray Airport weather station using the historical weather station records for the same years.

```
done =False
b=(e+α)/e   where e = base of natural log = 2.71828
While Not done
   u = Uniform(0,1)
   w = b*u
   If w < 1 Then
         y = w^(1/α)
         v = Uniform(0,1)
         If v <= e^(-y) Then done = True
   Else
         y = -ln[(b-w)/α]
         v = Uniform(0,1)
         If v <= y^(α-1) Then done = True
   End If
End While
GammaVariate = β(y)
```

Figure 3-2. Pseudo Code for Ahrens and Dieter Gamma Variate Procedure ($0<\alpha<1$, $0<\beta$)

3.3.2. Temperature and Relative Humidity Module

In principle, temperature and relative humidity variables are less difficult to work with and to generate than precipitation. The reason for that lies in the absence of the high proportion of zero observations in the daily precipitation amount for these meteorological variables (Richardson 1981). For the generation of the maximum temperature, minimum temperature, maximum relative humidity, and minimum relative humidity, the technique presented by Yevjevich (1972) was used to study the processes.

Table 3-2. Precipitation Parameters (Edmonton International Airport Station)

Month (m)	$P_m(w)$	$P_m(w/w)$	$P_m(w/d)$	α	β
January	0.364	0.568	0.246	0.514	3.915
February	0.299	0.494	0.215	0.706	2.399
March	0.305	0.475	0.230	0.585	2.853
April	0.256	0.407	0.205	0.417	7.545
May	0.343	0.495	0.263	0.521	8.073
June	0.450	0.549	0.371	0.491	12.052
July	0.453	0.548	0.373	0.529	13.043
August	0.390	0.515	0.310	0.474	11.654
September	0.327	0.478	0.253	0.468	9.714
October	0.220	0.369	0.177	0.432	6.622
November	0.284	0.513	0.194	0.804	2.570
December	0.322	0.523	0.227	0.744	2.313

The historic time-series of each variable was reduced to a time-series of residual elements by removing the daily mean and standard deviation. Equations 3-8 and 3-9 (Richardson 1981) were used to determine the residual elements of each series. The elements time dependence (i.e. serial correlation within each variable and cross correlation between each pair of variables) was also determined in the process.

Table 3-3. Precipitation Parameters (Fort McMurray Airport Station)

Month (m)	P_m(w)	P_m(w/w)	P_m(w/d)	α	β
January	0.406	0.536	0.317	0.731	2.085
February	0.369	0.545	0.265	0.736	1.999
March	0.316	0.480	0.240	0.611	2.764
April	0.262	0.429	0.203	0.530	5.151
May	0.338	0.476	0.270	0.460	7.848
June	0.452	0.560	0.364	0.556	9.432
July	0.498	0.581	0.416	0.518	10.024
August	0.422	0.548	0.331	0.410	12.795
September	0.412	0.577	0.296	0.431	9.389
October	0.349	0.508	0.264	0.481	5.516
November	0.415	0.574	0.302	0.747	2.520
December	0.410	0.534	0.324	0.666	2.422

$$x_d(i) = \frac{X_d(i) - \overline{X_d^0}(i)}{\sigma_d^0(i)}, \quad if \quad \Pr_d = 0$$ Equation 3-8

$$x_d(i) = \frac{X_d(i) - \overline{X_d^1}(i)}{\sigma_d^1(i)}, \quad if \quad \Pr_d > 0$$ Equation 3-9

Where:

$x_d(i) =$ Residual element of parameter i for day d in the records;

$X_d(i) =$ Value of parameter i for day d in the records;

$\sigma_d^0(i) =$ Periodic std. deviation of parameter i for a dry day d in the records;

$\overline{X_d^0}(i) =$ Periodic mean of parameter i for a dry day d in the records;

$\sigma_d^1(i) =$ Periodic std. deviation of parameter i for a wet day d in the records;

$\overline{X_d^1}(i)$ = Periodic mean of parameter i for a wet day d in the records; and

$\Pr_d$ = Precipitation amount for day d in the records.

The daily mean and standard deviation for each variable are determined for each day of the year for both "wet" and "dry" conditions using the available historical weather data. The daily means and standard deviations are then smoothed using the Fast Fourier Transform (FFT) method. The MatLab® version 6.5 pseudo-code for smoothing using the FFT is shown in Figure 3-3. The daily means and standard deviations for the parameter under consideration are listed in a data file in the form of a single column composed of 365 rows. The code simply reads the target variable's data and returns a smoothed array of 365 data points, which will then be used to determine the residual elements from Equations 3-8 and 3-9. Figure 3-4 shows a plot of the mean daily maximum temperatures for wet days along with a plot of their smoothed values. Residual elements will be the basis of the weather generation scheme used. Figure 3-5 shows the maximum temperature residual series for a sample year (1967).

Finally, this work uses the weekly stationary generating process, suggested by Matalas (1967), to generate the weather data for the four parameters under consideration. This generates residual elements of the weather parameters by considering the residual element from the previous day plus a random component. The actual weather parameter values are determined by back substituting in Equations 3-8 and 3-9. The weekly stationary generating process is defined by Equation 3-10 (Matalas 1967) for n weather parameters; n is a positive integer that stands for the number of weather parameters considered in the process. In our case n is equal to four parameters, and the weather parameters that we considered are max temperature, min temperature, max relative humidity, and min relative humidity.

```
OriginalData=importdata(OrigialData.txt')

f=fft(OriginalData)
fr=real(f)
fi=imag(f)

terms=An integer number most likely between 9 and 12, to be found by trials

for t=1 to 365
   for n=1 to terms
```

$$sm(t) = sm(t) + \frac{(fr(n)^2 + fi(n)^2)^{.5} \cos[2\pi(n-1)\frac{(t-1)}{365} + a\tan 2(fi(n), fr(n))]}{365}$$

```
   end
   for n=(365-terms+1) to 365
```

$$sm(t) = sm(t) + \frac{(fr(n)^2 + fi(n)^2)^{.5} \cos[2\pi\frac{(n-366)(t-1)}{365} + a\tan 2(fi(n), fr(n))]}{365}$$

```
   end
end
```

Figure 3-3. MatLab® Pseudo-Code for Smoothing

$$x_d = Ax_{d-1} + B\varepsilon_d \qquad \text{Equation 3-10}$$

Where:

x_d = (nx1) matrix of residual elements for day d for parameters 1 to n;

x_{d-1} = (nx1) matrix of residual elements for day *d-1* for parameters 1 to n;

A and B = (nxn) matrices defined so that the correlations within and among the residual series are preserved; and

$\varepsilon_d = (n\text{x}1)$ matrix of random components sampled from a standard normal distribution with a mean of 0 and a standard deviation of 1.

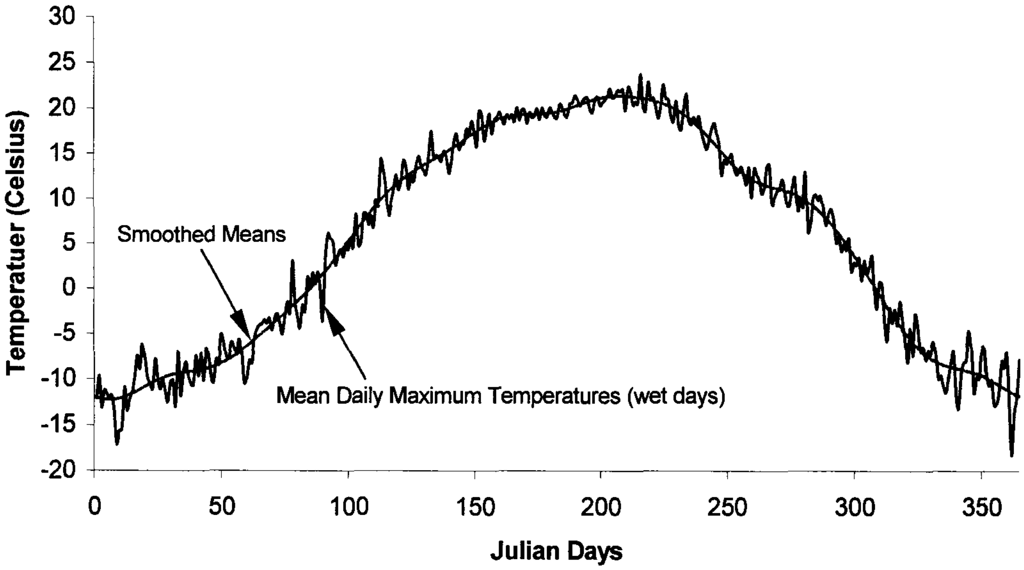

Figure 3-4. Maximum Temperature Means ("wet" days)

Equation 3-10 implies that the residuals of maximum temperature, minimum temperature, maximum relative humidity, and minimum relative humidity are normally distributed and that the serial correlation within each parameter can be described by a first-order linear autoregressive model (Matalas 1967). Matrices A and B can be determined from Equations 3-11 and 3-12 (Matalas 1967).

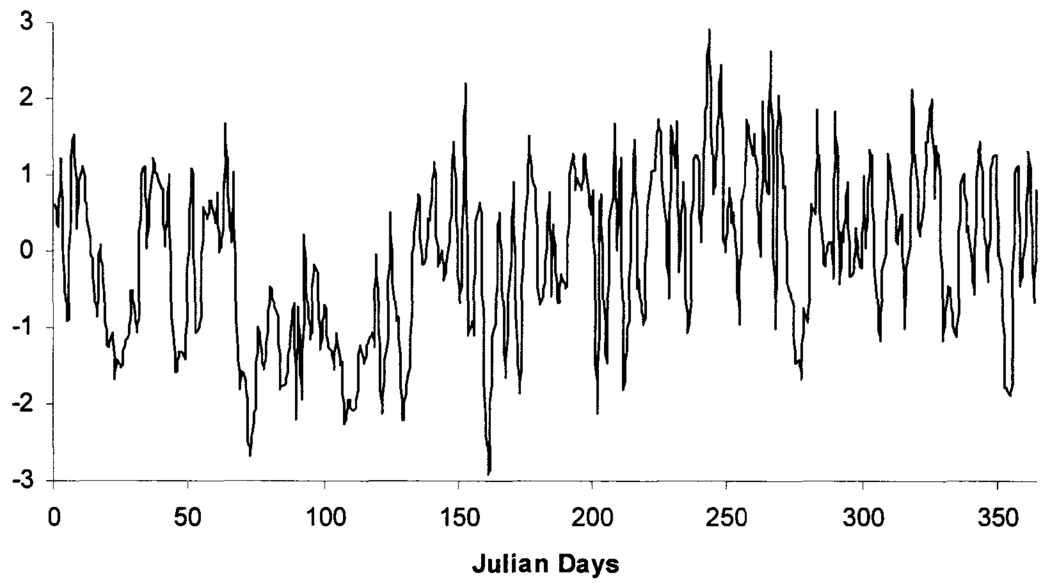

Figure 3-5. Maximum Temperature Residual Series (1967)

$A = M_1 M_0^{-1}$ Equation 3-11

$BB^T = M_0 - M_1 M_0^{-1} M_1^T$ Equation 3-12

Where:

M_0 = (nxn) lag 0 covariance matrix of the residual series; and

M_1 = (nxn) lag 1 covariance matrix of the residual series.

The variances of the residual series were found to equal approximately 1; consequently, M_0 and M_1 are (nxn) lag 0 and lag 1 cross correlation coefficients of the residual series. The components M_0 and M_1 are defined by the matrices in Equations 3-13 and 3-14.

$$M_0 = \begin{bmatrix} 1 & \rho_0(1,2) & \rho_0(1,3) & \rho_0(1,4) \\ \rho_0(2,1) & 1 & \rho_0(2,3) & \rho_0(2,4) \\ \rho_0(3,1) & \rho_0(3,2) & 1 & \rho_0(3,4) \\ \rho_0(4,1) & \rho_0(4,2) & \rho_0(4,3) & 1 \end{bmatrix}$$ Equation 3-13

$$M_1 = \begin{bmatrix} \rho_1(1) & \rho_1(1,2) & \rho_1(1,3) & \rho_1(1,4) \\ \rho_1(2,1) & \rho_1(2) & \rho_1(2,3) & \rho_1(2,4) \\ \rho_1(3,1) & \rho_1(3,2) & \rho_1(3) & \rho_1(3,4) \\ \rho_o(4,1) & \rho_o(4,2) & \rho_o(4,3) & \rho_1(4) \end{bmatrix}$$ Equation 3-14

Where:

$\rho_0(i,j)$ = Lag 0 cross correlation coefficient between the residual series for parameters i and j;

$\rho_1(i,j)$ = Lag 1 cross correlation coefficient between the residual series for parameters i and j with parameter j lagged one day with respect to parameter i; and

$\rho_1(i)$ = Lag 1 serial correlation coefficient for the residual series for parameters i.

For the proposed universal construction weather generator under consideration, four parameters are being generated (maximum temperature, minimum temperature, maximum relative humidity, and minimum relative humidity). The values of M_0 and M_1 for the Edmonton International Airport weather station were calculated using the historical records between the years of 1961 and 2002 and were found to be as follows:

$$M_{0Edmonton} = \begin{bmatrix} 1 & 0.673 & 0.004 & -0.410 \\ 0.673 & 1 & 0.0317 & -0.004 \\ 0.004 & 0.0317 & 1 & 0.489 \\ -0.410 & -0.004 & 0.489 & 1 \end{bmatrix}$$ Equation 3-15

$$M_{1Edmonton} = \begin{bmatrix} 0.643 & 0.471 & 0.085 & -0.189 \\ 0.634 & 0.632 & 0.105 & -0.029 \\ 0.013 & 0.093 & 0.613 & 0.428 \\ -0.206 & -0.003 & 0.319 & 0.526 \end{bmatrix}$$ Equation 3-16

The same calculations were carried out for the Fort McMurray Airport station for the years 1961 to 2002, and the M_0 and M_1 were found to be as follows:

$$M_{0FMac} = \begin{bmatrix} 1 & 0.442 & 0.008 & -0.270 \\ 0.442 & 1 & 0.012 & 0.020 \\ 0.008 & 0.012 & 1 & 0.476 \\ -0.270 & 0.02 & 0.476 & 1 \end{bmatrix}$$ Equation 3-17

$$M_{1FMac} = \begin{bmatrix} 0.378 & 0.148 & 0.052 & -0.121 \\ 0.213 & 0.103 & 0.024 & -0.020 \\ 0.019 & 0.042 & 0.524 & 0.417 \\ -0.090 & 0.020 & 0.291 & 0.451 \end{bmatrix}$$ Equation 3-18

Once the coefficients of the M_0 and M_1 matrices are calculated, solving for the A matrix is straightforward; however, solving for the B matrix is somewhat more complex. The B matrix can be calculated using the procedure suggested by Young (1968), in which matrix B is assumed a lower triangular matrix. In addition, matrix C is needed in the procedure to solve for matrix B. To solve for matrix B, the coefficients were derived and can be calculated from the set of equations shown in Figure 3-6. Using these equations, the A and B matrices for the Edmonton International Airport weather station for the years from 1961 to 2002 were found to be as follows:

$$A_{Edmonton} = \begin{bmatrix} 0.625 & 0.048 & 0.064 & 0.037 \\ 0.518 & 0.284 & 0.005 & 0.183 \\ 0.086 & 0.020 & 0.507 & 0.215 \\ -0.014 & 0.006 & 0.085 & 0.479 \end{bmatrix}$$ Equation 3-19

$$B_{Edmonton} = \begin{bmatrix} 0.760 & 0 & 0 & 0 \\ 0.316 & 0.630 & 0 & 0 \\ -0.084 & -0.089 & 0.761 & 0 \\ -0.422 & 0.221 & 0.284 & 0.641 \end{bmatrix}$$ Equation 3-20

The A and B matrices for the Fort McMurray Airport weather station for the years from 1961 to 2002 were calculated and were found to be as follows:

$$A_{FMac} = \begin{bmatrix} 0.368 & -0.014 & 0.077 & -0.058 \\ 0.221 & 0.004 & 0.004 & 0.037 \\ 0.085 & -0.005 & 0.406 & 0.246 \\ 0.020 & 0.002 & 0.095 & 0.411 \end{bmatrix}$$ Equation 3-21

$$B_{FMac} = \begin{bmatrix} 0.923 & 0 & 0 & 0 \\ 0.393 & 0.894 & 0 & 0 \\ -0.016 & -0.005 & 0.827 & 0 \\ -0.252 & 0.135 & 0.304 & 0.784 \end{bmatrix}$$ Equation 3-22

All the components of Equation 3-10 are now fully defined. With reference to Figure 3-1, the maximum temperature, minimum temperature, maximum relative humidity, and minimum relative humidity can be generated by applying the weekly stationary generating process using the previous day's residual elements and Equation 3-10. Nevertheless, the previous residual elements should only be initialized for the first day in the simulation run. The initialization process is accomplished by sampling the previous day's residuals from a normal distribution with a mean of 0 and a variance of 1. The weekly stationary generating process is then applied seven consecutive times. This is done to reduce any transitional start-up problems. In all cases, the values of the four parameters to be generated are determined by back substitution in Equation 3-8 or Equation 3-9; depending on the precipitation status.

3.3.3. Wind Speed Module

Wind speed is generated without any correlation to other variables. The variable of interest was the average daily wind speed. Environment Canada keeps historical records of the wind speed for the 24 hours of the day recorded every hour. The data was downloaded from Environment Canada's website using an online query. There were therefore 24 readings for each historical day; these readings were then averaged, resulting in the daily average wind speed. All these calculated daily averages were grouped into 12 groups based on the 12 months of the year. The data for each group was fit to a 2-parameter Gamma distribution. Three "goodness of fit" tests, Chi-square, Kolmogorov-Smirnov, and Anderson-Darling, were applied to the fitted distributions.

$$C = BB^T = M_0 - M_1 M_0^{-1} M_1^T \qquad C = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \qquad b_{11} = \sqrt{c_{11}}$$

$$b_{21} = \frac{c_{12}}{\sqrt{c_{11}}} \qquad b_{31} = \frac{c_{13}}{\sqrt{c_{11}}} \qquad b_{22} = \sqrt{c_{22} - \frac{c_{12}^2}{c_{11}}} \qquad b_{32} = \frac{c_{23} - \frac{c_{12}}{\sqrt{c_{11}}} * \frac{c_{13}}{\sqrt{c_{11}}}}{\sqrt{c_{22} - \frac{c_{12}^2}{c_{11}}}}$$

$$b_{41} = \frac{c_{14}}{\sqrt{c_{11}}} \qquad b_{42} = \frac{c_{24} - \frac{c_{12}}{\sqrt{c_{11}}} * \frac{c_{14}}{\sqrt{c_{11}}}}{\sqrt{c_{22} - \frac{c_{12}^2}{c_{11}}}} \qquad b_{33} = \sqrt{c_{33} - \frac{c_{13}^2}{c_{11}} - \frac{\left[c_{23} - \frac{c_{12} * c_{13}}{c_{11}}\right]^2}{c_{22} - \frac{c_{12}^2}{c_{11}}}}$$

$$b_{43} = \frac{c_{34} - \frac{c_{13}}{\sqrt{c_{11}}} * \frac{c_{14}}{\sqrt{c_{11}}} - \frac{\left[c_{23} - \frac{c_{12} * c_{13}}{c_{11}}\right]}{\sqrt{c_{22} - \frac{c_{12}^2}{c_{11}}}} * \frac{c_{24} - \frac{c_{12} * c_{14}}{c_{11}}}{\sqrt{c_{22} - \frac{c_{12}^2}{c_{11}}}}}{\sqrt{c_{33} - \frac{c_{13}^2}{c_{11}} - \frac{\left[c_{23} - \frac{c_{12} * c_{13}}{c_{11}}\right]^2}{c_{22} - \frac{c_{12}^2}{c_{11}}}}}$$

$$b_{44} = \sqrt{\frac{c_{44} - \frac{c_{14}^2}{c_{11}} - \frac{\left[c_{24} - \frac{c_{12} * c_{14}}{c_{11}}\right]^2}{c_{22} - \frac{c_{12}^2}{c_{11}}} - \left[c_{34} - \frac{c_{13}}{\sqrt{c_{11}}} * \frac{c_{14}}{\sqrt{c_{11}}} - \frac{\left[c_{23} - \frac{c_{12} * c_{13}}{c_{11}}\right]}{\sqrt{c_{22} - \frac{c_{12}^2}{c_{11}}}} * \frac{c_{24} - \frac{c_{12} * c_{14}}{c_{11}}}{\sqrt{c_{22} - \frac{c_{12}^2}{c_{11}}}}\right]^2}{c_{33} - \frac{c_{13}^2}{c_{11}} - \frac{\left[c_{23} - \frac{c_{12} * c_{13}}{c_{11}}\right]^2}{c_{22} - \frac{c_{12}^2}{c_{11}}}}}$$

Figure 3-6. Set of Equations to Solve for the B Matrix (4 parameters)

Table 3-4 lists the α and the β parameters of the Gamma distribution for the 12 months of the year along with the three "goodness of fit" test results for the Edmonton International Airport weather station for the years from 1961 to 2002. Table 3-5 lists the same information for the Fort McMurray weather station. Note in Table 3-5 that none of the tests passed for neither December nor January. A better option was to fit the data to a Beta distribution. For December, a Beta (1.719,3.561,0,25.709) and for January, a Beta (1.947,4.526,0,27.918) would pass two "goodness of fit" tests, but not the Chi-Square test. To ensure the consistency of the model, the Gamma distributions are used and their outputs will be tested in the next chapter.

Table 3-4. Gamma Distribution Parameters and Goodness of Fit Results Edmonton International Airport Weather Station

Month (*m*)	α	β	Chi-Square	Kolmogorov-Smirnov	Anderson-Darling
January	4.658	2.503	✓	✓	✓
February	5.431	2.134	✓	✓	✓
March	5.634	2.212	✓	✓	✓
April	6.551	2.200	✓	✓	✓
May	5.932	2.487	✓	✓	✓
June	6.387	2.208	✗	✓	✓
July	6.303	2.086	✓	✓	✓
August	6.264	1.976	✓	✓	✓
September	5.626	2.352	✓	✓	✓
October	5.769	2.261	✓	✓	✓
November	4.913	2.410	✓	✓	✓
December	4.715	2.475	✓	✓	✓

For sampling from the Gamma distribution, the α parameter for all the 12 months is greater than 1; the procedure outlined in Figure 3-2 cannot, therefore, be used.

Figure 3-7 illustrates a pseudo code for Cheng's (1977) acceptance-rejection procedure, which is suitable for situations where α is greater than 1. In the simulation run, an average wind speed for the day is sampled from the Gamma distribution of the appropriate month.

Table 3-5. Gamma Distribution Parameters and Goodness of Fit Results Fort McMurray Airport Weather Station

Month (*m*)	α	β	Chi-Square	Kolmogorov-Smirnov	Anderson-Darling
January	2.319	3.622	✗	✗	✗
February	3.579	2.519	✗	✓	✓
March	4.522	2.176	✓	✓	✓
April	6.525	1.688	✓	✓	✓
May	6.431	1.707	✓	✓	✓
June	5.904	1.634	✓	✓	✓
July	5.176	1.735	✓	✓	✓
August	4.693	1.856	✓	✓	✓
September	4.588	2.076	✗	✓	✓
October	4.651	2.215	✗	✓	✓
November	3.794	2.337	✗	✓	✓
December	2.019	4.146	✗	✗	✗

3.3.4. Frost Penetration Module

Frost penetration in the ground has a significant effect on many construction activities. Although frost penetration is not a weather parameter by itself, however, its value is highly dependent on the temperatures recorded. It could therefore be included in the weather model as a dependent variable, the value of which will be calculated from the generated temperature variables. It is very important to note that the source of all the definitions, equations, and tables in the frost penetration module is the course notes of an undergraduate course taught at the University of Alberta (CIVE 489). The basic definitions needed for the frost penetration module are shown as follows (Sego 2005):

```
done =False
a=(2*α−1)^-.5
b=a-Ln(4)
g=α+a^-1
d=1+Ln(4.5)
    While Not done
            u1= Uniform(0,1)
            u2= Uniform(0,1)
            v=a Ln(u1/(1-u1))
            y=α e^v
            z=u1^2 u2
            w=b + g v - y
            If (w + d - 4.5 z)>=0 Then
                    done = True
            Else
                    If w>=Ln(z) Then done = True
            End If
    End While
GammaVariate = β(y)
```

Figure 3-7. Pseudo Code for Cheng 1977 Gamma Variate Procedure (1<α, 0<β)

- Mean Daily Temperature (TM): Average of maximum and minimum daily temperature,
- Air Freezing Index (AFI): $\sum(TM)$, for the days when TM is below 0°C,
- Air Thawing Index (ATI): $\sum(TM)$, for the day when TM is above 0°C,
- Ground Freezing Index (GFI): N_f.AFI,
- Ground Thawing Index (GTI): N_t.ATI,
- For calculating the GFI or the GTI, values of N_f and N_t are shown in Table 3-6 (Sego 2005),
- Conductivity (K) (J/sec-m-°K): Quantity of heat flow through a unit area of substance of unit thickness in unit time under a unit temperature gradient. It depends on the mineral composition of the soil and the soil state; whether frozen (K_f) or unfrozen (K_u), and
- Latent Heat (L) (kJ/m^3): Quantity of heat liberated when a unit volume of soil undergoes phase change without a temperature change. Latent heat can be calculated using Equation 3-23 (Sego 2005).

$$L = 334 * \rho_d * m_c \qquad \text{Equation 3-23}$$

Where:

ρ_d = Dry density of soil (kg/m^3); and

m_c = Moisture content of soil.

Table 3-6. Values of Nf and Nt for Different Cover Conditions (Sego 2005)

Ground Surface Cover	N_f for Freezing	N_t for Thawing
Asphalt	0.3 – 1.0	1.4 – 2.3
Concrete	0.7 – 0.9	1.3 – 2.1
Gravel	0.6 – 1.0	1.3 – 2.0
Snow	1.0	--
Turf	0.5 (under snow)	1.0

Equation 3-24 (Sego 2005) shows the governing differential equation in one dimension required for calculating the frost penetration in the ground.

$$K\frac{\partial^2 T}{\partial z^2} + L = C\frac{\partial T}{\partial t} \qquad \text{Equation 3-24}$$

Where:

C= volumetric specific heat;

$\frac{\partial^2 T}{\partial z^2}$ = second derivative of temperature with respect to depth;

$\frac{\partial T}{\partial t}$ = first derivative of temperature with respect to time;

t= time;

z= depth; and

T= temperature.

Solving for Equation 3-24 is very complex, however, Stefan's equation offered a relatively simple approximation of the solution, which is widely accepted. Stefan's equation is presented in Equation 3-25. Table 3-7 lists all the material properties that are needed for different kinds of soils in applying Equation 3-25 (Sego 2005).

$$Z_0 = \left[\frac{2K_f * T_s * t}{L}\right]^{0.5} = \left[\frac{2K_f(GFI)}{L}\right]^{0.5} \qquad \text{Equation 3-25}$$

Where:

Z_0 = depth of frost penetration (m);

T_s = surface temperature (°C); and

t= time (day).

Table 3-7. Material Properties (Sego 2005)

Soil Type	ρ_d (Kg/m^3)	mc (%)	K_f (J/sec-m-°K)	K_u (J/sec-m-°K)	L (MJ/m^3)
Gravel	1800	3.0	0.8	1.4	18.0
	1800	5.0	1.3	1.7	30.1
	1800	10.0	2.2	2.1	60.1
Sand	1600	5.0	0.9	1.3	26.7
	1600	10.0	1.5	1.6	53.4
	1600	15.0	2.2	1.8	80.2
Clay (Saturated)	1600	20.0	2.0	1.4	113.6
	1400	30.0	2.0	1.2	140.3
	1100	50.0	2.1	.9	183.7

In reference to Figure 3-8, the day of the year for points A and B should be identified. This is accomplished by averaging the smoothed curves for the maximum and minimum temperatures resulting in the average temperature smoothed curve. The points of intersection with the zero temperature level are identified as points A and B. For calculating the incremental daily frost penetration depth, it is assumed that freezing can only occur between points A and point B (freezing period) and that thawing can only occur outside of this period.

Table 3-8 lists the calculated freezing period limits for the two weather stations under consideration. The assumption that freezing can only occur during the freezing period and thawing can only occur during the non-freezing period is an approximation; however, the margin for error in the frost depth created as a result of such an approximation is negligible.

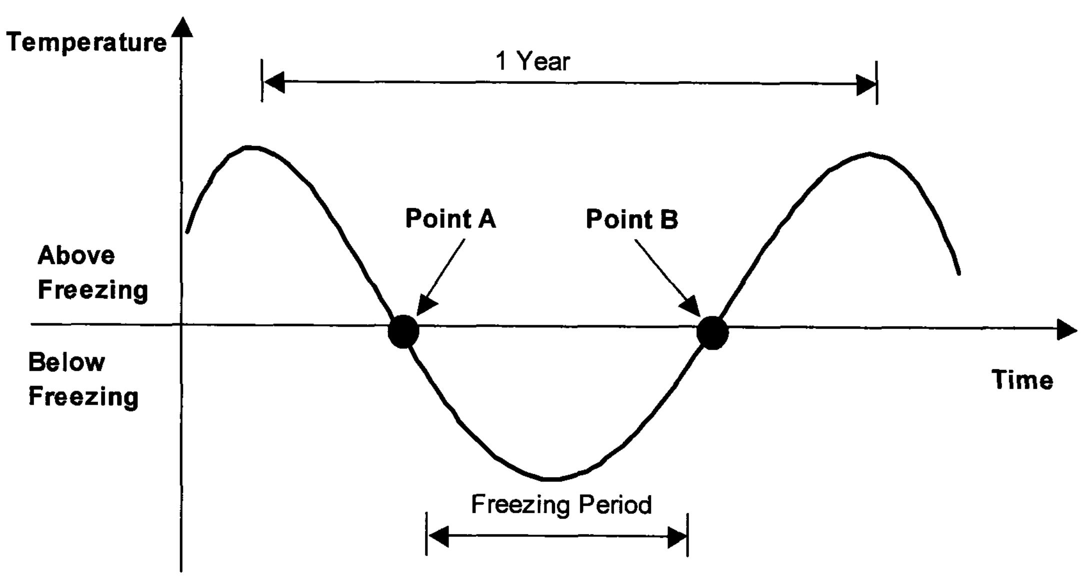

Figure 3-8. Typical Smoothed Temperature Curve

Equation 3-26 can be used for calculating the incremental daily frost depth increase (ΔZ_{+ve}) during the freezing period. Outside of the freezing period, the incremental daily frost depth decrease (ΔZ_{-ve}) will be calculated using Equation 3-27.

Table 3-8. Assumed Freezing Period Limits

Weather Station	Point A	Point B
Edmonton International	October 31st	April 3rd
Fort McMurray Airport	October 26th	April 8th

$$\Delta Z_{+ve} = \left[\frac{2K_f * N_f * TM}{L}\right]^{0.5}, \text{ TM<0 and freezing period} \qquad \text{Equation 3-26}$$

else $\Delta Z_{+ve} = 0$

$$\Delta Z_{-ve} = \left[\frac{2K_u * N_t * TM}{L}\right]^{0.5}, \text{ Z>0, TM>0 and thawing period} \qquad \text{Equation 3-27}$$

else $\Delta Z_{-ve} = 0$

Where:

ΔZ_{+ve} = Incremental daily increase in frost depth during freezing period; and

ΔZ_{-ve} = Incremental daily decrease in frost depth during thawing period.

The frost penetration module has to be initialized. Since the calculations are based on incremental daily freezing or thawing, the purpose of initialialization is to set the initial startup frost depth at a reasonable value on the project start date. In non-permafrost regions, it can be safely assumed that there is no frost at point A. The frost penetration module would therefore always start from point A that is prior to the construction project's start date. At that point in the simulation experiment, the weather model would generate weather solely for the frost penetration module's calculations. This would continue until the construction project's start date, after which time the simulation model and the weather generator will advance at a normal pace. The purpose of the proposed initialization was to ensure that a reasonable initial frost depth was assumed for the first day of the construction project. After this point in time, the incremental daily calculations would be performed as outlined.

CHAPTER 4. VALIDATION OF THE UNIVERSAL WEATHER GENERATOR

In this chapter, tests were made to validate the model assumptions for the historical weather data for the two weather stations under consideration. Next, statistical tests of the generated weather output for both stations were carried out to ensure that the similarity between the historical weather and the generated weather is statistically adequate.

4.1. Test of Assumptions

For the weather parameters generated using the weekly stationary generating process, i.e. max temperature, min temperature, max relative humidity, and min relative humidity, the first model assumption to be tested is that the residual series of the parameters are normally distributed. To test this, the moments of the residual series were first calculated, and then compared to the normal distribution values. In addition, the normal probability plots for the residuals were plotted to assess the normality assumption.

Table 4-1 shows the mean, standard deviation, skewness, and kurtosis for the residual data taken from the Edmonton International Airport weather station. Table 4-2 shows the same information for the Fort McMurray Airport weather station. Figure 4-1 to Figure 4-4 show the normal probability plots for the residual series of the weather parameters used for the Edmonton International Airport. Figure 4-5 to Figure 4-8 show the normal probability plots for the residual series for the Fort McMurray Airport weather parameters.

Table 4-1. Moments of Residual Data Edmonton International Airport

Variable	μ	σ	Skewness	Kurtosis
Maximum temperature	-0.00054	1.0036	-0.237	-0.066
Minimum temperature	-0.0017	1.0049	-0.369	0.1141
Maximum Rel. Humidity	0.3	0.886	-0.764	0.4241
Minimum Rel. Humidity	0.1538	1.022	0.404	0.1463

Table 4-2. Moments of Residual Data Fort McMurray Airport

Variable	μ	σ	Skewness	Kurtosis
Maximum temperature	-0.001	1.002	-0.051	-0.361
Minimum temperature	0.0	1.004	-0.247	-0.111
Maximum Rel. Humidity	0.0003	1.012	-0.9973	1.195
Minimum Rel. Humidity	0.0005	1.006	0.296	0.103

In general, for the normality of the residuals, the mean and standard deviation are very close to the standard normal distribution values, however, some skewness was detected and the residuals appeared to have flatter kurtosis. For the normal probability plots, the normality assumption was generally not violated; however, some deviation from normality was seen in the maximum relative humidity residuals plot for both weather stations. The normality assumption can, in this case, be accepted for the residual series. For those parameters violating the assumption, a final decision will be made in

Section 4.2 (Output Testing). In that section, the output of the model will be evaluated and a final decision will be made regarding the effect of the normality violation of certain parameters.

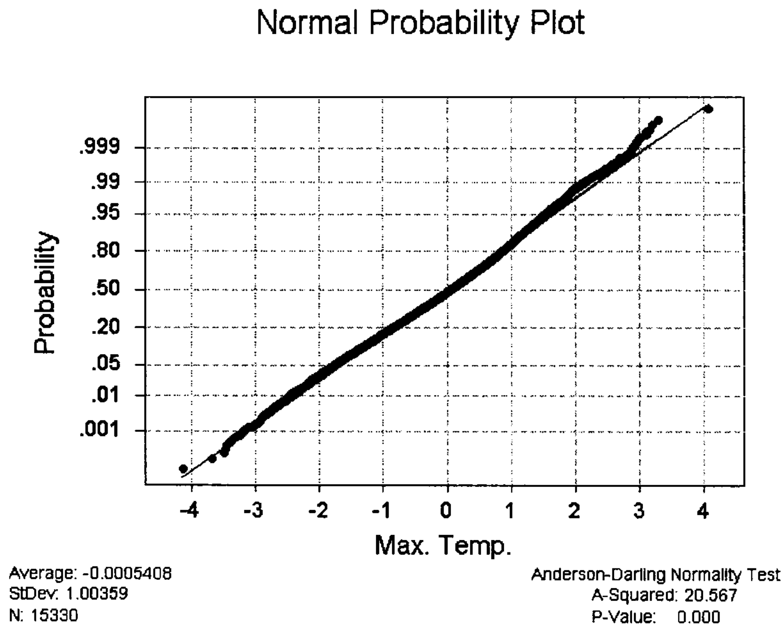

Figure 4-1. Maximum Temperature Residuals NPP (Edmonton International Airport)

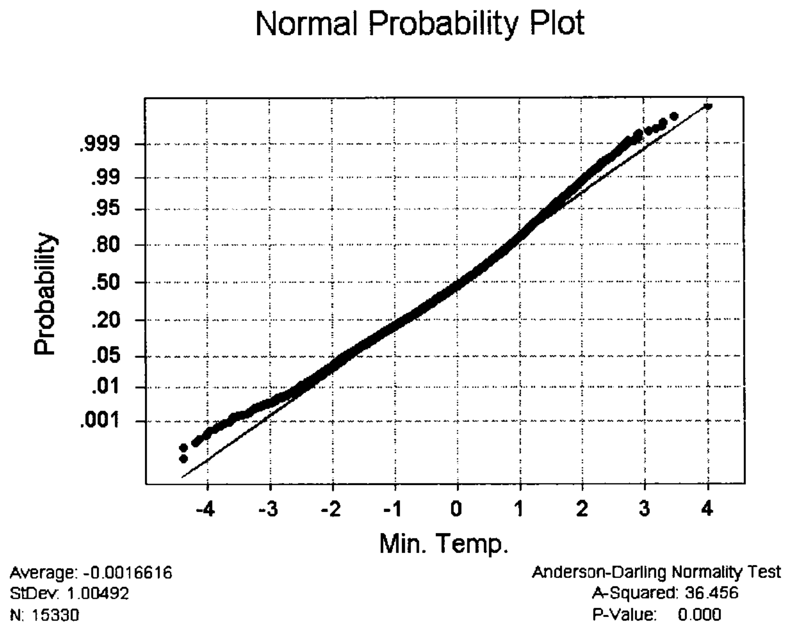

Figure 4-2. Minimum Temperature Residuals NPP (Edmonton International Airport)

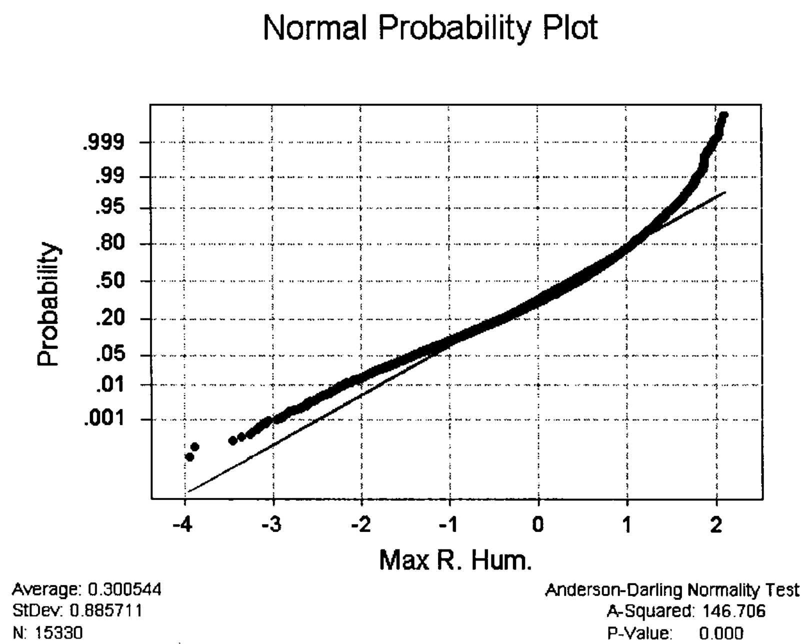

Figure 4-3. Maximum Rel. Humidity Residuals NPP (Edmonton International Airport)

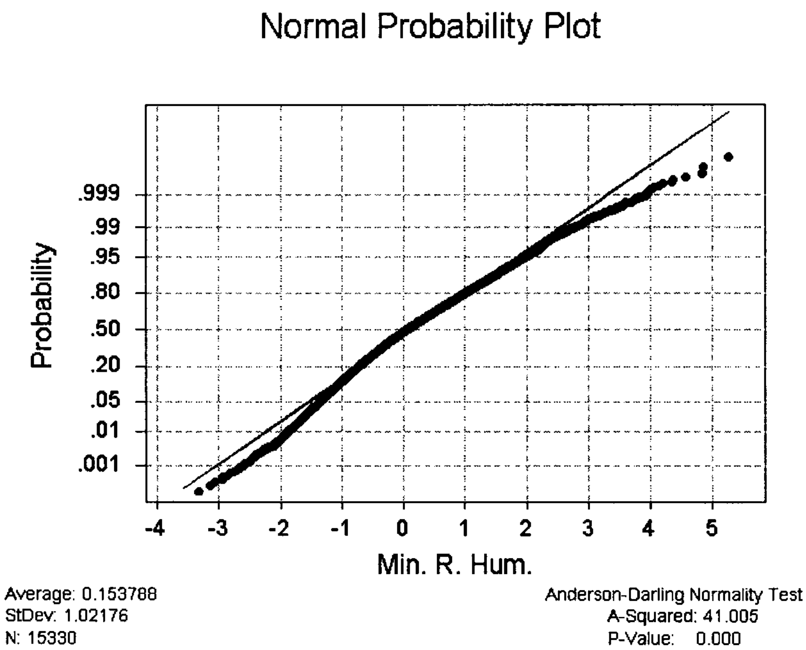

Figure 4-4. Minimum Rel. Humidity Residuals NPP (Edmonton International Airport)

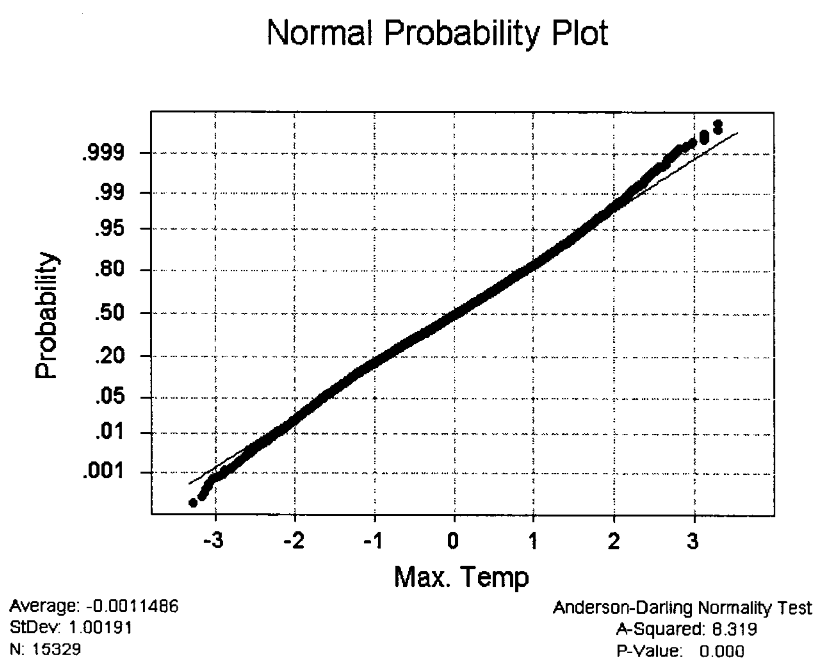

Figure 4-5. Maximum Temperature Residuals NPP (Fort McMurray Airport)

