Manitoba Hydro Risks:
An Independent Review

Submitted to

The Public Utility Board of Manitoba

Submitted By

Dr. Atif Kubursi
and
Dr. Lonnie Magee

November 15, 2010

Table of Contents

List of Tables

List of Figures

Executive Summary

Scope of the Assessment

The Public Utility Board of Manitoba issued an Order No. 30/10 on March 26, 2010 appointing Dr. Atif A. Kubursi and Dr. Lonnie Magee (“KM’) to provide an independent assessment of Manitoba Hydro (“MH”) risk management practices, policies, and a host of other related matters as part of its 2010/11 & 2011/12 General Rate Application.

PUB requested that KM provide comments and conclusions and complete tasks detailed in 10 items contained in the Terms of Reference (“TOR”) (Schedule “C” of Order No. 30/10.) which includes:

I. Explain general enterprise risk management concepts.
II. Review and evaluate all relevant available materials which address risk management for MH.
III. Review and evaluate MH’s water supply data and management model.
IV. Obtain any relevant information required from MH or other participants to the GRA pertaining to risk management issues;
V. Identify all material operational and business risks for MH’s 20 year IFF.
VI. Prepare statistical analyses and quantification of risks to consider the probabilities of all material operational and business risks of MH.
VII. Provide recommendations for risk mitigation measures by MH.
VIII. To be available through counsel for Consultants, as resource on general risk management inquiries.
IX. Provide a written report covering matters in items 1-7.
X. Participate as independent witnesses before the PUB in the current MH GRA.

Manitoba Hydro: The Context

The general context within which MH operates and its salient and unique features are presented first by way of setting the stage for the identification, quantification and analysis of the different risk factors faced by MH.

MH is a public utility, with some form of public control, judicial or administrative or both. The public control takes many forms, but typically includes the supervision of rates and service by a public utility board, public ownership and oversight over operations and expansions by public bodies.

The Crown Corporation structure in Canada places MH, as seen above in two categories at the same time. It has a business operating structure like any other business, but its shareholders are the people of Manitoba, and it is subject to a complicated governance regime with many overlapping jurisdictions.

The dual structure of the utility in Manitoba presents challenges and some critical advantages for MH. MH is able to borrow at preferred interest rates, to expand its operations with greater access and ease to capital markets, to pursue environmental and social objectives, and to be liberated from an undue short term focus in favour of long term objectives. This structure also insulates MH from strict and direct shareholder scrutiny and it may constrain it to compromise business objectives in favour of social and environmental goals.

MH is also unique in that over 95% of its total power generation is hydro. MH sells a large share of its generation outside Manitoba; exceeding 31% in 2007.

There are characteristics of MH that distinguish it from other utilities and private corporations including: Low rates, high exports, and sensitivity to drought.

Structure of the Report

This assessment is organized into seven parts, one for each of the seven items in the TOR, and in addition, a section briefly summarizing findings for each TOR.

The report is organized into eight chapters (including the introduction). With the remainder structured as follows:

- Chapter 2: Background information on Enterprise Risk Management.
- Chapter 3: Operational and planning models used by MH.

- Chapter 4: MH’s water supply data, water management models and volumetric risk mitigation measures.

- Chapter 5: Reviewing relevant reports that addressed risk management at MH.

- Chapter 6: Quantification of relevant risks pertaining to MH’s three systems of water, generation and finance.

- Chapter 7: A summary of the conclusions and recommendations.

Risk Management: Best Practices and MH Procedures

Risk management has evolved from an often overlooked Back Office discipline to a vital component of securing every business' future with it now having an increasingly Middle Office responsibility and typically placed in the Office of the highest ranking operational position.

Risk Management Evolution

Risk management has evolved from an obscure function of finance and insurance to an approach necessary for any organizational resilience.

The past 10 years have taught operational threats are wildly variable and totally unpredictable. And any analysts agree that the next decade will witness even greater potential threats, such as an accelerated global competition for resources like water and energy.

Risk Management Process

“The problem with the future is that more things might happen than will happen”. The range of possibilities is wide and it is costly and difficult to configure every possibility that may occur.

Risk management occurs on a daily basis and involves all aspects of business operations and the entire organization. With pro-active risk management one looks at events and processes in a comprehensive manner and assess *and document* risks and uncertainty. In the steps for risk management there are a few distinctions and a heavy emphasis on a number of activities and procedures including the following key elements:

> First, risk management is a serious on-going process.
>
> Second, it is about prioritizing risks in terms of probabilities and consequences.
>
> Third, it is not sufficient to recognize, identify and link risks to business operations and objectives but must be backed by quantitative calculations.
>
> Fourth, risk assessment is done with a purpose.
>
> Fifth, individual responsibilities for these risks must be assigned.
>
> Sixth, monitoring and tracking are essential components of the best practice system of risk management.

Risk Management Practices at MH

Manitoba Hydro has developed a risk management system to identify, control and manage risks. Specifically, MH has developed systems to monitor and control key risks and to sustain information flows within the organization and to appropriate stakeholders about changes in risk profiles. They are managed within the Corporation risk tolerances.

The Corporation has also developed and instituted a Management Control Plan (MCP) with several committees and mechanisms to oversee all power related transactions in both Canada and the United States.

Recommendations

A number of necessary steps have been taken for a comprehensive risk management plan and that a number of policies and procedures have been instituted to prepare the Organization to deal with risks.

A number of gaps emerge that MH can easily deal with in a manner that will increase and strengthen its resiliency and capacity to manage risks. Recommendations include:

- What is conspicuously needed at MH is an Individual Responsibility System where responsibilities for identification, assessment, quantification, mitigation and avoidance are clearly spelled out.
- To organize specialized teams to assess each identified risk for its probability of occurrence and its impact on business objectives. The Organization can surely benefit from greater visibility and use of statisticians and actuarial experts.
- The governance structure of risk management at MH can therefore benefit from some restructuring and alignment.
- Risk Preparedness Plans and manuals are needed for all costly risks.
- A detailed training and simulation games of risk occurrences and plans should be developed for the organization.

Manitoba Hydro Models

It is possible to think of the Corporation as consisting of three basic systems: hydrology, power and financial. These three systems are constantly interacting.

The modes of interaction and the relationships that govern the workings of these systems are quite complex. It is often necessary to construct models to represent, understand, explain and predict the outcome of changes in these complex systems.

A model is a theoretical construct that represents underlying processes by a set of variables and a set of logical and/or quantitative relationships between them. Models have two characteristics. **First**, they are a *simplification* of and an *abstraction* from observed data. **Second**, they are a means of selection of data based on the purpose for which the model is built.

Manitoba Hydro uses a large set of models to predict and optimize its operations, evaluate transmission options, quantify risk, forecast domestic load, and as tools for very short term to the very long term planning of operations and expansions.

The MH models are not much different from those used by Quebec Hydro's or Ontario Power Generation (OPG) and other domestic or international utilities that also use similar models to optimize operations and future plans. It seems that both Quebec and BC have adopted more advanced systems than MH's Hydro Electric Reservoir Management Evaluation System (HERMES) or Simulation Program for Long Term Analysis of System Hydraulics (SPLASH).

The entire spectrum of models used by MH are considered. The flow of the presentation will follow the time framework of the models.

The Market Optimized Short-Term (MOST) Model

MOST is a decision support system (DSS) for hourly scheduling of generation and reservoir operations for the entire Manitoba Hydro generating facilities and transmission network.

Findings

A number of questions about MOST (Vista) and a number of recommendations emerge:

- The model should be cast in an explicit stochastic framework given the many uncertainties that are embedded in the system.

- It is clear that a few price forecasts are embedded in the system; it would make more sense to represent these as probability densities using @RISK or any other probability generating system.

- More than one skilled person should be responsible for the model.

- It is recommended that the system be continuously subjected to validation and verification to improve its forecasting accuracy.

- It will be useful to formalise the integration of Vista with other models and bring those supporting and maintaining the system as part of a formal **Modelling Committee** that meets regularly with a sufficient budget and written terms of reference.

- Every effort should be made to establish full ownership of the model systems within MH and that no system is seen or perceived to be a "black box.

- Formulate the objective function to minimize cost of generation and delivery rather than maximizing net revenues.

The Hydro Electric Reservoir Management Evaluation System (HERMES) Model

The first optimization model at MH was Production Optimization Program (POP). It helped develop an operating plan for the use of the reservoir, hydro and thermal generation and inter-utility tie-lines.

The challenge of developing an operating system capable of dealing with all a number of issues and still provides the Reservoir Management Engineer with a long term capability to solve reservoir and energy management problems in a timely manner prompted the development of HERMES in 1984.

HERMES requires a long list of data that the RME provides in the same temporal and physical structure. The data describe both the current state and a forecast of the future resources available to the system.

Findings

By any standard HERMES is an impressive system. Our Recommendations include:

- Being an internally developed and maintained system it has advantages and disadvantages. It makes sense to subject the system to an external audit by the Committee of Experts (MAC).

- The deterministic nature of the model calls for more thorough adjustment and upgrades. It makes sense to move to a stochastic system or at least the addition of a few stochastic modules.

- The HERMES incorporation of weather variables. This is a crucial advantage given the sensitivity of load to this variable and the extent to which it is expected to vary in the future.

Simulation Program for Long Term Analysis of System Hydraulics (SPLASH)

The primary objective of SPASH is identified as determining the expected long-term operation of MH system under various alternatives of system expansion and under a range of flow conditions. SPLASH is based on representations of the hydraulic, thermal, wind and transmission systems, the constraints that the physical and regulatory regimes impose on the system and the financial parameters of the system embedded in input and output current and future prices.

The way SPLASH work is define an initial flow year to correspond to the first load year and the chronological flow record is maintained for each successive year. This implicitly assumes that each flow year on record is equally probable and the past will unfold to determine the future.

SPLASH simulations are run in three distinct steps. First run is the configuration of the dependable energy run. The second is the rule curve run and this is followed by the production costing run. The three distinct steps are consecutive since the output of one run produces input for the run to follow.

Findings

SPLASH is a critical component of the model family at MH.

A number of issues that need to be addressed before this system can deliver on its promises:

- There are grounds to question whether or not a nonlinear specification is now necessary to deal directly with this problem.
- The model is fully deterministic. Uncertainty is recognized but not dealt with directly. There are a number of areas where SPLASH can use @RISK particularly when it comes to export and import prices, water flows and reservoir elevation levels.
- SPLASH is an extension of HERMES and the two could sit on the same platform.
- SPLASH is an in-house developed system which can benefit from an audit by an external committee of experts.
- There should be a careful and formal documentation of the system in User and Technical manuals.
- The staff supporting the system are qualified but again this group should be formalized and expanded.

Power Risk System Model (PRISM)

The @RISK software is an "add-in" to Microsoft Excel PRISM model of flows, generation and financial results of electricity sale or purchases within the province or outside it. @RISK is a system designed to explicitly include the uncertainty present in the estimates in order to generate results that show all possible outcomes. This system is embedded into PRISM to evaluate a wide spectrum of forecasts using different probability distributions on forecast values and these results are complemented with Monte Carlo simulations. @RISK “links” the MH model in Excel to its Risk Analysis capabilities to generate profiles and ranges within which expected values are likely to occur.

Findings

PRISM fills a gap at MH. The aftermath of the 2003 drought highlighted the need for probabilistic models that can map a wide set of possibilities and introduces uncertainty into decision making and planning at MH avoiding arbitrary specifications of pessimistic and optimistic forecasts.

Recommendations include:

- Some of the concerns we have about PRISM are in fact associated with the adoption by PRISM of results and vectors from other systems. The concern is that problems or errors in one system may be propagated through the entire family of models. @RISK is a standard industry tool for dealing with uncertainty, it is a coarse system that requires customization and sophisticated knowledge of statistics and other related skills to become more flexible and produce genuine and desirable fruits.

- PRISM should be freed from the seasonal and annual structure and allowing it to deal with intra-year issues.

- A richer and a better statistical anchor could be used to model water variability than the SPLASH characterization. More than a 5 years time horizon can be adopted to highlight results.

- PRISM is only an energy model; it may be worth considering augmenting it into an energy capacity model.

- The price volatility modeling can be enhanced.

- There is a need to contrast and compare @RISK calculations with other quantitative risk calculations.

- Greater integration and harmonization of the PRISM model with other MH models.

- Documenting the system explicitly in User and Technical manuals must be made on a regular basis.

- Subjecting the system for external audit and verification.

Electric Load Forecast

The electric load forecast is a central and critical component of planning operations in the medium and long term at MH. It is used in most other models and therefore its accuracy is of critical importance to all these models and their forecasts.

Findings

The forecasting accuracy is deemed reasonable for the 5 year term and the move to integrate probabilistic forecasts is encouraging. The people responsible for maintaining and running the model are competent, enthusiastic about their work and dedicated.

Recommendations include:

- The structure of some of the regression equations can be strengthened. The use of one dependent variable may not suffice for basing future forecasts on it.

- The use of standard deviations for the explanatory variables is a good step but more sophisticated integration of probabilistic structures is advisable.

- Those responsible for the load forecast should become official members of the model community group at MH .

- The inclusion of weather related variables is explicit in only one equation.

Economic Outlook

In March of each year the Economic Analysis Department (EAD) of the Corporate Strategic Review Division of MH prepares an Economic Outlook (EO) that is becomes a reference for other departments and models. The forecasts included in the EO cover a wide range of variables. Only a limited number of forecasts are made in-house.

There are a number of issues that arise in connection with the use of multiple forecasts and forecasters.

The issue is not independence of forecasts and forecasters but their accuracy and consistency. EAD states, "…Forecasts from Consensus Economics, Province of B.C., Federal Finance, and Desjardins, will no longer be used as they are considered statistically independent.

It is possible to avoid this problem all together by developing an in-house macro econometric model. This may be asking too much given the resources it would require. It could be sourced out to a University in Manitoba or to a single consulting firm where tests about the accuracy of their forecasts has been established and tested.

Another way to deal with the problem of using an inappropriately specified forecast is for the EO to undertake a full @RISK specification of the underlying probability distributions that best capture the patterns of these forecasts.

Findings

A number of recommendations are in order here beginning with adding both human and financial resources to the EAD and ending with expanding the mandate of the Department and changing some of its operating procedure.

Other recommendations include:

- The Department can benefit from the addition of economists and econometricians with quantitative skills and experience in forecasting.
- There is a serious need to revisit the forecasting role of the Department.
- The forecasts adopted should abstract from the arbitrary specification of low (pessimistic) and high (optimistic) forecasts
- It is required that the EO group become part of the modeling family at MH.
- The terms of reference of this group should be expanded.

Overall Findings and Recommendations

There are other criteria to use in evaluating a model beside its logical consistency and accuracy. These criteria were used to evaluate the MH "model family". The assessment at the end of chapter 3 includes a summary of its findings and recommendations, organized by model.

Simplified Accounting Framework (Appendix B)

The Manitoba Hydro system involves issues of hydrology, power generation, and financial matters. These three subsystems are embedded within a broader politico-technical system of which Manitoba Hydro is a key component. More precisely, the three basic systems: hydrology, power and financial can be modeled separately or put on a common platform.

A very simplified accounting framework is presented that combines all of the three sub-systems. Our objective is to demonstrate that the system can be integrated as a whole. The structure of the relationships is such that this integration is seamless. A full integration of the system is called for in the recommendations and that is why this simple presentation is developed.

Water Flows: Statistical Modelling, Prediction of Droughts, and other Issues

Manitoba is blessed with water abundance but this abundance is only exceeded by its variability.

Statistical procedures often can estimate the distribution of a random variable such as an unknown future value. The most common numerical outputs of prediction exercises are point predictions, quantiles of predicted distributions, and simulated values from predicted distributions.

Since it has been estimated that 70% of MH's risk is volumetric, the prediction and modeling of water flows and/or rainfall must play an important role in its risk management procedures. Several types of prediction would be useful:

1) *Short term predictions* of water flows.

2) *Medium term predictions*, for example, predicting winter precipitation in the autumn.

3) *Long term predictions*, to help in deciding how much to invest in generation and when.

4) *Predicting the frequency and intensity of extreme outcomes*, to aid in forming a drought risk management strategy.

It is impossible to perfectly predict outcomes from complex systems such as weather, economies, or financial markets.

Not only is it difficult to predict accurately, it also is very difficult to decide which prediction method is the best.

There are three methods for generating predictions of future water flows based on observed past water flows. Each one can be thought of as being based on its own way of constructing and estimating an unknown underlying distribution or process that generated the observations, and will generate the future values.

The three methods are:

(a) Re-Sampling, or Historical Simulation

The observations form an *empirical distribution*. Use the empirical distribution as an estimate of the actual distribution.

This method is relatively simple and is based on the observations in a clear and reasonable way.

(b) Autoregressive (AR) time Series Models

The AR model is standard in many disciplines, including hydrology. This estimated model will be used to simulate water flow values for checking potential drought occurrences.

(c) Extreme Value Model

Extreme value theory (EVT) relies on a limit theorem that motivates the use of the generalized Pareto distribution to model the distribution of values in the extreme tails of distributions. It is based on a theoretical result that shows that for many distributions (including "all of the common continuous distributions used in statistics and actuarial science" (p.5)) the "natural model for the unknown excess distribution above sufficiently high thresholds" (p.5) is the generalized Pareto distribution.

Review of Risk Reports: A Critical Evaluation

In Chapter 5 we review most of the reports that deal directly and almost exclusively with the identification, measurement, control, mitigation and management of risks for MH that we were able to obtain.

All of the NYC's risk reports were not obtained. NYC insisted that any review of her reports will constitute an infringement on her intellectual property rights. Instead there was a review only of her public document but it was complemented with a face to face interview with her in New York City, as well as reviewing the reports prepared by MH and KPMG that dealt with her work and responded to her allegations. Another meeting was attempted following the release of her Public Document, but the attempt was unsuccessful.

There is more than one way of meeting the request of PUB to review and evaluate these documents. It is possible to take each of the 14 documents separately.

Instead in this chapter a small set of themes is defined each comprising a set of issues. The discussion below is centered on these issues considered from the various perspectives of the different authors and parties.

The Risk Themes and Issues

The common focus of the risk reports to be reviewed, are the following themes:

> First, the effectiveness, appropriateness and the predictive accuracy of Manitoba Hydro suite of models in supporting optimum operations, capacity planning, financial forecasting and budgeting processes.
>
> Second, volumetric and drought risks as these are considered substantive and unique to Manitoba Hydro.
>
> Third, the risk governance system at MH and its consistency with best practice will be evaluated.

Fourth, the risk management system at MH is evaluated in all areas including power generation, sales, reliability, equipment, human resources, finance and investment.

Fifth, issues of risk capital adequacy, self insurance, asset-backed power sales, moral hazard and financial viability will be summarized and evaluated under different risk management regimes.

MH Models

Manitoba Hydro supports, uses and relies on three major models (HERMES, SPLASH and PRISM) in its planning of operations, investment planning, financial forecasting and budgeting.

The NYC makes a number of serious allegations about defective, erroneous and stale inputs, flawed modeling structures particularly in the hydrology framework, manipulation of input and output data by Front Office, wrong forecasts, inappropriate use of the model outputs in power trading and FTR bids, the concealment of model data and results rendering the model a "black box". Furthermore, the Consultant claims that the Front Office engages in self-evaluation without any vetting and validation by Middle Office.

Findings

Different arguments are advanced by MH, KPMG and others in response to the concerns and issues raised by the Consultant. These are:

- **Model Inputs: Prices**

Findings

Prices in HERMES are not stale; they are based on adjusted forecasts from five reputable consulting groups. Making adjustments to expert forecasts is reasonable and necessary but MH may wish to be more formal, transparent and to document the adjustments it makes. MH may have to consider an alternative to purchase forecasts (this could be a complementary exercise) that uses forward price curves. NYC has raised a valid point about using the forward price curve alternative and the need for using the same price inputs in the Generation Estimate report, HERMES and SPLASH, but has not been justified in her general pronouncements on using stale and erroneous prices.

- **Model Inputs: Historical Water Flow Data**

Findings

The accuracy of the historical water flow data before 1942 is not high, but to discard this series is unjustified. The use of the historical series as if it is the only reliable series on which to base calculations of dependable energy is also not recommended. By drawing over a 100 different samples of 94 year flows generated by a statistical process complemented by an extreme value distribution, the minimum of the actual historical series is consistent with the average of all the minima computed from the stochastically generated series.

- **Model Inputs: Energy Coefficients**

Findings

Different production coefficients in HERMES and SPLASH are a problem. This problem pertains to the nonlinearity of the generation equation that links water flows to energy and the time strip differences in the two systems. This is why harmonising the two systems on a common platform will iron out these discrepancies. The revenue losses due to this problem are limited and nowhere close to the exaggerated calculation of $26 million by the Consultant.

- **Flawed Modeling Structures**

Neither KPMG nor NYC covered the domestic load forecast or the use of scenarios in the Economic Outlook exercise. We have tendered a few suggestions in Chapter 3 that we believe would complement the discussion and evaluation of HERMES, SPLASH and PRISM.

Findings

HERMES, SPLASH and PRISM are indispensable operational, planning and risk assessment tools at MH. These decision support tools represent standard systems that are currently used in many leading utilities in North America. They can be expanded, harmonized, integrated and expanded. They should be reviewed internally and externally and upgraded and updated regularly. BC Hydro and Hydro Quebec have or are moving to dynamic and stochastic systems, MH may wish to follow suit. A hydrological sub-model to complement HERMES and even SPLASH should be considered seriously as water management issues become more complicated under possible climatic changes.

- **Model Governance**

Findings

There is wide agreement among the reviewers of the models (KPMG, RiskAdvisory, KM and others) that the systems require formal documentation, more staff should be trained on using and supporting the systems, that external reviews are needed, and that the Middle Office should be involved particularly in verifying and checking the results. The PRISM model should also be run in the Middle Office.

- **Model Output: Lake Balances**

Findings

Notwithstanding the small dollar amount of discrepancy between the Generation Estimate and HERMES solutions, these discrepancies raise concern about the accuracy of the model and the reporting system. But the real problem is more profound. HERMES and SPLASH are static models and do not handle time in a manner consistent with dynamic programming. MH may wish to consider some of the existing dynamic programming systems in use at similar utilities in North America.

- **Model Output: Predictive Accuracy**

The forecasting accuracy of HERMES is analysed in detail in Chapter 3 and there are a number of relevant results on this issue.

Findings

Overall, the predictive accuracy of HERMES can be improved. The antecedent forecasts need to be reviewed. Back-testing should be used. The practice of continuous forecast reviews has definite benefits.

- **Model Use: Utility and Relevance**

Findings

HERMES is not directly linked to the trading floor and its forecasts are not used as bids on the floor. But HERMES is relied upon to in form decision in the opportunity market is another matter. It makes sense though to dispel this concern by streamlining and documenting trading decisions and practices.

- **MH Volumetric and Drought Risks**

Findings

The probability of a drought occurrence is higher than those estimated by the Consultant or ICF. The costs of a 5year drought are in the order of magnitude used by MH than the Consultant and the inclusion of other risk factors increases measurably the drought costs. It is also clear that the water flow data are serially correlated and that a statistical process confirms that Manitoba Hydro is correctly using the low flow years in 1937-1942 as the basis of its dependable energy calculations. While a more severe drought than the one experienced in 1937-1942 is possible, its probability of occurrence is 24 times in 9400 years.

- **MH Risk Governance Issues**

KPMG produced a long list of recommendations for MH to align its risk management with best practice. These include:

§ Contract review should include risk quantification and assessment.
§ Middle Office should be involved in the review of export contracts.
§ Mark-to-Market methodologies should be used to assess all risks.
§ Drought risk is quantified without using a probabilistic stress test, this should be done regularly.
§ MH has specified risk limits only to "power related transactions" in the area of Merchant Transactions and consumer credit. MH should continue to develop further limits on most transactions and VaR wherever possible.

The KPMG assessment and the set of recommendations are acceptable.

Findings

MH's Middle Office is evolving and that major strides have been made towards best practice. More is needed in terms of strengthening the HR expertise set at the Middle Office, the independence of its functions, the MTM measures of all risks, the expansion of risk limits standards and process control limitations to all aspects of MH functions, the development of an Internal Responsibility Matrix, the need for quantification of risks at Middle Office, and its involvement in contract risk assessment. There are some merit with NYC's comments about risk governance issues with respect to the independence of the Middle Office and the greater need for oversight. The NYC's claims of lack of competence in the CRMC and the concealment and manipulation of data by the Front Office are not accepted.

- **MH Risk Identification, Control, and Mitigation**

Manitoba Hydro faces many risks. Some are typically encountered by other power generating utilities and a few are unique to MH.

There is a wide divergence among the reports in terms of their coverage of risks. But a common list can be constructed and this includes a small subset of events that have high probability of occurrence and large consequences.

The common theme among these risks is their association with long term contracts.

MH Long Term Contract Risks

The issue of risks embedded in long term contracts more than any other has pre-occupied the authors of the reports and has received an inordinate attention.

The following themes are considered:

Appropriateness of Long Term Export Contracts

MH has by design, since its inception, installed more capacity than is needed to meet Manitoba load.

As long as installed capacity exceeds Manitoba peak load, there is always a surplus that Manitoba can sell comfortably outside the province.

The availability of power for exports is not a sufficient condition to do so. It is also necessary that net revenues from these exports are positive.

The following questions as deserving of further review and factual analysis:

Should Long Term Exports Be Stopped and Long Term Export Contracts Be Scrapped?

Findings

There are many benefits for MH to be in the export market and specifically, the the long term fixed price firm exports market. The long list advanced by KPMG and ICF outlined these benefits which include: diversification of the export portfolio, matching fixed costs to fixed revenues, guaranteeing secure investment in transmission infrastructure by counterparties and qualifying for priority transmission rights, pre-empting excess capacity by competitors, guaranteeing access to long term finance on favourable terms, raising export revenues in US dollars to defray import and debt costs in the same currency (providing MH a hedge against exchange rate fluctuations), greater access to firm imports when needed, and a host of other advantages.

Are Export Revenues Being Subsidized by Local Rates?

Contract prices embedded in long term contracts are sufficiently higher than historical average spot MISO prices. These prices are carefully constructed using weighted long term forecasts and hopefully???? estimates of the long run marginal cost of counterparties. The export prices are higher than long run marginal cost of MH and average total cost. This suggests that export revenues can be relied upon to subsidize domestic rates when they are higher than import prices.

Is MH’s Book Oversold?

The expanded capacity when Keeyask and Conawapa are completed will increase dependable energy and sales in the long term at higher prices than spot MISO prices will increase revenues. Expected declines in spot prices beyond 2011 will make these contacts more valuable. High import prices will remain a threat in time of shortages but new contract limit prices on these imports will define an upset price for MH.

Will the Prices, Curtailment Provisions and the Import Upset Price in the New Contracts Prove Sufficient to Prevent Seller and Buyer Regret?

The negotiated contract prices in the new contracts or binding term sheets with NPS, WPS and MP are higher than the weighted consensus price forecasts of the 5 international forecasters and the escalation clauses are firmly structured to protect the contracts’ real prices in the future. At this point in time, the contracted prices are sufficient to raise significant revenues for MH over its costs. The upset price on importing energy in the NPS contract will play a modest role in protecting MH from paying congestion prices in the event of a shortage. But the major achievements in these contracts are the curtailment provisions in the new contracts that could effectively decrease MH’s firm export commitments by 29% and 19% of the total volume in times of adverse water conditions.

Are the Consultant’s Estimates of Risk Exposure Correct and Warranted?

The Consultant’s calculations of the probability of a severe drought and the magnitude of drought losses are glaringly low and those that may result from LTC commitments considerably higher than those that reasonable calculations would produce. The need, however, for adequate risk capital to mitigate against MH's LTC risk exposures is a serious concern.

Conclusions

Fourteen documents have been reviewed in terms of five major themes.

The adversarial nature of the exercise has been reviewed. The aim was to explore the different perspectives taken in these reports and to relate them to the issue of risk management at MH.

Fourteen findings have been arrived at, as set out above.

Quantification of Manitoba Hydro Risks

Droughts of any severity and many other risks, separately or in combination, can adversely impact the net revenues of MH. To manage and protect its financial stability, MH must mitigate drought risks and simultaneously monitor all other potential risks that can threaten and prevent MH from realizing its business objectives and the optimization of its net revenues.

MH uses many different strategies to manage its risks and to mitigate their negative consequences. Risk identification has been dealt with at length. Risk mitigation strategies available to MH are considered. Three basic techniques are used in this estimation: (1) Two statistical methods that allowed us to estimate the probability of a minimum water flow lower than the actual minimum (Auto-regressive procedures and the Extreme Value Distribution); and (2) Monte Carlo estimates of likely financial damages using @RISK (the same system embedded in PRISM); and (3) variance-covariance estimates.

The estimation begins with a base case defined by the financial statements for MH prepared by Statistics Canada for the years 2001 to 2007.

In total the risk exposure are estimated of 15 different variables on MH's net revenue.

Using these averages and the selected probability distribution functions for each one of them in the calculation of net revenue were generated the mean, low and high values of net revenue at the 5% and 95% confidence levels.

Summary of the findings

First, low water flows have the largest impacts on net revenue of MH. A total of $788 million can be lost on account of a repeat of the worst drought on record.

Second, a more severe drought than the worst on record would trigger the Force Majeure clause in the contract. A lower flow than the worst drought on record with curtailment will have lower impacts than the worst historical drought. Losses are large but only $772 million compared to $788 million.

Third, a low flow year at the same level of the worst drought coupled by import prices at the upset price 120/MWh results in a drastic loss of $1.2 billion in one year.

Fourth, a severe drought with high export prices (at future contract levels) and an average import price will result in positive expected net revenue, but a loss of $331 million from the base case.

Fifth, a 10% variation of wind generation has very low impacts on net revenue (less than $1 million).

Sixth, a 10% increase in wages and benefits' cost will reduce net expected revenue by $29 million.

Seventh, 10% increases in purchased inputs, materials and fuel prices have limited effects on net revenue (less than $3 million each).

Eighth, a rise of 10% in load met by an equivalent rise in imports, with no change in import prices, leads to a rise in net revenue of $3 million.
Ninth, a 10% increase in load met by imports that are priced at $120/MWh, will lead to a loss of $397 million in revenue.

Tenth, surprisingly changes in the exchange rate are not particularly high. A 10% appreciation in the Canadian dollar (moving towards parity), results in a loss of $33 million.

Eleventh, the worst case scenario with very low probability of occurrence would result in a $1.8 billion loss in net revenue.

Conclusions and Recommendations

In chapter seven the major conclusions and recommendations found throughout the Report are compiled in an overall summary.

Chapter One

Introduction

1.1 Terms of Reference

On March 26, 2010 the Public Utility Board of Manitoba (also referred to in this report as "PUB ") issued Order No. 30/10 in which it appointed Dr. Atif A. Kubursi and Dr. Lonnie Magee ("KM') to provide an independent assessment of Manitoba Hydro (also referred to in this report as "MH")--its risk management practices, policies, quantification, identification, tolerance, mitigation, governance structure and a host of other related matters as part of its 2010/11 & 2011/12 General Rate Application (GRA).

Specifically, PUB requested that KM provide comments and conclusions and complete the tasks detailed in 10 items contained in the Terms of Reference ("TOR") for the assignment in Schedule "C" of Order No. 30/10. The assignment includes:

XI. Identify and explain general enterprise risk management concepts and best practices.

XII. Review and evaluate all relevant available reports and supporting data, systems, models and analyses which address risk management or contain information affecting risk management for MH and report on findings arising from this review.

XIII. Review and evaluate MH's water supply data and management models for impact upon identified risk factors, opportunities and risk mitigation options.

XIV. Obtain any relevant information required from MH or other participants to the GRA process pertaining to risk management issues and impacts on MH's 20 year Integrated Financial Forecasts (IFF).

XV. Identify all material operational and business risks for MH and MH's 20 year IFF.

XVI. Prepare statistical analyses, quantification of risks and provide other analytical reports to consider the probabilities of all material operational and business risks of MH.

XVII. Provide recommendations for risk mitigation measures to be considered by MH and future reporting requirements for regulatory purposes.

XVIII. Be available through counsel for Consultants, as resource on general risk management inquiries, as reasonably required, to any Party to the GRA and receive input on possible relevant risk issues from any Party to the GRA (but not bind the Consultants). Any additional costs are subject to PUB approval.

XIX. Provide a written report covering matters in items 1-7 herein with supporting data for use in the current MH GRA and any related applications before the PUB.

XX. Participate as independent witnesses before the PUB in the current MH GRA and all related Applications before the PUB, including pre-hearing processes, responding to Information requests and testifying/attending for cross examination at oral hearings of the MH GRA and all related Applications before the PUB.

1.2 Unique Features of Manitoba Hydro

The general context within which MH operates and its salient and unique features are presented first by way of setting the stage for the identification, quantification and analysis of the different risk factors faced by MH and in order to anchor the conclusions and recommendations reached. This context is complex, given the inherent difficulties of being a public utility--both a business entity seeking positive, if not maximum, net income, and a public organization serving the best interests of the residents of Manitoba. Compared to other Canadian public power generators, MH is very hydro-oriented and export-oriented. As a major hydro generator it is critically dependent on weather and the environment. MH is a monopoly, selling power without competitors in the domestic market but faces stiff competition in the export market where it is generally a price taker. These characteristics will prove crucial for our understanding of the conditions, challenges and risks facing MH.

1.2.1 MH is a Public Utility

MH is a public utility. This means it is an industry that provides the public with what are considered necessary services and that has, either through a relatively large initial investment or other unique operational conditions, the traits of a natural monopoly - traits which from early times inevitably tended to bring it within some form of public control, judicial or administrative or both. The public control takes many forms, but typically includes the supervision of rates and service by a public utility board, public ownership and oversight over operations and expansions by public bodies. Significantly, public ownership and oversight imply that the residents served by the utility are both shareholders and consumers. They are the main "clients" of MH and are at the same time the owners of the enterprise, and bear the final responsibility and consequences of its financial viability and success.

Public ownership of utilities is more widely developed in Canada than in the United States, a fact which is due less to ideology than to peculiar exigencies in the development of the state and the economy in Canada. Such a development was inevitable because in this industry genuine economies (of scale and scope) could only be effected by linking all of the productive units together in a highly co-ordinated system. Private capital markets in Canada have not been developed sufficiently to finance the large investments required by utilities at the early stages of their inception.

Over this integrated system some control had to be exercised by the public through government and its many different agencies and institutions. This is done in order to maintain an independent and effective accountability and control governance regime over this natural monopoly. The provincial government exercises vital direction over the entire hydro-electric system in Manitoba as it guarantees its loans for expansion, underwrites its losses, appoints its regulatory Board, and ensures that MH management is accountable to responsible cabinet ministers, public bodies (e.g., Provincial Auditor) and the legislature (Standing Committee of the Legislature). MH is also subject to a broader network of regulation from the Federal Government (National Energy Board, Department of Fisheries and Oceans, etc.), and must comply in the US market with US regulatory bodies such as FERC and NERC, and has a contractual relationship with MISO.

In most activities competitive forces ensure that prices for goods and services tend towards the cost of providing them plus a margin for the supplier. The size of this margin will depend upon the extent of the competition – if many potential suppliers compete to provide a particular product or service the margin is small, but if only one or a few suppliers are willing or able to provide that service the margin is likely to be larger. Utility services are characterised by large capital investments, economies of scale in service, and high barriers (technical, legislative, financial) to entry. Some utility activities (e.g. network operation, system control, etc.) can be carried out only by a single entity, and others (e.g., power generation, water production, customer service, metering and billing) have such economies of scale that it is unlikely that there will be more than one supplier of these services in a small market. Public regulation is premised on simulating competitive market conditions that force the natural monopoly to moderate its market power and charge prices reflective of marginal costs. This is often done through a hard budget constraint imposed on the utility where it has to explain and justify any rate change by justifiable cost increases and where it has to demonstrate that its cost of service is minimal and all efficiency requirements are met.

Economic, or price and service quality, regulation is not required when the service is provided by government entities, but it becomes necessary as the service provider moves out from direct government control; and it is absolutely essential to control the activities of independent service providers seeking to make profits. The Crown Corporation structure in Canada places MH, as seen above, in two categories at the same time. Firstly, it has a business operating structure like any other business. Secondly, its shareholders are the people of Manitoba, and it is subject to a complicated governance regime with many overlapping jurisdictions. These special characteristics set it apart from the general run of Canadian business. It is also important to note that the workability of the competitive market place, which is relied upon to set the terms of trade in other businesses, is generally absent in the case of public utilities. This duality of character creates a principal agent problem because of information asymmetries between the principal (the public) and the agent (MH).[1] The government or its agencies and bodies are interested in overcoming information asymmetries with the operator and in aligning the operator's interest with those of the public. The information asymmetry arises in the context of utility regulation because the operator knows far more about its abilities and effort and about the utility market than does the regulator or the public.[2]

---

[1] Baldwin, Robert, and Martin Cave, Understanding Regulation: Theory, Strategy, and Practice, Oxford: Oxford University Press, 1999, Chapters 2-3. and,
Kahn, Alfred. The Economics of Regulation: Principles and Institutions. Cambridge, MA: MIT Press, 1988, Reissue Edition, vol. I, Chapter 1.

[2] Newbery, David M., Privatization, Restructuring, and Regulation of Network Industries. Cambridge, MA: MIT Press, 1999, Chapters 1 and 4.

In general, utility regulation can occur for several reasons. Common arguments in favour of regulation include the desire to control market power, facilitate competition, promote investment or system expansion, or stabilize markets and overcome information asymmetries.[3] These objectives can be met through:

- Setting the rates levied by the regulated entities for certain prescribed services, to ensure that they are fair and reasonable.
- Safeguarding the financial health, reliability and safety of industry.
- Monitoring and regulating customer service standards achieved by the utilities to ensure a balance between consumer and producer interests.
- Hearing and determining any serious customer complaints against the utility organisations (if unresolved by the utility organisations themselves).
- Providing relevant information (operational and financial) on the industries it regulates to consumers, government, and other stakeholders and maintaining transparency.

The dual structure of the utility in Manitoba presents challenges and difficulties for MH but it also confers some critical advantages. MH is able to borrow at preferred interest rates, to expand its operations with greater access and ease to capital markets, to pursue environmental and social objectives, and to be liberated from an undue short term focus in favour of long term objectives (creating jobs, maintaining balanced relationships with First Nations, taking environmentally friendly initiatives, and so on). However, this structure also insulates MH from strict and direct shareholder scrutiny and it may constrain it to compromise business objectives in favour of social and environmental goals.

The public guarantees of debt can tempt a public utility to undervalue risk and behave more recklessly than if it were to bear alone the consequences of its risky behaviour.[4] This temptation is further complicated by a regulatory regime that may set rates to cover

---

[3] Garfield, P.J. and W. F. Lovejoy, Public Utility Economics. Englewood Cliffs, New Jersey: Prentice Hall Inc.1964, Chapter 2, pp. 15-26.

[4] Mas-Colell, A., M. Whinston, and J. Green, Microeconomic Theory. Chapter 14, 'The Principal-Agent Problem', 1995, p. 477, and B. Holmstrom, 'Moral Hazard and Observability'. Bell Journal of Economics, 1979, pp. 74-91.

the public utility costs and errors, and that allows it to pass the costs of its mistakes, inefficiencies and risks to domestic consumers.

Profit optimization is not necessarily consistent with revenue optimization. The former would require higher prices, lower output, and lower employment. Socioeconomic and environmental concerns can trump some efficiency criteria. The fact that the residents of Manitoba are the owners of the utility and that the government guarantees the utility's loans may prompt MH to tolerate more risks than the shareholders would like it to or are willing to support. This proclivity to engage in risky behaviour or to accept different tolerance for risk between the residents of Manitoba and MH is a crucial problem for the regulators as they attempt to align the two interests and dispositions and minimize the tolerance differential between them.

Put differently, the real issue is for the regulators to align the risk exposure and tolerance of MH to match that of the citizens on behalf of whom the government and/or the Public Utility Board typically act. Citizens, in general, are risk averse, and Manitobans are likely no exception. Roughly speaking, this means that they would prefer to take on financial risk only if the probability of gain outweighs the probability of loss. MH tolerance and acceptance of risks may be different from that of the public. The issue is, then, one of a potential lack of alignment between the two and the extent to which regulators are forced to govern the risk tolerance and appetite of MH to match that of the shareholders (the people of Manitoba). This misalignment in risk tolerance arises not only because of different appetites for risk but also from the fact that the public assumes the costs of any losses either in higher electricity rates (if PUB allows it) or through debt payment charges, whereas the potential rewards of the risk-taking are internalized within MH.

1.2.2 MH is Hydro-Oriented

MH is also unique in that over 95% of its total power generation is hydro. This characteristic is not shared with many other power generators in North America or the world. This heavy dependence on hydrological conditions subjects MH to severe volumetric risks embedded in droughts and weather related determinants with unknown probabilities and wide fluctuations. The lack of alignment of risk tolerance between the shareholders and management of MH is compounded by these large volumetric risks with substantial consequences in terms of reliability and profitability. The shareholders will bear the costs of any risk undervaluation and errors without being directly able to impose their risk tolerance on the management of the utility in the same manner that shareholders of private entities are believed to be able to do.

1.2.3 MH is Export-Oriented

MH sells a large share of its generation outside Manitoba. This share exceeded 31% in 2007. Complications arise due to the resulting dependence of MH's revenues on markets over which Manitobans have little or no control. Exports to the US constitute the largest share in these exports of about 80%. The utility is subjected to the vagaries of market fluctuations and competition which it is insulated from in the domestic market. In tight situations MH is more likely to be able to pass its costs to domestic consumers, whereas it acts as a price taker in the competitive export market.

1.2.4 Summary

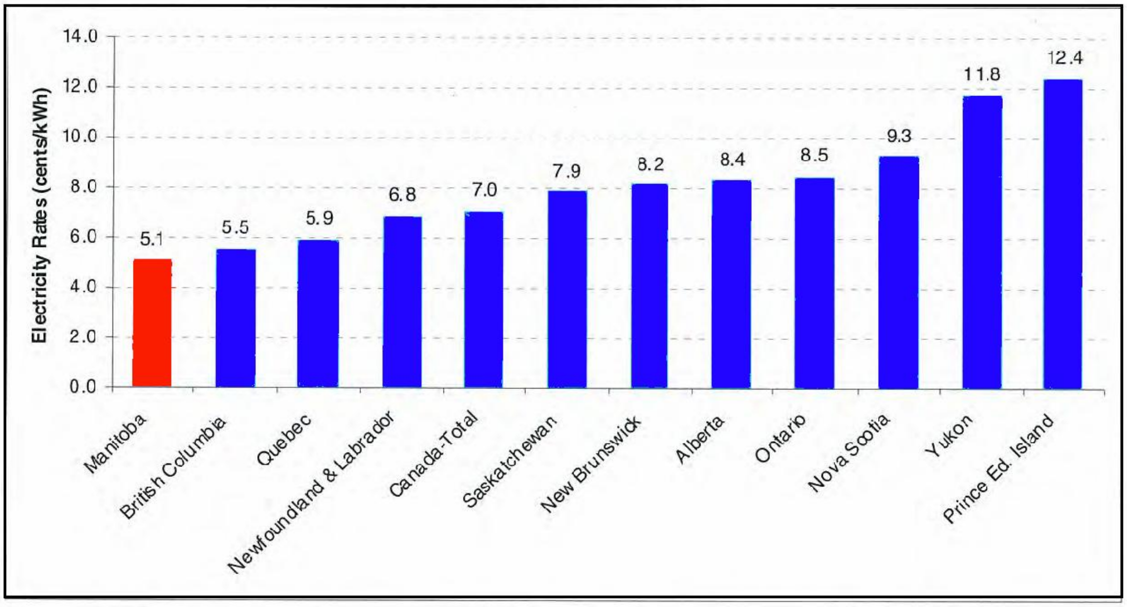
Information asymmetries, principal-agent problems, moral hazard and risk tolerance misalignment issues raise serious challenges for regulators and for shareholders. These problems exist in business corporations but they are far more prevalent in public corporations, particularly those in monopoly positions facing soft budget constraints.

1.3 The Historical Record

There are a few historical characteristics of MH that distinguish it from other utilities and private corporations in Canada and North America: low rates, high exports, and sensitivity to drought. A brief account of these salient features is undertaken here to situate the analysis that follows.

MH has one of the lowest electricity rates in Canada—a rate that is perhaps lower than most of the rates in North America. In 2007 MH's electricity rate averaged 5.1 cents per kWh, whereas this rate exceeded 12.4 cents in PEI and 5.9 cents in Quebec (Figure 1.1). In New York the rate per kWh exceeded 17 cents in the same year.[5]

Figure 1.1 – Canadian Retail Electricity Sales in 2007

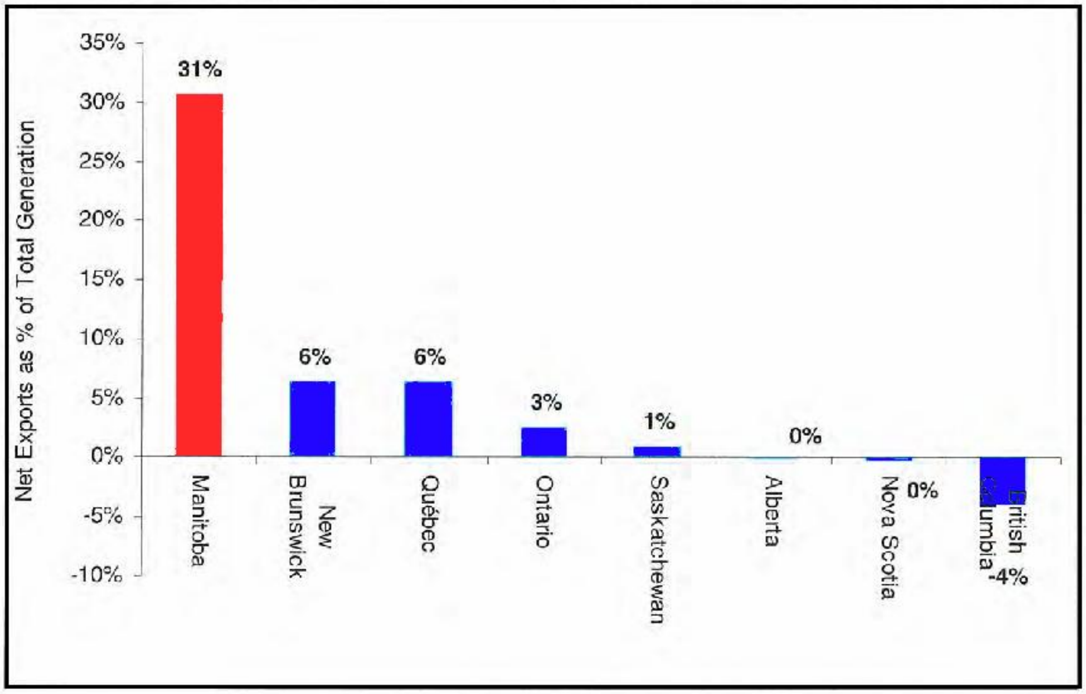


Source: 2007 Annual Electric Power Generation, Transmission and Distribution Report, Statistics Canada

Net exports accounted for 31% of total generation of electricity in Manitoba in 2007. This is by far the largest share of net exports to total generation in Canada. Quebec, which is known to export a large volume of electricity to the US, shows a share of only 6%, and Ontario has an even lower share of 3%. On the other hand, British Columbia had electricity imports that exceeded its exports, ending up with a negative net export share of 4% (Figure 1.2).

[5] ICF. 2009. Independent Review of Manitoba Hydro Export Power sales and associated Risks, p.4.

Figure 1.2 - Net Electricity Exports to US as a Percentage of Total Generation in 2007



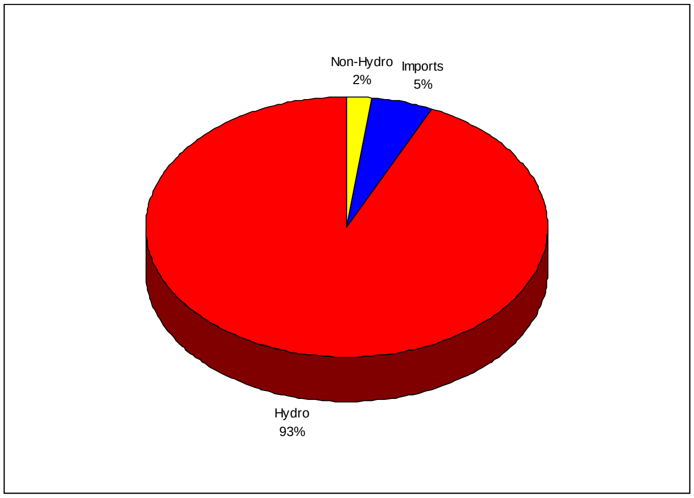
Source: 2007 Annual Electric Power Generation, Transmission and Distribution Report, Statistics Canada, pp.11-12

The heavy dependence of MH on hydrology is noted in Figure 1.3, which shows that 93% of total supply comes from hydro sources. This is the highest share in Canada. If imports were not considered this share would jump to 98%. This relatively heavy dependence on hydrology instils a significant element of variability in electricity generation capacity in Manitoba. As is clear from its variation in Figure 1.4, MH power generation is more variable than any other Canadian utility including Newfoundland & Labrador.

Volumetric risk is closely associated with supply variability, and the greater sensitivity in Manitoba to water conditions and weather, highlights the importance for MH of managing this significant source of risk.

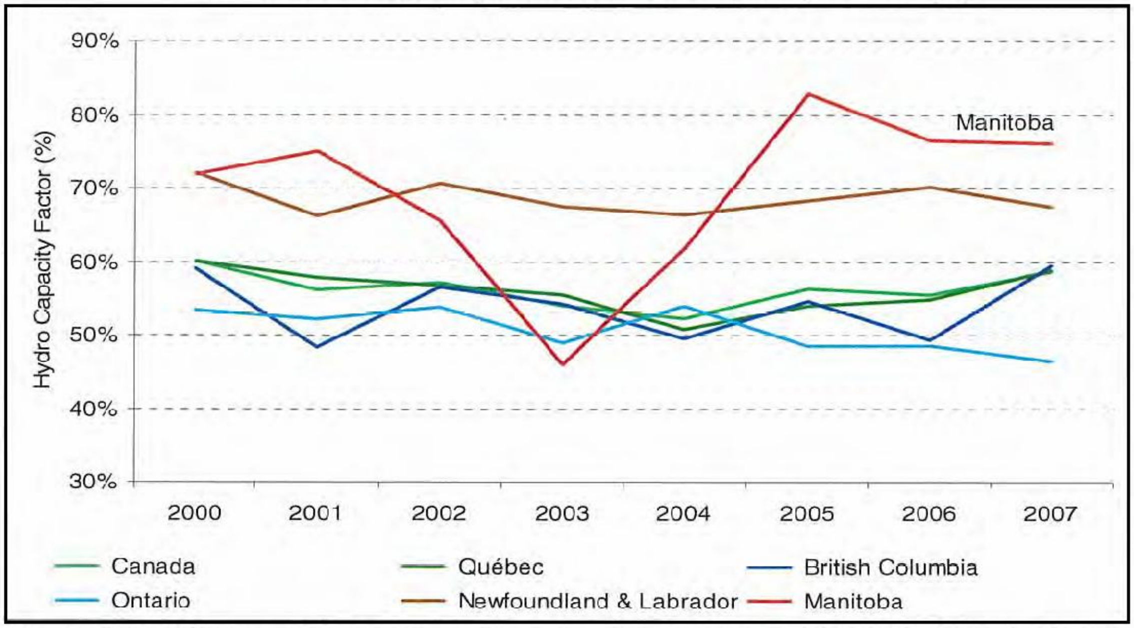
The increased variability in weather conditions experienced in the past decade or two in Central Canada, and the possibility that this variability may rise further as climate conditions and changes begin to take hold, suggest that MH, more than any other utility in Canada, must pay close attention to climatic conditions in order to cope with the resulting supply variability.