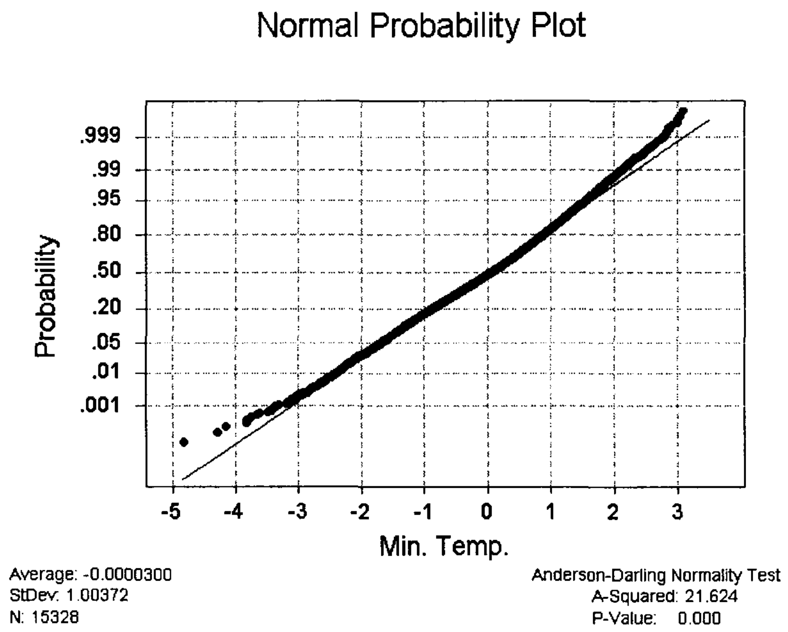

Figure 4-6. Minimum Temperature Residuals NPP (Fort McMurray Airport)

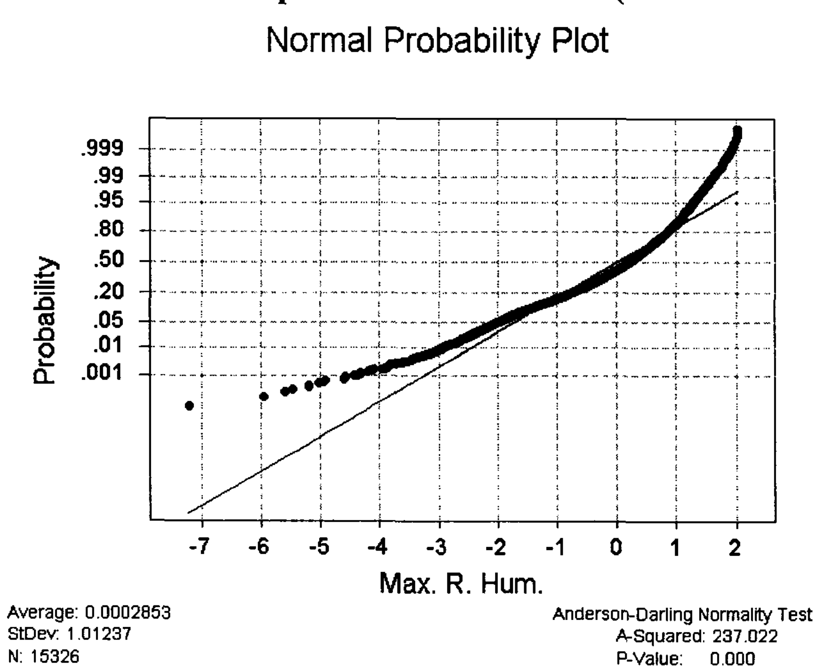

Figure 4-7. Maximum Rel. Humidity Residuals NPP (Fort McMurray Airport)

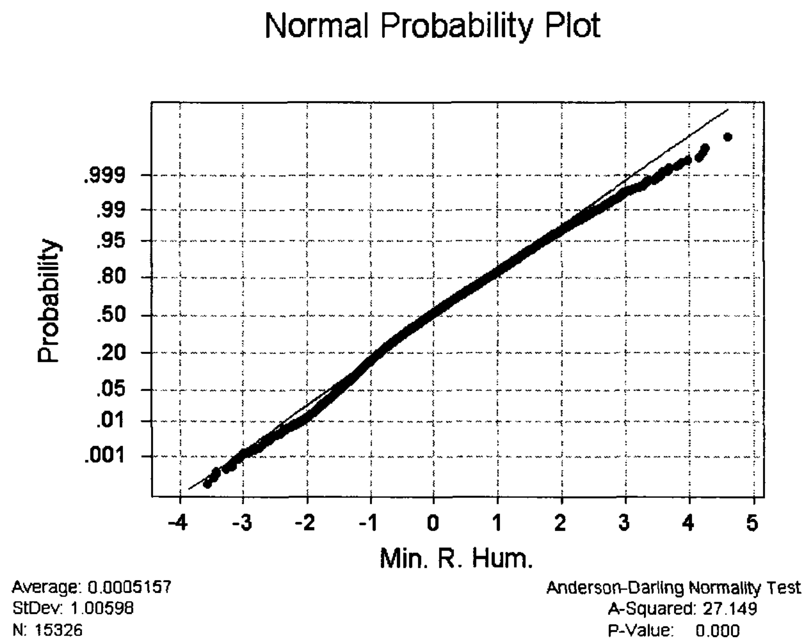

Figure 4-8. Minimum Rel. Humidity Residuals NPP (Fort McMurray Airport)

The second assumption to be tested is that the serial dependence of the residual series approximates a first-order linear autoregressive model. Serial dependence of a first-order autoregressive model can be defined as shown in Equation 4-1 as (Richardson 1981):

$$\delta_k = \delta_1{}^k \qquad \text{Equation 4-1}$$

Where:

δ_k = Serial correlation with lag of k days

Figure 4-9 to Figure 4-12 show the comparisons between the first-order model and the serial correlation of the residual series for the maximum temperature, the minimum temperature, the maximum relative humidity, and the minimum relative humidity for the Edmonton International Airport weather station. Figure 4-13 to Figure 4-16 show the same plots for the Fort McMurray Airport weather station. Based on these, it can be concluded that the serial dependence of the residual series did not significantly deviate from the first-order autoregressive assumption and can be approximated by a first-order autoregressive model. In the next section, the output of the weather generator will be tested statistically to ensure that the weather generator produces an acceptable output.

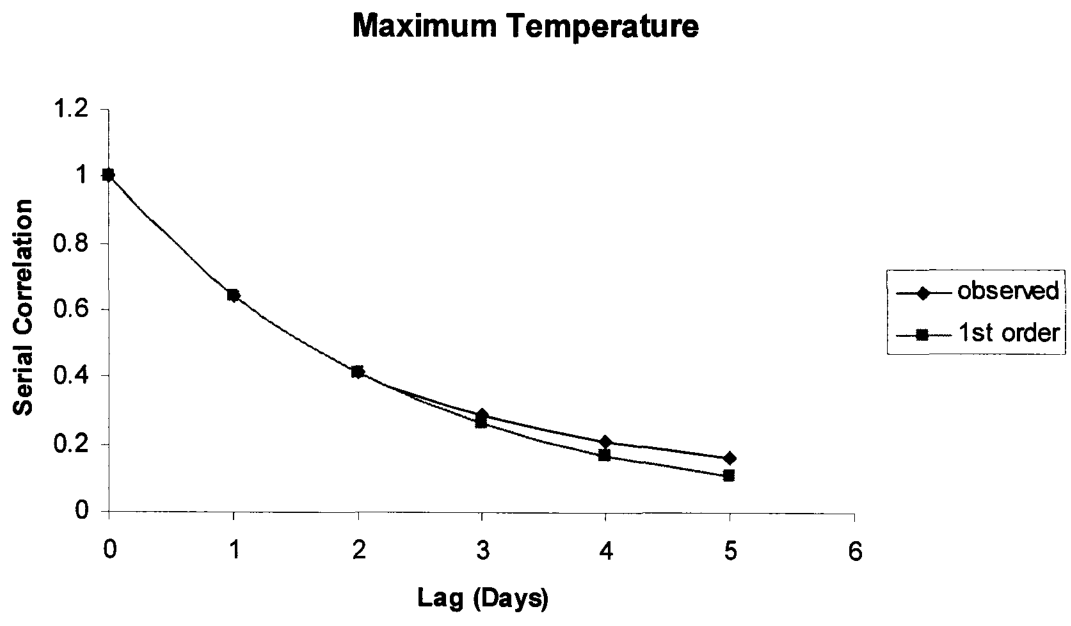

Figure 4-9. Autoregressive Model vs. Serial Correlation for Maximum Temperature (Edmonton International Airport)

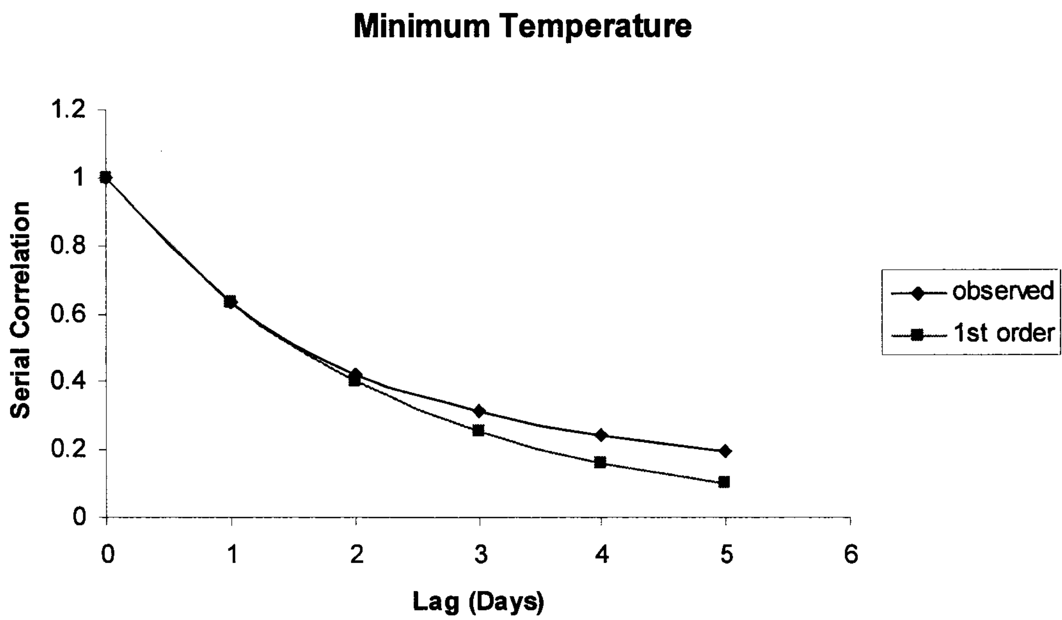

Figure 4-10. Autoregressive Model vs. Serial Correlation for Minimum Temperature (Edmonton International Airport)

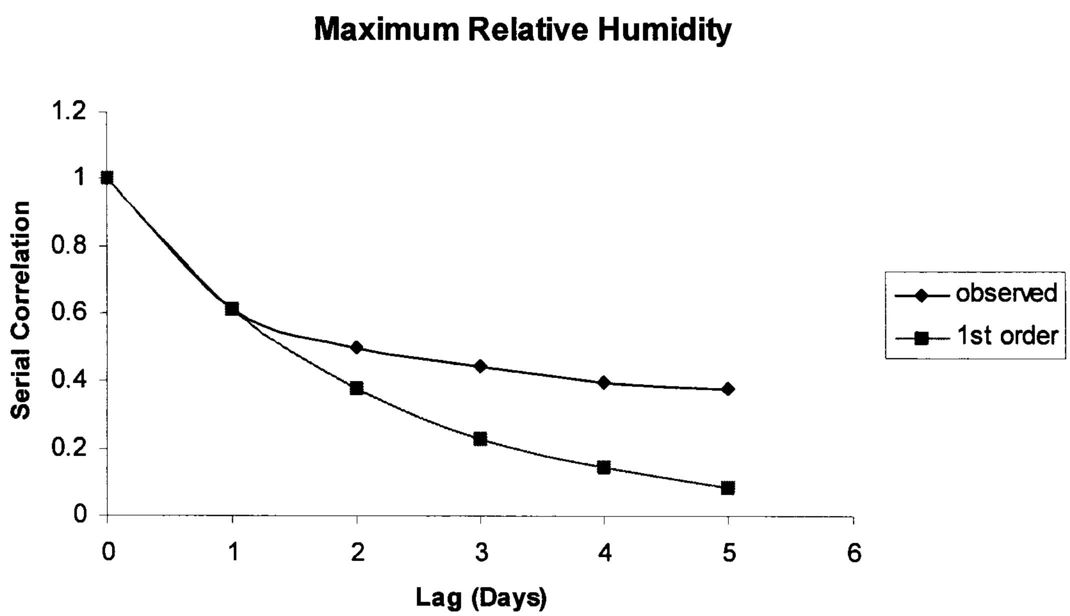

Figure 4-11. Autoregressive Model vs. Serial Correlation for Maximum Relative Humidity (Edmonton International Airport)

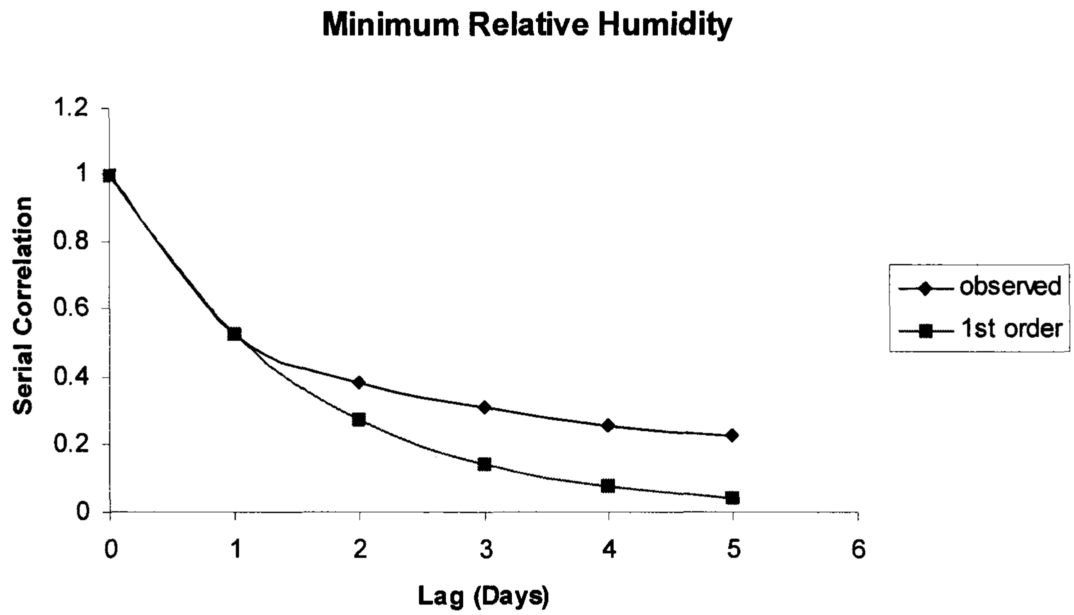

Figure 4-12. Autoregressive Model vs. Serial Correlation for Minimum Relative Humidity (Edmonton International Airport)

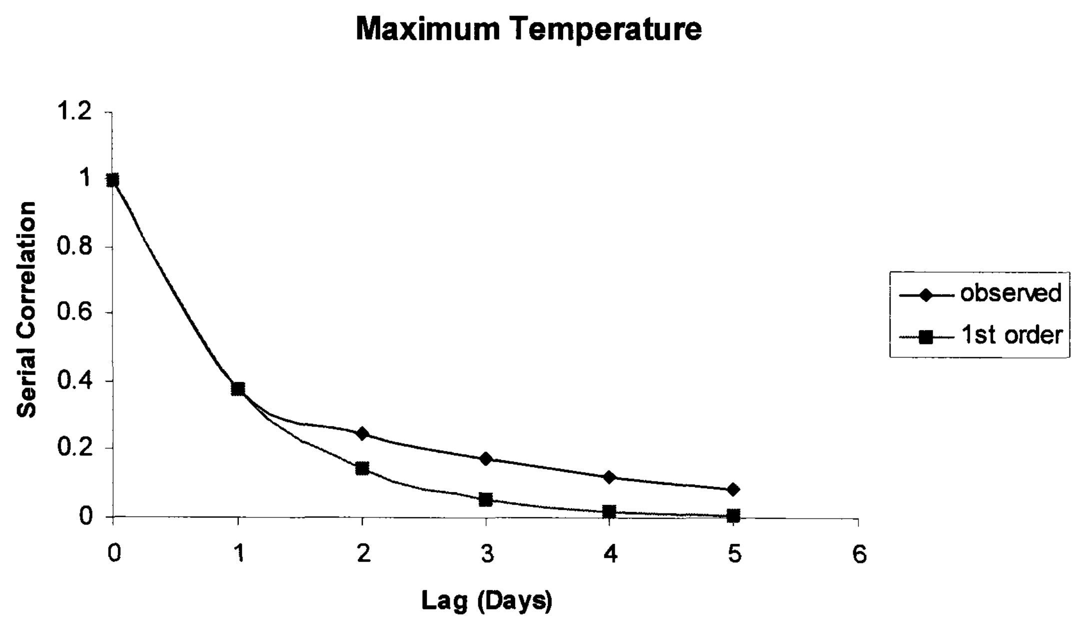

Figure 4-13. Autoregressive Model vs. Serial Correlation for Maximum Temperature (Fort McMurray Airport)

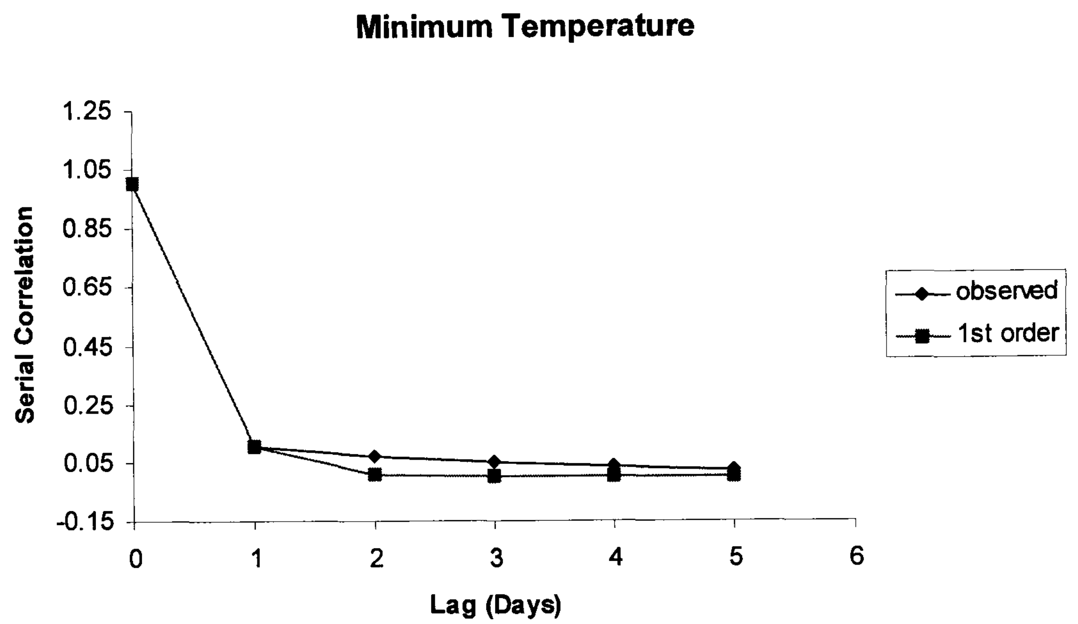

Figure 4-14. Autoregressive Model vs. Serial Correlation for Minimum Temperature (Fort McMurray Airport)

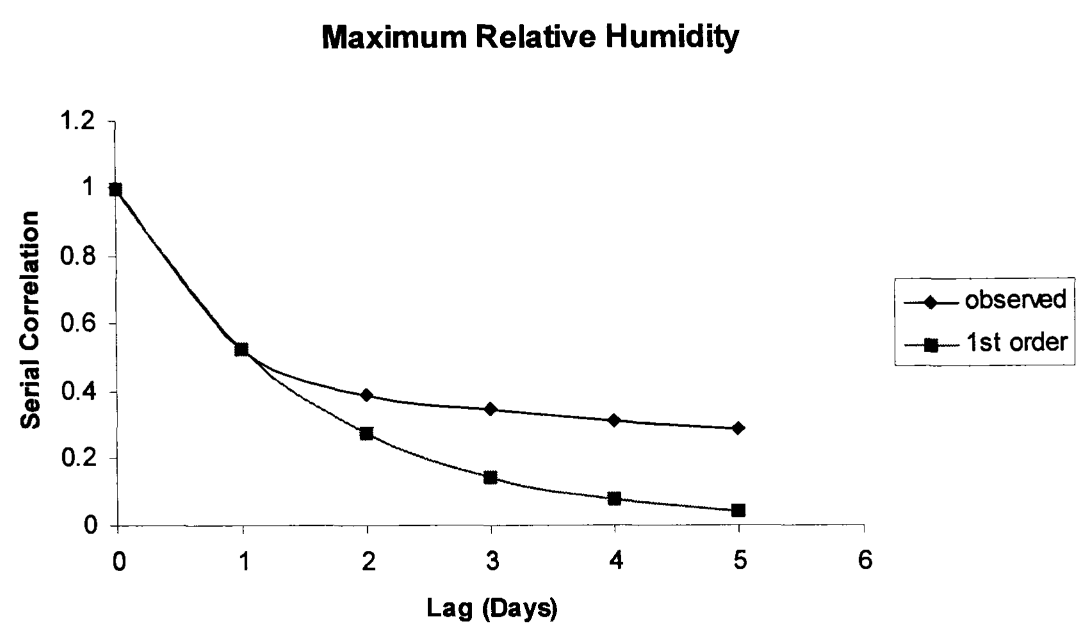

Figure 4-15. Autoregressive Model vs. Serial Correlation for Maximum Relative Humidity (Fort McMurray Airport)

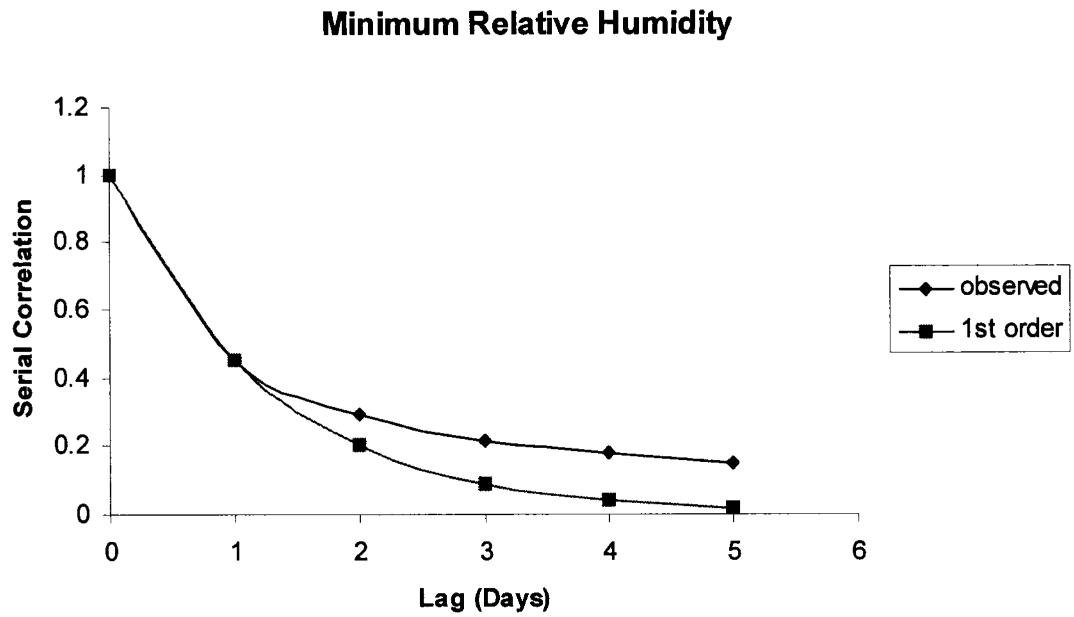

Figure 4-16. Autoregressive Model vs. Serial Correlation for Minimum Relative Humidity (Fort McMurray Airport)

4.2. Output Testing

To test the output of the weather generator statistically, 30 years of simulated data were generated for the Edmonton International Airport weather station and for the Fort McMurray Airport weather station, respectively. For the generated data, the number of wet days per month, the amount of daily precipitation, the maximum temperature, the minimum temperature, the maximum relative humidity, the minimum relative humidity, and the average daily wind speed were computed. The monthly means of the weather parameters' values were then calculated for each month of the year. The historical monthly means of the weather parameters were also calculated for the above mentioned weather parameters. Means and standards deviations for each month were calculated for the historical data. Confidence intervals for the historical weather parameters were constructed at the 1% level for each of the 12 months. Finally, the simulated means were compared to see if they fell within the constructed confidence interval. Table 4-3 to Table 4-9 summarize the above calculations for the Edmonton International Airport weather station. Another summary is shown in Table 4-10 to Table 4-16 for the Fort McMurray Airport weather station.

Table 4-3. Comparison of Number of Wet Days at Edmonton International Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	10.214	4.951	8.110	12.319	10.300	✓
February	7.357	3.484	5.876	8.838	8.233	✓
March	8.238	3.799	6.624	9.853	9.533	✓
April	7.024	2.959	5.766	8.281	8.067	✓
May	9.786	3.220	8.417	11.154	11.200	✗
June	12.619	3.193	11.262	13.976	13.400	✓
July	13.262	3.013	11.982	14.542	13.367	✓
August	11.357	4.047	9.637	13.077	12.100	✓
September	9.167	3.378	7.731	10.602	11.767	✗
October	6.024	2.646	4.899	7.148	7.267	✗
November	7.833	3.882	6.184	9.483	7.700	✓
December	8.952	3.774	7.349	10.556	9.400	✓

Table 4-4. Comparison of Rainfall Amounts at Edmonton International Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	22.690	17.495	15.255	30.126	27.037	✓
February	14.193	8.448	10.602	17.783	15.748	✓
March	15.769	9.028	11.932	19.606	20.303	✗
April	24.212	14.835	17.907	30.517	31.358	✗
May	44.679	25.537	33.825	55.532	63.088	✗
June	79.893	42.630	61.775	98.011	91.701	✓
July	96.855	39.430	80.097	113.613	111.087	✓
August	66.805	38.714	50.351	83.258	80.371	✓
September	44.607	29.286	32.161	57.054	65.521	✗
October	19.460	13.995	13.512	25.407	26.817	✗
November	17.607	12.244	12.403	22.811	19.663	✓
December	17.171	9.080	13.312	21.031	18.664	✓

Table 4-5. Comparison of Maximum Temperature at Edmonton International Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	-8.543	5.423	-10.847	-6.238	-7.553	✓
February	-4.622	4.428	-6.504	-2.741	-4.463	✓
March	0.326	3.788	-1.284	1.936	1.158	✓
April	10.071	3.067	8.768	11.375	10.754	✓
May	17.364	1.851	16.578	18.150	17.650	✓
June	20.707	1.577	20.037	21.377	20.774	✓
July	22.468	1.276	21.926	23.010	22.726	✓
August	21.902	2.237	20.951	22.853	21.835	✓
September	16.901	2.771	15.723	18.079	16.758	✓
October	10.824	2.221	9.880	11.768	11.156	✓
November	-0.316	3.955	-1.997	1.365	0.181	✓
December	-6.392	4.717	-8.396	-4.387	-4.867	✓

Table 4-6. Comparison of Minimum Temperature at Edmonton International Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	-19.638	5.341	-21.908	-17.368	-20.287	✓
February	-16.307	4.632	-18.275	-14.338	-17.143	✓
March	-10.899	4.528	-12.824	-8.975	-10.352	✓
April	-2.585	1.937	-3.409	-1.762	-2.254	✓
May	3.155	1.099	2.688	3.622	3.382	✓
June	7.577	1.388	6.987	8.167	7.594	✓
July	9.494	1.012	9.064	9.924	9.533	✓
August	8.261	1.514	7.618	8.904	8.107	✓
September	3.237	1.667	2.528	3.945	3.201	✓
October	-2.437	1.531	-3.088	-1.786	-1.788	✓
November	-10.822	3.411	-12.271	-9.372	-11.017	✓
December	-17.224	4.646	-19.198	-15.249	-17.345	✓

Table 4-7. Comparison of Maximum Rel. Humidity at Edmonton International Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	81.360	5.894	78.855	83.865	83.925	✗
February	82.509	6.942	79.559	85.460	82.030	✓
March	84.806	5.359	82.528	87.083	82.685	✓
April	84.179	5.274	81.938	86.421	77.676	✗
May	81.679	5.101	79.511	83.847	77.061	✗
June	88.086	4.039	86.369	89.802	83.333	✗
July	92.260	3.335	90.842	93.677	86.403	✗
August	92.846	3.645	91.296	94.395	87.761	✗
September	90.444	4.536	88.517	92.372	87.084	✗
October	86.823	4.157	85.057	88.590	82.183	✗
November	86.926	4.066	85.198	88.654	85.017	✗
December	83.130	5.183	80.927	85.333	83.535	✓

Table 4-8. Comparison of Minimum Rel. Humidity at Edmonton International Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	62.146	5.876	59.649	64.643	63.257	✓
February	61.639	6.440	58.901	64.376	58.785	✗
March	58.784	7.005	55.807	61.761	53.718	✗
April	42.639	8.748	38.921	46.357	38.481	✗
May	35.588	5.378	33.302	37.874	33.831	✓
June	43.370	5.803	40.904	45.836	40.993	✓
July	49.762	5.623	47.372	52.152	45.636	✗
August	49.406	6.526	46.633	52.180	46.224	✗
September	47.472	7.099	44.455	50.489	48.134	✓
October	47.141	6.290	44.467	49.814	48.398	✓
November	62.652	7.620	59.414	65.891	59.979	✓
December	63.432	5.159	61.239	65.624	62.725	✓

Table 4-9. Comparison of Av. Daily Wind Speed at Edmonton International Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	12.409	2.089	11.521	13.297	11.253	✗
February	12.390	2.081	11.506	13.275	11.777	✓
March	12.835	1.544	12.179	13.491	12.750	✓
April	14.545	2.085	13.659	15.431	14.683	✓
May	15.276	2.144	14.365	16.187	14.844	✓
June	13.248	1.451	12.632	13.865	13.904	✗
July	10.922	1.662	10.216	11.629	12.903	✗
August	10.458	1.561	9.794	11.121	12.202	✗
September	12.491	1.693	11.771	13.210	12.806	✓
October	13.063	1.381	12.476	13.649	13.056	✓
November	11.946	1.698	11.224	12.667	11.749	✓
December	12.335	1.527	11.686	12.984	11.552	✗

Table 4-10. Comparison of Number of Wet Days at Fort McMurray Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	11.524	4.080	10.249	12.798	12.633	✓
February	8.929	3.834	7.731	10.126	9.800	✓
March	9.048	3.629	7.914	10.181	10.233	✗
April	7.268	2.684	6.430	8.106	8.300	✗
May	9.714	3.300	8.683	10.745	11.900	✗
June	12.976	3.578	11.859	14.094	13.200	✓
July	14.762	3.779	13.581	15.942	14.733	✓
August	12.262	3.939	11.032	13.492	13.300	✓
September	11.500	3.717	10.339	12.661	12.300	✓
October	9.857	4.475	8.459	11.255	10.367	✓
November	11.500	3.909	10.279	12.721	9.233	✗
December	11.238	3.635	10.103	12.373	11.000	✓

Table 4-11. Comparison of Rainfall Amounts at Fort McMurray Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	19.190	9.698	16.161	22.220	22.109	✓
February	15.212	9.657	12.195	18.228	17.784	✓
March	16.564	8.979	13.760	19.369	19.823	✗
April	21.452	12.837	17.443	25.462	29.421	✗
May	37.798	23.613	30.422	46.841	53.249	✗
June	71.210	35.160	60.227	82.192	78.910	✓
July	80.167	33.175	69.805	92.873	89.972	✓
August	68.540	39.346	56.251	83.610	92.903	✗
September	49.950	30.657	40.374	61.692	61.798	✗
October	28.748	18.716	22.902	35.916	37.774	✗
November	49.950	30.657	40.374	59.526	32.717	✗
December	28.748	18.716	22.902	35.916	22.797	✗

Table 4-12. Comparison of Max. Temperature at Fort McMurray Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	-14.116	5.270	-15.762	-12.469	-12.138	✗
February	-7.888	4.817	-9.393	-6.383	-5.985	✗
March	-0.537	3.662	-1.681	0.607	0.549	✓
April	6.065	3.076	5.104	7.025	10.490	✗
May	17.059	2.052	16.418	17.700	16.743	✓
June	21.442	1.252	21.051	21.834	21.901	✗
July	23.237	1.306	22.829	23.645	23.239	✓
August	22.011	2.237	21.312	22.710	21.819	✓
September	15.306	2.604	14.493	16.120	15.436	✓
October	7.917	2.556	7.118	8.715	11.093	✗
November	-4.169	3.579	-5.287	-3.051	5.606	✗
December	-12.625	6.580	-14.680	-10.569	-3.333	✗

Table 4-13. Comparison of Min. Temperature at Fort McMurray Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	-24.752	5.261	-26.395	-23.109	-26.364	✓
February	-20.480	5.077	-22.065	-18.894	-20.795	✓
March	-14.341	4.530	-15.755	-12.926	-14.257	✓
April	-3.821	2.405	-4.572	-3.070	-3.443	✓
May	2.869	1.462	2.412	3.326	3.146	✓
June	7.693	1.142	7.336	8.049	7.910	✓
July	10.103	1.076	9.766	10.439	9.910	✓
August	8.534	1.469	8.075	8.992	8.313	✓
September	3.236	1.691	2.707	3.764	3.161	✓
October	-3.012	4.927	-4.551	-1.125	-0.476	✗
November	-13.016	3.898	-14.233	-11.799	-4.399	✗
December	-22.282	6.626	-24.352	-20.212	-14.062	✗

Table 4-14. Comparison of Max. Rel. Humidity at Fort McMurray Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	83.198	5.709	81.414	84.981	83.450	✓
February	82.988	5.917	81.140	84.836	82.458	✓
March	82.395	5.696	80.616	84.174	82.526	✓
April	81.259	5.592	79.512	83.005	81.177	✓
May	81.957	5.397	80.271	83.643	83.348	✓
June	87.322	4.527	85.908	88.736	87.059	✓
July	90.647	3.543	89.540	91.753	90.847	✓
August	92.374	3.725	91.211	93.537	91.912	✓
September	91.943	4.273	90.608	93.278	91.659	✓
October	89.178	3.792	87.994	90.363	88.978	✓
November	88.183	4.040	86.921	89.445	88.720	✓
December	84.954	5.371	83.276	86.631	88.762	✗

Table 4-15. Comparison of Min. Rel. Humidity at Fort McMurray Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	65.565	4.788	64.069	67.060	64.790	✓
February	58.860	6.842	56.723	60.997	58.498	✓
March	48.578	7.140	46.348	50.809	48.709	✓
April	37.834	6.411	35.832	39.837	38.238	✓
May	33.807	4.532	32.392	35.223	35.727	✗
June	39.925	5.055	38.346	41.503	39.682	✓
July	44.434	3.975	43.192	45.676	44.341	✓
August	46.344	5.468	44.636	48.052	46.454	✓
September	50.513	6.895	48.359	52.666	49.625	✓
October	54.798	6.420	52.793	56.803	52.267	✗
November	68.567	5.219	66.936	70.197	58.430	✗
December	68.504	5.707	66.721	70.286	68.465	✓

Table 4-16. Comparison of Av. Daily Wind Speed at Fort McMurray Airport

Month	Actual μ	Actual σ	Lower Limit	Upper Limit	Generated μ	Pass / Fail
January	8.397	1.556	7.911	8.883	8.417	✓
February	9.011	1.113	8.663	9.358	9.260	✓
March	9.840	1.094	9.498	10.181	9.839	✓
April	11.015	1.199	10.641	11.390	10.997	✓
May	10.979	1.183	10.609	11.348	10.922	✓
June	9.647	1.225	9.264	10.029	9.505	✓
July	8.978	1.066	8.645	9.311	8.732	✓
August	8.710	1.137	8.355	9.065	8.692	✓
September	9.524	1.279	9.125	9.924	9.398	✓
October	10.302	1.552	9.817	10.786	10.339	✓
November	8.867	1.394	8.431	9.302	10.252	✗
December	8.371	1.313	7.961	8.781	8.950	✗

In Table 4-7, it appears that the statistical testing failed for nine months; however, by relaxing the confidence interval limits by 3% on both sides, this number can be reduced to four months. Due to the fact that this difference in relative humidity is insignificant in the construction field, the test can be considered successful. In addition, in Table 4-14, the same weather parameter passed the test at the Fort McMurray Airport weather station over 11 months.

In a similar way, the maximum temperature parameter used at Fort McMurray Airport, as shown in Table 4-12, failed the statistical test over seven months; however, relaxing the confidence interval limits by 0.4 °C on both sides, reduces this number to only four months. The same weather parameter passed the test at the Edmonton International Airport weather station in the 12 months shown in Table 4-5.

For the total monthly rainfall amount at Fort McMurray Airport, as shown in Table 4-11, eight months failed the statistical test; however, by relaxing the confidence interval limits by 2 cm on both sides, this number is reduced to four months. The same weather parameter passed the test for the Edmonton International Airport weather station over seven months, as shown in Table 4-4. At the same time, the "goodness of fit" tests for fitting the Gamma Distribution generally passed the statistical tests for the weather stations shown in Table 3-4 and Table 3-5. The only exception was at the Fort McMurray Airport weather station for the months of December and January. In that case, fitting a Beta Distribution was recommended in order to enable the statistical tests to pass.

In the previous sections, it was noted that, for some weather parameters (i.e. maximum relative humidity at the Edmonton International Airport weather station), there was some deviation in the normality assumption. The model output, however, seems not to be affected by this level of deviation from normality. The final decision in this regard is to accept this level of deviation from the normality assumption.

The above statistical tests were generally successful at the 1% level, and, since the number of failing tests is limited, the conclusion is that the models for these two weather stations were successful. It is believed that the weather generators for the two cities will operate efficiently in the construction simulation models. These will be introduced in the next chapter.

CHAPTER 5. APPLICATIONS OF THE COLD WEATHER CONSTRUCTION FRAMEWORK

In this chapter, two construction processes, High Density Poly-Ethylene (HDPE) pipe installation and tunnelling construction, will be studied. The proposed Cold Weather Construction Simulation Framework will be employed to determine the weather effects on both processes. Relevant simulation findings will be reported at the end of each process study.

5.1. Application of the Framework to the HDPE Pipeline Installation Construction Process

In applying the cold weather construction framework to the HDPE pipeline installation, collaboration with North American Construction Group (NACG) was initiated. Through this collaboration, site visits were arranged to the company's Fort McMurray construction sites. During these visits, interviews were conducted with NACG's personnel and pipeline superintendents in order to develop an HDPE construction simulation model that would:

- Assist in planning for pipeline installation projects in a consistent way, and
- Include the weather impacts on the process, especially with regards to the Fort McMurray area, which is known for its severe winter conditions.

To simulate the pipeline installation process and include the winter impacts, the steps suggested by the cold weather construction simulation framework were followed and described in the following sections. A systematic application of the framework will follow.

5.1.1. Detailed HDPE Pipeline Installation Process Study

A meeting took place with an NACG field engineer in which members reviewed the HDPE pipeline installation process in detail. The meeting revealed the HDPE pipeline process activities and their logic. Figure 5-1 shows the general flow chart of the process.

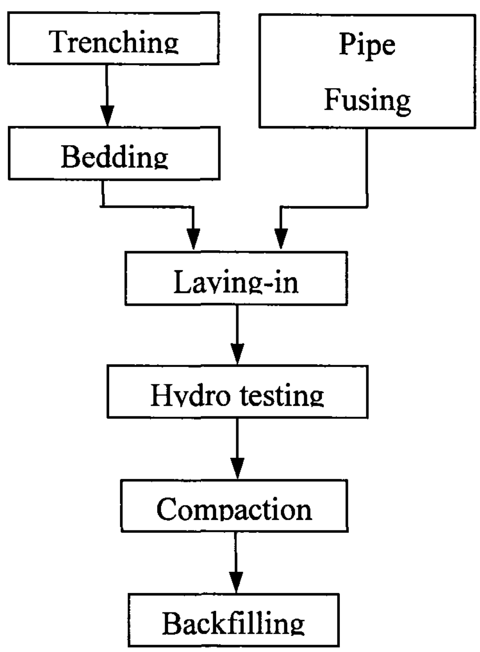

Figure 5-1. HDPE Pipeline Installation Process Flow Chart

As demonstrated in Figure 5-1, the HDPE pipeline installation process can be executed in the following steps:

1. Right-of-way (does not exist in Figure 5-1): To ensure that a suitable work area is provided along the pipe corridor path where the construction crews and equipment can safely operate, clearing and grading crews are sent in. First, the clearing crew clears the corridor of vegetation and boulders; the grading crew then prepares the pipeline corridor. This work ensures a safe environment for the crews and construction equipment.
2. Trenching: Dozers and/or excavators excavate the pipeline trench to provide the required design section, which generally varies with depth, type of soil, the number of pipes in the trench, and the horizontal spacing between them. Vertical rectangular sections are normally specified for pipe depths less than four feet. For deeper pipes, sloping sides are generally specified.
3. Bedding: To provide a clean and compacted bed below the pipe, sand is compacted to a thickness of about one foot according to specifications. This is executed in lifts of 150 mm each.
4. Pipe Fusing: In parallel to the above two steps, HDPE pipes, which arrive on site in 40 feet lengths, are fused together using a pipe-fusing machine, in order to produce the required pipe length. This task entails cutting the pipe ends and smoothing them to provide a clean, straight surface. Next, the pipes' ends are heated and pressed against another pipe. This results in a watertight pipe length.
5. Laying-in: Following trenching and pipe fusion, the fused pipe length is picked up by coordinated side booms. The side booms lower the pipe to its design location at the bottom of the trench over the bedding. The side booms then travel forward

while lifting the pipe section using pipe roller cradles, and lay the pipe section into place inside the trench.

6. Hydro testing: To ensure that the pipe sections and fusions are watertight; the laid-in pipe is filled with water. The volume of water normally required for this process is approximately 20% more than the pipe's inner volume. This will account for air bleeding out of the pipe and for pipe expansion when the water is compressed. After filling the pipe with water, hydrostatic pressure is applied for one hour. During that time, the pipe pressure gauges are monitored to ensure that no drop in pressure. A drop in pressure would signal a leak. In some cases, the pipe walls and fusions are visually inspected; however, this is not recommended, as the pipe might explode due to the high pressure therein (e.g. as much as 240 psi). Hydro testing for HDPE pipes rarely fails, but it must be done in all cases. If a pipe section or a fusion fails the test, the pipe has to be changed and the fusions redone.
7. Compaction: Compaction, in this context, refers to two different stages:
    a. Haunching: Backfilling and compacting the area around the pipe from the invert level of the pipe to its centreline.
    b. Compaction over the pipe: a minimum of one foot over the pipe is backfilled and compacted. In the case of heavy equipment needing to pass over the pipe, a minimum of four feet over the pipe is compacted.
8. Backfilling: The remaining volume over the compacted region is backfilled with the soil originally excavated from the trench. The topsoil is returned in place on top of the backfilling to enable vegetation.

Figure 5-2 shows a cross-section of a typical pipeline construction area showing the pipe and its relation to the bedding, haunching, and backfilling areas.

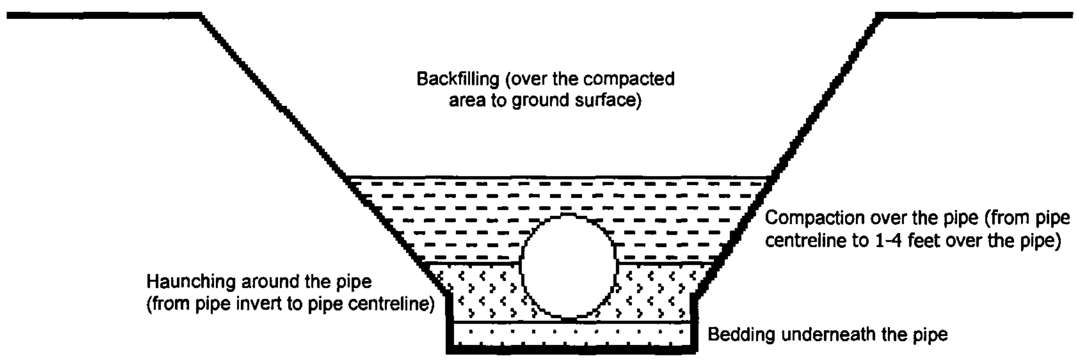

Figure 5-2. Section through Pipeline Construction Area

5.1.2. Developing the HDPE Pipeline Installation Basic Simulation Model

For the HDPE pipeline installation process, a combined discrete-continuous event simulation model was developed. Figure 5-3 shows the developed model, which is composed of eight segments representing the eight activities explained in the previous sub-section. The process begins with an entity entering. It is split into eight entities for the eight segments. Each of the eight entities is assigned relevant attributes. These attributes include the hourly advance rate of the activity, generally in m/hr, and the buffer distances between the activity and any predecessor activity. After the attributes are assigned, the entity requests the required resources. Table 5-1 shows an example of the resource requirements for the eight pipeline construction activities. Upon granting the required resources, the entity advances into the production stage of the activity. During this stage, the entity enters into an hourly loop. The loop starts with a one-hour delay in the activity. At the end of the loop, the entity checks the distance it was allowed to advance. This is normally the lesser value from the specified activity hourly advance rate or the distance between the current activity and its predecessor activity less the specified buffer distance between them. If the activity was allowed to advance, it updates the activity state based on the total distance completed; however, if the activity was not allowed to advance, the activity state is left unchanged. In either case, another cycle of the one-hour loop starts and the activity state is updated again. At the completion of the activity (i.e., when it reaches the end of the pipeline length), the entity is allowed to exit the loop and release the resources it was holding. Only when all eight entities exit their loops, the construction of the pipeline segment is considered complete.

Table 5-1. Sample Pipeline Construction Resource Requirement

Activity	Resource Needed	Resource Level
Right of way	Dozer	One
Pipe fusion	Side Boom + Fusion Machine	One of each
Trenching	Excavator	Two
Bedding	Excavator + Plate compactor	One excavator + two plate compactors
Laying-in	Side Boom	Two – Three
Hydro testing	Pump	One
Compaction	Excavator + Plate compactor	One excavator + two plate compactors
Backfilling	Excavator or Dozer	One

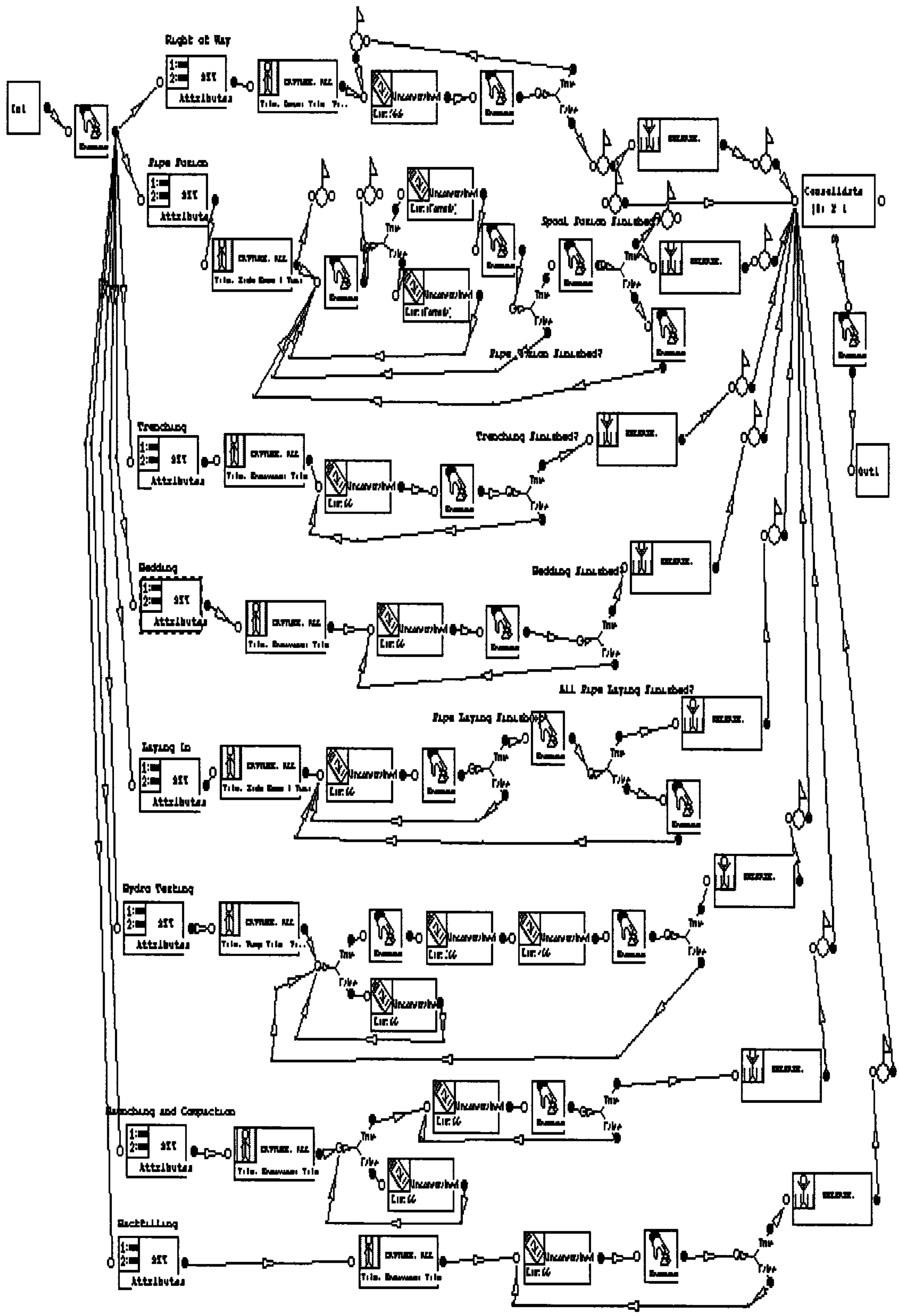

Figure 5-3. Pipeline Construction Basic Simulation Model

Two trips to NACG's Fort McMurray site were made at which a number of meetings with NACG's pipeline construction superintendents took place. In the meetings, the details of the process were reviewed in greater depth, and the activities advance rates and buffers were discussed. Table 5-2 shows an example of the advance rates and buffers agreed upon in the meetings. It should be noted that the activity advance rates vary depending on the resources assigned to the pipeline segment.

Table 5-2. Sample Advance Rates / Buffer Distances for Pipeline Construction Activities

Activity	Advance Rate	Buffer Distance (m)	Buffer Predecessor Activity
Trenching	200 m^3/hour	250	Right of Way
Bedding	30 m/hour	50	Trenching
Laying-in	100 m/hour	100	Bedding
Hydro testing	N/A	Finish	Laying-in
Compaction	20 m/hour	Finish	Hydro testing
Backfilling	400 m^3/hour	120	Compaction

5.1.3. Documenting Cold Weather Impacts on the HDPE Pipeline Installation Process

The pipeline installation process is an example where documenting the cold weather impacts on the process depended on expert opinion as well as data collection from the field. As mentioned, to document the cold weather impacts on the pipeline installation activities, a number of meetings were held with NACG's pipeline installation superintendents to review the process details and document the cold weather impacts. These meetings resulted in the following summarized list:

1. Fusion times depend on the ambient temperature; more time is needed for lower temperatures. If the weather is very cold, then the HDPE pipes must first be heated before fusion. Cooling time must also be controlled to allow the proper material properties to form.
2. If the trench is to be dug in frozen ground, ripping might be required or else the excavator's productivity will be reduced.
3. Compacting the soil in cold weather should only be done using warm sand.
4. In hydro testing, methanol should be added to water (edible methanol should be used to minimize the negative impact that spilling might have on the environment). Adding methanol is expensive and a methanol recovery system should be used to reuse the methanol.
5. Snow must be removed from the ditches before the laying-in of any pipe.
6. If large ambient temperature changes occur (>15 °C in one day), the HDPE pipe could substantially extend or shrink in length (up to 6" causing misalignment or snaking in the pipe).

After evaluating these factors, it was concluded that the most prevalent were points 1 and 2. These were therefore included in the simulation model.

For point 1, it was noted that the fusion times are dependant on the ambient temperature as well as the diameter of the pipe. Fusion times generally increase with the decrease of the ambient temperature and with the increase in pipe diameter.

For point 2, and discussing with the superintendents, it was concluded that trenching activity is affected by the frost depth, whenever the frost depth exceeds one foot. In such a case, there are two options for trenching. The first option is to let the excavator trench through the frozen soil. If it does that, its productivity is reduced by 40% - 50% to allow for cutting through the frozen ground. The second option is to use a ripper to assist the excavator in trenching through the frozen soil. The excavator's productivity will then be reduced only 10% - 15%.

Referring to Figure 2-2, the next step is to document the process stoppage conditions. If the effective temperature drops to less than –45 ^{o}C, it triggers a process stoppage condition. Next, the process activities were examined to check for weather sensitivity. Pipe fusion was identified as weather-sensitive; that is, it is sensitive to ambient temperature. Trenching is also weather-sensitive. Trenching productivity is affected by the frost depth in the ground whenever the frost depth exceeds one foot. Table 5-3 summarizes those findings.

Table 5-3. Pipeline Installation Process Weather Impact Summary

Activity	Type	Influencing Factor	Triggering Condition	Influence on the Process	Accounted for in Simulation Model
Pipe Installation Process	Process Stoppage	Temperature	<-45 °C	Significant	✓
Pipe Fusion	Productivity Reduction	Ambient Temperature	N/A	Significant	✓
Trenching	Productivity Reduction	Frost Depth	> 1 foot	Significant	✓

5.1.4. Developing the Integrated HDPE Pipeline Installation Simulation Model

The integrated process simulation model is the basic process simulation model, already developed, integrated with the following:

- A stochastic weather generator element to add the daily weather variables, values to the simulation model,
- A calendar element to enable the specification of the project start date and to track the working / vacation days,
- Process stoppage conditions,
- Weather-sensitive activities that account for the weather impacts,
- Activity stoppage conditions (if applicable), and
- Mitigating activities (if applicable).

The basic simulation model for pipeline installation was modified to account for the cold weather impacts on the pipeline installation process. An explanation of the way the previous modifications were adopted follows.

Figure 5-4 shows the parent-pipeline installation element. This element contains both the stochastic weather generator element, used to specify the project location, and the calendar element, for specifying the project start date. On site, the number of working hours per day was 11.5 hours/day; however, in the model the number of minutes per day was set to 600 minutes/day to account for the breaks.

The process stoppage conditions were modeled by modifying the code that updates each activity state (i.e. completed distance). Whenever the average temperature is less than –45 °C, the process activities record no advance in their state. According to the model, the triggering condition is checked every hour.

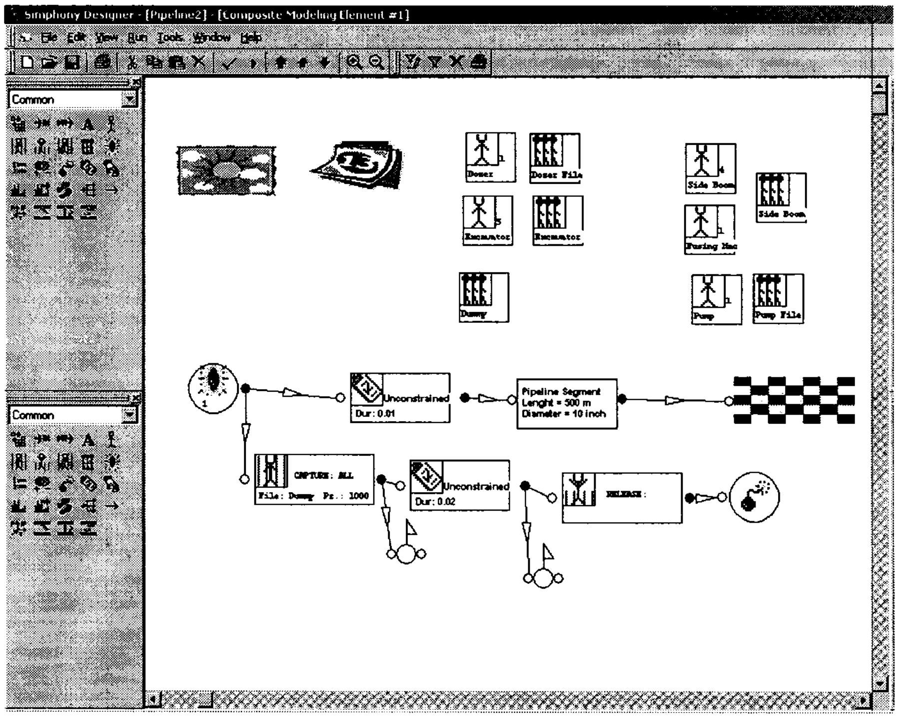

Figure 5-4. Pipeline Integrated Simulation Model at the Parent Level

To model the impact on weather-sensitive activities, Figure 2-3 was consulted, which gives guidance to facilitate the integrated simulation model choices. The following logic, used in Figure 2-3, was followed to guide the simulation modelling and to assess the impact of weather on the pipes' fusion activities

- Q. Does the pipe fusion activity occur conditionally?

  A. No, it always occurs as long as the pipe segment fusions are not completed. There is no need to add an additional node to the model.

- Q. Is the quantity executed a discrete number?

  A. Yes, normally pipes are fused one at a time. When a pipe is fused to the already fused string of pipes, the state of pipe fusing activity is increased by a distance equal to the standard length of pipe used.

- Q. Is the pipe fusing a multiple day task?

A. Yes, pipe fusing activity extends for the duration of the project.

At this point, Figure 2-3 recommends the use of a combined discrete-continuous simulation approach to model the weather-sensitive activity. For the task progress, it is recommended to collect pipe fusion duration data. The time interval between progress updates (i.e. activity state updates) will be the duration required to fuse one pipe (n=1).

631 data points were collected, representing the pipe fusion durations data for six fusing machines in a period of seven months (from January to August). For each day, the ambient temperature, the total fusing time, the total diameter inches fused, and the total number of fusions were recorded. A regression model was constructed for the collected data. Equation 5-1 shows the regression model for the total fusion time per day. The regression model had an R^2 value of .734. From the collected data it was seen that the average number of fusions per day per fusing machine was close to four.

$$T = .74 - .048(Tm) + .0325(DI) + .193(NF) \qquad \text{Equation 5-1}$$

Where:

T= total fusing time (hours);

Tm = average temperature (°C);

DI = the total diameter inches fused in a single day (inch); and

NF = the total number of fusions for a single fusing machine in a day.

Once a pipe fusion entity enters the pipe fusion loop, it is delayed for a time equal to the time needed to fuse a pipe. This time depends on the average temperature for the day and the diameter of the pipe. After that delay, the state of the pipe fusions is increased by the specified length of a standard pipe. A very important parameter is the percentage of fittings fusions. Fusing fittings to the pipeline takes more time than the amount of time needed to fuse two pipes together; the major difference is that fusing fittings does not add length to the fusion state.

Finally, in assessing the cold weather impact on the trenching activity, and consulting with Figure 2-3, the following logic was followed:

- Q. Does the trenching activity occur conditionally?

  A. No, trenching activity occurs continuously until the trenching distance for the entire pipeline segment is complete. There is therefore no need to create a conditional node in the model.

- Q. Is the quantity executed a discrete number?

  A. No, trenching is a continuous activity and trenching length is a continuous quantity.

- Q. Is trenching a multiple day task?

  A. Yes, trenching for the entire pipeline segment typically takes days or weeks to accomplish.

At this point, Figure 2-3 recommends using a combined discrete-continuous approach to model the activity. Productivity factor (PF) will be used to update the progress and the state of the trenching activity. Discussions with NACG's pipeline superintendents concluded that the impact on the trenching activity's productivity is triggered when the frost depth is more than one foot. If no ripper is used, the trenching rate through the frozen soil can be reduced by 40% to 50%. If a ripper is used, the rate can be reduced by only 10% to 15%. Equation 5-2 shows the equation used to calculate the trenching rate PF. Equation 5-2 makes an approximation by assuming a rectangular trenching section. The time between trenching state updates was chosen to be one hour (less than one day, according to Figure 2-3). For calculating the trenching through frozen soil productivity factor (FSPF), the reciprocal of Equation 2-2 was used, in which the average productivity was taken as the average trenching productivity through unfrosted soil (m^3/hour); the actual productivity was taken as the actual trenching productivity (m^3/hour).

$$PF = \frac{1}{\frac{1}{FSPF} * \frac{FrostD}{SecD} + \left(1 - \frac{FrostD}{SecD}\right)} \qquad \text{Equation 5-2}$$

Where:

PF = productivity factor for the trenching activity;

FSPF = trenching through frozen soil productivity factor;

FrostD = frost depth (m); and

SecD = trenching section depth (m).

Equation 5-2 compares the relative section depth, assumed unity, to a relative equivalent unfrosted section. The denominator represents an equivalent unfrosted section depth. The relative frosted depth is magnified by dividing it by FSPF, which is added to the originally relative unfrosted depth.

Thus, in the simulation model, when the trenching entity enters the trenching loop, it calculates the PF based on the trenching section depth and the frost depth. This PF is multiplied by the specified basic trenching advance rate, which enables calculating the trenching activity advancement length. The trenching state can therefore be updated in the model for each hour.

5.1.5. Experimentation with the HDPE Pipeline Installation Integrated Simulation Model

Once the integrated simulation model is completely developed, the first experiment validates the superintendents' inputs and compares their expected activity durations for both 8-inch and 42-inch diameter pipes. These pipes are to be installed in a 500 feet single pipe trench. The integrated model advance rates and buffers are shown in Table 5-2; Table 5-4 shows the comparison between the superintendents' input and the integrated model output for the Fort McMurray project location. An Edmonton project location was also simulated and included in Table 5-4 to give an insight into the effect of location change. Figure 5-5 shows the speed diagram for the 500 feet, 8-inch single trench pipe with a July 8th project start date. The simulated project is executed in Fort McMurray to be analogous with the superintendents' inputs. By examining the model, and looking at the output numbers for the Fort McMurray location, it was concluded that the integrated model generally follows the superintendents' pipeline installation logic. Also, the output activity durations and total project duration are close to the superintendents' projections, though do not always match due to the differences between the productivity rates assumed in the model and the superintendents comparable assumptions.

Table 5-4. Comparison between Superintendents' Input and Model Output for two Pipeline Cases

Activity	8-inch Pipe			42-inch Pipe		
	Superintendents' Input (day)	Model Output (day)		Superintendents' Input (day)	Model Output (day)	
		Edm.	Ft. Mc.		Edm.	Ft. Mc.
Pipe Fusion	2	1.1	2.1	4	2.8	4.2
Trenching	3	2.1	4	3	2.2	3
Laying-in	.5	.3	.4	.75	.2	.2
Hydro testing	1	1.2	1.2	1	1.2	1.2
Backfilling	3	1.7	1.7	3	1.7	1.7
Total	6-7	6	7.1	8-9	6	8

For the 8-inch pipe, it is clear that trenching took longer time than the pipe fusion, and was therefore governing in affecting the total project duration. For the City of Edmonton, with a project start date of February 1^{st}, the frost depth that penetrated the soil at this point was about 0.7 meters. This affected the excavation rate. The trenching time increased from 2.1 days to 3.6 days, thereby increasing the total project duration to seven days.

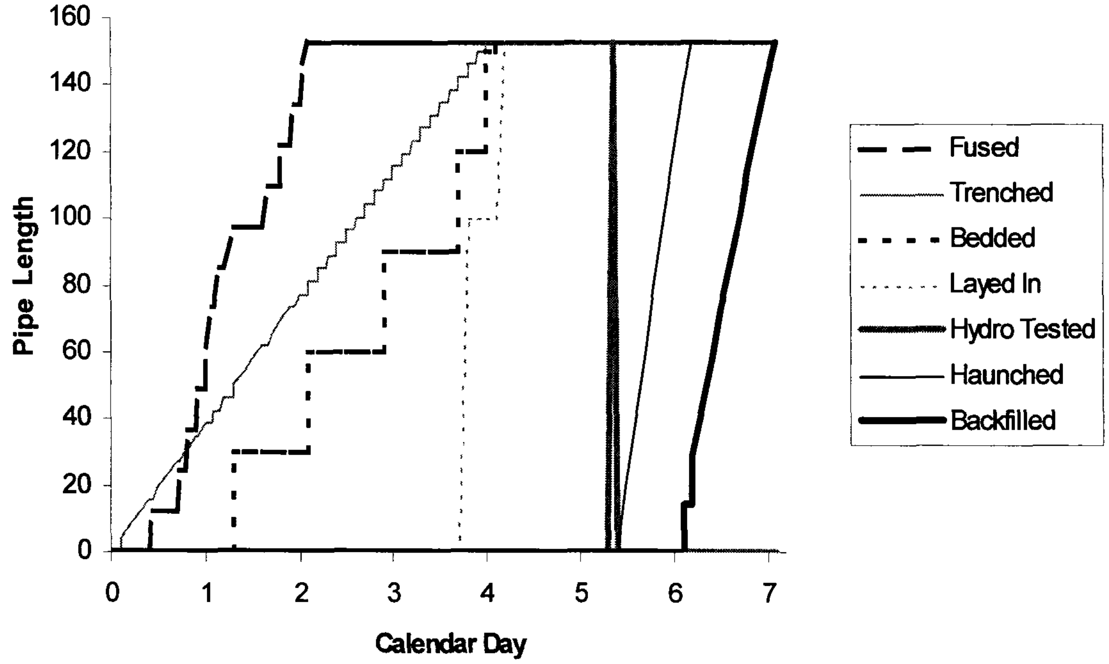

Figure 5-5. Speed Diagram (1x8-inch, 500 feet, July 8th, Fort McMurray)

Different variations of the speed diagram shown in Figure 5-5 were experimented with. The first experiment considered a multiple pipe trench. Figure 5-6 shows the model output for an input similar to Figure 5-5 (i.e. 8-inch pipe, 500 feet), except that there are three 8-inch pipes in the trench laid side by side. The selected project start date was January 5th. Figure 5-6 demonstrates that the project duration was 13 days. If the project start date is moved to August 2nd, the project duration changes to 8 days, as shown in Figure 5-7. This indicated that, for the previous pipe segment, winter could affect the total project duration by as much as 38.5% when compared to a summer project start date.

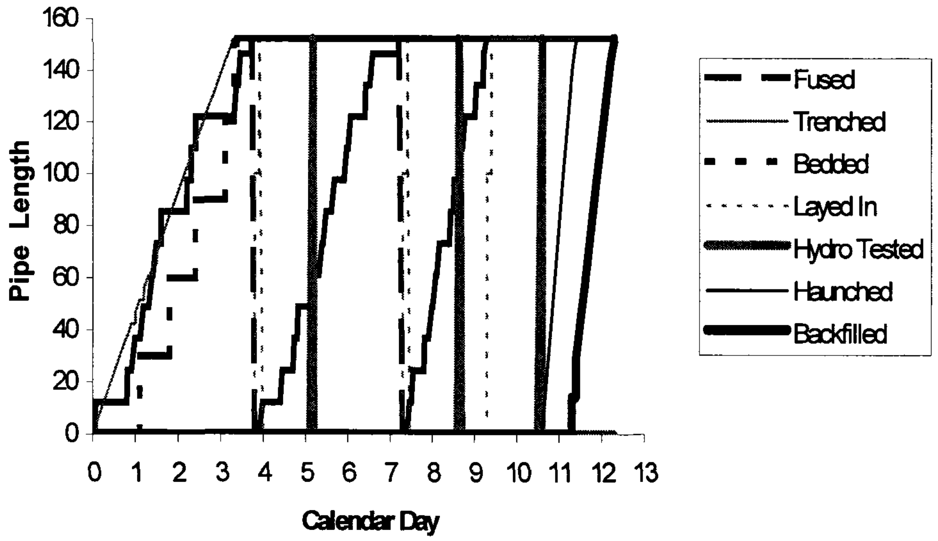

Figure 5-6. Speed Diagram (3x8-inch pipes, 500 feet, January 5th, Fort McMurray)

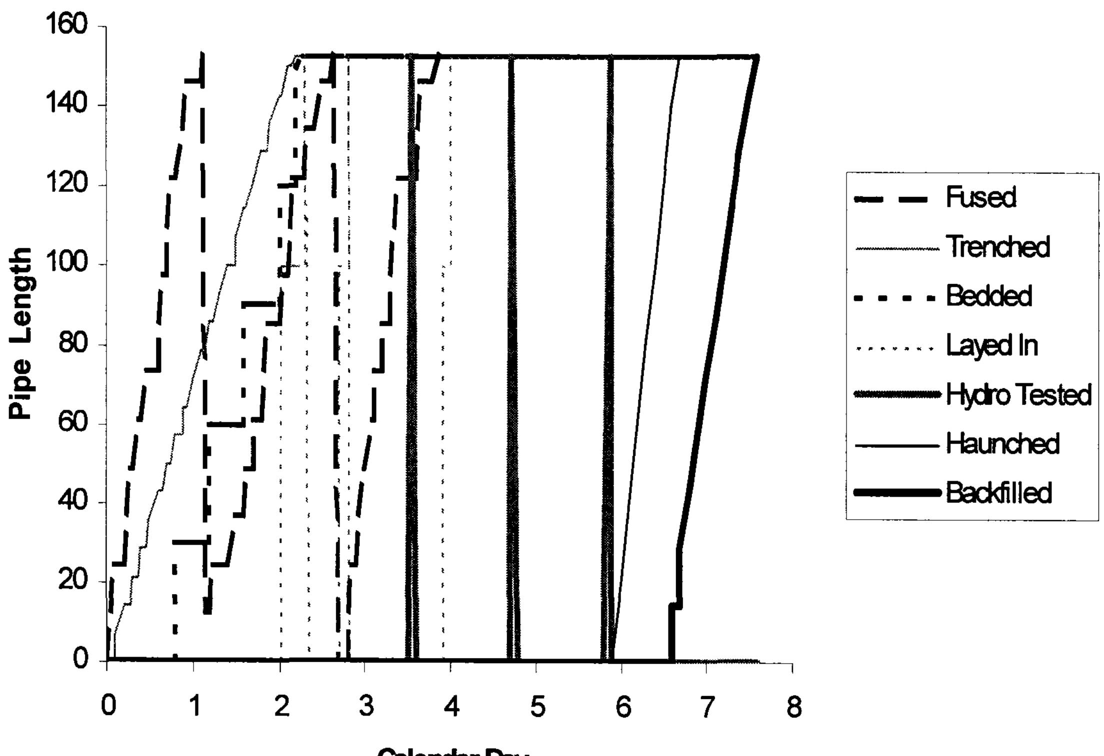

Figure 5-7. Speed Diagram (3x8-inch pipes, 500 feet, August 2nd, Fort McMurray)

In the previous experiments, the available resources exceeded the resource requirement shown in Table 5-1. Limiting the number of available side booms to three, Figure 5-8 shows that the project duration is 12 days. This increase in duration is due to the limitation in the number of available side booms. If additional side booms were available, the duration would be shorter; as it stands, the pipe laying activity must wait for the completion of the fusing activity, since there will not be enough side booms until fusion is complete.

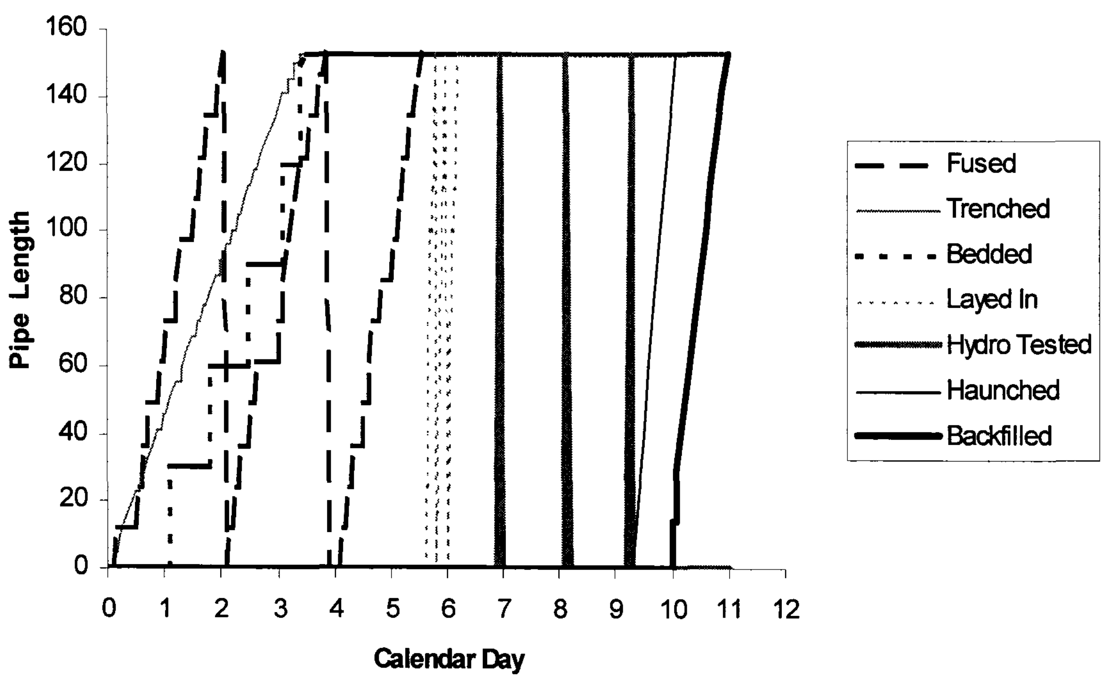

Figure 5-8. Speed Diagram (3x8-inch pipes, 500 feet, January 5th, 3 Side Booms, Fort McMurray)

Another important variation is the case where the pipeline project has more than one pipe segment. Resource sharing between segments plays an important role in determining the project duration in these situations. Figure 5-9 and Figure 5-10 show the speed diagrams of the two segments of a pipeline project. Segment "A" is a two-pipe trench; each pipe is 42 inches in diameter. Segment "B" is a three-pipe trench; each pipe is 8 inches in diameter. Segment "A" has a higher priority than segment "B"; resources will therefore be assigned to it first. Moreover, segment "A" needs three side booms to lower the 42-inch pipes, whereas segment "B" only needs two side booms to lower the 8-inch pipes. Only four side booms are available for the two segments. February 10^{th} is assumed for the project start date. The total project duration was 20 days. It can clearly be seen that segment "B" was able to start trenching and bedding right away, as the required resources were available; however, fusing for segment "B" could not start until day 11, after the laying-in activity of segment "A" released the three side booms.

A Monte Carlo simulation was applied to the simulation experiment and run 250 times, revealing that the total project duration ranged from 16 to 25 days. A cumulative density function (CDF) of the number of working days is shown in Figure 5-11. It should be noted that variations in the total project duration seen are primarily due to differences in the generated weather. The information contained in Figure 5-11 can be presented to the construction planner, enabling a decision regarding the project duration, which takes weather into account, to be reached based on the decision maker's risk tolerance. Approaching the decision regarding total project duration this way clearly facilitates the selection. Furthermore, the decision would be based on a sound and consistent analysis.

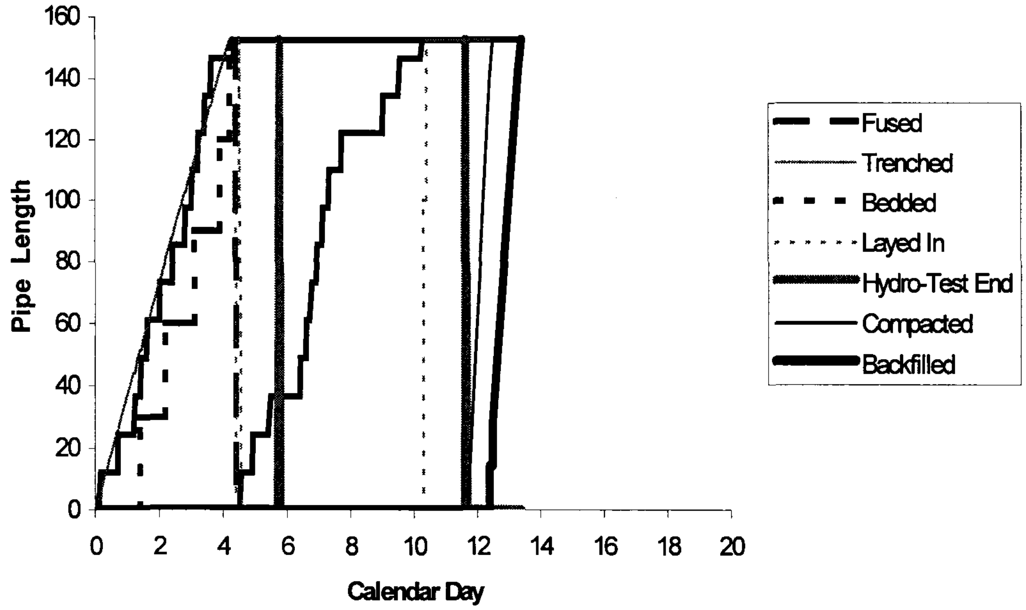

Figure 5-9. Speed Diagram for Segment "A", February 10th, Fort McMurray

A final trial was attempted based on discussions with superintendents. It was noted that in cases where the sides of the excavation are unstable, trenching could not proceed very far ahead of the other activities. All the activities must be executed in close succession to each other. The goal is to backfill early, leaving the trench open for as short a time as possible. Figure 5-12 shows the speed diagram for that case.

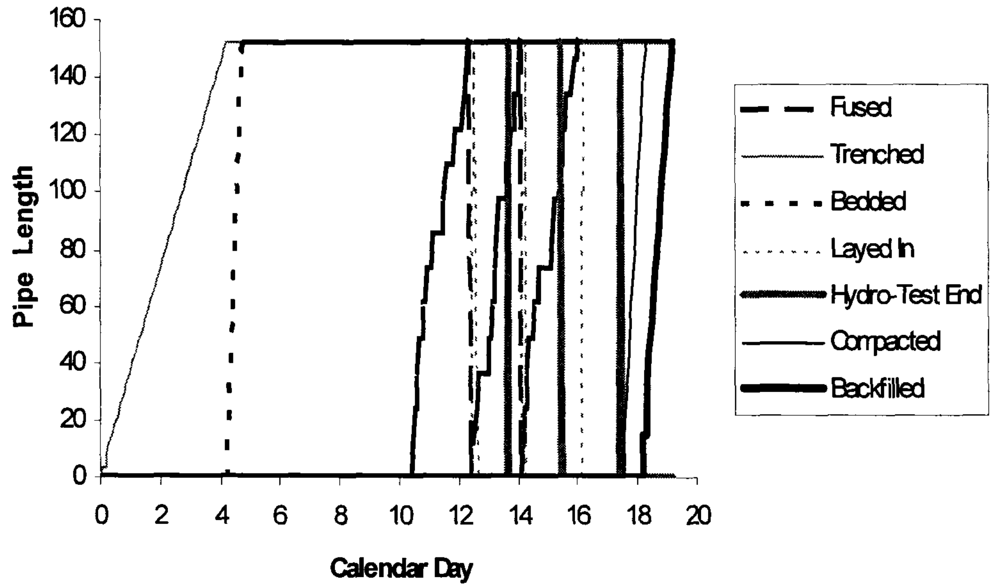

Figure 5-10. Speed Diagram for Segment "B", February 10th, Fort McMurray

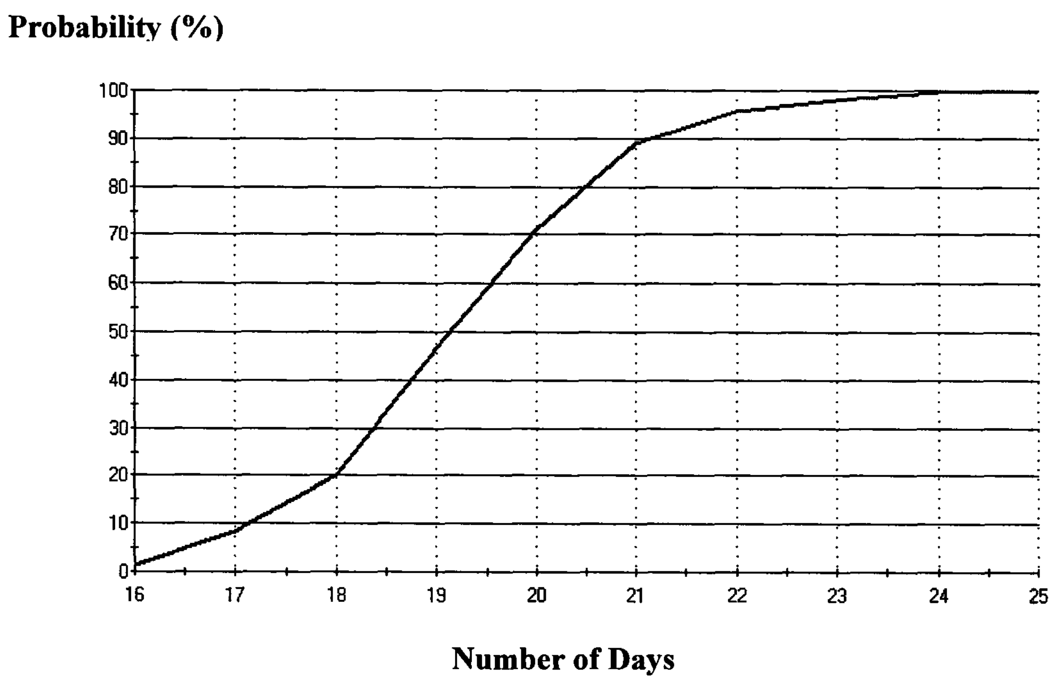

Figure 5-11. CDF of the Total Project Duration

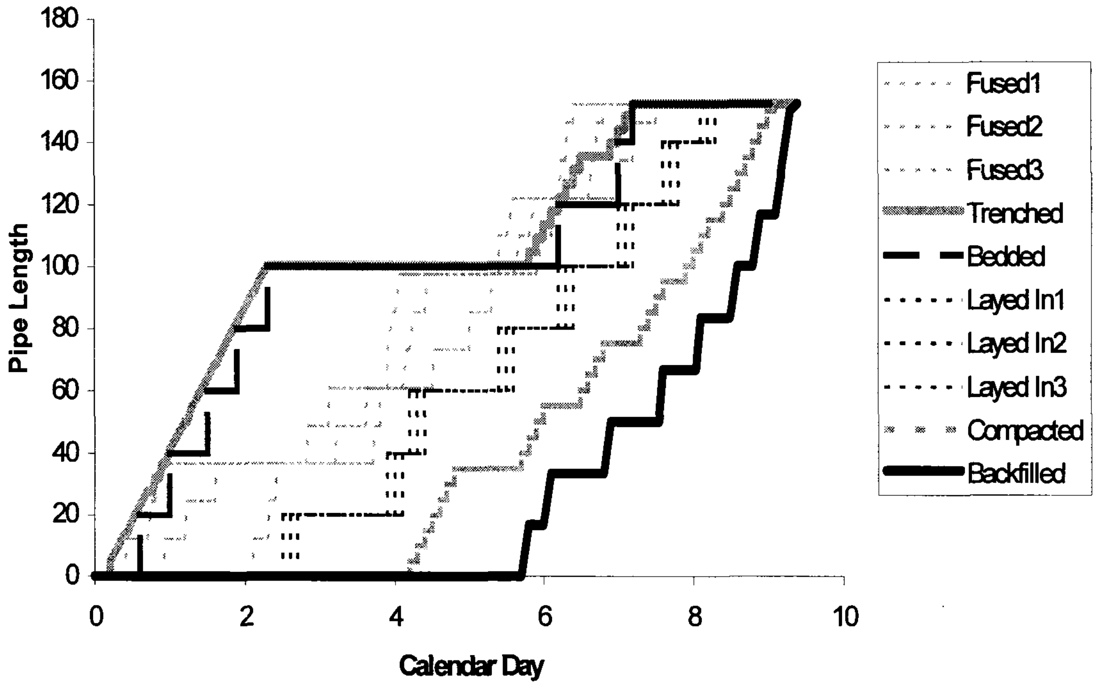

Figure 5-12. Speed Diagram (3x8-inch pipes, 500 feet, January 5th, Edmonton, Stepped Scenario for Unstable Excavation Sides)

For the case shown in Figure 5-12, the hydro testing is usually done after the backfilling. This is based on the assumption that hydro testing rarely fails. By adding the hydro testing duration to the total project duration shown in Figure 5-12 and comparing it to the total project duration shown in Figure 5-6, it can be seen that conducting the pipe installation using the stepped approach does not negatively influence the total project duration. An unfortunate aspect of this approach is that the resources are freed only after the pipe segment installation ends, whereas, for the scenario in Figure 5-6, the resources are freed earlier. In addition, the stepped case would normally require tighter control and supervision over the process.