Figure 1.3 – Average Electricity Generation, 2000-2007



Source: 2000-2007 Annual Electric Power Generation, Transmission and Distribution Reports, Statistics Canada

Figure 1.4 – Canadian Utilities Hydro Historical Capacity Factor (%)

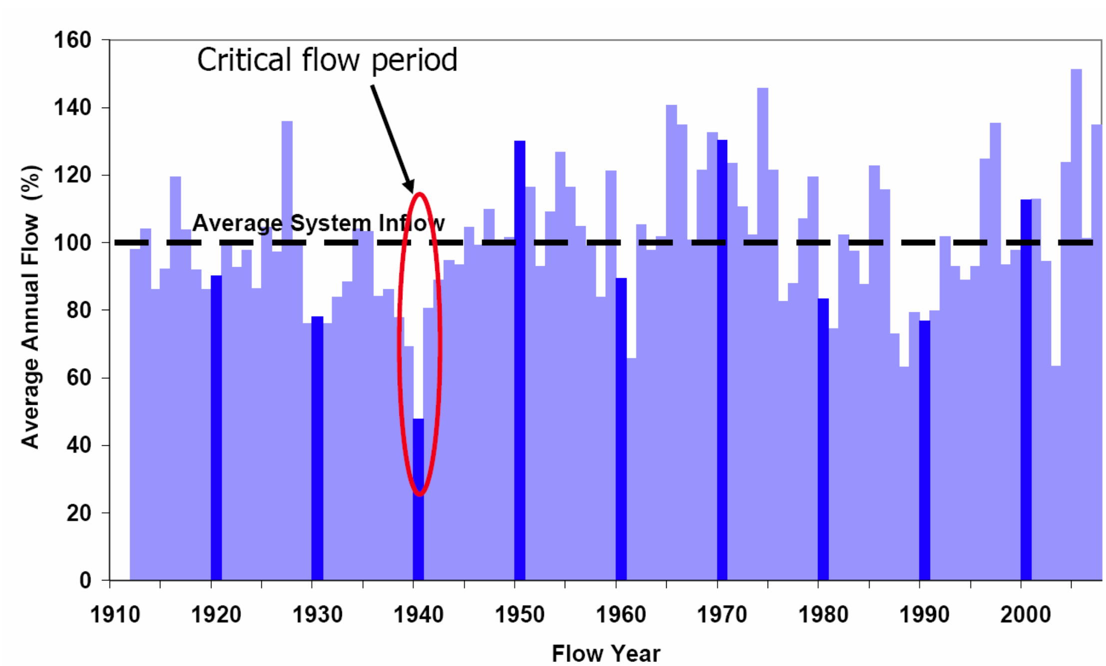


Source: 2000-2007 Annual Electric Power Generation, Transmission and Distribution Reports, Statistics Canada

The historical record of water availability in Manitoba shows an obvious tendency towards drought recurrence. The drought of 2003-04 was severe but did not last as long as several previous droughts. The worst recorded drought, 1937-1943, lasted almost seven years, causing water levels to dip to the lowest levels in the period extending from 1912 to 2008.

Water flow variability between 1912 and 2007 is presented in Figure 1.5, where the flow rate in 1940 was 40% of the average flow and reached 152% of this average in 2005. The data in Figure 1.5 also show that a number of major droughts have occurred with severe water shortages.

Figure 1.5 – Variation in Flow Related Revenue, 1912-2007
(Average Annual Flow - %)

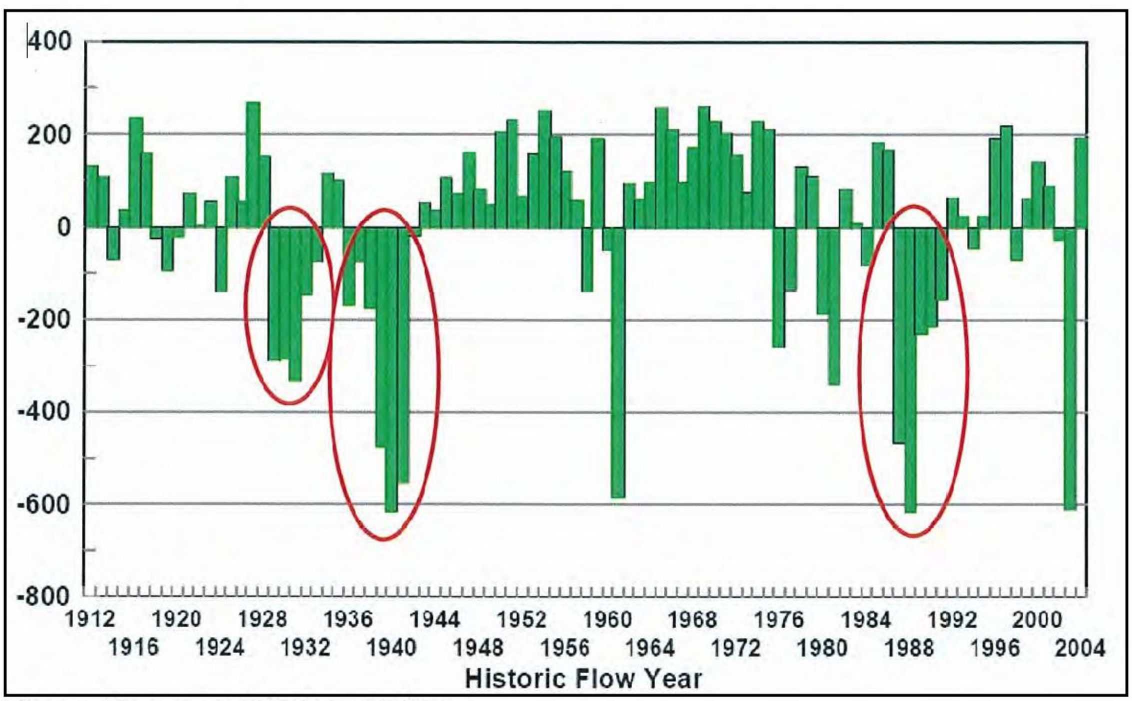


Source: Manitoba Hydro

Droughts do not only create volumetric shortages, they also create financial challenges (Figure 1.6). MH suffered major losses in 2003-04, as retained earnings declined by $436 million. No blackouts were experienced, however, as imports made up for domestic hydraulic shortages, and alternative generation was used. Firm export commitments required expensive book-outs as alternative supplies had to be purchased to make up for committed sales. But the 2003 drought is just one of three major droughts experienced since 1912, when water flow records began. It was neither the worst nor the longest drought. It is possible that a more serious drought may occur. Comprehensive water modelling is required to map all possibilities and prepare a credible drought response.

An entire chapter will be devoted to drought and water management issues and conditions in this Report. What we want to establish here is the crucial significance of water flow conditions in several watersheds to the financial health and reliability of MH as well as their implications for the utility's operations, financial stability and ability to meet its commitments domestically and internationally. Careful planning requires that extreme events be identified, their probability of occurrence acknowledged and a plan put in place to deal with their occurrences via detailed responsibilities and accountability measures.

Figure 1.6 – Variation in Flow Related Revenue, 1912-2004
(Millions of $)



Source: Response to PUB Order 117/06, p.1
Notes:
1. The calculations for the graph above assume current generation capability and a single base case for other parameters.
2. The circled time periods indicate extended drought years

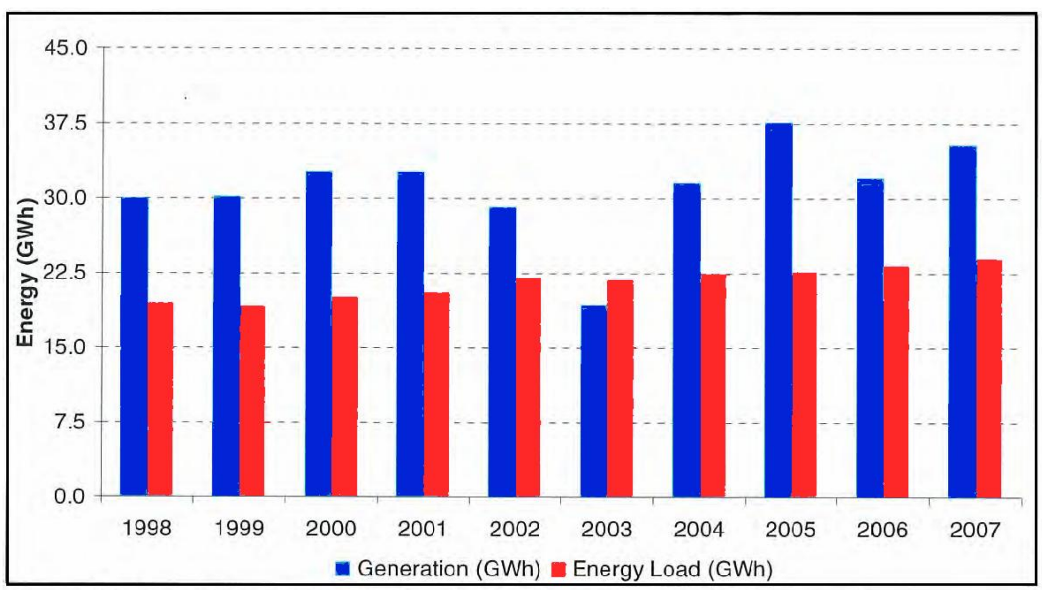
We also wish to draw attention from the outset to the inherent competition between domestic load and firm exports. Power generation has exceeded domestic load in all but

2003 during the decade 1998-2007 in Manitoba (Figure 1.7). This suggests that although droughts do occur and will occur, the normal course of events is one where MH's supply of power exceeds domestic load and generates exportable electricity.

Exports of electricity are two kinds, firm exports and opportunity exports. MH has made sure that the two have both types and in many cases these two alternatives had equal shares. Opportunity exports over the period 2000-2007 averaged 16% of total generation, whereas firm exports constituted 14% (Figure 1.8). It is also worth emphasizing that Manitoba's peak electricity demand is in the winter, whereas export demand peaks in the summer. This out-of-phase peaking in seasonal energy demands between the US export markets and Manitoba has important implications.

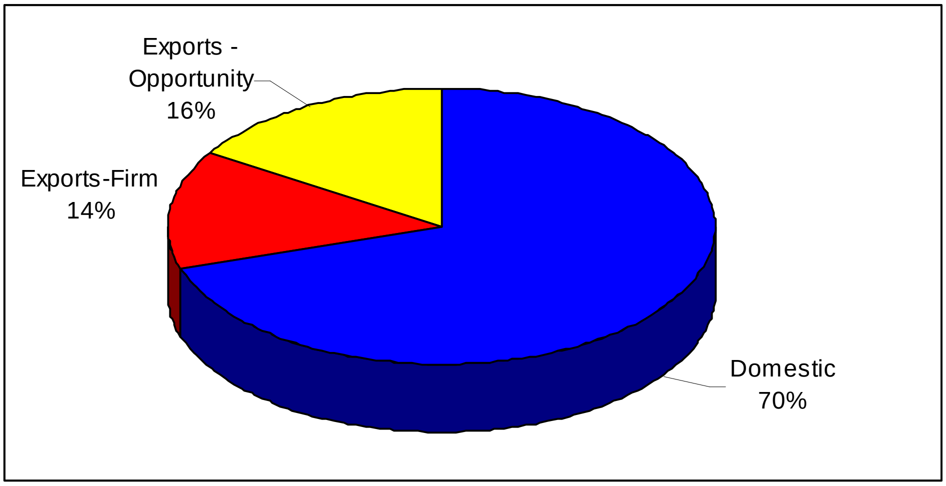
It is also worth noting that MH insists that it sells its surplus energy supply after meeting its domestic demand through long term contracts and short term opportunity sales. But what happens when domestic supply falls short of domestic demand? This has occurred in the past and is likely to occur in the future. If firm exports are committed exports that must be delivered, alternative energy generation or imports must be available and suitably priced and/or provisions must be introduced in long term contracts for curtailment; otherwise MH will face losses and possible shortages.

Figure 1.7 – Manitoba Electricity Supply and Demand, 1998-2007



Source: Manitoba Hydro-Electric Board 57th Annual Report, March 31, 2008, p.112
Note: Annual Generation and Energy Load numbers represent the numbers for a financial year; for example, 2007 numbers represent the numbers for year ended March 31, 2008.

Figure 1.8 - Average Disposition, Manitoba Hydro, 2000-2007 (GWh)



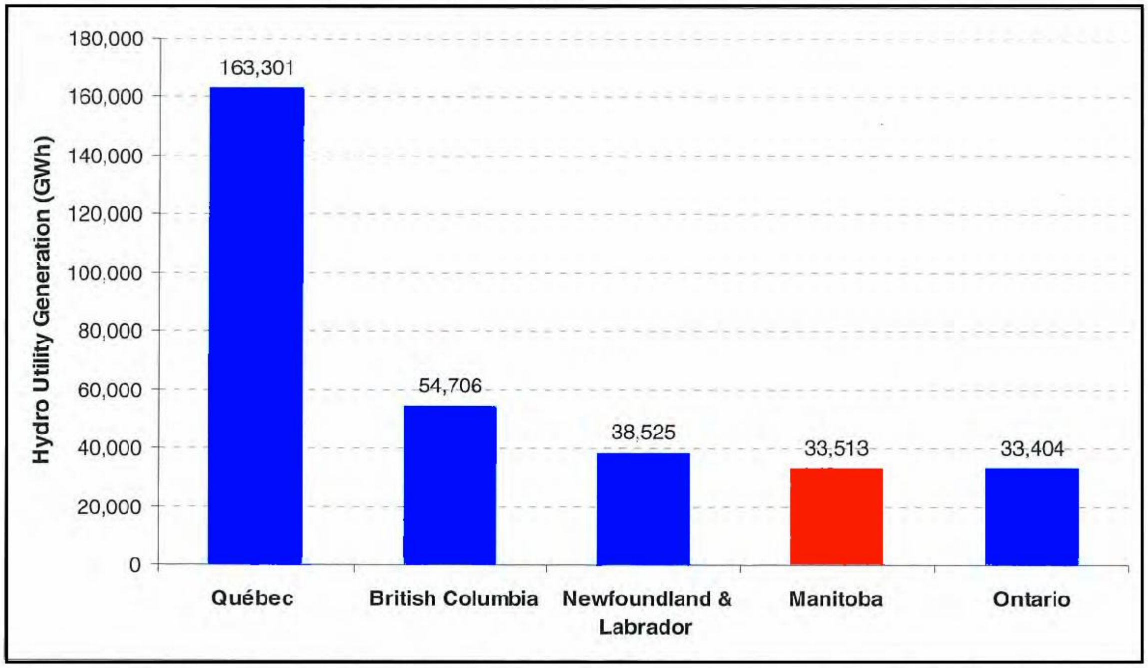
Source: 2000-2007 Annual Electric Power Generation, Transmission and Distribution Reports, Statistics Canada

MH generated over 33,513 GWh in 2007. This is slightly larger than Ontario's 33,404 GWh, but significantly smaller than Quebec's 163,301 GWh and British Columbia's 54,706 GWh or Newfoundland & Labrador's 38,525 GWh (Figure 1.9). On a per capita basis Manitoba and Newfoundland & Labrador will assume higher ranks. On a per capita basis Manitoba's generation is second to none in Canada.

The prominence of MH as a leading economic node in the province is quite recognizable and any development affecting this key export oriented sector is of serious interest and concern for Manitobans. While Albertans think of their oil as a major defining characteristic of their economy, Manitobans think of their hydro power as a defining comparative advantage of their economy. The public interest in MH is unmatched by any other sector in the provincial economy.

A total of 10,550 GWh represented the net exports of electricity to the US from Manitoba in 2007. While this amount may not seem large, it is just a little smaller than Quebec's net exports to the US in 2007 and significantly larger than Ontario's or New Brunswick's (Figure 1.10).

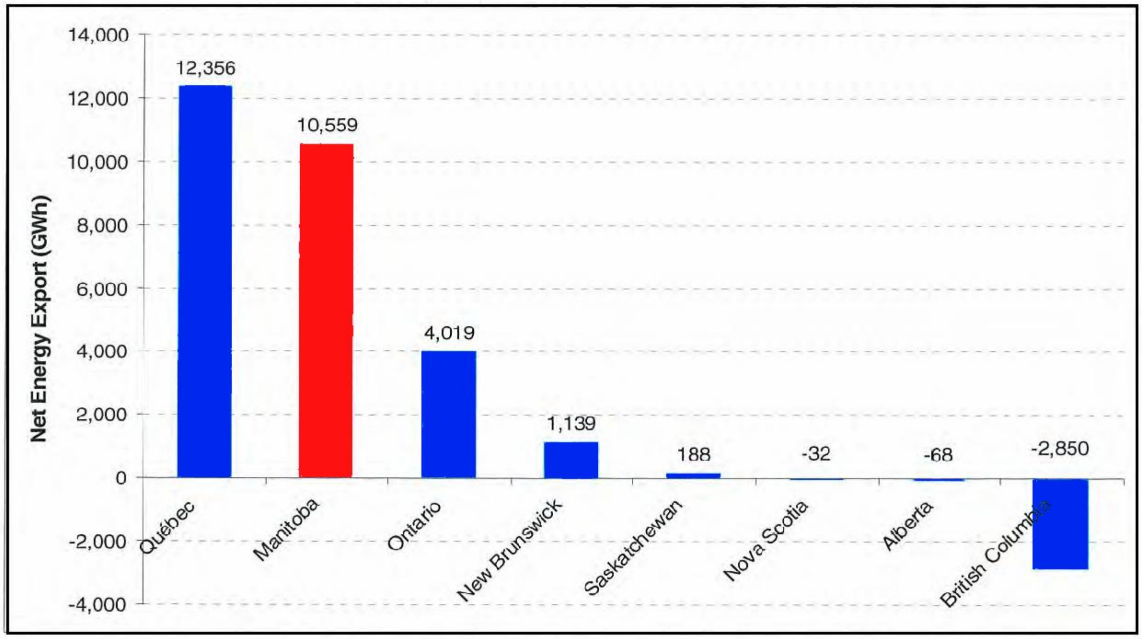
Figure 1.9 – Canadian Hydro Utilities Generation – 2007



Source: 2007 Annual Electric Power Generation, Transmission and Distribution Report, Statistics Canada, pp. 11-12

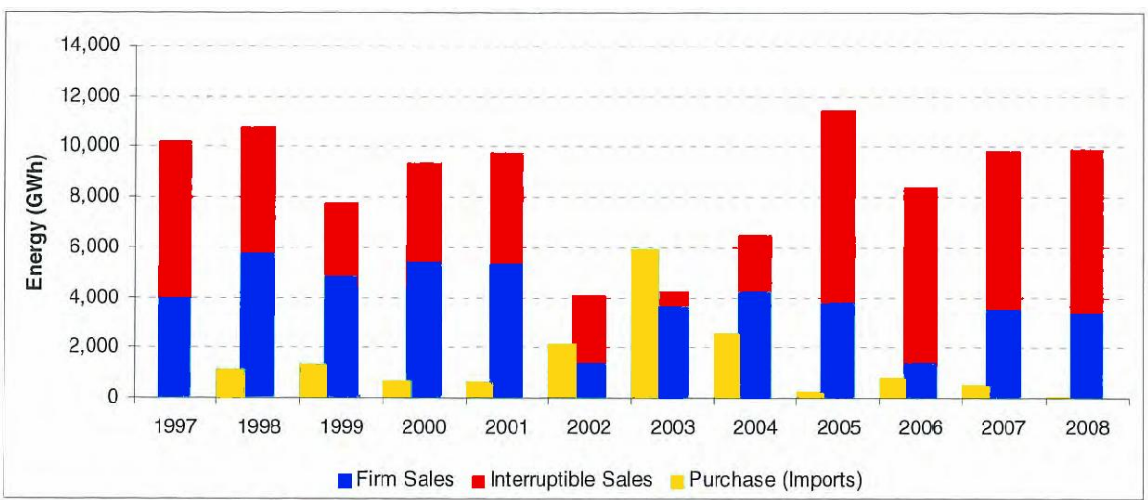
Net exports are exports minus imports. Disentangling imports from exports is meaningful and necessary. The capacity to export is significantly constrained by transmission availability, cost and capacity. The fact that transmission capacity can be used by both exporters and importers is a strong argument for validating the importance and contribution of exports and imports. This is all the more important when the export and import markets do not peak at the same time. It becomes a serious problem when shortages develop, causing exports to dry up and imports to rise at a time when prices are high.

Figure 1.10 – Net Electricity Exports to US from Canadian Provinces, 2007



Source: 2007 Annual Electric Power Generation, Transmission and Distribution Report, Statistics Canada, pp.11-12

Figure 1.11 – Manitoba Imports and Exports



Source: Canada National Energy Board website

Notes:

1. The annual Energy Import and Export values represent values for a calendar year i.e., January to December.
2. The Export values in the graph do not include exports represented under the 'Non-Revenue' category

The largest share of Manitoba exports is sold in the US through the Midwest Independent System Operator (MISO). This share constituted over 82% in 2007/08. The remaining 18% is sold to Ontario and western provinces. Such a heavy exposure to a foreign market presents great opportunities, but also great challenges.

In 2003 imports exceeded both firm and interruptible sales but in all other years between 1997 and 2008 the opposite is true (Figure 1.11). Following the drought in 2003, it is clear that interruptible sales exceeded firm sales and imports declined measurably.

1.4 Synopsis of the Findings

This section briefly summarizes major findings and areas and issues identified for improvement. Some of the recommendations for improvement include activities already under way at MH, but a few call for new activities and procedures. We have made a special attempt to make positive recommendations that we believe would improve the identification, quantification, management, control, mitigation, oversight and reporting of risk. The number of these recommendations is large; below we list only the key findings.

First, the actual minimum used by MH is within the 95% interval of all simulated statistical minima. MH is using a reasonable water flow reference in calculating dependable energy. There may be a worse drought than the 1937-1942 the most severe drought in the historical record between 1912 and 2008, but the probability of occurrence of such a drought is less than 1 in 392 years.

Second, there are no grounds to believe that there exists a serious material risk for blackouts in Manitoba.

Third, the financial losses of a severe drought are massive and these can deplete accumulated retained earnings of MH in less than three years.

Fourth, MH models are serving their purposes and can be relied upon for operational planning and long term planning, but they need to be upgraded to include stochastic and dynamic modules. They also need to be reviewed and authenticated by external subject matter experts. It is desirable and beneficial to initiate formal documentation and integration of these models on a common platform.

Fifth, the Middle Office is evolving and assuming more effectively its functions and responsibilities. It is recommended that it is placed directly in the office of the Senior Vice President for Administration and Finance and that it is charged with reviewing and quantification of all risks and particularly Long Term Contracts' risks. This will require more skills and more resources for this function, but this investment is warranted and will pay off high dividends.

Sixth, Long Term Contracts are now well structured and include many new and innovative curtailment provisions, reasonable escalators and upset heat rate based import prices. But these contracts need to be staggered over time and diversified over a larger group of counterparties.

Seventh, the NYC has alerted MH and Manitobans to a number of issues and concerns. Some are valid but many are not. The Consultant's contributions to the improvement of risk governance, oversight and back testing of MH models, the quantification of risks, the use of stress tests and the need for provisioning of adequate risk capital are undeniably valuable and have prompted MH to rise to the challenge and to introduce several improvements in its operations and models.

Eighth, the quantification of risk exercise we have undertaken confirms the criticality of volumetric risks and the wide exposure to the risk of severe import price increases, particularly when the increases in import prices are coupled water flow shortages. The interest rate and domestic load growth have only a moderate impact on net revenue, while changes in fuel prices, the exchange rate, labour costs and material costs have very limited impacts on net revenue.

Ninth, the real material risks that can have drastic impacts on MH are financial. The Corporation is vulnerable to large financial risks and must take a bundle of measures with lower bounds that include building sufficient equity (accumulated retained earnings), keeping adequate volumes of water in storage above deterministic, perfect foresight model solutions, judicious use of sophisticated hedging instruments (derivatives, puts and calls, FTRs, etc.) and fair rate adjustments (avoiding rate shocks). The weights to put on these different items can crucially alter the final outcome, but a target of equity of at least a high percentage of the full cost of a seven year severe drought with high import prices, high interest rates, and an appreciated Canadian dollar must guide the selection of these weights. We argue strongly in favour of avoiding targeting massive borrowing, the debt structure of MH is already high and moral hazard behaviour must be avoided.

Tenth, future long contracts should include a higher proportion of the value of embedded environmental attributes for MH, it is very likely that the heightened concern for the environment will soon translate into higher carbon charges. This likelihood should be factored more visibly in the future contracts.

Eleventh, system expansion is necessary and massive capital will be needed sooner or later to meet the expanding load in Manitoba. The timing and scale should be flexible and appropriately phased, however, in order to allow MH to undertake these expansions in times when material, labour and other costs are low and other complementary transmission capacities are firmly in place.

Twelfth, there are many other risks and issues ranging from strategic, political, reputation and infrastructure that we did not deal with at length in this Report. Not that they are not important. They are, but most of these fall within the qualitative area and outside of our expertise.

1.5 Report Organization

The report is organized into eight chapters, including the introduction. Following the introduction the report is structured as follows:

- Chapter 2 provides background information on Enterprise Risk Management.

- Chapter 3 reviews and evaluates several operational models used by MH including MOST, HERMES (EMMA and QSIM), SPLASH, PROMOD and PRISM, as well as the Domestic Load Forecasting Model and the Economic Outlook document.

- Chapter 4 reviews MH's water flow data, water flow predictions, management models and volumetric risk profiles.

- Chapter 5 reviews and evaluates several relevant reports that addressed risk management at MH including MH's Corporate Risk Management Report (CRM), ICF International (ICF) Independent Review of Manitoba Hydro Export Sales and Associated Risks' Report, NYC Reports, KPMG Report and other relevant but less detailed documents and submissions such as that of Risk Advisory and Deloitte & Touche.

- Chapter 6 identifies, quantifies and analyzes most of the relevant risks pertaining to MH's three systems of water, generation and finance and their relationship to the assumptions and structure of the IFF.

- Chapter 7 presents a summary of the conclusions and recommendations.

Chapter Two

Enterprise Risk Management: Best Practices and MH Procedures

2.1 Introduction

Over the past 10 years, risk management has evolved from an often overlooked Back Office discipline to a vital component of securing every business' future. It is now an increasingly Middle Office responsibility and typically placed in the Office of the highest ranking operational position. Surely, a few companies still have not embraced and cultivated the outlooks of the risk management culture or placed risk management professionals on their payroll, but the events of the past two decades have made the core concepts impossible to ignore.

From Y2K, 9/11 and Enron through Katrina, pandemic threats of SARS and Swine Flu, and the sub-prime debacle and Wall Street collapse, the world has faced a relentless onslaught of risky and uncertain developments from all directions. In looking back at recent history there is only one logical conclusion: risk management is now a critical need. In the decade of the 1990s and up until 2007, the world has experienced a period of unprecedented economic growth. This growth has been exceeded only by the growth and multiplicity in the risks facing organizations. From the grim realities of international terrorism and recessionary economic forces to the proliferation of environmental threats and climate change, a rapidly changing set of challenges are likely to jeopardize businesses in every sector.

The result has been a major change for the risk management industry. In the past decade, business executives have recognized the need to implement new policies to confront these new risks. This has led to the emergence of risk management as a critical support industry and to the rise of risk management officers as vital to executive decision-making.

Up until the year 2000, risk managers focused on two main issues: financial risk management and a technical glitch many at the time predicted would bring industry and government to a standstill, something they called the Y2K bug.

2.1 Risk Management Evolution

Risk management has evolved from an obscure function of finance and insurance to an approach necessary for any organizational resilience. What started as a niche department with little or no ability to influence organizational behaviour has been transformed into a critical source of strategic planning with a direct line to top management. Best practice risk management puts this function at the heart of the Middle Office at the higher echelons of the Corporation's management. More importantly best practice risk management has migrated to all aspects of the organization and is a concern at every operating node and for every employee.

These changes seem to have been set in motion over fears about a computer programming glitch and some misplaced ones and zeros. Predictions about the impact of the Y2K bug were dire: without intensive investment in IT infrastructure, updates and redundancies, the moment January 1, 2000 hit the clocks airplanes could fall from the skies, electric grids could shut down and bank accounts could be erased.

Instead, nothing happened. Aside from small, localized disruptions of minor consequence the year 2000 entered with a whimper and the risk manager's worst fears never materialized. Nevertheless, Y2K triggered a shift in how organizations thought about risk management, and investment in the "space" changed significantly. For the first time risk managers were looking at how a single event could impact the entire operation. Focus shifted away from looking merely at financial risk implications and internal investment flows into IT risk management. The after-effects of Y2K engendered two distinct changes. The first argued that proactive investment in IT risk management and cooperative efforts across industries had averted disaster. The counter view suggested the entire saga was much ado about nothing. In the absence of a crisis it was hard to tell if investment in risk management was working. The occurrence of a crisis is considered as necessary for a culture shift. This has been, and continues to be, at the foundation of a corporation's interest in the discipline. MH is no exception to this rule. Without the dramatic events that came in the wake of the short-lived but devastating drought, the interest in risk management may not have surfaced.

2.1.1 September 11 Events, SARS, Katrina and the Economic Meltdown

September 11, 2001 would irrevocably change the terms of the debate, however, permanently altering how organizations thought about "black swans", threat assessments, preparedness and response. As the shock of the 9/11 tragedy slowly wore off corporations realized that they were largely unaware of their risk exposure to catastrophic events with major consequences but low probabilities.

Risk management firms stepped up to meet this challenge with a variety of innovative solutions. Thus an enduring focus within the industry emerged: visibility. Corporations began to demand a more detailed and comprehensive picture of all the moving parts throughout their operations. They wanted to know how vulnerable facilities and supply chains were to threats and crises, both obvious and unforeseen.

The events of 9/11 also brought the issue of enterprise wide risk management to the forefront. They demonstrated the devastating impact an external event could have on business operations -- and the need to understand and plan for potentially catastrophic threats, however distant they may seem and however low their probability of occurrence. While the 9/11 events may have brought the deep need for enterprise wide risk management into focus, as the decade progressed it was environmental threats that tested these new ideas and pushed the burgeoning risk management industry to mature. The dot.com collapse and the recent economic meltdown engendered the need for comprehensive enterprise risk management practices and governance.

In 2003, a strange new virus, Severe Acute Respiratory Syndrome, terrorized China, Canada and the global travel industry. The pandemic planning services of several risk-management firms and the infectious disease preparedness plans in many companies are the direct result of the SARS scare, which highlighted the need for monitoring pandemics in real time and adapting policies to meet each season's new challenges. We can see the effects of this change in mindset today, as pandemic preparedness plans are continually being re-written to account for variations in the recent H1N1 pandemic.

Events like 9/11 and worries about the impact of possible natural disasters, severe droughts, pandemic and the continuation of the economic recession drove a new way of thinking about risk management and mitigation. Increasingly, managers began to focus on systemic risks and preserving the integrity of business operations as a whole. Focus shifted from simply anticipating threats and preparing for crises in any one sector of a corporation toward concepts such as business continuity, resiliency, and optimality.

In 2005 another unprecedented disaster tested this new idea of resiliency and forever changed assumptions about maintaining business continuity in the face of catastrophic events. As the massive devastation of Hurricane Katrina became apparent, complacency surrounding the ability of businesses to anticipate and respond to major natural disruptions within the United States was washed away along with large parts of New Orleans and the Gulf Coast region. It soon became apparent that state, local and federal systems were ineffectual in handling this crisis. Many risk managers came to the same stark conclusion: this could happen here or anywhere.

Katrina became a giant wake-up call for risk managers whose mitigation planning often relied on local, state and federal authorities to take the lead in response. Moving forward, risk managers and companies began to rethink this strategy and incorporate responsibility for business continuity and resiliency in their organizational plans and search for optimal strategies of mitigation and containment.

Katrina underscored the need for greater operational visibility, employee tracking and, most of all, enhanced communications. During and immediately after Katrina, business continuity collapsed not only because of physical damage to infrastructure but also due to an acute breakdown of communications. Employees were scattered, cell phones were not working and managers had a difficult time locating personnel, understanding their status and reconstituting operations.

This communications breakdown drove new thinking in contingency planning, leading to the development of systems that would allow operations to rebound more smoothly and quickly following a crisis. Perhaps workers could log into a pre-established central website to find information? Perhaps companies could compile a database of contact information and send updates via text message? Katrina taught risk managers and organizations harsh lessons about the importance of communications and physical operational redundancies in business continuity planning. What are these lessons? Are they relevant to MH? What components of these can be drawn upon in devising best practice systems of risk management of relevance to MH? These are relevant questions for this Chapter as we go through some of the best practices in enterprise risk management.

2.1.2 Recent Developments

Recent developments are yet again causing major changes in the industry and will define what is to come in 2010 and beyond. Old risk management questions are new again as companies grapple with the after-effects of the global economic meltdown. Well into 2010 risk management will refocus on financial risk mitigation, as companies struggle with how to anticipate, prepare for, avoid and emerge stronger from future economic disasters.

But as the past 10 years have taught us, operational threats are wildly variable and totally unpredictable. And many analysts agree that the next decade will witness even greater potential threats, such as an accelerated global competition for resources like water and energy. Such conflicts could cripple supply chains by making it significantly harder for companies to produce and distribute their products. Additionally, access to skilled employees may pose continuity challenges as an aging population is replaced by a younger workforce poorly trained in mathematics and sciences (at least in developed countries), which will shrink the pool of capable workers.

As our economy becomes more globalized it also becomes more fragmented and brittle. The entities to which large multinationals outsourced operations are in turn outsourcing, while the network of suppliers and producers grows more and more complex. Any breakdown in this chain could create significant challenges for business continuity and resiliency.

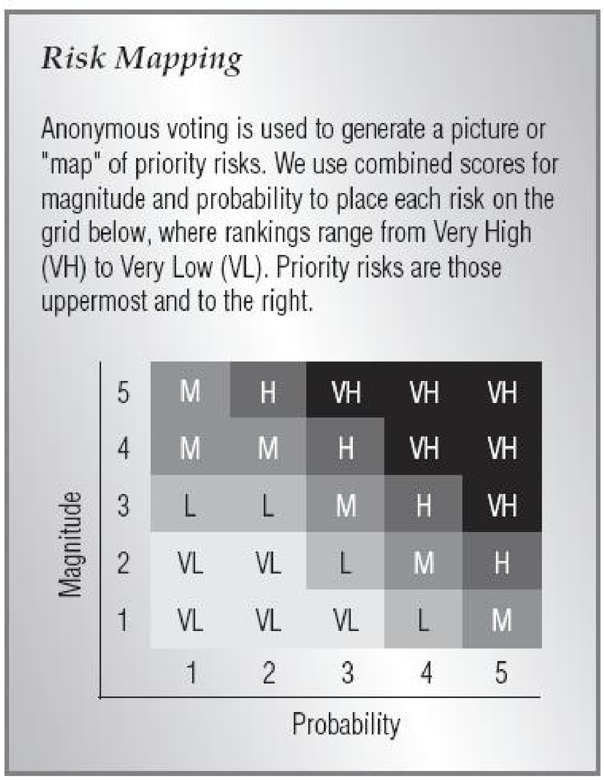
2.2 Risk Management Process

Plato is credited with stating that “The problem with the future is that more things might happen than will happen”. There are many potential events that may or may not occur. The range of possibilities is wide and it is costly and difficult to configure every possibility that may occur. In such circumstances it would make more sense to assign two measures to narrow the range of the potential set of events and to assign some parameters to their probability of occurrence and a magnitude of their expected consequence.

2.2.1 Risk Maps

A map or matrix can easily be organized as in Figure 2.1 where the columns express the probability of occurrence of an event with rankings from low to high while rows express the outcome of an event's occurrence with rankings from low to high. In the southwest corner will be events with low probability of occurrence and low outcomes. In the northeast corner will be events that are very likely to occur with very major and costly consequences.

Figure 2.1 – Risk Mapping



Source: The Conference Board of Canada. Enterprise Risk Management at Hydro One Inc. P.4.

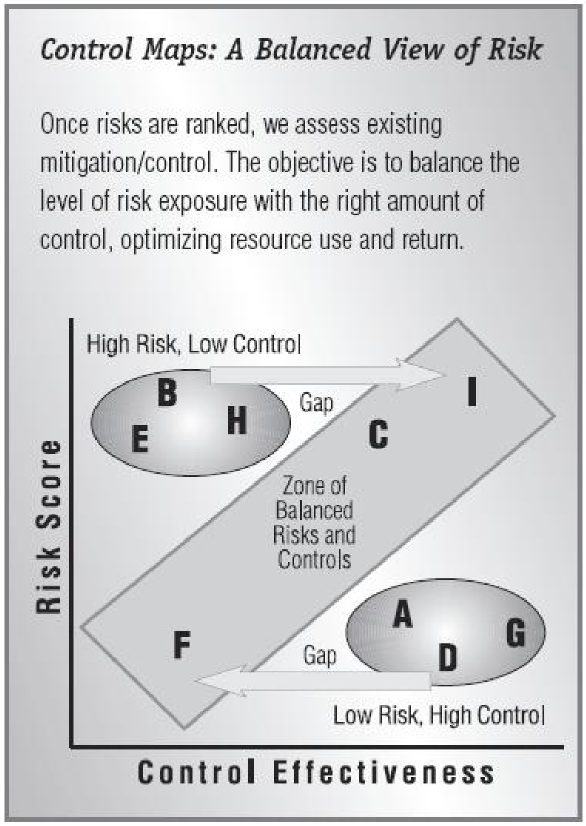
The whole notion of risk is about the potential of an event or an action or inaction to adversely affect an organization's ability to achieve one or more of its objectives. It relates to an objective measure of probability of occurrence and a quantitative measure of expected consequences and outcome. It follows that Enterprise Risk Management is the process of systematically identifying, assessing, quantifying, prioritizing, mitigating and controlling all significant risk sources, with a view to optimizing the balance of risk and return across the organization. Enterprise Risk Management (ERM) is also about a structured approach, with a shared risk language, common analytical tools and appropriate management responsibilities and accountability. Risk Maps are typically qualitative in nature and may be ad hoc unless complemented by a detailed quantification of the risks and the expected value of their consequences. Even this may not be enough. A full representation of the probability density functions is needed as well as a well-defined delineation of the 95% level of confidence that brackets the spread of possible outcomes.

2.2.2 Control Maps

Once risks are identified, assessed and quantified they need to be controlled and mitigated. An ownership structure is necessary to assign the various functions from identification to mitigation to specific management nodes that will be accountable to the upper management structures for discharging their responsibilities.

Control maps are essential components of the risk management process (Figure 2.2). The control maps are drawn to complement the risk maps using the data from the risk map to build the control structure within the enterprise. The control maps without the risk maps will lack focus, the quantitative base and the responsibility structure. Once the metrics of quantifying the probabilities of occurrence and expected values of consequences are determined in the risk map, a set of scores are assigned to them to reflect their risk ranks. These risk scores are matched with congruent control measures and procedures together with a responsibility matrix to optimize the balance between risk and outcomes.

Figure 2.2 – Risk Control Map



Source: Conference Board of Canada. Enterprise Risk Management at Hydro One Inc.P.4.

2.2.3 The Best Practice Risk Management Steps

Risk management occurs on a daily basis and involves all aspects of business operations and the entire organization. With pro-active risk management we look at events and processes in a comprehensive manner and assess ***and document*** risks and uncertainty. The steps for risk management are provided in Table 2.1. There are a few distinctions and a heavy emphasis on a number of activities and procedures. The list is long but includes the following key elements:

First, risk management is not a one time event or a window dressing exercise. It is a serious on-going process. It is a systematic process based on feasible options and choices to optimize results and outcomes.

Second, it is about prioritizing risks in terms of probabilities and consequences, and segregating risks in areas of specific concern. Risky events with high probability of occurrence and large consequences are grouped together and should receive more attention than those with low probability and small consequences.

Third, it is not sufficient, although it is important, to simply recognize, identify and link risks to business operations and objectives. This qualitative assessment must be backed by quantitative calculations. Objective and numerical procedures for estimating probability density functions and ranges must be undertaken in a systematic, transparent and replicable ways. The statistical procedures should be verified and validated by subject matter experts in both the Front and the Middle Office. Verification and validation of calculations should never be left to those who make the calculations. It is always beneficial to cross check and repeat these calculations in different offices and by different people.[6] Furthermore, the quantitative analysis and estimation of risks should also be based on a simultaneous evaluation of the impacts of all identified and quantified risks. Separate estimates of individual risks must be synthesized and articulated within their natural networks of impacts.

Fourth, risk assessment is done with a purpose. It is not sufficient to know what the risks are: it is equally important to devise strategies and procedures to deal with them and reduce their threat to the realization of the objectives of the enterprise.

Fifth, individual responsibilities for these risks must be assigned. Individual responsibility must be backed by authority, resources, expertise and oversight.

Sixth, monitoring and tracking are essential components of the best practice system of risk management. Organizations that optimize risk management are those that learn from mistakes and treat risk management as a continuously optimizing process. It is also true that in these organizations risk managers are regularly audited and rewarded in line with their success or failure to control risk, ensure the execution of risk plans, and reduce effectively the enterprise's risk exposure and losses attributed to risk mismanagement.

This framework will be adopted to evaluate MH's risk management system and governance structure. The objective is not to point out deficiencies but to suggest ways

[6] Committee of Chief Risk Officers. February, 2006. *Enterprise Risk Management and Supporting Metrics*.

and means to align MH's risk management practices with those considered to represent best practice. We will consider here only MH's macro-risk perspective and reserve the discussion of individual risk assessment to later chapters.

Table 2.1 – The Risk Management Process

1) Risk Management Planning	Risk Management Planning is the systematic process of deciding how to approach, plan, and execute risk management activities throughout the organization. It is intended to maximize the beneficial outcome of the opportunities and minimize or eliminate the consequences of adverse risk events.
2) Identify Risk Events	Risk identification involves determining which risks might affect any aspect of business and documenting their characteristics. It may be a simple risk assessment organized by a project team, or a drastic event that can affect the business continuity and survival of the entire organization. Risk identification is crucial as it forms the basis of risk assessment and risk response.
3) Qualitative Risk Analysis	Qualitative risk analysis assesses the impact and likelihood of the identified risks and develops prioritized lists of these risks for further analysis or direct control and mitigation. Specialized teams assess each identified risk for its probability of occurrence and its impact on business objectives. Risk teams may elicit assistance from "Subject Matter Experts (SME)" or functional units to assess the risks in their respective fields.
4) Quantitative Risk Analysis	Quantitative risk analysis is a way of numerically estimating the probability that an activity, process and operation will meet its financial, technical and time objectives. Quantitative risk analysis is based on a simultaneous evaluation of the impacts of all identified and quantified risks. The Middle Office should independently identify and quantify each risk.
5) Risk Response Planning	Risk response strategy is the process of developing options and determining actions to enhance opportunities and reduce threats to the business' objectives. It identifies and assigns parties to take responsibility for each risk response. This process ensures that each risk requiring a response has an *"owner*." Each Manager and his/her team will identify which strategy is best for each risk, and then select specific actions to implement that strategy. Each strategy will undergo the specified risk management protocol for approval identified and codified in an "Internal Responsibility System (IRS)" managed by the Middle Office.
6) Risk Monitoring & Control	Risk Monitoring and Control tracks identified risks, monitors residual risks, and identifies new risks—ensuring the execution of risk plans, and evaluating their effectiveness in reducing risk. Risk Monitoring and Control is an ongoing process for the business.

Source: Based on Washington State Department of Transportation. Project Risk Management. May, 2009. P. XV, with significant additions by KM. and Committee of Chief Risk Officers. September, 2004. *Enterprise Risk Management: Integrated Framework.*

Before delving into assessing MH's risk management practices there remains a few qualifications about best practice risk management that need to be made. Best practice Enterprise Risk Management (ERM) is presumed to stand on two pillars. The first has to do with identification and analysis of the risk sources in the enterprise. It does not include quantification of the risks and their prioritization, but it should (Figure 2.3). The second pillar has to do with responding to, monitoring, and controlling risks. It is now a standard proposition in best practice ERM to conceptualize a three pillar approach by adding the Internal Responsibility System (IRS) which identifies the ownership structure of the identification, quantification, response, monitoring and controlling of risk, and aims at creating an environment conducive to joint resolution of risk problems without absolving individuals of their designated responsibilities.

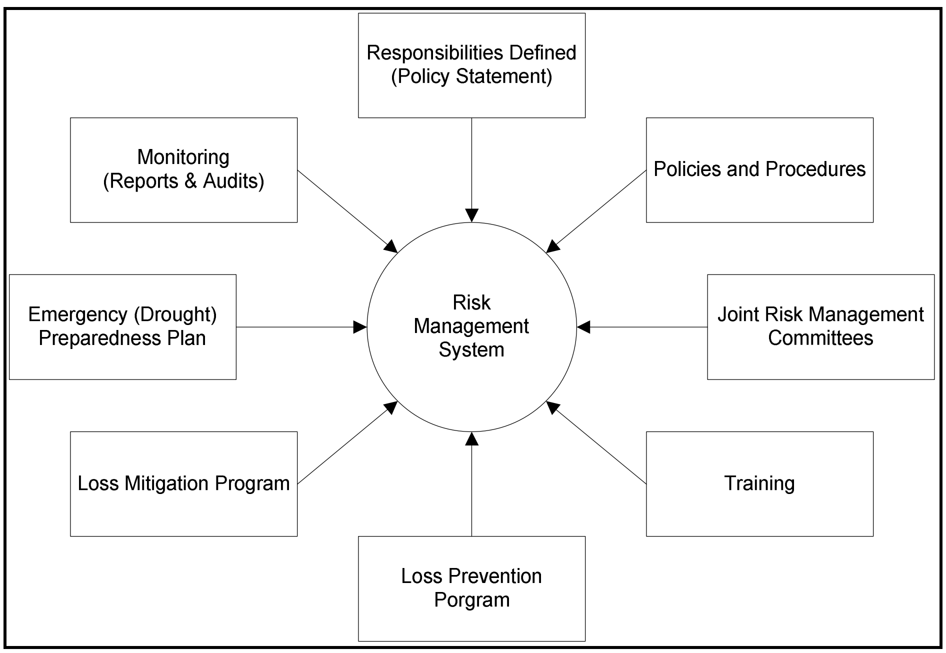
Figure 2.3 – The Two Pillars of Risk Management

Source: Washington State Department of Transportation. Project Risk Management. May 2009, P.3.

In assigning responsibilities for risk management a major consideration is the requirement that the organization, its managers and employees take personal and direct responsibility for risks, provided that they are accorded sufficient resources and empowered by the assignment of adequate authority. But devolving responsibilities must be linked to accountability and oversight. One without the other is not advisable.

The IRS principles must be applied consistently to all areas of risk identified within the Risk Management System indicated in Figure 2.4.

Figure 2.4 – IRS Based Risk Management System



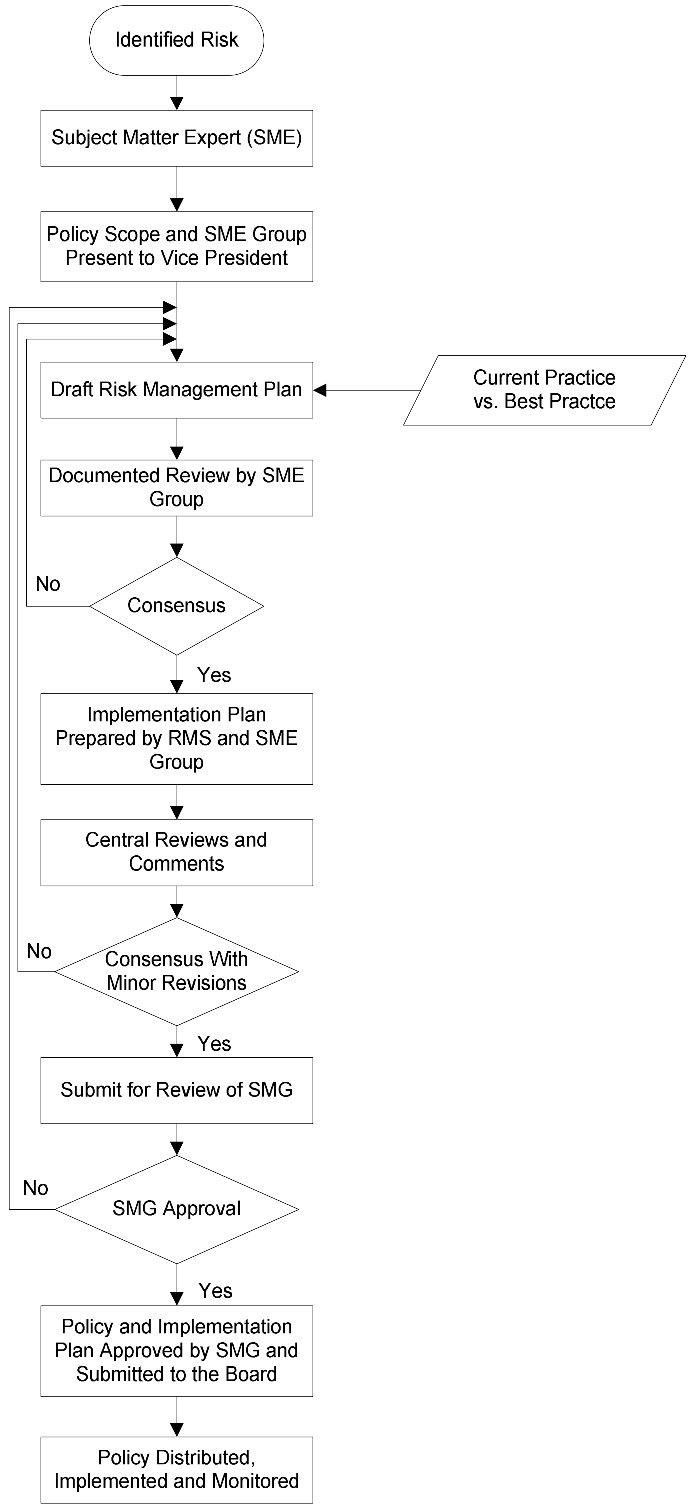
The IRS is premised on a number of crucial factors and requirements. These include:

- Individual responsibilities for risk are identified and assigned..
- A central and independent system with adequate resources to support the risk management system is designated.
- A centralized system for issuing policies, procedures and support services for risk identification, quantification, control, monitoring and mitigation at the highest executive level in the organization is established.

- Each new or revised policy and/or procedure is accompanied by an implementation plan that defines the schedule and resources required for its implementation. The implementation plans will map the process of transition from current practice to the new practice prescribed in the new or revised policy and/or procedures.
- Regular reports on risk management activities and performance are submitted to Senior Management Group (SMG).
- Auditing procedures are put in place to review, re-calculate and provide a serious system of checks and balances.

This best practice decision system is outlined in Figure 2.5. This system is designed to create the appropriate process for joint action, individual responsibility, well defined lines of reporting, and engagement of all components of the organization with centralized command headed by an SMG. The reporting to the most senior VP should be in place to make decisions, monitor, audit and control assign SMEs at each stage, continuously paring actual practice with best practice.

Figure 2.5 – The Best Practice Risk Management System

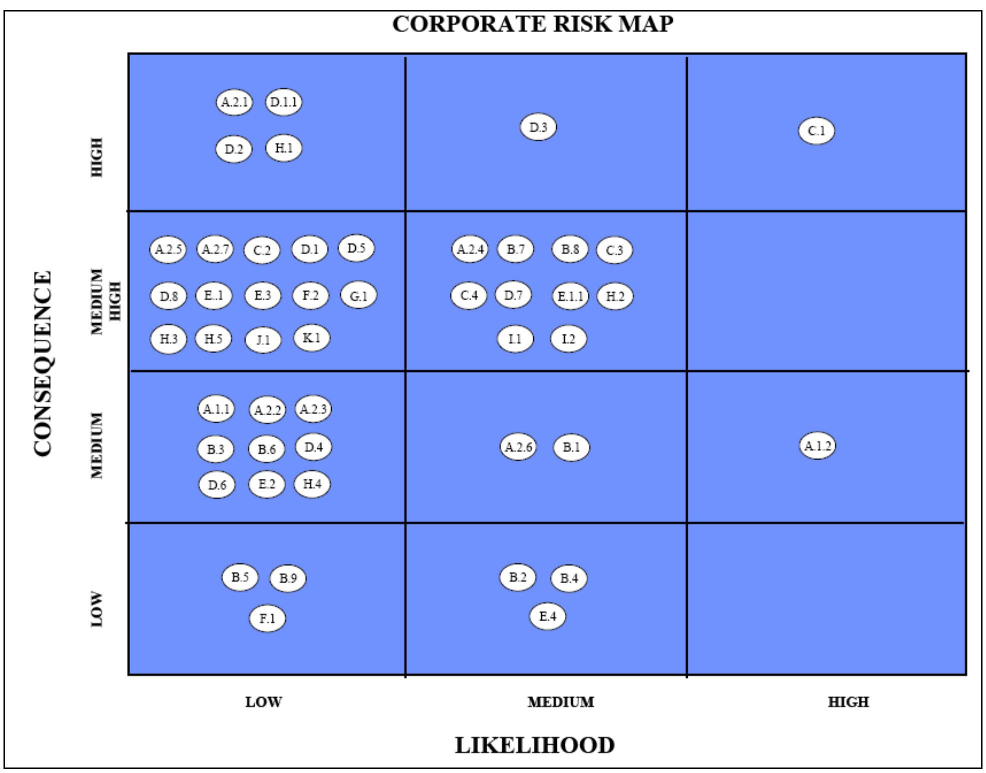


Definitions: SME – Subject Matter Experts
SMG – Senior Management Group
RMS – Risk Management Services

2.2 Risk Management Practices at MH

Manitoba Hydro has developed an extensive and elaborate risk management system to identify, control and manage risks. This system is still evolving making difficult any generalization about its status as new developments and adjustments are on-going as we write this report. It is clear, however, that there A Risk Management Policy is in place and Risk Management Reports are produced annually. The policy document and the reports are on the whole consistent with best practice in similar public utilities. Risks are identified under 11 categories and 48 sub-categories and mapped within the traditional two variables—likelihood of a risk event and its consequences. The Corporation also summarizes these risks into risk profiles that are regularly updated. Profiles typically include an assessment of the potential impact of a risky event on financial, safety, reliability, environment and customer services of the Corporation. They also include the risk tolerance levels assigned to the event and the required responses if and when the tolerance levels are exceeded.

Figure 2.6 – Manitoba Hydro Risk Map



Source: Manitoba Hydro Corporate Risk Management Report. October, 2008. P 7.

Where the definition of the terms in Figure 2.6 are:

A. **Market**
   1. Domestic
      1. Competition
      2. Uneconomic loads
   2. Export
      1. Regulatory Environment
      2. Competition
      3. Transmission
      4. Special Interest Groups
      5. Protectionism
      6. Domestic Requirements
      7. Commodity Availability

B. **Financial**
   1. Exchange
   2. Interest Rates
   3. Credit
   4. Inflation
   5. Gas Price Volatility
   6. Gas Derivative Instruments
   7. Capital Structure
   8. Shortage Pricing/ Fuel Price Volatility
   9. Power Financial Instruments

C. **Environmental**
   1. Water Supply/ Drought
   2. Climate Change/ Kyoto
   3. Operational Impact and infrastructure
   4. Reliability of Supply

D. **Infrastructure**
   1. Loss of plant (all property, all perils)
      1. Dam and Dike Structures
   2. Insufficient supply (drought peril)
   3. Prolonged Loss of System Supply
   4. System Shutdown (Short Term)
   5. System Shutdown (Natural Gas – S.T.)
   6. Technology
   7. Special Interest Groups.
   8. Emergency Response/ Business Continuity

E. **Human**
   1. Safety / Health / Workplace Violence

1. Infectious Disease
2. Union/ Employee Issues
3. Succession Planning
4. Technology

F. **Business Operational**
1. Supply Chain
2. Operational Controls

G. Reputation

H. **Governance / Regulatory / Legal**
1. Regulation and Licensing
2. Export Market Access
3. Legal Compliance
4. Contracts and Ventures
5. NERC/MRO Reliability Standards

I. **Aboriginal**
1. Relationships
2. Legal

J. Emerging Energy Technologies

K. Strategic

MH has developed systems to monitor and control key risks and to sustain information flows within the organization and to appropriate stakeholders concerning changes in risk profiles and their management within the Corporation risk tolerances. Likelihood, consequences and tolerances are colour coded and ranked as low, medium or high. The basis of this coding is not very clear and certainly is not based on revealed quantitative calculations.

The Corporation has also developed and instituted a Management Control Plan (MCP) with several committees and mechanisms to oversee all power related transactions in both Canada and the United States. The MCP is also supported by Power Sales Approval Authority Table. Under the MCP oversight of activities and processes, primarily those with major impact on business continuity and mission, is provided by three main bodies, the Manitoba Hydro Electric Board (MHEB), the Export Power Risk Management Committee (EPRMC) and the Power Sales and Operations Management Committee (PSOMC). There are also several other committees of supposedly significant influence which can assume critical roles in the overall functioning of the Organization. We will single out here the Corporate Risk Management Committee (CRMC), the Planning

Review Committee (PRC) and the Rates Review Committee (RRC). These are advisory and information generating committees but assume no executive and decision powers.

The MHEB exercises general oversight of the Corporation's operations and approves sales requiring new generation in concert with approving new generation or long-term sales exceeding 5 years and 100 MW. It carries out the duties, powers and functions of MH as set out in the Manitoba Hydro Act including:

- Provide for the continuance of a supply of power adequate for the needs of the Province.
- Engage in and promote economy and efficiency in the development, generation, transmission, distribution, supply and end-use power.
- Provide and market products, services and expertise related to development, generation, transmission, distribution, supply and end-use power, within and outside the Province.
- Market and supply power to persons outside the province on terms and conditions acceptable to the Board.
- Has the Statutory authority and obligation to provide policy direction to and oversee the management of the business and affairs of the Corporation and to ensure that the Corporation fulfills its statutory objectives in the public interest.

The EPRMC provides oversight of the management of financial risks and energy supply associated with MH's export activities. It is primarily responsible for the review and approval of risk mitigation strategies dealing with both long term and short term export sales. It reviews and approves criteria for managing risks associated with energy planning and operation as well as criteria for managing risks associated with short-term marketing transactions. It is also responsible for general drought management strategies and export market policies. It reviews and approves exceptions to the MCP.

The PSOMC provides oversight of financial products and transactions such as Financial Transmission Rights (FTRs) or Auction Revenue Rights (ARRs) and for the use of puts and call options, contracts for differences, swaps and other hedging instruments.

The three committees above are given executive authority and obligations. The committees below are not empowered to take decisions. They are primarily review committees and provide platforms for discussion and information.

The CRMC provides a forum for guiding and monitoring the processes whereby MH's principal risks are identified, assigned, assessed, managed and communicated. Its membership includes broad senior managers across the Corporation.

The PRC provides in-depth peer review of long-term planning reports, forecasts and analyses and reviews all major assumptions for the planning cycle, in addition to other items of strategic interest. It also provides feedback and commentary, but the VP retains responsibility for recommendations to the Executive Committee.

The RRC reviews proposed electricity and gas tariffs, policies, strategies and applications.

Front, middle and back offices have been created at MH to facilitate the implementation of the MCP. The Front Office is responsible for energy sales, export marketing strategies, market access, long term contract negotiations and power trading. The Middle Office is responsible for risk management activities and the Back Office is tasked with ensuring the integrity of systems and processes for transaction settlements. There are also in place a number of reporting requirements that facilitate the implementation of the MCP including the Energy Resources Review and Outlook Committee (ERRO) that monitors and reports on water conditions and recent operating conditions, and provides an outlook on immediate future opportunities. Equally relevant is the Credit Exposure Review (CER) that summarizes the credit exposure by customer and by bond rating agencies. These reporting reviews are intended to keep management abreast of developments on a proactive basis in order to take the necessary responses.

MH has already defined specific risk limits on power related transactions in two areas (November 2007). First, MH has defined time and dollar limits on all Merchant Transactions (pure and related). These are transactions involving the purchase of power by MH from one or more parties for resale to one or more parties. The clear and well defined set rules and limits include:

- All Merchant Transactions shall have a maximum duration of six months.
- A maximum net power position of 1000 GWh.

- Fixed price transactions may be entered into only if there is a positive profit margin.

- All other transactions may be entered into only if there is a positive expected value with a term no more than three days in duration.

- A stop loss limit of US $500,000; all pure Merchant trade transactions would be cancelled if losses exceed US $500,000 and a report would be sent automatically to EPRMC. The stop loss limit on related merchant transactions is US $250,000.

- At any point in time, the Value at Risk VaR (see the next section for details on this concept and procedure) in the portfolio must be less than the Stop Loss Limit. The VaR must be calculated daily.

Also MH has stipulated that MH enters into transactions with credit worthy customers and shall at no time extend credit beyond a fixed short period. Credit risks arise because counterparties may fail to perform their obligations under a given contract today. The current practice of assigning the long term probability of default to all credit including accounts receivables exaggerates the exposure but not using MTM under-estimates the exposure. It would make sense to get the appropriate credit default risks by the maturity of the debt and using MTM values.

The setting of Stop Loss and the requirement for a VaR calculation is a welcomed MH initiative and in line with best practices at other well run public utilities. It is now limited in scope to the two areas above but should set the stage for extension to other areas.

Water conditions, reservoir levels, inflows and outflows are constantly monitored and forecasted to avoid surprises and keep ahead of drought development. The events in 2003/04 prompted MH to institute a Drought Management Plan (DMP) to minimize losses and put in place mitigation strategies. MH has been working on a Drought Preparedness Plan (DPP). To the best of our knowledge this Plan has not been completed. It is also claimed that MH has sponsored and continues to sponsor drought and weather related research in Manitoba universities, research institutes and the International Institute for Sustainable development. We have seen a report that alleges that a model has been developed and that research on weather and climate effects on precipitation and evaporation have been conducted on behalf of MH at The University of Manitoba but we have not seen these models.

We have called for quantification of risks. Below we present two simple but generally used methodologies for quantification of risk and for defining adequate reserve capital as a measure of risk mitigation. We begin first with VaR and then present a brief discussion of Capital Adequacy Ratio (CAR). Both will be defined below.

2.3 The VaR Method of Risk Quantification

Risk and Uncertainty[7]

Conditions that investors face in the long run can either be unpredictable or predictable. If the situation is unpredictable, the investor is facing uncertainty and anything can happen. If the conditions are predictable, the investor is facing risk. What distinguishes risk from uncertainty is that risk is characterized by three dimensions:

1. A time horizon, e.g., 1, 2, 5 or more years;
2. A magnitude, e.g. x, y or z amount; and
3. Level of confidence in the estimated magnitude within the time horizon, e.g., 95% confidence, 99% confidence, but never 100% confidence

Value at Risk (VaR)

In the financial assets field, the investor's decision to invest or not depends, to a large extent, on the amount of risk his/her investment is likely to be exposed to. In other words, if he/she are going to invest a sum of money in the market, (s)he would like to know how much they could lose in that investment (magnitude) in one day, one month or one year (time horizon), with what level of confidence (confidence level, 95% or 99%).

---

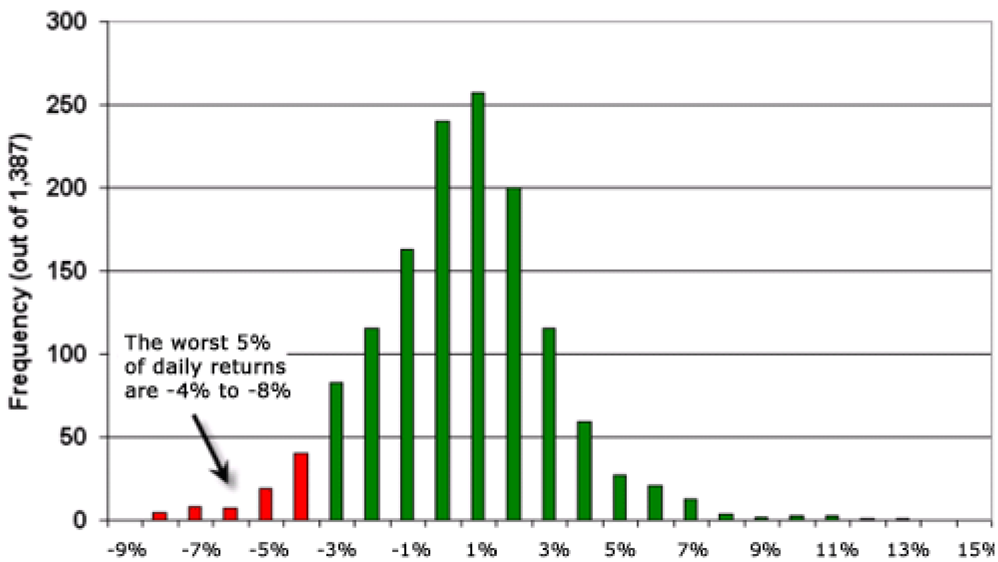
[7] This section is based on the work of David Harper. An Introduction To Value at Risk (VaR). http://www.investopedia.com/articles/04/092904.asp

Value at Risk (VaR) is a technique that helps estimate these three attributes. There are three methods for estimating this parameter.

Method 1 focuses on the real data as observed in the market place, groups it in a set of convenient categories, and then computes the sought attributes from the observed data. This method is known as the historical data approach and it is used to predict the future on the assumption that the future will reflect the past (Figure 1).

For example, assume that QQQ started trading in Mar 1999, and if we were to calculate each daily return, we would produce a rich data set of almost 1,400 points. Assembling this data in a histogram that compares the frequency of return over time, we would have a clear idea of the distribution of these returns over time. For example, at the highest point of the histogram (the highest bar), there were more than 250 days when the daily return was between 0% and 1%. At the far right, you can barely see a tiny bar at 13%; it represents the one single day (in Jan 2000) within a period of five-plus years when the daily return for the QQQ was a stunning 12.4%.

Figure 2.7 – Distribution of Daily Returns, NASDAQ 100 Ticker: QQQ



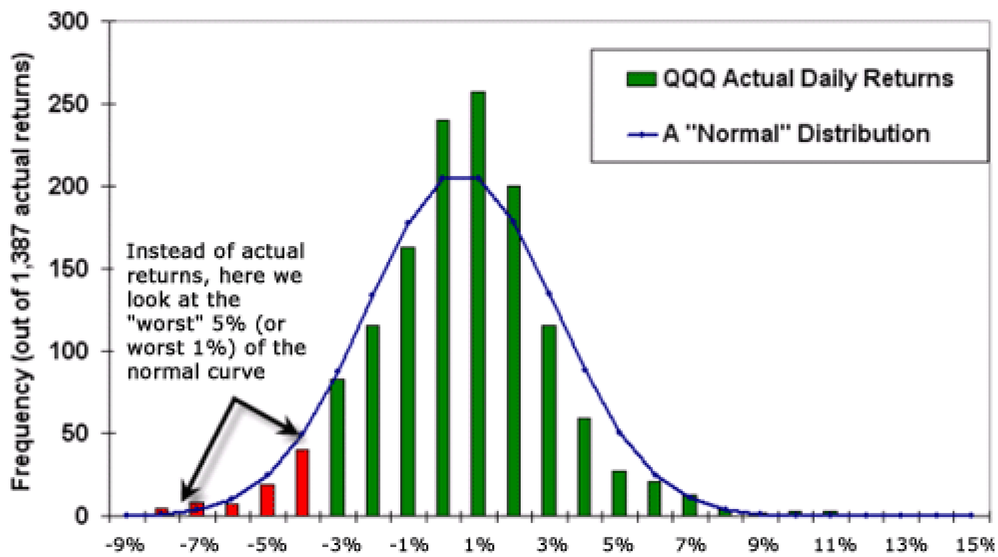
Source: David Harper. An Introduction To Value at Risk (VaR).
htttp://www.investopedia.com/articles/04/092904.asp

The red bars are in the "left tail" of the histogram. These are the lowest 5% of daily returns. The red bars run from daily losses of 4% to 8%. Because these are the worst 5%

of all daily returns, we can say with 95% confidence that the worst daily loss will not exceed 4%. Put another way, we expect with 95% confidence that the gain will exceed 4%. This is what is referred to as VaR. Let's re-phrase the statistic into percentage terms, with 95% confidence; we expect that the worst daily loss will not exceed 4%.

Method 2 focuses on extracting the characteristics of the observed data, translates it into a statistical curve with its descriptors, and applies the laws of statistical inference to that curve in order to predict future risk. Again it is based on the assumption that future experiences will be a reflection of the past but on a more generalized statistical basis. See the diagram below:

Figure 2.8 – Distribution of Daily Returns, NASDAQ Ticker: QQQ



Source: David Harper. An Introduction To Value at Risk (VaR).
htttp://www.investopedia.com/articles/04/092904.asp

The idea behind the variance-covariance is similar to the ideas behind the historical method - except that we use a normal distribution curve instead of actual data. The advantage of the normal curve is that we automatically know where the worst 5% and 1% lie on the curve. They are a function of our desired confidence and the standard deviation (σ):

Table 2.2 – Confidence Intervals

Confidence	# of Standard Deviations (σ)
95% (high)	$- 1.65 \times \sigma$
99% (really high)	$- 2.33 \times \sigma$

Source: David Harper. An Introduction To Value at Risk (VaR). htttp://www.investopedia.com/articles/04/092904.asp

The blue curve above is based on the actual daily standard deviation of the QQQ, which is 2.64%. The average daily return happened to be fairly close to zero, so we will assume an average return of zero for illustrative purposes. Here are the results of plugging the actual standard deviation into the formulas above:

Table 2.3 – Value of Returns at Risk

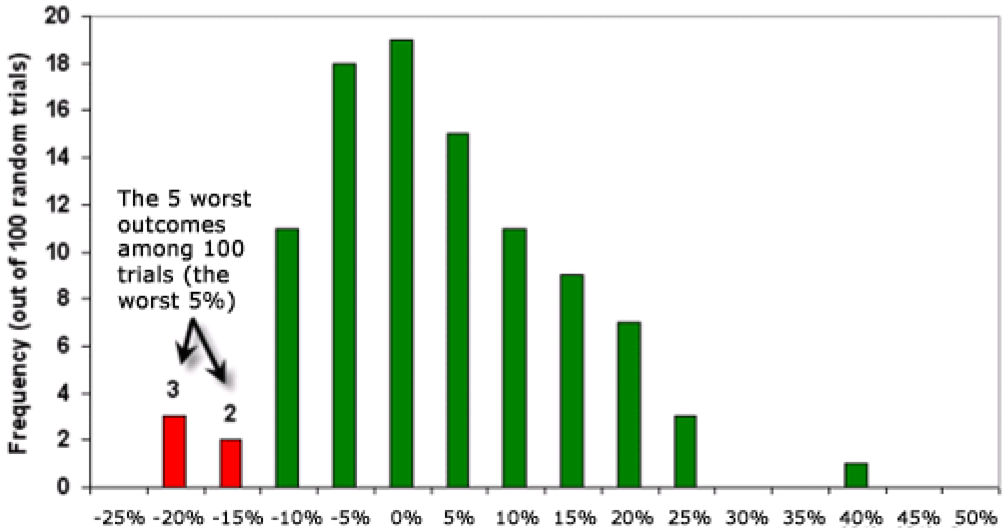
Confidence	# of σ	Calculation	Equals:
95% (high)	$- 1.65 \times \sigma$	$- 1.65 \times (2.64\%) =$	- 4.36%
99% (really high)	$- 2.33 \times \sigma$	$- 2.33\times (2.64\%) =$	- 6.16%

Source: David Harper. An Introduction To Value at Risk (VaR). htttp://www.investopedia.com/articles/04/092904.asp

With 95% confidence, the losses will not exceed 4.36% and with a 99% confidence, the worst of the losses is 6.16%.

Method 3 uses a simulation technique (known as Monte Carlo) that varies randomly the basic conditions for the investment and generates different scenarios of risk (magnitude, horizon and confidence) that are used by the analyst as a sample space for determining the worst risk scenario that the investor faces. See the diagram below:

Figure 2.9 – Monte Carlo Simulation, 100 Random Trials (Using Historical Volatility of QQQ)



Source: David Harper. An Introduction To Value at Risk (VaR). htttp://www.investopedia.com/articles/04/092904.asp

A Monte Carlo simulation on the QQQ based on its historical trading pattern is presented in the figure above. In this simulation, 100 trials were conducted. If it was run again, we would get a different result--although it is highly likely that the differences would be narrow (the differences would narrow substantially as we increase the number of runs from 100 to 500 to 1000). The results are arranged into a histogram (please note that while the previous graphs have shown daily returns, this graph displays monthly returns):

The results of the Monte Carlo simulation show that two outcomes were between -15% and -20%; and three were between -20% and 25%. That means the worst five outcomes (that is, the worst 5%) were less than -15%. The Monte Carlo simulation therefore leads to the following VaR-type conclusion: with 95% confidence, we do not expect to lose more than 15% during any given month.

This third method, although uses past information to define the possible combination of factors that could create serious risk, can generate potential serious risk situations that were not experienced before.

Regardless of which method is used to generate the indicators of the risk involved, the investor's tolerance to risk and previous experience will be major determining factors if he or she would invest.

2.4 Risk Capital Reserves[8]

Protecting Investments in Organizations

Organizations generally have assets that could be physical (water), financial, or intellectual rights. They also have liabilities and face risks of various types such as credit risk, operational risk, and so on. The organization's equity can be thought of as a "cushion" against potential losses. This cushion protects the organization's shareholders or other lenders.

The **Capital Adequacy Ratio** (**CAR**) is one parameter that is well defined and used to monitor the adequacy of organizations' risk protection measures. This protection is considered crucial to shield their investors and shareholders from financial meltdowns and disasters. This, in turn, promotes confidence in the organization.

$$\text{CAR} = \frac{\text{Tier One Capital} + \text{Tier Two Capital}}{\text{Risk Weighted Assets}}$$

CAR is defined as the ratio of equity to assets and is used as an indicator of the security of investments in the organization. The assets of an organization are by definition equal to its debt plus its equity. In comparison, the well known debt to equity ratio is used to determine the leveraging strength of the organization whereas CAR is a risk exposure measure.

[8] A concise discussion of this concept can be found at
http://www.investopedia.com/terms/c/capitaladequacyratio.asp

CAR Calculation

The specifics of CAR calculation vary from one jurisdiction to another, but general approaches tend to be similar for jurisdictions within the same system – otherwise comparisons would become difficult if not meaningless.
There are two main corrections associated with CAR

a. An adjustment to the "Assets". Assets have varying degrees of risk exposure. As a result, CAR requires some adjustments to be made to the assets in order to compensate for their risks, e.g., CAR allows organizations to discount lower-risk-assets. And

b. An adjustment to the mix of the types of assets held by the organization. Different types of equity are more important than others and the two types are referred to as Tier I Capital and Tier II Capital. To recognize this, different adjustments are made as follows:
    - Tier I Capital: Actual contributed equity plus retained earnings.
    - Tier II Capital: Preferred shares plus 50% of subordinated debt (Some jurisdictions may assign a maximum for this category)

We will use risk capital concepts and calculations in assessing MH's risk exposure and risk management.

2.5 Risk Management at MH: Some Recommendations

The drastic events and the significant financial losses caused by the drought in 2003/04 drove home the need for instituting a comprehensive risk management plan to identify, assess and mitigate possible recurrence of drought. The plan has since been extended to cover a broader spectrum of anticipated risks. The discussion above suggests that a number of necessary steps have been taken and that a number of policies and procedures have been instituted to prepare the Organization to deal with risks.

When the best practice structure defined earlier is super-imposed on the current practices of MH a number of gaps emerge that MH can easily deal with in a manner that will increase and strengthen its resiliency and capacity to manage risks.

The Risk Map and the Control Map are clearly in place at MH. There may be some questions about how comprehensive the list of identified risks is, as well as the extent to which the probabilities and expected values of outcomes and consequences are the products of objective criteria but this is a separate issue and we will offer some suggestions to deal with it later. What is conspicuously needed at MH is an Individual Responsibility System where responsibilities for identification, assessment, quantification, mitigation and avoidance are clearly spelled out and where these responsibilities are assigned clearly and unequivocally to specific managers and staff. This process ensures that each risk requiring a response has an "owner" and that responsibilities are segregated.

The Corporate Risk Management Report (CRMR) will be more complete if there is attached to each risk identified and colour coded, a component of the Organization identified as responsible for it. In the absence of this responsibility matrix, it will be difficult to define and implement a risk accountability structure for the Organization. It is only when responsibility is clearly identified that we can hold specific offices and people accountable for their actions or inactions. Surely a system of rewards and penalties is also needed to avoid a culture of impunity and moral hazard that is often endemic to public organizations. Furthermore, a superstructure is needed to evaluate, validate and verify different assessments. At each level a dual structure is needed; one to undertake the assessment in situ at the operation level and another to validate it at a management level. The function of the Middle Office here is critical for the success of the management of risk function.

The qualitative aspects of risk management are well in place at MH. Unfortunately, this is not the case when it comes to the quantitative areas of risk management. There is hardly a mention of the word "quantitative" in the CRMR. Risk management is ultimately about quantification of exposure and calculation of the magnitudes of losses and threats. It is about statistical density functions, confidence intervals, expected values and variances. Quantification of risk and expected values are calculated at MH. There exits a number of models (particularly PRISM) and systems that are used as part of the operations of MH particularly at the Front Office – but these are not part of the function of risk management at the Middle Office. Their use and their numbers should be part and parcel of the risk management plan that needs to be verified by the Middle Office. Depending on a single risk tool is not advisable. There exits many commercially viable risk analysis tools (software) that may be worth evaluating and adopting to complement the existing system @RISK at MH.

The quantification of financial exposure should use fair market values (replacement costs). The Mark to Market (MTM) measures shall take precedence over other benchmark evaluations of financial risks. This preferred measure of value in the energy market is premised on calculating the true exposure (taking account of unrealized losses and gains of the portfolio) as current prices differ from forward settlement prices. In this respect MTM prices gauge the true value of the financial risk exposure and can be compared to stop loss provisions and other risk tolerance rules. The MTM measures also define the requisite financial hedges and their effectiveness. The use of MTM may have to be limited, however, to financial risks. MH may use MTM too value future contracts. If it does so it opens MH to the exposure of new risks but it also avails MH the opportunity to use hedging instruments.

It would make a great deal of sense to organize specialized teams to assess major identified risks for their probability of occurrence and their impact on business objectives. Risk teams should elicit assistance from “Subject Matter Experts (SME)” or functional units to assess the risks in their respective fields, but they should all funnel their expertise and calculations to the Middle Office. The Organization can surely benefit from greater visibility and use of statisticians and actuarial experts and from instituting these expert committees, especially when they are all linked and integrated to the risk management function and the responsible body (Middle Office) for it within the Organization. The Middle Office can surely benefit from recruiting specialized experts in statistics and risk analysis, at present it appears to be under staffed.

The governance structure of risk management at MH can benefit from some needed restructuring and alignment. The CRMC is now part of Finance & Administration Division and reports to the Senior VP of the Division. It is now on the Organizations’ Organogram at the lowest slot. Perhaps unintentionally, this placement conjures an image of lack of importance and lack of centrality of its stature, functions and contributions. Being at the Middle Office is the appropriate place for the CRMC, but it has to be part of the SVP Office, may be in the first slot. At this time the CRMC is only an advisory body and is without any executive powers.

There is an evident multiplicity of bodies dealing with risk (EPRMC, PSOMC, and CRMC, etc.). In itself, this is not a problem, but it becomes a problem in the absence of a well defined integrated and centralized structure that can harmonize the lines of authority, obligations and accountability. In the final analysis all of the risks must be combined and integrated. Dealing with all of them simultaneously is critical for the success of the Organization. Quantitative assessments of risks are based on a simultaneous evaluation of the impacts of all identified and quantified risks on a coherent basis with a focussed approach and integrated administrative structure. This can best be achieved through Joint Risk Management Committees organized and supervised by the Middle Office through CRMC.

Risk Preparedness Plans and manuals are needed for all costly risks. A Drought Preparedness Plan is a critical necessity. It must be completed and instituted in the working mechanisms of the organization immediately. The preparedness plans should not stop at the Drought Plan. There are many other emergencies and drastic events that may occur that need to be expected and plans made to deal with them. A broad preparedness plan can make substantial contributions to the effectiveness of risk management services and plans at MH.

MH has set limits and tolerance levels quantitatively in the areas of Merchant Transactions and Customer Credit. The setting of quantitative targets and rules should be extended to all areas of operations particularly power trading and export sales. The exposure versus limits reports should cover all aspects of operations with financial implications for MH. Variance and Exception reports should be all encompassing and produced routinely.

Best practice requires that any business transaction should be evaluated on its own but particularly for all the risks that it may encounter. This should be done by the business unit directly involved (Front Office) but an independent review must be undertaken by the Middle Office. Before a business opportunity is approved the Middle Office should validate its appropriateness of the market research, models, curves used to value the opportunity. But more importantly, the Middle Office should independently identify and quantify the various risks involved in accepting the new business.[9] We urge MH to direct the Middle Office to undertake such an assessment with every business opportunity above a certain dollar limit but particularly all Long Term Contracts.

Many functions and activities in the organization are operating with deterministic models and frameworks. This is not particularly helpful for an organization that has taken the challenge to manage and control effectively and proactively all of its risks.

Last but not least, detailed training and simulation games dealing with risk occurrences and plans should be developed for the organization. These training programs and learning by practicing simulations have helped other organizations in dealing with their risk exposures and threats.

---

[9] Committee of Chief Risk Officers. November 2002. Governance and Controls Whitepaper, Vol. 2. P.18.

Chapter Three

Manitoba Hydro Models

3.1. Introduction

In Manitoba, hydrology, power generation, and financial systems are subsystems of a broader politico-technical network of which Manitoba Hydro is a key component. It is possible to think of the Corporation as consisting of three basic systems: hydrology, power and financial. Each of these systems is managed by its own group of experts. However, These three systems are constantly interacting. When all is well, they are balancing each other, compensating for failures in one system and taking advantage of success in another.

Every publicly owned hydro corporation has a different configuration within and between these systems. Although the relative importance of each system and its managers may differ across these corporations, they each contain these systems, and no one system exists without the other two (see Appendix B for more details).

The modes of interaction and the relationships that govern the workings of these systems are quite complex. The number of variables within each system is very large and is exceeded only by the number of relationships that balance the complex interactions among these variables. The variables and equations are basically quantitative and technical in nature. No expert can be expected to know fully and deeply how these relationships work and unfold. It is often necessary to construct models to represent, understand, explain and predict the outcome of changes in these complex systems. But why build a model and, more basically, what is a model?

Models are of central importance in many scientific contexts. The centrality of models such as the billiard ball model of a gas, the Bohr model of the atom, the MIT bag model of the nucleon, the Gaussian-chain model of a polymer, the Lorenz model of the atmosphere, the Lotka-Volterra model of predator-prey interaction, the double helix model of DNA, agent-based and evolutionary models in the social sciences, or general equilibrium models of markets in their respective domains are cases in point. Scientists spend a great deal of time building, testing, comparing and revising models, and much journal space is dedicated to these valuable tools. In short, models are one of the principal instruments of modern science.[10]

Philosophers are acknowledging the importance of models with increasing attention and are probing the assorted roles that models play in scientific practice. The result has been an incredible proliferation of model-types in the philosophical literature. Probing models, phenomenological models, computational models, developmental models, explanatory models, impoverished models, testing models, idealized models, theoretical models, scale models, heuristic models, caricature models, didactic models, fantasy models, toy models, imaginary models, mathematical models, substitute models, iconic models, formal models, analogue models and instrumental models are but some of the notions that are used to categorize models.[11] While at first glance this abundance is overwhelming, it can quickly be brought under control by recognizing that these notions pertain to different problems that arise in connection with models. For example, models raise questions in semantics (what is the representational function that models perform), ontology (what kind of things are models), epistemology (how do we learn with models), and, of course, in philosophy of science (how do models relate to theory); what are the implications of a model-based approach to science for the debates over scientific realism, reductionism, explanation and laws of nature).[12]

In simple language, a model is a theoretical construct that represents underlying processes by a set of variables and a set of logical and/or quantitative relationships between them. Thus, a model is a simplified framework designed to illustrate an

[10] Mary Morgan (2001) "Models, Stories and the Economic World", Journal of Economic Methodology 8:3, 361-84. Reprinted in Fact and Fiction in Economics, edited by Uskali Mäki, 178-201. Cambridge: Cambridge University Press, 2002. and L. Magnani, and N. Nersessian (eds.) (2002), Model-Based Reasoning: Science, Technology, Values. Dordrecht: Kluwer.

[11] Hans Freudenthal (ed.) (1961). The Concept and the Role of the Model in Mathematics and Natural and Social Sciences. Dordrecht: Reidel

[12] Ibid.

underlying complex process, often using mathematical techniques. A model may have various parameters and those parameters may change to create various properties.

Generally models have two characteristics. First, they are a simplification of and an abstraction from observed data. It is impossible to include and represent the entire complex reality. Abstraction and generalization are necessary. Second, they are a means of selection of data based on the purpose for which the model is built. Choice of what is pertinent is crucial; otherwise the task of explaining and predicting a phenomenon will become impossible. Even with the largest and fastest computers, there are limitations on what can be included in the focus set.

Simplification is particularly important given the enormous complexity of reality. In the case of hydro generation the three subsystems of hydrology, power and finance are complex and involve a large number of variables and relationships. This complexity can be attributed to the diversity of factors that determine hydrology, power generation, finance, political options and policies. These factors include: individual and public decision processes, resource limitations, environmental and geographical constraints, institutional and legal requirements and purely random fluctuations. Analysts must make a reasoned choice of which variables and which relationships between these variables are relevant and which ways of analyzing and presenting this information are useful.

Selection is important because the nature of a model will often determine what facts will be looked at and how they will be compiled. For example, precipitation is a general hydrological concept, but to measure precipitation requires a model of its determinants, so that hydrologists can differentiate between real changes in its quantity and temporary changes attributed to different climatic conditions.

The details of model construction vary with type of model and its application, but a generic process can be identified. Generally any modelling process has three steps: First, constructing a logically consistent model (heuristically making sure that the number of relationships is equal to the number of variables); second, checking the model for accuracy and validating its ability to track the observed data; finally, using the model for explaining and/or predicting the underlying complex reality.

The validation of its accuracy is important because a model is useful only to the extent that it accurately mirrors the relationships that it purports to describe. Creating and diagnosing a model is frequently an iterative process in which the model is modified (and hopefully improved) with each iteration of diagnosis and re-specification. Once a satisfactory model is found, it should be double checked by applying it to a different data set and using it to predict within the sample (observed data) the values in the sample not used to estimate it (back testing or intra-sample validation). [13]

There are other criteria to use in evaluating the model beside its logical consistency and accuracy. These include its overall structure (linear or non-linear) and type (deterministic or stochastic), complexity, completeness, ease of use and interpretation, its designers' skills, and the competence of the backstopping technical and professional staff. Other factors include flexibility and capacity to be integrated with new subsystems, the ease with which the model communicates with other models in the Organization, its contribution to improving the overall performance and efficiency of the Organization, the documentation of its procedures for other users and for institutional memory, whether there is training and support from within and outside the Organization, the sophistication of the “solvers”, their vintage and those that support them, the vintage and computational capacity and ratings of the hardware used to process the model and, finally, the nature and extent of “ownership” over the system. These criteria will be used to evaluate the MH model family.

Depending on whether all the model variables are deterministic, models can be classified as stochastic or non-stochastic. According to whether all the variables are quantitative, models are classified as discrete or continuous choice. According to the model's intended purpose/function, it can be classified as quantitative or qualitative. According to the model's ambit, it can be classified as general equilibrium, partial equilibrium, or non-equilibrium, According to the economic agent's characteristics; models can be classified as rational agent models, representative agent models, and so on.[14]

---

[13] For example, if it is used to predict the value of a variable in 2009, the model should be estimated with data until 2008. Then the value of factors (independent or exogenous variables) in 2009 should be used to predict the value of the dependent variable in 2009. The forecast value in 2009 should be compared to the actual value in 2009 to guage the forecast accuracy of the model. Several forecast error measures can be used, the most typically used measure is being that of the mean of absolute errors which we use later on in this chapter.

[14] Allan Gibbard and Hal Varian (1978), “Economic Models”, Journal of Philosophy 75: 664-677.

Models suffer, in general, from two problems. First, they cannot capture the full detail of the underlying system: they rely on approximate equations to represent the complex reality. Second, they are sensitive to small changes in the exact form of these equations. This is because complex systems like the economy or the climate consist of a delicate balance of opposing forces, so a slight imbalance in their representation has big effects. Thus, predictions of things like economic recessions or weather are still highly inaccurate, despite the use of large models running on fast computers. The "quality" of the model becomes inseparable from the results that it generates and predictions it makes but these may have more to do with the quality and accuracy of the data and initial conditions than with the model itself.

Models are necessary but suffer from many limitations in addition to those listed above. They need to be evaluated in terms of multiple criteria as was discussed earlier. In general, their utility is contingent on their accuracy, capacity to inform decisions and choices, the integrity and competence of those that use them and backstop their operations, interpretation of their results, the sophistication of their solvers, the extent to which hardware is up-to-date and of the most recent vintage, and accuracy of the data they process.

3.2 Manitoba Hydro Models.

Manitoba Hydro uses a large set of models to predict and optimize its operations, evaluate transmission options, quantify risk, forecast domestic load, and as tools for short term operations to long term planning and expansions. In this regard Manitoba Hydro is not different from BC Hydro which uses HYSIM (Hydrological Simulation) and Short Term Optimizer (SO) models. HYSIM uses historical data on hydrological variables and system constraints to generate operational forecasts for generation and costs and these feed into SO which calculates the optimal expansion path given the forecasts of HYSIM.

BC Hydro's Short Term Optimization Model (SO) has been developed to determine the optimal hourly generation and trading schedules in a competitive power market. The model is one of the tools that is currently used by the BC Hydro system operation engineers to determine the optimal schedules that meet the hourly domestic load and that maximize the value of the BC Hydro resources from spot transactions in the Western US and Alberta energy markets. The optimal hydro scheduling problem for the third largest power utility in Canada is formulated as a large-scale linear programming algorithm and is solved using an advanced commercially available algebraic modeling language and a linear programming package. The model has been designed and implemented to be user-friendly, flexible, dynamic and a fast real time operational tool that portrays the complex nature of the optimization problem. Aside from the detailed representation of more than twenty hydro generating stations and a system of reservoirs, the model incorporates market information on the Alberta Power Pool and the US Markets and tie-line transfer capabilities. The optimizing model generates the maximum expected future value of net income and explicitly considers the uncertainty of system inflows and market prices. It has been upgraded to incorporate decision support for hedging of energy purchases with the goal of minimizing the risk exposure to commodity markets.[15]

The MH models are not very different from those used by Quebec Hydro or Ontario Power Generation (OPG) and other domestic or international utilities. The explicit modeling of uncertainty has not yet been incorporated into the similar MH models, although some, if not all, of the MH models have some heuristic dynamics and stochastic elements. It is worth noting here that Quebec too has developed "GESTAU" a stochastic and dynamic optimizing model.

It seems that both Quebec and BC have adopted more advanced systems than MH's Hydro Electric Reservoir Management Evaluation System (HERMES) or Simulation Program for Long Term Analysis of System Hydraulics (SPLASH), but these are still in the same general class of optimizing models of power operations and planning. The advantage of Quebec's and BC's is in the stochastic nature of their systems, which makes them more complex and perhaps more useful tools for risk management. But admittedly they are both difficult to manage and present results that are more difficult to interpret. They also fail to include all the complexities that HERMES encompasses. The stochastic nature is an improvement in that expected values (variables multiplied by their probability of occurrence) replace deterministic variables. HERMES is dynamic in a special way in that the HERMES variables have different time coordinates and are treated as different variables. HERMES, however, does not incorporate the hedging options for uncertain commodity markets.

---

[15] Doug Smith. "BC. Hydro's Integration of Commodity Risk Management and Operations Planning." Water Management Decision-Support Software, A Two-Day Workshop, November 16-17, 2005.

The entire spectrum of models used by MH will be presented starting with MOST, which is a control oriented model that deals with the very short run. HERMES, SPLASH, PRISM, the LOAD FORECAST and the Economic Outlook (EO) focus on different time scales and issues and these will also be discussed and evaluated (Figure 3.1).

The flow of the presentation will follow the time framework of the models as depicted in Figure 3.2. From the hourly MOST to monthly HERMES, then to annual and long term horizon SPLASH and then PRISM, LOAD FORECAST and Economic Outlook, each will be summarized and evaluated using the multiple criteria identified in the preceding section.

Figure 3.1 – Manitoba Hydro Models

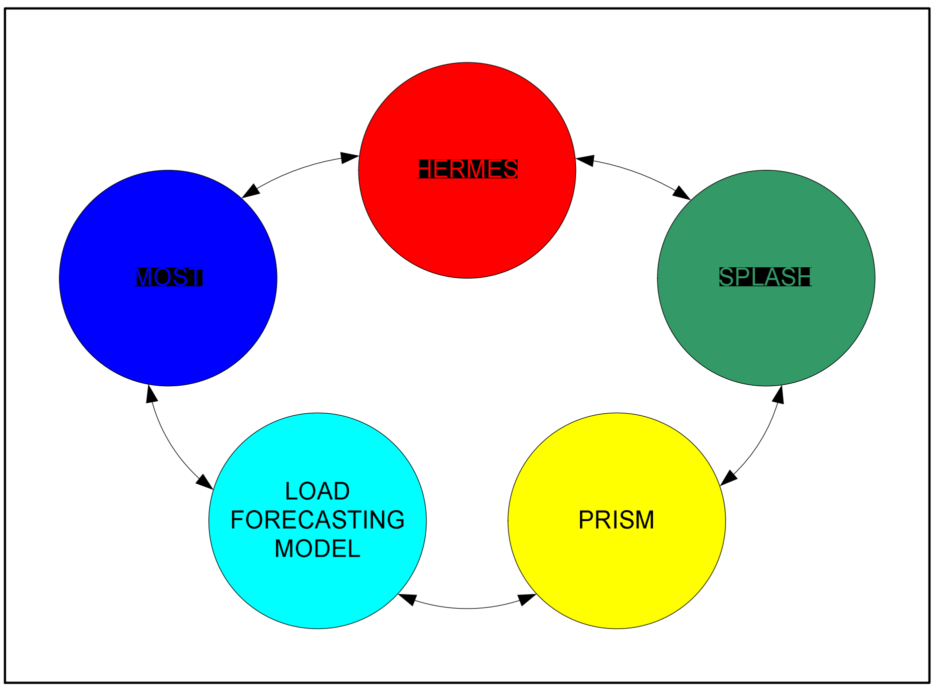
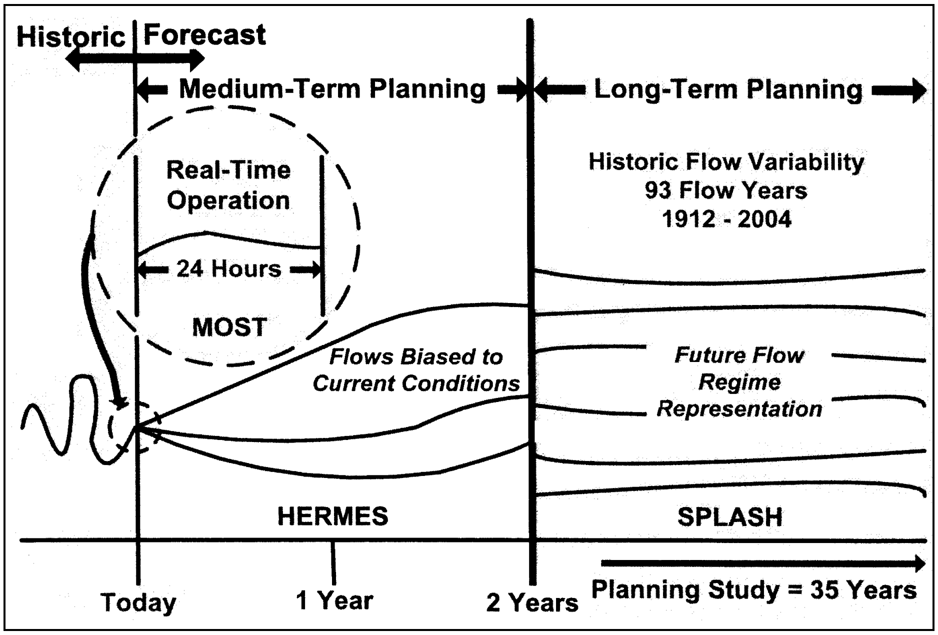


Figure 3.2 – Planning Horizons and Inflow Forecasts



Source: V. Kaushik. MOST Implementation at Manitoba Hydro. PPT Presentation, 2010

3.2.1 The Market Optimized Short-Term (MOST) Model

MOST is a decision support system (DSS) for hourly scheduling of generation and reservoir operations for the entire Manitoba Hydro generating facilities and transmission network. Bi-directional line limits and HVDC line losses are explicitly represented within the optimization of generation. The system, VISTA based, performs a number of tasks that include:

- One-day-ahead capacity planning in order to provide information to day-ahead traders.
- Scheduling of resources for the entire week.
- Hour ahead for committed load and transactions
- Post audits and outage planning

The allocation of generation resources, whether hydraulic, thermal or wind, and the identification of transaction opportunities are done in an efficient manner where the system maximizes net benefits of operations. Synexus Global Inc. set up and installed the

VISTA system at MH. The system has seven modules and operates under the Windows operating system.[16]

The system modules include:

1. Data Vista for defining system configuration, facility data, and operational constraints related to water flows and levels, value generation, outage or maintenance schedules.

2. RT Data Vista for processing real-time data including SCADA data, weather forecasts and back route inflows.

3. Inflow Vista for generating short-term and medium-term inflow forecasts.

4. Load Vista for defining load forecasts.

5. Xchange Vista for identifying transaction opportunities including thermal generation resources.

6. ST Vista for short-term hourly scheduling for a two week scheduling horizon.

7. Vista Service for automatically loading and processing input data from external sources.

The various modules have different functions but all serve to optimize scheduling and allocating scarce power resources. Vista aids dispatchers in making decisions about unit generation and water release scheduling. The optimization is carried out to reconcile the trade-off between economic benefits of the current and future hydropower generation within the constraints of the water resource system and the inherent uncertainty of future events and prices. The current week operating decisions are traded against longer term considerations of annual reservoir storage levels. The long term generation scheduler (LT Vista) involves issues of reservoir management over a week defining the value of water in storage and/or water levels and discharge.

[16] The discussion about Vista is based on D. Shiels, T. Olason and F. Welt. "Short-term Generation and Transaction Scheduling at Manitoba Hydro Using the Vista Decision Support System". Mimeograph copy.

The optimization of the dispatch is either to maximize net benefits from generation within the given market information or to minimize the cost of meeting the system load demand within the available resources or import/export opportunities. Either firm water storage levels or value of water (energy) will be used to define the trade-off between benefits during the current week versus expected future benefits.