This application showed a typical example of studying a construction process, identifying the weather-sensitive activities, and modelling their impact on the process. This ensures that the weather impacts on a construction process can be accounted for during the detailed planning phase using the proposed framework steps. These can be experimented with at the activity level. Incorporating the speed diagrams in the analysis, the impact of winter on each weather-sensitive activity can be isolated, offering a clearer picture to the project planner.

5.2. Application of the Framework to the Tunnelling Construction Process

The City of Edmonton wanted to explore the cold weather impacts on their tunnelling projects. A number of meetings with the City of Edmonton's top tunnelling supervisors were scheduled to approach the issue.

The steps suggested by the cold weather construction framework were generally followed to assess the cold weather impacts on the tunnelling process in a process simulation model. The following sections are a direct application of the cold weather construction framework progressed generally in the same sequence suggested. This will be demonstrated through a systematic application of the proposed cold weather construction simulation framework to the tunnelling process.

5.2.1. Detailed Tunnelling Process Study and the Basic Simulation Model

In this section the tunnelling construction process will be briefly introduced, paving the way for the assessment of the winter weather impacts on the tunnelling process. The North Edmonton Sanitary Trunk (NEST) will be used as a case study, which the simulation models will use for experimentation.

In a tunnelling process, three main sub-processes are involved: excavation, dirt removal, and tunnel body support (Ruwanpura 2001). The three sub-processes' activities are interrelated. The tunnel boring machine (TBM) used in the NEST project was a closed face shielded TBM with a boring diameter of 3.2 meters. The finished NEST diameter was 2.92 meters.

In a tunnelling project, a group of activities are typically executed before a TBM commences excavation. These activities are:

- Excavation and lining of a vertical shaft to the design invert level of the tunnel.
- Excavation of an undercut area below the shaft, which is used to facilitate the dirt trains' manoeuvring and dirt handling.
- Excavation of a tail tunnel, which facilitates dirt handling and hoisting.
- Hand tunnelling, excavation, and lining, for a distance that would provide enough liners' friction to support the TBM thrust in order to advance forward.

During tunnelling, two groups of activities are interrelated and executed concurrently:

- Tunnel face activities:
    - TBM boring and advance into the soil,
    - Loading the excavated dirt into the muck cars,
    - Unloading the liners from the arriving trains,
    - Liner installation to support the excavated tunnel body,
    - TBM resetting, and
    - Extending the tracks and services following the advancement of the TBM and tunnel face.
- Shaft activities:
    - Manoeuvring the trains at the undercut area,
    - Hoisting the muck cars to the ground level,
    - Dumping the dirt in preparation to haul it to landfills,
    - Lowering the muck cars to the undercut level, and
    - Loading the material car with liners.

Figure 5-13 shows a bar chart for the tunnelling activities and their interrelation. After the tunnel excavation is completed, a removal shaft is constructed and supported for TBM exit.

For the basic tunnelling simulation model, the University of Alberta's CEM group had previously developed a tunnelling simulation template. The model was developed using the Simphony simulation environment and was previously tested and reported to be successful. To avoid effort duplication of work, the existing template was used and extended whenever needed.

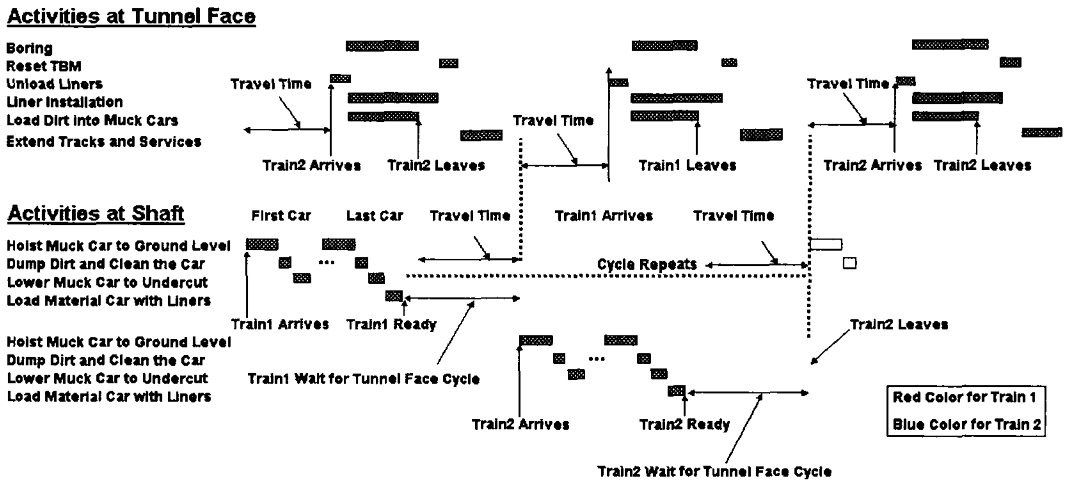

Figure 5-13. Tunnelling Activities Interrelation

For the NEST simulation model, the progress of the tunnel was tracked and all the model input parameters were acquired as the tunnel was being constructed. A simulation model reflecting the actual construction was developed. Figure 5-14 shows the actual tunnelling simulation model developed. A summary of the input model parameters is summarized in Table 5-5. Ten separate runs were executed for the actual case simulation model.

The TBM excavated a total length of 1446 meters, and there was a total number of 163 shifts. The actual recorded tunnel productivity rate was 8.87 meters per shift. This record was comparable to the 9.68 meters per shift productivity rate, which was based on the actual case simulation model that resulted from about 150 working shifts. Eight delay reasons were identified in the actual tunnel construction: cable pulling, muck cars breakdown, crane, TBM mechanical downtime, TBM teeth cleaning, surveying, encountering rocks, and rock drilling. Out of the eight identified delay reasons, only three were significant: TBM mechanical downtime, surveying, and rock drilling. These were therefore modeled in the actual case simulation model. Due to model abstraction, the remaining five non-significant delay reasons were not modelled in the NEST simulation model.

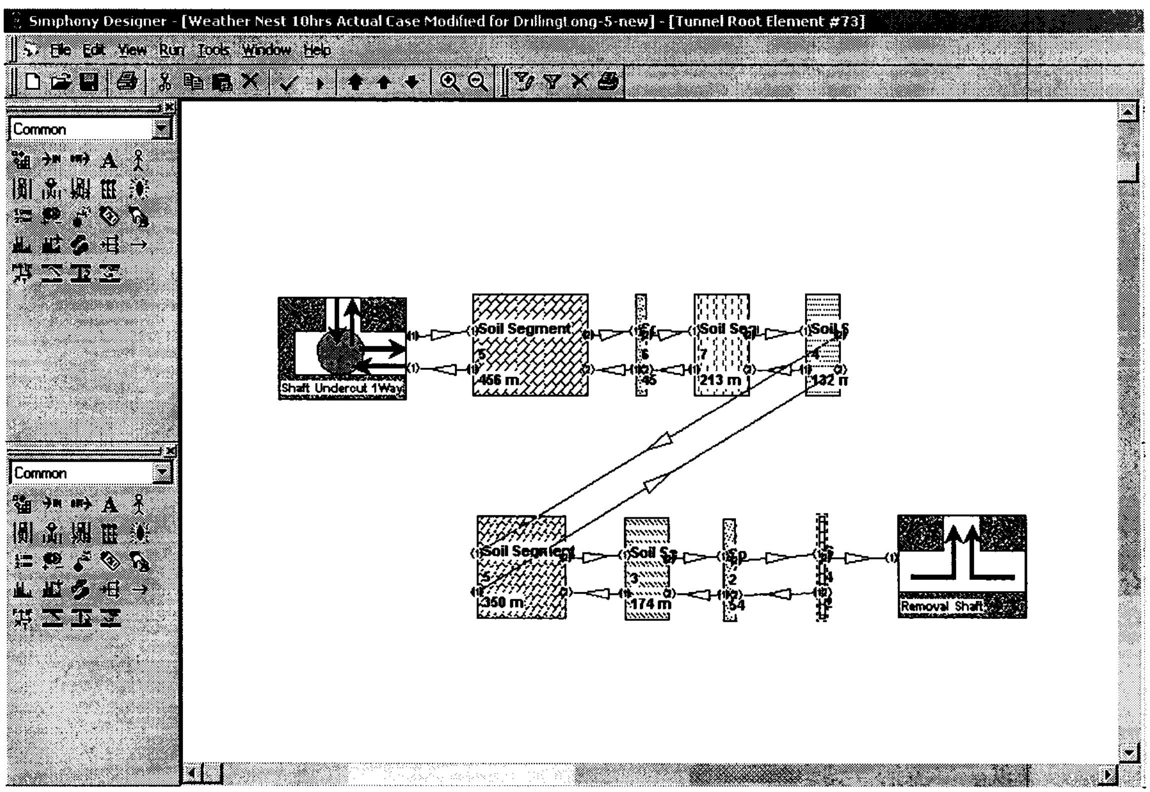

Figure 5-14. NEST Model Reflecting the Actual Construction Case

Table 5-5. Input Parameters for the NEST Model

Element	Parameter	Value
Trains	Empty speed (km/hr)	5
	Loaded speed (km/hr)	5
	Number of muck cars	3
	Number of material cars	1
	Muck car capacity (m^3)	4.2
TBM	Excavation Diameter (m)	3.2
	Resetting time (min)	Uniform (2,4)
	Liners installation time (min)	Triangular (15,18,25)
	Time between breakdowns (min)	Exponential (7440)
	Time to repair (min)	Beta (1.055,2.33,.5,7)
Hoisting	Muck car cycle	Uniform (4.00,7.00)
	Material car cycle	Uniform (7.00,10.00)
Shift control	Start time	800
	Mobilization time (min)	Uniform (10,15)
	Coffee break at	1000
	Coffee break time (min)	Uniform (25,35)
	Lunch break at	1200
	Lunch break time (min)	Uniform (40,50)
	Finish time	1700
Soil Segment 1	Length (m)	456
	Penetration Rate (m/hr)	Beta (3.48,2.90,1.00,8.08)
	Survey frequency (m)	13
	Survey time (min)	Uniform (120.00,180.00)
Soil Segment 2	Length (m)	45
	Penetration Rate (m/hr)	Triangular (2.82,5.24,8.20)
	Survey frequency (m)	13
	Survey time (min)	Uniform (120.00,180.00)

Table 5-5. (Cont.)

Element	Parameter	Value
Soil Segment 3	Length (m)	213
	Penetration Rate (m/hr)	Beta (2.89,2.41,0.90,7.97)
	Survey frequency (m)	13
	Survey time (min)	Uniform (120.00,180.00)
Soil Segment 4	Length (m)	132
	Penetration Rate (m/hr)	Triangular (0.73,5.39,7.95)
	Survey frequency (m)	13
	Survey time (min)	Uniform (120.00,180.00)
Soil Segment 5	Length (m)	350
	Penetration Rate (m/hr)	Beta (3.48,2.90,1.00,8.08)
	Survey frequency (m)	50
	Survey time (min)	Uniform (120.00,180.00)
Soil Segment 6	Length (m)	174
	Penetration Rate (m/hr)	Beta (1.96,2.01,2.72,9.00)
	Survey frequency (m)	50
	Survey time (min)	Uniform (120.00,180.00)
Soil Segment 7	Length (m)	54
	Penetration Rate (m/hr)	Beta (1.63,1.31,1.21,5.63)
	Survey frequency (m)	50
	Survey time (min)	Uniform (120.00,180.00)
Soil Segment 8	Length (m)	22
	Penetration Rate (m/hr)	Triangular (0.73,5.39,7.95)
	Survey frequency (m)	50
	Survey time (min)	Uniform (120.00,180.00)

An analysis of the NEST data indicated that five days recorded zero production for reasons that were not included in the simulation model. To be able to compare to the model output, those five days were deducted from the actual 163 shifts resulting in a productivity of 9.15 meters per shift. The difference between the two productivity figures (i.e. 9.15 and 9.68), which is about 5.8% less than the actual productivity achieved, is mainly due to the combined effect of the non-significant delay reasons that were not included in the simulation model.

An analysis of the records for the daily delays indicated that the non-significant delays (i.e. not modeled in the simulation model) resulted in about 51 hours (i.e. 5.5 days) of lost time. To enable the comparison of productivity numbers, the 5.5 days were deducted from the 158 shifts, resulting in a productivity of 9.48 meters per shift.

The difference between the two productivity figures (i.e. 9.48 and 9.68) was not justified by the actual case simulation model. The intent was to include the winter effects in the simulation model once the TBM started working on July 23, 2001 until February 8, 2002. The next two sections will show how the tunnelling winter effects were included in the final integrated simulation model.

5.2.2. Documenting the Cold Weather Impacts on the Tunnelling Process

The tunnelling application is an example in which documenting the cold weather impacts on the tunnelling process were dependent on expert opinions. To document the cold weather impacts on the tunnelling construction process, a number of meetings with the City of Edmonton personnel and their top tunnelling project superintendents were scheduled. These meetings reviewed the tunnelling process and focused on the cold weather impacts. The result of the meetings was a list of the winter effects, which can be summarized as follows:

1. The work will stop when the ambient temperature drops to less than –40 °C (stoppage condition).
2. The crane will stop when the wind speed is more than 50 km/hr (stoppage condition).
3. In cases when the temperature drops below –20 °C and wind speed is more than 35 km/hr, the signalman's (i.e. top man) efficiency drops considerably. This slows the entire tunnelling process.
4. With the impact of the first severe cold weather, problems due to equipment breakdown arise in the weakest links.
5. When operating equipment with hydraulic systems operate under very cold conditions, the equipment operates with less power until heated and more breakdowns are noticed.

6. High wind speed (i.e. more than 35 km/hr) causes an increase in crane or hoisting time due to reduced precision.
7. Cold and wet conditions influence the capacity of muck cars. The problem begins when the muck cars are unloaded. Muck often sticks to the sides of the muck car and, under such conditions, will rapidly freeze inside the muck cars, thereby reducing the total capacity of the muck car. The maximum capacity reduction permitted in muck cars is 10%-15%, after which point the muck cars should be stopped and cleaned with jackhammers. This injunction is critical, as a significant capacity loss is not affordable due to the need to transport the pre-cast liners (four pre-cast segments each weighing about 825 kg need to be transported to the tunnel face).
8. In cold temperatures, the pre-cast segments' seal does not stick to the pre-cast segments, and heating is needed.
9. When water must be pumped out under very cold and wet conditions, this often leads to hoses freezing up and further problems with filters.

After evaluating the most effective factors, it was decided to include the winter impacts resulting from points 1, 2, and 7.

With regards to point 7, dirt removal is generally not affected by winter weather in slurry type tunnelling systems, however, when dirt is removed from the tunnel and hoisted out via muck cars in wet sticky conditions, winter becomes a factor affecting the tunnel construction productivity. Further discussion revealed that the problem is triggered when the temperature drops below –5 °C. The remedy is to clean the muck cars after every dirt unloading. The cleaning process takes about five minutes per muck car. Due to the work sequence, only the last muck car of the train delays the train unloading cycle as the other muck cars can be cleaned at the same time the following muck car is hoisted to the ground level and unloaded.

As demonstrated by Figure 2-2, when documenting the cold weather impact on tunnelling, temperatures dropping to less than –40 °C represents a process stoppage condition. Next, all the tunnelling process activities were examined to see if any were weather-sensitive. Muck cars hoisting was sensitive to wind speed; hoisting times increase with wind speeds exceeding 35 km/hr and crane activities stop when the wind speed exceeds 50 km/hr. The increase in hoisting times was determined to be ineffective and was therefore ignored. The crane stoppage due to wind speeds exceeding 50 km/hr represents an activity stoppage condition. Lastly, muck car cleaning due to muck freezing and sticking to muck cars represents a mitigating activity. If the temperature drops below –5 °C, train cleaning duration was found to be about five minutes per train to account for cleaning the frozen dirt that stuck to the muck car. This delay takes place at the shaft. Table 5-6 summarizes these findings.

Table 5-6. Tunnelling Process Weather Impact Summary

Activity	Type	Influencing Factor	Triggering Condition	Influence on the Process	Accounted for in Simulation Model
Tunnelling Process	Process Stoppage	Temperature	<-40 °C	Significant	✓
Hoisting	Productivity Reduction	Wind Speed	>35 km/hr	Insignificant	✗
Hoisting	Activity Stoppage	Wind Speed	>50 km/hr	Significant	✓
Muck car cleaning	Productivity Reduction (Mitigating)	Temperature	<-5 °C	Significant	✓

5.2.3. Developing the Integrated Tunnelling Process Simulation Model

The basic tunnelling process simulation model was modified to account for the cold weather impacts on the tunnelling process. The following modifications to the tunnelling basic simulation model were made:

- A stochastic weather generator element was added to incorporate the daily weather variables values into the simulation model,
- A calendar element was added to allow for specifying the project start date and to track the working / vacation days,
- The process stoppage conditions were imposed, and
- The mitigating activities were added which ease the negative impact of winter on the tunnelling process.

Figure 5-15 shows the parent-tunnelling element for the NEST simulation model. It illustrates both the weather generator element and the calendar element. The weather generator was set for the Edmonton location. The TBM work start date was set in the calendar element to July 23rd. The number of working minutes per day was set in the calendar element to 540 minutes/shift, which corresponds to the actual working shift minutes recorded. The breaks were already accounted for in the simulation model.

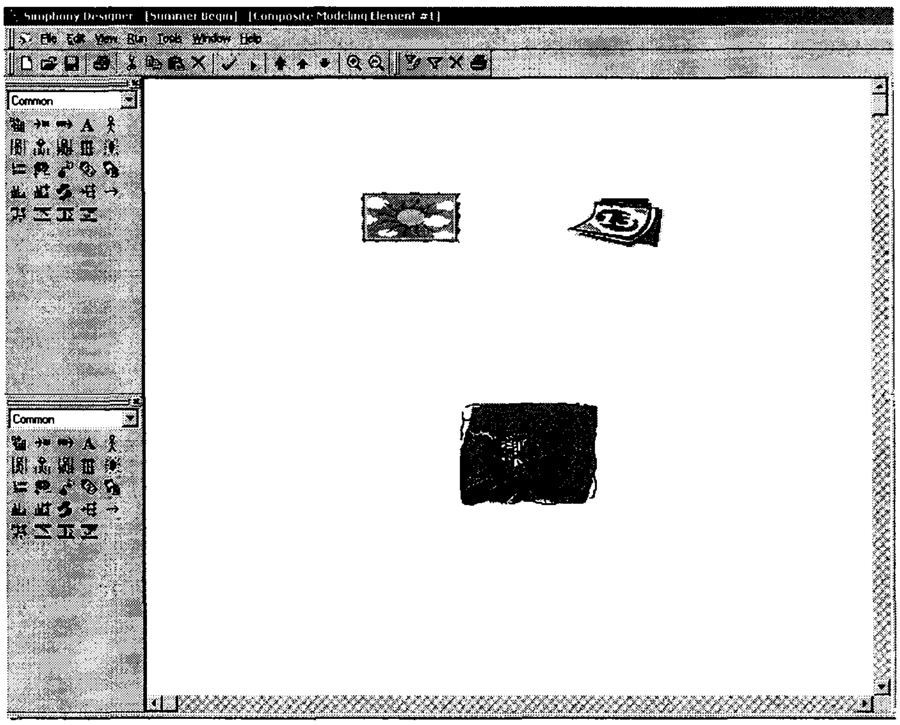

Figure 5-15. NEST Integrated Simulation Model at the Parent Level

The tunnelling process and hoisting activity stoppage conditions, shown in Figure 5-16, were modeled by adding a crane stoppage cycle. The cycle had a high priority, and acquired the crane resource whenever the average temperature dropped below –40 °C (i.e. process stoppage condition), or whenever the average wind speed for the day exceeds 30 km/hr (i.e. hoisting activity stoppage condition). The check for these triggering conditions is conducted at the start of each working day.

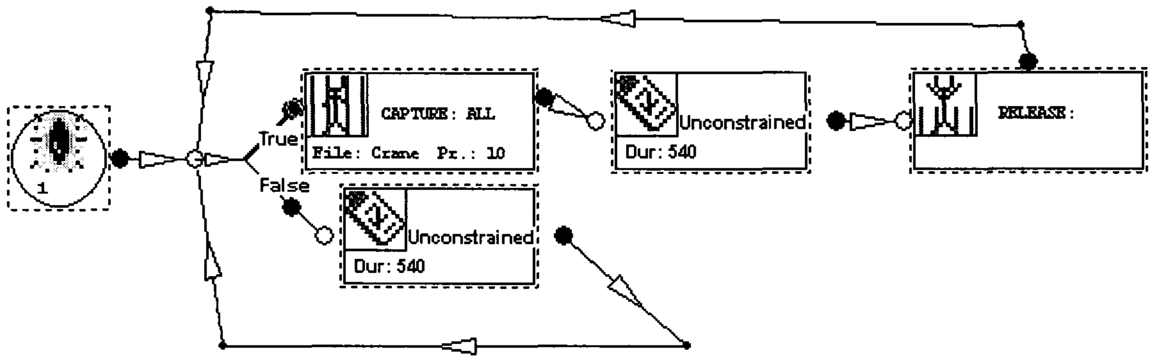

Figure 5-16. Modelling of the Stoppage Conditions

Finally, to model the mitigating activity (i.e. muck car cleaning), Figure 2-3 was consulted. Figure 2-3 gives good guidance, which can facilitate the integrated simulation model choices. To model the muck cleaning activity, using the process of Figure 2-3, the following logic was used:

- Q. Does the muck car cleaning activity occur conditionally?

  A. Yes. This leads to the creation of a new element (i.e. conditional node) that would only have a delay value whenever the average temperature drops below –5 °C.

- Q. Is the quantity executed a discrete number?

  A. Yes, as the muck cars are cleaned one at a time.

- Q. Is muck car cleaning a multiple day task?

  No, as cleaning muck cars typically requires several minutes for completion.

At this point, Figure 2-3 recommends the use of a discrete event simulation approach, namely, a task element, to model the cleaning activity. In addition, Figure 2-3 recommends collecting data about the total duration needed to clean a muck car. Discussions with the tunnelling superintendents concluded that cleaning a muck car typically takes about five minutes.

To conclude the above section, the muck car cleaning activity was modeled by inserting a task element immediately after the hoisting down of the muck car. The cleaning activity's duration is normally set to zero minutes except when the average temperature for the day is below –5 °C, in which case the muck car cleaning task delay duration is five minutes. Figure 5-17 shows the insertion of the muck car-cleaning task in the basic model, which serves as a mitigating activity that would reduce the winter impact on the process.

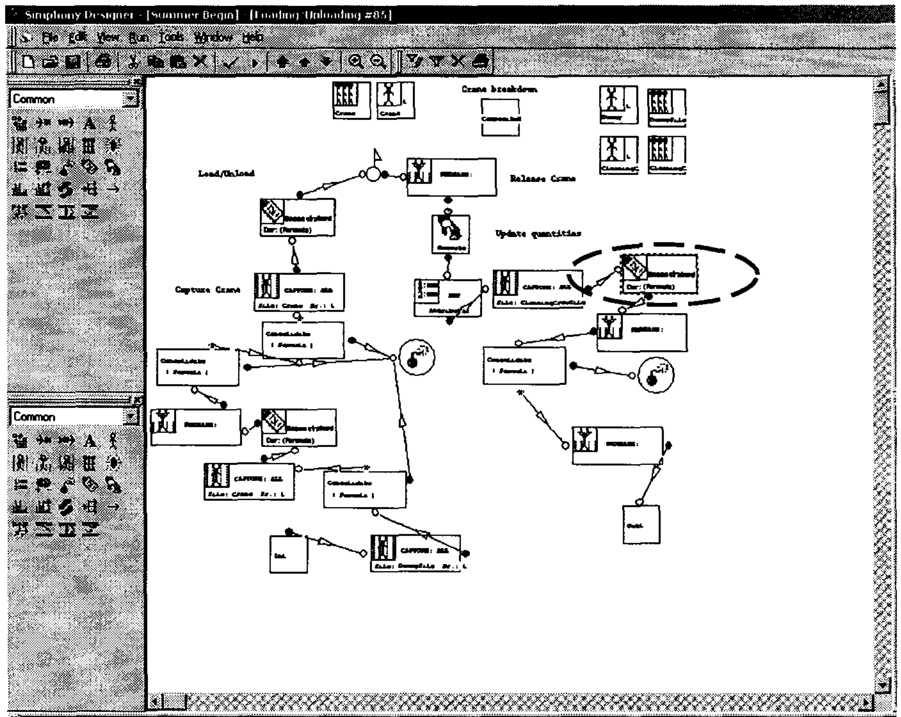

Figure 5-17. Insertion of the Muck Car Cleaning Mitigating Activity

5.2.4. Experimentation with the Integrated Tunnelling Simulation Model and Conclusions

After completion of the integrated simulation model, the NEST tunnel was re-examined with the winter impacts being modeled. The integrated simulation model was executed ten times to test the model output productivity per shift. The results were surprising: the tunnel productivity averaged 9.63 meters per shift. Compared with the 9.68 meters per shift, the output seemed to be unchanged and the NEST seemed to be unaffected by the winter weather. At first, these results seemed illogical. If every train is delayed about 5 minutes, and an average of close to ten meters per shift (i.e. ten trains) was achieved, this should have resulted in 50 minutes of productive time to be lost on a winter day, corresponding to about one meter per day reduction in productivity. Since the number of winter construction days were more than 50% of the total construction days, the difference should have been more significant. Further investigation into the matter revealed very interesting findings.

Finding 1:

Changing the project start date to November 1st resulted in an average productivity of 9.44 meters per shift. The difference in productivity figures between the summer start date and the winter start date was significant. Further analysis revealed the reason for this difference (i.e. the reason for the NEST construction productivity to be unaffected by a summer start date though a significant part of the construction was executed in winter). For tunnelling construction, two cycles for the trains exist. The first is the unloading cycle, in which the train moves through the undercut to the shaft location where the muck cars are successively lifted by the crane to the surface, emptied, and lowered back to the undercut level, and finally cleaned of the frozen muck sticking to the sides of the muck car. Included also in this cycle is the time that the crane needs to load the material car with the precast segments. The second train cycle is the tunnel face cycle in which the train leaves the undercut area, travels toward the TBM at a speed of about five km/hr, arrives at the tunnel face, and starts loading dirt from the TBM. When the train is full, it travels back to the undercut. The two trains meet at the undercut area and swap cycles. Tunnel productivity is normally determined by the longer of the two cycles; the train executing the shorter cycle has to wait at the undercut area for the other train until it finishes executing the longer cycle. When this is done, both trains can swap cycles.

Winter impacts the unloading cycle by adding approximately five minutes to it, which is the time needed to clean the final muck car of the train. As seen in the previous two paragraphs, winter influences the overall tunnel productivity only if the unloading cycle is larger than the tunnel face cycle. When this happens and when the winter conditions are met, each train is delayed approximately five more minutes. The project start date for the actual NEST integrated simulation model was on July 23rd (summer time). Initially, therefore, winter conditions had no effect on productivity. In Edmonton, temperatures are typically seen dropping by November (i.e. 99th working shift in the NEST tunnel construction). By that time, about 900 meters of the tunnel were completed. At this point and comparing the two train cycle times, the unloading cycle time averages 30 minutes, including the delay due to winter. On the other hand, the tunnel face cycle time averages 44 minutes of which about 22 minutes are spent travelling back and forth to the tunnel face. Since the tunnel face cycle in longer than the unloading cycle, the unloaded train would have to wait for the tunnel face train until it returns to the undercut area. This would mean that weather factors related to the winter would have no impact on the unloading cycle as it relates to the tunnel productivity. In conclusion, between July 23rd and October 31st, the temperatures are generally not low enough to affect tunnel productivity. Starting November 1st, the temperatures could generally be low enough to affect the unloading cycle. On the other hand, the completed tunnel is long (i.e. about 900 meters), making the tunnel face cycle time larger than the unloading cycle time, and thereby cancelling the winter impacts on the overall tunnelling productivity. This cancellation occurs because the unloaded train had to wait at the undercut area for the tunnel face train for a period that is more than the unloaded train delay due to winter (i.e. about five minutes).

Finding 2:

In experimenting with the model, the order of doing the tasks at the shaft was found to have a significant impact on the unloading cycle delay due to winter. Typically, loading the segments to the material car can be done before or after the muck cars are unloaded. On a normal summer day, both alternatives should have the same total unloading cycle time. However, during winter, the two alternatives result in different unloading cycle times. In cases where the segment loading is done first, the total unloading cycle time is composed of the segment loading time added to the train unloading time. However, in cases where the segment loading is done last, the last muck car can be cleaned parallel to the segments being loaded into the material car. This cancels most or all of the final muck car cleaning time, thereby removing most or all of the unloading cycle time winter delay (i.e. about five minutes per train).

To show the effect of the previous two findings, the same NEST simulation model was changed to produce the four model variations:

1. July 23rd start date, in which the segment loading is done first,
2. November 1st start date, in which the segment loading is done first,
3. July 23rd start date, in which the segment loading is done last, and
4. November 1st start date, in which the segment loading is done last.

Table 5-7 summarizes the resulting average tunnel productivity per shift for the four cases averaged over 10 simulation runs.

Table 5-7. Average NEST Tunnelling Productivity for the Four Cases

	July 23rd start date (meters per shift)	**November 1st start date (meters per shift)**
Segment loading first	9.63	9.44
Segment loading last	9.66	9.58

Commenting on Table 5-7:

1. If the above summer start productivity numbers are compared with the base case productivity of 9.68 meters per shift, winter did not affect the tunnelling productivity for the NEST as the tunnel face cycle time was longer than the unloading cycle time by the time the severe winter weather struck (i.e. November 1st).
2. Winter can have an effect on tunnelling productivity; however, this effect can be cancelled or at least mitigated by following the following two simple recommendations:

Recommendation 1: A tunnelling project should not start in winter. It should start in the summer to make sure that enough tunnel length has been constructed before the onset of severe winter weather. This should ensure that the tunnel face cycle time is longer than the unloading cycle time, thereby cancelling the negative impacts of winter on tunnelling productivity.

Recommendation 2: In the case where a winter project start time is inevitable, segment loading into the material car should be done after the last muck car has been lowered into the undercut level. This should cancel or at least mitigate the winter impact on the tunnelling productivity due to the ability to work on cleaning the last muck car while loading the material car.

CHAPTER 6. HIGH LEVEL ARCHITECTURE AND IT'S WEATHER SIMULATION APPLICATION

6.1. Introduction

High Level Architecture (HLA) provides a framework that allows several computer simulations (federates) to be combined into a larger simulation model (federation). For example, for a tunnelling federation to be developed using the tunnelling construction application, a number of supporting tunnelling federates may be required. A tunnel face federate simulates the TBM soil penetration, loads the muck cars with the excavated soil, and lines the tunnel, which supports the excavated tunnel section. A transportation federate is responsible for transporting the dirt removal trains back and forth between the tunnel face and the shaft. A soil removal federate is responsible for operating the crane that hoists the muck cars at the shaft location to get rid of the excavated soil. Each of these federates can be developed separately; however, for seamless communication between federates to be possible, each federate must conform to the HLA framework specifications.

6.2. Why is HLA needed?

In today's complex simulation models, a simulation model can be composed of multiple simulations, each simulating the role of a specific aspect of the environment it is modelling. In many cases, parts of those simulations may have already been developed for another application, and the task is to link the simulation models to simulate the environment of interest. Unfortunately, this task is not as simple as it sounds. For example, it may be necessary to make extensive modifications to the simulation models in order to adapt the simulation components to one another. In many cases, it might prove more convenient to redevelop the simulation component from scratch than to make the necessary modifications. This difficulty introduces two properties of HLA-compliant simulations: *reusability* and *interoperability*.

Reusability: The simulation model can be reused with a different simulation scenario or even with an entirely different simulation application.

Interoperability: The reusable simulation component can be combined with the other simulation components without the need for recoding. This means that component simulations that are running on a number of distributed platforms can be combined together even if the platforms are different in type.

HLA helps combine the distributed simulation components together in a single simulation execution. It also helps extend the functionality of the combined simulation model by introducing other simulation components and adding them to the collection of distributed simulation models.

6.3. Components of an HLA Compliant Federation

In this chapter, two terms need to be defined:

- **Federation:** An HLA-compliant simulation model composed of a collection of constituent simulation components (federates).
- **Federate:** Simulations model that is part of an HLA-compliant federation. It is one point of contact with the run time infrastructure (RTI).

HLA is defined by a number of documents. It has three main components:

- Federation rules: A collection of principles to ensure the proper interaction of federates during a simulation. It also outlines the federates and simulation responsibilities.
- Object Model Template (OMT): A meta-model for all Federation Object Models (FOM), which establishes their allowed structure.
- Interface Specifications: Specifies a standardized interface between the simulation federates and the Run Time Infrastructure (RTI).

HLA is an architecture, not a software implementation; however, the RTI and the developed federates are coded software that should conform to the HLA specifications. In HLA, a federation needs to have access to the following components (Kuhl et al. 1999).

- Run Time Infrastructure (RTI): A software that conforms to the HLA specifications. It provides all the software services that are needed to support the HLA federation execution. It is considered to be the backbone through which all the communications and interactions between the federates go through.

- Federation Object Model (FOM): A single, common object model per federation, which is developed for the data exchange between the federates (e.g. objects, interactions).
- A collection of federates composing the federation.

6.4. HLA and the Weather Simulation Application

The literature review phase of this research uncovered several developments regarding weather generation. One example is the work of Wales and AbouRizk (1996). Enhancements to that work were almost non-existent. A possible explanation is the amount of coding effort needed to recode the weather generators. This effort might take weeks or months of work, depending on the developer's understanding of the principles and his or her coding experience.

HLA, as reported earlier in this chapter, has two appealing properties: reusability and interoperability. These properties make a perfect match with our needs. The idea is to develop the universal weather generator as a stand-alone HLA federate. Such a tool will enable the integration with other construction federates (for example, tunnelling or pipeline installation) without recoding, which should relieve the researchers of the overhead effort involved in using a weather generator in their work, giving them a chance to concentrate more on the process they are developing.

Currently the Construction Engineering and Management (CEM) group at the University of Alberta envision HLA as an immerging simulation technology for the future. The architecture has gone through a number of successful steps to make this a possibility for researchers all around the globe. The CEM group is developing a second version of an HLA computer framework, using Visual Basic .NET ® and C-Sharp ®. An RTI has also been developed for use with the HLA-compliant federates. The HLA development status, in spite of these major efforts, is still in its infancy. Development of federates that describe the different construction processes is only beginning. The CEM group is currently experimenting with HLA federate prototypes and documenting their findings for use by future researchers who will further advance this work.

6.5. Application of the Weather Generator Federate as Part of an HLA Construction Federation

An HLA-compliant replica of the Universal Weather Generator, which was developed for Simphony, was developed for the version 2 HLA framework to run with the current version of the RTI.

To make this federate part of a construction process federation that accounts for the weather impacts on the process, the developers of the construction federation should develop an HLA-compliant federate (or number of federates) describing the process they are modelling. They would then have to combine the FOMs of the federates into one FOM that describes the data exchange between the federates (i.e. the federates describing the construction process and the weather generator federate). After this, testing is required to ensure that everything is working in an HLA-compliant manner and that the data exchange between the federates is seamless.

In developing a simulation prototype of a general construction process, an HLA-compliant Universal Weather Generator was developed. This weather generator generates all the weather parameters previously identified in the research objectives (Section 1.4). A prototype of an HLA-compliant general construction federate was developed. This federate is responsible for reading the weather parameters values generated by the weather federate for use in the context of a construction process simulation. As this step was successful, it was time to combine the two federates together in a step to simulate the weather impacts on a construction process.

The first step was to combine the FOMs of both federates. This was practically easy using the OMT editor developed by the University of Alberta's CEM group, which helps in creating FOMs for HLA federates. The combination was accomplished using the capabilities of the FOM editor. At this point, each federate would know what attributes to publish and what attributes to expect from the RTI, which reflects all the published attribute values from the different federates and makes them available to the interested ones.

The next step is to further develop the general construction federate in order to simulate the impact of the weather parameters, which are published by the RTI, while the simulation is running.

For the federates to work together, at time zero, the construction federate should publish the location and start date of the project. At the beginning of each day, the RTI sends messages to the construction federate about the weather parameters values that it got from the weather generator. The attribute values received by the RTI are time-stamped to indicate when the RTI should publish those values.

Next, after some testing, it was time to run both simulation models together on different computers. The results were as hoped for: the two models communicated successfully without the need for either side to know about the details of how the other side worked. From the construction federate side, there was no need to know about the coding that was developed for the weather generator federate, conversely, from the weather generator side, there was also no need to know how the construction federate operates. The only items of interest are that the needed attributes are published at the right time for the models to continue working simultaneously. Figure 6-1 shows the output interface of the weather generator. Figure 6-2 shows the output interface of the general construction federate, illustrating the received weather attributes on the 11th day of the project.

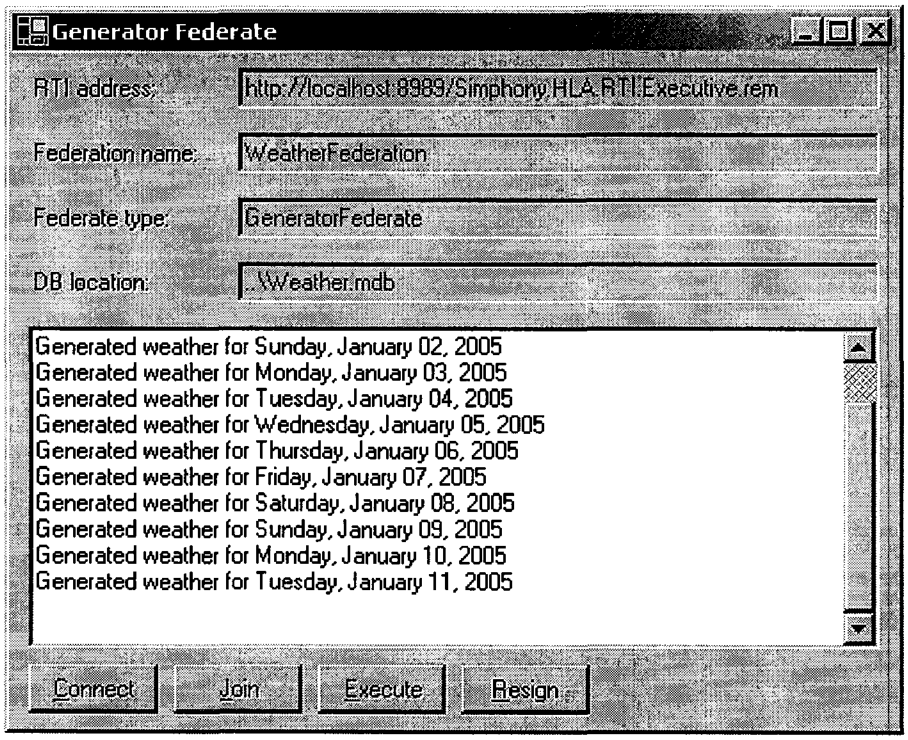

Figure 6-1. Weather Generator Federate Output Interface

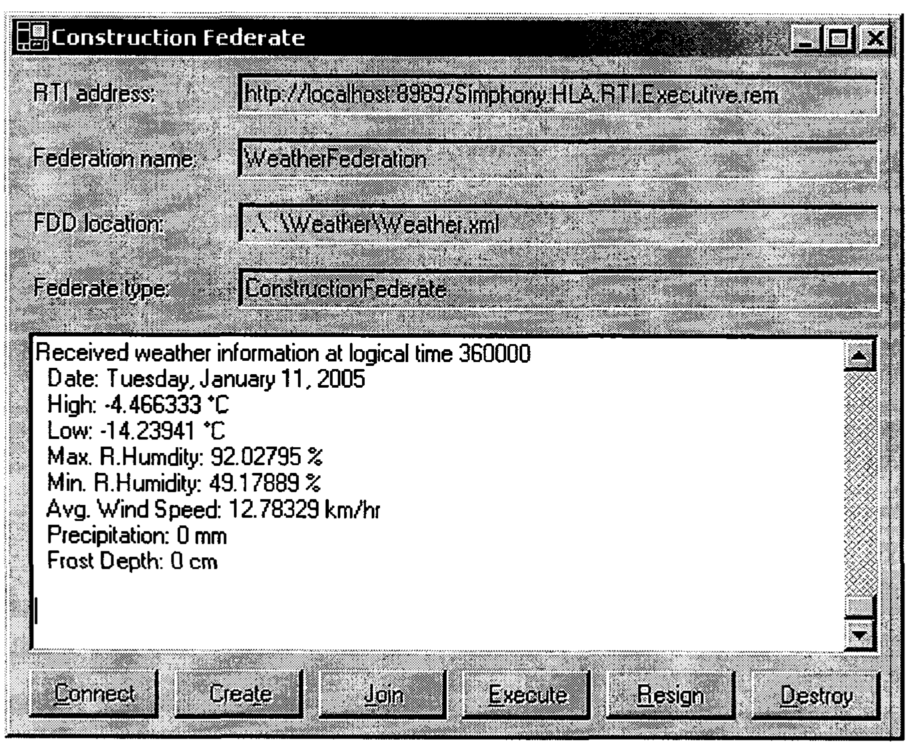

Figure 6-2. General Construction Process Federate Output Interface

6.6. Realised Benefits of Using an HLA-Compliant Construction Federation

With the previous Simphony HLA experiment, some benefits were realised following the HLA specifications, which can be summarized as follows:

- HLA possesses two main advantages for the development of a weather federate: interoperability and reusability. It relieved the overhead of having to include a weather generator in each construction process simulation model. The same weather generator federate can now be used, without modification, with any other construction process simulation federate. This is a great advantage to the developer of the process simulation federate as he or she will have the chance to focus his or her attention on the process being modelled, so that more time can be allocated to understanding the process and documenting the impacts of weather. This significantly reduces the amount of work and time needed to model the impact of weather on a construction process. In the future, more work, research, and developments can be expected in this area. This is very crucial to the success of the proposed framework; it is felt that incorporating the HLA will help in disseminating the technology and also in enabling further developments in this area.
- Developing a discrete-continuous event model using Simphony can be done, but in a very discrete event manner. Each activity is modeled using discrete event simulation and a loop is constructed that would update the production attributes whenever the loop cycle is executed. In addition, the time at which

each loop is executed is dependent on the start time of executing the first loop for the activity (assigning the required resources, for example). This creates some synchronization problems, as it would have been preferable to update the entire model when the time step has passed. On the other hand, using the HLA framework developed by the University of Alberta CEM Group can enhance the development of combined discrete-continuous event simulation models. Different federates joining in a single federation can be developed using different simulation types. One can be a discrete event federate, the other can be a time-stepped federate. The process of joining the federates in one federation is seamless using the Simphony HLA framework version 2. The framework takes care of all the calculations and the developer does not have to worry about the synchronization between the federates. The combined discrete-continuous event simulations can be better modeled using the developed HLA framework.