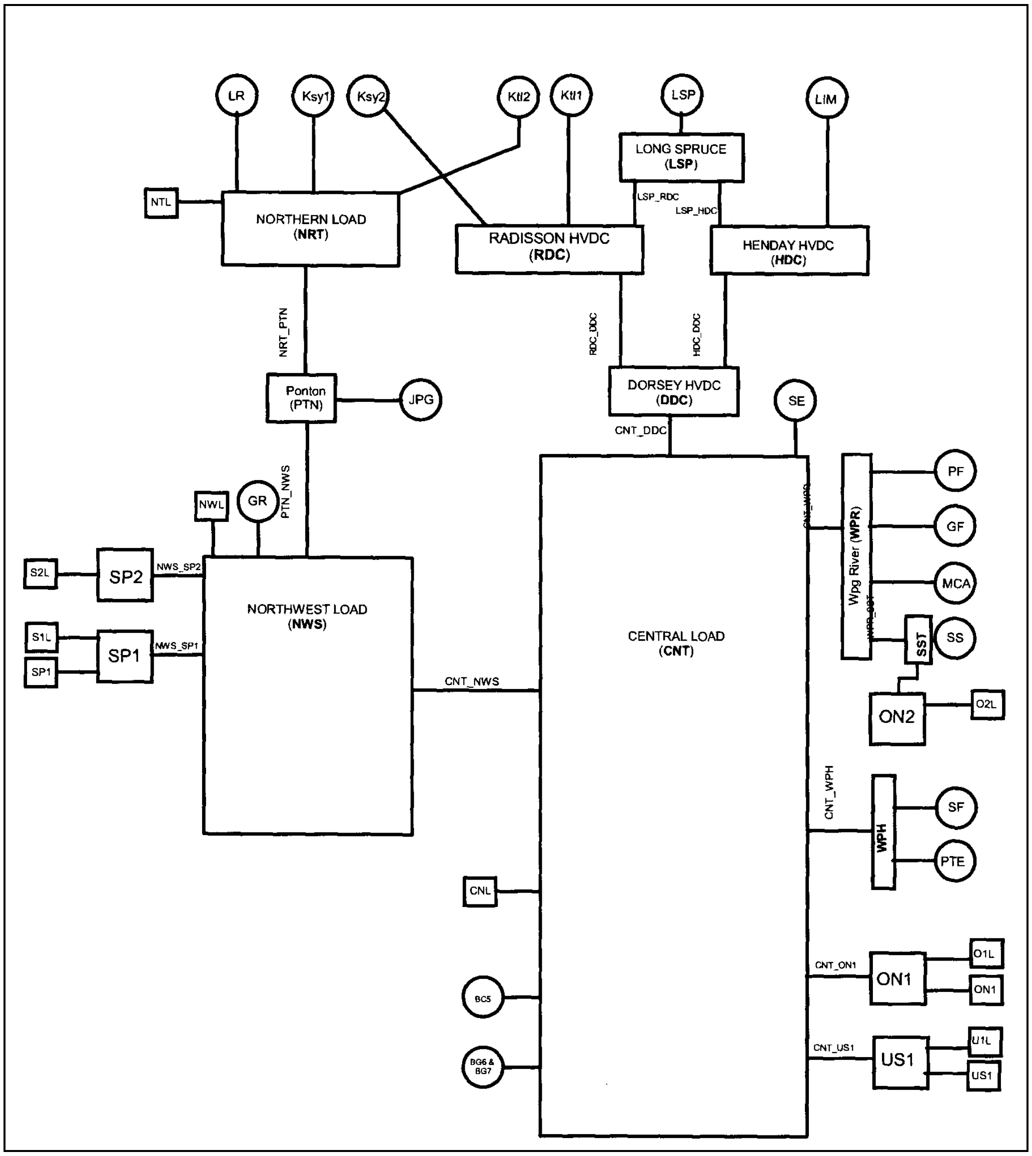
ST Vista is designed for real time operations and will automatically advance in time and refresh data. It can handle all requirements from “must run” to Automatic Generation Control (AGC) plans, always optimizing the hourly generation schedule and the simulation of water levels and flows for modified schedules.

Vista has multi-area functionality that allows it to represent the transmission system by regional load buses and tie-lines. Generation can be assigned to regional load buses and inter-connections with Ontario and Saskatchewan and the United States. Multiple customers are defined and each customer is mapped to a load bus. Short-term and long-term forecasts can be generated or imported for each customer. The load forecasts are updated several times each hour and fed automatically into Vista. Transaction opportunities are defined for the spot market that exists at any given time and long term contracts are entered as fixed load on these buses. As contracts are firmed they are tagged and become part of the load.

The constraints within which optimization is carried out include both hydraulic and transmission constraints that represent license requirements, operational commitments and/or preferences. The enormous size of the drainage area for the four main rivers (Nelson, Red, Saskatchewan and Churchill) in the system, and the great distances water travels to reach generation stations, complicate the time-specific formulation of the model. This also requires that the water management decisions for water storage in Lake Winnipeg, Cedar Lake and Kettle Lake be made part of the long term strategy and the short term flow constraints. In addition, there are dynamic discharge constraints that smooth out the spill operations.

Generation and sale of power are separated and information flows between the two are restricted. MH System Control Department of the Transmission and Business Unit determines the generation scheduling, whereas marketing of power is the responsibility of Power Sales and Operations Department of the Power Supply Business Unit. Transmission information cannot be shared with the marketers of power. This negates one of the principal advantages of Vista where it allows multiple users and the sharing of information in real time.

Figure 3.3 – AC/DC Transmissions Systems in MOST



Source: D. Shiels, T. Olason and F. Welt. "Short-term Generation and Transaction Scheduling at Manitoba Hydro Using the Vista Decision Support System. P 7.

The MH process of optimization and use of Vista involves reviewing long term water management decisions once a day and making adjustments to constraints and/or the value of water in storage curves. Then a one week optimization analysis is conducted, reviewed and saved to the official schedule. This determines unit commitments schedules that are exported. The weekly schedule provides 24-hour-ahead schedules that are updated twice an hour and then tagged and converted into committed load and a generation schedule.

There are many advantages to Vista. First, it can optimize the hourly generation and transaction schedules within constraints on the generating facilities transmission network. Second, it provides hourly capacity forecasts and recommended transactions. Third, it provides information and analysis that can help improve water management and reduce the gap between actual and optimal schedules of generation and, in turn, optimal schedules for outage and maintenance. Fourth, it provides a central location for data storage, retrieval and updates for all hydraulic data for automatic and real time computations, forecasts and report generation. Fifth**,** it provides a post-audit capability that allows users to initialize the scheduler in a historic week, optimize and compare to actual operations.

We have reviewed Vista and many of the claims made by its developers as summarized above. Vista is undoubtedly a powerful tool and a thoroughly tested system. We have talked to a number of staff members involved in running and supporting MOST and were impressed by their knowledge of the inner workings of the system and with their ability to explain its mechanics and its results. We did not see a demonstration of how it works or see the User or Technical Manuals but we are comfortable that such manuals exist or could easily be made available since this is a standard commercial system.

We would like to see the skills of the staff responsible for the Model be used to train a core of users, and that this knowledge not only be shared but also codified. We would also like to see the system be thoroughly indigenised within MH; as a commercial system it is not fully owned by MH. The post-audit function of Vista is of crucial importance and we would like to see it expanded and performed on a routine basis. The model depends on a large set of external forecasts and it generates several forecasts of its own. It would make sense that these forecasts and their errors be reduced through continuous validation and verification. We saw an error forecast report that the system produced, but it is a single report which limits the forecasting audit function. It is recommended that wherever a forecast is made it be squared against the actual values on a regular and systematic basis, that a record be kept of these errors and steps taken to contain and minimize them.

3.2.2. Summary and Recommendations

We have a number of questions about MOST (Vista) and a number of recommendations that we would like to tender at this stage. Some of these questions will be raised and repeated in the case of each model system at MH.

First, we would like to see the model cast in an explicit stochastic framework given the many uncertainties that are embedded in the system. It is possible to solve the Linear Programming Problem (LP) several times under different specifications of the parameters to take into account possible variations in these coefficients, but this is not necessary if other systems at MH (for example, PRISM) can be used to generate distributions of the exogenous forecasts.

Second, it is clear that a few price forecasts are embedded in the system; it would make more sense to represent these as probability densities using @RISK or any other probability generating system.

Third, we would like to see more than one skilled person responsible for the model. It would make more sense to train a designated group of the staff to work on any given model: this will guarantee that a pool of skilled staff is always available at any time to support the model.

Fourth, it is recommended that the system be continuously subjected to validation and verification to improve its forecasting accuracy. Stressing the system (stress tests of the model) should be a regular and routine operation and reports about these tests should be funnelled to the Risk Management Committee and an MH Modelling Committee. There are many ways this can be accomplished, but using typical forecasting error formulas can be helpful.

Fifth, it will be useful to formalise the integration of Vista with other models and bring together those supporting and maintaining the system as part of a formal **Modelling Committee (MC)** that meets regularly with a sufficient budget and written terms of reference that will entrust the MC with the task of internal oversight, review, upgrading, documenting and internalizing the ownership of the models. This function should also be augmented by arms length verification, review and evaluation of the model by a **Model Audit Committee (MAC)** comprised of experts from outside MH with no commercial connections to any of the models who will be involved on needs basis and consulting assignments.

Sixth, we would like to see that every effort is made to establish full ownership of the model systems within MH and that no system is seen or perceived to be a “black box” developed generically outside the full control and mandate of the organization.

Seventh, we would like to formulate the objective function to minimize cost of generation and delivery rather than maximizing net revenues. The public nature of the utility puts it outside profit maximization strictures. This is not an issue of semantics: the concerns are far deeper. The public utility is a natural monopoly; the last thing the citizen shareholder would like to see is the utility using its market power to maximize its rents, especially given the inherent concern about the implicit trade off between domestic load and exports.

3.2.3 The Hydro Electric Reservoir Management Evaluation System (HERMES) Model

3.2.3.1 History of HERMES

Simulation techniques were, in the 1970s and early 1980s, the dominant tool for assessing, evaluating and even predicting flows and generation requirements at MH. The Reservoir Management Engineer (RME) at MH used these simulations in order to develop a workable understanding of what could be expected from the river system and what constitutes normal operations. The simulations used daily time steps and supplied information that the RME exploited in planning reservoir and river operations. Releases from upstream reservoirs were planned first to determine inflows to downstream reservoirs. This was followed by determining outflows from these downstream reservoirs to all generating stations. From these flows the system energy was calculated and compared to firm system energy requirements. If the energy in the system were to exceed domestic load (that must be met at all times), a review was initiated to find out whether the energy could be sold and if necessary adjustments were needed to regulation until there was a satisfactory export schedule. Any surplus that remained would be added to storage or spilled. If the system energy were to fall below firm energy requirements thermal energy, imports or reservoir levels were adjusted in a manner that would seek to reduce costs.[17]

A number of computer routines were needed to generate the simulation results but even at this early stage it was recognized that computer simulations are simply an input in the decision process where experience, expertise and judgment are required for planning any course of action. As the system grew and became more complex the inadequacy of these simulation techniques became common knowledge. This set the stage for exploring some of the standard tools of optimization that other Canadian utilities had already adopted.

A recommendation came from MH's Computer Department and Water Resources Engineer that an optimization model was required to handle the increased complexity of the system particularly as it embarked on exporting larger volumes of electricity sales to the US. At that time there were many LP programs off the shelf at reasonable prices. The LP was recognized as a suitable model for reservoir management which had already demonstrated its usefulness in other utilities. This recognition was reinforced by the fact that the hydrology problem can easily be formulated as an LP problem, where its solution is relatively standard, simple, and easily interpretable, and that it typically generates a single optimum. These advantages were quickly recognized by MH. The first application of the optimization model was dispatching energy from a single fixed reservoir and the applications quickly escalated from there to cover the entire system of 13 reservoirs and 13 generating stations, including seasonal variations.

The first optimization model at MH was Production Optimization Program (POP). It helped develop an operating plan for the use of the reservoir, hydro and thermal generation and inter-utility tie-lines. The generation met the system load and maximized profit from operations over a specified period for a specific stream flow scenario. The period that followed the development and use of POP was one that created comfort in the application of the system and its interpretation and in the data that was collected and used. The work on data covered the following areas:

[17] This presentation is based on two papers and many discussions with MH Staff.

A. Cormie and P. Barritt-Flatt. "HERMES: A Decision Support System for Reservoir Operations at Manitoba Hydro." Presented at Operations Planning section, Canadian Electrical Association, Vancouver, BC, March 1987. and P. Barritt-Flatt and A.Cormie. "A Comprehensive Optimization Model for Hydro-Electric Reservoir Operations." Unpublished Manuscript.

- Physical system data (capabilities, rating curves, etc.).
- Operating constraints (reliability requirements, practical limits, etc.).
- Management constraints (financial, social and environmental objectives, etc.).
- Regulatory constraints (licenses).

As time progressed improvements in the specification of the model were made and adopted from forecasting the interruptible export market to water inflows forecasting making the data cumulatively more consistent with the model requirements.

The preparation of monthly generation plans still took time and substantial calculations outside the model were still being made to determine water flow forecasts, future export prices, load forecasts, market forecasts, and maintenance scheduling. The challenge of developing an operating system capable of dealing with all of the preceding issues and still providing the RME with a long term capability to solve reservoir and energy management problems in a timely manner, prompted the development of HERMES in 1984.

3.2.3.2 Structure of HERMES

The goals of the system were clear and precise. They included:

- To produce an energy production schedule.
- To maximize operating profits.
- To link generation maintenance to reservoir operations.
- To maintain system firmness.
- To maintain system reliability.
- To repeat the system optimization weekly.

The system produces an optimum production schedule for the integrated reservoirs, hydro-thermal generating stations, and the HVDC system and inter-utility tie-lines. Not only is the schedule feasible, meeting all the constraints, but it maximizes the system's net income. Maintenance scheduling is linked to operations so as to minimize dislocations and opportunity costs. Firmness of the system is accomplished through imposing tight energy reserve constraints in storage reservoirs. The analysis is updated weekly in order to incorporate any new developments and changes in the system, particularly those that concern water inflows into reservoirs, precipitation levels, loads, export markets and equipment outages. These changes, once incorporated into the system, would allow the RME to change current operating orders.

HERMES requires a long list of data that the RME provides in the same temporal and physical structure. The data describe both the current state and a forecast of the future resources available to the system. Since the underlying reality of the system is non-linear but the variables that the model accepts are all linear, a number of adjustments have to be made involving numerical approximations, linearization, segmentation, aggregations and other interpolations, all of which introduce errors and reduce the accuracy of the model. This is here where HERMES would require careful assessment and its forecasting errors would need to be calculated and understood. Successive LP runs may be required and should be used. The modular nature of the model could be an advantage in the sense that continuous calibration and adjustments to the data and results should be a predominant concern. Given some of the new solvers (General Algebraic Mathematical Systems (GAMS) found at www.gams.com and Advanced Integrated Multidimensional Modeling Software (AIMMS) found at www.aimms.com) some serious consideration should be given to the introduction of some nonlinear modules.

One of the recognized advantages of HERMES is the continuous updating that has continued throughout its development and use. The weekly updates of data and information and scrutiny of results at Power Sales and Operations is also a recognized advantage for keeping the solutions current and relevant. HERMES involves a weekly revision of the plan; it is updated as new information is incorporated once it becomes available. Storms, outages, changes power efficiency coefficients, lake outlet rating curves, tail-water levels, in reservoir or transmission capabilities, increased demand for electricity, weather changes or random changes can all change the assumptions made in the last operating plan and these are included in the preparation of the new operating plan. It is also true that new forecasts are made starting from the current state of the system. Water flow forecasts for all drainage basins are updated using forecasting models which have been developed using regression estimation based on historical data.

We have gone over some of these regression equations and it is clear that some of the regression diagnostics are high but we are still concerned about using a single past variable as a predictor of the next period value. Admittedly, the period is short but our experience and econometric work using Manitoba water flow data suggests that a longer and a richer lag structure may be needed. Export market forecasts for interconnected utilities are also updated; both on peak and off peak price-volume relationships for various periods of the year are revised. It is legitimate to wonder here about the interconnectivity of the MH models' family and why the results of @RISK in PRISM are not utilized by HERMES. What is preventing HERMES from using some probability distributions (@RISK has a suite of about 37 different probability distribution functions) that can help map a useful probabilistic profile and avoid using a single array. This will add a stochastic element to the results and save the system from being overly dependent on any single forecast vector (array).

The development of an optimization model for hydro-electric reservoir operations at MH evolved over time. POP was upgraded and developed into a full-fledged Energy Management and Maintenance Analysis (EMMA). The purpose of operations planning as captured by EMMA is the selection of an optimum schedule of reservoir releases, hydro generation, thermal generation, imports and exports. The main goals of the plan are to:

- Ensure sufficient energy is produced to meet forecasted demands.
- Ensure sufficient capacity is in place to meet peak demands.
- Maintain acceptable levels of system reliability.
- Minimize negative environmental and social impacts.
- Operate economically.

Realistic operational plans require a time horizon of one to two years. Planning within this horizon permits choices between current and future costs and revenues while considering operation of the multi-year reservoir storage in the system. EMMA is a deterministic optimization model with a medium term planning horizon of two years. The stochastic nature of flows is dealt with by re-optimizing with different flows and loads. This is possible but it is an inefficient way of dealing with probabilistic structures. It may make more sense to change the structure of the model into a full fledged stochastic model.

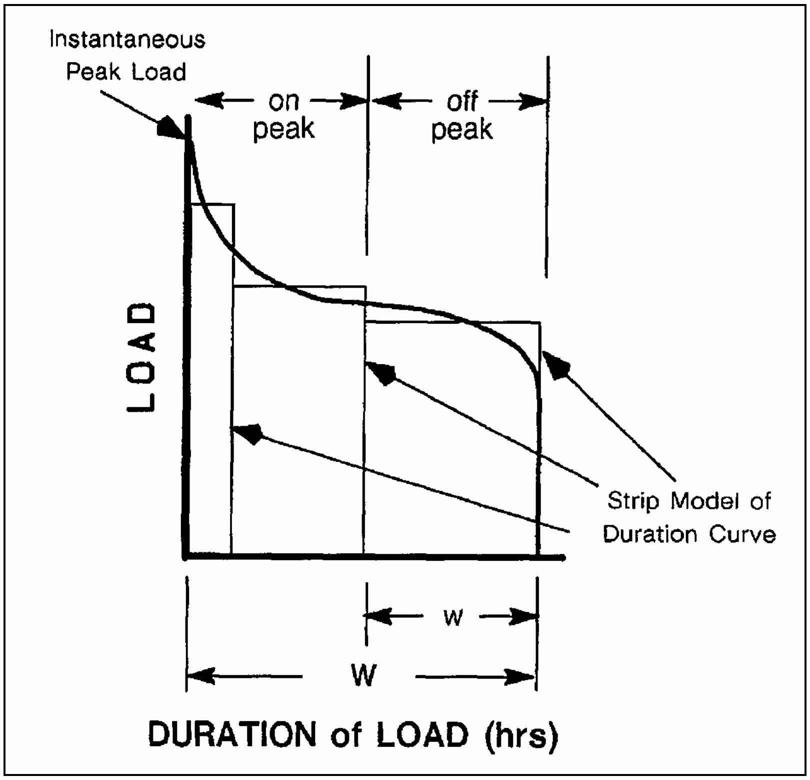
The three subsystems of EMMA include the hydraulic system, power generation and the maintenance system. Within each subsystem there are many components. In the hydraulic subsystem there are reservoirs, lakes and rivers. Each reservoir has at least two outlets: a spillway and a penstock to the turbines. Lakes may be controlled by natural outlets or gated control structures. Time delays arising on account of open channel flow can be modelled by a lake with the appropriate stage-storage and outlet ratings. EMMA allows these modeling capabilities and different variations on how to configure these bodies of water.

The electrical system has generators, loads and transmission lines. Loads may be fixed or price sensitive; they can be firm or interruptible. Load may be for on peak time or for off peak time. Exports and imports must be modeled differently. They may be under firm contracts or simply in the opportunity market. They may be scheduled for day ahead or on time. Maintenance crews have limited availability on both a monthly and a seasonal basis. Maintenance may be scheduled before the process of preparing an operating plan or it may be assigned by the optimizing run. The net effect of maintenance is to reduce generating capacity. These choices and options enrich the LP structure and result in a more useful system.

The electrical system models describe electricity generation, transmission and load. Losses in transmission are included in the domestic load and losses in imports and exports are modeled directly. The deterministic domestic load is represented by a load duration curve represented by a number of vertical strips and an instantaneous peak load. Two strips are used to represent the on peak and only one to represent the off peak (See Figure 3.4). Each strip of the load represents an average load which must be met for a specific duration. The separation of the strips reflects the fact that they have different cost and revenue implications.

EMMA system of modules is complemented by a Flow Simulation Model (QSIM). The latter is focused on deriving a daily flow and elevation values along MH's hydraulic network. QSIM generates daily flow estimates compared to the weekly or monthly forecasts of EMMA.

Figure 3.4 – Load Duration Curve Model



Source: P. E. Barritt-Flatt and A.D. Cormie. A comprehensive Optimization Model for Hydro-Electric Reservoir Operations. P. 6.

3.2.3.3 Forecasting Accuracy of HERMES

"The taste of the pudding is in the eating." Many forecasters have argued that the utility of a model and its worth are singularly dependent on forecasting accuracy. While this notion has been challenged, it is still valid for forecasting models that seek to calculate future values with accuracy as guides to operations and plans. Forecasting errors arise from two sources—errors in the data used or in the structure (logic) of the model. When input data are checked and validated, it is only then that forecasting errors can be used to validate the structure of the model.

HERMES generates a large set of forecasts from generation to net income. These forecasts are used with other information to plan operations and exports. The accuracy of the forecasts is not of mere academic interest: the viability and reliability of the system depends upon them.

We have obtained from MH data on the discrepancies between annual forecast values and annual actual values for generation, total revenues, total costs, net revenues and exports between 1999 and 2009.

Positive errors (under-predicting) are not equivalent to negative errors (over-predicting). This fact is also contingent on the nature of the variable predicted. For example, under-predicting revenue is not a problem but under-predicting costs are a major problem. This is why different forecasting error measures have been devised to deal with this issue. We will here restrict our presentation to the simple variance of the predicted from the actual values. We will not use the average of the error variance because it is meaningless when positive and negative values are averaged (negative and positive errors cancel each other). A better measure would be one that takes the average of the absolute values of the errors, which in the case of the numbers in Table 3.1 would be an average of 3.3% instead of the 0% reported by MH.

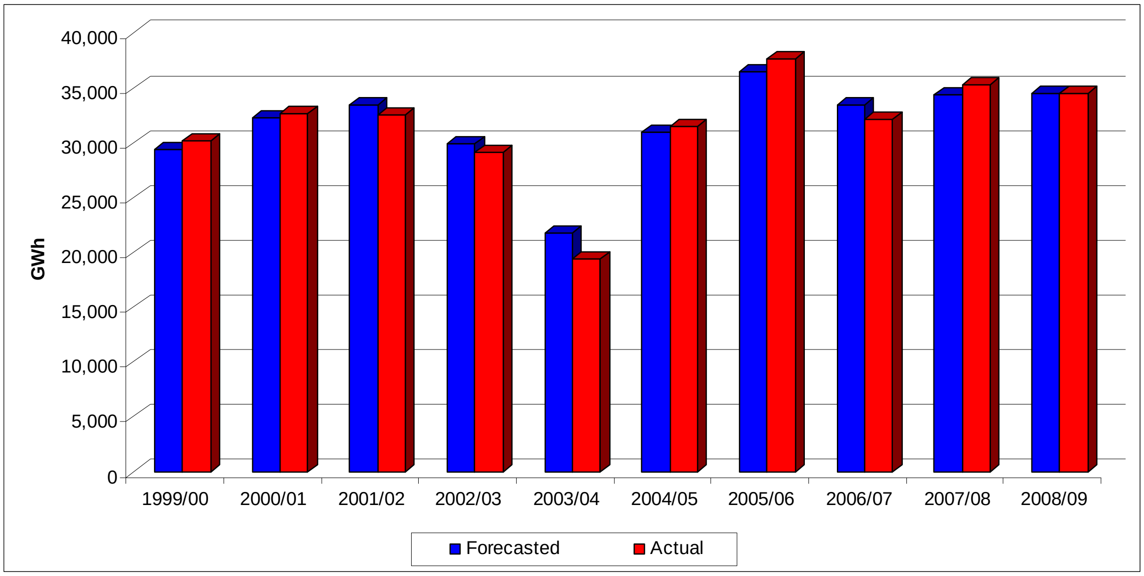
On average the HERMES model predicts annual generation well. It over-predicts almost equally to what it under-predicts. Where it failed, however, was in the crucial period of a critical year of low flow. The error in 2003/04 is large, with over 11% (see Table 3.1 and Figure3.5).

Table 3.1 – Forecast and Actual Generation, 1999-2009

FISCAL YEAR	TOTAL GENERATION			
END MAR 31	FORECASTED	ACTUAL	Variance	% Variance
1999/00	29,347	30,146	799	3%
2000/01	32,265	32,687	422	1%
2001/02	33,419	32,557	-862	-3%
2002/03	29,924	29,118	-806	-3%
2003/04	21,820	19,369	-2451	-11%
2004/05	30,918	31,534	616	2%
2005/06	36,516	37,629	1113	3%
2006/07	33,515	32,121	-1394	-4%
2007/08	34,330	35,354	1024	3%
2008/09	34,547	34,528	-19	0%
Average	31,660	31,504	-156	0%

Source: Manitoba Hydro. HERMES.

Figure 3.5 - Forecast and Actual Generation, 1999-2009



Source: Manitoba Hydro. HERMES.

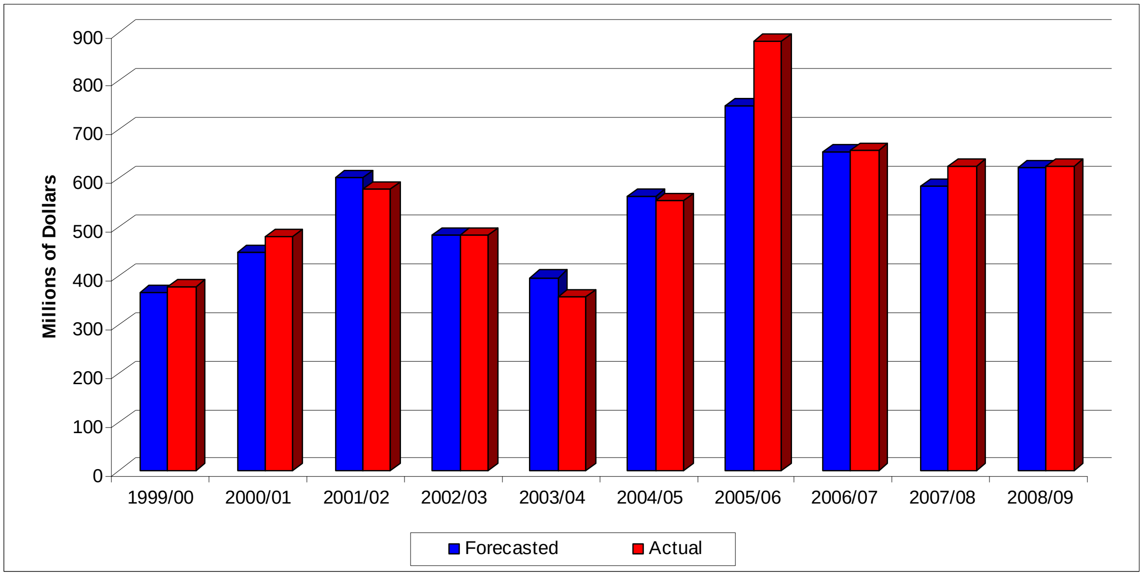
HERMES under-predicts total export revenues. For the ten year period of forecasts, it under-predicted three times (3 out of 10) in 2001/02, 2003/04 and 2004/05 (Table 3.2 and Figure 3.6). The overall error is relatively low except in 2003/04 and 2005/06--two widely different years. The average of the absolute errors is 5.1% instead of the 3% reported in Table 3.2.

Table 3.2 – Forecast and Actual Total Export Revenue, 1999-2009

FISCAL YEAR	TOTAL EXPORT REVENUE			
END MAR 31	FORECASTED	ACTUAL	Variance	% Variance
1999/00	365	377	12	3%
2000/01	448	481	33	7%
2001/02	602	578	-24	-4%
2002/03	485	485	0	0%
2003/04	397	357	-40	-10%
2004/05	564	555	-9	-2%
2005/06	748	882	134	18%
2006/07	656	657	1	0%
2007/08	583	626	42	7%
2008/09	621	624	3	0%
Average	547	562	15	3%

Source: Manitoba Hydro.

Figure 3.6 – Forecast and Actual Total Export Revenue, 1999-2009



Source: Manitoba Hydro.

The simple forecasting errors of total cost are large and, unfortunately, there is an obvious strong trend to underestimate the rise in costs. The forecasting errors are quite large in several years. In 2002/03 HERMES under-predicted total cost by 31% and in 2006/07 by 36% (Table 3.3 and Figure 3.7). Only in one year (1999/00) did HERMES over-predict total cost.

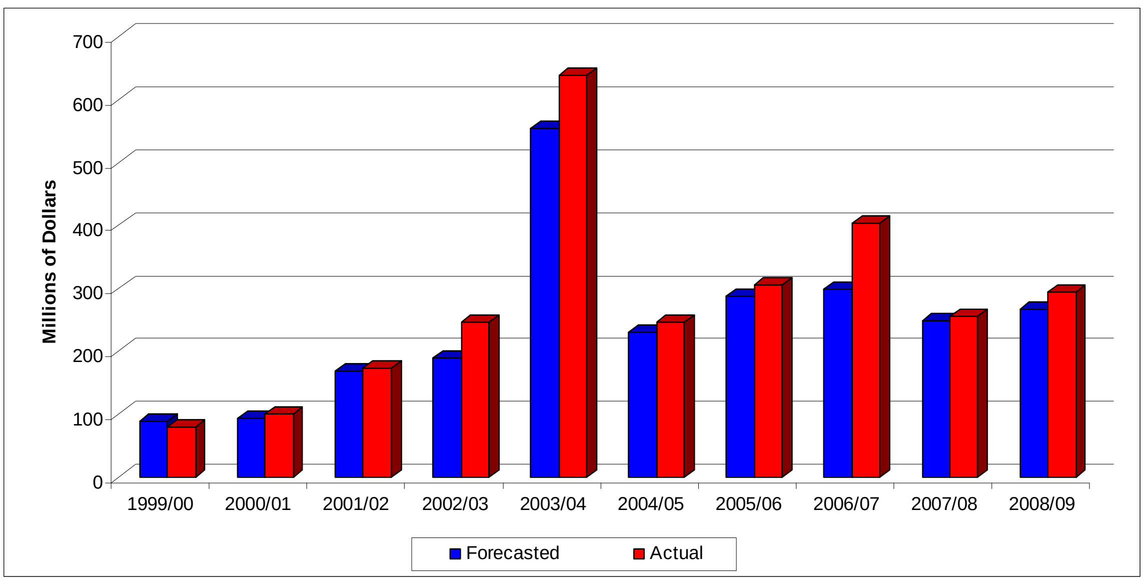
The absolute value errors (actual values minus predicted values irrespective of sign) are not large except in 2006/07, where the error exceeded $106 million--this is why the simple average of the errors (13%) is almost equal to the average of the absolute errors (12.8%).

Table 3.3 – Forecast and Actual Total Cost, 1999-2009

FISCAL YEAR	TOTAL COST			
END MAR 31	FORECASTED	ACTUAL	Variance	% Variance
1999/00	88	80	-8	-9%
2000/01	92	100	8	8%
2001/02	168	174	6	3%
2002/03	188	246	59	31%
2003/04	555	639	84	15%
2004/05	231	245	14	6%
2005/06	288	306	18	6%
2006/07	298	404	106	36%
2007/08	248	255	7	3%
2008/09	267	295	29	11%
Average	242	274	32	13%

Source: Manitoba Hydro.

Figure 3.7 – Forecast and Actual Total Cost, 1999-2009



Source: Manitoba Hydro.

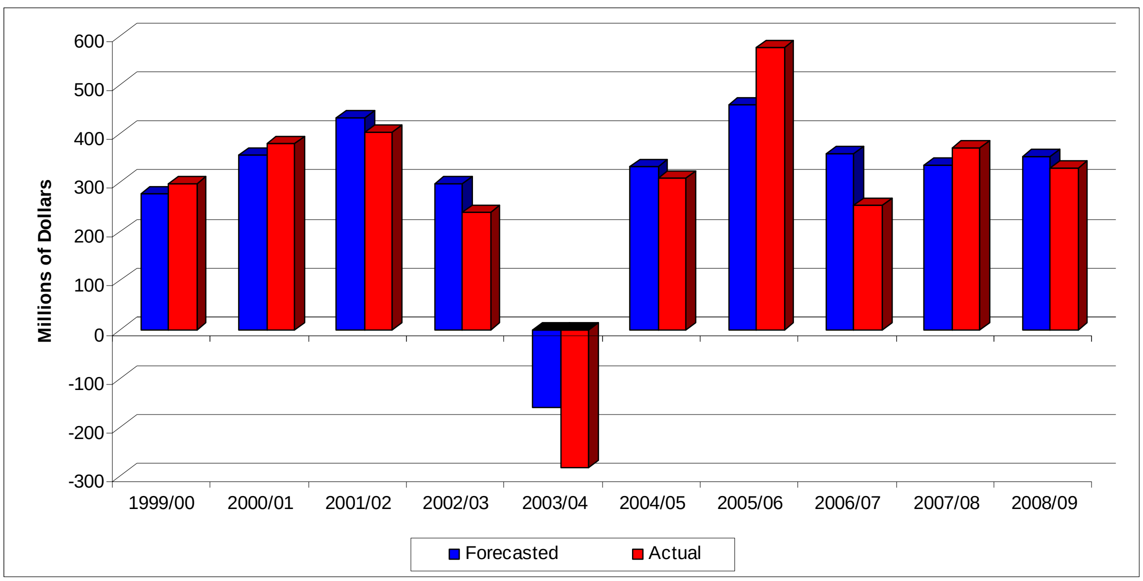
The prediction errors of net revenues are high and vary between over-predicting and under-predicting. There is a concentration of over-predicting in the latter year of the sample but with limited errors but large errors and over-predicting in the middle period around the drought. It is interesting to note that HERMES captures the turning points in the system. It predicts a loss when a loss occurs, although the magnitude of the errors is very large. The average of the absolute errors is almost 20% when it is only 6% when the simple average is used.

Table 3.4 – Forecast and Actual Net Revenue, 1999-2009

FISCAL YEAR	NET REVENUE			
END MAR 31	FORECASTED	ACTUAL	Variance	% Variance
1999/00	278	298	20	7%
2000/01	356	381	26	7%
2001/02	433	404	-29	-7%
2002/03	298	239	-59	-20%
2003/04	-158	-282	-124	-79%
2004/05	333	309	-24	-7%
2005/06	460	577	117	25%
2006/07	358	253	-105	-29%
2007/08	335	371	35	10%
2008/09	354	329	-26	-7%
Average	305	288	-17	-6%

Source: Manitoba Hydro.

Figure 3.8 – Forecast and Actual Net Revenue, 1999-2009



Source: Manitoba Hydro.

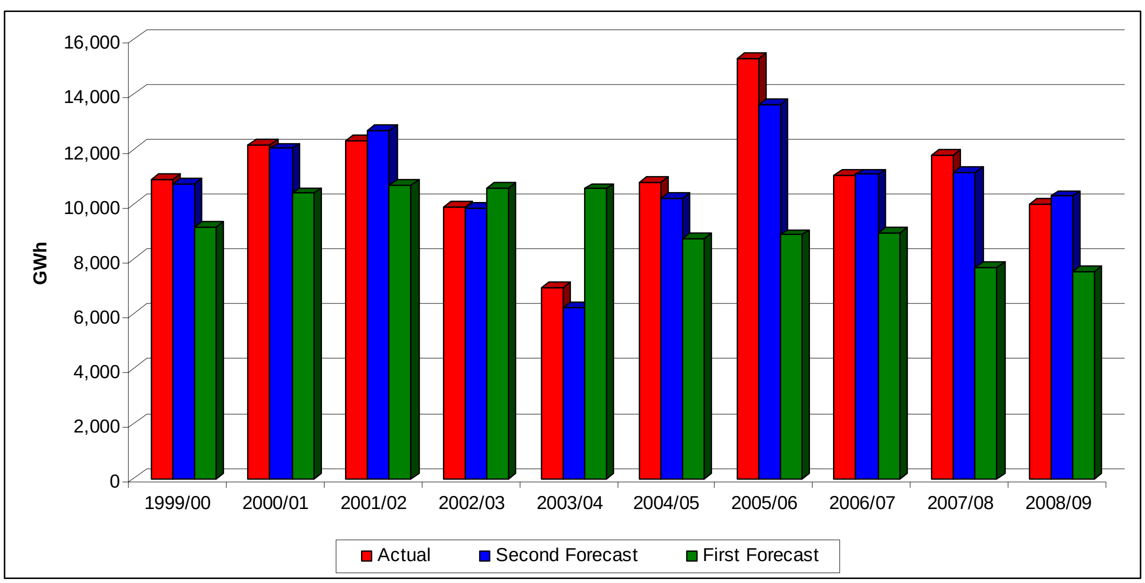
Another perspective on HERMES predictive accuracy is presented in Table 3.5 and Figure 3.9. It is clear that the second forecast is far better (lower prediction errors) than the first forecast. The accuracy of HERMES rises with time and the incorporation of more recent information improves the forecasts. It seems that when in the year the forecasts are made is crucial. Forecasts made in July are far better than those made earlier. By July the water conditions after spring rain are more reliable. Errors of the first forecast are high and reveal over-prediction. The second forecast still suffers from over-prediction of exports but the relative magnitudes of the deviations decrease (Table 3.5 and Figure 3.9). The improvement in the second forecast over the first forecast could be an indication of a deficiency of HERMES lag structure. The concentration on a single lag in the flow equations may need some adjustment to improve the forecasts.

Table 3.5 – Forecast and Actual Exports, 1999-2009

Fiscal Year	Actual GWh	Second Forecast Variance GWh	Second Forecast Variance GWh	Second Forecast Issue %	Second Forecast Date mmm-yy	First Forecast Variance GWh	First Forecast Variance GWh	First Forecast Issue GWh	First Forecast Date mmm-yy
1999/00	10,881	10,704	177	2%	Sep-99	9,148	1,733	19%	Sep-98
2000/01	12,150	12,010	140	1%	Sep-00	10,383	1,767	17%	Sep-99
2001/02	12,293	12,676	-383	-3%	Sep-01	10,651	1,642	15%	Sep-00
2002/03	9,900	9,843	57	1%	Sep-02	10,578	-678	-6%	Sep-01
2003/04	6,975	6,220	755	12%	Sep-03	10,542	-3,567	-34%	Sep-02
2004/05	10,798	10,188	610	6%	Oct-04	8,731	2,067	24%	Sep-03
2005/06	15,290	13,597	1,693	12%	Aug-05	8,864	6,426	72%	Oct-04
2006/07	11,061	11,067	-6	0%	Aug-06	8,934	2,127	24%	Aug-05
2007/08	11,788	11,152	636	6%	Nov-07	7,707	4,081	53%	Aug-06
2008/09	10,008	10,279	-271	-3%	Sep-08	7,549	2,459	33%	Nov-07

Source: Manitoba Hydro.

Figure 3.9 – Forecast and Actual Exports, 1999-2009



Source: Manitoba Hydro.

3.2.4 Summary and Recommendations

By any standard HERMES is an impressive system: it developed over time and grew in complexity and utility. Its developers are on staff and the source code is home stored. We are satisfied that the technical staff that support and run the model are competent and committed. We have seen a couple of demonstrations of the system and we have seen its objective function, constraints and inner workings. It is a large system with over 8000 constraints and bounds and a larger number of variables. It is capable of generating a rich set of bases (linearly independent vectors) that define feasible solutions for the objective function to choose from among them the optimal one.

We noticed, however, that a forced solution is made by assigning huge costs to particular objective function coefficients. This is a standard practice in large LP systems but still worrisome. There is always the fear that users will select optimum solutions close to actual operations or desired solutions.

Being an internally developed and maintained system, HERMES has advantages and disadvantages. Among the advantages is the ease and flexibility of changing and upgrading the system. We understand that this is a continuous process at MH. But being a home grown product it may not be documented sufficiently or regularly. We have not seen a User Manual or a Technical Manual--typical products of commercially developed systems. Home grown products are protected and defended with zeal by their developers. This is why it makes sense to subject the system to an external audit by the Committee of Experts (MAC) we mentioned in the context of MOST. The need for this validation and audit is doubly important when the model is home grown.

The deterministic nature of the model calls for more thorough adjustment and upgrades. It makes sense to move to a stochastic system or at least to add a few stochastic modules. The same goes for some non-linear modules in the system. Since the underlying structure is nonlinear and new solvers (GAMS or AIMMS) can easily solve large nonlinear and stochastic systems, it is worth considering these upgrades. Successive optimization may reduce this need, but in our opinion this will be a poor substitute.

The availability of PRISM and its gut @RISK at MH should facilitate using stochastic forecasts instead of the arbitrary optimistic and pessimistic variants.

HERMES is one of many systems within the general class of LP system. It is for a medium term horizon. It sits between MOST and SPLASH. We would like to urge the model builders and users to fine tune their models' integration and collectively work on synchronization and communication. It would make sense to insure that the same data inputs are shared among all of the models. Using different data inputs or different coefficients raises red flags and detracts un-necessarily from the usefulness of the system.

We would like to single out for praise HERMES' incorporation of temperature (HDD and CDD) variables. This is a crucial advantage given the sensitivity of load to this variable and the extent to which it is expected to vary in the future. But we implore MH to consider moving more into stochastic and dynamic contexts. There are associated costs with the development of these capacities both in terms of human resources, software and hardware. There will be many added complexities to finding an initial solution and other time sensitive problems, but the benefits may and can outweigh the costs.

The use of antecedent forecasts and relying on regression equations to use the past and/or the present to predict the future values of flows is justifiable; care however, should be exercised to explore multiple lags, different estimating equations and the inclusion of meteorological variables that many hydro utilities use in the US and elsewhere (New York Power Authority (NYPA)). The heavy reliance on a single lag is these antecedent forecasts needs some reconsideration. Indeed the t-statistics on some of these regressions used by MH are reasonably high month to month, the R^2 are not on the whole particularly high but the real issue is that with missing variables in the regression equations the single variable may be picking the influences of the missing variables and the standard regression diagnostic measures need to be interpreted with caution.

A serious alternative to antecedent forecasts, even those that include multiple lags and other meteorological data, is the use of full-blown hydrological models with full accounting of precipitation, evaporation and flows. Manitoba Hydro's excessive dependence on water and its unique sensitivity to different water flows are strong arguments for a serious consideration of building or sourcing out this capacity. There are some unique hydrological and regulatory features that make these models particularly difficult for MH such as the multiple watersheds, out of province control of water flows to Manitoba, and the shallow and porous waterbeds. But the expected benefits from such models and systems cannot be exaggerated.

3.2.5 Simulation Program for Long Term Analysis of System Hydraulics (SPLASH)

While MOST is an hourly and daily planning operational planning tool and HERMES is for medium-term operational planning, SPLASH is a long-term planning tool. Its horizon can extend up to 40 years.

Its name suggests that it is a simulation model but in fact it also belongs to the general linear programming models that optimize net revenues with embedded simulation routines. The primary objective of SPLASH is identified as determining the expected long-term operation of the MH system under various alternatives of system expansion and under a range of flow conditions that may be considered representative of the future.

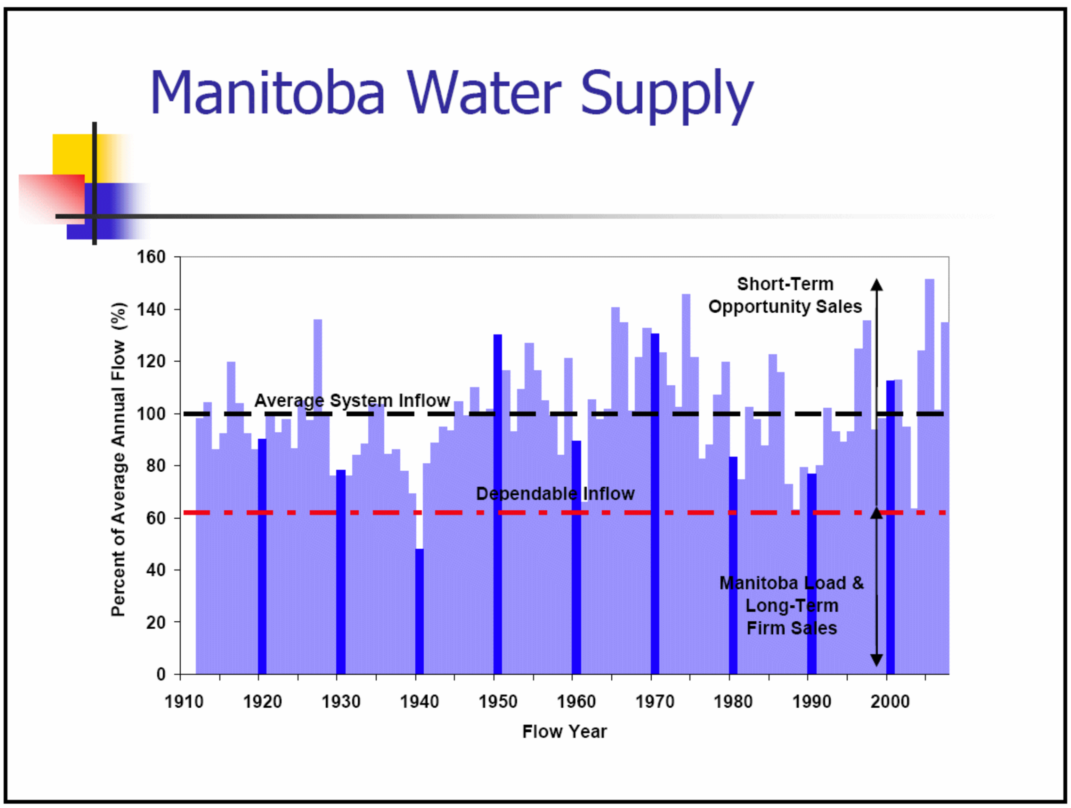
SPLASH is based on representations of the hydraulic, thermal, wind and transmission systems, the constraints that the physical and regulatory regimes impose on the system, and the financial parameters of the system embedded in input and output, current and future prices, including exchange rate and interest rate variables. Also modeled are the export markets, both those under a firm contract and those in the opportunity segment. This is done through a user-defined pricing structure. The outcome of this optimization routine defines the optimal energy production structure, production costs and the water regime under perfect foresight conditions.

Since hydro energy represents over 98% of typical MH energy generation, water variability is a major concern. SPLASH represents this water variability by using the 94 historical years of monthly flows. Each of the 94 flow years is chronologically cycled through the simulation period (typically 40 load years), in a way that guarantees that every flow year occurs in every load year. This results in a series of 94 different "flow cases" to map the hydrological variability. These different flow years are represented in Figure 3.10.

The way SPLASH works is to define an initial flow year to correspond to the first load year; the chronological flow record is maintained for each successive year. This implicitly assumes that each flow year on record is equally probable and that the past will be repeated in the future. The flow cases are in Figure 3.11 below.

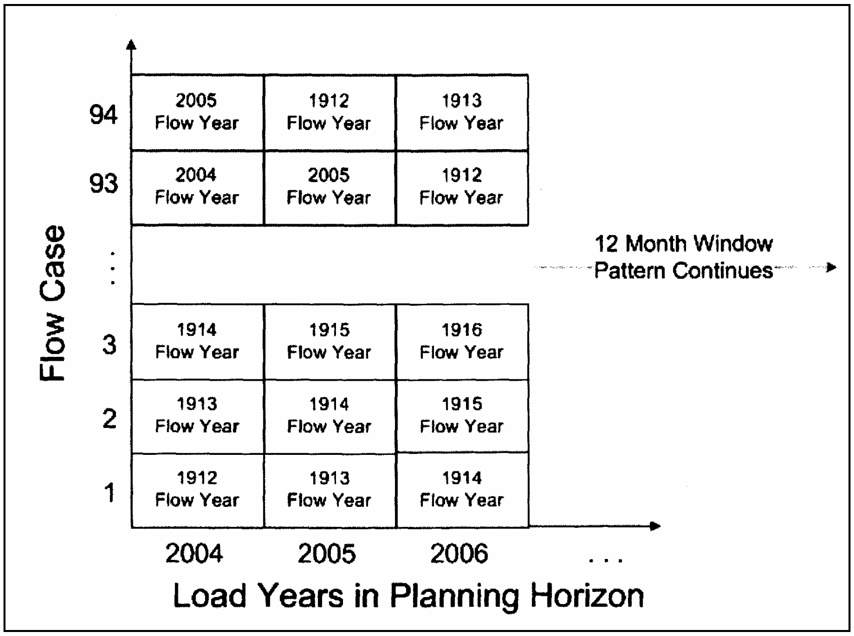
The simulations of the system operations extend for long periods up to 40 years. This long term horizon is chosen to represent the planning horizon. SPLASH is not modeled as a continuous flow; instead it is modeled in small time increments called "windows" where each window represents a year and these years are broken down into variable lengths of "time-steps". Within each strip there are several segments. Currently SPLASH has two strips—one for on-peak hours and another for off-peak hours. While the use of 94 flow possibilities increases the chances of picking a "correct flow" level, the procedure is still limited to the actual occurrences of these flows as determined by history. In Chapter 4 we develop a statistical approach to capture the information embedded in the 94 water flow series to generate a stochastic water flow density function. This is helpful in abstracting from the use of a water flow single series and augments the flow data with a large series of stochastic flows. Even this stochastic enrichment is not sufficient and does not substitute fully for the need of a hydrological model for informing MH water and generation management.

Figure 3.10 – Manitoba Annual Water Flows



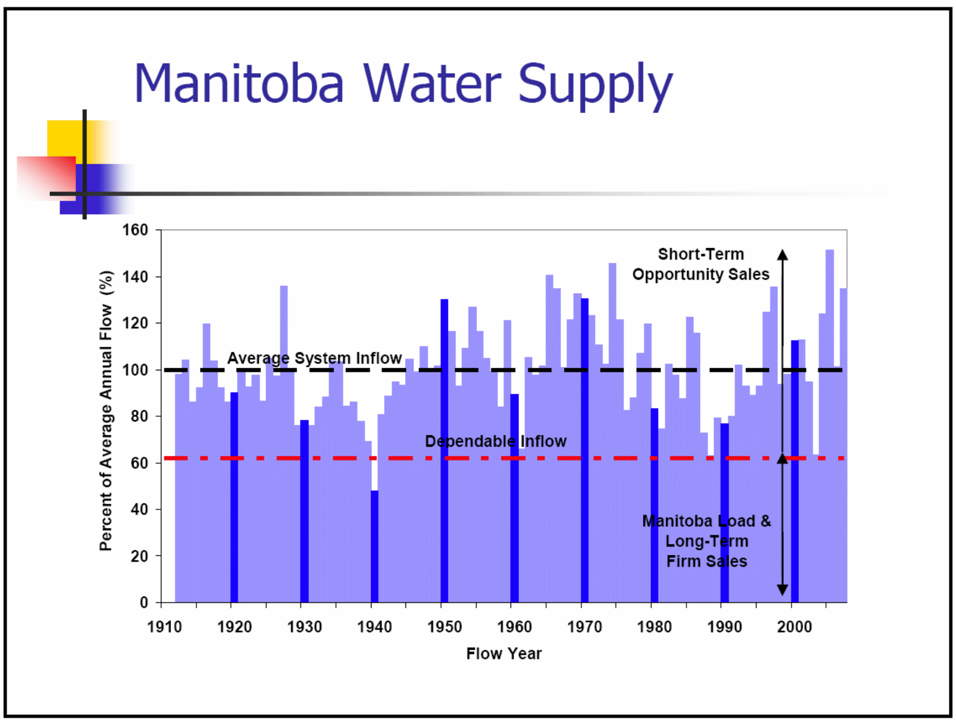
Source: Manitoba Hydro. Modeling Tools Utilized in Long Term Resource Planning. March 17, 2010.

Figure 3.11 – Chronological Cycling of Historical Flow Years



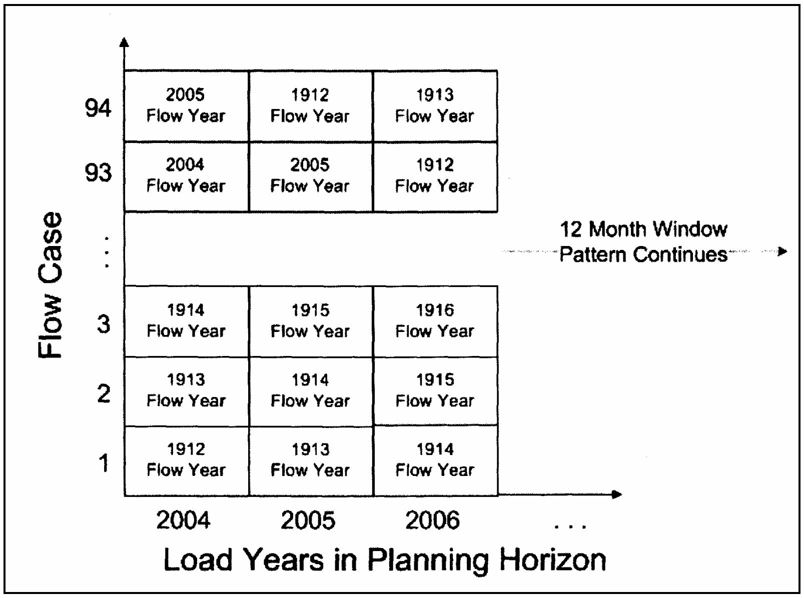
Source: Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

Figure 3.10 – Manitoba Annual Water Flows



Source: Manitoba Hydro. Modeling Tools Utilized in Long Term Resource Planning. March 17, 2010.

Figure 3.11 – Chronological Cycling of Historical Flow Years



Source: Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

The SPLASH model resides on a UNIX operating system and is accessed through Windows via an X-Windows emulator. The Solver is a commercially supported CPLEX. The objective of the optimization run is to maximize net revenues. There is no indication that this maximization is over time because if it is it would be necessary to define the discount rate. The revenues appear implicitly to mean net export revenues as Manitoba's load must be met as an equality constraint. Unfortunately, these ambiguities (about a discount rate or whether or not net export revenues are what is maximized) are not clarified in the documentation of the model that we were provided. We have seen written power point presentations and a documentation paper about SPLASH but we have not seen an actual demonstration of the model or copies of output.

We are warned in the SPLASH documentation about the many aspects of the problem that are non-linear in nature. It is admitted that successive iterations are run until a convergence is achieved that is deemed to represent the underlying nonlinear values. This means that a global maximum will not be obtained of the realistic nonlinear problem. This is a similar problem to the one encountered in HERMES. Thus any reference to optimization of the converged linear approximation of the basically nonlinear problem should not be confused with the true global optimization of the nonlinear problem. This raises a question about the need to solve nonlinear programs. Surely these would be more complex problems and a solution may not be obtained without starting with one, but computer capacities and solvers (GAMS and AIMMS) have advanced to the point where large nonlinear optimization problems are easily and quickly solved.

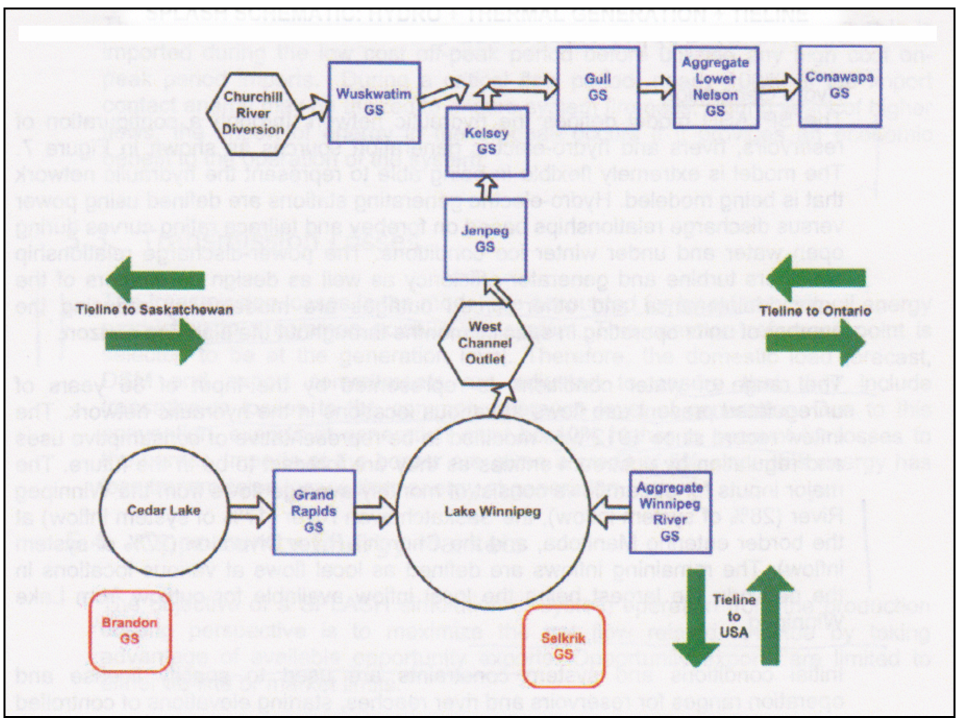
The graphical user interface allows the display of specific runs of interest. For example, the documentation shows that users may concentrate on the discharge from Lake Winnipeg for load year 2008 and the drought flow case of 1940. Common output data extracted include monthly and annual energy supply or demand values, monthly or annual revenues and costs (in constant dollars). It is also possible to extract information on reservoir elevation and river flows at different locations in the system. The results and runs are very similar to those that HERMES generates; the main difference is the time horizon. But a deeper analysis is perhaps needed to reveal and highlight the differences between SPLASH and HERMES that can justify the use of different systems with different solvers and resources. The time difference in our opinion is not a sufficient reason for supporting the two systems. The use of different flow assumptions in SPLASH is not warranted if the future is any different from the past. This we intend to do in Chapter 4.

The abstraction of the underlying system that the SPLASH model uses is presented in Figure 3.12. The modeling begins by specifying the domestic load forecast for energy on a monthly basis in GWh and capacity in MW. Each time step is separated into an on-peak and an off-peak period during which energy requirements are met. Both firm and non-firm (opportunity) export transactions are represented in SPLASH. Firm exports are treated as if they are domestic load since contractual obligations require specific quantities of energy that must be supplied during a specific period of time. This raises questions about interruptible system participation obligations negotiated for the new contracts. The quantity of contractual firm energy for on-peak and off-peak periods for each month is provided as an input to the model and should reflect these alterations. We cannot comment on whether this was done or not as we have not seen the model in operation or had documentation suggesting it has been done..

This export energy demand is combined with domestic load and Demand Side Management (DSM) to obtain a total firm energy requirement for each on-peak and off-peak period. "The simulation must ensure that sufficient energy is available to meet the total firm energy requirement in each time period under all flow conditions including the lowest flow period on record." These requirements will have to be adjusted given that interruptible clauses have been added in the new export contracts negotiated by MH that would allow it to back out from supplying firm energy exports in periods of water stress and even in times of critical reductions in energy supply that could fall below domestic load.

Hydro generation is defined by the hydraulic network through a configuration of reservoirs, rivers and hydro-electric generating stations as depicted in Figure 3.12 above. Hydro generating stations are "..defined using power versus discharge relationships based on Forebay and Tailrace rating curves during open water and under winter ice conditions."[18] All of the technical details governing the network of generators are taken into account here from turbine efficiency ratings to design parameters. The planned outages and maintenance schedules are also taken into consideration over the entire planning horizon.

Figure 3.12 – SPLASH Schematic: Hydro + Thermal Generation + Tieline



Source: Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

[18] This discussion is based on Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

The range of water conditions is captured by the input of 94 years of unregulated present use flows at the various locations in the network. The inflow record since 1912 is adjusted to represent the consumptive uses and regulatory licenses by upstream entities as forecast for the future. The inputs of the stream flows are the monthly **average** flows from the Winnipeg River (28% of total system inflow), the Saskatchewan River (17%), and the Churchill River Diversion (27%). The remaining inflows are considered as local inflows, the largest being the local inflow available for outflow from Lake Winnipeg.

A large number of constraints are added to represent the initial conditions and the license and operating ranges for reservoirs, specific flow sequences, storage and outflow capacities of both controlled and uncontrolled reservoirs. The costs of water or water rental rates are used during costing simulations.

Monthly minimum and maximum output from each thermal station are defined and included in the simulations. The minimum levels are those required to test and maintain the units on an annual basis, whereas the maximum output reflects the expected output at full runs after deducting forced outages and scheduled maintenance.

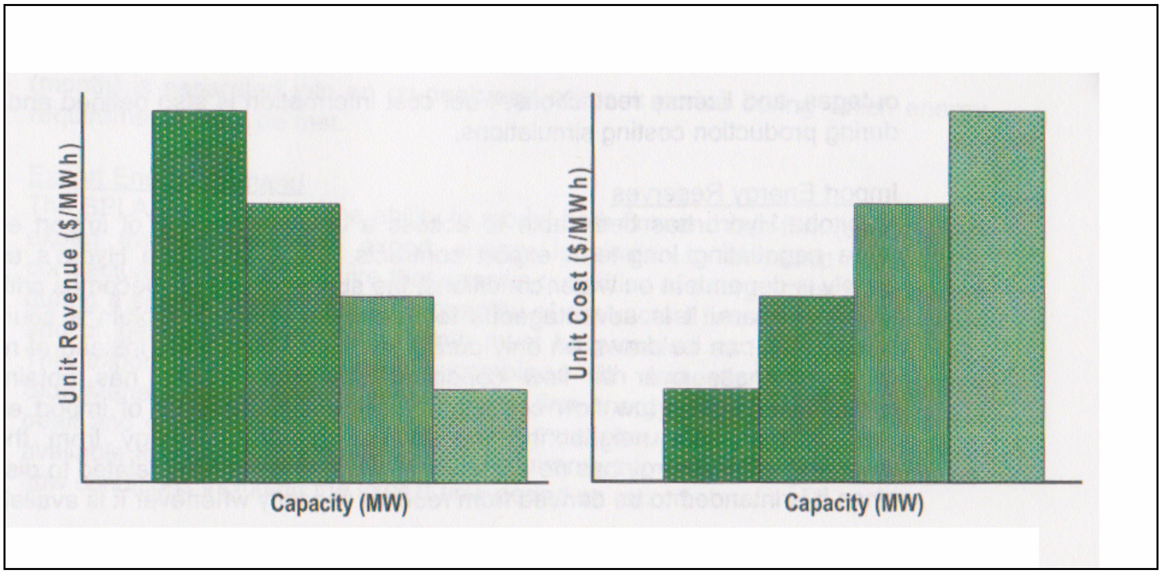
There are many instances where imports of energy are necessary. There are firm energy imports governed by diversity contracts and there are opportunity imports. The total amount of imports is constrained by both tie-line capacities and cost. The modeling of imports assumes that as much energy as possible can be imported during low cost off-peak periods before drawing on more expensive imports in on-peak periods. During a critical period the model assumes that 100% of needed imports are available.

Transmission losses are accounted for by referencing all energy production to a common point in the system. The reference point is typically selected to be at the generation point. Because of this convention exports are escalated by 10% to account for losses to the border. Imports at the border are given a credit of 5%.

The objective of maximization of net flow related revenues translates into maximizing opportunity net exports as the other components are constrained by equality limits. But opportunity exports have an upper bound defined by tie-line capacity or market limits.

Exports and imports are defined by piece-wise linear unit costs or revenue function for each month as depicted in Figure 3.13. The export demand schedule has a negative slope to portray the fact that additional units of exports offered can only be cleared at lower prices. The import demand schedule has a positive slope suggesting that additional units of imports can only be acquired at higher prices.

Figure 3.13 – Representation of Opportunity Export and Import Markets

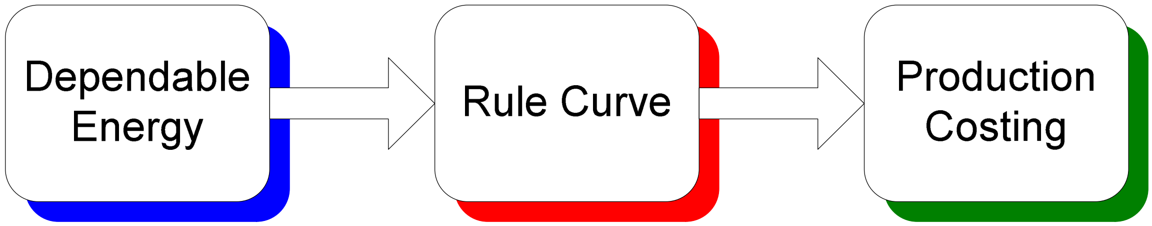


Source: Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

3.2.5.1 SPLASH Sequences

SPLASH simulations are run in three distinct steps. The first run is the configuration of the dependable energy run. The second is the rule curve run and this is followed by the production costing run. The three distinct steps are consecutive since the output of one run produces input for the run to follow. These steps are presented in Figure 3.14 below.

Figure 3.14 – Typical Full SPLASH Run



Source: Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

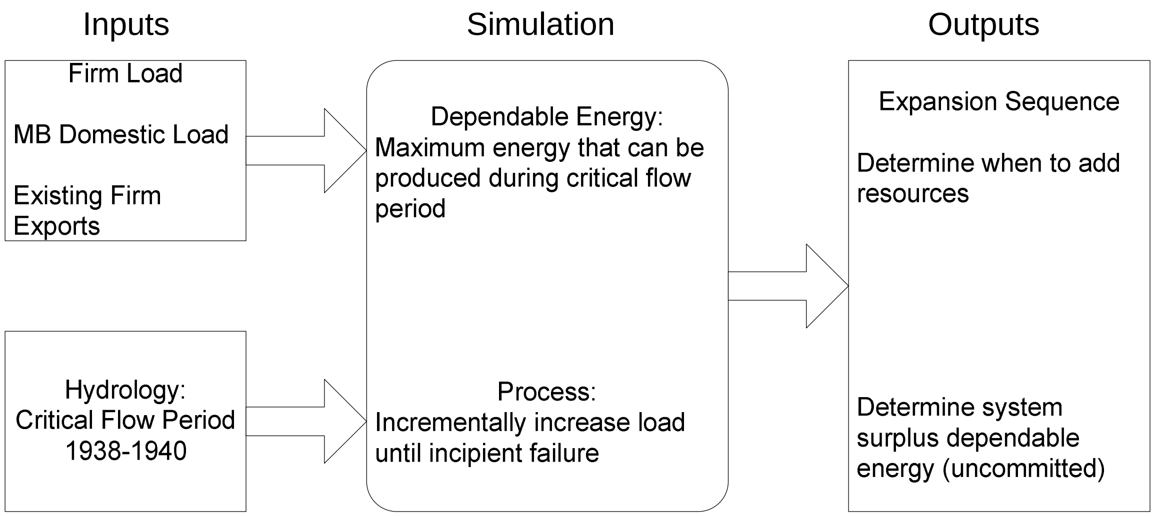
3.2.5.2 The Dependable Energy Simulation

The Dependable energy run determines the surplus energy, if any. It maximizes the total system energy demand given the critical sequence. The Rule Curve ensures that water levels at the start of the period (water year) are sufficient to validate system firmness through the critical sequence. The Production Costing phase simulates the system for all flow cases in each load year.

Dependable energy is also referred to as firm energy and is defined as the maximum energy that MH can generate during a critical hydrological period (lowest water flow on record during 1912-2005). This is the energy that is produced from the available water flow, from the water that is drawn from storage during this period in addition to available wind and thermal energy. It is also defined to include firm imports. If this dependable energy supply exceeds total firm demand, a surplus is identified for exports.

Reliability of supply is critical for MH being energy constrained. The dependable energy criterion is specified to maintain system reliability. This criterion is used to determine if expansions are needed over the planning horizon to ensure that a sufficient dependable energy is there over the entire planning horizon. All that is needed for a dependable energy simulation run is a critical year flow, and a specification of the firm load is clear in Figure 3.15.

Figure 3.15 – Dependable Energy Run

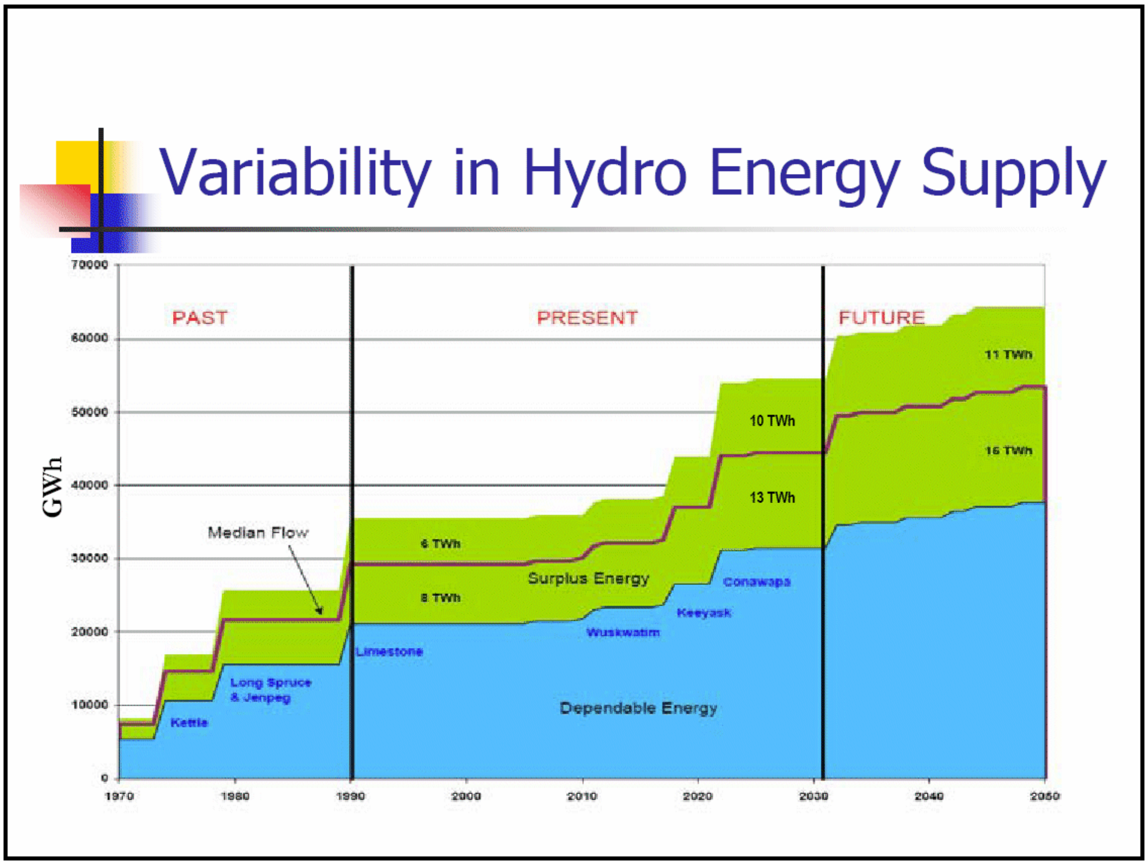


Source: Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

The dependable energy sequence can vary with the expansion sequence. Actually the logic of the system begins by defining the dependable energy projections. These are depicted by the blue area in Figure 3.16. Dependable energy increases as the system expands. Or, put differently, expansions are planned to ensure that dependable energy supplies are there to meet firm loads. Surpluses are projected given flows that exceed the critical flow. In Figure 3.16 median flows are also represented to show expected surpluses under these flows. There could be years where the flows exceed the median flows up to the maximum system generating capacities before spilling would become necessary. The planned addition of capacities is presented in Figure 3.16. Historical additions of capacity, such as that of Limestone, are clearly shown to correspond to a period where dependable energy was raised. It is also shown that Wuskwatim, Keeyask and Conawapa are justified on the basis of meeting firm future load. If the expected level of firm load is lower than predicted a large surplus may arise, which may not be sold at scheduled forecast prices.

To calculate the need for expansions a number of iterative simulations are run by successively increasing the export of energy or domestic load until the system with its existing capacity is just about to fail to meet the total energy demand. At this point the system produces the maximum quantity of hydro power while no system constraint has been violated. The reservoirs start at Full Supply Level (FSL) on April 1 of the critical period (1938) and remain at this level as long as is possible before it is absolutely necessary to withdraw water from storage to meet demand. Water is drawn first from Lake Winnipeg and then from Cedar Lake. The model is designed this way as a result of the fact that Lake Winnipeg's outlet becomes increasingly restricted through the winter months.

Figure 3.16 – Variability in Hydro Energy Supply



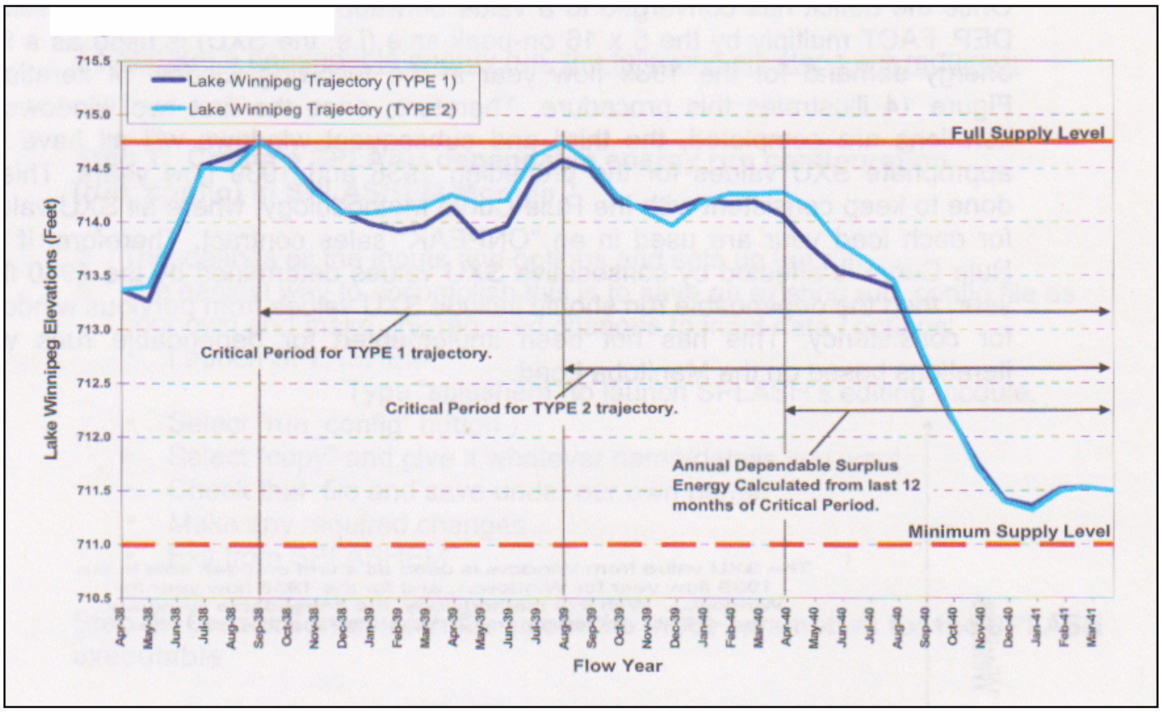
Source: Manitoba Hydro. Modeling Tools Utilized in Long Term Resource Planning. March 17, 2010.

The lake level trajectories during the critical period for Lake Winnipeg are presented in Figure 3.17. The last month in which it is possible to maintain full reservoirs is determined to be the beginning of the critical drought period. This level corresponds to that of the month of August during a critical first year period. The load growth in the years corresponding to flow years 1, 2 and 3 of the critical period is the factor used to determine the pattern of the trajectory in Figure 3.17.Lake Winnipeg is the largest storage reservoir in the system but it has limited outflow capability at low elevations and also under ice conditions. This is why it is not possible to use the entire storage range to determine the dependable energy capacity of the system.

3.2.5.3 The Rule Curve Simulation

The rule curve simulation is designed to ensure that the system works under operation rules and guidelines that will result in an adequate supply of hydro power over all water flow conditions. These guidelines include the end of month reservoir levels that will provide the required storage in the system reservoirs and will guarantee adequate generation to meet forecasted dependable energy requirements during critical flow years.

Figure 3.17 – Lake Winnipeg Critical Period Trajectory



Source: Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

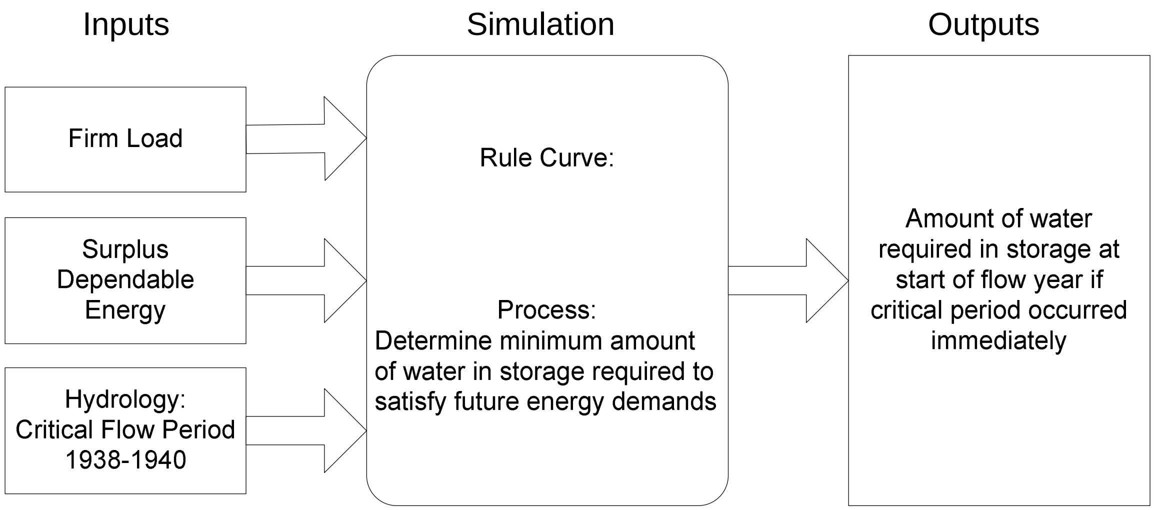
The input data for the rule curve run as shown in Figure 3.18 include the surplus dependable energy determined in the preceding Dependable Energy Run. The requirement for this simulation is the minimum amount of water in storage required to satisfy future energy demand and the output is the amount of water required in storage at start of water year in the critical period. The methodology here can be represented as a simulation of the critical flow period working backwards through the months of a load year. By working backwards through time, the required reservoir elevation at the beginning of a month is determined by calculating whether the controlled reservoirs should release or store water in order to meet firm energy demands for the month. This logic will require determining the needed storage amount by stepping back one month at a time through the sequence of low flows until the entire low flow period has been considered. Water levels are determined by an iterative process that achieves balance between supply and demand in the system at all times within a "perfect foresight" framework. This run is similar to the dependable energy run but starts off with different reservoir levels. The starting level is at the minimum supply level (MSL). The reservoirs are forced to remain at this level by using non-hydraulic resources first but will use hydro only in order to guarantee that the system will be firm for the duration of the critical period. The choice of resources below the rule curve is affected by setting high costs on hydro and low costs on non-hydraulic resources. The issue here is to conserve as much hydro as is possible until it is absolutely required.

One of the serious assumptions made by SPLASH in this case is related to the fact that the rule curve is designed to satisfy all firm requirements by the end of the critical period, when failure occurs, it is assumed that flows will increase. This is the result of the deterministic structure of SPLASH and the fact that it is limited to the historical chronologies.

One of the most interesting insights of SPLASH is embedded in the outcome of simulating all possible sequences of the low flow. The emerging envelope of the highest required reservoir elevations will be determined and referred to as the rule curve elevations. If the controlled reservoirs are kept at or above these levels in forward simulations the system is guaranteed to meet all firm energy demands even if low flows on record were to be repeated.

When the simulations are run to meet firm energy demands under critical conditions, market prices are not considered. Regardless of the cost of imports the system will import all it can to remain in a position to meet the firm load. If prices were to change no adjustment is made to the rule or dependable energy runs. But volume quantities in either supply or demand will change the rule curve reservoir levels. The rule curve elevation will decrease with new energy sources and will increase with higher new demands.

Figure 3.18 – The Rule Curve Run



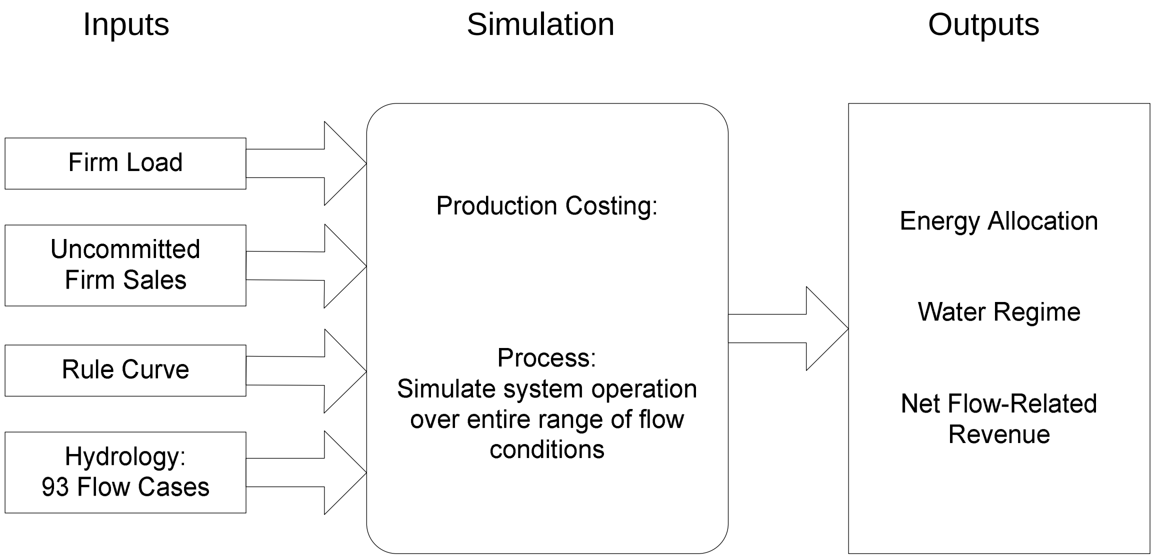
Source: Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

3.2.5.2 The Production Cost Run

This is the final step in the process and is used to determine the operation of the system over the full range of historical flow conditions and over all of the load years in the planning horizon.

Its inputs are the full range of inputs from the previous SPLASH runs but more specifically the uncommitted opportunity export sales and the rule curve data. The simulation is based on the deterministic linear programming exercise to maximize net revenues resulting from the operations of the integrated MH system using chronological flows derived from the 94 historical flows over a 40 year planning horizon (See Figure 3.19). The optimum will maximize net export revenues while maintaining system firmness. The surplus energy resulting from the earlier simulations is translated in 5x16 long term contracts assuming that this is the market segment that will yield the maximum returns to MH. These exports will be assumed to be delivered under all flow conditions and are configured as a uniform distribution over the entire period of commitment. Rule curve elevations will be adjusted to ensure that there is enough water in storage to deliver it. These elevation levels will be entered into the model as lower bounds that must be always exceeded.

Figure 3.19 – Production Cost Run



Source: Manitoba Hydro. An Introduction to the SPLASH Model. August 31, 2009.

The optimality of the system is now dependent on the value of exports and the costs of water, fuel and imports. The LP solution will determine the best allocation of hydro energy given the resources and constraints of the system. Water levels will be allocated over time. The rule curve will help determine the minimum level of water that should be transferred between one year and the next. Storage of water for a future period will be chosen as long as the opportunity revenue (lost export sales) is lower than the opportunity cost (generating energy from non-hydraulic sources). It is also critical to ensure that if next year is a high flow year spillage will become necessary as export prices could become very low. The risk of spillage has to be factored in these decisions. But the model introduces all variables as if they are certain (with the exception of water flows) and no probability distributions are assigned to them. The only consideration of the variability of the elevation levels to avoid the risk of spill is to operate at mid point of the elevations. Rule curves are adjusted to generate this mid point citing economic guidelines. It is claimed that this has been verified by analysis of different levels of end of year target but nothing is presented to back up this claim.

Different production run simulations can be performed using SPLASH. Two special runs are particularly interesting. The first application is for an economic evaluation of alternative generation expansion scenarios and the second is a calculation of the incremental value of energy supply relative to the case that results from adding one unit of capacity or relaxing an upper or lower bound constraint.

The flexibility of SPLASH is a noted advantage. The core structure allows for the use of different scenarios for probing the sensitivity of the optimal solution to different specification of values (coefficients of the objective function) or changes in the constraint constants.

3.2.6 Summary and Recommendations

SPLASH is a critical component of the model family at MH. It plays a crucial role in simulating future alternatives and is depended upon to plan the system requirements for expansion in the future. Given this critical role, any weakness or gap can have serious implications for decisions based upon it, or alternatively any improvement and upgrade can yield high returns.

We are happy with the simulation structure of the system and the insights this can add to its utility. The three phased process of determining dependable energy to rule curve determination of elevation levels to minimizing production costs are interesting and valuable applications.

There are a number of issues, however, that need to be addressed:

First, the system relies heavily on linear approximations to deal with a basically nonlinear underlying structure. There are grounds to question whether or not a nonlinear specification is now necessary to deal directly with this problem. Given the major advances in computer languages in the optimization field, this consideration is not far fetched.

Second, the model is fully deterministic and operates with perfect foresight. Uncertainty is recognized but not dealt with directly. There are a number of areas where the simple introduction of some elements of PRISM can be relied upon to broaden the probabilistic base of the model. This will also increase and improve on the integration of the models at MH and add value to both models. We see a number of areas where SPLASH can use

@RISK, particularly when it comes to export and import prices, water flows and reservoir elevation levels.

Third, SPLASH is and is not an extension of HERMES but the two need to be reconciled and situated on a common platform. At the moment they are not fully integrated. There is more room for linking explicitly the two systems to benefit from their commonalities. The real danger lies in the fact that they can and have produced different results. SPLASH results are more “optimistic” than those of HERMES. In some respects they impose different structures. For example, SPLAH fixes ending lake levels in its simulations to guarantee next period’s firm requirements, in HERMES these are part of the optimal solution.

Fourth, SPLASH is an in-house developed system which can benefit from an audit by an external committee of experts.

Fifth, we have seen some good documentation covering the components of the system but nothing formal. Again we would like to suggest careful and formal documentation of the system in User and Technical manuals.

Sixth, the staff supporting the system are qualified but again this group should be formalized and expanded to be an identifiable group that is continuously trained and integrated in the overall model community at MH.

Seventh, we have not seen a real demonstration of the model and did not have the opportunity to get to look at the gear work of the model, its forecasts and their accuracy. This was not offered despite our interest in seeing an actual demonstration. We were readily and openly allowed to examine and see the guts of HERMES and its forecasts but not SPLASH.

Eighth, we are not convinced that the integration of the past 94 flows is a sufficient procedure for taking account of water volumetric risks unless it can be shown that this possibility is remote. There may be situations where a more severe or a longer drought could take place, besides the recourse to an average or median flow is simply dismissing the embedded deviations of the system from central tendencies. The use of statistical processes to entertain multitudes of runs is necessary; it will enrich the base of alternatives and can settle whether a lower minimum is likely and with what likelihood.

Ninth, SPLASH working within the perfect foresight framework, always uses to the utmost available water leaving no room for uncertainty. It seems from our discussion with MH that this is not the operating principle at work.

Tenth, SPLASH only permits the availability imports at 100% of their need and as such it tends to underestimate the costs and volumes of these import needs.

Eleventh, the cost and implications of the assumption of perfect foresight must be determined. It is generally assumed that this assumption is necessary and almost costless. When major investment decisions are informed by SPLASH and when drought costs are estimated using its results, the implications of this assumption in a world rife with uncertainty must be fully identified and measured. When water levels in reservoirs are kept at their minimum levels because we know exactly when a drought will begin and end, the actual costs of a drought would be seriously understated.

3.2.7 Power RIsk System Model (PRISM)

Traditionally, quantitative analyses combine single “point” estimates of a model's variables to predict a single result. Estimates of model variables must be used because the values which actually will occur are not known with certainty. Some estimates may be too conservative and others may be too optimistic. The combined errors in each estimate often lead to a real-life result that is significantly different from the estimated result. Decisions based on “expected” results might be wrong and could have been avoided if one had a more complete picture of all possible outcomes. @RISK is a system designed to explicitly include the uncertainty present in the estimates in order to generate results that show all possible outcomes. This system is embedded into PRISM to evaluate a wide spectrum of forecasts using different probability distributions on forecast values, and these results are complemented with Monte Carlo simulations.

The way @RISK works is to generate “simulations” which combine all the uncertainties identified in a modeling situation. Point estimates of variables are no longer one number. Instead, the full range of possible values and some measures of likelihood of occurrence for each possible value can be used. @RISK uses all of this information, along with the model, to analyze a rich menu of possible outcomes. It is designed to reflect the information that would be generated if hundreds or thousands of “what-if” scenarios were to be run at once. In effect, this is done to allow the user to see the full range of possible outcomes in any given application of the model. It is as if the same situation were to be run over and over again, each time under a different set of conditions, with a different set of results occurring.

The @RISK software is an "add-in" to the Microsoft Excel PRISM model of flows, generation and financial results of electricity sale or purchases within the province or outside it. @RISK "links" the MH model in Excel to its Risk Analysis capabilities to generate profiles and ranges within which expected values are likely to occur. The @RISK system provides within PRISM a set of tools for setting up, executing and viewing the results of Risk Analyses.

The way @RISK works in PRISM is through allowing the user to define uncertain cell values in Excel as probability distributions using functions. @RISK adds a set of new functions to the Excel function set, each of which allows the user to specify a different distribution type for cell values. Distribution functions can be added to any number of cells and formulas throughout the worksheets of PRISM and can include arguments which are cell references and expressions — allowing a variety of specifications of uncertainty. The choice of the distributions to uncertain values is done through a graphical pop-up window where distributions can be previewed and added to formulas.

Many probability distributions are provided by @RISK that allow the specification of nearly any type of uncertainty in cell values in the spreadsheet. A cell containing the distribution function NORMAL(5,2), for example, would return samples during a simulation drawn from a normal distribution (mean = 5, standard deviation = 2).

All distributions may be truncated to allow only samples within a given range of values within the distribution to influence the results. Also, many distributions can also use alternate percentile parameters. This allows the user to specify values for specific percentile locations of an input distribution as opposed to the traditional arguments used by the distribution.

Available distribution types include:

Beta	BetaGeneral	Beta-Subjective	Binomial
Chi-Square	Cumulative	Discrete	Discrete Uniform
Error Function	Erlang	Exponential	Extreme Value
Gamma	General	Geometric	Histogram
Hypergeometric	Inverse Gaussian	IntUniform	Logistic
Log-Logistic	Lognormal	Lognormal2	Negative Binomial
Normal	Pareto	Pareto2	Pearson V
Pearson VI	PERT	Poisson	Rayleigh
Student's t	Triangular	Trigen	Uniform
Weibull			

Within @RISK both Monte Carlo and Latin Hypercube sampling techniques are supported, and distributions of possible results may be generated for any cell or range of cells in the spreadsheet model. Both simulation options and the selection of model outputs are possible but PRISM uses only Monte Carlo simulations.

The output distributions from the @RISK simulations are presented in different graphs including -- Histograms, cumulative curves and summary graphs. A large number of output distributions may be generated from a single simulation — allowing for the analysis of very larges and complex problems. Samples of these results are presented in figures 3.8 and 3.9 below.

PRISM is an in-house model that was developed at MH with the help of RiskAdvisory of Calgary. It marks a major step toward integrating probabilistic models in the planning and decision making structures at MH. The system incorporates load forecasts from the Electric Load Forecast Model, water flow and other hydraulic conditions from SPLASH, monthly distributions of electricity export prices, exchange rates, gas price forecasts, and scheduled maintenance from different sources including HERMES. PRISM analysis introduces volatility in these variables and chooses probability distributions to represent them.

Hydraulic variables are assumed to replicate the 94 flows actually experienced between 1912 and 2005. Each year in this series is assumed to have an equal chance (probability) of being the first year. But once a given year is assumed to occur the pattern (using the serial correlation among the years) that followed that year in the actual data will be forced on the system for five years. The translation of the assumed pattern of flows is translated into power and it is sold at forecast prices and terms. These prices and volumes are assumed to be probabilistic and assumptions are made about the distributions that define the range of these forecasts. When the outcomes (e.g., net revenues) are generated based on these probabilistic forecasts a 1000 (more simulations can be prescribed in @RISK) simulations are run using Monte Carlo assumptions to map all the possible net revenue outcomes that could emerge from the randomly generated values but particularly those that are bracketed between the lower tail of the distribution at 5% level of confidence and the upper tail at the 95% level. In other words, it defines the range of values of the variable that would occur 19 out of 20, or at the 95% level of confidence that the estimated value will be above the lowest number at the 5% tail of the distribution and below the highest number at the 95% level of the probability distribution.

The total hydro energy to be generated from the different flows is provided from SPLASH and the load distribution comes from HERMES with 50 discrete load values per season. Loads for years 2, 3, 4, and 5 are scaled from Year 1 based on annual load growth rate that comes from the Electric Load Forecast Model.

PRISM runs require the specification of the underlying probability distribution of the key determining inputs. For example in the runs to determine the implications of volumetric and financial risks on MH's net income, the pattern of future gas prices is assumed to follow a truncated normal distribution and electricity prices are assumed to follow a normal distribution. These specifications begin with the mean of the historic series and its standard deviation. The results are quite sensitive to the assumptions made about the shape of the distribution governing these key inputs. Assuming that these prices replicate a normal distribution is very restrictive and demanding. Normally distributed prices must exhibit independence, the value of the price of electricity in any given year is independent and unrelated to the value in any other year and these values must have a constant standard deviation.

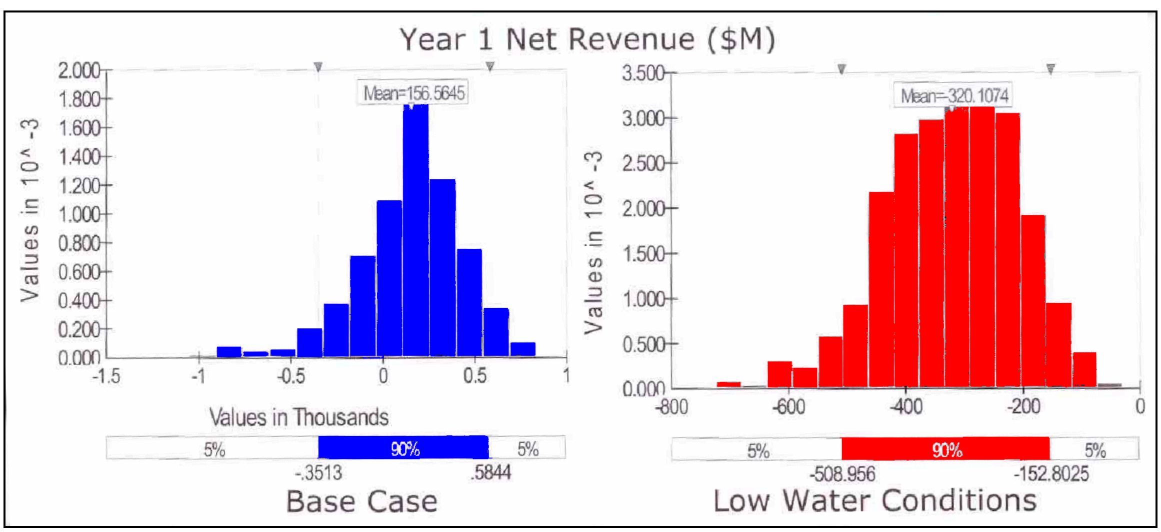
It is obvious that PRISM requires not only mastery of Window's Excel, but more importantly a thorough knowledge and competence in statistics. Familiarity with probability distributions, their shapes, patterns and implications and competence in selecting the appropriate assumptions about which of these underlying distributions are the relevant ones to profile the forecast of key inputs are critical skills that MH must acquire and develop.

PRISM is a seasonal model with summer months including April through October (7 months) and winter including the months from November through March (5 months). The model also includes all modes of generation—wind, thermal and hydro. Constraints on storage and tie-lines are specified. In the case of thermal generation Brandon 5, Brandon CT and Selkirk GS are included. Capacity is specified with annual maintenance and outages coming from HERMES. The Power Resource Plan defines the forward contracts, opportunity sales are based on surplus energy, on and off peak prices and inter-tie capacities.

A base case is used as a benchmark against which a number of alternative runs are compared. A sample of the results is presented below in figures 3.20 and 3.21.

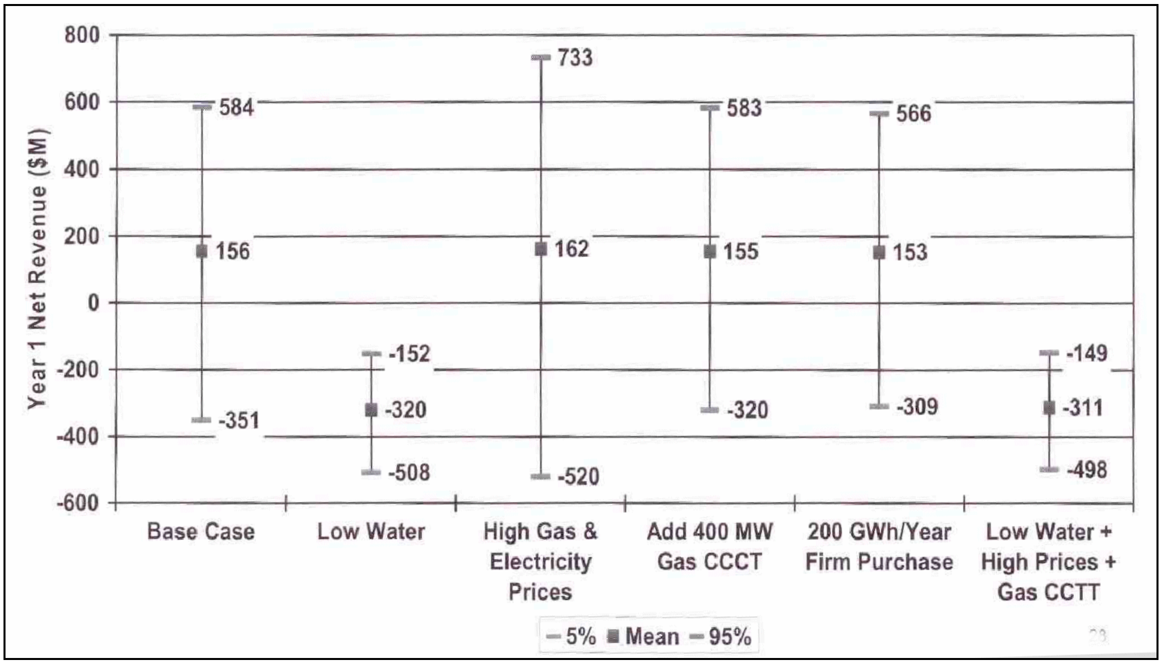
In Figure 3.20 a drought case example is presented where the mean (average) net revenue from exports during a severe drought year (similar to 1939) is estimated to result in a loss of $320 million. In the Base Case scenario the mean net revenues are estimated to be about $156 million. This suggests that an average loss of $476 million can be expected. What is more instructive is the information about extreme values. There is a probability of 5% that net revenue losses can be $502 million in the low water year or losses from base case can exceed $658 million (see Figure 3.21).

Figure 3.20– Risk Analysis: Low Water Conditions, 1939



Source: Lindsay Melvin. Risk Analysis Using PRISM. Power Point Presentation. 2010.

Figure 3.21 – Summary of Risk Analysis with Confidence Levels



Source: Lindsay Melvin. Risk Analysis Using PRISM. Power Point Presentation. 2010.

3.2.8 Summary and Recommendations

PRISM fills a gap at MH. The aftermath of the 2003 drought highlighted the need for probabilistic models that can map a wide set of possibilities and introduce uncertainty into decision making and planning at MH, avoiding arbitrary specifications of pessimistic and optimistic forecasts. Besides, it enriches the set of what-if runs to a large magnitude from randomly generated values, replacing the limited number of possibilities typically used.

As an in-house system it allows staff at MH to customize the model to the specific needs of the Organization. We met the staff responsible for PRISM and we are convinced that they have the required computer and engineering skills to deal with its extensions and use. We are also convinced that the staff can be beefed up to include statisticians who are familiar and competent to make informed selections and representations of the underlying probability distributions available in @RISK. We have already alluded to the sensitivity of the results in PRISM to the choice of the underlying probability distributions. The competent choice of these distributions is of crucial importance to the usefulness and relevance of the results to risk management.

Some of the concerns we have about PRISM are in fact associated with the adoption by PRISM of results and vectors from other systems. The concern is that problems or errors in one system may be propagated through the entire family of models.

While @RISK is a standard industry tool for dealing with uncertainty, it is a coarse system that requires customization and sophisticated knowledge of statistics and other related skills to become more flexible and produce genuine and desirable fruits. There are other systems in the field and there is no substitute for detailed and painstaking analyses of the individual risks and the use of standard Value at Risk calculations (VaR).

Nonetheless, we are happy that PRISM draws on other models at MH, when appropriate and the materials drawn upon is vetted. It is generally our belief that the various and separate models that MH uses should all be integrated and should be adjusted to operate on a common platform. Indeed, there is always a concern that errors could be propagated throughout the system, but having separate and disjointed models that do not conform to a consistent set of operations is also problematic. In this regard, it would be helpful if @RISK is used in the other models too. The relationships between these models are two-way streams of interdependence in which the outputs of one system become the inputs to another.

Some of the noted and preferred uses of @RISK have coupled it with other statistical models where it comes into play after other sources of uncertainty have been identified and exploited. For example, in the context of a specific application at MH, the model parameters of the Electric Load Forecast can be represented by their distributions using the standard errors of the coefficients. It is then that @RISK could be used to model the exogenous variables' distributions. The ultimate outcomes would represent the combined influence of parameter imprecision and uncertainty about forecast values of exogenous (independent or determining) variables.