CHAPTER 7. CONCLUSIONS AND FUTURE WORK

7.1. Conclusion

This thesis presented the development and successful implementation of a framework for simulating construction projects that take place in cold regions. It began by identifying the problem of producing reliable schedules for top management. The high level of uncertainty in cold regions' winter weather coupled with the variation of the project planners' experiences and the anticipation of the impact of cold weather on the construction projects were identified as factors contributing to the uncertainty experienced in cold regions construction planning. The need for a well-structured and consistent approach to account for cold weather impacts on a construction project was obvious. Due to its efficiency and flexibility in modelling construction processes, simulation was chosen as the main tool to host the proposed framework.

The next step was to develop the framework. The framework's requirements were identified. The overall structure of the framework was developed. To ensure consistency, defined steps were given and the details involved in applying the framework were outlined using flowcharts, enabling construction planners to apply the framework in order to assess the impact of cold weather on a construction process.

Following the development of the overall structure of the framework, the work on a construction weather generator was initiated. The needed weather parameters to be generated for the construction field were identified. The work on developing a weather generator that supplied all the identified weather parameters was reported in the thesis. To raise the confidence in the developed weather generator, successful statistical testing of the weather generator was conducted for two Canadian cities: Edmonton and Fort McMurray.

To ensure the success of the framework, its flexibility, and its ability to model the impact of cold weather on a construction process, the framework was followed systematically for two construction processes: pipeline installation and tunnelling. The pipeline installation application showed a typical case in which the process was detailed at the activity level, and for which the cold weather impacts were accounted for in planning. Coupled with the strength of simulation as a tool, this application demonstrated the high flexibility of the proposed framework in producing the schedules for a variety of project conditions. Varying and experimenting with the work scenario was possible. The developed schedules were consistent in showing the impact of the variable weather conditions on the project.

The tunnelling application considered a case in which the framework was used to account for the impact of cold weather on a construction process resulting in defining recommendations that, if followed, can mitigate and possibly cancel the impact of cold weather on the tunnelling process.

Finally, due to the amount of effort expended in the development of the weather generator, there were fears that it would be an obstacle against the reapplication of the framework in modelling other construction processes. The weather generator was therefore redeveloped using High Level Architecture, which enabled distributed simulation. This facilitated the reuse of the weather generator without the need to redevelop it, which is anticipated to promote the reuse and reapplication of the developed framework to assess the impact of cold weather on the various construction processes.

7.2. Research Contributions

The accomplishment of the objectives of this research effectively contributes to both the academic as well as the practical construction industry applications. These can be described as follows:

- The use of HLA in developing the weather generator and the models for different Canadian stations would relieve researchers from having to redevelop the weather model each time they want to simulate the effect of weather on construction. This will enable them to focus their attention on the construction process they are working on.

- The proposed framework identifies and integrates different tools, including analytical weather generator, HLA, process simulation modelling, regression, and statistical methods. This framework was effectively structured and tested to accommodate the manner in which researchers approach the problem of planning for different winter construction processes.

- Extending the analytical weather generator models in order to generate the different weather parameters significantly affecting construction enables construction researchers to study and model the impact of weather on the different construction processes.

- The current state of practice works by attempting to directly estimate the impacts on the activity durations. This research promoted another approach, which is more consistent and offers great flexibility to industry practitioners in accounting for the impacts of the different weather factors on the construction process by:
    - Providing construction planners with a sound and structured way to account for the cold weather uncertainties in their planning.

    - Helping construction planners to develop realistic schedules that take into consideration the location of the project, the time of the year in which the project is to be executed, and the impact of cold weather on the project they are planning for.

    - Promoting changing the state of practice to process modelling.

7.3. Recommendations for Future Research

During the development and testing of the cold weather construction simulation framework, the following items have been noted as recommendations for further research and development that would complement this research.

1. The success of the framework greatly depends on building an information database in which the impact of cold weather on the various construction processes will be documented. It is recommended to start documenting the impact of winter weather on the various construction processes. The impacting weather factors should be documented as well. Finally, the model relating the level of the impacting weather factor to the level of the impact should also be documented. This step is essential to the execution of the next step in the recommendations.

2. Following the previous recommended item, it is recommended to apply the framework to the various construction processes requiring an assessment of the impact of cold weather on the project schedule. This will subject the framework to further testing, through which enhancement modifications can be recommended to the framework to increase its flexibility and use.

3. The current framework depends largely on quantitative means to assess the impact of cold weather on the construction schedule. It is recommended to start incorporating qualitative means, such as fuzzy theory, into the framework

for documenting and assessing the impact of cold weather on the construction processes. This recommendation is due to the fact that humans, in many cases, prefer to respond in qualitative terms rather than offering specific quantitative information in assessing the impact of various parameters on productivity and schedules.

4. In the weather generator, one weather variable that is of particular significance on construction operations is the snow accumulation and depletion on the ground. The thickness of the snow cover on the ground has been found to be very complex in modelling. It is recommended to further develop the weather generator to include this variable, which will prove invaluable in modelling the impact on workers and equipment mobility.

5. Another variable that is also important to the construction field is the amount of sunlight, which affects visibility in construction sites. It is recommended to further develop the weather generator to generate this variable.

6. The framework was developed to target the cold weather impact on the construction project schedule. Other targets could be recommended as well. It is recommended to modify the framework to have the capability of assessing the impact of cold weather on construction project cost, quality, and safety.

REFERENCES AND BIBLIOGRAPHY

Ahrens, J.H., and Dieter, U. (1974). "Computer Methods for Sampling from Gamma, Beta, Poisson and Binomial Distributions." *Computing*, 12, pp. 223-246.

Andersland, O.B., and Anderson, D.M., eds. (1978). *Geotechnical Engineering for Cold Regions*. McGraw Hill Book Company, New York, NY, USA.

Banks, J. (1998). *Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice*. John Wiley and Sons Inc., New York, NY, USA.

Benjamin, N.B.H., and Greenwald, T.W. (1973). "Simulating Effects of Weather on Construction." *Journal of the Construction Division*, 99(CO1), pp. 175-190.

Berg, R.L., and Wright, E.A. (1984). *Frost Action and its Control*. American Society of Civil Engineers, New York, NY, USA.

Chang, D. (1987). *RESQUE: A Resource Based Simulation System for Construction Process Planning*. Ph.D. thesis, Department of Civil Engineering, University of Michigan, Ann Arbor, MI, USA.

Cheng, R.C.H. (1977). "The Generation of Gamma Variables with Non-Integral Shape Parameter." *Applied Statistics*, 26, pp. 71-75.

El-Rayes, K., and Moselhi, O. (2001). "Impact of Rainfall on the Productivity of Highway Construction." *Journal of Construction Engineering and Management.* 127(2), pp. 125-131.

Frederick, K., Weatherly, R., and Dahmann, J. (1999). *Creating Computer Simulation Systems: An Introduction to the High Level Architecture.* Prentice Hall PTR, Upper Saddle River, NJ, USA.

Freitag, D.R., and McFadden, T.T. (1997). *Introduction to Cold Regions Engineering.* ASCE Press, New York, NY, USA.

Grimm, C.T., and Wagner, N.K. (1974). "Weather Effects on Mason Productivity." *Journal of Construction Division*, 100(3), pp. 319-335.

Hajjar, D. (1999). *A Unified Modelling Methodology for Planning Construction Projects.* Ph.D. thesis, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada.

Hajjar, D., and AbouRizk, S. (1996). "Building a Special Purpose Simulation Tool for Earth Moving Operations." *Proceedings of the Winter Simulation Conference*, ASCE, pp. 1313-1320.

Hajjar, D., and AbouRizk, S. (1998). "Modelling and Analysis of Aggregate Production Operations." *Journal of Construction Engineering and Management*, ASCE, 124(5), pp. 390-401.

Halpin, D.W. (1976). "CYCLONE—A Method for Modelling Jobsite Processes." *Journal of the Construction Division*, 103(3), pp. 489-499.

Jordan, D.F., and McDonald, G.N. (1983). *Cold Regions Construction: A State of the Practice Report*. American Society of Civil Engineers, New York, NY, USA.

Katz, R.W. (1985). "Probabilistic Models." In: Murphy, A.H., and Katz, R.W., eds. (1985). *Probability, Statistics, and Decision Making in the Atmospheric Sciences*, Westview Press, Boulder, CO, USA, pp. 261-285.

Kavvas, M.L., Aksit, A.A., and Tulanay, Y.K. (1977). "A First Order Non-Homogeneous Markov Chain for the Daily Rainfall Occurrences." *Proceedings of the Symposium on Modelling Hydro. Process*, pp. 44-59.

Koehn, E., and Brown, G. (1985). "Climatic Effects on Construction." *Journal of Construction Engineering and Management*, 111(2), pp. 129-137.

Koehn, E., and Meilhede, D. (1981). "Cold Weather Construction Costs and Accidents." *Journal of the Construction Division*, 107(CO4), pp. 585-595.

Korman, R., Setzer, S.W., and Powers, M.B. (1992). "Rains Wreck Summer Schedules." Engineering News Record, *McGraw-Hill Construction Weekly*, August 31, pp. 6-7.

Koskela, L. (2000). *An Exploration towards a Production Theory and Its Application to Construction*. VTT Technical Research Centre of Finland, Espoo, Finland.

Krylov, B.A. (1998). *Cold Weather Concreting*. CRC Press, Boca Raton, FL, USA.

Kuhl, F., Weatherly, R., and Dahmann, J. (1999). *Creating Computer Simulation Systems: An Introduction to the High Level Architecture*. Prentice Hall PTR, Upper Saddle River, NJ, USA

Laufer, A., and Cohenca, D. (1990). "Factors Affecting Construction Planning Outcomes." *Journal of Construction Engineering and Management*, 116(1), pp. 135-156.

Martinez, J., and Ioannou, P.G. (1994). "General Purpose Simulation with STROBOSCOPE." *Proceedings of the 1994 Winter Simulation Conference*, Institute of Electrical and Electronics Engineering, Piscataway, NJ, USA, pp. 1159-1166.

Matalas, N.C. (1967). "Mathematical Assessment of Synthetic Hydrology." *Water Resources Research*, 3(4), pp. 937-945.

McFadden, T.T., and Bennett, F.L. (1989). *Construction in Cold Regions: A Guide for Planners, Engineers, Contractors, and Managers*. John Wiley & Sons, Inc. New York, NY, USA.

Mohamed, Y. (2002). *Systematic Improvement Framework.* Ph.D. thesis, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada.

Moselhi, O., Gong, D., and El-Rayes, K. (1995). "Weather: A DSS for Estimating Weather Impact on Construction Productivity." *Proceedings of the Annual Conference of the Canadian Society of Civil Engineering*, Ottawa, Ontario, pp. 369-376.

Moselhi, O., Gong, D., and El-Rayes, K. (1997). "Estimating Weather Impact on the Duration of Construction Activities." *Canadian Journal of Civil Engineering*, 24, pp. 359-366.

Moselhi, O., and Nicholas, M.J. (1990). "Hybrid Expert System for Construction Planning and Scheduling." *Journal of Construction Engineering and Management*, 116(2), pp. 221-238.

National Electric Contractors Association (1974). *The effect of Temperature on Productivity*. Washington, D.C, USA.

Pritsker, A.B., O'Reilly, J.J., and Laval, D.K. (1997). *Simulation with Visual SLAM and AweSim*. John Wiley & Sons, Inc. New York, NY, USA.

Richardson, C.W. (1981). "Stochastic Simulation of Daily Precipitation, Temperature, and Solar Radiation." *Water Resources Research*, 17(1), pp. 182-190.

Russell, E.C. (1993). "SIMSCRIPT II.5 and SIMGRAPHICS Tutorial." *Proceedings of the 1993 Winter Simulation Conference*, Institute of Electrical and Electronics Engineering, Piscataway, NJ, USA, pp. 427-430.

Ruwanpura, J.Y. (2001). *Special Purpose Simulation for Tunnel Construction Operations*. Ph.D. thesis, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada.

Sego, D.C. (2005). Geotechnical Design: Frost Penetration into the Ground. Edmonton, Alberta, Canada: University of Alberta. [Course Notes.]

Shahbodaghlou, F. (1987). *A Feasibility Model for the Use of Weather Protection in Cold Region Construction*. Ph.D. thesis, School of Civil Engineering, Purdue University, West Lafayette, IN, USA

Smith, D.W., Barber, L., and Low, N. eds. (1996). *Cold Regions Utilities Monograph*. American Society of Civil Engineers, New York, NY, USA.

Smith, G.R., and Hancher, D.E. (1989). "Estimating Precipitation Impacts for Scheduling." *Journal of Construction Engineering and Management*, 115(4), pp. 552-566.

Shi, J., and AbouRizk, S. (1998). "Continuous and Combined Event-Process Models for Simulating Pipeline Construction." *Construction Management and Economics*, 16, pp. 489-498.

Smith, G.R., and Hancher, D.E. (1989). "Estimating Precipitation Impacts for Scheduling." *Journal of Construction Engineering and Management*, 115(4), pp. 552-566.

Thomas, H.R., and Yiakoumis, I. (1987). "Factor Model of Construction Productivity." *Journal of Construction Engineering and Management*, 113(4), pp. 623-639.

Wales, R.J. (1994). *Incorporating Weather Effects in Project Simulation*. MSc. thesis, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada.

Wales, R.J., and AbouRizk, S. (1996). "An Integrated Simulation Model for Construction." *Simulation Practice and Theory*, 3, pp. 401-420.

Yevjevich, V. (1972). "Structural Analysis of Hydrologic Time Series." *Colorado State University Hydrology Paper No 56.*

Young, G.K. (1968). "Discussion of Mathematical Assessment of Synthetic Hydrology." *Water Resources Research*, 4(3), pp. 681-682.

APPENDIX A. EDMONTON INTERNATIONAL AIRPORT

SMOOTHED PARAMETERS VALUES

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
1	0	-6.4089	9.6158	-17.452	9.6419	82.1085	9.8437	60.8916	11.1742
2	0	-6.5369	9.715	-17.5912	9.7137	82.1258	9.8507	60.8857	11.1715
3	0	-6.6595	9.8152	-17.7316	9.7863	82.1447	9.8557	60.8783	11.1654
4	0	-6.7754	9.9152	-17.8717	9.8596	82.1648	9.8589	60.8694	11.1559
5	0	-6.8833	10.0138	-18.01	9.9332	82.1862	9.8601	60.8589	11.1433
6	0	-6.982	10.1098	-18.1448	10.0066	82.2087	9.8592	60.8467	11.1277
7	0	-7.0703	10.2018	-18.2746	10.0793	82.2321	9.8564	60.8327	11.1098
8	0	-7.1473	10.2886	-18.3976	10.1506	82.2564	9.8518	60.817	11.0899
9	0	-7.212	10.3686	-18.5122	10.2198	82.2814	9.8453	60.7993	11.0687
10	0	-7.2636	10.4407	-18.6168	10.2862	82.3069	9.8373	60.7796	11.0468
11	0	-7.3014	10.5037	-18.7099	10.3488	82.3328	9.8279	60.7576	11.025
12	0	-7.3249	10.5563	-18.7901	10.4068	82.359	9.8173	60.7333	11.0039
13	0	-7.3338	10.5975	-18.8561	10.4593	82.3853	9.8058	60.7065	10.9843
14	0	-7.3279	10.6266	-18.9069	10.5054	82.4114	9.7937	60.6768	10.967
15	0	-7.3071	10.6428	-18.9416	10.5441	82.4373	9.7812	60.6442	10.9528
16	0	-7.2717	10.6455	-18.9594	10.5747	82.4626	9.7688	60.6081	10.9423

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
17	0	-7.2218	10.6344	-18.96	10.5964	82.4872	9.7568	60.5685	10.9363
18	0	-7.1579	10.6095	-18.9431	10.6085	82.5108	9.7454	60.5249	10.9354
19	0	-7.0807	10.5708	-18.9087	10.6103	82.5331	9.7351	60.4771	10.9401
20	0	-6.9908	10.5186	-18.8571	10.6014	82.5539	9.7261	60.4246	10.9509
21	0	-6.889	10.4535	-18.7888	10.5815	82.5729	9.7188	60.3672	10.9682
22	0	-6.7763	10.3761	-18.7046	10.5504	82.5898	9.7135	60.3044	10.9923
23	0	-6.6537	10.2876	-18.6053	10.5081	82.6043	9.7103	60.2359	11.0233
24	0	-6.5222	10.1888	-18.4922	10.4547	82.6162	9.7097	60.1614	11.0613
25	0	-6.3829	10.0812	-18.3665	10.3906	82.6252	9.7117	60.0807	11.1063
26	0	-6.2371	9.9662	-18.2298	10.3162	82.631	9.7166	59.9933	11.1581
27	0	-6.0857	9.8452	-18.0837	10.2323	82.6333	9.7244	59.8992	11.2165
28	0	-5.9299	9.7198	-17.9298	10.1397	82.632	9.7352	59.7981	11.281
29	0	-5.7708	9.5917	-17.77	10.0394	82.6268	9.7491	59.6898	11.3511
30	0	-5.6094	9.4626	-17.606	9.9326	82.6176	9.766	59.5743	11.4264
31	0	-5.4466	9.334	-17.4396	9.8206	82.6043	9.7857	59.4517	11.5061
32	0	-5.2834	9.2077	-17.2725	9.7047	82.5866	9.8083	59.3218	11.5895
33	0	-5.1204	9.085	-17.1064	9.5865	82.5647	9.8335	59.1849	11.6759
34	0	-4.9584	8.9674	-16.9428	9.4674	82.5385	9.861	59.0412	11.7643
35	0	-4.7979	8.8561	-16.7831	9.3491	82.5081	9.8907	58.891	11.8539

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
36	0	-4.6394	8.7523	-16.6287	9.233	82.4735	9.9221	58.7345	11.9439
37	0	-4.4832	8.6567	-16.4805	9.1208	82.4348	9.955	58.5722	12.0332
38	0	-4.3296	8.5702	-16.3394	9.0139	82.3924	9.9889	58.4045	12.1211
39	0	-4.1786	8.4932	-16.206	8.9137	82.3464	10.0235	58.2321	12.2068
40	0	-4.0302	8.426	-16.0807	8.8216	82.2972	10.0583	58.0554	12.2893
41	0	-3.8845	8.3685	-15.9637	8.7386	82.2451	10.0929	57.8751	12.3679
42	0	-3.7412	8.3206	-15.8549	8.6657	82.1905	10.1269	57.6918	12.442
43	0	-3.6001	8.2819	-15.7539	8.6038	82.1339	10.1597	57.5062	12.511
44	0	-3.4608	8.2517	-15.6602	8.5534	82.0757	10.1911	57.3191	12.5744
45	0	-3.3231	8.2293	-15.573	8.515	82.0165	10.2205	57.131	12.6318
46	0	-3.1865	8.2136	-15.4915	8.4887	81.9567	10.2475	56.9427	12.6828
47	0	-3.0507	8.2035	-15.4144	8.4745	81.897	10.2719	56.7547	12.7274
48	0	-2.9152	8.1977	-15.3405	8.4721	81.8379	10.2933	56.5677	12.7655
49	0	-2.7795	8.1949	-15.2685	8.4809	81.7799	10.3114	56.3822	12.7971
50	0	-2.6433	8.1936	-15.1967	8.5003	81.7237	10.326	56.1987	12.8225
51	0	-2.5061	8.1925	-15.1236	8.5293	81.6697	10.337	56.0175	12.8419
52	0	-2.3677	8.19	-15.0478	8.5667	81.6185	10.3441	55.8388	12.8558
53	0	-2.2276	8.1849	-14.9675	8.6113	81.5706	10.3473	55.663	12.8646
54	0	-2.0856	8.1756	-14.8813	8.6616	81.5264	10.3467	55.49	12.869

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
55	0	-1.9413	8.1611	-14.7877	8.7161	81.4863	10.3423	55.3198	12.8697
56	0	-1.7947	8.1403	-14.6853	8.773	81.4507	10.3341	55.1521	12.8675
57	0	-1.6455	8.112	-14.5728	8.8307	81.4198	10.3225	54.9867	12.8631
58	0	-1.4935	8.0757	-14.4491	8.8873	81.3939	10.3077	54.8232	12.8574
59	0	-1.3388	8.0307	-14.3132	8.9411	81.373	10.2899	54.6608	12.8514
60	0	-1.1811	7.9766	-14.1643	8.9903	81.3573	10.2695	54.4989	12.8459
61	0	-1.0204	7.9133	-14.0019	9.0332	81.3466	10.247	54.3367	12.8419
62	0	-0.8567	7.8407	-13.8255	9.0682	81.3408	10.2227	54.1732	12.8402
63	0	-0.6899	7.7592	-13.6348	9.0938	81.3397	10.1972	54.0073	12.8416
64	0	-0.52	7.6693	-13.43	9.1085	81.343	10.1711	53.8378	12.847
65	0	-0.3469	7.5716	-13.2112	9.1113	81.3503	10.1448	53.6635	12.8571
66	0	-0.1705	7.4669	-12.9787	9.1011	81.361	10.119	53.483	12.8724
67	0	0.0094	7.3563	-12.7332	9.077	81.3745	10.0942	53.2949	12.8937
68	0	0.1927	7.2409	-12.4753	9.0384	81.3902	10.071	53.0979	12.9212
69	0	0.3798	7.122	-12.2059	8.9849	81.4072	10.0501	52.8905	12.9553
70	0	0.5709	7.0011	-11.926	8.9163	81.4248	10.032	52.6712	12.9963
71	0	0.7662	6.8794	-11.6366	8.8325	81.442	10.0173	52.4387	13.0441
72	0	0.9661	6.7585	-11.3391	8.734	81.4578	10.0065	52.1915	13.0987
73	0	1.1709	6.6398	-11.0345	8.6209	81.4711	10.0002	51.9283	13.1599

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
74	0	1.3811	6.5248	-10.7242	8.4941	81.4809	9.9988	51.6479	13.2274
75	0	1.5969	6.4148	-10.4095	8.3543	81.4861	10.0027	51.3492	13.3007
76	0	1.8188	6.311	-10.0917	8.2024	81.4854	10.0124	51.0311	13.3791
77	0	2.0474	6.2147	-9.7721	8.0397	81.4779	10.0282	50.6928	13.4619
78	0	2.2829	6.1268	-9.4518	7.8673	81.4621	10.0504	50.3335	13.5484
79	0	2.5259	6.0482	-9.132	7.6866	81.4372	10.0793	49.9528	13.6375
80	0	2.7768	5.9796	-8.8139	7.499	81.4018	10.1149	49.5502	13.7283
81	0	3.0358	5.9215	-8.4984	7.3059	81.3549	10.1574	49.1255	13.8195
82	0	3.3033	5.8741	-8.1864	7.1089	81.2955	10.2069	48.6788	13.9101
83	0	3.5796	5.8375	-7.8787	6.9094	81.2225	10.2634	48.2103	13.9987
84	0	3.8648	5.8117	-7.5761	6.7089	81.1351	10.3268	47.7203	14.0842
85	0	4.1589	5.7963	-7.279	6.5088	81.0323	10.397	47.2095	14.1653
86	0	4.4619	5.7908	-6.988	6.3105	80.9136	10.4739	46.6788	14.2407
87	0	4.7737	5.7946	-6.7034	6.1152	80.7781	10.5572	46.1291	14.3091
88	0	5.0941	5.8068	-6.4256	5.9242	80.6254	10.6467	45.5616	14.3694
89	0	5.4226	5.8264	-6.1546	5.7384	80.455	10.7421	44.9778	14.4204
90	0	5.7588	5.8524	-5.8906	5.5589	80.2667	10.8431	44.3791	14.4611
91	0	6.1021	5.8837	-5.6336	5.3864	80.0602	10.9493	43.7673	14.4904
92	0	6.4518	5.9188	-5.3836	5.2217	79.8355	11.0602	43.1443	14.5074

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
93	0	6.8071	5.9566	-5.1403	5.0652	79.5928	11.1756	42.5119	14.5114
94	0	7.1671	5.9958	-4.9036	4.9174	79.3323	11.2949	41.8722	14.5017
95	0	7.5308	6.035	-4.6734	4.7785	79.0543	11.4178	41.2273	14.4778
96	0	7.8973	6.0731	-4.4495	4.6488	78.7594	11.5437	40.5795	14.4394
97	0	8.2653	6.1087	-4.2315	4.5281	78.4483	11.6723	39.931	14.3861
98	0	8.6339	6.1408	-4.0191	4.4164	78.1218	11.803	39.284	14.318
99	0	9.0018	6.1685	-3.8123	4.3136	77.7807	11.9354	38.6407	14.235
100	0	9.368	6.1908	-3.6105	4.2193	77.4263	12.0691	38.0034	14.1375
101	0	9.7314	6.207	-3.4137	4.1332	77.0596	12.2036	37.3743	14.0258
102	0	10.0909	6.2165	-3.2214	4.055	76.6821	12.3385	36.7554	13.9004
103	0	10.4456	6.2189	-3.0335	3.984	76.2951	12.4734	36.1487	13.7619
104	0	10.7946	6.2139	-2.8496	3.92	75.9002	12.6079	35.5562	13.6113
105	0	11.1371	6.2015	-2.6695	3.8622	75.499	12.7416	34.9798	13.4493
106	0	11.4723	6.1816	-2.493	3.8103	75.0932	12.8742	34.4209	13.2771
107	0	11.7999	6.1545	-2.3197	3.7637	74.6846	13.0052	33.8813	13.0956
108	0	12.1192	6.1207	-2.1495	3.722	74.2751	13.1344	33.3623	12.9063
109	0	12.4301	6.0804	-1.9819	3.6846	73.8665	13.2614	32.8652	12.7103
110	0	12.7324	6.0344	-1.8168	3.6511	73.4607	13.3859	32.391	12.5089
111	0	13.0261	5.9834	-1.6538	3.6211	73.0598	13.5075	31.9406	12.3036

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
112	0	13.3113	5.9281	-1.4926	3.5943	72.6656	13.6261	31.5149	12.0958
113	0	13.5883	5.8694	-1.3328	3.5703	72.2802	13.7413	31.1144	11.8868
114	0	13.8575	5.8082	-1.174	3.5489	71.9053	13.8528	30.7395	11.6781
115	0	14.1193	5.7454	-1.016	3.5298	71.5431	13.9603	30.3907	11.4711
116	0	14.3743	5.6818	-0.8582	3.513	71.1952	14.0636	30.0679	11.2672
117	0	14.6233	5.6184	-0.7003	3.4982	70.8634	14.1624	29.7712	11.0676
118	0	14.8668	5.556	-0.5417	3.4854	70.5496	14.2565	29.5005	10.8735
119	0	15.1056	5.4952	-0.3822	3.4744	70.2553	14.3455	29.2556	10.6862
120	0	15.3405	5.437	-0.2212	3.4654	69.9821	14.4292	29.0361	10.5068
121	0	15.5722	5.3817	-0.0583	3.4583	69.7313	14.5073	28.8416	10.3362
122	0	15.8014	5.33	0.107	3.453	69.5044	14.5796	28.6715	10.1753
123	0	16.0288	5.2822	0.2749	3.4496	69.3024	14.6458	28.5252	10.0249
124	0	16.255	5.2385	0.4459	3.4482	69.1265	14.7057	28.4022	9.8857
125	0	16.4805	5.1991	0.6204	3.4486	68.9774	14.7589	28.3016	9.7582
126	0	16.7057	5.1641	0.7984	3.451	68.856	14.8053	28.2228	9.6428
127	0	16.9309	5.1333	0.9804	3.4553	68.7629	14.8447	28.165	9.5399
128	0	17.1564	5.1066	1.1663	3.4615	68.6984	14.8768	28.1273	9.4497
129	0	17.3822	5.0835	1.3563	3.4694	68.6629	14.9014	28.1091	9.3721
130	0	17.6081	5.0638	1.5504	3.4791	68.6563	14.9184	28.1094	9.3073

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
131	0	17.834	5.0469	1.7483	3.4905	68.6787	14.9276	28.1275	9.2549
132	0	18.0597	5.0323	1.95	3.5032	68.7297	14.9288	28.1626	9.2149
133	0	18.2846	5.0193	2.1551	3.5172	68.809	14.9221	28.214	9.1867
134	0	18.5082	5.0074	2.3633	3.5324	68.916	14.9073	28.2809	9.1699
135	0	18.7298	4.9959	2.574	3.5483	69.0499	14.8845	28.3625	9.1641
136	0	18.9488	4.984	2.7867	3.5648	69.2099	14.8536	28.4583	9.1686
137	0	19.1644	4.9713	3.0008	3.5816	69.3948	14.8147	28.5673	9.1826
138	0	19.3757	4.957	3.2156	3.5985	69.6037	14.7679	28.6891	9.2056
139	0	19.5819	4.9406	3.4302	3.615	69.835	14.7135	28.8229	9.2367
140	0	19.7821	4.9216	3.644	3.631	70.0875	14.6515	28.9682	9.275
141	0	19.9756	4.8995	3.856	3.646	70.3596	14.5823	29.1242	9.3198
142	0	20.1616	4.8741	4.0654	3.6598	70.6496	14.5061	29.2905	9.3702
143	0	20.3392	4.845	4.2713	3.6721	70.956	14.4234	29.4663	9.4252
144	0	20.508	4.812	4.4729	3.6827	71.2769	14.3344	29.6512	9.4841
145	0	20.6673	4.7751	4.6694	3.6912	71.6106	14.2397	29.8444	9.5459
146	0	20.8167	4.7344	4.8598	3.6975	71.9552	14.1397	30.0455	9.6097
147	0	20.9558	4.69	5.0436	3.7014	72.3088	14.0349	30.2537	9.6748
148	0	21.0846	4.642	5.2201	3.7026	72.6696	13.9258	30.4686	9.7402
149	0	21.203	4.5908	5.3887	3.7012	73.0358	13.8131	30.6895	9.8053

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
150	0	21.311	4.5368	5.5489	3.697	73.4054	13.6972	30.9158	9.8693
151	0	21.4088	4.4805	5.7003	3.69	73.7768	13.5789	31.1468	9.9315
152	0	21.497	4.4224	5.8427	3.6802	74.1483	13.4587	31.382	9.9912
153	0	21.5758	4.3631	5.976	3.6677	74.5181	13.3373	31.6206	10.0478
154	0	21.6461	4.3031	6.1	3.6525	74.8847	13.2151	31.8621	10.1009
155	0	21.7084	4.2432	6.215	3.6348	75.2467	13.0929	32.1058	10.1498
156	0	21.7637	4.1839	6.3211	3.6148	75.6026	12.9712	32.3511	10.1941
157	0	21.8127	4.1259	6.4187	3.5926	75.9512	12.8505	32.5973	10.2335
158	0	21.8565	4.0698	6.5082	3.5685	76.2915	12.7314	32.8438	10.2676
159	0	21.896	4.0161	6.5901	3.5427	76.6223	12.6142	33.0901	10.2962
160	0	21.9322	3.9653	6.6651	3.5156	76.9429	12.4996	33.3355	10.3191
161	0	21.966	3.918	6.7339	3.4873	77.2525	12.3878	33.5796	10.3361
162	0	21.9986	3.8745	6.7973	3.4582	77.5506	12.2791	33.8217	10.3471
163	0	22.0307	3.8351	6.856	3.4286	77.8367	12.1739	34.0615	10.352
164	0	22.0634	3.8	6.911	3.3988	78.1105	12.0723	34.2985	10.3509
165	0	22.0972	3.7693	6.963	3.369	78.3719	11.9745	34.5323	10.3438
166	0	22.133	3.7432	7.0131	3.3395	78.6209	11.8805	34.7627	10.3309
167	0	22.1714	3.7215	7.0619	3.3106	78.8576	11.7905	34.9894	10.3122
168	0	22.2129	3.704	7.1104	3.2825	79.0822	11.7043	35.2121	10.288

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
169	0	22.2578	3.6907	7.1594	3.2553	79.2952	11.6219	35.4307	10.2584
170	0	22.3063	3.6811	7.2095	3.2292	79.4968	11.5431	35.6452	10.2238
171	0	22.3587	3.675	7.2615	3.2045	79.6878	11.4677	35.8555	10.1845
172	0	22.415	3.6718	7.3158	3.181	79.8687	11.3955	36.0617	10.1408
173	0	22.4751	3.6711	7.373	3.1591	80.0402	11.326	36.2639	10.093
174	0	22.5387	3.6723	7.4335	3.1385	80.203	11.2591	36.4622	10.0416
175	0	22.6057	3.675	7.4976	3.1195	80.3581	11.1943	36.6569	9.9869
176	0	22.6756	3.6785	7.5654	3.1018	80.5062	11.1313	36.8482	9.9294
177	0	22.7481	3.6823	7.637	3.0855	80.6481	11.0696	37.0363	9.8696
178	0	22.8226	3.6859	7.7125	3.0704	80.7846	11.0089	37.2216	9.8078
179	0	22.8986	3.6887	7.7917	3.0565	80.9167	10.9487	37.4044	9.7445
180	0	22.9756	3.6903	7.8744	3.0436	81.0451	10.8886	37.5851	9.6802
181	0	23.053	3.6903	7.9603	3.0315	81.1706	10.8282	37.7639	9.6154
182	0	23.1303	3.6884	8.049	3.0202	81.2939	10.7672	37.9413	9.5506
183	0	23.207	3.6841	8.1402	3.0093	81.4156	10.7052	38.1174	9.4861
184	0	23.2825	3.6774	8.2333	2.9989	81.5364	10.642	38.2927	9.4225
185	0	23.3565	3.6681	8.3277	2.9887	81.6566	10.5773	38.4673	9.3602
186	0	23.4285	3.6562	8.4229	2.9786	81.7769	10.5109	38.6414	9.2997
187	0	23.4981	3.6417	8.5183	2.9684	81.8975	10.4426	38.8152	9.2412

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
188	0	23.5653	3.6248	8.6133	2.9581	82.0187	10.3723	38.9887	9.1853
189	0	23.6296	3.6056	8.7072	2.9475	82.1406	10.3001	39.1621	9.1322
190	0	23.6911	3.5846	8.7994	2.9367	82.2633	10.2259	39.3351	9.0823
191	0	23.7496	3.562	8.8894	2.9256	82.3868	10.1498	39.5077	9.0359
192	0	23.8052	3.5384	8.9764	2.9142	82.511	10.072	39.6797	8.9932
193	0	23.8579	3.5141	9.06	2.9025	82.6358	9.9927	39.8508	8.9546
194	0	23.9077	3.4897	9.1397	2.8907	82.7607	9.9122	40.0207	8.9201
195	0	23.9549	3.4658	9.2149	2.8788	82.8856	9.8307	40.1888	8.89
196	0	23.9995	3.443	9.2853	2.867	83.01	9.7486	40.3548	8.8643
197	0	24.0418	3.4218	9.3504	2.8554	83.1335	9.6663	40.518	8.8432
198	0	24.082	3.4027	9.41	2.8442	83.2556	9.5843	40.6779	8.8267
199	0	24.1202	3.3864	9.4636	2.8337	83.3759	9.503	40.8338	8.8148
200	0	24.1565	3.3732	9.511	2.824	83.4937	9.4229	40.9851	8.8075
201	0	24.1911	3.3638	9.5521	2.8154	83.6086	9.3445	41.1309	8.8047
202	0	24.2242	3.3583	9.5867	2.8081	83.72	9.2684	41.2707	8.8063
203	0	24.2556	3.3573	9.6146	2.8023	83.8275	9.195	41.4038	8.8122
204	0	24.2853	3.3608	9.6357	2.7983	83.9305	9.1248	41.5293	8.8223
205	0	24.3134	3.369	9.65	2.7963	84.0286	9.0583	41.6468	8.8363
206	0	24.3395	3.382	9.6574	2.7964	84.1214	8.9959	41.7555	8.8541

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
207	0	24.3636	3.3998	9.6578	2.7989	84.2087	8.9381	41.855	8.8755
208	0	24.3852	3.4223	9.6513	2.8039	84.29	8.8852	41.9446	8.9002
209	0	24.404	3.4491	9.6379	2.8114	84.3653	8.8375	42.0242	8.928
210	0	24.4197	3.4801	9.6176	2.8215	84.4344	8.7953	42.0932	8.9586
211	0	24.4318	3.5149	9.5903	2.8342	84.4973	8.7588	42.1516	8.9919
212	0	24.4396	3.5529	9.5562	2.8495	84.554	8.7281	42.1992	9.0275
213	0	24.4428	3.5937	9.5152	2.8673	84.6046	8.7034	42.2361	9.0653
214	0	24.4407	3.6368	9.4674	2.8874	84.6494	8.6846	42.2623	9.1051
215	0	24.4327	3.6815	9.4128	2.9097	84.6886	8.6717	42.2782	9.1466
216	0	24.4184	3.7272	9.3515	2.934	84.7226	8.6645	42.2841	9.1896
217	0	24.3971	3.7734	9.2834	2.96	84.7518	8.663	42.2804	9.234
218	0	24.3683	3.8193	9.2087	2.9873	84.7767	8.6668	42.2679	9.2796
219	0	24.3316	3.8645	9.1274	3.0157	84.7978	8.6756	42.2472	9.3264
220	0	24.2865	3.9083	9.0396	3.0448	84.8157	8.689	42.2192	9.3741
221	0	24.2327	3.9502	8.9453	3.0743	84.831	8.7068	42.1846	9.4229
222	0	24.17	3.9899	8.8447	3.1037	84.8444	8.7284	42.1446	9.4726
223	0	24.0982	4.0268	8.7378	3.1327	84.8564	8.7533	42.1	9.5231
224	0	24.0172	4.0609	8.6249	3.1609	84.8676	8.7811	42.052	9.5746
225	0	23.9269	4.0918	8.5061	3.1879	84.8788	8.8112	42.0017	9.6271

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
226	0	23.8276	4.1195	8.3815	3.2134	84.8903	8.8432	41.9502	9.6805
227	0	23.7194	4.1439	8.2514	3.2371	84.9028	8.8763	41.8985	9.735
228	0	23.6027	4.1653	8.1161	3.2587	84.9167	8.9103	41.8478	9.7906
229	0	23.4779	4.1837	7.9757	3.278	84.9323	8.9444	41.799	9.8474
230	0	23.3454	4.1995	7.8306	3.2949	84.95	8.9784	41.7531	9.9056
231	0	23.2058	4.213	7.681	3.3093	84.97	9.0116	41.711	9.9651
232	0	23.0599	4.2249	7.5274	3.321	84.9924	9.0437	41.6734	10.0262
233	0	22.9082	4.2355	7.3701	3.3302	85.0171	9.0744	41.641	10.0888
234	0	22.7515	4.2455	7.2094	3.3368	85.0442	9.1032	41.6143	10.1531
235	0	22.5906	4.2556	7.0457	3.3411	85.0733	9.13	41.5938	10.2191
236	0	22.4262	4.2663	6.8795	3.3432	85.1041	9.1546	41.5796	10.2867
237	0	22.2592	4.2785	6.7111	3.3434	85.1362	9.1768	41.5718	10.3561
238	0	22.0903	4.2928	6.5409	3.342	85.169	9.1965	41.5705	10.4272
239	0	21.9203	4.3099	6.3693	3.3394	85.2019	9.2138	41.5752	10.4998
240	0	21.7498	4.3304	6.1968	3.3359	85.234	9.2286	41.5858	10.574
241	0	21.5796	4.3548	6.0235	3.332	85.2646	9.2412	41.6016	10.6496
242	0	21.4101	4.3837	5.85	3.3281	85.2926	9.2517	41.6219	10.7264
243	0	21.2418	4.4176	5.6765	3.3247	85.3172	9.2604	41.646	10.8042
244	0	21.0753	4.4567	5.5033	3.3222	85.3371	9.2675	41.6729	10.8828

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
245	0	20.9108	4.5014	5.3307	3.3211	85.3514	9.2733	41.7015	10.9619
246	0	20.7486	4.5516	5.1589	3.3216	85.3589	9.2784	41.7308	11.0412
247	0	20.5888	4.6075	4.9881	3.3243	85.3585	9.283	41.7595	11.1204
248	0	20.4314	4.6689	4.8184	3.3294	85.3491	9.2877	41.7865	11.199
249	0	20.2765	4.7356	4.65	3.3372	85.3297	9.2929	41.8103	11.2768
250	0	20.1238	4.8072	4.4829	3.3479	85.2991	9.299	41.8298	11.3534
251	0	19.9731	4.8833	4.3171	3.3617	85.2565	9.3067	41.8437	11.4283
252	0	19.8242	4.9634	4.1526	3.3785	85.2009	9.3162	41.8509	11.5013
253	0	19.6768	5.0467	3.9894	3.3985	85.1317	9.3281	41.8502	11.5718
254	0	19.5302	5.1325	3.8275	3.4214	85.0482	9.3429	41.8407	11.6396
255	0	19.3842	5.22	3.6665	3.4472	84.9498	9.3609	41.8214	11.7043
256	0	19.2382	5.3085	3.5065	3.4755	84.8362	9.3824	41.7916	11.7657
257	0	19.0917	5.3968	3.3473	3.5061	84.7072	9.408	41.7508	11.8234
258	0	18.944	5.4843	3.1886	3.5386	84.5628	9.4377	41.6986	11.8772
259	0	18.7948	5.5698	3.0302	3.5725	84.4031	9.4719	41.6348	11.9271
260	0	18.6433	5.6526	2.8718	3.6074	84.2284	9.5106	41.5596	11.9729
261	0	18.4892	5.7319	2.7134	3.6427	84.0392	9.5541	41.4731	12.0145
262	0	18.3318	5.8067	2.5545	3.6779	83.8362	9.6024	41.376	12.0521
263	0	18.1708	5.8763	2.395	3.7125	83.6203	9.6553	41.2689	12.0857

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
264	0	18.0057	5.9402	2.2346	3.7459	83.3926	9.7129	41.1529	12.1155
265	0	17.8361	5.9978	2.0731	3.7776	83.1542	9.775	41.0292	12.1418
266	0	17.6616	6.0486	1.9102	3.807	82.9064	9.8414	40.8993	12.165
267	0	17.4821	6.0923	1.7457	3.8338	82.6509	9.9118	40.7649	12.1855
268	0	17.2972	6.1288	1.5794	3.8575	82.3893	9.9859	40.6278	12.2037
269	0	17.1068	6.1579	1.4112	3.8778	82.1233	10.0632	40.4901	12.2203
270	0	16.9108	6.1797	1.2408	3.8945	81.8548	10.1434	40.354	12.2358
271	0	16.709	6.1943	1.0682	3.9074	81.5857	10.226	40.222	12.251
272	0	16.5014	6.2021	0.8932	3.9164	81.318	10.3105	40.0965	12.2666
273	0	16.288	6.2035	0.7157	3.9217	81.0538	10.3964	39.9801	12.2833
274	0	16.0689	6.1989	0.5357	3.9233	80.7951	10.483	39.8753	12.302
275	0	15.844	6.189	0.3531	3.9215	80.5439	10.5699	39.7849	12.3235
276	0	15.6135	6.1744	0.1678	3.9166	80.3021	10.6565	39.7114	12.3485
277	0	15.3773	6.1558	-0.0201	3.9091	80.0719	10.7422	39.6575	12.3779
278	0	15.1356	6.1341	-0.2106	3.8996	79.8549	10.8263	39.6256	12.4125
279	0	14.8885	6.1099	-0.4037	3.8887	79.653	10.9085	39.6181	12.4529
280	0	14.636	6.0842	-0.5994	3.877	79.4677	10.9881	39.6372	12.5
281	0	14.3782	6.0577	-0.7976	3.8652	79.3007	11.0647	39.6851	12.5542
282	0	14.1151	6.0311	-0.9983	3.8543	79.1531	11.1378	39.7635	12.6162

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
283	0	13.8466	6.0052	-1.2013	3.845	79.0261	11.2069	39.8742	12.6865
284	0	13.5729	5.9807	-1.4067	3.8381	78.9207	11.2717	40.0184	12.7653
285	0	13.2939	5.9582	-1.6143	3.8344	78.8377	11.3319	40.1972	12.8529
286	0	13.0095	5.9383	-1.8242	3.8347	78.7775	11.387	40.4115	12.9495
287	0	12.7197	5.9213	-2.0361	3.8399	78.7406	11.437	40.6617	13.055
288	0	12.4243	5.9077	-2.2502	3.8505	78.7271	11.4815	40.9481	13.1693
289	0	12.1233	5.8977	-2.4663	3.8673	78.7368	11.5205	41.2704	13.2922
290	0	11.8165	5.8915	-2.6844	3.8907	78.7694	11.5539	41.6282	13.4232
291	0	11.5037	5.8893	-2.9045	3.9211	78.8244	11.5815	42.0207	13.5617
292	0	11.185	5.8909	-3.1267	3.959	78.901	11.6035	42.4467	13.7072
293	0	10.8601	5.8963	-3.3509	4.0046	78.9983	11.6199	42.9049	13.8587
294	0	10.5289	5.9053	-3.5771	4.0579	79.1152	11.6307	43.3936	14.0153
295	0	10.1915	5.9178	-3.8055	4.1189	79.2504	11.636	43.9108	14.1759
296	0	9.8476	5.9333	-4.0361	4.1875	79.4024	11.6361	44.4541	14.3394
297	0	9.4973	5.9518	-4.269	4.2634	79.5696	11.6312	45.0213	14.5045
298	0	9.1407	5.9726	-4.5044	4.3462	79.7504	11.6214	45.6095	14.6698
299	0	8.7778	5.9956	-4.7422	4.4355	79.9429	11.607	46.2161	14.8339
300	0	8.4088	6.0203	-4.9828	4.5307	80.1452	11.5882	46.8379	14.9953
301	0	8.0339	6.0464	-5.2261	4.6311	80.3554	11.5654	47.472	15.1525

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
302	0	7.6534	6.0736	-5.4724	4.7359	80.5715	11.5387	48.1151	15.304
303	0	7.2676	6.1015	-5.7217	4.8445	80.7916	11.5086	48.7641	15.4483
304	0	6.877	6.1299	-5.9743	4.9559	81.0136	11.4752	49.4158	15.5838
305	0	6.4821	6.1587	-6.2302	5.0692	81.2357	11.4388	50.0669	15.7091
306	0	6.0835	6.1876	-6.4895	5.1838	81.4559	11.3997	50.7145	15.8228
307	0	5.6818	6.2166	-6.7524	5.2987	81.6725	11.3583	51.3554	15.9236
308	0	5.2779	6.2457	-7.0187	5.413	81.8837	11.3146	51.9868	16.0103
309	0	4.8726	6.275	-7.2886	5.5261	82.0879	11.269	52.6059	16.0818
310	0	4.4666	6.3045	-7.562	5.6373	82.2836	11.2217	53.2102	16.1371
311	0	4.0611	6.3344	-7.8388	5.7459	82.4694	11.1729	53.7972	16.1754
312	0	3.6569	6.365	-8.1188	5.8513	82.6442	11.1228	54.3649	16.196
313	0	3.2552	6.3965	-8.402	5.9531	82.8069	11.0717	54.9112	16.1986
314	0	2.8569	6.4292	-8.6879	6.0511	82.9566	11.0195	55.4345	16.1826
315	0	2.4632	6.4634	-8.9763	6.1448	83.0926	10.9666	55.9333	16.1482
316	0	2.0752	6.4995	-9.2667	6.2342	83.2142	10.913	56.4066	16.0952
317	0	1.6939	6.5377	-9.5587	6.3193	83.3212	10.859	56.8533	16.0239
318	0	1.3206	6.5785	-9.8518	6.4	83.4133	10.8045	57.2728	15.9349
319	0	0.9561	6.6219	-10.1453	6.4767	83.4905	10.7498	57.6648	15.8286
320	0	0.6015	6.6684	-10.4385	6.5494	83.5527	10.695	58.0291	15.7059

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
321	0	0.2578	6.7181	-10.7308	6.6186	83.6004	10.6402	58.3658	15.5677
322	0	-0.0741	6.771	-11.0214	6.6845	83.6338	10.5855	58.6752	15.4152
323	0	-0.3936	6.8273	-11.3094	6.7477	83.6535	10.531	58.9579	15.2496
324	0	-0.6997	6.887	-11.5939	6.8087	83.6602	10.4768	59.2145	15.0723
325	0	-0.992	6.95	-11.8742	6.8679	83.6544	10.4231	59.4461	14.8847
326	0	-1.27	7.016	-12.1492	6.9258	83.6372	10.3701	59.6536	14.6885
327	0	-1.5333	7.0849	-12.4181	6.9831	83.6093	10.3177	59.8383	14.4852
328	0	-1.7816	7.1564	-12.68	7.04	83.5717	10.2663	60.0014	14.2766
329	0	-2.0148	7.2301	-12.934	7.0972	83.5255	10.2159	60.1443	14.0645
330	0	-2.2331	7.3055	-13.1794	7.155	83.4716	10.1667	60.2685	13.8504
331	0	-2.4364	7.3822	-13.4154	7.2139	83.4112	10.1189	60.3755	13.6362
332	0	-2.6251	7.4596	-13.6413	7.274	83.3452	10.0727	60.4668	13.4235
333	0	-2.7997	7.5373	-13.8565	7.3357	83.2748	10.0281	60.5439	13.2139
334	0	-2.9608	7.6146	-14.0605	7.3991	83.201	9.9855	60.6083	13.009
335	0	-3.1089	7.6911	-14.253	7.4644	83.1247	9.9449	60.6615	12.8101
336	0	-3.245	7.7662	-14.4336	7.5315	83.0469	9.9065	60.7049	12.6187
337	0	-3.3698	7.8395	-14.6024	7.6004	82.9686	9.8706	60.7397	12.436
338	0	-3.4845	7.9104	-14.7592	7.6711	82.8904	9.8371	60.7673	12.2629
339	0	-3.5902	7.9788	-14.9044	7.7433	82.8133	9.8064	60.7889	12.1005

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
340	0	-3.6879	8.0442	-15.0381	7.8168	82.7379	9.7784	60.8055	11.9494
341	0	-3.7788	8.1065	-15.1608	7.8915	82.6649	9.7533	60.8182	11.8103
342	0	-3.8643	8.1657	-15.2732	7.9669	82.5947	9.7312	60.8277	11.6836
343	0	-3.9455	8.2216	-15.376	8.0429	82.5279	9.7122	60.8348	11.5695
344	0	-4.0237	8.2745	-15.47	8.1191	82.4649	9.6962	60.8402	11.4681
345	0	-4.1001	8.3245	-15.5562	8.1953	82.406	9.6833	60.8445	11.3793
346	0	-4.1759	8.372	-15.6357	8.271	82.3513	9.6734	60.8481	11.3029
347	0	-4.2522	8.4174	-15.7097	8.3462	82.3012	9.6666	60.8513	11.2385
348	0	-4.3301	8.4611	-15.7793	8.4205	82.2557	9.6626	60.8545	11.1855
349	0	-4.4104	8.5037	-15.8458	8.4937	82.2148	9.6615	60.8578	11.1433
350	0	-4.4941	8.5459	-15.9105	8.5659	82.1786	9.663	60.8613	11.1111
351	0	-4.5819	8.5883	-15.9747	8.6368	82.1469	9.6669	60.8651	11.0882
352	0	-4.6743	8.6317	-16.0396	8.7064	82.1198	9.6731	60.8691	11.0734
353	0	-4.7717	8.6767	-16.1064	8.7749	82.0971	9.6814	60.8734	11.0659
354	0	-4.8745	8.724	-16.1761	8.8423	82.0785	9.6914	60.8778	11.0645
355	0	-4.9827	8.7743	-16.2499	8.9087	82.064	9.7029	60.8822	11.0683
356	0	-5.0963	8.8281	-16.3285	8.9744	82.0533	9.7157	60.8865	11.0761
357	0	-5.2151	8.886	-16.4127	9.0395	82.0462	9.7293	60.8906	11.087
358	0	-5.3386	8.9484	-16.5031	9.1044	82.0424	9.7436	60.8942	11.0998

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
359	0	-5.4665	9.0155	-16.6	9.1692	82.0419	9.7581	60.8973	11.1136
360	0	-5.598	9.0877	-16.7036	9.2343	82.0442	9.7727	60.8996	11.1276
361	0	-5.7322	9.1648	-16.814	9.2999	82.0493	9.7869	60.9011	11.1408
362	0	-5.8683	9.2468	-16.9309	9.3662	82.0569	9.8005	60.9016	11.1526
363	0	-6.0052	9.3334	-17.0538	9.4335	82.0668	9.8132	60.901	11.1622
364	0	-6.1417	9.4242	-17.1822	9.5018	82.0788	9.8248	60.8991	11.1693
365	0	-6.2767	9.5186	-17.3153	9.5713	82.0927	9.835	60.8961	11.1734
1	1	-11.998	9.5066	-22.1562	8.9251	85.0502	9.2813	67.665	9.6259
2	1	-12.0873	9.55	-22.2485	8.9598	85.0693	9.2451	67.7194	9.6213
3	1	-12.1591	9.595	-22.3269	8.9972	85.087	9.2147	67.7616	9.6216
4	1	-12.2125	9.6406	-22.3901	9.037	85.1033	9.1903	67.7908	9.627
5	1	-12.2467	9.686	-22.4372	9.0785	85.1179	9.1721	67.8067	9.6375
6	1	-12.2613	9.7304	-22.4671	9.121	85.1308	9.1601	67.8091	9.6532
7	1	-12.2561	9.7728	-22.4794	9.1638	85.1419	9.1543	67.7981	9.6739
8	1	-12.2313	9.8122	-22.4736	9.206	85.1511	9.1547	67.7738	9.6996
9	1	-12.1875	9.8478	-22.4495	9.2469	85.1586	9.1609	67.7367	9.7302
10	1	-12.1254	9.8787	-22.4074	9.2857	85.1643	9.1729	67.6876	9.7653
11	1	-12.0462	9.9041	-22.3476	9.3214	85.1683	9.1902	67.6273	9.8046
12	1	-11.9511	9.9232	-22.2708	9.3533	85.1706	9.2124	67.5568	9.8479

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
13	1	-11.8418	9.9355	-22.1778	9.3805	85.1715	9.239	67.4772	9.8947
14	1	-11.72	9.9404	-22.0697	9.4023	85.1709	9.2695	67.3898	9.9445
15	1	-11.5876	9.9375	-21.9479	9.418	85.1692	9.3034	67.2959	9.9969
16	1	-11.4466	9.9266	-21.8139	9.4271	85.1664	9.3399	67.197	10.0513
17	1	-11.2991	9.9076	-21.6694	9.429	85.1627	9.3786	67.0946	10.1072
18	1	-11.1472	9.8805	-21.516	9.4233	85.1583	9.4185	66.99	10.1639
19	1	-10.993	9.8456	-21.3557	9.4097	85.1535	9.4592	66.8848	10.221
20	1	-10.8385	9.803	-21.1904	9.388	85.1485	9.4999	66.7804	10.2779
21	1	-10.6856	9.7533	-21.0219	9.3582	85.1434	9.5399	66.6782	10.3338
22	1	-10.536	9.6971	-20.8521	9.3203	85.1385	9.5786	66.5795	10.3884
23	1	-10.3914	9.6351	-20.6829	9.2745	85.134	9.6152	66.4855	10.441
24	1	-10.2532	9.5679	-20.516	9.2212	85.1301	9.6492	66.3972	10.4911
25	1	-10.1225	9.4965	-20.353	9.1608	85.1271	9.6799	66.3157	10.5382
26	1	-10.0001	9.4217	-20.1954	9.0937	85.1251	9.7068	66.2417	10.582
27	1	-9.8868	9.3446	-20.0443	9.0207	85.1243	9.7295	66.1759	10.622
28	1	-9.783	9.2658	-19.9009	8.9425	85.125	9.7473	66.1189	10.6579
29	1	-9.6886	9.1865	-19.7659	8.8599	85.1273	9.7601	66.0708	10.6894
30	1	-9.6037	9.1075	-19.64	8.7738	85.1313	9.7674	66.0319	10.7164
31	1	-9.5277	9.0295	-19.5236	8.6851	85.1372	9.7689	66.0023	10.7387

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
32	1	-9.4601	8.9533	-19.4167	8.5947	85.1452	9.7645	65.9816	10.7562
33	1	-9.4	8.8795	-19.3191	8.5036	85.1553	9.754	65.9695	10.769
34	1	-9.3463	8.8087	-19.2306	8.4127	85.1676	9.7374	65.9657	10.7771
35	1	-9.2979	8.7412	-19.1506	8.3231	85.1822	9.7147	65.9694	10.7808
36	1	-9.2533	8.6774	-19.0782	8.2356	85.1993	9.686	65.9798	10.7802
37	1	-9.2113	8.6173	-19.0123	8.1511	85.2187	9.6514	65.9962	10.7758
38	1	-9.1702	8.561	-18.952	8.0704	85.2406	9.6112	66.0175	10.7677
39	1	-9.1286	8.5084	-18.8958	7.9942	85.2649	9.5655	66.0425	10.7566
40	1	-9.0849	8.4591	-18.8424	7.9232	85.2917	9.5148	66.0703	10.7428
41	1	-9.0376	8.4129	-18.7903	7.8579	85.3208	9.4594	66.0995	10.727
42	1	-8.9854	8.3692	-18.7378	7.7988	85.3524	9.3997	66.129	10.7097
43	1	-8.9268	8.3275	-18.6835	7.7462	85.3863	9.3363	66.1574	10.6916
44	1	-8.8608	8.2872	-18.6258	7.7004	85.4224	9.2696	66.1836	10.6733
45	1	-8.7861	8.2476	-18.5632	7.6615	85.4607	9.2002	66.2061	10.6555
46	1	-8.702	8.208	-18.4941	7.6294	85.5011	9.1287	66.224	10.6389
47	1	-8.6076	8.1676	-18.4173	7.6042	85.5435	9.0556	66.2358	10.6243
48	1	-8.5023	8.1258	-18.3315	7.5856	85.5878	8.9815	66.2406	10.6122
49	1	-8.3859	8.082	-18.2356	7.5734	85.6339	8.9071	66.2372	10.6035
50	1	-8.258	8.0355	-18.1286	7.5672	85.6817	8.833	66.2246	10.5988

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
51	1	-8.1186	7.9858	-18.0098	7.5665	85.7311	8.7596	66.202	10.5986
52	1	-7.9679	7.9326	-17.8785	7.5709	85.782	8.6877	66.1685	10.6038
53	1	-7.8062	7.8754	-17.7343	7.5797	85.8343	8.6178	66.1234	10.6146
54	1	-7.6337	7.8142	-17.5769	7.5924	85.8879	8.5503	66.0661	10.6318
55	1	-7.4512	7.7489	-17.4064	7.6083	85.9427	8.4859	65.996	10.6557
56	1	-7.2593	7.6795	-17.2227	7.6267	85.9986	8.4249	65.9128	10.6868
57	1	-7.0586	7.6063	-17.0261	7.647	86.0556	8.3679	65.816	10.7252
58	1	-6.85	7.5296	-16.817	7.6684	86.1135	8.3151	65.7055	10.7713
59	1	-6.6342	7.45	-16.5961	7.6902	86.1723	8.2669	65.5811	10.8253
60	1	-6.4123	7.3679	-16.3639	7.7118	86.232	8.2236	65.4427	10.8871
61	1	-6.1849	7.2843	-16.1212	7.7325	86.2924	8.1853	65.2904	10.9569
62	1	-5.9529	7.1997	-15.8688	7.7516	86.3536	8.1524	65.1242	11.0345
63	1	-5.717	7.1151	-15.6077	7.7686	86.4156	8.1249	64.9443	11.1197
64	1	-5.478	7.0314	-15.3387	7.7829	86.4781	8.1028	64.7508	11.2124
65	1	-5.2366	6.9495	-15.0628	7.794	86.5413	8.0863	64.5441	11.3123
66	1	-4.9931	6.8703	-14.7808	7.8014	86.6051	8.0751	64.3243	11.4188
67	1	-4.7482	6.7948	-14.4938	7.8047	86.6695	8.0693	64.0919	11.5316
68	1	-4.5021	6.7238	-14.2024	7.8034	86.7344	8.0686	63.8471	11.6502
69	1	-4.2551	6.658	-13.9075	7.7972	86.7998	8.073	63.5903	11.774

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
70	1	-4.0074	6.5981	-13.6098	7.7858	86.8656	8.082	63.3217	11.9024
71	1	-3.7588	6.5448	-13.3098	7.7689	86.9318	8.0956	63.0419	12.0347
72	1	-3.5094	6.4984	-13.0081	7.7463	86.9982	8.1133	62.7512	12.1703
73	1	-3.259	6.4592	-12.705	7.7178	87.0649	8.1348	62.4498	12.3083
74	1	-3.0074	6.4274	-12.4007	7.6831	87.1317	8.1598	62.1381	12.4482
75	1	-2.7541	6.4029	-12.0956	7.6422	87.1985	8.1878	61.8165	12.589
76	1	-2.4988	6.3855	-11.7896	7.5949	87.2651	8.2184	61.4853	12.7302
77	1	-2.241	6.3749	-11.4827	7.5411	87.3314	8.2512	61.1448	12.871
78	1	-1.9803	6.3705	-11.1747	7.4809	87.3971	8.2859	60.7953	13.0106
79	1	-1.7161	6.3716	-10.8655	7.414	87.4622	8.3218	60.4371	13.1484
80	1	-1.4479	6.3776	-10.5548	7.3407	87.5264	8.3588	60.0704	13.2838
81	1	-1.1751	6.3873	-10.2422	7.2607	87.5893	8.3962	59.6957	13.416
82	1	-0.8973	6.3999	-9.9275	7.1743	87.6508	8.4338	59.3131	13.5447
83	1	-0.6139	6.4143	-9.6102	7.0815	87.7105	8.4711	58.923	13.6693
84	1	-0.3246	6.4292	-9.2899	6.9824	87.7682	8.5078	58.5258	13.7892
85	1	-0.0288	6.4435	-8.9665	6.8771	87.8235	8.5436	58.1217	13.9043
86	1	0.2735	6.4561	-8.6394	6.7658	87.8761	8.5782	57.7111	14.0141
87	1	0.5829	6.4658	-8.3085	6.6488	87.9256	8.6113	57.2945	14.1184
88	1	0.8993	6.4716	-7.9736	6.5263	87.9717	8.6428	56.8723	14.2171

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
89	1	1.2229	6.4725	-7.6346	6.3986	88.014	8.6723	56.4449	14.3101
90	1	1.5536	6.4676	-7.2914	6.2661	88.0521	8.6998	56.013	14.3974
91	1	1.8914	6.4561	-6.9443	6.1292	88.0858	8.7252	55.577	14.4789
92	1	2.236	6.4376	-6.5934	5.9883	88.1147	8.7485	55.1376	14.5549
93	1	2.5872	6.4114	-6.2391	5.8441	88.1385	8.7695	54.6955	14.6255
94	1	2.9445	6.3775	-5.8818	5.697	88.1569	8.7883	54.2513	14.691
95	1	3.3074	6.3357	-5.522	5.5476	88.1696	8.8051	53.8059	14.7516
96	1	3.6753	6.2861	-5.1606	5.3966	88.1764	8.8199	53.3601	14.8078
97	1	4.0476	6.229	-4.7983	5.2446	88.1772	8.8327	52.9148	14.86
98	1	4.4236	6.1649	-4.436	5.0925	88.1717	8.8439	52.4708	14.9085
99	1	4.8023	6.0945	-4.0747	4.9409	88.1599	8.8536	52.0292	14.9538
100	1	5.183	6.0185	-3.7154	4.7907	88.1418	8.8619	51.5909	14.9965
101	1	5.5646	5.9378	-3.3593	4.6425	88.1174	8.8692	51.1568	15.0369
102	1	5.9463	5.8536	-3.0075	4.4972	88.0867	8.8757	50.7282	15.0757
103	1	6.3269	5.7668	-2.6611	4.3555	88.05	8.8817	50.3059	15.1133
104	1	6.7056	5.6788	-2.3214	4.2182	88.0073	8.8874	49.891	15.1503
105	1	7.0811	5.5907	-1.9895	4.0861	87.9591	8.8931	49.4845	15.187
106	1	7.4526	5.5038	-1.6665	3.9597	87.9055	8.8991	49.0876	15.2239
107	1	7.819	5.4193	-1.3533	3.8397	87.8471	8.9056	48.701	15.2615

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
108	1	8.1793	5.3384	-1.0509	3.7266	87.7843	8.9129	48.3259	15.3
109	1	8.5326	5.2621	-0.7601	3.621	87.7175	8.9212	47.9631	15.3399
110	1	8.878	5.1914	-0.4817	3.5233	87.6475	8.9308	47.6136	15.3814
111	1	9.2148	5.1273	-0.2162	3.4337	87.5748	8.9418	47.2779	15.4247
112	1	9.5421	5.0703	0.0361	3.3526	87.5	8.9543	46.9571	15.4699
113	1	9.8594	5.0211	0.2749	3.28	87.4239	8.9686	46.6515	15.5173
114	1	10.1662	4.98	0.5001	3.216	87.3473	8.9846	46.362	15.5667
115	1	10.4619	4.9473	0.7118	3.1606	87.2709	9.0025	46.0889	15.6182
116	1	10.7464	4.923	0.9103	3.1134	87.1954	9.0223	45.8327	15.6717
117	1	11.0195	4.9069	1.0962	3.0744	87.1217	9.044	45.5936	15.727
118	1	11.2811	4.8987	1.27	3.0431	87.0506	9.0674	45.372	15.7839
119	1	11.5313	4.8979	1.4325	3.0191	86.9829	9.0926	45.1679	15.8421
120	1	11.7704	4.9038	1.5846	3.0019	86.9192	9.1194	44.9814	15.9014
121	1	11.9987	4.9157	1.7276	2.9909	86.8604	9.1476	44.8123	15.9614
122	1	12.2166	4.9325	1.8624	2.9854	86.8071	9.1771	44.6607	16.0217
123	1	12.4248	4.9534	1.9905	2.9848	86.76	9.2076	44.5263	16.0818
124	1	12.624	4.9771	2.1133	2.9884	86.7196	9.2389	44.4087	16.1413
125	1	12.815	5.0027	2.232	2.9953	86.6865	9.2707	44.3076	16.1996
126	1	12.9986	5.0288	2.3481	3.005	86.6611	9.3026	44.2226	16.2564

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
127	1	13.1759	5.0545	2.4632	3.0166	86.6438	9.3345	44.1531	16.3111
128	1	13.3478	5.0785	2.5785	3.0294	86.6349	9.366	44.0987	16.3633
129	1	13.5154	5.0999	2.6955	3.0427	86.6347	9.3967	44.0588	16.4124
130	1	13.6797	5.1177	2.8154	3.0559	86.6431	9.4263	44.0327	16.4579
131	1	13.8418	5.131	2.9395	3.0685	86.6603	9.4546	44.0199	16.4995
132	1	14.0026	5.1391	3.0686	3.0799	86.6863	9.4811	44.0197	16.5368
133	1	14.1633	5.1414	3.2039	3.0896	86.7207	9.5056	44.0314	16.5694
134	1	14.3247	5.1375	3.346	3.0974	86.7634	9.5278	44.0544	16.597
135	1	14.4875	5.1271	3.4955	3.1029	86.8141	9.5474	44.0881	16.6193
136	1	14.6525	5.11	3.6528	3.106	86.8724	9.5642	44.1319	16.6362
137	1	14.8204	5.0865	3.8181	3.1065	86.9377	9.5779	44.1851	16.6474
138	1	14.9915	5.0565	3.9914	3.1044	87.0095	9.5884	44.2473	16.653
139	1	15.1661	5.0206	4.1726	3.0998	87.0871	9.5955	44.3179	16.6528
140	1	15.3444	4.9792	4.3612	3.0928	87.17	9.5991	44.3965	16.6469
141	1	15.5265	4.9329	4.5567	3.0835	87.2573	9.599	44.4825	16.6354
142	1	15.712	4.8826	4.7584	3.0724	87.3484	9.5953	44.5757	16.6185
143	1	15.9007	4.8289	4.9654	3.0595	87.4423	9.5879	44.6757	16.5964
144	1	16.0921	4.7729	5.1767	3.0453	87.5385	9.5769	44.7822	16.5693
145	1	16.2855	4.7154	5.3911	3.0302	87.6359	9.5622	44.895	16.5377

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
146	1	16.4801	4.6574	5.6073	3.0145	87.7339	9.544	45.0139	16.5018
147	1	16.6751	4.5999	5.8242	2.9986	87.8317	9.5224	45.1388	16.4621
148	1	16.8694	4.5438	6.0402	2.9828	87.9285	9.4974	45.2694	16.4189
149	1	17.062	4.4899	6.254	2.9676	88.0237	9.4694	45.4058	16.3729
150	1	17.2517	4.4391	6.4644	2.9531	88.1166	9.4384	45.5478	16.3244
151	1	17.4373	4.392	6.6698	2.9398	88.2066	9.4047	45.6956	16.2739
152	1	17.6178	4.3493	6.8691	2.9278	88.2931	9.3685	45.8489	16.222
153	1	17.7919	4.3115	7.0611	2.9172	88.3759	9.33	46.0079	16.1691
154	1	17.9585	4.2788	7.2447	2.9083	88.4544	9.2894	46.1726	16.1156
155	1	18.1166	4.2515	7.4189	2.9009	88.5284	9.247	46.3429	16.0622
156	1	18.2653	4.2296	7.583	2.8952	88.5977	9.203	46.5188	16.0091
157	1	18.4039	4.2132	7.7362	2.891	88.6622	9.1576	46.7003	15.9567
158	1	18.5316	4.2019	7.8782	2.8881	88.7219	9.111	46.8873	15.9055
159	1	18.6479	4.1954	8.0086	2.8864	88.7769	9.0634	47.0797	15.8557
160	1	18.7527	4.1933	8.1273	2.8856	88.8273	9.0149	47.2774	15.8075
161	1	18.8457	4.1949	8.2345	2.8854	88.8733	8.9658	47.4803	15.7612
162	1	18.927	4.1997	8.3303	2.8854	88.9154	8.9162	47.688	15.7168
163	1	18.9969	4.2069	8.4152	2.8853	88.9538	8.8661	47.9004	15.6745
164	1	19.056	4.2157	8.4899	2.8847	88.9891	8.8156	48.1172	15.6343

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
165	1	19.1047	4.2253	8.5549	2.8831	89.0217	8.7648	48.3378	15.596
166	1	19.144	4.2349	8.6113	2.8803	89.0522	8.7137	48.562	15.5597
167	1	19.1749	4.2436	8.6599	2.8759	89.0811	8.6623	48.7892	15.5251
168	1	19.1985	4.2507	8.7019	2.8695	89.1092	8.6106	49.0188	15.492
169	1	19.2159	4.2555	8.7384	2.8608	89.137	8.5585	49.2504	15.4601
170	1	19.2287	4.2572	8.7705	2.8496	89.1651	8.506	49.4831	15.4292
171	1	19.238	4.2553	8.7995	2.8358	89.1942	8.4529	49.7164	15.3989
172	1	19.2455	4.2493	8.8264	2.8191	89.2249	8.3992	49.9494	15.3687
173	1	19.2524	4.2389	8.8525	2.7996	89.2576	8.3448	50.1813	15.3384
174	1	19.2602	4.2238	8.8788	2.7772	89.293	8.2895	50.4115	15.3074
175	1	19.2702	4.204	8.9064	2.7522	89.3315	8.2331	50.6389	15.2753
176	1	19.2837	4.1794	8.936	2.7246	89.3734	8.1757	50.8628	15.2417
177	1	19.3017	4.1503	8.9684	2.6948	89.4193	8.1171	51.0822	15.2062
178	1	19.3254	4.1168	9.0044	2.6629	89.4692	8.0572	51.2963	15.1684
179	1	19.3554	4.0794	9.0444	2.6295	89.5233	7.9958	51.5041	15.1279
180	1	19.3924	4.0387	9.0888	2.595	89.5819	7.933	51.7049	15.0844
181	1	19.4369	3.9951	9.1376	2.5599	89.6448	7.8688	51.8977	15.0375
182	1	19.4891	3.9495	9.1911	2.5247	89.7119	7.803	52.0818	14.9871
183	1	19.5491	3.9026	9.249	2.4899	89.7832	7.7357	52.2563	14.9329

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
184	1	19.6167	3.8552	9.311	2.4561	89.8584	7.667	52.4205	14.8749
185	1	19.6915	3.8081	9.3769	2.424	89.937	7.597	52.5738	14.8129
186	1	19.7731	3.7622	9.4459	2.394	90.0187	7.5259	52.7155	14.7469
187	1	19.8606	3.7183	9.5175	2.3667	90.1031	7.4536	52.8451	14.6772
188	1	19.9533	3.6773	9.591	2.3426	90.1895	7.3806	52.9621	14.6038
189	1	20.0502	3.64	9.6654	2.3222	90.2773	7.307	53.0661	14.5269
190	1	20.15	3.607	9.7401	2.3058	90.3659	7.2332	53.1569	14.4469
191	1	20.2517	3.579	9.8139	2.2937	90.4546	7.1594	53.2342	14.3641
192	1	20.3541	3.5566	9.8861	2.2863	90.5427	7.0859	53.2979	14.279
193	1	20.4558	3.5401	9.9557	2.2836	90.6295	7.0132	53.3482	14.1921
194	1	20.5557	3.53	10.0219	2.2858	90.7142	6.9417	53.385	14.104
195	1	20.6526	3.5263	10.0838	2.2927	90.7962	6.8717	53.4087	14.0153
196	1	20.7453	3.5292	10.1407	2.3044	90.8747	6.8037	53.4195	13.9266
197	1	20.8327	3.5387	10.1918	2.3206	90.9491	6.7382	53.418	13.8387
198	1	20.914	3.5545	10.2367	2.341	91.0189	6.6754	53.4047	13.7522
199	1	20.9883	3.5764	10.2747	2.3653	91.0835	6.616	53.3803	13.6679
200	1	21.055	3.604	10.3056	2.3929	91.1424	6.5602	53.3456	13.5866
201	1	21.1135	3.6368	10.329	2.4235	91.1953	6.5085	53.3015	13.5089
202	1	21.1634	3.6742	10.3449	2.4564	91.2418	6.4613	53.2489	13.4356

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
203	1	21.2046	3.7155	10.3531	2.491	91.2817	6.4188	53.1891	13.3674
204	1	21.237	3.76	10.3538	2.5267	91.315	6.3813	53.1231	13.3049
205	1	21.2606	3.8069	10.3472	2.5629	91.3416	6.349	53.0522	13.2488
206	1	21.2757	3.8554	10.3334	2.5989	91.3617	6.3223	52.9777	13.1995
207	1	21.2826	3.9048	10.3128	2.6339	91.3753	6.3011	52.9011	13.1576
208	1	21.2816	3.954	10.2858	2.6675	91.3829	6.2855	52.8238	13.1235
209	1	21.2732	4.0025	10.2529	2.6991	91.3847	6.2756	52.7473	13.0975
210	1	21.258	4.0494	10.2145	2.728	91.3814	6.2713	52.6731	13.0799
211	1	21.2364	4.094	10.1711	2.7538	91.3734	6.2724	52.6028	13.0707
212	1	21.209	4.1356	10.1231	2.7762	91.3614	6.2788	52.5379	13.0702
213	1	21.1762	4.1738	10.0711	2.7947	91.3461	6.2902	52.4799	13.0782
214	1	21.1386	4.208	10.0153	2.8092	91.3283	6.3062	52.4304	13.0947
215	1	21.0963	4.2378	9.9563	2.8196	91.3089	6.3265	52.3909	13.1193
216	1	21.0497	4.2631	9.8942	2.8257	91.2886	6.3506	52.3627	13.1519
217	1	20.999	4.2835	9.8293	2.8276	91.2683	6.378	52.3472	13.1919
218	1	20.944	4.2991	9.7617	2.8254	91.2489	6.4082	52.3458	13.2389
219	1	20.8847	4.3098	9.6915	2.8195	91.2314	6.4405	52.3595	13.2924
220	1	20.8208	4.3159	9.6187	2.81	91.2165	6.4744	52.3895	13.3516
221	1	20.7518	4.3175	9.5431	2.7975	91.205	6.5092	52.4367	13.416

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
222	1	20.6774	4.3151	9.4645	2.7823	91.1978	6.5442	52.5019	13.4847
223	1	20.5967	4.309	9.3827	2.7651	91.1955	6.5787	52.5858	13.557
224	1	20.5091	4.2997	9.2972	2.7463	91.1989	6.6121	52.6889	13.632
225	1	20.4138	4.2877	9.2077	2.7267	91.2083	6.6438	52.8115	13.709
226	1	20.3097	4.2737	9.1137	2.7069	91.2244	6.673	52.9538	13.787
227	1	20.1961	4.2583	9.0148	2.6874	91.2475	6.6992	53.1157	13.8652
228	1	20.072	4.242	8.9104	2.6691	91.2779	6.7219	53.297	13.9429
229	1	19.9364	4.2257	8.8	2.6524	91.3156	6.7404	53.4972	14.0191
230	1	19.7886	4.2099	8.6832	2.6381	91.3607	6.7544	53.7158	14.0933
231	1	19.6279	4.1952	8.5596	2.6266	91.4132	6.7635	53.9519	14.1646
232	1	19.4536	4.1822	8.4287	2.6186	91.4729	6.7673	54.2045	14.2324
233	1	19.2651	4.1715	8.2903	2.6144	91.5393	6.7656	54.4723	14.2962
234	1	19.0624	4.1636	8.1441	2.6144	91.6122	6.7582	54.754	14.3556
235	1	18.8451	4.1588	7.99	2.6189	91.6909	6.7451	55.0479	14.41
236	1	18.6136	4.1575	7.828	2.6281	91.7748	6.7263	55.3522	14.4592
237	1	18.368	4.16	7.6581	2.6422	91.8632	6.7019	55.6652	14.5031
238	1	18.1089	4.1665	7.4805	2.661	91.9553	6.6721	55.9846	14.5415
239	1	17.8372	4.177	7.2957	2.6846	92.0502	6.6371	56.3083	14.5744
240	1	17.554	4.1915	7.1039	2.7128	92.1469	6.5974	56.634	14.6019

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
241	1	17.2603	4.2101	6.9057	2.7453	92.2446	6.5534	56.9594	14.6243
242	1	16.9578	4.2324	6.7018	2.7818	92.3421	6.5057	57.2819	14.6419
243	1	16.6481	4.2584	6.4929	2.8218	92.4384	6.4547	57.5992	14.6551
244	1	16.333	4.2876	6.2798	2.8649	92.5326	6.4012	57.9087	14.6643
245	1	16.0143	4.3198	6.0634	2.9105	92.6235	6.3459	58.208	14.6702
246	1	15.6942	4.3544	5.8446	2.958	92.7102	6.2894	58.4947	14.6734
247	1	15.3746	4.3911	5.6243	3.0067	92.7918	6.2327	58.7663	14.6746
248	1	15.0578	4.4293	5.4036	3.0561	92.8672	6.1766	59.0207	14.6746
249	1	14.7458	4.4685	5.1833	3.1055	92.9358	6.1217	59.2557	14.6741
250	1	14.4405	4.5081	4.9645	3.1541	92.9967	6.0689	59.4693	14.6741
251	1	14.144	4.5477	4.748	3.2013	93.0493	6.0191	59.6599	14.6753
252	1	13.8579	4.5867	4.5346	3.2466	93.093	5.973	59.8257	14.6785
253	1	13.5838	4.6246	4.3251	3.2894	93.1274	5.9313	59.9655	14.6847
254	1	13.3231	4.6609	4.1202	3.3291	93.1521	5.8947	60.0782	14.6946
255	1	13.077	4.6952	3.9204	3.3653	93.1668	5.8639	60.163	14.7089
256	1	12.8464	4.7272	3.7261	3.3976	93.1716	5.8393	60.2193	14.7283
257	1	12.6317	4.7565	3.5377	3.4257	93.1662	5.8216	60.2469	14.7535
258	1	12.4333	4.7829	3.3553	3.4493	93.151	5.811	60.246	14.7851
259	1	12.2512	4.8062	3.1791	3.4684	93.1262	5.8079	60.217	14.8234

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
260	1	12.0851	4.8263	3.0089	3.483	93.092	5.8124	60.1606	14.8689
261	1	11.9344	4.8432	2.8446	3.4931	93.049	5.8248	60.0779	14.9218
262	1	11.7982	4.8569	2.6859	3.4988	92.9977	5.845	59.9704	14.9822
263	1	11.6754	4.8676	2.5324	3.5004	92.9388	5.8729	59.8397	15.0502
264	1	11.5646	4.8753	2.3836	3.4983	92.8731	5.9083	59.6879	15.1256
265	1	11.4643	4.8805	2.2389	3.4928	92.8012	5.9509	59.5174	15.2083
266	1	11.3727	4.8834	2.0976	3.4846	92.7241	6.0004	59.3307	15.2979
267	1	11.2878	4.8844	1.9592	3.474	92.6427	6.0561	59.1307	15.3939
268	1	11.2077	4.8839	1.8227	3.4618	92.558	6.1176	58.9205	15.4958
269	1	11.1303	4.8823	1.6876	3.4485	92.4707	6.1841	58.7033	15.6028
270	1	11.0535	4.8801	1.5529	3.435	92.382	6.255	58.4826	15.7141
271	1	10.9751	4.8778	1.418	3.4218	92.2927	6.3295	58.2619	15.8288
272	1	10.8932	4.8759	1.2821	3.4098	92.2037	6.4068	58.0449	15.9459
273	1	10.8057	4.875	1.1446	3.3996	92.116	6.4859	57.8353	16.0643
274	1	10.7109	4.8753	1.0047	3.392	92.0302	6.5661	57.6366	16.1829
275	1	10.6069	4.8775	0.8619	3.3876	91.9473	6.6463	57.4527	16.3005
276	1	10.4922	4.882	0.7156	3.387	91.8678	6.7257	57.2871	16.4158
277	1	10.3655	4.889	0.5653	3.3909	91.7923	6.8035	57.1432	16.5275
278	1	10.2256	4.8989	0.4106	3.3998	91.7214	6.8787	57.0243	16.6344

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
279	1	10.0714	4.9119	0.2512	3.4141	91.6554	6.9506	56.9335	16.7353
280	1	9.9024	4.9284	0.0867	3.4342	91.5946	7.0183	56.8737	16.8288
281	1	9.7178	4.9483	-0.0831	3.4605	91.5393	7.0813	56.8474	16.9137
282	1	9.5174	4.9718	-0.2584	3.4932	91.4894	7.1388	56.8569	16.9889
283	1	9.3009	4.9988	-0.4394	3.5323	91.4449	7.1904	56.9041	17.0533
284	1	9.0686	5.0293	-0.6263	3.5781	91.4058	7.2355	56.9906	17.1058
285	1	8.8204	5.0632	-0.8191	3.6304	91.3717	7.274	57.1174	17.1455
286	1	8.5569	5.1002	-1.0181	3.6892	91.3422	7.3054	57.2853	17.1717
287	1	8.2783	5.1401	-1.2233	3.7543	91.317	7.3298	57.4946	17.1835
288	1	7.9854	5.1826	-1.4348	3.8255	91.2954	7.347	57.7452	17.1804
289	1	7.6787	5.2275	-1.6528	3.9023	91.2769	7.3572	58.0366	17.1619
290	1	7.3589	5.2742	-1.8776	3.9845	91.2607	7.3606	58.3676	17.1277
291	1	7.0268	5.3226	-2.1093	4.0717	91.2461	7.3575	58.7369	17.0776
292	1	6.6831	5.3721	-2.3483	4.1633	91.2322	7.3483	59.1426	17.0116
293	1	6.3286	5.4225	-2.5947	4.2589	91.2183	7.3336	59.5824	16.9297
294	1	5.9639	5.4733	-2.849	4.3579	91.2034	7.314	60.0537	16.8322
295	1	5.5899	5.5242	-3.1116	4.4599	91.1866	7.2902	60.5535	16.7195
296	1	5.2071	5.575	-3.3828	4.5644	91.167	7.2629	61.0785	16.5921
297	1	4.8162	5.6254	-3.6631	4.6708	91.1438	7.2331	61.625	16.4506