A few minor but important issues for PRISM improvement would include, first, freeing it from the seasonal and annual structure and allowing it to deal with intra-year issues. Second, a richer and a better statistical anchor could be used to model water variability than the SPLASH characterization. More than a 5 years time horizon can be adopted to highlight results. Third, as it stands now it is only an energy model; it may be worth considering augmenting it into an energy capacity model. Fourth, price volatility modeling can be enhanced. The simple inert acceptance of external forecasts may be supported by a firmer probabilistic approach. Fifth, there is a need to contrast and compare @RISK calculations with other quantitative risk calculations. Sixth, there ought to be greater integration and harmonization of the PRISM model with other MH models. Seventh, documentation of the system explicitly in User and Technical manuals must be carried out on a regular basis. Eighth, the system should be subjected to external audit and verification. Ninth a statistician/econometrician should be added to the model support team.

3.2.9 Electric Load Forecast

The electric load forecast is a central and critical component of planning operations in the medium and long term at MH. It is used in most other models and therefore its accuracy is of critical importance to all these models and their forecasts.[19]

3.2.9.1 The Residential Sector

The forecasts are prepared by market segment. The residential sector share in total electricity sales in Manitoba was 32.8% in the base year 2008/09. This market segment includes electricity sales to individually metered residential customers for non-business operations. The residential sector is comprised of four forecast groups:

- Basic
- Seasonal
- Flat Rate Water Heating
- Diesel

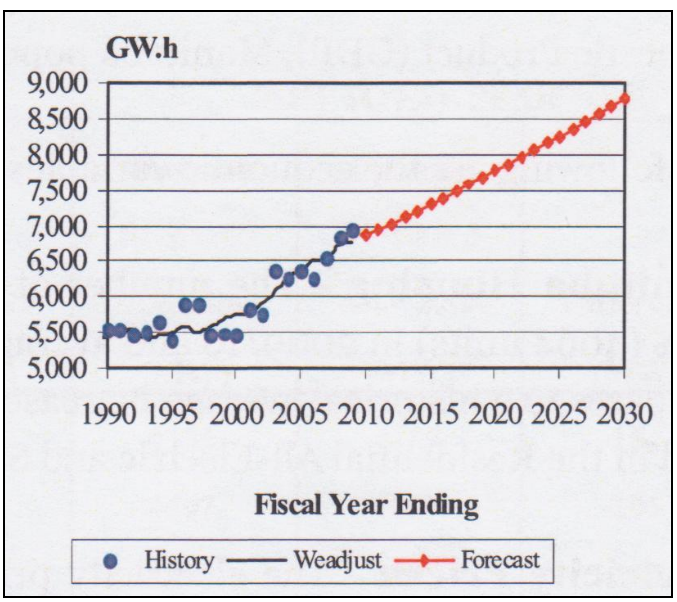
This segment of the market has typically shown very minor variations and had a very low growth rate in the past until 1998 when it changed course and started to exhibit a steadily rising rate (Figure 3.22).

[19] This section is based on Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30, May, 2009.

The methodology used in forecasting residential electricity sales is simple but solid. It starts with a forecast of residential customers from MH's 2009 Economic Outlook. It specifies a number of regression equations to deal differently with All-electric customers (capable of heating with electricity) and Standard customers (incapable). The customer forecasts become primary inputs in the End Use Model (EUM).

The residential energy forecast is the product of the EUM. The most recent of the Residential Surveys (conducted by MH where 19,000 forms are mailed and generally return a response rate of about 25%) provides current appliance saturation rates, appliance age distribution and appliance lifetimes. This information is combined with previous survey results to prepare future forecasts. Conditional Demand Analysis (CDA) is performed on the survey data to calculate the unit energy consumption data for each type of appliance. Energy management standards are used to reflect engineering and technological knowledge to estimate future unit energy consumption by appliance. Energy savings are used to adjust future energy consumption patterns.

Figure 3.22 – Residential Electricity Sales



Source: Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30.

The structure of the model requires forecasts provided by the Economic Analysis Department at MH on:

- Total Number of Residential Customers
- Price of Electricity
- Price of Natural Gas

These forecasts become inputs to the model as depicted below:

The number of customers at fiscal year-end is calculated as follows:

Number of All-electric customers at time t = Number of All-electric customers at time t-1 + change in the number of all electric customers at time t.

Number of Standard customers at time t = Total number of Residential customers at time t – Number of All-electric customers at time t.

Total number of customers comes from Economic Outlook and last year's number of customers is a historical number; what is left is the change in the number of All-electric customers and this is modeled as follows:

Change in the number of All-electric customers at time t is

= a + b*CTNRC+c*CTNRC*(PE/PNG)

Where:

a, b and c	are constant coefficients
CTNRC	is the Change in Total Number of Residential Customers
PE	is the Price of Electricity
PNG	is the Price of Natural Gas

The major assumption here is the sensitivity of the number of All-electric to changes in the price of electricity and that of natural gas. Any rise in the price of electricity over the price of natural gas is presumed to result in a lower number of customers in the All-electric category.

The regression results are interesting and fail to reject the hypotheses.

$$=266.03+1.0787*CTNRC - 0.4057*CTNRC*(PE/PNG)$$

The R^2 = 86.7%

The t-statistics

The constant (a)	0.72
CTNRC (b)	7.99
CTNRC (PE/PNG)	-3.70.

The regression results are acceptable: the R^2 (it would have made more sense to use the adjusted R^2) is relatively high and the t-scores are significant (this is not explicitly calculated in the Report although it would make sense to present the significance level of these t-statistics). We would have liked to see the weather adjustment and what weather related forecasts were used in the projections made. The Report shows reports on the weather adjustment in the past but not in the future forecasts.

Once the total number of customers is forecast this is multiplied by the unit energy consumptions derived from surveys and engineering information to arrive at the residential forecasts. The major component of residential demand is the Basic component; the others are small and are not discussed in any details.

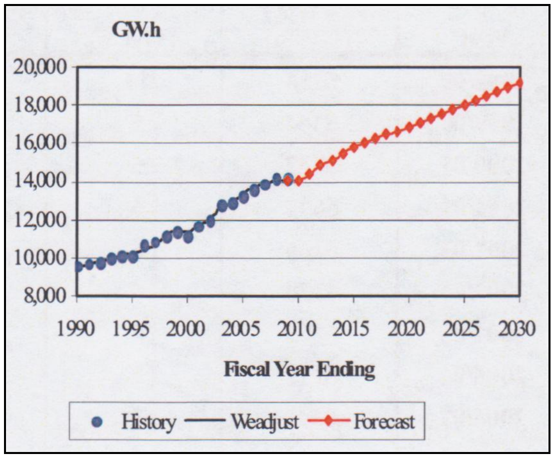
3.2.9.2 General Service

The General Service market segment is the largest with 66% of total electricity sales in Manitoba in 2008/09. This segment includes all electricity sales to commercial and industrial businesses in Manitoba and includes six forecast groups:

- Mass Market
- Top Consumers
- Diesel
- Seasonal
- Water Heating
- Surplus Energy Program

The General Service load exhibits a steady historical growth rate from 1990 to 2008 (See Figure 3.23).

Figure 3.23 – General Service Electricity Sales



Source: Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30.

3.2.9.3 General Service – Mass Market

The Mass Market and Top Consumers account for the entire load in the General Service segment with Diesel, Seasonal, Water Heating and the Surplus Energy Program together making up less than 0.3% of the total of this segment. The future value of general service electricity sales mass market is presented in Figure 3.24.

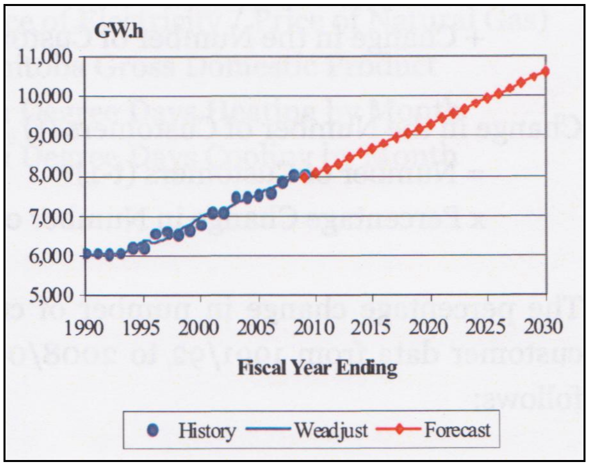
A similar methodology is used here to project future sales in this segment of the market. First, the total number of customers is determined and this is multiplied by estimated monthly unit energy consumption.

The number of customers at fiscal year-end is forecast using the following relationship:

Number of customers at time t = Number of customers at time t-1 + Change in the Number of customers between t and t-1.

Change in the number of customers at time t = Number of customers at t-1 * Percentage Change in Number of customers between t-1 and t.

Figure 3.24 – General Service – Mass Market



Source: Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30.

The percentage change in the number of customers is modeled using year-end historical customer data from 1991/92 to 2008/09:

Percentage change in the number of customers at time t = 0.0023+ 0.13171 * CGDP

CGDP is the annual percentage change in Manitoba Gross Domestic Product. It is not indicated that this is the percentage change in real GDP but it is safe to assume that it probably is.

R^2	29.6%
Constant	1.79
CGDP	2.59

The R^2 is relatively low but this is the result of using changes and eliminating trends. The t-statistics are border line values but it makes sense to use the percentage change in GDP as a proxy for increased economic activity that is believed to derive the use of electricity as an input (electricity's demand is a derived demand).

The average monthly electricity use is modeled as a variable using the regression equation below:

Change in Average Monthly Use per Customer =

68.7-60.126*CPENG+1,555.6*CGDP+2.793CDDH+7.635CDDC

Where:

CPENG Annual % Change in the relative Price of Electricity to the Price of Natural Gas

CDDH Year to year change in Degree Days Heating per Month

CDDC Year to year change in Degree Days Cooling by Month

The regression results are below:

R^2	57.1%
t-statistics:	
Constant	1.84
CPENG	-0.29
CGDP	0.98
CDDH	15.69
CDDC	6.29

The R^2 is actually relatively high but this may be an overstatement as we do not know the adjusted $R,^2$ but the use of percentage changes typically reduces the magnitude of the coefficient of multiple determination, and values above 50% are considered high. The t-statistics are quite low for the GDP and price variables. The use of annual changes for monthly data is problematic and the suspiciously low t-scores for these key variables may be the result of this mixing of annual and monthly data. The weather variables are highly significant as expected.

3.2.9.4 General Service Top Consumers

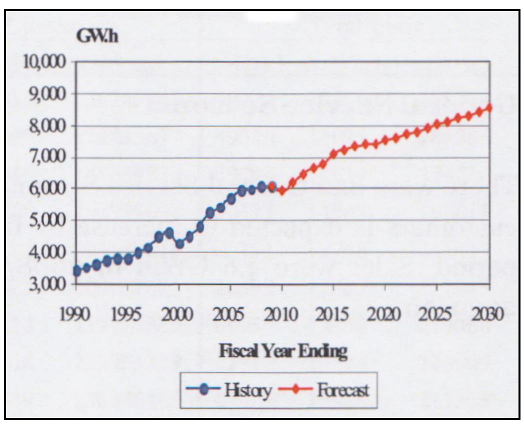
This group alone accounts for 43% of all electricity consumed in the General Service sector in 2008/09. It includes 16 major customers in the Primary Metals, Chemicals, Petrol/Oil/Natural Gas, Pulp/Paper, Food/Beverage, Mining, and Colleges/Universities. Most of these customers belong to an energy intensive sector and have been attracted to Manitoba because of the abundance of energy at relatively cheap prices. Load growth in this category is consistently positive with the exception for the downturn in 1999/2000 (See Figure 3.25).

The past is not a good indicator of the future and major changes can be expected. This is why the Report suggests that MH has created a classification called Potential Large Industrial Loads to take into account the possibility of attracting large consumers that typically agglomerate near energy sources.

Each of the 16 customers in this group is treated individually and its consumption is forecast separately. Information on individual company operating plans is collected from industry news, MH's economic experts and MH's Key & Major Account Representatives. This information is used to make the load forecasts for this group.

The remaining components of this sector are projected to preserve the historical growth trends of the last decade or so.

Figure 3.25 – General Service – Top Consumers

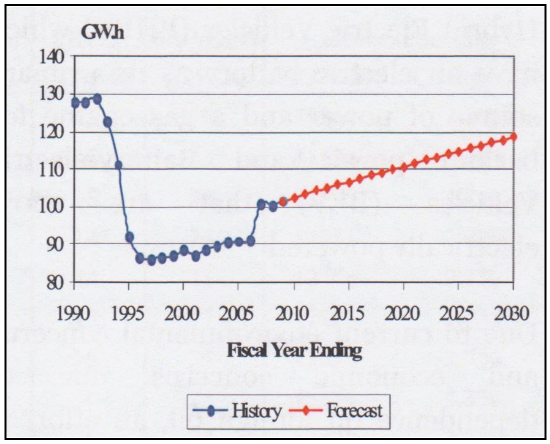


Source: Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30.

3.2.9.5 Area & Roadway Lighting

This segment is quite small with about 0.5% of all sales in Manitoba in 2008/09. The sector includes electricity sales for the Sentinel Lighting and Street Lighting rate classes. The Sentinel Lighting is an outdoor lighting service where units are available as rentals to an existing metered service or an un-metered flat rate basis. Street light includes all roadway lighting in Manitoba (Figure 3.26).

Figure 3.26 – Area & Roadway Lighting



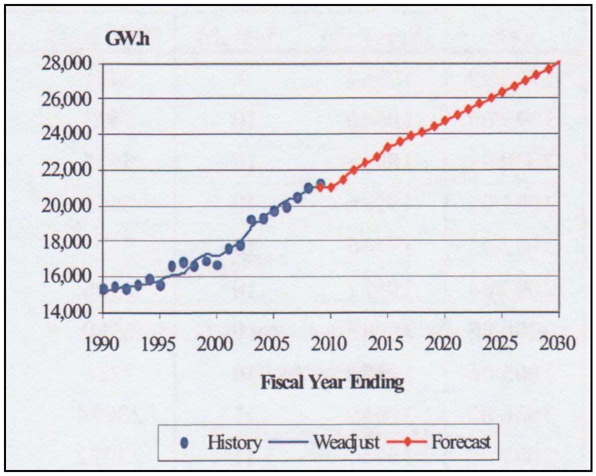
Source: Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30.

The energy usage in this segment has been declining due to conservation efforts and the conversion to energy-efficient sodium vapour street lighting. The forecast value for the entire segment is for an increase by 1.15 GWh per year only.

3.2.9.6 Total Sales and Distribution Losses

The sum of all the components adds to a forecast of all sales of electricity in Manitoba (see Figure 3.27). The total sales are forecast to increase from a weather adjusted base of 20,983 GWh in 2008/09 to 28,002 GWh by 2029/30.

Figure 3.27 – Total Electricity Sales in Manitoba



Source: Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30.

Distribution losses are resistance losses and other factors (fraud, un-metered inaccuracies, etc). These are forecast to be around 4.94% of the General Consumers less Diesel sales. There are also additions made to the overall forecast to take into account energy used by MH and its contractors in the construction of major capital works such as generating stations, converter stations and major transmission lines. Manitoba load at Common Bus, Firm Energy and Net Total Peak are projected separately by making appropriate reductions and additions. These are post forecast adjustments and are therefore contingent on the original forecasts.

3.2.9.7 Load Forecast Variability

The variability of the forecast from the base values is calculated on the basis of the standard deviations in the historical changes in the independent variables. Two specific variations are considered. First, the changes in the weather variations below or above normal temperatures and, second, the changes in economic conditions are considered in calculating the variability of the forecast. These two measures were combined with the forecasts of Net Firm Energy and Net Total Peak to calculate the load variability.

A probabilistic framework is worked out to identify the load given the probability of the actual load will be less than the forecast load. This calculation is done using the following structure:

Load=base forecast + Z(probability)*standard deviation

The translation of the number of standard deviations corresponding to a probability grid for a normal distribution is given in Table 3.6 below:

Table 3.6 – Standard Deviation and Probability Levels for a Normal Distribution

Prob	0.1%	2.5%	10%	20%	50%	80%	90%	97.5%	99.9%
Z(Prob)	-3.09	-1.96	-1.28	-0.84	0.00	0.84	1.28	1.96	3.09

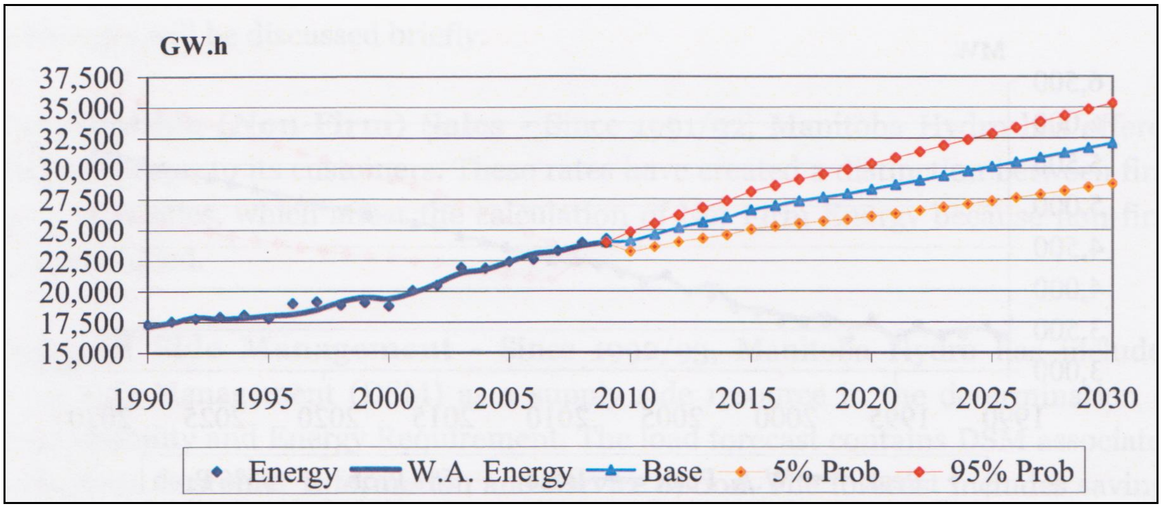
Source: Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30.

This is an improvement on using arbitrary pessimistic or optimistic forecasting to bracket the forecast values. The methodology used is based on an objective criterion and a probabilistic one. However, this is a truncated and limited perspective given the availability of @RISK at MH and where the exogenous variables can be assigned any of a large set of probability distributions and the final outcome subjected to a Monte Carlo simulation.

3.2.9.8 Forecast Accuracy

It is a welcome and refreshing addition to models at MH that the Report devotes a section to forecast accuracy. Indeed, many changes and definitions and products have complicated the task but still the Report presents five year earlier and 10 year earlier forecasts and the percentage deviation of the forecasts from actual values. These forecasting errors are presented in Table 3.7 and Figures 3.28.

Figure 3.28 – Load Forecast Variability – Net Firm Energy



Source: Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30.

Table 3.7 – Load Forecast Variability at Different Probability Levels
Net Firm Energy

Fiscal Year	Net Firm Energy Base Fcst	Wthr and Misc Std Dev	Econ and Model Std Dev	Total Std Dev	2.5% Prob Point	5.0% Prob Point	10.0% Prob Point	90.0% Prob Point	95.0% Prob Point	97.5% Prob Point
2009/10	24080	403	263	481	23138	23289	23464	24697	24872	25023
2010/11	24600	411	405	577	23469	23651	23860	25340	25550	25732
2011/12	25159	421	522	671	23844	24056	24299	26018	26262	26473
2012/13	25599	428	627	759	24111	24350	24626	26572	26847	27087
2013/14	26012	435	723	844	24358	24624	24930	27094	27401	27667
2014/15	26618	445	814	928	24799	25092	25429	27808	28145	28437
2015/16	26973	451	901	1008	24998	25316	25682	28264	28630	28948
2016/17	27331	457	984	1085	25204	25546	25940	28722	29116	29458
2017/18	27644	462	1065	1161	25368	25734	26156	29132	29554	29920
2018/19	27923	467	1143	1235	25502	25892	26340	29506	29955	30344
2019/20	28288	473	1220	1308	25723	26135	26611	29964	30440	30852
2020/21	28654	479	1295	1381	25948	26383	26884	30423	30925	31360
2021/22	29021	485	1368	1452	26175	26633	27160	30881	31409	31866
2022/23	29391	491	1440	1522	26408	26887	27440	31342	31894	32374
2023/24	29762	498	1512	1591	26643	27145	27723	31802	32380	32882
2024/25	30136	504	1582	1660	26882	27405	28009	32263	32866	33389
2025/26	30516	510	1651	1728	27130	27674	28302	32731	33358	33903
2026/27	30899	517	1719	1795	27380	27946	28598	33199	33851	34417
2027/28	31285	523	1787	1862	27636	28223	28899	33671	34348	34934
2028/29	31674	530	1854	1928	27895	28503	29203	34144	34845	35452
2029/30	32066	536	1920	1993	28158	28787	29511	34620	35345	35973

Source: Manitoba Hydro. Electric Load Forecast 2009/10 to 2029/30.

The errors become larger as the time of the forecast extends into the future. This is a good argument for continuously visiting the forecasts and limiting reliance on them to five years.

3.2.10 Summary and Recommendations

The load forecast plays a central role in the running of all MH models and contributes to both operational efficiency and future expansion plans. Errors in these forecasts can be costly and could result in faulty decisions and plans.

The combination of survey results, technical and engineering information and regression techniques results in a rich base for the forecasts. The forecasting accuracy is deemed reasonable for the 5 year term and the move to integrate probabilistic forecasts is encouraging. The people responsible for maintaining and running the model are competent, enthusiastic about their work and dedicated. We were impressed with their knowledge and expertise. There remain a number of issues that we would like to raise as we suggest a few steps to be taken to expand on the strengths and utility of the model.

First, the structure of some of the regression equations can be strengthened. The use of one dependent variable may not suffice for future forecasts. Since the main objective is to forecast future values some experimentation with other variables and specifications should be encouraged.

Second, the use of standard deviations for the explanatory variables is a good step but more sophisticated integration of probabilistic structures is advisable. Some of the advanced uses of econometric models for risk analysis combine the use of the standard errors of the coefficients with different probability distributions for the independent variables and then a final Monte Carlo simulation to define the probabilistic range of the key variables of the system. MH could easily develop a similar framework to the one suggested above given that all of the pieces are available in-house for such an analysis.

Third, it will make sense that those responsible for the load forecast become official members of the model community group at MH and that greater integration of their model with the rest of the models at MH be made seamless and interactive.

Fourth, the inclusion of weather related variables is explicit in only one equation. It would make sense to have this as a key variable in most of the equations given its high significance in the equation in which it was included. But the question remains as to what procedure will be used to forecast this variable in the future?

3.2.11 Economic Outlook

In March of each year the Economic Analysis Department (EAD) of the Corporate Strategic Review Division of MH prepares an Economic Outlook (EO) that becomes a reference for other departments and models. The forecasts included in the EO cover a wide range of variables from Gross Provincial Product to short and long term interest rates, the short term and long term exchange rate of the Canadian dollar, population, employment, unemployment rate, residential customers and commodity prices.

Only a limited number of forecasts are made in-house. Most of the forecasts are derived from consulting companies (HIS Global Insight, Infometrica, and Spatial Economics), Canadian banks (BMO, CIBC, RBC, TD Bank, and the National Bank of Canada), and statistical bureaus (Manitoba Bureau of Statistics (MBS) and Statistics Canada) as well as the Conference Board of Canada.

In April 2010 EAD circulated a document where it outlined its forecasting methodology and the definition and sources of its data. This is a welcome addition. EAD also discontinued the use of a couple of far-fetched scenarios that it prepared in the past. This is also a step in the right direction.

There are a number of issues that arise in connection with the use of multiple forecasts and forecasters. Most of these forecasts are made in the context of consistent models (e.g., Infometrica uses its CANDIDE model), and the Conference Board has its own model, as do many of the banks' economic departments. The forecasts they generate are outcomes of the use of their models' structures and assumptions. This fact makes it difficult and inappropriate to lift a single variable forecast from one model and to use it independent of the other forecasts that were simultaneously generated. This, of course, creates a dilemma. If one uses the Infometrica's forecasts of interest rates or exchange rates, then one needs to use all other forecasts from Infometrica. If other forecast variables are drawn from other models this will amount to mixing apples and oranges.

In our first review of the EO before the recent review we were struck by forecasts that showed high interest rates with low exchange rate values, or high GDP growth rates with high unemployment rates. Fortunately, these scenarios were correctly eliminated but there is still the concern that the combination of different forecasts on different variables will involve mixing inappropriately variables outside the overall consistency of the models within which they were developed. The issue is not independence of forecasts and forecasters but their accuracy and consistency. EAD states, "…Forecasts from Consensus Economics, Province of B.C., Federal Finance, and Desjardins, will no longer be used as they are considered statistically independent."[20]

It is possible to avoid this problem all together by developing an in-house macro econometric model. This may be asking too much given the resources it would require. It could be sourced out to a University in Manitoba or to a single consulting firm where tests of the accuracy of their forecasts have been carried out. The eclectic approach, if it is the only alternative, should be based not on a large number of forecasters but only on those that meet the accuracy criterion that MH must establish. Averaging their forecasts assumes that they are equally accurate, but they are not.

Another way to deal with the problem of using an inappropriately specified forecast is for the EO to undertake a full @RISK specification of the underlying probability distributions that best capture the patterns of these forecasts. If this is not within the capacity and expertise available at EAD, then the experts using PRISM should work closely with EAD to re-generate the forecasts as a full probability distribution instead of a single deterministic vector (series).

The centrality and criticality of the EO should be enough to persuade MH to devote more resources and expertise to this strategic group. We have met repeatedly with the staff of EAD and we are convinced they have the right skills and commitments, but they at this time constitute a minor group playing a major role. This imbalance between functions and status is glaring and should be rectified. This Department could do more than just eclectic forecasts. We were told that they conduct impact analysis and cost/benefit studies in conjunction with environmental impact qualifications. These functions can be extended to a greater familiarity and expertise in modeling and forecasting.

---

[20] Manitoba Hydro. Forecasting Methodology. April 22, 2010.

3.2.12 Summary and Recommendations

A number of recommendations are in order here beginning with adding both human and financial resources to the EAD and ending with expanding the mandate of the Department and changing some of its operating procedure. The centrality of the uses of the EO necessitates elevating this function from a purely eclectic assembly of others' forecasts to a more nuanced and effective contribution.

First, the Department can benefit from the addition of economists and econometricians with quantitative skills and experience in forecasting.

Second, there is a serious need to revisit the forecasting role of the Department. At this time the eclectic selection of forecasts and forecasters is simplistic and driven by availability and untested presumptions. Far more productive procedures would include in-house development of a forecasting model, cooperation with a Manitoba university department of economics, or the development of selection criteria based on a track record of accuracy.

Third, the forecasts adopted should abstract from the arbitrary specification of low (pessimistic) and high (optimistic) forecasts and move to generate probabilistic forecasts from standard risk tools.

Fourth, it is required that the EO group become part of the modeling family at MH and that their procedures be scrutinized and jointly developed with those that use their forecasts in their respective models.

Fifth, the terms of reference of this group should be expanded to involve serious contributions and evaluations of all economic matters at MH.

3.3 Conclusions and Recommendations

In Manitoba hydrology, power generation, and financial systems are subsystems of a broader politico-technical system of which Manitoba Hydro is a key component. More precisely, three basic systems comprised of hydrology, power and finance interact with one another to define a complex underlying reality.

The number of variables within each of the three systems above is very large and is exceeded only by the number of equations that balance the complex interactions among these variables. The variables and equations are basically quantitative and technical in nature. No expert can be expected to know fully and deeply how these relationships work and unfold. It is necessary to construct models to represent, understand, explain and predict the outcome of changes in these complex systems. MH has developed a family of such models, each with its own unique objectives and structure, to deal with operational and planning purposes.

Generally models have two characteristics. First, they are a simplification of and an abstraction from observed data. It is impossible to include and represent the entire complex reality. Abstraction and generalization are necessary. Second, they are a means of selection of data based on the purpose for which the model is built. Choice of what is pertinent is crucial; otherwise the task of explaining and predicting a phenomenon will become impossible. Even with the largest and fastest computer there are limitations on what can be included in the focus set.

The details of model construction vary with type of model and its application, but a generic process can be identified. Any modelling process has three steps: First, one constructs a logically consistent model (heuristically making sure that the number of relationships is equal to the number of variables). Second, one checks the model for accuracy and validates its tracking of the observed data. Third, one uses the model for explaining and predicting the underlying reality.

The validation of the model accuracy is important because a model is useful only to the extent that it accurately mirrors the relationships that it purports to describe. Creating and diagnosing a model is frequently an iterative process in which the model is modified (and hopefully improved) with every iteration. Once a satisfactory model is found, it should be double-checked by applying it to a different data set and using it to predict within the sample (observed data) the values in the sample not used to estimate it (Back testing or intra-sample validation).

There are other criteria to use in evaluating a model beside its logical consistency and accuracy. These include:

- Its overall structure (linear or non-linear).
- Type (deterministic or stochastic).
- Complexity, completeness, and ease of use and interpretation.
- Its designers' skills.
- The competence of the backstopping technical and professional staff.
- Its flexibility and capacity to integrate with new subsystems.
- The ease with which it communicates with other models in the Organization.
- Its contribution to improving the overall performance and efficiency of the Organization.
- The documentation of its procedures for other users and for institutional memory.
- The training and support from within the Organization and outside it available on demand.
- The sophistication of the "solvers", their vintage and those that support them.
- The vintage and computational capacity and ratings of the hardware used to process the model.
- The nature and extent of "ownership" exercised by the Organization over the system.

These criteria were used to evaluate the MH model family. Below is a summary of our findings and recommendations, organized by model.

3.3.1 MOST

First, we would like to see the MOST model cast in a stochastic framework given the many uncertainties that are embedded in the system. It is possible to re-solve the Linear Programming Problem (LP) several times under different specifications of the parameters to take into account possible variations in these variables, but this is not necessary if other systems at MH (for example, PRISM) can be used to generate distributions of the exogenous forecasts.

Second, it is clear that a few price forecasts are embedded in the MOST system; it would make more sense to represent these as probability densities using @RISK in PRISM or any other probability generating system.

Third, we would like to see more than one or two skilled persons responsible for the model. It would make more sense to train a designated group of the staff to work on any given model: this will guarantee that a pool of skilled staff is always available to support the model.

Fourth, we recommend that the system be continuously subjected to validation and verification to improve its forecasting accuracy. Stressing the system (stress tests of the model) should be a regular and routine operation and reports about these tests should be funnelled to the Risk Management Committee.

Fifth, it will be useful to formalise the integration of Vista with other models and bring together those supporting and maintaining the system as part of a formal Modelling Committee at MH that meets regularly with a sufficient budget and that is entrusted with the task of internal oversight, review, upgrading, documenting and internalizing the ownership of the models.

Sixth, internal audits are necessary but not sufficient. This function should also be augmented by arms length verification, review and evaluation by an external Model Audit Committee comprised of experts from outside MH with no commercial connections to any of the models. These experts will be involved on a needs basis and granted consulting assignments.

Seventh, we would like to see that every effort is made to establish full ownership of the model systems within MH and that MOST is not seen or perceived as being a “black box” that was developed generically outside the full control and mandate of the Organization.

Eighth, we would like to formulate the objective function wherever possible to minimize cost of generation and delivery rather than maximizing net revenues.

3.3.2 HERMES

First, by any standard HERMES is an impressive system; it developed over time and grew in complexity and utility.

Second, its developers are on staff and the source code is home stored.

Third, we are satisfied that the technical staff that support and run the model are competent and committed.

Fourth, we have seen a couple of demonstrations of the system and have seen its objective function and constraints as well as solution runs and outputs.

Fifth, it is a large system with over 8000 constraints and bounds and a larger number of variables. It is capable of generating a rich set of bases (linearly independent vectors) that define feasible solutions for the objective function to choose from among them the optimal one.

Sixth, we have seen forced solutions which reflected assigning huge costs to particular objective function coefficients. This is a standard practice in large LP systems but is still worrisome. There is always the fear that users select optimum solutions close to actual operations or desired solutions.

Seventh, being an internally developed and maintained system it has advantages and disadvantages. Among the advantages is the ease and flexibility of changing and upgrading the system. This seems to be a continuous process at MH. But being a home grown product it may not be documented sufficiently or regularly. We have not seen a User Manual or a Technical Manual which are typical products of commercially developed systems. Home grown products are also protected and defended with zeal by their developers. It makes sense to subject the system to an external audit by an External Committee of Experts in a similar way to what was suggested above. The need for this validation and audit is doubly important when it is home grown.

Eighth, the deterministic nature of the model calls for more thorough adjustment and upgrades. It makes sense to move to a stochastic system or at least add a few stochastic modules. The system is flexible enough to accept new modules. This feature can be exploited here to add the stochastic framework.

Ninth, the same goes for some non-linear modules in the system. Since the underlying structure is nonlinear and new solvers (GAMS or AIMMS) can easily solve large nonlinear and stochastic systems, it is worth considering these upgrades. Successive optimization may reduce this need, but in our opinion this will be a poor substitute.

Tenth, the availability of PRISM and its subordinate @RISK at MH should facilitate using stochastic forecasts instead of the arbitrary optimistic and pessimistic variants.

Eleventh, HERMES is one of many systems within the general class of LP system. It is for a short to a medium term horizon. It sits between MOST and SPLASH. We would like to urge the model builders and users to fine-tune their models' integration and collectively work on synchronizing their work and improving their communication with one another.

Twelfth, we note with satisfaction that HERMES incorporates weather variables. This is a crucial advantage given the sensitivity of load to this variable and the extent to which it is expected to vary in the future.

Thirteenth, the forecasting accuracy of HERMES is not very high, particularly on the first round, but it improves on the second round. A thorough review of where the forecasting accuracy of the model can be improved on the first round is necessary. Continuous forecasting should be adopted. We noticed that in the regression equations only the first lag is adopted. Surely incorporating a more sophisticated lag structure could help in this regard.

3.3.3 SPLASH

SPLASH is a critical component of the model family at MH. It plays a crucial role in simulating future alternatives and is dependent upon to plan the system requirements for expansion in the future. Given this critical role any weakness or gap can have serious implications for decisions based upon it, or alternatively any improvement and upgrades can yield high returns.

A number of issues are noted below that need to be addressed:

First, the system relies heavily on linear approximations to deal with a basically nonlinear underlying structure. There are grounds to ask whether a nonlinear specification might now be necessary to deal directly with this problem. Given the major advances in computer languages in the optimization field, this consideration is not far fetched.

Second, the model is fully deterministic. Uncertainty is recognized but not dealt with directly. There are a number of areas where the simple introduction of some elements of PRISM can be relied upon to broaden the probabilistic base of the model. This will also increase and improve on the integration of the models at MH and add value to both models. We see a number of areas where SPLASH can use PRISM or simply @RISK particularly to represent a probabilistic structure for export and import prices, water flows and reservoir elevation levels.

Third, SPLASH is an extension of HERMES and the two could sit on the same platform. At the moment they are not fully integrated. There is more room for linking more explicitly the two systems to benefit from their communality.

Fourth, SPLASH is an in-house developed system which can benefit from both internal and external audits.

Fifth, we have seen some good documentation about the components of the system but have seen nothing formal. Again, we would like to suggest careful and formal documentation of the system in User and Technical manuals.

Sixth, although the staff supporting the system are qualified this group should be formalized and expanded to be an identifiable group that is continuously trained and integrated in the overall model community at MH.

Seventh, we have not seen a real demonstration of the model and did not have the opportunity to get to look at the gear work of the model, its forecasts and their accuracy. This was not offered despite our interest in seeing an actual demonstration. We were readily and openly allowed to examine and see the guts of HERMES and its forecasts but not SPLASH. This is another reason for formal external audits.

Eighth, we are not convinced that the integration of the past 94 flows is a sufficient procedure for taking account of water volumetric risks. There may be situations where a more severe or a longer drought could take place, besides the recourse to an average or median flow is simply dismissing the embedded deviations of the system from central tendencies.

3.3.4 PRISM

PRISM fills a gap at MH. The aftermath of the 2003 drought highlighted the need for probabilistic models that can map a wide set of possibilities and introduce uncertainty into decision making and planning at MH, avoiding arbitrary specifications of pessimistic and optimistic forecasts. Besides, it enriches the set of what-if runs to a large magnitude from randomly generated values, replacing the limited number of possibilities typically used.

The following recommendations and comments about PRISM are tendered:

First, as an in-house system it allows staff at MH to customize the model to the specific needs of the Organization. We met the staff responsible for PRISM and we are convinced that they have the required computer and engineering skills to deal with its extensions and use. But we are also convinced that the staff can be beefed up to include statisticians who are competent to make informed selections and representations of the underlying probability distributions available in PRISM and @RISK. We have already alluded to the sensitivity of the results in PRISM to the choice of the underlying probability distributions. The competent choice of these distributions is of crucial importance to the usefulness and relevance of the results to risk management.

Second, some of the concerns we have about PRISM are in fact associated with the adoption by PRISM of results and vectors from other systems. The concern is that problems or errors in one system may be propagated through the entire family of models.

Third, while @RISK is a standard industry tool for dealing with uncertainty, it is a coarse system that requires customization and sophisticated knowledge of statistics and other related skills to become more flexible and produce genuine and useful results. There are other systems in the field and there is no substitute for detailed and painstaking analyses of the individual risks and the use of standard Value at Risk calculations (VaR). The two systems when used judiciously can be complementary to one another.

Fourth, we are happy that PRISM draws on other models at MH. It is our belief that the various and separate models that MH uses should all be integrated and should be adjusted to operate on a common platform (in Appendix B we present a simplified version of a fully integrated system for MH). Although there is always a concern that errors could be propagated throughout the system, having separate and disjointed models that do not conform to a consistent set of operations is also problematic. In this regard, it would be helpful if @RISK were used in the other models too. The relationships between these models are two-way streams of interdependence in which the outputs of one system become the inputs to another.

Fifth, some of the noted and preferred uses of @RISK have coupled it with other statistical models where it comes into play after other sources of uncertainty have been identified and exploited. For example, in the context of a specific application at MH, the model parameters of the Electric Load Forecast can be represented by their distributions using the standard errors of the coefficients. It is then that @RISK could be used to model the exogenous variables' distributions. The ultimate outcomes would represent the combined influence of parameter imprecision and uncertainty about forecast values of exogenous (independent or determining) variables.

Sixth, a few minor but important issues for improving PRISM would include freeing it from the seasonal and annual structure and allowing it to deal with intra-year issues. Also a richer and a better statistical anchor could be used to model water variability than the SPLASH characterization. More than a 5 years time horizon can be adopted to highlight results. Furthermore, as it stands now PRISM is only an energy model; it may be worth considering augmenting it so that it can become as well an energy capacity model. Price volatility modeling can be enhanced. The simple inert acceptance of external forecasts may be supported by a firmer probabilistic approach. There is also a need to contrast and compare @RISK calculations with other quantitative risk calculations. Greater integration and harmonization of the PRISM model with other MH models should be initiated quickly. Documenting the system explicitly in User and Technical manuals on a regular basis is essential. Equally relevant is subjecting the system to external audit and verification. Finally, adding statisticians/econometricians to the model support team is a critical necessity.

3.3.5 Load Forecast Model

The load forecast also plays a central role in the running of all MH models and contributes to both operational efficiency and future expansion plans. Errors in these forecasts can be costly and could result in faulty decisions and plans.

The following is a short list of our comments on and recommendations for improving the system:

First, the combination of survey results, technical and engineering information and regression techniques results in a rich base for the forecasts.

Second, the forecasting accuracy of the load forecasts is deemed reasonable for the 5 year term and the move to integrate probabilistic forecasts is encouraging.

Third, the staff responsible for maintaining and running the model is competent, enthusiastic about their work and dedicated. We were impressed with their knowledge and expertise.

Fourth, the structure of some of the regression equations can be strengthened. The use of one dependent variable may not suffice for future forecasts. Since the main objective is to forecast future values with accuracy, some experimentation with other variables and specifications should be encouraged.

Fifth, the use of standard deviations of the explanatory variables is a good step but more sophisticated integration of probabilistic structures is advisable. Some of the advanced uses of econometric models for risk analysis combine the use of the standard errors of the coefficients with different probability distributions for the independent variables and then a final Monte Carlo simulation to define the probabilistic range of the key variables of the system. MH could easily develop a similar framework to the one suggested above given that all of the pieces are available in-house for such an analysis.

Sixth, it will make sense that those responsible for the load forecast become official members of the model community group at MH and that integration of their model with the rest of the models at MH be made seamless and interactive.

Seventh, the inclusion of weather related variables is explicit in only one equation. It would make sense to have this key variable in most of the equations given its high significance in the equation in which it was included. But the question remains as to what procedure will be used to forecast this variable in the future. It may be worth considering developing in-house, or adopting, weather related forecasts from Environment Canada.

3.3.6 The Economic Outlook

A number of recommendations are made with regard to the preparation and use of the Economic Outlook beginning with adding both human and financial resources to the EAD and ending with expanding the mandate of the Department and changing some of its operating procedure. The centrality and pervasive uses of the EO necessitates elevating this function from a purely eclectic assembly of others' forecasts to a more nuanced and effective function.

First, the Department can benefit from the addition of economists and econometricians with quantitative skills and experience in forecasting to its staff.

Second, there is a serious need to revisit the forecasting role of the Department. At this time the eclectic selection of forecasts and forecasters is simplistic and driven by the commercial availability of the forecasts, while untested assumptions about their relevance and accuracy are accepted. Far more productive procedures would include in-house development of a forecasting model and/or cooperation with a Manitoba university department of economics for the development of selection criteria based on track record of forecasting accuracy.

Third, the forecasts adopted should abstract from the arbitrary specification of low (pessimistic) and high (optimistic) forecasts and move to generate probabilistic forecasts from standard risk tools available at MH.

Fourth, it is important that the EO group become part of the modeling family at MH and that their procedures be scrutinized and jointly developed with those who use their forecasts in their respective models.

Fifth, the terms of reference of this group should be expanded to involve serious contributions and evaluations of all economic matters at MH.

Manitoba Hydro supports and uses a number of models beside those discussed above, including PROMOD and others. The focus on the subset above is justified given its centrality and wide use.

Chapter Four

Water Flows: Statistical Modeling, Prediction of Droughts, and other Issues

4.1 Introduction

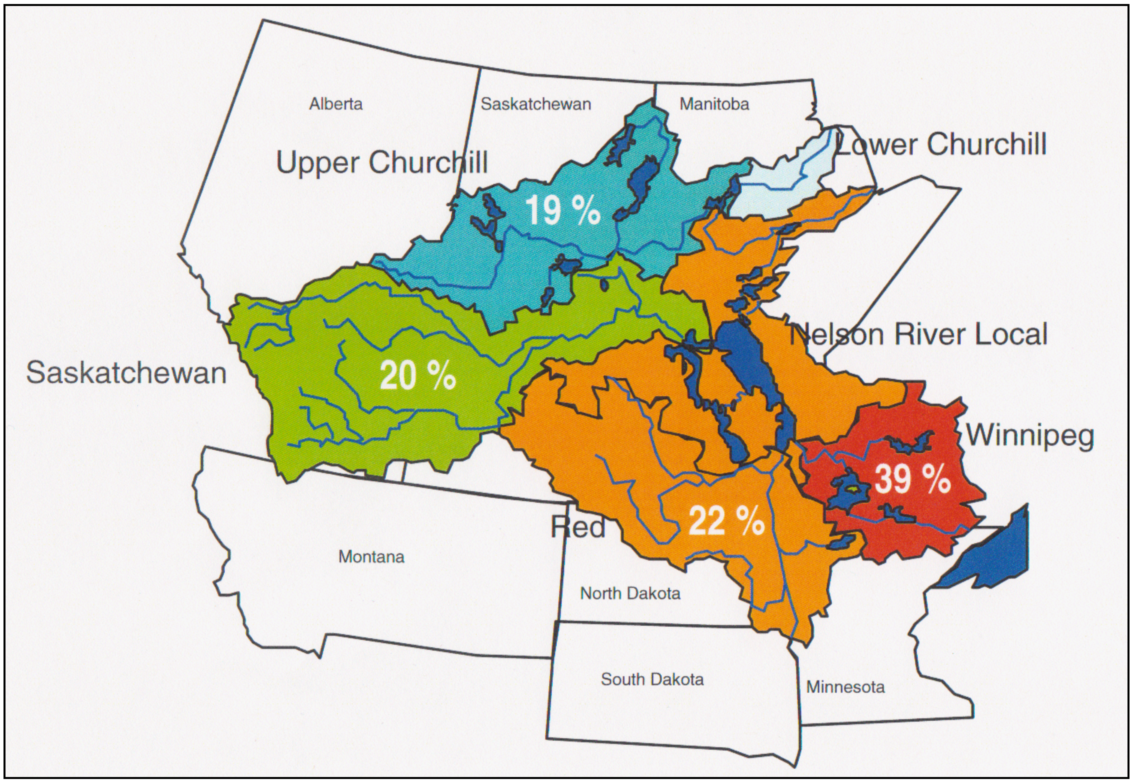
Manitoba is blessed with water abundance, but this abundance comes with the price of high variability. Over the past 98 years since records began to be kept for water flows in the Manitoba hydro system, this water was in critical shortage (drought) at least three times, and has varied by about 200% around the average recorded flow. In 1940 it was 40% of the average flow and in 2007 it exceeded the average flow by 160% (See Figure 3.10).

Water flows into Manitoba from three Canadian provinces and 2 US states. There are five river basins and a few different climatic zones, all of which combine to make forecasting water flows challenging and often inaccurate. About 39% comes from Lake Winnipeg, 22% from the Nelson River Basin, 20% from the Saskatchewan River Basin and the remaining 19% comes from the Churchill River Basin (see Figure 4.1).

This variability in water flows is reflected in a high variability in revenues. Water flow records have only been kept for the last 97 years (between 1912 and 2008). Over this period, droughts of varying severity and duration have occurred in Manitoba. Three severe droughts occurred during this 97 years—a severe seven year drought between 1937-1943, a five year drought during 1987-1992, and a one year drought in 2003-2004. ICF (2009) estimated that a drought as severe as the 2003-2004 drought can be expected once every fifteen years.[21]

[21] ICF International. 2009. Independent Review of Manitoba Hydro Export Power Sales and Associated Risks. P.111 and 112.

Figure 4.1 Basin Energy Supply



Source: Manitoba Hydro

The methodology used by ICF and others is just one of several possible methods. In Sections 4.4, we describe two distinct alternative methods, autoregressions and extreme value theory, and then set up simulations that suggest other possible 94-year outcomes. They are different from the one we actually observed, but still consistent with it, in terms of certain basic statistical properties.

The statistical procedures used in this Chapter allow for the consideration of many possible series of 94 years flows. These imply a set of outcomes that include many sets with lower minimum levels than the actual recorded minimum.[22]

Before describing these alternative methods, we first discuss some general aspects of these prediction problems: what aspects of the prediction to report or calculate, what to

[22] We study aggregate data exclusively, for simplicity. By doing so, we do not account for the fact that water shortages in certain river systems may have more serious implications for MH than shortages in other river systems.

predict, and the difficulty in finding a consensus on the best prediction method. We then describe the AR and extreme value methods, and apply them to MH monthly and annual water flow data.

4.2. Alternative Outputs of Predictions Generated by Statistical Models

Statistical procedures can often estimate the distribution of a random variable such as an unknown future value. This information can be used to incorporate not just a prediction itself but the uncertainty surrounding the prediction. The most common numerical outputs of prediction exercises are point predictions, quantiles of predicted distributions, and simulated values from predicted distributions. In this section these three outputs are briefly described.

4.2.1 Point Predictions

This is prediction in the usual first-blush sense -- for example “I predict we will receive 100 mm. of rain next month.” If a statistical model estimates the entire distribution of the variable being predicted, then the point prediction usually is the expected value or mean of the variable according to that distribution. In a regression model where the variable has not been transformed, this is just the $\hat{y}$ evaluated at the desired levels of the predictor variables. Basing the point prediction on the expected value in this way is, in effect, minimizing the expected squared difference between the prediction and the realized outcome.

A less commonly used, but still reasonable, point prediction is the median of the distribution. The median minimizes the expectation of the absolute value of the difference between the prediction and the realized outcome. If the distribution is symmetric, then the mean and median are equal.

In general, for a given estimated distribution, the best point predictor is the one that minimizes the expected loss function, which depends on the needs of the end-user.

Expressing these point predictions in mathematical terms, let the point prediction be *p*. Let the variable being predicted be *y*, let the loss function be *L(p,y)*, and let the predicted probability density function of *y* be $\hat{f}(y)$. Then the best predictor is the value of *p* that minimizes the expected loss:

$$\int L(p,y)\hat{f}(y)dy\,.$$

If $L(p,y)=(y-p)^2$, then the expected-loss-minimizing p is the mean, $p=\int y\hat{f}(y)dy$.

If $L(p,y)=|y-p|$, then the best *p* is the median, which is the value of *p* that satisfies

$$\int_{-\infty}^{p}\hat{f}(y)dy=0.5$$

If the loss associated with over-predicting is greater than the loss from under-predicting, then the best point prediction is lower than it would be otherwise. In many situations, there is no consensus on what the appropriate loss function should be, and the point prediction that gets used is the mean. In regression models, the mean and median can be estimated without having to estimate the entire distribution.

In conclusion, it may be worth noting that if there is consensus within MH on a loss function, and it is not the quadratic loss, then a better point predictor than the mean can be found using the above framework.

4.2.2 Quantiles

The point predictions discussed above do not convey information about the uncertainty of the prediction. This can be addressed by reporting numbers that indicate the lower and upper ends of the distribution in some sense. For example, the 2.5% and 97.5% quantiles of the predicted density function $\hat{f}(y)$ produce a bound that will contain the realized value 95% of the time, if it were produced by $\hat{f}(y)$. This is akin to 95% confidence intervals commonly reported in statistics for parameter estimates. The estimated a^{th} quantile (or $(100\times a)\%$ percentile) of y is the value of q_a that solves

$$\int_{-\infty}^{q_a} \hat{f}(y)dy = a$$

Predictions often are not simply reported for their own sake, but are required as inputs into other modeling exercises. The lower and upper bounds described above can be used as alternative inputs to check the sensitivity of the ensuing results to the uncertainty in the value of the predicted variable. For a more rigorous sensitivity check, one can use a wider interval, such as a 99% interval based on the 0.5% and 99.5% quantiles of $\hat{f}(y)$.

4.2.3 Simulated Values and Nonlinearity

As mentioned above, the predicted value of *y* may be required as an input into another model, and quantiles can be used as a sensitivity check. A more thorough way to incorporate the uncertainty about *y* into the ensuing calculations is to simulate many values of *y* using a pseudo-random number generator to produce many random draws of *y* from the estimated distribution $\hat{f}(y)$. This involves an increased computational burden, but may be worth it, especially if the variable in question plays a key role in the subsequent analysis and affects other variables in a nonlinear way.

To illustrate why nonlinearity matters, suppose we need to predict *y* in order to compute some other variable *z*, where $z = g(y)$, that we are interested in the expected value of *z*, E(*z*), and g(*y*) is linear, as in $z = a + by$. Then since E(*z*) = a + bE(*y*), we can estimate E(*z*) by estimating E(*y*), and we need not worry about other aspects of the distribution of *y*.

If g(*y*) is nonlinear, however, then the effect of *y* on E(*z*) cannot be captured by g(*y*) and E(*y*) alone. It is necessary then to describe the distribution of *y* more thoroughly. A relevant example of a nonlinear relationship is when *y* is water flow and *z* is either power generation or net revenue. A simple way to capture E(*z*), or even the distribution of *z*, is to simulate a large number of values of *y* from $\hat{f}(y)$, then compute $z = g(y)$ for each simulated value of *y*, resulting in a set of simulated values for *z*. From this set, E(*z*) can be estimated, or quantiles of the distribution of *z*, and so on.

4.3 What to Predict? How to Choose a Predictor?

4.3.1 Time Horizons of Water Flow Predictions

Since it has been estimated that 70% of MH's risk is volumetric, the prediction and modeling of water flows and/or rainfall must play an important role in its risk management procedures. Several types of prediction would be useful:

1) *Short term predictions* of water flows to inform water management decisions and one or two-month-ahead power sales.

2) *Medium term predictions*, for example, predicting winter precipitation in the autumn, in order to inform on winter water use decisions.

3) *Long term predictions*, to help in deciding how much to invest in generation and when.

4) *Predicting the frequency and intensity of extreme outcomes*, to aid in forming a drought risk management strategy.

The applications given later in this Chapter are examining issue (4), although predictions of all four types are carried out within MH's operations. We comment in Chapter 3 on short- and medium-term predictions (1) and (2), and make some brief comments here. The AR method described below is already in widespread use by MH for these purposes. Our main suggestion for prediction types (1) and (2) is to explore the use of other AR specifications, both including more lags, other variables (e.g. lagged water flow data from nearby water systems, or predictors used in meteorological models) and variable transformations (such as the Box-Cox transformation described in Appendix C.2), on a case-by-case basis. It is easier to construct a good-fitting model for short-run than long-run prediction. A high R-squared on an AR(1) model with monthly data does not imply that the model cannot be improved, or even that it would work well when used iteratively for medium or longer-term prediction.

An example of a long-term prediction (3) is given below in subsection 4.5.4. As the effects of the initial conditions wear off, long run predictions inevitably settle on the predicted long-run or "steady-state" distribution, unless some intervening factors are explicitly introduced. We do not introduce any such factors here, but we do briefly mention climate change considerations in Section 4.6.

The prediction of extreme values, prediction type (4), is especially difficult. Suppose you have 94 observations of annual water flows. If your goal is to estimate the "one in 94" lowest outcome, then in an important sense you only have one observation, since you only have one group of 94 observations to look at. In this situation, assumptions about the shape of the tail distribution enable more than just that one observation to be used to estimate the distribution from which the smallest observation was generated. A common distributional assumption for modeling extreme values is the Generalized Pareto distribution. We employ this method below, and find that it gives similar results to the AR(p) simulation method in terms of its predicted distribution of extreme low water flow outcomes.

4.3.2 Choosing a Prediction Method

It is impossible to perfectly predict outcomes from complex systems such as weather, economies, or financial markets. Yet these predictions need to be made, leaving us to choose from an array of less-than-perfect methods.

Not only is it difficult to predict accurately, it also is very difficult to decide which prediction method is the best. Comparing the accuracy of different predictions of the same variable after the fact can be informative, but misleading. There are many prediction methods to choose from, and usually there is not enough data to be able to tell on purely statistical grounds whether the best-performing predictors were truly the best method or just happened to be lucky in those few cases. Users are forced into a tricky decision involving conflicting causal claims, information, and statistical theory.

Standard statistical approaches to prediction assume that the observed data were generated by a statistical process or model. A frequently-used one is the AR(p) model, in which the observation in time period t, y_t, is a linear function of: an unknown constant, α;

the previous *p* observations, $y_{t-1}, y_{t-2}, \ldots, y_{t-p}$, weighted by unknown coefficients $\rho_1, \rho_2, \ldots, \rho_p$; and random disturbance term u_t, resulting in the model:

$$y_t = a + r_1 y_{t-1} + r_2 y_{t-2} + \ldots + r_p y_{t-p} + u_t$$

4.4 Methods for Generating Predictions

This section describes three methods for generating predictions of future water flows based on observed past water flows. Each one can be thought of as being based on its own way of constructing and estimating an unknown underlying distribution or process that generated the observations, and will generate the future values. Once this distribution has been estimated, then pseudo-random number generators can be used to produce hypothetical future values that are based on past values in specific known ways that can be critically evaluated and compared.

4.4.1 Re-Sampling, or Historical Simulation

The observations form an *empirical distribution*. For example, suppose there are 94 observations. One of the observations (and none of the other 93) is 54 Kcfs. Then the empirical distribution says that the probability of observing 54 is 1/94. Use the empirical distribution as an estimate of the actual distribution. If a quarter of the observations are less than 103, then the empirical distribution of X implies Prob{X < 103} = 0.25, and so would the estimated distribution. If the smallest observation is 54, then the smallest possible value that could be generated by the estimated distribution also is 54.

This method is relatively simple and is based on the observations in a clear and reasonable way. Autocorrelation can be accommodated to some extent in sampling experiments by sampling strings of consecutive observations from the original distribution. Re-sampling from the observe distribution is one of the basic ideas underlying *bootstrapping*, which is a computer-intensive statistical methodology that has had a huge impact on statistical practice over the last 30 years. This is the method used in the ICF report mentioned in the introduction to this chapter, in much of MH's own studies, and elsewhere.

A disadvantage of this method for modeling extreme values is that, without modifications, it does not allow for future observations to lie outside the range of observed values. For example, this method cannot predict future values to be smaller than the observed minimum or greater than the observed maximum. This restriction contrasts with the spirit of risk management principles, where it is essential to think about how to manage events that have never happened before.

4.4.2 Autoregressive Time Series Models

4.4.2.1 Annual Data

The AR model is standard in many disciplines, including hydrology. For the annual water flow data, significance tests suggested an AR(3) model:

$$y_t = a + r_1 y_{t-1} + r_2 y_{t-2} + r_3 y_{t-3} + u_t$$

where y_t represents the water flow in year t; a, r_1, r_2, r_3 are coefficients that are estimated by ordinary least squares (OLS) and u_t is a random disturbance term. When applied to the 94 years of water flow data, the coefficient estimates were as follows.

Table 4.1 – Least Square Estimates

Coefficient	Estimated Value	Standard Error	*t*-Statistic
a	49.86	14.3	3.47
r_1	0.59	0.10	5.88
r_2	-0.39	0.11	-3.37
r_3	0.35	0.11	3.36

Model Residual Checks

This estimated model will be used to simulate water flow values for checking potential drought occurrences. It is important first to check the validity of the assumption that the error distribution is the same during low and high water flow periods. Suppose that the actual process is best described by an error distribution that has a left-hand tail that gets thinner in lower water flow periods. This is another way of supposing that there is some unknown soft lower bound on how bad a drought can get, that is not captured by the AR(3) model. If this were so, then the model would predict too many bad droughts than it should, even if it does a very good job of tracking the water flow behaviour during normal periods.

We checked into this possibility by examining the residuals, $e_t = y_t - (\hat{a} + \hat{r}_1 y_{t-1} + \hat{r}_2 y_{t-2} + \hat{r}_3 y_{t-3})$, which can be viewed as estimates of the disturbance terms u_t in the AR(3) model. We split these residuals into two groups, depending on whether the previous period's water flow, y_{t-1}, was smaller or greater than its sample average. We then computed the standard errors, the skewness coefficients, and the kurtosis coefficients, of these two groups of residuals. If they are similar across groups, the AR(3) assumptions are supported and the concern expressed in the above paragraph is allayed somewhat.

The standard error, *s*, measures the square root of the average of the e_t^2's, and indicates how "spread out" the e_t's are. If the standard error of the low water flow group's e_t's is much smaller, then imposing the incorrect assumption of a constant error variance at all water levels will result in too much variation, at low water levels, resulting in over-prediction of the severity and frequency of drought events.

The skewness coefficient is the average of the (e_t^3 / s^3)'s. It indicates how skewed, or asymmetric, the distribution is. A skewness coefficient of zero indicates that the distribution is not skewed in either direction, such as a symmetric distribution like the Normal.

The kurtosis coefficient is the average of the (e_t^4 / s^4)'s, and indicates how "thick-tailed" the distribution is, that is, the tendency for e_t to take on extreme values. Standardizing for the spread of the distribution by dividing by s^4 produces a common benchmark for the kurtosis coefficient of 3, which is the kurtosis of a Normal distribution. The values of these statistics are given in the following table, in which the two groups are defined by whether the previous period's water flow is below or above average.

Table 4.2 Residual Statistics: Annual AR(3) Model

Statistic	Low y_{t-1}	High y_{t-1}
Standard error	19.720	17.677
Skewness	0.26887	0.60712
Kurtosis	2.9820	3.0407

Although there are some differences in the values of these statistics between the low and high water flow groups, overall we find the results reassuring. One concern we had was that the AR(3) model may be missing some natural tendency for the low end of the water flow distribution not to get very low. If this were the case, then the lower range of our simulated values would be too low, based on a model that allowed for worse droughts than it should. However, the residuals would not exhibit the properties in the table if this were the case. The standard error would be lower for the low y_{t-1} group, since there would be some compression of the possible water flow outcomes when the recent past water flow has been low. This is not seen in Table 4.2 - in fact, the standard error is higher for the low y_{t-1} group.

We would also expect to see more positively-skewed residuals in the low y_{t-1} group if there was some force preventing the residuals from being too negative (that is, a reduction in the odds of moving toward a worse drought) when the water flow is already below average. Although we do see positively skewed residuals for the low y_{t-1} group, they are even more positively skewed in the high y_{t-1} group. This suggests that the positive skew is due to some reason other than the one that concerned us. For example, water flows could rapidly increase due to high rainfall, whereas low-rainfall periods may cause the water flow to decline in a more gradual fashion. If so, we would see this observed pattern of bigger positive than negative water flow “surprises” year-to-year. We capture this effect later, by simulating with re-sampled residuals in addition to simulating with (symmetric) normally distributed errors.

Finally, the kurtosis measures are about equal in the two groups, and both measures are remarkably close to the 3.0 kurtosis value taken on by the normal distribution.

To summarize, this residual check was looking for evidence that the AR(3) model might be making assumptions about the distribution of the disturbances that allows for worse droughts than it should. We find no evidence of this in the residuals. Might the model be less likely to predict droughts than it should? Possibly, but when the model uses normally distributed errors, it is simulating with a relatively thick left tail compared to the actual residuals, which gives the model a greater tendency to quickly move to low water flow conditions than is indicated in the data.

Note also that our simulation takes into account the sampling error in the AR coefficients themselves by re-sampling the coefficients values themselves in addition to the disturbances. This adds variation in the predictive distribution, increasing the chances of generating extreme outcomes such as low water flows levels associated with drought conditions.

4.4.2.2 Monthly Data

To model the monthly data, it was necessary to take into account the substantial variation in the distribution by month, while still accounting for the correlation across time. There are two ways to interpret this model. Let ***t*** indicate the monthly time period, and let ***m(t)*** indicate the month of the year corresponding to time ***t***. $m_{m(t)}$ is a parameter representing the mean water flow in month ***m(t)*** and $s^2_{m(t)}$ represents the variance of the water flow distribution in month ***m(t).*** Then the water flow distribution for a given month ***m(t)*** can be standardized to have zero mean and unit variance as z_t, where

$$z_t = \frac{y_t - m_{m(t)}}{s_{m(t)}}$$

The z_t's are assumed to follow an AR(p) process, with coefficients that vary by month. In the current application, significance testing suggested that p = 2.

$$z_t = r_{1,m(t)} z_{t-1} + r_{2,m(t)} z_{t-2} + f_{m(t)} e_t$$

Substituting out the *z*'s and re-arranging gives a similar month-specific AR(2) model for the *y*'s:

$$y_t = a_{m(t)} + b_{1,m(t)} y_{t-1} + b_{2,m(t)} y_{t-2} + w_{m(t)} e_t$$

where the parameters of the two models are related as:

$$a_{m(t)} = m_{m(t)} - \frac{r_{1,m(t)} s_{m(t)} m_{m(t-1)}}{s_{m(t-1)}} - \frac{r_{2,m(t)} s_{m(t)} m_{m(t-2)}}{s_{m(t-2)}},$$

$$b_{1,m(t)} = \frac{r_{1,m(t)} s_{m(t)}}{s_{m(t-1)}} \quad \text{and} \quad b_{2,m(t)} = \frac{r_{2,m(t)} s_{m(t)}}{s_{m(t-2)}}, \quad \text{and}$$

$$w_{m(t)} = s_{m(t)} f_{m(t)}.$$

4.4.2.3 Transforming the Water Flow Variable

The coefficients of the AR(2) model in the y_t's can be estimated by ordinary least squares separately by month. When we did this and proceeded to simulate from the predicted distribution in the same manner as reported above for the annual data, we noted an anomaly which has important implications for predicting low water flow outcomes. Unlike the annual data, changing coefficients in the month-to-month time series processes and the extra randomness in flows resulted in occasional unrealistically low, even negative, simulated water flow values. This is likely due to the model allowing for the same shape of error term distribution in low and high water flow conditions. Observed patterns in the high water flow periods influence the coefficient estimates and result in the generation of occasional implausible negative water flow values when applied to low water flow conditions.

One way to address this issue is to allow the coefficients to be different in low water flow periods from those in high flow periods. Although we did not pursue this option here, it might prove useful. Another variation on this idea is threshold models, which are used in some areas of time series analysis. These models' characteristics change when the y_t

value crosses some threshold or thresholds, which themselves may be treated as parameters and estimated.

We chose to address this issue by transforming y_t. Specifically, we replaced y_t by its square root. This does not pose any technical difficulties. The simulated values are "untransformed" at the end of the exercise, by squaring them back into the original "scale".

A new question surfaces once we start considering this approach. Is the square root the best transformation? Why not the cube root, or natural logarithm? All of these possibilities are nested in the Box-Cox transformation, where the exact transformation is determined by a parameter l that is estimated along with the others by maximum likelihood. We discuss this Box-Cox approach in Appendix C. What we have done here in effect is to impose the value $l = 0.5$ instead of the usual no-transformation "default" choice of $l = 1.0$.

Residual checks

Table 4.3 - Residual Statistics: Monthly AR(2) Model, y_t is Square Root

Month	Standard Error		Skewness		Kurtosis	
	low y_{t-1}	high y_{t-1}	low y_{t-1}	high y_{t-1}	low y_{t-1}	high y_{t-1}
Jan	0.27	0.21	-0.72	-0.07	2.63	4.36
Feb	0.24	0.15	-0.22	-0.23	2.17	5.12
Mar	0.28	0.32	-0.31	0.02	4.48	3.57
Apr	0.95	1.25	-0.47	0.50	3.55	2.04
May	1.34	3.69	0.29	0.82	11.60	1.52
Jun	1.32	1.11	-0.01	0.23	2.37	3.34
Jul	1.12	1.50	0.82	1.05	6.24	3.45
Aug	1.62	1.38	0.79	-0.19	5.37	7.40
Sep	1.09	0.79	-0.07	-0.33	1.84	3.51
Oct	1.13	1.69	0.42	-0.52	6.55	2.92
Nov	0.84	0.67	-0.21	-0.07	2.72	4.38
Dec	0.43	0.40	-0.26	-0.20	2.03	2.42

Table 4.3 above reports residual checks by month. Seasonal variation is apparent in the standard errors, which grow much larger in the summer months. There is no tendency for

any of the three statistics to be consistently higher or lower in the low y_{t-1} group than the high y_{t-1} group. This suggests that the error distribution, while changing from month to month, does not display predictable variation in its <u>shape</u> during low water flow periods than high water periods.

4.4.2.4 Coefficient Estimates for Monthly Data

Table 4.4 shows the coefficient estimates from the AR(2) models for the monthly square root water flows. These are not estimates of a stationary AR(2) process. When time steps ahead one month, the time series process also steps ahead to the next month's model. The coefficients (referred to as b 's above) are capturing more than just the time dependencies of a stationary AR(2) model (the r 's) – they also respond to the changes in the month-specific means (m 's) and variances (s 's) .

Table 4.4 - Regression Results For Monthly AR(2)s, y_t is Square Root

	Constant			First Lag: y_{t-1}			Second Lag: y_{t-2}		
	coeff	st.err.	*t*	coeff	st.err.	*t*	coeff	st.err.	*t*
Jan	2.65	0.52	5.09	0.76	0.08	9.55	-0.05	0.06	-0.81
Feb	3.40	0.54	6.34	0.38	0.10	3.99	0.26	0.08	3.20
Mar	1.77	0.80	2.21	0.59	0.12	4.78	0.22	0.10	2.15
Apr	-6.22	1.60	-3.90	0.78	0.20	3.97	1.02	0.22	4.64
May	-1.99	2.07	-0.96	0.58	0.14	4.12	0.87	0.29	3.01
Jun	3.76	0.85	4.43	0.71	0.07	9.97	-0.01	0.10	-0.11
Jul	3.58	0.83	4.34	0.61	0.11	5.61	0.05	0.09	0.48
Aug	1.95	0.98	1.99	0.67	0.11	5.89	-0.01	0.10	-0.08
Sep	0.77	0.75	1.02	0.67	0.08	8.13	0.16	0.08	1.90
Oct	5.23	0.79	6.65	0.59	0.13	4.60	-0.12	0.12	-1.00
Nov	3.12	0.64	4.89	0.46	0.07	6.19	0.25	0.07	3.81
Dec	4.24	0.53	7.99	0.54	0.07	7.40	0.04	0.06	0.62

Because the j^{th} lag coefficients, $b_{j,m(t)} = \frac{r_{j,m(t)} s_{m(t)}}{s_{m(t-j)}}$, $j = 1,2,$ can only equal zero when $r_{j,m(t)} = 0$ their *t*-statistics can be interpreted as tests of the null hypotheses $r_{j,m(t)} = 0$. The *t*-statistics for the second lag coefficient estimates in Table 4.4 are effectively testing whether it is valid to remove the second lag from the regression, restricting its coefficient to equal zero. For many of the months this hypothesis is accepted at the usual significance levels, since several *t* statistics are smaller than 2 in magnitude. However, four of them exceed 3 in magnitude, which is significant at any reasonable level, providing strong evidence that the second lag is required for those months. In the interest of simplicity, we chose to impose the same number of lags on each month's model, which is a common practice in multi-equation time series models in economics such as vector auto-regressions. When the model was extended to an AR(3), the results, not reported here, suggested that most of the third lags could be removed.

Apart from this number of lags issue, the main thing to take from Table 4.4 is that the coefficients fluctuate quite a bit from month to month, particularly the constant term. They, along with the estimated error variance for each month, the w's, are used to simulate monthly data, producing the results reported later on.

4.4.3 Extreme Value Model

Extreme value theory (EVT) relies on a limit theorem that motivates the use of the generalized Pareto distribution to model the distribution of values in the extreme tails of distributions. An accessible introduction is McNeil[23], from which all of the quotations below are taken. It is based on a theoretical result (Theorem 1 in McNeil) that shows that for many distributions (including "all of the common continuous distributions used in statistics and actuarial science" (p.5)) the "natural model for the unknown excess distribution above sufficiently high thresholds" (p.5) is the generalized Pareto distribution. The theory applies equally well to values below thresholds in the left-hand tail of a distribution, such as droughts in a hydrological setting.

In his conclusion, McNeil (p.17) argues: "Methods based around assumptions of normal distributions are likely to underestimate tail risk. Methods based on historical simulation can only provide very imprecise estimates of tail risk. EVT is the most scientific approach to an inherently difficult problem – predicting the size of a rare event."

[23] McNeil, A.J. (1999), "Extreme Value Theory for Risk Managers," manuscript, ETH Zentrum, Zurich

Although we would hesitate to describe the merits of EVT quite this strongly, these methods do appear at least to be worthy of consideration for modeling extreme hydrological events (droughts). EVT provides a rationale for imposing a particular family of shapes, namely the generalized Pareto distribution (GPD), to the tail of a distribution, enabling the tail shape to be estimated with a small number of observations.

Turning to the details, the cumulative distribution function (cdf) of the GPD as presented in McNeil is:

$$G_{x,b}(x) = 1 - \left(1 + \frac{xx}{b}\right)^{-\frac{1}{x}} \qquad \text{when } x \neq 0$$

$$= 1 - \exp(-x/b) \quad \text{when } x = 0$$

where $b > 0, x \geq 0$ when $x \geq 0$, and $0 \leq x \leq -\left(\frac{b}{x}\right)$ when $x < 0$.

This model is not applied to the entire data set, only to the tail of the distribution. As presented above, it is the right-hand tail. We will proceed as if it is the right-hand tail, then convert the problem later to left-hand tail estimation. Since we are not concerned with the rest of the distribution, specify a threshold value ***u***, where N_u out of the ***n*** observations are greater than ***u***. The value of ***u*** is chosen such that N_u is much smaller than ***n***. The GPD model is then dealing with the right-hand (N_u/n) proportion, with cdf:

$$G_{x,b}(x) = \left(\frac{1-N_u}{n}\right) + \left(\frac{N_u}{n}\right)\left(1 - \left(1 + \frac{x(x-u)}{b}\right)^{-\frac{1}{x}}\right)$$

$$= 1 - \left(\frac{N_u}{n}\right)\left(1 + \frac{x(x-u)}{b}\right)^{-\frac{1}{x}} \qquad \text{when } x \neq 0$$

and

$$G_{x,b}(x) = \left(\frac{1-N_u}{n}\right) + \left(\frac{N_u}{n}\right)\left(1 - \exp\left(\frac{-(x-u)}{b}\right)\right)$$

$$= 1 - \left(\frac{N_u}{n}\right)\exp\left(\frac{-(x-u)}{b}\right) \qquad \text{when } x = 0$$

where $b > 0, x \geq u$ when $x \geq 0$, and $u \leq x \leq -\left(\frac{b}{x}\right)$ when $x < 0$.

This formulation applies to situations where the extreme values of interest are the large ones, in the right tail of the distribution. In our case, the random variable *x* represents water flow. We are interested in the left tail, since the extreme end of the distribution that we wish to model corresponds to the low water flow outcomes. Converting the above to a left-tail distribution, where the threshold is now chosen so that N_u out of the *n* observations are less than *u*, the GPD model becomes

$$G_{x,b}(x) = \left(\frac{N_u}{n}\right)\left(1 + \frac{x(u-x)}{b}\right)^{-\frac{1}{x}} \qquad \text{when } x \neq 0$$

and

$$G_{x,b}(x) = \left(\frac{N_u}{n}\right)\exp\left(\frac{-(u-x)}{b}\right) \qquad \text{when } x = 0$$

where $b > 0, x \leq u$ when $x \geq 0$, and $-\left(\frac{b}{x}\right) \leq (u-x) \leq u$ when $x < 0$.

Since we know that *x*>0, we can focus on the $x < 0$ case and impose $G_{x,b}(x) = 0$ at *x=0*. This implies a restriction $\left(1 + \frac{x(u-x)}{b}\right) = 0$ at *x=0*, which can be re-written as $\frac{x}{b} = -\left(\frac{1}{u}\right)$ and as $-\left(\frac{1}{x}\right) = \frac{u}{b}$. Substituting out x in the $G_{x,b}(x)$ function gives a left-tail "Pareto type II" ($x < 0$) model:

$$G_b(x) = \left(\frac{N_u}{n}\right)\left(\frac{x}{u}\right)^{\frac{u}{b}}, \quad \text{where } b > 0 \text{ and } 0 \leq x \leq u.$$

To use this model to estimate extreme low water flow probabilities using MH's data, the threshold parameter u was chosen so that there are enough observations below it to enable reasonably accurate estimation of the shape parameter b, yet there are a small enough number of observations that we are indeed focusing on the tail of the distribution. We chose a few different u values as a sensitivity check. For each choice of u, b was estimated by maximum likelihood. From the above expression for $G_b(x)$, the density function $g_b(x)$ and log likelihood function for b can be obtained, from which the maximum likelihood estimator can be derived as

$$\hat{b} = -\frac{u}{N_u}\sum_{i=1}^{N_u}\ln\left(\frac{x_i}{u}\right),$$

where the data have been ordered such that $x_1.x_2,...,x_{N_u}$ are the N_u observations that are less than the threshold.

Given $\hat{b}$, then an estimate of the a^{th} quantile, x_a, can be obtained for $a < \frac{N_u}{n}$ by setting $G_b(x) = a$ and inverting the $G_b(x)$ function to solve for $\hat{x}_a$, which gives

$$\hat{x}_a = u\left(a\left(\frac{n}{N_u}\right)\right)^{\frac{\hat{b}}{u}}.$$

Because this method provides an analytically tractable distribution, and does not model the autoregressive aspect of the water flow process, quantiles of the distribution of the 94-year minimum can be obtained without simulation. Let the w^{th} quantile of the minimum of n independent draws from a distribution be $q_w(n)$. This is equal to the a^{th} quantile of the underlying distribution (which in the present case is the Pareto type II distribution described above) according to the relation

$$w \equiv \Pr\{\min(x) < q_w(n)\} = 1 - \prod_{i=1}^{n}\Pr\{x_i > q_w(n)\} = 1 - (1-a)^n$$

Solving for a gives

$$a = 1 - (1 - w)^{\frac{1}{n}}$$

When $n = 94$, then $w = .025 \Rightarrow a = .0002693$, $w = .50 \Rightarrow a = .007347$, and $w = .975 \Rightarrow a = .038483$. This calculation makes it starkly apparent just how extremely far out in the tail of the underlying distribution is the 2.5% quantile of the distribution of the 94-year minimum, $q_w(n)$. The chance of drawing such an extreme observation in any given year is one in 3,713 (=1/.0002693). Another way to look at it is that if we had 1,000 different 94-year periods, only 24 of them would have minima smaller than $q_w(n)$. If none of those 24 had a second year that was also smaller than $q_w(n)$, then $q_w(n)$ is the 25th smallest out of 94,000 (94 times 1000) observations, and 25/94,000 = .00026596, which is approximately equal to a. Simply put, the 2.5% quantile of the distribution of 94-year minima is a <u>very</u> rare (but not impossible) occurrence in a given year.

Quantiles that correspond to the simulated minima quantiles from the AR(3) model can be computed for this EVT-based model directly, by substituting the appropriate values of u, a, n, N_u, and $\hat{b}$ into the above formula for $\hat{x}_a$. We used $u = \{80,90,100\}$, which resulted in $N_u = \{5,13,26\}$ and $\hat{b} = \{11.037, 10.916, 13.447\}$ when applied to the annual water flow data.

We have not pursued the computation of standard errors to assess the precision of these estimates. The autocorrelation in the annual water flow series, described by the AR(3) results given at the beginning of subsection 4.4.2.1, would need to be accounted for in a proper calculation of these standard errors.

4.5. Prediction Results

4.5.1 Minimum Annual Water Flow Over 94-Year Period

The estimated AR(3) model was simulated according to the procedure in Appendix C.1. Method A uses normally distributed errors and method B re-samples the residuals from the fitted model. In both cases the coefficients are also drawn afresh according to the estimated sampling distribution of the OLS estimators for each replication.

Table 4.5 - Single-Year Minimum Over 94-Year Period (Kcfs)

Simulation Method	Actual Minimum	Mean of Simulated Minima	2.5% Quantile of Simulated Minima	Median (50% Quantile) of Simulated Minima	97.5% Quantile of Simulated Minima
AR(3) method A	54.378	57.802	29.451	----	80.197
AR(3) method B	54.378	63.019	38.862	----	82.831
EVT method (u=80)	54.378	----	38.576	60.881	76.506
EVT method (u=90)	54.378	----	42.210	63.043	77.066
EVT method (u=100)	54.378	----	39.351	61.391	76.703

Some notable results are:

1) The actual minimum lies roughly in the middle of the 95% intervals

The actual minimum is not unusually small or large compared to the estimated range of likely minima. Because this estimated range is constructed using the one data set from which the actual minimum is observed, the procedure itself will have an unavoidable tendency to have this property. Still, this result suggests that on one hand the practice of taking the actual 94-year minimum, 54.378, and using it as a worst-case scenario, does not capture the fact that the next 94-year minimum, and the one after that, may be very different. On the other hand, this actual minimum is not horribly biased one way or another.

2) The means and medians are greater than the actual minimum

As an addendum to the more important point (1), we observe that the actual 94-year minimum is slightly lower than the means or medians of the various predicted distributions. The actual minimum is a slightly worse-than-average "worst-case" scenario, when the average worst-case scenario is deduced from the data using these standard statistical modeling techniques.

3) The 95% intervals are fairly wide

We can roughly characterize the results as saying "over a typical 94-year period, the minimum annual average water flow will be between 40 and 80 (Kcfs) 95% of the time." This is a pretty wide interval. The actual minimum of 54.378, while not unreasonably high or low, is also not a particularly accurate representation of what the minimum is in the other hypothetical 94-year periods.

4) The 95% intervals are very similar across very different statistical methods. The one exception is the 2.5% quantile from the AR(3) method A.

The AR(3) approach is totally different from the extreme value approach. The only thing they have in common is that their coefficients were estimated using the same data set. It is reassuring to see that the quantiles generated from the two methods are so similar. An important exception is the low value of the 2.5% quantile generated by the AR(3) model with normally distributed errors. As discussed in the model residual checks part of subsection 4.4.2.1, this might be attributable to a right-skewness in the actual error distribution at low water flow periods that is not captured by the symmetric normal distribution.

4.5.2 Minimum 5-year Water Flow Within a 94-Year Period

For long range drought planning purposes, it may be useful to know the properties of low water flow outcomes when averaged over a multi-year period, in addition to the single-year outcomes that we have focused on so far. The minimum 5-year average water flow in the observed 94-year period is 82.085. How representative is this of the minimum 5-

year average that would be observe in other 94-year periods? This question can be easily addressed using the same simulated AR(3) data that was used in the above subsection.

We were not able to use the EVT method for this exercise for two reasons. First, it does not model autocorrelation, which plays an important role in increasing the variability of the 5-year averages. When there is more autocorrelation, the water flows in adjacent years are more similar to each other, giving a smaller averaging-out effect and more variability in the 5-year averages. Second, 5-year intervals will often contain some annual observations from a tail, however it is defined, and some that are not in the tail. The EVT model, unlike the AR(3) model, does not have anything to say about the observations that are not in the tail. We cannot solve these problems by aggregating our data into a sequence of 5-year averages, because then we would no longer have enough observations (94/5 = 18.8) to provide reliable tail shape estimates.

Table 4.6 - Minimum Five-Year Average Over 94-Year Period

Simulation Method	Actual Minimum	Mean of Simulated Minima	2.5% Quantile of Simulated Minima	97.5% Quantile of Simulated Minima
AR(3) method A	82.085	83.440	58.681	101.87
AR(3) method B	82.085	85.062	61.640	101.54

Unsurprisingly, the numbers are higher than the corresponding one-year minima. The results exhibit two notable features:

1) The actual minimum is very close to the mean of the simulated minima.

Similar to the one-year results, it appears that the actual 5-year minimum is not too out of line with what it would be on average from other potential 94-year water flow outcomes.

2) The 95% intervals are still fairly wide.

One might have expected that the 5-year averaging would result in a substantially less uncertainty about the minimum than what we observed in the single-year analysis. Somewhat surprisingly, this is not the case. The 95% intervals for the 5-year average minimum roughly spans the 60 to 100 (Kcfs) range. This interval, while higher, is just as wide as the 40 to 80 (Kcfs) range observed for the single-year minimum.

4.5.3 Minimum Monthly Water Flow Over 94-Year Period

Table 4.7 provides estimated means and 95% intervals for the distribution of the minimum water flow observed in any single month over a 94-year period. The four methods all use the 12 monthly AR(2) models sequentially. As before, method A uses normally distributed errors (with a month-specific variance), while method B uses re-sampled residuals from the month in question. We also report "fixed coefficients" results, where the coefficients are fixed at the point estimates reported in Table 4.6, as opposed to drawing new coefficients for each replication based on the sampling distribution of the estimates. The actual minimum was 16.320.

Table 4.7 - Minimum Single-Month Water Flow Over 94-Year Period

Simulation Method	Actual Minimum	Mean of Simulated Minima	2.5% quantile of Simulated Minima	97.5% quantile of Simulated Minima
Monthly AR(2) method A	16.320	29.070	15.610	40.380
Monthly AR(2) method A – fixed coefficients	16.320	24.405	11.417	36.148
Monthly AR(2) method B	16.320	25.282	13.621	36.791
Monthly AR(2) method B – fixed coefficients	16.320	24.077	12.540	35.507

Some aspects of these results are:

1) The actual minimum is substantially lower than the mean of the simulated minima.

The simulated minima take a mean value in the 25 to 30 (Kfcs) range, which is much higher than the actual minimum of 16.320.

2) The 95% intervals are wide.

The values of the lower bounds of these intervals are about 12 or 13, ranging up to an upper bound at around 38 (Kfcs). While the actual minimum lies within this interval, at 16.3 it is distinctly near the lower end.

Like the annual data results, the intervals are wide, and the actual minimum is within the bound. Unlike the annual data results, the actual minimum is clearly below the mean of the simulated minima.

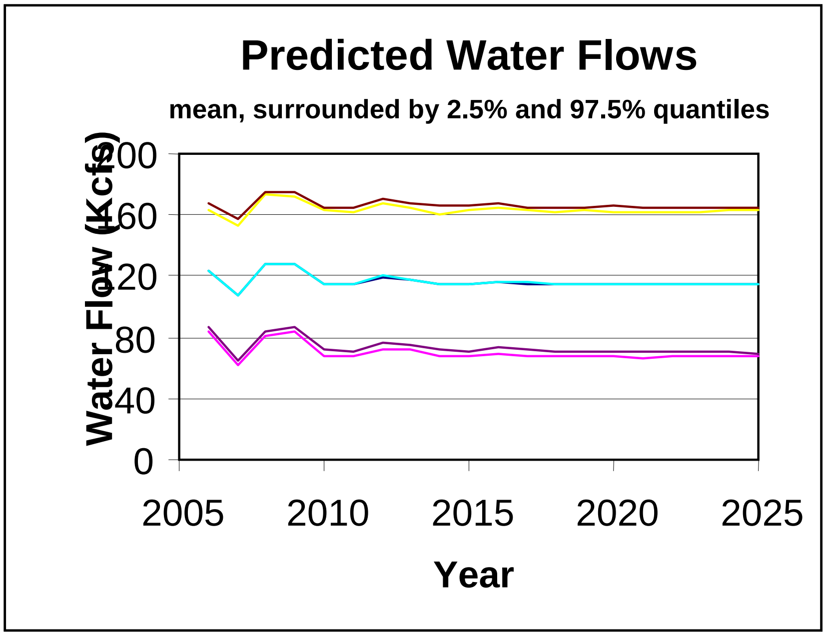
3) The intervals from the fixed coefficients method are just as wide as those produced by the random coefficients method.

Our expectation was that allowing the coefficients to change from one data set replication to the next would add "noise" to the results, making the 95% intervals wider than they would be if the coefficients were held fixed. This is not the case here.

4.5.4 Twenty-Year Predictions

We used a simulation method similar to the one used in subsection 4.5.1 to simulate forecast distributions with the annual AR(3) model. Figure 4.2 shows the mean and 95% bounds (the 2.5% and 97.5% quantiles) from methods A (normally distributed errors) and B (re-sampled residuals). The results of the two methods were nearly identical. The slightly higher plot of each pair came from method B.

Figure 4.2 – Predicted Water Flows, 2005-2015



The only difference from the earlier simulation procedure is that this time, the first simulated observation from each replication, which is a draw from the predicted distribution for 2006, is generated using the observed three previous water flows 2003, 2004 and 2005, instead of the burn-in method described in Appendix C. The levelling-out of the plots from about 2012 onward indicates that by that point, the effect of the 2003-2005 start-up observations has worn off, and the distribution has largely settled into its long-run steady-state. (This in fact is the goal of the burn-in phase of the earlier simulations -- in order to begin each simulated 94-year period already in the steady-state.)

The main general property illustrated by this exercise is that the autocorrelation, or persistence, in the annual water flow series is not strong enough to enable very accurate predictions using the initial conditions. If it were, there would be a more pronounced "fanning-out" shape in the picture, due to the forecast distribution having a smaller spread (being more accurate) in the earlier years of the forecast horizon.

4.6 Climate Change

There is even more uncertainty about future water flows than is captured by the above approaches, given the ever-increasing and overwhelming evidence of climate change. Any conclusions based solely on the past evidence would be thrown into question by the prospect of relatively rapid changes in weather patterns. Below, we provide maps taken from the Natural Resources Canada's Atlas of Canada web site:

http://atlas.nrcan.gc.ca/site/english/maps/climatechange

Each map gives information about the expected change in precipitation or temperature, for the summer or winter seasons, predicted to occur from the 1961-90 period to the 2040-60 period.

The summer precipitation map indicates a slight increase in precipitation for the majority of the northern basin energy supply area, and a slight decrease for the other relevant areas. Similarly, the winter precipitation map shows slight increases in some energy basin areas and slight decreases in other areas. According to this NRC scenario, the changes precipitation patterns expected over this time period appear to be small relative to the inherent uncertainty in year-to-year precipitation patterns.

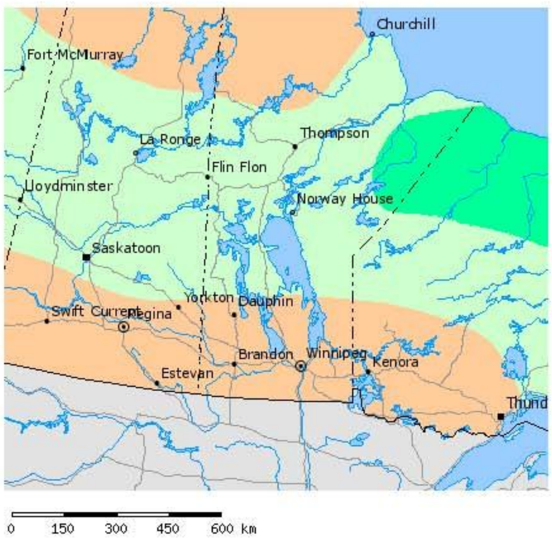
The temperature scenarios tell a different story. The summer temperature is expected to increase by three to four degrees Celsius, and the winter temperatures by four to five degrees. The implications of these expected changes on MH's production and finances are not straightforward, and we do not attempt to delineate them here. Revenue and cost implications vary greatly by season, and evaporation loss would be affected.

Natural Resources Canada | Ressources naturelles Canada | Canada

The Atlas of Canada

Print Map | Return to Map

National Summer Precipitation Scenario: 2050



Summer Precipitation Change from 1961-90 to 2040-60 (%)
- -20 - -10
- -10 - 0
- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50

Capitals (Canada)
- National
- Provincial and Territorial

Populated Places
- 1 - 4999
- 5 000 - 49 999
- 50 000 - 99 999
- 100 000 and greater

International Boundaries
- EEZ (200 mile)
- Canada / Kalaallit Nunaat dividing line
- International

Provincial and Territorial Boundaries
- Provincial / Territorial

Road network
- Road Network
- Ferry route

Drainage
- Coastline / River / Lake shoreline

Water areas
- Water area

Regions outside Canada
- Land Area

Abstract:

A simulation of projected changes in summer (June to August) precipitation from the period 1961 to 1990 to the period 2040 to 2060 for Canadian lands is shown here. Projected precipitation changes would not be evenly distributed geographically. Summer patterns show regions with both increases and decreases in precipitation. Warmer surface temperature would speed up the hydrological cycle at least partially, resulting in faster evaporation and more precipitation. The results are based on climate change simulations made with the Coupled Global Climate Model developed by Environment Canada.

Natural Resources Canada Ressources naturelles Canada

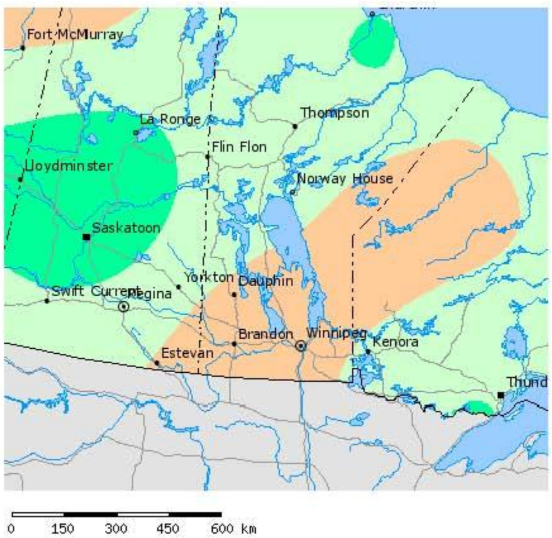
Canada

The Atlas of Canada

Print Map

Return to Map

National Winter Precipitation Scenario: 2050



Winter Precipitation Change from 1961-90 to 2040-60 (%)

- -30 - -20
- -20 - -10
- -10 - 0
- 0 - 10
- 10 - 20
- 20 - 30

Capitals (Canada)

- National
- Provincial and Territorial

Populated Places

- 1 - 4999
- 5 000 - 49 999
- 50 000 - 99 999
- 100 000 and greater

International Boundaries

- EEZ (200 mile)
- Canada / Kalaallit Nunaat dividing line
- International

Provincial and Territorial Boundaries

- Provincial / Territorial

Road network

- Road Network
- Ferry route

Drainage

- Coastline / River / Lake shoreline

Water areas

- Water area

Regions outside Canada

- Land Area

Abstract:

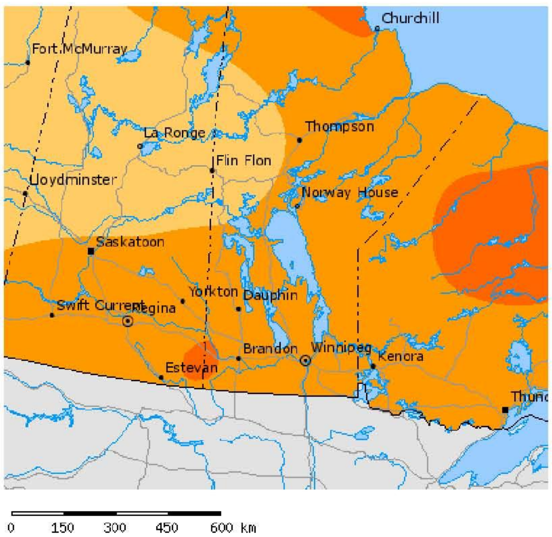
A simulation of projected changes in winter (December to February) precipitation from the period 1961 to 1990 to the period 2040 to 2060 for Canadian lands is shown here. In general, precipitation would increase as the century progresses and the climate warms. Projected precipitation changes are not evenly distributed geographically or seasonally. Precipitation is projected to decrease slightly for some higher latitude regions. Warmer surface temperature would speed up the hydrological cycle at least partially, resulting in faster evaporation and more precipitation. The results are based on climate change simulations made with the Coupled Global Climate Model developed by Environment Canada.

Natural Resources Canada | Ressources naturelles Canada | Canada

The Atlas of Canada

Print Map | Return to Map

National Summer Temperature Scenario: 2050



Summer Temperature Change from 1961-90 to 2040-60 (°C)
- -1 - 0
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6

Capitals (Canada)
- National
- Provincial and Territorial

Populated Places
- 1 - 4999
- 5 000 - 49 999
- 50 000 - 99 999
- 100 000 and greater

International Boundaries
- EEZ (200 mile)
- Canada / Kalaallit Nunaat dividing line
- International

Provincial and Territorial Boundaries
- Provincial / Territorial

Road network
- Road Network
- Ferry route

Drainage
- Coastline / River / Lake shoreline

Water areas
- Water area

Regions outside Canada
- Land Area

Abstract:

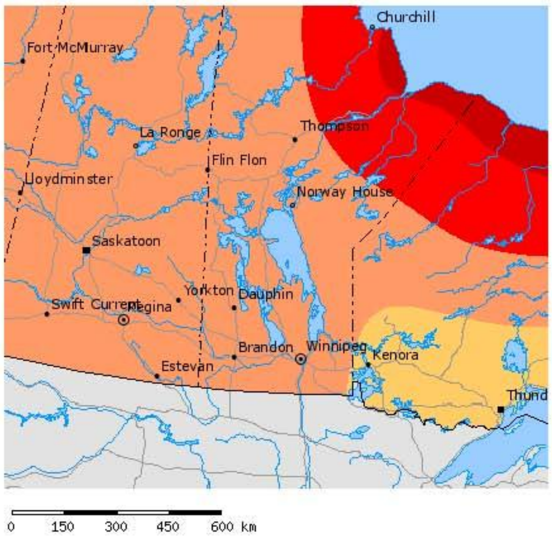
A simulation of projected changes in summer (June to August) temperatures from the period 1961 to 1990 to the period 2040 to 2060 for Canadian lands is shown here. The temperature changes would not be evenly distributed geographically. The model shows broadly similar but weaker and less geographically structured pattern than the winter pattern, which is warming for the interior and northern parts of the country. Temperatures would generally increase as a consequence of the projected increase in greenhouse gas concentrations in the atmosphere. The results are based on climate change simulations made with the Coupled Global Climate Model developed by Environment Canada.

Natural Resources Canada | Ressources naturelles Canada | Canada

The Atlas of Canada

Print Map | Return to Map

National Winter Temperature Scenario: 2050



Winter Temperature Change from 1961-90 to 2040-60 (° C)

- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8

Capitals (Canada)

- National
- Provincial and Territorial

Populated Places

- 1 - 4999
- 5 000 - 49 999
- 50 000 - 99 999
- 100 000 and greater

International Boundaries

- EEZ (200 mile)
- Canada / Kalaallit Nunaat dividing line
- International

Provincial and Territorial Boundaries

- Provincial / Territorial

Road network

- Road Network
- Ferry route

Drainage

- Coastline / River / Lake shoreline

Water areas

- Water area

Regions outside Canada

- Land Area

Abstract:

A simulation of projected changes in the winter (December to February) temperatures from the period 1961 to 1990 to the period 2040 to 2060 for Canadian lands is shown here. The temperature changes would not be evenly distributed geographically. The largest warming projected is for the interior and northern parts of the country. Temperatures are projected to continue increasing as the century progresses. Temperatures would generally increase as a consequence of the projected increase in greenhouse gas concentrations in the atmosphere. The results are based on climate change simulations made with the Coupled Global Climate Model developed by Environment Canada.

4.7 Conclusions

We wish to emphasize our view that for MH’s forecasting challenges, as in many others involving complex systems, it is not possible to show conclusively that any one prediction method is better than any other. Our goal in this chapter has been to describe some alternative approaches to the ones that MH has used, and apply them to MH’s aggregate water flow data. These approaches involve different statistical models, varying the number of lags in AR models, suggesting the use of other variables in AR models, and using variable transformations.

Our main focus, in keeping with the risk management element in our terms of reference, was on predicting the frequency and severity of low water flow events. We use simulations based on estimated AR models, and an entirely different method that uses results from extreme value theory (EVT) in which the observed low water flow events are used to fit the tail shape of that extreme end of the distribution.

We are then able to simulate the distribution of the minimum annual water flow that would be observed over a 94-year period. This is more informative than simple historical simulation. We find that the actual minimum lies roughly in the middle of our 95% intervals, and the means and medians of our simulated minima are greater than the actual minimum. On the one hand, this reassures us that the use of the actual minimum as a kind of benchmark worst-possible-case scenario is not unduly optimistic or pessimistic. On the other hand, because we find that the 95% intervals are fairly wide, we wish to caution that an over-reliance on the actual minimum could result in a mind-set in which it is not necessary tot consider the possibility of even worse outcomes, or indeed more beneficial water flow conditions.

The totally-different AR and EVT approaches provided very similar 95% intervals, which we consider to be an important check on the sensitivity of the results to the choice of model.

The same AR simulation method produces simulated five-year water flow minima within the same 94-year periods. Again, we find that the actual minimum is very close to the mean of the simulated minima, which is again reassuring, but we note that the 95% intervals are still fairly wide. The lowest five-year event in the next 94-year period may be very different from the one observed in the previous 94 years – the averaging-out effect in switching the outcome from one year to five years makes the outcome less severe, but no less variable.

We also suggest an AR model for monthly data that accommodates the strong seasonal patterns in monthly flows. We found a square-root transformation resulted in a model with better residual diagnostics tests, and found that the actual minimum is a worse outcome than the average of the simulated minima.

When the AR method was used for longer-run (20-year) predictions for the 2006-2025 period based on the record up to 2005, we find the predictive power of the model rapidly ebbs, which is typical of AR models and reflects the inherent difficulty of long-run predictions.

Our review of the climate change implications for MH water flows suggests that while precipitation patterns may not change a lot, fairly large temperature changes are predicted.

Chapter Five

Review of Risk Reports: A Critical Evaluation

5.1 Introduction

Our terms of reference stipulate that we review and evaluate all relevant reports and supporting data, systems, models and analyses which address risk management or contain information affecting risk management for MH and report on findings arising from this review. We have already reported on the models and systems used by MH in optimizing operations in the short term and planning in the long term in Chapter 3. We have also reported on best practices in enterprise risk management and Manitoba Hydro's risk management procedures, policies and practices in Chapter 2 and on minimum water flows and water flow modelling in Chapter 4. In this Chapter we will review most of the reports that deal directly and almost exclusively with the identification, measurement, control, mitigation and management of risks that we were able to obtain. Our review will rely on our analysis and findings in the previous chapters.

The reports that will be reviewed below include the following:

1) MH. Corporate Risk Management Report, October 2008.

2) The NYC's June 20, 2010 Public Document (Appendix A).

3) NYC Power Point Presentation on Manitoba Hydro. Risk Management Presentation. January 10, 2008 (Appendix G).

4) MH's March 2007 Comments on NYC's December 4, 2010 Report (Appendix B).

5) MH's May 2007 Comments on NYC's December 4, 2006 Report (Appendix C).

6) MH’s 2008 Middle Office Review of the NYC’s Reports (Appendix D).

7) MH’s October 2008 Middle Office Comments on NYC’s Long Term Contracts Risk Report (Appendix E).

8) MH’s May 2008 Review of NYC’s January 2008 and December 2006 Reports (Appendix F).

9) MH’s December 2008 Export Power Sales Risk Management Issues (Appendix G).

10) Nalinaksha Bhattacharrya. Report on Risks Faced by Manitoba Hydro in Power Exports. July 4, 2007.

11) Alan Peretz. MH Corporate Risk Management. Deloitte. January 26, 2004.

12) ICF International. Independent Review of Manitoba Hydro Export Power Sales and Associated Risks, September 11, 2009.

13) KPMG. April 2010 Reports and Appendices (Appendix H).