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
298	1	4.4177	5.6751	-3.9529	4.7786	91.1161	7.2016	62.1892	16.2958
299	1	4.0123	5.724	-4.2526	4.8873	91.0831	7.1693	62.767	16.1286
300	1	3.6004	5.7721	-4.5627	4.9966	91.0441	7.1373	63.3542	15.9499
301	1	3.1826	5.8193	-4.8836	5.1061	90.9982	7.1065	63.9464	15.7608
302	1	2.7593	5.8658	-5.2155	5.2153	90.9449	7.0779	64.5393	15.5625
303	1	2.3311	5.9115	-5.5588	5.3241	90.8836	7.0524	65.1283	15.3562
304	1	1.8984	5.9568	-5.9135	5.4322	90.8139	7.0311	65.7091	15.1431
305	1	1.4618	6.0019	-6.2798	5.5393	90.7352	7.0148	66.2775	14.9246
306	1	1.0219	6.047	-6.6576	5.6453	90.6475	7.0043	66.8291	14.702
307	1	0.5793	6.0926	-7.0467	5.7503	90.5503	7.0005	67.3599	14.4765
308	1	0.1348	6.1391	-7.4468	5.854	90.4438	7.004	67.8663	14.2496
309	1	-0.3109	6.1869	-7.8574	5.9566	90.3278	7.0155	68.3447	14.0226
310	1	-0.7567	6.2365	-8.2778	6.0581	90.2025	7.0355	68.7918	13.7966
311	1	-1.2018	6.2883	-8.7072	6.1585	90.0681	7.0645	69.2048	13.5731
312	1	-1.645	6.3429	-9.1446	6.258	89.9249	7.1026	69.5812	13.353
313	1	-2.0851	6.4005	-9.5889	6.3566	89.7734	7.1502	69.9188	13.1376
314	1	-2.5208	6.4617	-10.0387	6.4546	89.6141	7.2073	70.216	12.9278
315	1	-2.9508	6.5269	-10.4927	6.552	89.4475	7.2739	70.4714	12.7245
316	1	-3.3736	6.5963	-10.9491	6.649	89.2743	7.3497	70.6844	12.5286

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
317	1	-3.7877	6.6701	-11.4065	6.7457	89.0952	7.4346	70.8544	12.3409
318	1	-4.1917	6.7485	-11.8629	6.8422	88.911	7.5281	70.9815	12.1618
319	1	-4.5841	6.8317	-12.3165	6.9385	88.7226	7.6298	71.0663	11.992
320	1	-4.9634	6.9195	-12.7656	7.0346	88.5308	7.7389	71.1097	11.8318
321	1	-5.3282	7.0119	-13.2081	7.1307	88.3366	7.8548	71.113	11.6815
322	1	-5.6771	7.1085	-13.6424	7.2265	88.1409	7.9768	71.078	11.5412
323	1	-6.0091	7.2092	-14.0666	7.322	87.9446	8.1038	71.0067	11.411
324	1	-6.3229	7.3135	-14.479	7.417	87.7487	8.2351	70.9017	11.2908
325	1	-6.6179	7.4209	-14.8781	7.5114	87.554	8.3695	70.7655	11.1804
326	1	-6.8932	7.5307	-15.2624	7.6049	87.3615	8.506	70.6011	11.0797
327	1	-7.1484	7.6424	-15.6307	7.6972	87.1722	8.6436	70.4119	10.9882
328	1	-7.3833	7.7551	-15.9819	7.788	86.9867	8.7813	70.2011	10.9055
329	1	-7.598	7.8681	-16.3152	7.8769	86.806	8.9177	69.9723	10.8312
330	1	-7.7927	7.9806	-16.63	7.9635	86.6308	9.052	69.729	10.7646
331	1	-7.9681	8.0917	-16.926	8.0476	86.4617	9.183	69.4749	10.7051
332	1	-8.1249	8.2006	-17.2029	8.1285	86.2994	9.3098	69.2136	10.6521
333	1	-8.2642	8.3065	-17.4611	8.2061	86.1445	9.4312	68.9486	10.6049
334	1	-8.3873	8.4085	-17.7008	8.2798	85.9975	9.5465	68.6835	10.5628
335	1	-8.4958	8.5061	-17.9227	8.3492	85.8586	9.6548	68.4215	10.5251

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
336	1	-8.5914	8.5983	-18.1276	8.4141	85.7284	9.7553	68.1658	10.4911
337	1	-8.676	8.6848	-18.3167	8.4742	85.6071	9.8473	67.9194	10.46
338	1	-8.7515	8.765	-18.4911	8.5292	85.4948	9.9302	67.6849	10.4313
339	1	-8.8201	8.8384	-18.6523	8.5789	85.3916	10.0036	67.4649	10.4043
340	1	-8.8839	8.9049	-18.8018	8.6231	85.2976	10.0671	67.2614	10.3784
341	1	-8.945	8.9643	-18.9412	8.6619	85.2128	10.1205	67.0762	10.3531
342	1	-9.0055	9.0165	-19.0722	8.6953	85.1371	10.1635	66.9109	10.3279
343	1	-9.0674	9.0618	-19.1966	8.7233	85.0702	10.1962	66.7667	10.3023
344	1	-9.1326	9.1002	-19.316	8.7461	85.012	10.2186	66.6442	10.276
345	1	-9.2027	9.1322	-19.4321	8.7641	84.9622	10.231	66.544	10.2488
346	1	-9.2793	9.1583	-19.5464	8.7775	84.9204	10.2335	66.4663	10.2204
347	1	-9.3636	9.179	-19.6604	8.7867	84.8863	10.2266	66.4107	10.1907
348	1	-9.4566	9.195	-19.7753	8.7923	84.8594	10.2109	66.3769	10.1596
349	1	-9.5588	9.2071	-19.8922	8.7947	84.8393	10.1867	66.3639	10.1272
350	1	-9.6708	9.2159	-20.0121	8.7946	84.8255	10.155	66.3707	10.0934
351	1	-9.7925	9.2225	-20.1355	8.7926	84.8175	10.1162	66.396	10.0585
352	1	-9.9236	9.2275	-20.263	8.7893	84.8148	10.0713	66.4381	10.0226
353	1	-10.0637	9.232	-20.3946	8.7853	84.8169	10.021	66.4952	9.9861
354	1	-10.2117	9.2367	-20.5304	8.7815	84.8232	9.9663	66.5656	9.9492

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
355	1	-10.3665	9.2424	-20.67	8.7783	84.8332	9.9079	66.6471	9.9122
356	1	-10.5267	9.2499	-20.8127	8.7765	84.8464	9.847	66.7375	9.8757
357	1	-10.6907	9.2597	-20.9579	8.7766	84.8623	9.7842	66.8347	9.8399
358	1	-10.8564	9.2725	-21.1045	8.7791	84.8803	9.7207	66.9364	9.8054
359	1	-11.022	9.2887	-21.2512	8.7845	84.9	9.6572	67.0405	9.7725
360	1	-11.1854	9.3086	-21.3967	8.7933	84.921	9.5947	67.1447	9.7418
361	1	-11.3443	9.3323	-21.5396	8.8057	84.9427	9.5339	67.247	9.7137
362	1	-11.4966	9.3601	-21.6782	8.8219	84.9648	9.4756	67.3453	9.6885
363	1	-11.6401	9.3916	-21.8108	8.8419	84.9869	9.4206	67.4379	9.6668
364	1	-11.7728	9.4269	-21.9358	8.8659	85.0087	9.3695	67.523	9.6489
365	1	-11.8927	9.4653	-22.0515	8.8937	85.0299	9.3229	67.5991	9.6352

APPENDIX B. FORT MCMURRAY AIRPORT SMOOTHED PARAMETERS VALUES

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
1	0	-14.2361	11.0055	-24.3127	10.5122	82.7643	9.2607	65.9487	10.2582
2	0	-14.3436	11.0307	-24.502	10.5165	82.7186	9.2253	65.7613	10.1446
3	0	-14.442	11.0556	-24.6862	10.5227	82.6839	9.1908	65.5746	10.0322
4	0	-14.5305	11.0801	-24.8636	10.5312	82.6599	9.1582	65.3908	9.9229
5	0	-14.6083	11.1038	-25.0323	10.5422	82.6462	9.1287	65.2119	9.8189
6	0	-14.6743	11.1265	-25.1903	10.5557	82.6422	9.1031	65.0395	9.7219
7	0	-14.7278	11.1479	-25.3358	10.5719	82.6471	9.0824	64.8751	9.634
8	0	-14.7679	11.1676	-25.4671	10.5907	82.6597	9.0674	64.72	9.5569
9	0	-14.7938	11.1854	-25.5826	10.6119	82.679	9.0586	64.5749	9.4922
10	0	-14.8045	11.2009	-25.6806	10.6353	82.7037	9.0566	64.4402	9.4415
11	0	-14.7995	11.2138	-25.76	10.6605	82.7325	9.0618	64.3161	9.4058
12	0	-14.7781	11.2239	-25.8195	10.6873	82.7639	9.0743	64.2023	9.3863
13	0	-14.7396	11.2308	-25.8582	10.7151	82.7965	9.0943	64.098	9.3837
14	0	-14.6837	11.2344	-25.8755	10.7436	82.829	9.1216	64.0022	9.3986
15	0	-14.61	11.2343	-25.871	10.7722	82.8601	9.1558	63.9136	9.4311
16	0	-14.5183	11.2304	-25.8444	10.8004	82.8885	9.1967	63.8305	9.4811
17	0	-14.4084	11.2225	-25.7959	10.8278	82.9131	9.2435	63.751	9.5483

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
18	0	-14.2804	11.2106	-25.7258	10.8538	82.933	9.2955	63.673	9.6321
19	0	-14.1346	11.1945	-25.6347	10.878	82.9473	9.3519	63.5941	9.7315
20	0	-13.9712	11.1743	-25.5234	10.9	82.9555	9.4117	63.512	9.8454
21	0	-13.7907	11.15	-25.393	10.9194	82.9572	9.4739	63.4243	9.9724
22	0	-13.5937	11.1215	-25.2447	10.9359	82.9521	9.5374	63.3284	10.1108
23	0	-13.381	11.0891	-25.0798	10.9492	82.9402	9.601	63.2221	10.259
24	0	-13.1535	11.0529	-24.9001	10.9593	82.9216	9.6635	63.1031	10.4149
25	0	-12.912	11.0131	-24.7072	10.9659	82.8968	9.7239	62.9692	10.5766
26	0	-12.6576	10.9697	-24.5028	10.9691	82.8662	9.781	62.8186	10.7419
27	0	-12.3916	10.9232	-24.2889	10.9688	82.8304	9.8338	62.6495	10.9088
28	0	-12.1151	10.8738	-24.0671	10.9653	82.7903	9.8813	62.4607	11.0752
29	0	-11.8293	10.8218	-23.8396	10.9586	82.7466	9.9227	62.251	11.239
30	0	-11.5356	10.7674	-23.6079	10.9491	82.7002	9.9572	62.0197	11.3984
31	0	-11.2352	10.711	-23.374	10.9369	82.6521	9.9844	61.7664	11.5514
32	0	-10.9295	10.6529	-23.1394	10.9224	82.6032	10.0038	61.491	11.6966
33	0	-10.6197	10.5935	-22.9058	10.9058	82.5543	10.0152	61.1936	11.8324
34	0	-10.307	10.533	-22.6745	10.8877	82.5061	10.0184	60.8748	11.9576
35	0	-9.9926	10.4717	-22.4468	10.8683	82.4595	10.0137	60.5354	12.0713
36	0	-9.6777	10.4101	-22.2238	10.8479	82.4149	10.0014	60.1767	12.1727

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
37	0	-9.3631	10.3482	-22.0065	10.827	82.3727	9.9818	59.7997	12.2614
38	0	-9.0499	10.2864	-21.7956	10.8058	82.3334	9.9557	59.4062	12.3373
39	0	-8.7388	10.2249	-21.5916	10.7846	82.2968	9.9237	58.9978	12.4002
40	0	-8.4307	10.1639	-21.3949	10.7637	82.2631	9.8868	58.5764	12.4507
41	0	-8.1259	10.1036	-21.2057	10.7433	82.232	9.846	58.1438	12.4892
42	0	-7.8252	10.044	-21.024	10.7234	82.203	9.8024	57.7021	12.5165
43	0	-7.5288	9.9853	-20.8496	10.7043	82.1756	9.757	57.2532	12.5336
44	0	-7.237	9.9274	-20.6822	10.686	82.1493	9.7111	56.7991	12.5415
45	0	-6.9501	9.8705	-20.5214	10.6684	82.1231	9.6659	56.3417	12.5416
46	0	-6.668	9.8145	-20.3666	10.6515	82.0962	9.6224	55.8827	12.5352
47	0	-6.3907	9.7593	-20.2172	10.6353	82.0678	9.5818	55.4239	12.5236
48	0	-6.1183	9.7048	-20.0724	10.6194	82.0368	9.545	54.9669	12.5083
49	0	-5.8505	9.6509	-19.9313	10.6039	82.0024	9.513	54.5129	12.4906
50	0	-5.5871	9.5974	-19.7931	10.5884	81.9636	9.4866	54.0632	12.472
51	0	-5.328	9.5442	-19.6568	10.5727	81.9198	9.4663	53.6188	12.4537
52	0	-5.0727	9.4911	-19.5216	10.5566	81.87	9.4526	53.1807	12.4368
53	0	-4.8209	9.4378	-19.3865	10.5397	81.8139	9.4459	52.7493	12.4222
54	0	-4.5724	9.384	-19.2505	10.5219	81.751	9.4462	52.3253	12.4109
55	0	-4.3268	9.3297	-19.1128	10.5029	81.6809	9.4534	51.9089	12.4035

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
56	0	-4.0838	9.2744	-18.9725	10.4823	81.6038	9.4674	51.5003	12.4004
57	0	-3.8429	9.2181	-18.8288	10.46	81.5197	9.4876	51.0995	12.4018
58	0	-3.604	9.1604	-18.6807	10.4357	81.4291	9.5134	50.7064	12.4078
59	0	-3.3666	9.1012	-18.5277	10.4092	81.3324	9.5442	50.3206	12.4182
60	0	-3.1304	9.0403	-18.369	10.3803	81.2305	9.5791	49.942	12.4327
61	0	-2.8951	8.9775	-18.2039	10.3489	81.1244	9.6171	49.57	12.4507
62	0	-2.6605	8.9127	-18.0318	10.3149	81.015	9.6571	49.2042	12.4715
63	0	-2.4262	8.8458	-17.8522	10.2781	80.9038	9.698	48.844	12.4942
64	0	-2.1919	8.7767	-17.6645	10.2385	80.7921	9.7387	48.4889	12.5181
65	0	-1.9574	8.7055	-17.4684	10.196	80.6812	9.778	48.1382	12.542
66	0	-1.7223	8.6321	-17.2633	10.1504	80.5728	9.815	47.7914	12.5649
67	0	-1.4863	8.5566	-17.0489	10.1019	80.4683	9.8484	47.4478	12.5857
68	0	-1.2491	8.479	-16.8248	10.0503	80.3692	9.8775	47.1069	12.6035
69	0	-1.0103	8.3997	-16.5907	9.9956	80.2769	9.9014	46.768	12.6172
70	0	-0.7696	8.3186	-16.3463	9.9378	80.1926	9.9194	46.4306	12.6259
71	0	-0.5265	8.236	-16.0915	9.8767	80.1174	9.9312	46.094	12.629
72	0	-0.2807	8.1523	-15.8259	9.8124	80.0524	9.9362	45.7577	12.6257
73	0	-0.0317	8.0676	-15.5495	9.7447	79.9982	9.9346	45.4211	12.6156
74	0	0.2209	7.9822	-15.262	9.6736	79.9554	9.9262	45.0837	12.5984

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
75	0	0.4777	7.8965	-14.9635	9.5988	79.9241	9.9115	44.7451	12.574
76	0	0.739	7.8109	-14.6538	9.5204	79.9044	9.8909	44.4045	12.5425
77	0	1.0055	7.7256	-14.3332	9.4381	79.896	9.8652	44.0616	12.5042
78	0	1.2775	7.6411	-14.0016	9.3518	79.8982	9.8352	43.7159	12.4596
79	0	1.5555	7.5576	-13.6592	9.2613	79.9102	9.8019	43.3668	12.4093
80	0	1.8399	7.4754	-13.3065	9.1664	79.9309	9.7666	43.014	12.3542
81	0	2.1311	7.395	-12.9436	9.0669	79.9589	9.7306	42.6569	12.2951
82	0	2.4295	7.3166	-12.571	8.9627	79.9927	9.6954	42.2951	12.2333
83	0	2.7352	7.2405	-12.1894	8.8536	80.0304	9.6623	41.9282	12.1698
84	0	3.0485	7.1669	-11.7994	8.7394	80.0702	9.6329	41.556	12.1059
85	0	3.3694	7.0961	-11.4018	8.6201	80.1101	9.6087	41.178	12.0428
86	0	3.6979	7.0281	-10.9973	8.4956	80.1479	9.5912	40.794	11.9817
87	0	4.0339	6.9632	-10.5871	8.3659	80.1815	9.5818	40.4039	11.9239
88	0	4.3772	6.9014	-10.1721	8.231	80.2089	9.5818	40.0075	11.8703
89	0	4.7274	6.8428	-9.7535	8.091	80.228	9.5923	39.6049	11.822
90	0	5.084	6.7873	-9.3326	7.9462	80.2369	9.6144	39.196	11.7798
91	0	5.4464	6.735	-8.9107	7.7966	80.2337	9.6489	38.7812	11.7444
92	0	5.814	6.6857	-8.4892	7.6427	80.2169	9.6965	38.3607	11.7162
93	0	6.1858	6.6394	-8.0694	7.4848	80.1851	9.7575	37.9349	11.6954

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
94	0	6.561	6.596	-7.6527	7.3234	80.1372	9.8321	37.5043	11.6821
95	0	6.9386	6.5552	-7.2407	7.1591	80.0723	9.9203	37.0697	11.6761
96	0	7.3174	6.5169	-6.8348	6.9923	79.9899	10.0217	36.6318	11.6769
97	0	7.6964	6.4808	-6.4362	6.8239	79.8898	10.1358	36.1915	11.6839
98	0	8.0744	6.4468	-6.0463	6.6545	79.772	10.2618	35.7498	11.6961
99	0	8.4502	6.4147	-5.6664	6.485	79.6369	10.3989	35.3079	11.7126
100	0	8.8227	6.3842	-5.2976	6.316	79.4852	10.5457	34.8668	11.7321
101	0	9.1906	6.355	-4.9408	6.1484	79.3179	10.701	34.4279	11.7531
102	0	9.5529	6.3271	-4.597	5.9832	79.1363	10.8633	33.9925	11.7742
103	0	9.9086	6.3001	-4.2669	5.821	78.942	11.0309	33.5619	11.7938
104	0	10.2567	6.2739	-3.9509	5.6629	78.7367	11.2022	33.1377	11.8103
105	0	10.5964	6.2484	-3.6495	5.5095	78.5225	11.3755	32.721	11.8221
106	0	10.927	6.2235	-3.3629	5.3616	78.3014	11.5489	32.3134	11.8277
107	0	11.248	6.1989	-3.0909	5.2199	78.0757	11.7208	31.9161	11.8255
108	0	11.559	6.1747	-2.8334	5.0852	77.8478	11.8894	31.5304	11.8142
109	0	11.8597	6.1507	-2.5901	4.9579	77.6201	12.053	31.1576	11.7927
110	0	12.1501	6.127	-2.3602	4.8386	77.3951	12.2102	30.7987	11.7599
111	0	12.4303	6.1035	-2.143	4.7276	77.1752	12.3596	30.4549	11.7152
112	0	12.7006	6.0803	-1.9377	4.6253	76.9627	12.4998	30.1269	11.6579

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
113	0	12.9614	6.0573	-1.7431	4.5318	76.7598	12.63	29.8157	11.588
114	0	13.2132	6.0346	-1.5581	4.4473	76.5688	12.7491	29.5219	11.5054
115	0	13.4569	6.0123	-1.3814	4.3718	76.3916	12.8565	29.246	11.4105
116	0	13.6931	5.9904	-1.2116	4.3051	76.23	12.9517	28.9886	11.304
117	0	13.9229	5.9689	-1.0473	4.2471	76.0856	13.0346	28.7499	11.1867
118	0	14.1472	5.9478	-0.8871	4.1974	75.9598	13.1049	28.53	11.0599
119	0	14.3672	5.9273	-0.7295	4.1558	75.8537	13.163	28.3292	10.9251
120	0	14.5837	5.9073	-0.5731	4.1217	75.7684	13.2091	28.1474	10.7839
121	0	14.7981	5.8879	-0.4167	4.0946	75.7046	13.2437	27.9846	10.6382
122	0	15.0112	5.8689	-0.2588	4.0741	75.6626	13.2675	27.8404	10.4901
123	0	15.224	5.8503	-0.0984	4.0594	75.6428	13.2813	27.7149	10.3418
124	0	15.4376	5.8321	0.0656	4.05	75.6452	13.2861	27.6076	10.1953
125	0	15.6527	5.814	0.2341	4.0452	75.6697	13.2829	27.5183	10.0531
126	0	15.87	5.7961	0.4078	4.0444	75.7157	13.2726	27.4467	9.9174
127	0	16.0901	5.778	0.5872	4.0469	75.7828	13.2565	27.3925	9.7903
128	0	16.3134	5.7597	0.7728	4.052	75.8703	13.2357	27.3552	9.6739
129	0	16.5401	5.7408	0.9648	4.0593	75.9773	13.2111	27.3345	9.5702
130	0	16.7704	5.7211	1.1632	4.0681	76.1027	13.184	27.3302	9.4808
131	0	17.0042	5.7005	1.3678	4.0778	76.2454	13.1553	27.3418	9.4072

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
132	0	17.2412	5.6785	1.5782	4.0881	76.4043	13.1258	27.369	9.3507
133	0	17.4811	5.655	1.7941	4.0985	76.578	13.0965	27.4115	9.3122
134	0	17.7233	5.6296	2.0146	4.1087	76.7652	13.068	27.4689	9.2923
135	0	17.9672	5.6021	2.2392	4.1182	76.9645	13.0408	27.5407	9.2913
136	0	18.212	5.5724	2.4668	4.127	77.1744	13.0155	27.6267	9.3091
137	0	18.4567	5.5401	2.6965	4.1347	77.3935	12.9923	27.7263	9.3453
138	0	18.7005	5.5051	2.9273	4.1412	77.6204	12.9713	27.839	9.3992
139	0	18.9423	5.4672	3.158	4.1464	77.8537	12.9525	27.9642	9.4697
140	0	19.1811	5.4265	3.3876	4.1503	78.0918	12.936	28.1013	9.5556
141	0	19.4159	5.3827	3.6149	4.1528	78.3335	12.9212	28.2495	9.6552
142	0	19.6457	5.336	3.8389	4.154	78.5773	12.908	28.4079	9.7666
143	0	19.8696	5.2863	4.0585	4.1538	78.8221	12.8959	28.5756	9.8878
144	0	20.0865	5.2339	4.2727	4.1523	79.0665	12.8843	28.7516	10.0166
145	0	20.2959	5.1788	4.4808	4.1495	79.3094	12.8725	28.9347	10.1505
146	0	20.4969	5.1213	4.6819	4.1456	79.5498	12.8599	29.1236	10.2872
147	0	20.6892	5.0618	4.8753	4.1405	79.7865	12.8457	29.3169	10.4242
148	0	20.8721	5.0004	5.0607	4.1343	80.0187	12.8293	29.5134	10.5591
149	0	21.0455	4.9377	5.2375	4.1271	80.2455	12.8099	29.7114	10.6894
150	0	21.2092	4.874	5.4056	4.1188	80.4663	12.7867	29.9096	10.8129

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
151	0	21.3634	4.8098	5.5648	4.1095	80.6804	12.759	30.1063	10.9274
152	0	21.508	4.7455	5.7153	4.0991	80.8873	12.7263	30.3002	11.0309
153	0	21.6436	4.6817	5.8571	4.0877	81.0866	12.6878	30.4896	11.1218
154	0	21.7704	4.6187	5.9906	4.0751	81.2782	12.6432	30.6734	11.1985
155	0	21.8891	4.5571	6.1163	4.0615	81.4618	12.5918	30.8502	11.2599
156	0	22.0002	4.4973	6.2346	4.0465	81.6375	12.5335	31.0189	11.3049
157	0	22.1046	4.4398	6.3462	4.0303	81.8054	12.4678	31.1786	11.3329
158	0	22.2029	4.3849	6.4517	4.0128	81.9658	12.3947	31.3286	11.3436
159	0	22.296	4.333	6.552	3.9938	82.1191	12.3141	31.4684	11.337
160	0	22.3847	4.2843	6.6478	3.9733	82.2659	12.2259	31.5978	11.3134
161	0	22.4697	4.2392	6.7399	3.9512	82.4067	12.1303	31.7168	11.2733
162	0	22.5519	4.1978	6.8292	3.9276	82.5424	12.0276	31.8258	11.2175
163	0	22.6321	4.1602	6.9163	3.9024	82.6738	11.9179	31.9254	11.1472
164	0	22.7107	4.1264	7.0022	3.8757	82.8018	11.8017	32.0165	11.0636
165	0	22.7885	4.0965	7.0874	3.8474	82.9275	11.6794	32.1003	10.9682
166	0	22.8658	4.0702	7.1727	3.8176	83.0518	11.5515	32.1783	10.8627
167	0	22.9431	4.0475	7.2586	3.7864	83.1759	11.4185	32.2521	10.7488
168	0	23.0206	4.028	7.3457	3.754	83.3009	11.2811	32.3237	10.6284
169	0	23.0985	4.0116	7.4342	3.7205	83.4278	11.1399	32.3951	10.5035

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
170	0	23.1768	3.9979	7.5246	3.686	83.5576	10.9956	32.4686	10.3759
171	0	23.2554	3.9865	7.6171	3.6509	83.6914	10.8488	32.5462	10.2476
172	0	23.3342	3.977	7.7117	3.6153	83.83	10.7003	32.6305	10.1203
173	0	23.4128	3.969	7.8085	3.5794	83.9741	10.5508	32.7234	9.9958
174	0	23.4911	3.9621	7.9074	3.5436	84.1245	10.4009	32.8273	9.8758
175	0	23.5685	3.9559	8.0082	3.5081	84.2817	10.2514	32.9442	9.7617
176	0	23.6447	3.9499	8.1107	3.4732	84.4459	10.103	33.0756	9.6549
177	0	23.7192	3.9438	8.2145	3.4392	84.6175	9.9563	33.2233	9.5564
178	0	23.7916	3.9372	8.3194	3.4063	84.7962	9.8119	33.3883	9.4672
179	0	23.8614	3.9299	8.4248	3.3748	84.982	9.6705	33.5715	9.388
180	0	23.9282	3.9215	8.5302	3.3449	85.1744	9.5327	33.7734	9.3192
181	0	23.9917	3.9119	8.6352	3.3169	85.3729	9.3989	33.9939	9.2613
182	0	24.0517	3.901	8.7392	3.2909	85.5766	9.2698	34.2325	9.2142
183	0	24.1078	3.8888	8.8416	3.2672	85.7846	9.1457	34.4885	9.1778
184	0	24.1599	3.8751	8.942	3.2459	85.9959	9.0271	34.7605	9.1518
185	0	24.2082	3.8603	9.0399	3.227	86.2092	8.9143	35.0466	9.1357
186	0	24.2526	3.8444	9.1346	3.2107	86.4231	8.8077	35.3447	9.1288
187	0	24.2933	3.8276	9.2258	3.197	86.6363	8.7075	35.6523	9.1304
188	0	24.3306	3.8102	9.3131	3.186	86.8472	8.6139	35.9665	9.1396

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
189	0	24.3649	3.7927	9.3959	3.1775	87.0543	8.527	36.284	9.1553
190	0	24.3966	3.7753	9.474	3.1717	87.2562	8.447	36.6015	9.1764
191	0	24.4263	3.7586	9.547	3.1684	87.4515	8.3738	36.9155	9.202
192	0	24.4544	3.743	9.6148	3.1676	87.6386	8.3073	37.2224	9.2308
193	0	24.4816	3.7289	9.677	3.1692	87.8165	8.2476	37.5186	9.2619
194	0	24.5085	3.7168	9.7336	3.173	87.9839	8.1943	37.8007	9.294
195	0	24.5358	3.7072	9.7845	3.179	88.1399	8.1473	38.0654	9.3262
196	0	24.5638	3.7006	9.8294	3.1871	88.2838	8.1061	38.3096	9.3576
197	0	24.5932	3.6973	9.8685	3.1972	88.4151	8.0704	38.5307	9.3873
198	0	24.6244	3.6977	9.9017	3.2091	88.5334	8.0398	38.7264	9.4145
199	0	24.6577	3.7021	9.9291	3.2227	88.6386	8.0137	38.8947	9.4387
200	0	24.6933	3.7107	9.9506	3.238	88.7311	7.9915	39.0346	9.4594
201	0	24.7314	3.7238	9.9664	3.2549	88.811	7.9727	39.1451	9.4762
202	0	24.7718	3.7414	9.9766	3.2732	88.8793	7.9566	39.2261	9.4889
203	0	24.8145	3.7635	9.9811	3.2929	88.9366	7.9424	39.2781	9.4974
204	0	24.8589	3.79	9.9802	3.314	88.9842	7.9295	39.3021	9.5018
205	0	24.9046	3.8209	9.9738	3.3363	89.0233	7.9172	39.2998	9.5024
206	0	24.951	3.8558	9.9622	3.3598	89.0554	7.9047	39.2732	9.4994
207	0	24.9972	3.8946	9.9452	3.3844	89.082	7.8912	39.2253	9.4933

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
208	0	25.0423	3.9366	9.923	3.41	89.1049	7.8762	39.1591	9.4846
209	0	25.0852	3.9817	9.8956	3.4365	89.1257	7.8589	39.0783	9.4741
210	0	25.1246	4.0291	9.863	3.4639	89.1462	7.8387	38.9867	9.4623
211	0	25.1594	4.0785	9.8253	3.492	89.1681	7.8151	38.8887	9.4502
212	0	25.1882	4.1292	9.7823	3.5207	89.193	7.7877	38.7885	9.4385
213	0	25.2097	4.1806	9.7341	3.5498	89.2226	7.756	38.6905	9.4281
214	0	25.2225	4.2322	9.6806	3.5792	89.2581	7.7198	38.5992	9.4199
215	0	25.2253	4.2833	9.6218	3.6086	89.3009	7.6789	38.5186	9.4146
216	0	25.2167	4.3335	9.5575	3.6378	89.3521	7.6332	38.453	9.4132
217	0	25.1957	4.382	9.4876	3.6665	89.4123	7.5828	38.4059	9.4163
218	0	25.161	4.4286	9.4122	3.6946	89.4821	7.5278	38.3807	9.4248
219	0	25.1118	4.4726	9.331	3.7218	89.5619	7.4686	38.3801	9.4393
220	0	25.0471	4.5138	9.244	3.7476	89.6517	7.4055	38.4064	9.4602
221	0	24.9666	4.5519	9.151	3.772	89.7512	7.3391	38.4613	9.4881
222	0	24.8695	4.5866	9.052	3.7944	89.8598	7.2701	38.5458	9.5233
223	0	24.7558	4.6178	8.947	3.8148	89.9768	7.1991	38.6603	9.5661
224	0	24.6254	4.6455	8.8358	3.8328	90.1012	7.127	38.8045	9.6165
225	0	24.4784	4.6696	8.7183	3.8482	90.2317	7.0547	38.9774	9.6745
226	0	24.3154	4.6904	8.5947	3.8607	90.3668	6.9832	39.1774	9.7401

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
227	0	24.1368	4.7081	8.4647	3.8702	90.5049	6.9135	39.4023	9.8128
228	0	23.9435	4.7228	8.3286	3.8766	90.6442	6.8466	39.6492	9.8923
229	0	23.7364	4.7351	8.1863	3.8799	90.7828	6.7836	39.915	9.9781
230	0	23.5168	4.7453	8.0379	3.8799	90.9189	6.7256	40.1958	10.0696
231	0	23.2858	4.7538	7.8836	3.8769	91.0505	6.6735	40.4877	10.1661
232	0	23.0448	4.7613	7.7234	3.8709	91.1756	6.6283	40.7863	10.2667
233	0	22.7955	4.7682	7.5576	3.8621	91.2924	6.5909	41.0872	10.3705
234	0	22.5392	4.7751	7.3864	3.8508	91.3991	6.5621	41.3859	10.4767
235	0	22.2775	4.7825	7.2101	3.8373	91.494	6.5426	41.6779	10.5842
236	0	22.0122	4.7911	7.0288	3.8221	91.5757	6.533	41.9589	10.6919
237	0	21.7446	4.8014	6.8431	3.8056	91.6427	6.5338	42.2248	10.799
238	0	21.4764	4.8138	6.6531	3.7883	91.6941	6.5453	42.4718	10.9042
239	0	21.209	4.8289	6.4594	3.7708	91.7288	6.5676	42.6966	11.0067
240	0	20.9436	4.847	6.2624	3.7537	91.7463	6.6008	42.8962	11.1055
241	0	20.6815	4.8684	6.0625	3.7375	91.7461	6.6447	43.0683	11.1997
242	0	20.4237	4.8935	5.8602	3.7229	91.728	6.6992	43.2111	11.2885
243	0	20.1712	4.9225	5.656	3.7105	91.6921	6.7636	43.3234	11.3711
244	0	19.9246	4.9555	5.4504	3.7008	91.6387	6.8376	43.4047	11.4469
245	0	19.6846	4.9925	5.2441	3.6944	91.5681	6.9203	43.4549	11.5155

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
246	0	19.4515	5.0334	5.0375	3.6918	91.4812	7.011	43.4747	11.5765
247	0	19.2256	5.0783	4.8312	3.6934	91.3786	7.1088	43.4654	11.6296
248	0	19.0068	5.1269	4.6258	3.6994	91.2616	7.2126	43.4288	11.6748
249	0	18.795	5.1789	4.4218	3.7103	91.131	7.3213	43.3671	11.7123
250	0	18.59	5.234	4.2198	3.726	90.9882	7.434	43.2832	11.7421
251	0	18.3914	5.2919	4.0202	3.7467	90.8344	7.5493	43.18	11.7648
252	0	18.1986	5.3521	3.8237	3.7722	90.671	7.6661	43.0611	11.7808
253	0	18.011	5.4141	3.6305	3.8024	90.4992	7.7833	42.9299	11.7908
254	0	17.8279	5.4775	3.4413	3.837	90.3204	7.8997	42.7904	11.7957
255	0	17.6484	5.5418	3.2563	3.8755	90.136	8.0143	42.6462	11.7963
256	0	17.4718	5.6064	3.0758	3.9175	89.9471	8.126	42.5013	11.7938
257	0	17.2972	5.6708	2.9002	3.9623	89.755	8.2339	42.3592	11.7892
258	0	17.1238	5.7344	2.7297	4.0091	89.5609	8.3372	42.2236	11.7838
259	0	16.9506	5.7969	2.5643	4.0574	89.3656	8.435	42.0977	11.7788
260	0	16.7769	5.8576	2.4041	4.1061	89.1703	8.5268	41.9846	11.7754
261	0	16.602	5.9163	2.2492	4.1546	88.9758	8.612	41.887	11.7751
262	0	16.425	5.9724	2.0994	4.2019	88.7829	8.6902	41.8073	11.779
263	0	16.2453	6.0256	1.9546	4.2471	88.5924	8.7612	41.7474	11.7885
264	0	16.0624	6.0757	1.8145	4.2895	88.4049	8.8248	41.7091	11.8046

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
265	0	15.8756	6.1223	1.6789	4.3282	88.221	8.881	41.6934	11.8285
266	0	15.6847	6.1653	1.5473	4.3625	88.0413	8.9298	41.7013	11.8612
267	0	15.4892	6.2044	1.4193	4.3919	87.8663	8.9714	41.7333	11.9035
268	0	15.2887	6.2396	1.2943	4.4157	87.6966	9.0061	41.7897	11.9562
269	0	15.0831	6.2709	1.1718	4.4336	87.5326	9.0342	41.8703	12.0198
270	0	14.8722	6.2981	1.0511	4.4454	87.3748	9.0561	41.9749	12.0948
271	0	14.6558	6.3213	0.9316	4.4509	87.2239	9.0722	42.103	12.1812
272	0	14.4339	6.3406	0.8125	4.4501	87.0802	9.0832	42.254	12.2792
273	0	14.2063	6.3561	0.6931	4.4434	86.9445	9.0894	42.4273	12.3886
274	0	13.9729	6.3678	0.5726	4.431	86.8172	9.0914	42.6222	12.5089
275	0	13.7338	6.3759	0.4502	4.4134	86.699	9.0897	42.838	12.6397
276	0	13.4888	6.3807	0.3251	4.3913	86.5905	9.0848	43.0741	12.7801
277	0	13.238	6.3821	0.1967	4.3656	86.4923	9.0771	43.3301	12.9292
278	0	12.9811	6.3805	0.064	4.3371	86.4051	9.0672	43.6056	13.086
279	0	12.718	6.376	-0.0736	4.3069	86.3296	9.0553	43.9004	13.249
280	0	12.4487	6.3688	-0.2168	4.2761	86.2662	9.0418	44.2144	13.417
281	0	12.1729	6.3591	-0.3663	4.2458	86.2156	9.0269	44.5479	13.5883
282	0	11.8903	6.3471	-0.5228	4.2174	86.1781	9.0109	44.9012	13.7614
283	0	11.6009	6.333	-0.6868	4.1921	86.1543	8.9937	45.2748	13.9346

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
284	0	11.3042	6.317	-0.8587	4.1711	86.1443	8.9755	45.6693	14.1061
285	0	11	6.2993	-1.0392	4.1556	86.1483	8.9563	46.0853	14.274
286	0	10.6879	6.2802	-1.2286	4.1467	86.1663	8.936	46.5238	14.4367
287	0	10.3677	6.2597	-1.4273	4.1456	86.1981	8.9145	46.9853	14.5923
288	0	10.0391	6.2383	-1.6355	4.1531	86.2434	8.8916	47.4707	14.7392
289	0	9.7017	6.216	-1.8535	4.1701	86.3015	8.867	47.9806	14.8756
290	0	9.3553	6.1933	-2.0815	4.1973	86.3719	8.8406	48.5155	15
291	0	8.9998	6.1702	-2.3197	4.2352	86.4536	8.8121	49.0756	15.1111
292	0	8.6348	6.1472	-2.5682	4.2841	86.5455	8.7812	49.661	15.2073
293	0	8.2604	6.1246	-2.827	4.3442	86.6462	8.7477	50.2715	15.2876
294	0	7.8764	6.1027	-3.0961	4.4156	86.7543	8.7114	50.9062	15.3511
295	0	7.483	6.0818	-3.3755	4.498	86.8682	8.6719	51.5644	15.3967
296	0	7.0802	6.0624	-3.6653	4.5911	86.9861	8.6292	52.2445	15.424
297	0	6.6684	6.0449	-3.9652	4.6943	87.1063	8.5831	52.9447	15.4324
298	0	6.2477	6.0297	-4.2753	4.807	87.2267	8.5334	53.6628	15.4217
299	0	5.8188	6.0174	-4.5954	4.9284	87.3454	8.4803	54.3961	15.3918
300	0	5.382	6.0083	-4.9255	5.0574	87.4605	8.4236	55.1416	15.3429
301	0	4.9381	6.003	-5.2652	5.1932	87.5699	8.3635	55.8958	15.2752
302	0	4.4877	6.002	-5.6145	5.3345	87.6719	8.3002	56.6549	15.1893

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
303	0	4.0316	6.0058	-5.9732	5.4802	87.7645	8.2338	57.4149	15.0859
304	0	3.5707	6.0149	-6.3411	5.6291	87.8463	8.1648	58.1716	14.9657
305	0	3.106	6.0298	-6.7178	5.7801	87.9158	8.0934	58.9206	14.8298
306	0	2.6383	6.0509	-7.1032	5.9319	87.9716	8.0201	59.6573	14.6793
307	0	2.1689	6.0786	-7.4968	6.0834	88.0127	7.9454	60.3774	14.5154
308	0	1.6987	6.1135	-7.8984	6.2336	88.0384	7.8699	61.0765	14.3395
309	0	1.2287	6.1557	-8.3075	6.3815	88.0481	7.7942	61.7503	14.1532
310	0	0.7602	6.2056	-8.7236	6.5263	88.0416	7.7189	62.3949	13.9578
311	0	0.294	6.2635	-9.1462	6.6671	88.0189	7.6448	63.0066	13.755
312	0	-0.1687	6.3294	-9.5747	6.8035	87.9803	7.5724	63.5822	13.5464
313	0	-0.627	6.4036	-10.0084	6.935	87.9263	7.5026	64.1189	13.3337
314	0	-1.0799	6.4858	-10.4466	7.0612	87.8579	7.4361	64.6144	13.1186
315	0	-1.5266	6.5762	-10.8885	7.182	87.7759	7.3736	65.0671	12.9027
316	0	-1.9662	6.6745	-11.3331	7.2974	87.6818	7.3158	65.4757	12.6877
317	0	-2.3981	6.7805	-11.7796	7.4075	87.5768	7.2634	65.8398	12.4751
318	0	-2.8217	6.8938	-12.2268	7.5125	87.4627	7.2171	66.1595	12.2666
319	0	-3.2363	7.014	-12.6736	7.6127	87.341	7.1775	66.4354	12.0636
320	0	-3.6416	7.1406	-13.119	7.7087	87.2136	7.1451	66.6688	11.8675
321	0	-4.0371	7.273	-13.5616	7.8009	87.0821	7.1206	66.8617	11.6797

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
322	0	-4.4226	7.4105	-14.0003	7.89	86.9483	7.1042	67.0164	11.5013
323	0	-4.798	7.5526	-14.4337	7.9765	86.8139	7.0964	67.1356	11.3336
324	0	-5.1631	7.6983	-14.8606	8.0611	86.6804	7.0975	67.2226	11.1775
325	0	-5.5179	7.847	-15.2798	8.1445	86.5494	7.1076	67.2809	11.0339
326	0	-5.8625	7.9977	-15.6899	8.2273	86.4221	7.127	67.3143	10.9034
327	0	-6.1969	8.1496	-16.0898	8.31	86.2996	7.1556	67.3266	10.7868
328	0	-6.5214	8.3019	-16.4783	8.3932	86.1827	7.1933	67.3218	10.6845
329	0	-6.8362	8.4537	-16.8545	8.4773	86.0722	7.2401	67.3039	10.5967
330	0	-7.1414	8.6041	-17.2172	8.5626	85.9685	7.2956	67.2767	10.5236
331	0	-7.4375	8.7524	-17.5658	8.6495	85.8717	7.3594	67.2439	10.4652
332	0	-7.7248	8.8978	-17.8996	8.7381	85.7817	7.4313	67.2088	10.4212
333	0	-8.0035	9.0395	-18.2179	8.8283	85.6982	7.5105	67.1745	10.3914
334	0	-8.2741	9.177	-18.5205	8.9202	85.6208	7.5965	67.1436	10.3752
335	0	-8.5369	9.3095	-18.8071	9.0136	85.5488	7.6886	67.1184	10.3719
336	0	-8.7923	9.4367	-19.0777	9.1081	85.4812	7.786	67.1006	10.3809
337	0	-9.0406	9.558	-19.3325	9.2034	85.4172	7.8878	67.0916	10.401
338	0	-9.2822	9.6731	-19.572	9.299	85.3555	7.9932	67.092	10.4312
339	0	-9.5174	9.7818	-19.7965	9.3944	85.2951	8.1012	67.1021	10.4704
340	0	-9.7467	9.8838	-20.007	9.489	85.2347	8.2108	67.1217	10.5171

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
341	0	-9.9703	9.9791	-20.2043	9.5821	85.1733	8.321	67.15	10.57
342	0	-10.1885	10.0677	-20.3894	9.6732	85.1096	8.4308	67.1861	10.6276
343	0	-10.4016	10.1496	-20.5636	9.7615	85.0427	8.5391	67.2283	10.6883
344	0	-10.61	10.225	-20.7281	9.8465	84.9716	8.645	67.2749	10.7505
345	0	-10.814	10.2942	-20.8845	9.9275	84.8957	8.7474	67.3239	10.8127
346	0	-11.0136	10.3574	-21.0341	10.004	84.8143	8.8454	67.3729	10.8731
347	0	-11.2093	10.415	-21.1786	10.0755	84.727	8.9381	67.4197	10.9303
348	0	-11.4012	10.4673	-21.3194	10.1416	84.6337	9.0247	67.4618	10.9827
349	0	-11.5894	10.5149	-21.458	10.2019	84.5344	9.1044	67.4969	11.0289
350	0	-11.7743	10.5582	-21.596	10.2563	84.4294	9.1766	67.5227	11.0676
351	0	-11.9558	10.5976	-21.7346	10.3047	84.3191	9.2408	67.5373	11.0975
352	0	-12.1341	10.6337	-21.8752	10.347	84.2043	9.2965	67.5386	11.1175
353	0	-12.3093	10.6669	-22.0189	10.3833	84.0858	9.3435	67.5252	11.1269
354	0	-12.4814	10.6978	-22.1666	10.4139	83.9646	9.3815	67.4957	11.1248
355	0	-12.6504	10.7266	-22.3192	10.4391	83.8419	9.4106	67.4494	11.1109
356	0	-12.8161	10.754	-22.4771	10.4592	83.719	9.4308	67.3857	11.0847
357	0	-12.9785	10.7803	-22.6408	10.4748	83.5972	9.4424	67.3046	11.0464
358	0	-13.1374	10.8057	-22.8103	10.4863	83.478	9.4458	67.2062	10.996
359	0	-13.2924	10.8307	-22.9856	10.4945	83.3626	9.4414	67.0913	10.934

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
360	0	-13.4434	10.8555	-23.1662	10.5	83.2525	9.43	66.961	10.8611
361	0	-13.5898	10.8801	-23.3515	10.5033	83.1489	9.4122	66.8166	10.7781
362	0	-13.7313	10.9049	-23.5408	10.5053	83.053	9.3889	66.6597	10.6862
363	0	-13.8673	10.9298	-23.7329	10.5066	82.9658	9.3611	66.4923	10.5867
364	0	-13.9972	10.955	-23.9265	10.5078	82.8882	9.3297	66.3165	10.4811
365	0	-14.1204	10.9802	-24.1204	10.5094	82.8209	9.2959	66.1345	10.371
1	1	-14.2471	8.8098	-23.8273	8.373	84.351	8.6938	69.0097	9.4616
2	1	-14.3828	8.8643	-23.961	8.3411	84.2642	8.6819	68.9006	9.409
3	1	-14.5068	8.9171	-24.0857	8.3085	84.1856	8.6613	68.794	9.3519
4	1	-14.6173	8.9675	-24.2001	8.2761	84.116	8.6323	68.6911	9.2913
5	1	-14.713	9.0148	-24.303	8.2446	84.0562	8.5955	68.5928	9.2284
6	1	-14.7925	9.0585	-24.3932	8.215	84.0066	8.5516	68.5002	9.1644
7	1	-14.855	9.0979	-24.4697	8.188	83.9676	8.5014	68.414	9.1005
8	1	-14.8997	9.1324	-24.5317	8.1645	83.9394	8.4458	68.3348	9.038
9	1	-14.9259	9.1617	-24.5787	8.1449	83.9219	8.3861	68.263	8.978
10	1	-14.9335	9.1853	-24.6101	8.13	83.9149	8.3231	68.1989	8.9218
11	1	-14.9225	9.203	-24.6259	8.1203	83.9179	8.2583	68.1425	8.8704
12	1	-14.8931	9.2146	-24.626	8.1161	83.9304	8.1926	68.0936	8.8248
13	1	-14.8459	9.22	-24.6108	8.1176	83.9516	8.1274	68.0516	8.7859

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
14	1	-14.7816	9.2192	-24.5807	8.1252	83.9805	8.0639	68.0159	8.7543
15	1	-14.7012	9.2124	-24.5364	8.1387	84.0162	8.003	67.9856	8.7307
16	1	-14.606	9.1997	-24.4787	8.158	84.0574	7.946	67.9595	8.7153
17	1	-14.4971	9.1816	-24.4087	8.183	84.103	7.8936	67.9364	8.7085
18	1	-14.3761	9.1584	-24.3277	8.2132	84.1517	7.8468	67.9147	8.7101
19	1	-14.2447	9.1306	-24.2367	8.2482	84.2023	7.8062	67.8928	8.72
20	1	-14.1043	9.0987	-24.1374	8.2875	84.2535	7.7723	67.869	8.738
21	1	-13.9567	9.0633	-24.031	8.3302	84.304	7.7456	67.8414	8.7634
22	1	-13.8036	9.025	-23.9189	8.3757	84.3527	7.7261	67.8084	8.7958
23	1	-13.6465	8.9845	-23.8027	8.4232	84.3985	7.7138	67.768	8.8343
24	1	-13.487	8.9424	-23.6837	8.4717	84.4406	7.7087	67.7185	8.8781
25	1	-13.3265	8.8992	-23.563	8.5202	84.478	7.7104	67.6583	8.9264
26	1	-13.1662	8.8557	-23.442	8.568	84.5103	7.7184	67.5858	8.9781
27	1	-13.0073	8.8121	-23.3215	8.6139	84.5368	7.732	67.4996	9.0324
28	1	-12.8507	8.7692	-23.2025	8.657	84.5575	7.7505	67.3986	9.0883
29	1	-12.697	8.7271	-23.0856	8.6964	84.572	7.773	67.2819	9.145
30	1	-12.5468	8.6863	-22.9712	8.7314	84.5807	7.7984	67.1488	9.2017
31	1	-12.4003	8.6469	-22.8595	8.7609	84.5837	7.8259	66.9989	9.2577
32	1	-12.2575	8.609	-22.7507	8.7845	84.5815	7.8542	66.8321	9.3124

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
33	1	-12.1184	8.5727	-22.6445	8.8014	84.5747	7.8823	66.6487	9.3654
34	1	-11.9824	8.5378	-22.5405	8.8111	84.5642	7.9092	66.449	9.4165
35	1	-11.8489	8.5043	-22.4382	8.8133	84.5509	7.9337	66.234	9.4654
36	1	-11.7173	8.4717	-22.3367	8.8077	84.5357	7.9549	66.0046	9.5124
37	1	-11.5866	8.4398	-22.2351	8.7942	84.5198	7.972	65.7621	9.5574
38	1	-11.4557	8.4082	-22.1325	8.7727	84.5042	7.9842	65.508	9.601
39	1	-11.3236	8.3763	-22.0275	8.7435	84.4903	7.9908	65.2442	9.6435
40	1	-11.1889	8.3436	-21.9191	8.7068	84.4791	7.9914	64.9724	9.6855
41	1	-11.0506	8.3096	-21.8059	8.663	84.4718	7.9857	64.6946	9.7278
42	1	-10.9073	8.2738	-21.6867	8.6126	84.4695	7.9735	64.413	9.7709
43	1	-10.7578	8.2355	-21.5602	8.5564	84.4731	7.9548	64.1295	9.8159
44	1	-10.6011	8.1943	-21.4253	8.4949	84.4836	7.9299	63.8463	9.8633
45	1	-10.4361	8.1496	-21.2808	8.4292	84.5017	7.8991	63.5653	9.9139
46	1	-10.2618	8.101	-21.1259	8.3599	84.5279	7.8629	63.2884	9.9685
47	1	-10.0775	8.0481	-20.9598	8.2882	84.5628	7.822	63.0174	10.0276
48	1	-9.8827	7.9907	-20.7818	8.215	84.6065	7.7772	62.7538	10.0917
49	1	-9.6768	7.9285	-20.5914	8.1413	84.6593	7.7294	62.4989	10.1612
50	1	-9.4597	7.8615	-20.3885	8.0681	84.7209	7.6796	62.2539	10.2363
51	1	-9.2314	7.7896	-20.1731	7.9964	84.7912	7.6287	62.0195	10.317

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
52	1	-8.992	7.713	-19.9452	7.9272	84.8698	7.5779	61.7962	10.4032
53	1	-8.7419	7.6318	-19.7054	7.8612	84.956	7.5283	61.5843	10.4944
54	1	-8.4817	7.5465	-19.4542	7.7995	85.0493	7.4808	61.3838	10.5902
55	1	-8.2121	7.4576	-19.1924	7.7426	85.1487	7.4365	61.1943	10.6898
56	1	-7.9341	7.3654	-18.921	7.6911	85.2534	7.3963	61.0152	10.7923
57	1	-7.6487	7.2707	-18.6411	7.6457	85.3624	7.361	60.8456	10.8969
58	1	-7.3571	7.1742	-18.3538	7.6066	85.4748	7.3312	60.6845	11.0023
59	1	-7.0605	7.0767	-18.0605	7.5741	85.5895	7.3076	60.5307	11.1073
60	1	-6.7602	6.9789	-17.7626	7.5483	85.7055	7.2905	60.3827	11.2106
61	1	-6.4576	6.8817	-17.4614	7.5292	85.8218	7.2801	60.2391	11.3111
62	1	-6.1541	6.786	-17.1582	7.5165	85.9376	7.2765	60.0983	11.4075
63	1	-5.8509	6.6926	-16.8545	7.51	86.0521	7.2795	59.9587	11.4986
64	1	-5.5494	6.6025	-16.5515	7.5091	86.1646	7.2888	59.8187	11.5834
65	1	-5.2507	6.5163	-16.2503	7.5134	86.2745	7.304	59.677	11.6609
66	1	-4.9558	6.4348	-15.9518	7.522	86.3813	7.3244	59.5321	11.7306
67	1	-4.6658	6.3587	-15.6571	7.5342	86.4848	7.3493	59.3828	11.7919
68	1	-4.3813	6.2886	-15.3666	7.549	86.5848	7.3778	59.2281	11.8446
69	1	-4.1029	6.225	-15.0808	7.5655	86.6815	7.409	59.0671	11.8887
70	1	-3.8311	6.1683	-14.8001	7.5827	86.7748	7.4418	58.8993	11.9246

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
71	1	-3.5661	6.1187	-14.5244	7.5994	86.8652	7.4751	58.7244	11.9529
72	1	-3.3079	6.0764	-14.2536	7.6146	86.953	7.5078	58.5421	11.9745
73	1	-3.0563	6.0415	-13.9873	7.6271	87.0389	7.539	58.3528	11.9907
74	1	-2.8109	6.0138	-13.7249	7.6359	87.1234	7.5676	58.1568	12.0029
75	1	-2.5712	5.9933	-13.4657	7.6399	87.2072	7.5927	57.9547	12.0128
76	1	-2.3365	5.9795	-13.2087	7.6381	87.2911	7.6134	57.7473	12.0225
77	1	-2.1059	5.972	-12.9529	7.6295	87.3758	7.6291	57.5357	12.0339
78	1	-1.8785	5.9705	-12.6971	7.6134	87.4621	7.6393	57.321	12.0493
79	1	-1.6529	5.9742	-12.4401	7.5889	87.5507	7.6435	57.1044	12.071
80	1	-1.4282	5.9827	-12.1806	7.5555	87.6423	7.6415	56.8873	12.1013
81	1	-1.2031	5.995	-11.9173	7.5127	87.7374	7.6334	56.6709	12.1425
82	1	-0.9761	6.0106	-11.649	7.46	87.8365	7.6193	56.4566	12.1967
83	1	-0.7462	6.0286	-11.3743	7.3973	87.9399	7.5997	56.2455	12.2661
84	1	-0.512	6.0483	-11.0923	7.3244	88.0478	7.575	56.0386	12.3523
85	1	-0.2723	6.069	-10.8019	7.2414	88.1603	7.5459	55.837	12.4569
86	1	-0.0261	6.0898	-10.5023	7.1485	88.2772	7.5135	55.6412	12.5811
87	1	0.2278	6.1101	-10.1927	7.0461	88.3983	7.4786	55.4518	12.7257
88	1	0.4901	6.1292	-9.8727	6.9346	88.523	7.4423	55.2688	12.8913
89	1	0.7617	6.1466	-9.5421	6.8146	88.6508	7.4059	55.0923	13.0778

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
90	1	1.043	6.1617	-9.2007	6.6869	88.781	7.3705	54.9219	13.2848
91	1	1.3346	6.1741	-8.8488	6.5523	88.9125	7.3375	54.7568	13.5115
92	1	1.6366	6.1834	-8.4867	6.4117	89.0444	7.3081	54.5961	13.7565
93	1	1.9491	6.1894	-8.1151	6.2661	89.1756	7.2833	54.4386	14.0182
94	1	2.2719	6.1919	-7.7347	6.1165	89.3049	7.2644	54.2827	14.2944
95	1	2.6048	6.1908	-7.3467	5.9642	89.4311	7.2522	54.1268	14.5826
96	1	2.9471	6.1861	-6.9521	5.8101	89.553	7.2476	53.9689	14.8799
97	1	3.2984	6.1779	-6.5523	5.6556	89.6694	7.2513	53.8071	15.1833
98	1	3.6576	6.1664	-6.1489	5.5016	89.7792	7.2637	53.6392	15.4894
99	1	4.024	6.1517	-5.7433	5.3494	89.8812	7.285	53.4631	15.7948
100	1	4.3964	6.1343	-5.3373	5.2001	89.9746	7.3154	53.2767	16.0959
101	1	4.7737	6.1144	-4.9325	5.0546	90.0584	7.3546	53.0779	16.3891
102	1	5.1546	6.0924	-4.5305	4.914	90.132	7.4021	52.865	16.6709
103	1	5.5379	6.0688	-4.1331	4.7792	90.195	7.4574	52.6362	16.9381
104	1	5.9222	6.0439	-3.7418	4.6509	90.247	7.5196	52.3901	17.1874
105	1	6.3062	6.0183	-3.3581	4.5299	90.2879	7.5876	52.1258	17.4159
106	1	6.6886	5.9924	-2.9834	4.4168	90.3179	7.6603	51.8423	17.6213
107	1	7.0682	5.9665	-2.619	4.3121	90.3372	7.7362	51.5395	17.8013
108	1	7.4437	5.9412	-2.2658	4.2161	90.3465	7.8139	51.2174	17.9543

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
109	1	7.814	5.9167	-1.9249	4.1291	90.3463	7.8917	50.8765	18.079
110	1	8.1781	5.8935	-1.5968	4.0513	90.3378	7.9682	50.5179	18.1748
111	1	8.5351	5.8717	-1.2822	3.9827	90.3218	8.0415	50.1428	18.2415
112	1	8.8842	5.8517	-0.9813	3.9231	90.2998	8.1102	49.7533	18.2794
113	1	9.2248	5.8335	-0.6942	3.8723	90.2729	8.1726	49.3515	18.2894
114	1	9.5562	5.8174	-0.4208	3.8302	90.2427	8.2274	48.9403	18.2729
115	1	9.8783	5.8033	-0.1608	3.7962	90.2106	8.2732	48.5225	18.2317
116	1	10.1906	5.7913	0.0862	3.7699	90.1782	8.3088	48.1015	18.168
117	1	10.4932	5.7812	0.3209	3.7507	90.147	8.3334	47.6809	18.0845
118	1	10.786	5.7731	0.544	3.738	90.1184	8.3461	47.2644	17.9841
119	1	11.0693	5.7666	0.7563	3.7312	90.0939	8.3466	46.8559	17.8699
120	1	11.3434	5.7616	0.959	3.7294	90.0749	8.3345	46.4593	17.7455
121	1	11.6085	5.7578	1.153	3.732	90.0624	8.3098	46.0783	17.6142
122	1	11.8653	5.755	1.3394	3.7381	90.0575	8.2729	45.7167	17.4796
123	1	12.1142	5.7528	1.5193	3.7471	90.0611	8.2242	45.3782	17.3451
124	1	12.356	5.7508	1.6939	3.7581	90.0738	8.1645	45.0661	17.2141
125	1	12.5912	5.7488	1.8641	3.7704	90.096	8.0949	44.7832	17.0898
126	1	12.8206	5.7464	2.0312	3.7833	90.1281	8.0164	44.5324	16.9751
127	1	13.0449	5.7432	2.196	3.796	90.1701	7.9306	44.3157	16.8726

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
128	1	13.2648	5.7389	2.3594	3.808	90.2217	7.8388	44.1351	16.7845
129	1	13.481	5.7332	2.5223	3.8186	90.2827	7.7428	43.9917	16.7128
130	1	13.6942	5.7258	2.6852	3.8273	90.3523	7.6442	43.8863	16.6589
131	1	13.9048	5.7164	2.8489	3.8337	90.4299	7.5449	43.8191	16.6237
132	1	14.1136	5.7048	3.0137	3.8373	90.5145	7.4464	43.79	16.6077
133	1	14.3209	5.6908	3.18	3.8378	90.6051	7.3505	43.7979	16.611
134	1	14.5272	5.6743	3.3479	3.835	90.7005	7.2589	43.8418	16.6331
135	1	14.7327	5.6551	3.5177	3.8286	90.7994	7.173	43.9198	16.6733
136	1	14.9377	5.6332	3.6892	3.8186	90.9007	7.0942	44.0297	16.7303
137	1	15.1424	5.6086	3.8624	3.805	91.0029	7.0235	44.1691	16.8026
138	1	15.3467	5.5813	4.0371	3.7876	91.1048	6.9621	44.335	16.8881
139	1	15.5506	5.5514	4.2131	3.7667	91.205	6.9105	44.5243	16.9847
140	1	15.7541	5.5191	4.3899	3.7424	91.3025	6.8694	44.7338	17.0901
141	1	15.9569	5.4845	4.5672	3.7149	91.396	6.8388	44.9599	17.2017
142	1	16.1587	5.4477	4.7447	3.6845	91.4847	6.8189	45.1993	17.317
143	1	16.3591	5.4091	4.9218	3.6514	91.5675	6.8093	45.4483	17.4332
144	1	16.5579	5.3689	5.0982	3.6159	91.6439	6.8096	45.7037	17.5478
145	1	16.7546	5.3274	5.2735	3.5786	91.7132	6.8189	45.9621	17.6584
146	1	16.9487	5.285	5.4473	3.5396	91.7751	6.8365	46.2204	17.7625

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
147	1	17.1397	5.2418	5.6191	3.4994	91.8294	6.861	46.4758	17.8581
148	1	17.3272	5.1984	5.7888	3.4585	91.8759	6.8914	46.7257	17.9433
149	1	17.5108	5.1549	5.9559	3.4172	91.915	6.9262	46.968	18.0164
150	1	17.6899	5.1118	6.1203	3.3759	91.9467	6.9639	47.2007	18.0761
151	1	17.8641	5.0694	6.2819	3.3349	91.9717	7.003	47.4223	18.1215
152	1	18.0331	5.028	6.4405	3.2948	91.9903	7.042	47.6316	18.1518
153	1	18.1965	4.9878	6.596	3.2557	92.0033	7.0794	47.8278	18.1668
154	1	18.3541	4.9492	6.7484	3.218	92.0115	7.1138	48.0106	18.1664
155	1	18.5056	4.9124	6.8978	3.182	92.0156	7.1437	48.1799	18.151
156	1	18.651	4.8775	7.0442	3.1478	92.0166	7.168	48.3358	18.1211
157	1	18.7901	4.8448	7.1878	3.1158	92.0153	7.1856	48.479	18.0775
158	1	18.923	4.8144	7.3288	3.0859	92.0126	7.1957	48.6101	18.0213
159	1	19.0497	4.7863	7.4671	3.0584	92.0095	7.1974	48.7302	17.9538
160	1	19.1705	4.7606	7.6031	3.0333	92.0067	7.1904	48.8404	17.8763
161	1	19.2855	4.7374	7.7369	3.0106	92.0049	7.1743	48.9419	17.7904
162	1	19.395	4.7164	7.8686	2.9903	92.005	7.1492	49.0362	17.6976
163	1	19.4994	4.6978	7.9984	2.9722	92.0076	7.115	49.1244	17.5993
164	1	19.5991	4.6812	8.1265	2.9564	92.013	7.0724	49.2079	17.4973
165	1	19.6946	4.6666	8.2528	2.9426	92.0218	7.0217	49.2881	17.3929

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
166	1	19.7863	4.6538	8.3776	2.9307	92.0342	6.9638	49.366	17.2875
167	1	19.8748	4.6424	8.5009	2.9205	92.0504	6.8994	49.4427	17.1824
168	1	19.9605	4.6322	8.6225	2.9117	92.0705	6.8298	49.519	17.0786
169	1	20.044	4.623	8.7426	2.9042	92.0945	6.7558	49.5956	16.977
170	1	20.1258	4.6144	8.8611	2.8976	92.1222	6.6789	49.6731	16.8784
171	1	20.2064	4.6062	8.9777	2.8917	92.1535	6.6001	49.7517	16.7833
172	1	20.2863	4.5979	9.0925	2.8863	92.188	6.5207	49.8316	16.6921
173	1	20.3659	4.5893	9.2052	2.8811	92.2256	6.442	49.9125	16.605
174	1	20.4455	4.58	9.3157	2.8759	92.2656	6.365	49.9944	16.5218
175	1	20.5255	4.5699	9.4236	2.8703	92.3079	6.2908	50.0768	16.4426
176	1	20.6062	4.5586	9.5289	2.8644	92.352	6.2205	50.1592	16.3669
177	1	20.6877	4.546	9.6313	2.8578	92.3974	6.1548	50.2408	16.2944
178	1	20.7702	4.5318	9.7305	2.8504	92.4438	6.0945	50.321	16.2245
179	1	20.8536	4.516	9.8263	2.8421	92.4909	6.04	50.3991	16.1567
180	1	20.938	4.4983	9.9185	2.8329	92.5383	5.9917	50.4742	16.0904
181	1	21.0231	4.4789	10.0068	2.8226	92.5858	5.9499	50.5456	16.0251
182	1	21.109	4.4578	10.0912	2.8114	92.6331	5.9144	50.6127	15.9601
183	1	21.1951	4.435	10.1714	2.7992	92.6801	5.8852	50.6748	15.895
184	1	21.2814	4.4106	10.2472	2.7861	92.7267	5.862	50.7315	15.8293

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
185	1	21.3673	4.385	10.3186	2.7723	92.773	5.8442	50.7824	15.7627
186	1	21.4524	4.3582	10.3854	2.7579	92.8189	5.8313	50.8273	15.6949
187	1	21.5363	4.3308	10.4477	2.743	92.8645	5.8225	50.8662	15.6258
188	1	21.6183	4.3029	10.5053	2.7279	92.91	5.8172	50.8993	15.5554
189	1	21.6981	4.2751	10.5583	2.7129	92.9555	5.8144	50.9269	15.4838
190	1	21.7751	4.2477	10.6066	2.6982	93.0012	5.8133	50.9495	15.4113
191	1	21.8486	4.2211	10.6503	2.6841	93.0473	5.813	50.9678	15.3383
192	1	21.9181	4.1959	10.6895	2.6708	93.0941	5.8127	50.9826	15.2651
193	1	21.9832	4.1725	10.7243	2.6587	93.1418	5.8114	50.9949	15.1924
194	1	22.0432	4.1514	10.7546	2.6481	93.1904	5.8085	51.0058	15.1207
195	1	22.0978	4.1329	10.7806	2.6391	93.2403	5.8032	51.0163	15.0508
196	1	22.1465	4.1175	10.8024	2.6321	93.2914	5.7951	51.0279	14.9833
197	1	22.1889	4.1055	10.82	2.6273	93.3438	5.7836	51.0416	14.9189
198	1	22.2247	4.0973	10.8336	2.6248	93.3976	5.7684	51.0587	14.8584
199	1	22.2536	4.093	10.8432	2.625	93.4527	5.7494	51.0805	14.8023
200	1	22.2754	4.0929	10.8488	2.6278	93.509	5.7265	51.108	14.7513
201	1	22.2899	4.097	10.8506	2.6335	93.5662	5.6997	51.1424	14.7057
202	1	22.2971	4.1053	10.8485	2.6419	93.6241	5.6694	51.1845	14.6662
203	1	22.2969	4.1178	10.8426	2.6532	93.6824	5.6357	51.2352	14.6328

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
204	1	22.2892	4.1343	10.8328	2.6673	93.7408	5.5993	51.2952	14.6059
205	1	22.2743	4.1544	10.8191	2.6841	93.7988	5.5605	51.3648	14.5855
206	1	22.252	4.178	10.8016	2.7034	93.8561	5.52	51.4445	14.5715
207	1	22.2226	4.2044	10.7801	2.725	93.9122	5.4784	51.5344	14.5638
208	1	22.1862	4.2333	10.7546	2.7488	93.9666	5.4365	51.6344	14.562
209	1	22.143	4.264	10.725	2.7744	94.019	5.3949	51.7444	14.5658
210	1	22.0931	4.2958	10.6912	2.8016	94.0689	5.3542	51.864	14.5747
211	1	22.0368	4.3282	10.6532	2.83	94.116	5.3151	51.9927	14.5881
212	1	21.9741	4.3604	10.6108	2.8592	94.1599	5.2782	52.13	14.6054
213	1	21.9052	4.3917	10.5639	2.8889	94.2005	5.2438	52.2752	14.6259
214	1	21.8302	4.4212	10.5124	2.9188	94.2374	5.2125	52.4276	14.6491
215	1	21.7493	4.4484	10.4563	2.9484	94.2708	5.1844	52.5864	14.6743
216	1	21.6624	4.4725	10.3953	2.9775	94.3005	5.1597	52.7507	14.7009
217	1	21.5696	4.4929	10.3295	3.0056	94.3267	5.1384	52.92	14.7283
218	1	21.4709	4.509	10.2587	3.0324	94.3495	5.1204	53.0933	14.756
219	1	21.3661	4.5203	10.1829	3.0577	94.3694	5.1054	53.2702	14.7836
220	1	21.2553	4.5265	10.1019	3.0812	94.3867	5.093	53.4501	14.8108
221	1	21.1381	4.5271	10.0157	3.1027	94.4019	5.0827	53.6325	14.8375
222	1	21.0145	4.5222	9.9242	3.122	94.4156	5.074	53.8171	14.8634

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
223	1	20.8842	4.5115	9.8273	3.1391	94.4284	5.0661	54.0038	14.8887
224	1	20.747	4.4953	9.7251	3.1539	94.441	5.0583	54.1924	14.9135
225	1	20.6026	4.4736	9.6175	3.1664	94.4541	5.0497	54.3832	14.938
226	1	20.4509	4.4469	9.5044	3.1767	94.4685	5.0396	54.5763	14.9626
227	1	20.2915	4.4155	9.3859	3.1848	94.4849	5.0271	54.772	14.9877
228	1	20.1243	4.3802	9.2619	3.191	94.504	5.0114	54.9709	15.0138
229	1	19.9491	4.3415	9.1325	3.1955	94.5265	4.9918	55.1734	15.0414
230	1	19.7656	4.3003	8.9976	3.1986	94.5531	4.9676	55.3801	15.0712
231	1	19.5739	4.2575	8.8573	3.2005	94.5841	4.9383	55.5917	15.1037
232	1	19.3739	4.214	8.7116	3.2016	94.6202	4.9034	55.8087	15.1395
233	1	19.1656	4.1708	8.5607	3.2022	94.6615	4.8627	56.0318	15.1792
234	1	18.9491	4.129	8.4045	3.2027	94.7084	4.8159	56.2615	15.2233
235	1	18.7246	4.0896	8.2432	3.2035	94.7608	4.7632	56.4983	15.2722
236	1	18.4924	4.0537	8.0768	3.205	94.8187	4.7048	56.7424	15.3263
237	1	18.2529	4.0222	7.9056	3.2074	94.8818	4.641	56.994	15.3857
238	1	18.0065	3.996	7.7298	3.2112	94.9497	4.5724	57.2531	15.4507
239	1	17.7538	3.9761	7.5494	3.2166	95.022	4.4998	57.5196	15.5212
240	1	17.4954	3.9632	7.3649	3.2239	95.0979	4.424	57.7931	15.597
241	1	17.2321	3.958	7.1763	3.2333	95.1767	4.3461	58.0729	15.678

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
242	1	16.9645	3.9609	6.9841	3.2449	95.2573	4.2673	58.3582	15.7638
243	1	16.6935	3.9724	6.7885	3.2588	95.3389	4.1889	58.6479	15.8537
244	1	16.4201	3.9927	6.59	3.275	95.4202	4.1122	58.9409	15.9473
245	1	16.1451	4.0218	6.3889	3.2934	95.5001	4.0386	59.2356	16.0439
246	1	15.8695	4.0597	6.1857	3.3141	95.5775	3.9695	59.5304	16.1425
247	1	15.5942	4.106	5.9808	3.3366	95.651	3.9064	59.8236	16.2424
248	1	15.32	4.1604	5.7747	3.3608	95.7195	3.8507	60.1132	16.3426
249	1	15.048	4.2223	5.5679	3.3864	95.7817	3.8036	60.3972	16.4423
250	1	14.779	4.291	5.3609	3.413	95.8367	3.7663	60.6737	16.5405
251	1	14.5137	4.3655	5.1543	3.44	95.8832	3.74	60.9406	16.6363
252	1	14.2527	4.445	4.9485	3.4672	95.9205	3.7255	61.196	16.7289
253	1	13.9969	4.5283	4.7442	3.4938	95.9477	3.7235	61.4379	16.8175
254	1	13.7465	4.6143	4.5417	3.5194	95.9642	3.7346	61.6646	16.9012
255	1	13.502	4.7019	4.3416	3.5435	95.9695	3.7591	61.8745	16.9796
256	1	13.2637	4.7897	4.1442	3.5655	95.9632	3.797	62.0662	17.0521
257	1	13.0316	4.8765	3.9501	3.5849	95.9453	3.8482	62.2387	17.1182
258	1	12.8058	4.9612	3.7595	3.6011	95.9158	3.9123	62.3912	17.1776
259	1	12.5862	5.0425	3.5728	3.6138	95.8749	3.9886	62.5231	17.2301
260	1	12.3723	5.1193	3.3901	3.6224	95.8232	4.0764	62.6343	17.2757

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
261	1	12.164	5.1905	3.2116	3.6268	95.7611	4.1744	62.7251	17.3143
262	1	11.9606	5.2554	3.0374	3.6266	95.6894	4.2815	62.796	17.3461
263	1	11.7615	5.3129	2.8675	3.6217	95.6092	4.3962	62.8479	17.3712
264	1	11.566	5.3625	2.7017	3.612	95.5215	4.517	62.8823	17.3898
265	1	11.3732	5.4037	2.5399	3.5975	95.4274	4.642	62.9007	17.4024
266	1	11.1824	5.436	2.3818	3.5784	95.3283	4.7696	62.9052	17.4091
267	1	10.9925	5.4593	2.2271	3.555	95.2255	4.8978	62.8981	17.4102
268	1	10.8026	5.4735	2.0752	3.5276	95.1204	5.0249	62.882	17.4062
269	1	10.6118	5.4787	1.9257	3.4966	95.0143	5.1488	62.8597	17.3973
270	1	10.419	5.4752	1.7779	3.4628	94.9088	5.268	62.8341	17.3837
271	1	10.2233	5.4634	1.6312	3.4266	94.8051	5.3806	62.8085	17.3655
272	1	10.0237	5.4438	1.4848	3.3891	94.7045	5.485	62.7861	17.3428
273	1	9.8194	5.4172	1.338	3.3509	94.6082	5.5798	62.7701	17.3157
274	1	9.6097	5.3843	1.19	3.313	94.5174	5.6637	62.7637	17.2839
275	1	9.3936	5.346	1.0398	3.2764	94.4329	5.7356	62.7702	17.2473
276	1	9.1707	5.3032	0.8866	3.2422	94.3555	5.7947	62.7924	17.2056
277	1	8.9403	5.2569	0.7295	3.2113	94.2859	5.8404	62.8333	17.1583
278	1	8.7021	5.2081	0.5677	3.1848	94.2244	5.8723	62.8953	17.105
279	1	8.4556	5.1579	0.4004	3.1639	94.1713	5.8903	62.9809	17.0449

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
280	1	8.2006	5.1073	0.2265	3.1494	94.1266	5.8944	63.092	16.9776
281	1	7.9371	5.0573	0.0455	3.1423	94.0901	5.8852	63.2301	16.9022
282	1	7.6649	5.0087	-0.1434	3.1436	94.0615	5.8632	63.3966	16.8181
283	1	7.384	4.9626	-0.341	3.1541	94.04	5.8293	63.5921	16.7245
284	1	7.0947	4.9196	-0.5479	3.1744	94.0251	5.7846	63.8171	16.6207
285	1	6.7971	4.8806	-0.7646	3.2052	94.0158	5.7303	64.0714	16.5061
286	1	6.4915	4.8461	-0.9916	3.247	94.0108	5.6678	64.3547	16.38
287	1	6.1782	4.8167	-1.2293	3.3001	94.0091	5.5989	64.6658	16.2419
288	1	5.8575	4.7927	-1.4781	3.3646	94.0092	5.525	65.0035	16.0914
289	1	5.5298	4.7745	-1.7382	3.4408	94.0097	5.448	65.366	15.9283
290	1	5.1955	4.7623	-2.0098	3.5283	94.0091	5.3698	65.7511	15.7524
291	1	4.855	4.7562	-2.293	3.6271	94.0058	5.2921	66.1564	15.5639
292	1	4.5086	4.7561	-2.5879	3.7366	93.9982	5.2167	66.579	15.3629
293	1	4.1568	4.7621	-2.8943	3.8564	93.9847	5.1454	67.016	15.1498
294	1	3.7997	4.774	-3.2123	3.9857	93.9638	5.0798	67.464	14.9253
295	1	3.4377	4.7915	-3.5417	4.1236	93.9341	5.0215	67.9196	14.6901
296	1	3.0712	4.8144	-3.8821	4.2693	93.894	4.972	68.3792	14.4451
297	1	2.7002	4.8424	-4.2335	4.4217	93.8425	4.9324	68.8394	14.1915
298	1	2.3251	4.8751	-4.5954	4.5796	93.7782	4.9038	69.2963	13.9304

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
299	1	1.9459	4.9122	-4.9676	4.7418	93.7003	4.8871	69.7465	13.6633
300	1	1.5629	4.9533	-5.3495	4.9071	93.6079	4.8829	70.1864	13.3917
301	1	1.1761	4.9981	-5.7408	5.0741	93.5005	4.8917	70.6126	13.1171
302	1	0.7857	5.0462	-6.1411	5.2416	93.3775	4.9136	71.022	12.841
303	1	0.3919	5.0974	-6.5497	5.4082	93.2388	4.9487	71.4116	12.5653
304	1	-0.0053	5.1513	-6.9661	5.5727	93.0844	4.9966	71.7786	12.2914
305	1	-0.4057	5.2077	-7.3898	5.7338	92.9145	5.057	72.1206	12.0211
306	1	-0.8089	5.2665	-7.8202	5.8904	92.7295	5.1292	72.4356	11.7559
307	1	-1.2148	5.3274	-8.2565	6.0414	92.53	5.2123	72.7216	11.4971
308	1	-1.623	5.3903	-8.6982	6.1859	92.3169	5.3053	72.9774	11.2463
309	1	-2.033	5.4551	-9.1443	6.3229	92.0911	5.4071	73.2019	11.0047
310	1	-2.4444	5.5218	-9.5943	6.4519	91.854	5.5164	73.3943	10.7733
311	1	-2.8566	5.5903	-10.0471	6.5721	91.6067	5.6318	73.5544	10.5531
312	1	-3.2688	5.6606	-10.5021	6.6831	91.3509	5.7519	73.6821	10.3449
313	1	-3.6803	5.7327	-10.9581	6.7848	91.0881	5.8753	73.778	10.1493
314	1	-4.0902	5.8066	-11.4143	6.8768	90.82	6.0005	73.8427	9.9667
315	1	-4.4974	5.8822	-11.8697	6.9593	90.5483	6.1259	73.8773	9.7974
316	1	-4.9011	5.9597	-12.3232	7.0323	90.2749	6.2503	73.8832	9.6415
317	1	-5.2999	6.0388	-12.7736	7.0963	90.0016	6.3722	73.862	9.4991

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
318	1	-5.6928	6.1197	-13.22	7.1515	89.7301	6.4905	73.8155	9.3698
319	1	-6.0784	6.202	-13.6612	7.1987	89.4623	6.6039	73.7459	9.2533
320	1	-6.4557	6.2858	-14.096	7.2384	89.1998	6.7115	73.6554	9.1494
321	1	-6.8231	6.3708	-14.5232	7.2715	88.9443	6.8125	73.5463	9.0574
322	1	-7.1797	6.4567	-14.9418	7.2986	88.6972	6.9062	73.4212	8.9768
323	1	-7.5241	6.5434	-15.3507	7.3209	88.4599	6.992	73.2825	8.907
324	1	-7.8552	6.6306	-15.7487	7.3391	88.2336	7.0697	73.1327	8.8473
325	1	-8.1721	6.7178	-16.1349	7.3543	88.0194	7.1391	72.9745	8.7971
326	1	-8.4738	6.8047	-16.5083	7.3674	87.8181	7.2002	72.8103	8.7558
327	1	-8.7595	6.8909	-16.8681	7.3793	87.6303	7.2533	72.6424	8.7227
328	1	-9.0287	6.976	-17.2136	7.391	87.4565	7.2987	72.4732	8.6973
329	1	-9.2809	7.0595	-17.5441	7.4034	87.297	7.337	72.3046	8.679
330	1	-9.5158	7.1411	-17.8591	7.4172	87.1518	7.3687	72.1387	8.6673
331	1	-9.7335	7.2203	-18.1584	7.4332	87.0206	7.3948	71.9772	8.6618
332	1	-9.934	7.2968	-18.4417	7.4519	86.9032	7.4159	71.8216	8.6622
333	1	-10.1179	7.3701	-18.709	7.4739	86.7988	7.4332	71.6731	8.6681
334	1	-10.2857	7.44	-18.9604	7.4996	86.7069	7.4476	71.5328	8.6792
335	1	-10.4383	7.5063	-19.1963	7.5293	86.6264	7.4601	71.4015	8.6952
336	1	-10.5766	7.5687	-19.4171	7.5631	86.5563	7.4718	71.2798	8.7161

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
337	1	-10.7019	7.6271	-19.6235	7.601	86.4953	7.4837	71.1677	8.7415
338	1	-10.8154	7.6815	-19.8163	7.6429	86.4423	7.4967	71.0655	8.7714
339	1	-10.9189	7.7319	-19.9965	7.6887	86.3957	7.5119	70.973	8.8054
340	1	-11.0138	7.7784	-20.165	7.7379	86.3542	7.5299	70.8896	8.8433
341	1	-11.1019	7.8212	-20.3231	7.7903	86.3163	7.5515	70.8148	8.885
342	1	-11.1849	7.8606	-20.4721	7.8451	86.2806	7.5773	70.7478	8.9301
343	1	-11.2646	7.8968	-20.6132	7.902	86.2456	7.6077	70.6876	8.9781
344	1	-11.3428	7.9304	-20.748	7.96	86.2099	7.6431	70.6332	9.0288
345	1	-11.4212	7.9616	-20.8777	8.0187	86.1724	7.6836	70.5835	9.0816
346	1	-11.5014	7.9911	-21.0038	8.0771	86.1319	7.7292	70.5371	9.1359
347	1	-11.585	8.0193	-21.1277	8.1345	86.0872	7.7797	70.4928	9.191
348	1	-11.6733	8.0468	-21.2505	8.1901	86.0376	7.8348	70.4494	9.2464
349	1	-11.7674	8.0742	-21.3735	8.2432	85.9823	7.894	70.4056	9.3012
350	1	-11.8683	8.1019	-21.4978	8.293	85.9208	7.9568	70.3603	9.3546
351	1	-11.9767	8.1304	-21.6243	8.3389	85.8526	8.0223	70.3123	9.4058
352	1	-12.0932	8.1604	-21.7536	8.3802	85.7778	8.0899	70.2607	9.454
353	1	-12.218	8.192	-21.8865	8.4165	85.6963	8.1584	70.2047	9.4983
354	1	-12.3509	8.2259	-22.0232	8.4472	85.6084	8.2269	70.1435	9.5378
355	1	-12.4918	8.2621	-22.164	8.4721	85.5144	8.2945	70.0767	9.5719

Day of Year	Wet State	TMAXM	TMAXSTD	TMINM	TMINSTD	RHMaxM	RHMaxSTD	RHMinM	RHMinSTD
356	1	-12.64	8.3009	-22.3087	8.4909	85.4151	8.3599	70.0039	9.5998
357	1	-12.7947	8.3424	-22.4572	8.5034	85.3112	8.4221	69.9251	9.6208
358	1	-12.9548	8.3867	-22.609	8.5097	85.2036	8.4801	69.8402	9.6344
359	1	-13.1192	8.4336	-22.7633	8.5099	85.0933	8.533	69.7496	9.6403
360	1	-13.2862	8.483	-22.9194	8.5042	84.9816	8.5797	69.6536	9.6382
361	1	-13.4543	8.5346	-23.0763	8.493	84.8696	8.6194	69.5529	9.6279
362	1	-13.6218	8.588	-23.2328	8.4767	84.7587	8.6515	69.4483	9.6095
363	1	-13.7867	8.6427	-23.3875	8.4559	84.65	8.6753	69.3406	9.5833
364	1	-13.9471	8.6984	-23.5391	8.4312	84.5451	8.6905	69.2308	9.5495
365	1	-14.1012	8.7543	-23.6862	8.4033	84.445	8.6967	69.1202	9.5087