14) T. Simard and J.R. Joyce. 2002-2004 Drought Risk Management Review, Risk Advisory, January 18, 2005.

We did not succeed in obtaining all of the NYC’s risk reports. NYC insisted that any review of her reports will constitute an infringement on her intellectual property rights. NYC was quite adamant in her request that we do not read any of her work and not even other reports that referenced her work. Obviously we could not comply with her requests fully and implement PUB’s terms of reference. We opted instead to review exclusively her public document but complemented it with a face to face interview with her in New York City, as well as reviewing the reports prepared by MH and KPMG that dealt with her work and responded to her allegations. We did not want, however, to rely exclusively on secondary sources about her work. We tried repeatedly to meet her in person again. The initial visit with her took place in New York City over a two day period between June 6 and 8, 2010. Dr. Kubursi, accompanied by Mr. Gavin Wood our counsel. We have tried subsequently to initiate another discussion following the release of her Public Document, June 20, 2010, but failed. Another meeting with her would have given us the chance to ask questions and for her to explain her logic, methodology, calculations and implications of her statements in the public document.[24]

There is more than one way of meeting the request of PUB to review and evaluate these documents. It is possible to take each of the 14 documents separately summarizing its findings and analysis and critically evaluating its methodology, calculations and recommendations. We opted not to do so for a number of reasons. First, there is a good deal of repetition in these reports within and between them. Second, the risk reports are not of equal quality or relevance. Third, some of the reports are old and their findings have been overridden by developments and changes at MH and by recent events.

We preferred to define a small set of themes, each addressing a set of issues. These issues were analyzed from the various perspectives of the different authors and parties involved. We abstracted from the adversarial positions of the authors of these reports and dealt directly with the core issues they raised, reporting here on those that we deemed to be particularly relevant and critical for risk management at MH.

5.2 The Risk Themes and Issues

A large set of issues define the common focus of the risk reports to be reviewed, but these can be summarized to include the following themes:

First, we will consider the effectiveness, appropriateness and the predictive accuracy of Manitoba Hydro's suite of models in supporting optimum operations, capacity planning, financial forecasting and budgeting processes.

Second, a special section will be devoted to volumetric and drought risks as these are considered substantive and unique to Manitoba Hydro.

Third, the risk governance system at MH and its consistency with best practice will be evaluated in terms of segregation of responsibilities, competencies of staff, transparency, limitations and ownership.

[24] The details of the emails exchanged with her and our repeated attempts to hold such a discussion can be produced in the Hearing if necessary.

Fourth, we will evaluate the risk management system at MH in all areas including power generation, sales, reliability, equipment, human resources, finance and investment. Issues of risk identification, measurement accuracy, control, and mitigation will be analyzed separately and in relevant combinations.

Fifth, issues of risk capital adequacy, self insurance, asset-backed power sales, moral hazard and financial viability will be summarized and evaluated under different risk management regimes.

Under each theme it is possible to enumerate a large number of specific issues. For example, under the theme of risk management we can deal separately with legal, regulatory, environmental and financial issues. Each of these issues raises major concerns that must be addressed. There is an unfortunate concentration in most of the reviewed reports on a subset of issues and an over concentration on financial risk issues. These are central issues, however, our analysis identifies and evaluates several other additional issues, of equal relevance and importance, which have not been sufficiently addressed by previous parties.

5.2.1 MH Models: Issues of Inputs, Model Logic, Model Outputs, Predictive Accuracy and Relevance.

Manitoba Hydro supports, uses and relies on three major models (HERMES, SPLASH and PRISM) in its planning of operations, investment planning, financial forecasting and budgeting. Although these three models define the core of the modelling system at MH, there are other relevant models that did not receive sufficient attention in the reports that we reviewed. We single out MOST, PROMOD and the Load Forecasting model. In our opinion, all of these models have major bearing on risk identification, measurement and management. We will try to integrate them in the review wherever we feel that they will inform the discussion and evaluation.

We will begin by highlighting NYC's allegations on the three models. This discussion is followed by grouping her concerns into major issues and incorporating the different perspectives of MH, KPMG, ICF and others on these issues. Finally, we evaluate the relevance of the claims and counter claims to risk management at MH.

NYC has made many claims and advanced serious criticisms of HERMES, SPLASH and PRISM. Below we summarize her arguments:

- No governance controls are imposed on HERMES (172).

- The SPLASH system is being used for purposes for which it was not designed, and errors in long term forecasts are also noticeable (173).

- Numerous errors were made in the Generation Estimate and the IFF which are impossible to notice under a review policy since the reports from HERMES and SPLASH are concealed from output (178).

- Losses were being misreported as Drought when in reality they are mistakes in computer models (178).

- Model mistakes have also impacted accurate projections on Generation Estimate included in the IFF forecast and faulty financial projections to PUB (185). None of these mistakes were reported in the Variance Report (185).

- Lone-wolf numbers are generated from these models by 1-2 select employees in the Front Office which has had a cascading impact on flawed financials and projections (187).

- No one outside PSO has access to models' computer runs (190).

- The PRISM system was found to have multiple oversights and shortcuts rendering any analysis erroneous and not useful for Drought Risk measurement, mitigation or management. The PRISM tool does not provide any guidance on how to mitigate risk (191).

- Errors in PRISM were found at over $500 million dollars in quantifications to the PUB (192).

- The PRISM system is being operated by Front Office personnel and again by the Division Manager. This allows Front Office to fudge and conceal the true causes of risks and this use of the system violates best practice (193).

- § PRISM does not report any of the errors in the HERMES and SPLASH systems (194).

- § PRISM is defective because it does not reveal the true risks faced by the Province. It does not have a correct domestic load specification; it does not have Bipole III. This has given MH a false sense of security in its energy exposure. Errors in PRISM measurement were over $0.5 billion and the system is simply not a reliable indicator of exposure (196).

- § In an initial RM review there appeared to be many variations to the forecasted P&L due to operational modeling discrepancies, misalignments and risks in the HERMES hydraulic water management system. The model errors, as calculated by the independent RM oversight, total over $80 million per fiscal year, with some case model runs increasing this exposure to over $150 million (198).

- § The model risks in HERMES have had a direct attainable loss to Rate-Payers and rate-payer increases have been unnecessary (198).

- § The RM (NYC) reported difficulties in obtaining data needed to complete her risk management exercise. In particular, the RM had considerable difficulty ascertaining the relevant data out of the HERMES system to adequately quantify risk, thus giving cause to more concerns about the necessity for segregation of duties (199).

- § The claims of $600-$700 million of drought risks for one year are grossly overstated and conceal internal flaws in HERMES (215).

- § Power trading Floors have also noted and reported errors in EPM positions that were incorrectly used as inputs into HERMES (224).

- § The untracked errors have been large (in the order of tens of millions of dollars) of misrepresented financial risks and exposure to book fluctuations in HERMES being used for weekly position optimization (225).

- § Power trading continued to report numerous unmonitored errors in HERMES. During 2006 (while the RM Report was being completed) numerous emails were received “about bugs” in EMMA causing delays in FTR submission analysis (226).

- § In April 2006, over 600 MW of errors were found in HERMES in the lowering in output of generation in January in Limestone (227).

- § In August 2006, several million dollars of errors occurred in short bidding in the FTR pool due to a sudden decline from EMMA caused by operational errors (228).

- § EPM input and delete contracts from HERMES on an ad hoc basis, creating swings in energy production? Prices? as the contracts are removed and entered without protocols, policy and procedures (230).

- § Only 1-2 select personnel know the source code of HERMES (EMMA) and the company is reliant on one person to fix “bugs”. This represents a major operational risk. Sometimes transactions in MISO are delayed as numerous bugs are found in the system. The reports are also archaic; there is no documentation of the system. It is known as a “black box” and nobody knows what is going on in there. Errors in the $90 million dollar range were observed by NYC over a period of just one month (232).

- § In December, available energy sale reports from EMMA were found to be inaccurate by several hundred millions of dollars (233).

- § The Trading floor records also verified figures showing several hundred MW of off peak short positions purchased in MISO at RT prices over $80/MWh to serve Manitoba provincial retail load at 3 cents per KWh. In the on-peak, the net position showed Hydro PSO purchasing power at $91/MWh (CDN) to support average sales of $67/MWh (CDN). These losses could have been avoided and were caused by evident mismanagement in the HERMES operations (234).

- § The Decision Support System (HERMES) was not updated for several years to be current with market deregulation. Using stale prices even in deregulation and the Drought shows serious oversights and mismanagement in the PSO department (235).

- The HERMES operations were found to be basing their analysis on flawed and incomplete pricing data (236).

- Price optimizations are not clearly captured in HERMES (245).

- HERMES incorrectly inputs an identical price curve shape between on and off peak markets with a 100% shaping correlation. This is clearly incorrect. In months like February, there is over 262% and 202% error in market pricing in HERMES (247).

- NYC does not agree with the choice of external consultants' forecasts being used to represent prices. Their forecasts are not consistent with deregulated prices.. HERMES operators were also found manually "self-creating" the prices using faulty assumptions and incomplete data sets (248).

- In November 2006 HERMES was forecasting on-off peak prices to be greater than $39 per MWh during April and $44 during May. MISO cash prices and forward broker quotes were clearly more realistic in the $20-$39 per MWh range. A consistent error of $14 per MWh was the result of an obvious error in HERMES (249).

- Direct pricing discounts and errors were found in the Generation Estimates relying on prices from HERMES (250). A direct example from HERMES is April 07 when off-peak prices were forecast to be $39.70 per MWh in the IFF Forecast. RM review of all quotes found the forward spread at $23.87 per MWh. This is a monthly forward price error of $15.83 per MWh. Both MISO and Forward Curves were consistently in the $20 MWh range showing again that HERMES is using erroneous prices (252).

- Electronic evidence in Web-trader can verify all such purchases as a direct consequence of HERMES mistakes (253).

- Variance reports of the PSO do not accurately reflect errors in HERMES (254).

- Over $44 million of errors and direct rate-payer losses were found as a result of market pricing errors in HERMES (261).

- HERMES prices are not reflective of today's transactional environment (264).

- Any self-generated results that HERMES forecasts have been tested by the Division Manager and deemed accurate over the last years can be demonstrated to be inaccurate. The Back-testing must be conducted by critical and objective persons with appropriate skills (272).

Disregarding the invective language, the claim of being privy to "insider information" and the presumption of being the de facto risk manager within MH, the NYC still makes a number of serious allegations about defective, erroneous and stale inputs, flawed modeling structures particularly in the hydrology framework, manipulation of input and output data by Front Office, wrong forecasts, inappropriate use of the model outputs in power trading and FTR bids, the concealment of model data and results rendering the model a "black box". Furthermore, the Consultant claims that the Front Office engages in self-evaluation without any vetting and validation by Middle Office raising serious issues about the lack of checks and balances in reviewing and validating the models, inconsistencies among the models inputs and outputs; HERMES and SPLASH use different model parameters, inappropriate use of the models in risk assessment, and the lack of any contribution to risk mitigation especially in PRISM. The Consultant also presents a number of estimates of the costs these mistakes would entail for MH and the rate payers of Manitoba.

The Consultant claims that not using current market prices in HERMES has resulted in inappropriate water releases that sub-optimised operations, resulted in lower revenues in the range of millions of dollars, and exposed MH to greater financial risks. Furthermore, the Consultant alleges that the prices used in the Generation Estimate Report and those used in HERMES are different. This gives rise to different financial results confusing decisions and engendering inefficiency at MH. The Consultant is particularly unhappy about the current MH use of antecedent forecasting. NYC believes that this method can be improved by back-testing and disregarding water flow data before 1942[25]. Another allegation is about the critical assumption in SPLASH of perfect foresight, where the model assumes lake ending water levels that cannot be expected in the real world, raising

[25] This point and several points that follow were not in the NYC Public Document. We were made aware of them by the KPMG Report.

concerns over using the SPLASH model to estimate the cost of drought. Furthermore, NYC alleges that there are serious discrepancies between SPLASH and HERMES in regard to lake level balances which has resulted in different financial forecasts used in the IFF.

Several reviews of the Consultant's claims were made by MH and these are in the 4th, 5th, 6th, 7th, 8th and 9th documents above. KPMG's report has also addressed each of these allegations in detail and in many respects the Report summarizes and extends MH's reviews. Other reports have not addressed directly the NYC's allegations but have contributed to the issues raised by the NYC. For example, the ICF International Report (#12) deals with most issues of risk management at MH but it devoted a very short section to HERMES, SPLASH and PRISM (ICF, PP.118-120).

We will consider at length KPMG's responses to NYC's arguments and claims while at the same time evaluating the validity of the claims and their relevance to risk issues and themes.

KPMG begins its Report with a cautionary note that it did not audit the models to verify their computational accuracy (P.23). Rather, KPMG claims to have assessed the overall reasonableness of the modeling approach, input assumptions and model results. KPMG's focus was on HERMES as most of the allegations were made about this system, but SPLASH and PRISM were also reviewed.

The discussion below will examine the different arguments advanced by MH, KPMG and others in response to the concerns and issues raised by the Consultant. We begin with model inputs, then model structure, and finally model results, uses and implications.

5.2.1.1 Model Inputs: Prices

The Consultant makes many claims about MH using incorrect and stale prices that do not reflect the new environment that came in the wake of MISO, or the general deregulation dynamic in North America's energy market. Furthermore, the Consultant claims that HERMES operations were found to be basing their analysis on flawed and incomplete pricing data and that price optimizations are not clearly captured in HERMES.

MH believes that the criticisms of NYC regarding its use of stale prices that do not take into account the deregulation environment post-MISO are no longer applicable as MH has updated its process for incorporating market price outlooks into the generation planning process. MH purchases price forecasts for the next 12 months on a monthly basis and uses these forecasts to update hourly pricing assumptions within HERMES. MH is willing to confirm that at the time the Consultant was evaluating HERMES the relationship between model price assumptions and acquired forecasts was not clear. Currently, MH evaluates price forecasts and invests time and other resources trying to understand the factors that influence their formation. Furthermore, KPMG is satisfied that MH updates these prices regularly as new information becomes available. Significant changes in MISO prices have been observed as dependence on wind generation rises and the recession in the US deepens. These changes are now incorporated in HERMES. MH maintains that the major source of uncertainty it faces is volumetric, and that changes in prices result in minor variations in demand, planned import and export activity, and planned generation operations. The reason this is true, MH argues, is because there are a number of system constraints that limit its ability to change production patterns. One of the major constraints has to do with maximizing outflows from Lake Winnipeg during winter months to meet temperature-related demand and to offset the impacts of winter ice cover on hydroelectric generation. Lake levels must be maintained within level ranges allowed by its licensing agreements while the transmission capacity constraints on tielines connecting Manitoba Hydro to neighbouring markets impose binding quantitative restrictions on MH's choices. All of these requirements, it is argued, are not sensitive to prices and tend to have more impact on scheduling production than prices do.

The quantitative factors listed above only suggest that prices may not be as important in determining releases as these factors. But do they actually have less impact? This requires a formal assessment by running HERMES with constant prices and varying other variables and then keeping constant other variables and changing prices.

The quantity constraints are obviously critical determinants of MH's operations, but this does not eliminate the concern that the correct and most up-to-date prices should be used. The financial implications of price-mistakes can not be exaggerated. KPMG created a number of scenarios where they use forecast prices versus actual MISO prices in the optimization runs. The differences they found ranged up to $45 million (KPMG, 104-108). This is not a small amount of money and serves to indicate that accurate price forecasts are a key determinant of forecast net revenues.

In our opinion, it would make more sense for MH to concentrate effort on translating average monthly price forecasts into daily quotes, and to adjust MINN hub into an MHEB node to derive relevant and realistic prices. MH is apparently doing this and perhaps greater effort can be directed to figure out the best and most robust way to fine-tune these prices to reflect MISO prices. There is a considerable margin here for judgement and experience to bear on price forecasts' adjustments. Management at MH has noted that they adjust the forecasts downward if they believe the forecasts are optimistic or overridden by events. KPMG provided evidence that showed that purchased forecasts (apparently purchased from one commercial source) in 2008 were optimistic as they were substantially higher than MISO prices (see Exhibit 3-6 in the KPMG Report). Given that errors are to be expected in the purchased forecasts, it is prudent that MH considers alternatives. One such alternative is the use of quoted future prices to forecast future spot prices. MH may have to consider the use of this alternative and the construction of forward price curves. There appears to be a consensus on the need to do so between KPMG and NYC and we agree with the need for the development of these forward price curves.

The Consultant believes that the discrepancies in the prices used in the Generation Estimate report and those used in HERMES are the result of the lack of checks and balances within MH and the shortfall in best practice in control governance. KPMG examined the discrepancies noted above and found that they reflect the fact that prices in the Generation Estimate report were actual average prices that were obtained by MH for import/export transactions in April 2006. In contrast, the prices in HERMES' runs reflect price inputs for April 2007 and were average time-weighted (by strip) price forecasts for on-peak and off-peak periods (KPMG, P.71). KPMG believes that some of the discrepancies that NYC has highlighted between Generation Estimate and HERMES are the result of the Consultant's misinterpretation of HERMES' output. Since the discrepancy noted by the Consultant referred to the same set of prices, this assertion by KPMG is correct.

The Consultant also alleged that MH assumes a 100% correlation between on-peak and off-peak prices. The actual prices in HERMES had a correlation coefficient of 0.59 and 0.62 whereas the actual market data (ex-post) show correlations of 0.81 and 0.84 for the MHEB node. The true correlations were higher than both MH's and the Consultant. The latter claimed that the correlation was only 40%. In this respect, neither party has used the correct correlations. The assumptions made about the presumed correlations between off-peak and on-peak prices need to be rooted in actual calculations.

Finding 1
Prices in HERMES are not stale; they are based on adjusted forecasts from a reputable forecast provider. Making adjustments to expert forecasts is reasonable and necessary but MH may wish to be more formal, transparent and to document the adjustments it makes. As well, MH may have to consider an alternative to purchase forecasts that uses forward price curves (this could be a complementary exercise). NYC has raised a valid point about using the forward price curve alternative and the need for using the same price inputs in the Generation Estimate report, HERMES and SPLASH, but has not been justified in her general pronouncements on using stale and erroneous prices.

5.2.1.2. Model Inputs: Historical Water Flow Data

The Consultant has expressed concerns that the historical water flow data that MH relies on in many of its calculations including dependable energy and drought costs is flawed. The concern is about the quality of this data. Using pre - 1942 water flow data is not justified in her opinion because water flow data for the period before 1942 is not high, and the numbers are not reliable for any serious use. Most of this data (before 1942) were interpolated from the limited number of gauging points available then.

MH has had to contend with the opposite criticism that it does not rely on a longer historical water flow series. Some have gone as far as looking at tree rings and other paleoclimatic data to warn of droughts that were more severe and longer than the worst on record using the 94 water flow series.[26]

We recognize the data interpolation concern, but we suggest a different approach for dealing with it. The Consultant recommends dropping the data points from year 1912 to

[26] McCullough Research. Review of ICF International Report on Manitoba Hydro Export Sales. December 2, 2009.

year 1942. That would be unfortunate. In contrast, we suggest that the data should be used as a single sample series from a large set of statistically developed series using different autoregressive processes. The concern that the given historical series may be flawed is understandable, but the solution recommended by the Consultant is not tenable or realistic.

KPMG calculated average flows using different starting periods to show that these averages would create an unjustified optimism. Keeping the data before 1942 depresses the average flow and lends an element of conservatism to the data. This is an interesting point of view but does not detract from the seriousness of the claim that the specific constructed series upon which MH bases much of its planning of dependable energy has to be verified statistically.

KPMG has also documented the use of average flows as the basis of integrated resource plans and in operations' models in several utilities. The list includes Bonneville Power Administration, BC Hydro, Puget Sound Energy and the US Bureau of Reclamation.

The Consultant has also argued that basing financial forecasts on average flows and mean reverting flows infuses the system with an element of uncertainty and therefore risk. This is true if water flows are below average (there is no real problem with above average flows as long as they are not sufficiently high to cause spillage and flooding). This is an issue of volumetric risk that we will deal with later in this Chapter. It is still an issue of accuracy of inputs to the extent that SPLASH is based on this average flow calculated from this single historical series to calculate revenues and other financial parameters. The Consultant thinks that this is an issue that requires assigning risk capital to deal with given that nothing can be done about changing water flows. In our opinion the issue is deeper than that. It is contingent on using the historical series as a basis for a statistical process that generates many series which can be used to define the 95% confidence intervals on expected minima and averages.

> ***Finding 2***
>
> The Consultant claims that the accuracy of the historical water flow data before 1942 is not high. However, in our opinion, to discard this series is unjustified. The use of the historical series as if it is the only reliable series on which to base calculations of dependable energy is also not recommended. By drawing over a 100 different samples of 94 year flows generated by a statistical process AR (3), which we have complemented by an extreme value distribution, we have demonstrated that the minimum of the actual historical series is consistent with the average of all the minima computed from the stochastically generated series (see Chapter 4).

5.2.1.3. Model Inputs: Energy Coefficients

The Consultant claims that that there are differences between HERMES and SPLASH: energy production coefficients used in both systems are not the same, and SPLASH is a more robust model in this regard.

Production coefficients are numerical parameters that transform water flow into energy.[27] They capture the relationship between the volume of water, head (forebay elevation minus tailrace elevation), and the quantity of water through the powerhouse. The head at each generating station tends to decrease with the increase of flow (making the equation above nonlinear and complex). This is especially so for MH which has a system with relatively large water volumes but low heads.

The nonlinearity of the relationship makes the efficiency of the generating turbine a variable which changes with the volume of water flow. This efficiency can change between 78% and 92% and may peak at a flow that is 70% to 80% of the maximum flow without spillage (KPMG, 87). To solve an LP problem with nonlinear coefficients requires an iterative process. HERMES simply iterates the solutions with different values

---

[27] The equation is specified as follows

$$P(Power) = [Fb - Tw(DSE, Q_T)] \times e(Head, Q_p) / 11.8^4 \times Q_p$$

(KPMG, 88). Fb=forebay evaluation, Tw = tailrace elevation (a function of downstream elevation (DSE) and total water (Q_T), e=efficiency, Q_p = quantity through powerhouse.

of the production coefficient until it converges to a single constant consistent with the production coefficient function.

The production coefficients in HERMES are the product of this iterative process and tend to vary with water volumes. In SPLASH, these coefficients are averaged. HERMES uses shorter time strips than those in SPLASH and these tend to be different than the average over the period of one month. This is perhaps the reason why the coefficients vary between the two models.

Actual production will reflect the actual efficiency factors at the generating stations. Different estimates of these coefficients are not likely to generate large financial implications as claimed by the Consultant (over $26 million annually) except in the intervening periods when the iterations have not converged to the true value of efficiency factor of the generator. This is based on the presumption that if there is an overestimate of the efficiency factor, then operators will run through less water to generate the target level of generation. If this water is spilled and not stored, it is lost and revenue is not derived from it. If it is stored for subsequent use there will be no real losses. There is then a potential for loss from over-estimates and possibly underestimates of the efficiency factor, but these losses are typically low. This is particularly the case if management decisions on forebay levels are made on an hourly basis to optimize arbitrage opportunities during the day. These represent overriding EMMA results based on inaccurate efficiency factors.

Finding 3

Different production coefficients in HERMES and SPLASH are a problem. This problem pertains to the nonlinearity of the generation equation that links water flows to energy and the time strip differences between the two systems. Harmonising the two systems on a common platform will minimize these discrepancies. The revenue losses due to this problem are limited and nowhere close to NYC's exaggerated calculation of $26 million.

5.2.1.4. Flawed Modeling Structures

NYC has made many disparaging remarks about errors in HERMES, SPLASH and PRISM. Most of these comments were not vague and unclear. HERMES consists of many modules but EMMA is the major core component. EMMA is linear programming system and similar systems constitute the standard operational planning tools at almost all large utilities in North America and abroad. Most of the detailed comments of NYC were about HERMES' predictive power, wrong inputs and inappropriate use. We have not seen any explicit or documented criticism of its logic.

We have reviewed HERMES and seen some of its runs. We are satisfied that there is nothing in its structure that is inconsistent with similar systems at other Canadian utilities in BC, Quebec or Ontario. We have made several remarks consistent with KPMG recommendations for formal documentation of the model, for the need to train a larger subset of staff on its use and support, on the need to consider coupling it with standard risk evaluation tools to transform it into a stochastic model, on the desirability to reconcile its structure, inputs and source code with other systems at MH (and perhaps situating it on a common platform with the other systems), on the need for external review and validation, and on the need to involve the Middle Office in backstopping and interpreting its results. On the whole, we felt strongly that HERMES is a valid model, it serves MH well and what is needed is an expansion of its structure and modules, some adjustments to its parameters, few add-ons, validation of its forecasts, and formal documentation of the system.

SPLASH is an equally relevant and useful system but again being a home-developed system it requires internal and external validation, formal documentation, oversight, broadening the human resource base working with and supporting the model, reconciliation and integration of the model with the rest of the systems at MH, and expanding and harmonising its solution routines with the most up-to-date solvers. We are in agreement with KPMG on these needs and suggestions. We are, however, cautious about the assumption of perfect foresight and its implications for SPLASH's results and calculations. This assumption leads to solutions that are not relevant in the uncertain real world and may lead to results that would preclude optimal responses. Again integrating into SPLASH's structure a stochastic core that goes beyond recycling 94 water flow assumptions would be a major improvement. KPMG does not explicitly recommend this, but they have recognized the need to introduce a margin of ignorance and uncertainty into SPLASH to make it more realistic and consistent with actual practice at MH.

PRISM has its own merits too and has introduced a new stochastic perspective to the suite of models at MH. We do not share NYC's judgement that PRISM is a faulty system, but we are sympathetic with her call for expanding the risk tools at MH, coupling the Web-trader with a risk tool, and moving towards evaluating hedging products and mitigation strategies using the model.

Neither KPMG nor NYC covered the domestic load forecast or the use of scenarios in the Economic Outlook exercise. We have tendered a few suggestions in Chapter 3 that we believe would complement the discussion and evaluation of HERMES, SPLASH and PRISM.

Finding 4

HERMES, SPLASH and PRISM are indispensable operational, planning and risk assessment tools at MH. These decision support tools are consistent with the standard systems currently used in many leading utilities in North America. They can be expanded, harmonized, and integrated. They should be reviewed internally and externally and upgraded and updated regularly. BC Hydro and Hydro Quebec have or are moving to dynamic and stochastic systems: MH may wish to follow suit. A hydrological sub-model to complement HERMES and even SPLASH should be considered seriously as water management issues become more complicated under possible climatic changes.

5.2.1.5. Model Governance

The Consultant claims that there is no governance of the models at MH, only 1-2 select personnel know the source code of HERMES (EMMA), and the company is reliant on one person to fix "bugs". In her opinion, this is a source of a huge operational risk as sometimes transactions in MISO were delayed as staff waited for someone to fix the numerous bugs that were found in the system.

KPMG notes that the operation of the models is heavily reliant on the knowledge of a few highly specialized individuals and that formal documentation of the systems appears to be very limited (KPMG, 109). Few expressed the concern that at this time the models appear as “black boxes” with a limited number of the staff understanding what is inside.

The Front Office alone is running the models, interpreting their results, validating the forecasts, reporting on forecasting accuracy, inputting the data and backstopping the entire systems. The Middle Office is conspicuously absent from this arena.

Finding 5

There is wide agreement among the reviewers of the models (KPMG, RiskAdvisory, KM and others) that the systems require formal documentation, more staff should be trained on using and supporting the systems, that external reviews are needed, and that the Middle Office should be involved (particularly in verifying and checking the results). The PRISM model should also be run in the Middle Office.

5.2.1.6. Model Output: Lake Balances

Water storage in the lakes is a crucial factor in drought risk management and in optimising inter-temporal allocations of production. One of the most serious advantages of dynamic programming is the explicit solution for the optimal path of releases and storages. Unfortunately, none of the current models at MH is a fully dynamic system. Both HERMES and SPLASH use proxy methods to take time and inter-temporal allocations into account. HERMES uses weekly time strips whereas SPLASH uses monthly time strips.

Low levels in storage in a given year leave less for the next year. This will compromise optimality over time if it violates Hotelling principle— with zero or low storage costs, refraining from drawing down the water stored is optimal if future price increases in energy exceed the real rate of interest.[28] Lower levels in a given year will leave less to sell in the future and may necessitate imports at higher prices and/or the use of alternative costly generation[29].

The Consultant has correctly noted that in some instances HERMES solutions called for lower levels of water balances in the lakes than is warranted by future prices and prudent risk management. Furthermore, the Consultant noted that there are discrepancies in lake water levels generated by HERMES and those reported in the Generation estimate.

The Consultant calculated losses of $78 million in 2006/07 fiscal year due to suboptimal end of period lake water balances.

KPMG was not able to duplicate the calculations of this loss claimed by NYC and has found that the discrepancies on the various lakes between the Generation Estimate and HERMES were minimal and could not have exceeded $1 million (KPMG, 83-85).

Finding 6

Notwithstanding the small dollar amount of discrepancy between the Generation Estimate and HERMES solutions, these discrepancies raise concern about the accuracy of the model and the reporting system. The real problem is more profound. HERMES and SPLASH are static models and do not handle time in a manner consistent with dynamic programming. MH may wish to consider some of the existing dynamic programming systems in use at similar utilities in North America.

[28] Harold Hotelling. April, 1931. The Economics of Exhaustible Resources. Journal of Political Economy. 30(2):137-175.

[29] The Hotelling principle applies within a range given an upper bound on the capacity to store water.

5.2.1.6. Model Output: Predictive Accuracy

No model can be expected to forecast the future with perfect accuracy. Many assumptions are typically made to simplify the structure of the model; these are necessary compromises to ensure that the model's complexity does not impede its usefulness.

The Consultant believes that the model is used to underpin trading and that its forecasts are used in formulating FTR and other price-volume bids in the Day Ahead and other future markets. The Consultant claims that many errors have been found in HERMES' forecasts and these have resulted in large financial losses.

The Consultant is particularly unhappy with MH's antecedent forecasts of the water flow. The antecedent forecasting model used in HERMES adds a layer of modelling assumptions and is responsible for operational error forecasting. These forecast errors result in financial losses for MH and rate payers. It is suggested that MH must back-test all forecasts for accuracy. The Consultant states that relying on simple regressions is not prudent or advisable; the erroneous forecasts can lead to mistimed anticipatory release of water, or falling lake levels due to operational mismanagement decision as opposed to true volumetric risk.

KPMG has evaluated the errors that arise from the use of antecedent forecasts by actually examining the regression equations. KPMG believes that these equations are used to optimize operations. It makes sense to predict accurately the historical relationship between current flows (releases) and future releases. The real argument here is about the risk exposure that a wrong forecast would entail for MH. KPMG argues that this risk should be balanced against the benefits of operational efficiencies.

KPMG reviewed the regression results that underlie the antecedent forecasting used by MH. It found that the R^2, t-statistics and p-values of the regression coefficients between energy-equivalent flows in a month and the energy-equivalent of flows in the remainder of the year are all robust and indicative of an appropriate statistical relationship to rely on for forecasting.

In Exhibit 3-5 (KPMG, 61), the regression results for the different months are presented. There are some high t-statistic values signifying that the null hypothesis (that the coefficient is zero) can be rejected. The low R^2 in March, April, May, August and

February are not comforting. Relying on a single variable (one lag) is perhaps not sufficient for most months to predict the next month's value[30]. Our monthly data regressions worked best when a longer lag structure was used (Chapter 4).

We have analysed the forecasting accuracy of HERMES in detail in Chapter 3 and have found a number of relevant results on this issue. In particular we can comfortably assert the following:

First, on average HERMES predicts annual generation well. It over-predicts almost equally to what it under-predicts. Where it failed, however, was in the crucial period of the critical year of low flow. The error in 2003/04 is large, with over 11% error (see Table 3.1 and Figure 3 in this Report).

Second, HERMES under-predicts total revenues. For the ten year period of forecasts, it under-predicted three times (3 out of 10) in 2001/02, 2003/04 and 2004/05 (Table 3.2 and Figure 3.6). The overall error is relatively low except in 2003/04 and 2005/06--two widely different years. The average of the absolute errors is 5.1% (Table 3.2).

Third, the simple forecasting errors of total cost are both large and frequent and there is an obvious strong trend to underestimate the rise in costs. In 2002/03 HERMES under-predicted total cost by 31% and in 2006/07 by 36% (Table 3.3 and Figure 3.7). Only in one year (1999/00) did HERMES over-predict total cost.

Fourth, the prediction errors of net revenues are high and vary between over-prediction and under-prediction. There is a concentration of over-prediction in the latter year of the sample but with limited errors, but large errors and over-prediction in the middle period around the drought. It is interesting to note that HERMES captures the turning points in the system. It predicts a loss when a loss occurs, although the magnitude of the errors is very large. The average of the absolute errors is almost 20%.

Fifth, another perspective on HERMES' predictive accuracy is presented in Table 3.5 and Figure 3.9. It is clear that the second forecast is far better (lower prediction errors) than the first. The accuracy of HERMES rises with time and the incorporation of more recent

---

[30] Many statistical problems arise regarding the validity of the regular statistical diagnostics when there are many missing variables.

information improves the forecasts. It seems that the time of the year the forecasts are made is crucial. Forecasts made in July are far better than those made earlier. By July the water conditions after spring rain are more reliable. Errors of the first forecast are high and reveal over-prediction. The second forecast still suffers from over-prediction of exports but the relative magnitudes of the deviations decrease (Table 3.5 and Figure 3.9). The improvement in the second forecast over the first forecast could be an indication of a deficiency of the HERMES model's lag structure and the antecedent forecasts. The concentration on a single lag in the flow equations may need some adjustment to improve the forecasts.

Finding 7

The predictive accuracy of HERMES can be improved. The antecedent forecasts need to be reviewed. Back-testing should be used. The practice of continuous forecast reviews has definite benefits.

5.2.1.7. Model Use: Utility and Relevance

The three models used at MH have a long track record in supporting operational planning, financial analysis, budgeting and system expansion. Their relevance is not in doubt. The issues are with predictive accuracy, governance, and most importantly uses.

The Consultant alleges that HERMES is used in supporting trading decisions. The Consultant contends that electronic evidence in the Webtrader can verify all such purchases as a direct consequence of HERMES mistakes (253). Also in August 2006 several million dollars of errors occurred in short bidding in the FTR pool due to sudden decline from EMMA due to operational errors (228). It is claimed that Power Trading Floors have also noted and reported errors in EPM positions being ad hoc and incorrectly used as inputs into HERMES without any governance (224). Furthermore, untracked errors in HERMES have been large (in the order of tens of millions of dollars of misrepresented financial risks and exposure) because HERMES is being used for weekly position optimization (225). It is also claimed that Power Trading Floors continued to report numerous unmonitored errors in HERMES. During the period 2006 while the RM Report was completed, numerous emails were received "with bugs" in EMMA causing delays in FTR submission and analysis (226).

There is no question that HERMES's outputs are of relevance for power trading and the relationship between HERMES and Power Trading is in both directions. KPMG and we concur that to suggest that HERMES is used exclusively or directly in power trading, or that its forecasts are directly used as bids for trade is far fetched. First, MH trades in both the long term firm energy and in the opportunity market (RT and DA). The latter are almost half of the total power trading outside domestic load. Second, decisions about trading are backstopped by traders and several groups within MH. It is difficult to imagine that the trading processes are mechanized and linked directly to HERMES runs without vetting and intervention of others.

Finding 8

HERMES is not directly linked to the trading floor and its forecasts are not used as bids on the floor. But whether HERMES is relied upon to inform decisions in the opportunity market is another matter; models are useful tools for informing users' decisions, not replacing them. It makes sense, however, to dispel this concern by streamlining and documenting trading decisions and practices.

5.2.2 MH Volumetric and Drought Risks

The heavy dependence of MH on "good water" conditions is a critical attribute of the utility. The Utility generates 98% of its power production from Hydro sources. The large financial losses in one year totalling $436 million triggered by a severe one-year (2003) drought underscored the volumetric risks to which MH is exposed. MH has committed itself to supplying large volumes of power under long term contracts and is committed to meeting domestic load fully and unconditionally. Supplying firm and dependable energy under high variability of water flows is a major challenge for MH.

The quantification of a drought risk is undertaken by many of the reports we reviewed. However, we will concentrate only on those that we believe to have quantifyied these risks systematically and appropriately.

ICF International considers MH's quantification of risk exposure to drought to be reasonable (ICF, 108). They assert that the scenario examined by MH is sufficiently stressful. They consider it equivalent to adopting a 95% confidence interval. This is based on the assumption that in any given year there is only a 3.1% chance (3 droughts in 97 years) of the onset of a drought equal or worse than the five year drought examined. A 95% confidence interval would have a 2.5% chance of occurring or being worse. They base this assertion on the assumption that conditions in any future year are unknown to MH and each year can independently be assumed to have an equal chance of being the first year of this severe drought.

ICF observed that other financial stress tests involved multiple risk factors changing simultaneously, and recommended that MH begin running tests of this nature. ICF also recommended the use of Monte Carlo simulations of cash flow or net revenue at risk. This, in their opinion, would serve to track risks and to facilitate communication across the organization and with stakeholders regarding progress of the drought and the likely financial impacts of the Drought Preparedness Plan. ICF believes this would build upon ongoing work and facilitate the additional examination of short term (1-2 years forward) hedging tools.

MH simulates the recurrence of water flows of the historic five year drought between April 1987 and March 1992 beginning the forecast year 2010/11 and extending through 2014/15. Then MH assesses the financial consequences of this drought relative to IFF 2008. More specifically, MH compares the net revenues in 2008 relative to those that would emerge under the drought.

Based on this methodology, MH has estimated that over a 5-year drought period, net export revenue would be reduced by $2.2 billion (excluding financing costs). Such a drought would have the potential of depleting MH's baseline retained earnings by 20% in the first year. If this drought continues to persist for 5 years, it has the potential to deplete 90% of baseline retained earnings. Including the cost of financing, the losses could exceed $2.7 billion. If other risk factors were to be included—higher import prices, appreciation in the exchange rate of the Canadian dollar, etc. the drought losses would increase.

According to ICF, MH is sensitive to the fact that while records have only been kept for the last 97 years, it is possible to face the risk of droughts of potentially longer durations

(ICF, 111). The treatment of joint events would reduce the probability of occurrence of the joint event. ICF calculates that the probability of occurrence of a drought of five years is 3.1% and if high electricity prices have a 50% chance of occurring during a drought this would reduce the probability of occurrence of both events to 1.5%; there would be only a probability of 1.5% for drought with high electricity prices to occur (ICF, 113).

There are a few problems with these calculations. First, the probability of occurrence of a 5 year drought is not 3.1% unless one assumes that the historical series is made of events having equal chances of occurrence. Considering this value to fall within the 2.5% tail of the distribution is based on considering the historical series to define a normal distribution. Furthermore, the assumption that higher electricity prices are a totally independent event and are not correlated with a drought is perhaps unrealistic.

The Consultant raises many questions about MH's exposure to drought risk and suggests that MH is exaggerating its risk estimates to conceal other operational inefficiencies.

"Manitoba Hydro has inadequately categorized and quantified its true 5-year Risk Capital exposure. The methodology being used to arrive at that $2 billion dollar number, that is in place to date, including the statistics is flawed in arriving at a true 95% exposure." (Public Document, 203).

The Consultant goes on to claim … "This stress test is an unrealistic and impractical measure of risk that provides Hydro with no secure basis for quantifying or expanding its risk capital or hedging its true exposure for financial planning. An overstatement of projected risk capital would also envelope millions of dollars of operating risks and errors in internal hydraulic systems" (Public Document, 206).

The Consultant produced its own estimates of the risk exposure of a 5 year drought. The Consultant states that over a 5 year drought period the order of magnitude of risk capital is between $760 million and $1,250 million. To this one can add operational risk capital exposure of $550 million to $860 million and Credit Risk Capital of less than $100 million. The Consultant suggests that all of these were derived by using a variation on a variance/covariance method at the 95% confidence level (Public Document, 198).

The estimates of the Consultant are based on assuming each year in the 97 water flow years to be independent of the other years. Her estimate of the probability of a drought of the magnitude used by MH to estimate its exposure to a drought risk is infinitesimally small; this probability is estimated as (1/93)^5 which is equivalent to a chance of one in 6.9 billion years.

This estimate is contingent on a number of seriously flawed assumptions (KPMG, 95). First, it assumes that the probability of a future year being a drought year is drawn as one observation from the 93 observations. Second, each flow year is totally independent of the prior years. Third, there are many low flow years other than the one drawn. Fourth, drought years appear in the very series the Consultant is drawing observations from to include successive (correlated) years.

KPMG examined the 94 years (1912 to 2005) of water flow data and found that many years are correlated and the Consultant did not take into account the statistical information embedded in the series. A simple examination of the data reveals that low flow years do not happen independently, rather they appear in clusters (KPMG, 97). Testing for autocorrelation, KPMG confirmed that indeed auto correlations among two, three and four years are positive.

In Chapter 4 we tested higher order autocorrelations and found that the AR(3) (three year dependence) is high and significant. We also examined extreme value distributions and concluded that repeated drawings from this series (100 drawings of 94 values) confirmed the AR (3) process, and allowed us to estimate the probabilities of observing the actual minimum and even lower minima. What emerged from this analysis is that the minimum used by MH to determine its dependable energy corresponds closely to the mean of all minima (the actual minimum lies roughly in the middle of the 95% intervals), and that the chance of getting a smaller minimum is less than 2.5%.

In Chapter 6 we quantify the drought risk under both MH conditions and more stringent ones. Our numbers are close to MH or even higher. We also include multiple risk factors working in combination and assess the probability of their occurrence.

Finding 9

The probability of a drought occurrence is higher than those estimated by the Consultant or ICF. The costs of a 5 year drought are in the order of magnitude used by MH rather than those calculated by the Consultant and the inclusion of other risk factors increases measurably the drought costs. It is also clear that the water flow data are serially correlated and that a statistical process confirms that Manitoba Hydro is correctly using the low flow years in 1937-1942 as the basis of its dependable energy calculations. While a more severe drought than the one experienced in 1937-1942 is possible, its probability of occurrence is 24 times in 9400 years (or 1 in 392 years).

5.2.3 MH Risk Governance Issues

MH has made major progress in streamlining its risk management governance architecture and is continuing to make strides towards best practice. The Middle Office is functional and is entrusted with increasing risk management policy formulation, oversight responsibilities, identification of risk and some risk measurement. A large set of committees and procedures have been instituted to ground governance of risk into the full spectrum of the Organization.

The Consultant has been adamant in her criticisms of the Front Office for monopolising decisions and information and for not sharing its knowledge and systems with the Middle Office. The Consultant calls for segregation of duties and instituting two sets of eyes for reviewing all major estimations, decisions, interactions and reporting. This is claimed to mitigate errors and opportunities for misreporting and misstating of financial earnings and fraud. The Middle Office must be wholly independent from the Front Office if it is to undertake correctly and appropriately its oversight functions. Furthermore, the Middle Office must report to the Senior Vice President Finance and Administration and should be situated at a higher level of the Organization in order to discharge its responsibilities. The Consultant also asserts that MH Middle Office and risk management functions do not meet the best practice standards at other utilities. Furthermore, the skill set at the Middle Office is not strong enough to undertake seriously its new functions and responsibilities.

KPMG reviewed the governance structure at MH and reported that it is evolving and converging toward best practice at other utilities and is consistent with the recommendations of the Committee of Chief Risk Officers. KPMG is particularly satisfied with the Export Power Middle Office relationship with the rest of the Organization and particularly with the Chief Financial Officer. However, KPMG would like to see the market risk quantification capabilities of the Middle Office enhanced and the skill set available to it augmented by the required expertise in market and risk management (Risk Market Analyst and Credit Risk Analyst). Furthermore, newer and top of the mark risk quantification technologies (both software and hardware) should be made available and used at this Office.

KPMG Report highlights the recent stipulations of risk limits and transaction processing controls at MH. These, it is argued, have added rigour, transparency and clarity to risk management. Operational staff know exactly the limits within which they can operate and the reporting structure for authorization and sign-offs. Moreover, risk reports are now regularly produced and circulated. These reports are in formats that can be easily read and understood by Management and Board. Given that most of the transactions of MH are low risk in nature (as they are for short durations and within set limits) and given the conservative nature of MH's risk management practices, it appears that MH is able to manage its market, credit and even volume risks in a prudent manner.

Still, KPMG produced a long list of recommendations for MH to align its risk management with best practice. These include:

- Contract review should include risk quantification and assessment.
- Middle Office should be involved in the review of export contracts.
- Mark-to-Market methodologies should be used to assess all risks.
- Drought risk should be calculated regularly using probabilistic stress tests.
- MH has specified risk limits only to "power related transactions" in the area of Merchant Transactions and consumer credit. MH should continue to develop further limits and limitations on most transactions and the calculation of VaR wherever possible.

We concur generally with the KPMG assessment and the set of recommendations they have tendered, but have added a few of our own.

The Risk Map and the Control Map are clearly in place at MH. There may be some questions about how comprehensive is the list of identified risks and the extent to which the probabilities and expected values of outcomes and consequences are the products of objective criteria. MH needs an Individual Responsibility System where responsibilities for identification, assessment, quantification, mitigation and avoidance are identified and specified and where these responsibilities are assigned clearly and unequivocally to specific managers and staff. This process ensures that each risk requiring a response has an "owner" and that responsibilities are segregated.

The CRMR will be more complete if there is attached to each risk identified and colour coded, a component of the Organization identified as responsible for it. In the absence of this responsibility matrix, it will be difficult to define and implement a risk accountability structure for the Organization. Furthermore, a superstructure is needed to evaluate, validate and verify different assessments. At each level a dual structure is needed; one to undertake the assessment in situ at the operation level and another to validate it at a management level. The function of the Middle Office here is critical for the success of the management of risk function.

The qualitative aspects of risk management are well in place at MH. Unfortunately, this is not the case when it comes to the quantitative areas of risk management. There is almost no mention of the word "quantitative" in the CRMR. Risk management is ultimately about quantification of exposure and calculation of the magnitudes of losses and threats. It is about statistical density functions, confidence intervals, expected values and variances. Quantification of risk and expected values are calculated at MH.

There exist a number of models (particularly PRISM) and systems that are used as part of the operations of MH particularly at the Front Office – but these are not part of the function of risk management at the Middle Office. Their use and numbers should be part of the risk management plan that needs to be verified by the Middle Office. Depending on a single risk tool is not advisable. Many commercial risk analysis tools (software) are now available that may be worth evaluating and adopting to complement the existing system @RISK at MH.

It is highly recommended that MH organize specialized teams to assess major identified risks for their probability of occurrence and their impact on business objectives. Risk teams should elicit assistance from "Subject Matter Experts (SME)" or functional units to assess the risks in their respective fields, but they should all funnel their expertise and calculations to the Middle Office.

The governance structure of risk management at MH can benefit from restructuring and re-alignment. The CRMC is now part of Finance & Administration Division and reports to the Senior VP of the Division. It is now on the Organizations' Organogram (Figure 2.7) at the lowest slot. Perhaps unintentionally, this placement conjures an image of lack of importance and lack of centrality of its stature, functions and contributions. The Middle Office is the appropriate place for the CRMC, but it has to be part of the SVP Office, possibly in the first slot. At this time, the CRMC is only an advisory body and is without any executive powers. The Front Office argues that it is not needed since 70% of the risks are volumetric and these can be easily, more efficiently and effectively handled by the Front Office.

There is an evident multiplicity of bodies dealing with risk (EPRMC, PSOMC, and CRMC, etc.). In itself, this is not a problem, but it becomes a problem in the absence of a well defined integrated and centralized structure that can harmonize the lines of authority, obligations and accountability. In the final analysis all of the risks must be combined and integrated. Dealing with all of them simultaneously is critical for the success of the Organization. Quantitative assessments of risks are based on a simultaneous evaluation of the impacts of all identified and quantified risks on a coherent basis with a focussed approach and integrated administrative structure. This can best be achieved through Joint Risk Management Committees organized and supervised by the Middle Office through CRMC.

Risk Preparedness Plans and manuals are needed for all costly risks. A Drought Preparedness Plan is a critical necessity. It must be completed and instituted in the working mechanisms of the organization immediately. The preparedness plans should not stop at the Drought Plan. There are many other emergencies and drastic events that may occur that need to be expected and plans made to deal with them. A broad preparedness plan can make substantial contributions to the effectiveness of risk management services and plans at MH.

Best practice requires that any business transaction should be evaluated on its own as well as in terms of all the risks that it may entail. This should be done by the business unit directly involved (Front Office) but an independent review must be undertaken by the Middle Office.

Many functions and activities in the organization are operating with deterministic models and frameworks. This is not particularly helpful for an organization that has taken the challenge to manage and control effectively and proactively all of its risks.

Finally, a detailed training program involving realistic simulation games dealing with risk occurrences and plans should be developed for the Organization. These training programs and learning by-doing practices have helped other organizations in dealing with their risk exposures and threats.

Finding 10

ICF International, Dr. Bhattachryya, KPMG, RiskAdvisory and KM all share the general appreciation that MH's Middle Office is evolving and that major progress has been made towards best practice. We all also recognize that much is needed in terms of strengthening the HR expertise set at the Middle Office, the independence of its functions, the MTM measures of all risks, the expansion of risk limits standards and process control limitations to all aspects of MH functions, the development of an Internal Responsibility Matrix, the need for quantification of risks at Middle Office, and its involvement in contract risk assessment. Most of us recognize that there is some merit in NYC's comments about risk governance issues with respect to the independence of the Middle Office and the greater need for oversight, but we all disagree with her claims of lack of competence in the CRMC, and the concealment and manipulation of data by the Front Office.

5.2.4 MH Risk Identification, Control, and Mitigation

Manitoba Hydro faces many risks, including some that are typically encountered by other power generating utilities and a few that are unique to MH. The generic list identified by MH includes 11 major categories and 48 subcategories. Even this list is not exhaustive. A few additional risks can be added. Forecasting risks and errors is not mentioned and can easily be included. Environmental portfolio standards, carbon taxes, etc. are also sources of risk that impinge on the business objectives of the Organization and their variability can substantially influence net earnings.

A good number of these risks are qualitative in nature and therefore are not amenable for measurement, but they still affect in a substantial way the operations of the enterprise.

The list of quantifiable risks is long, but can be prioritized with respect to the risks' probability of occurrence and the magnitude of their impact effects. In this way, it is possible to concentrate on a few critical risky events with large consequences.

A. **Market**
   1. Domestic
      1. Competition
      2. Uneconomic Loads
   2. Export
      1. Regulatory Environment
      2. Competition
      3. Transmission
      4. Special Interest Groups
      5. Protectionism
      6. Domestic Requirements
      7. Commodity Availability

B. **Financial**
   1. Exchange
   2. Interest Rates
   3. Credit
   4. Inflation
   5. Gas Price Volatility
   6. Gas Derivative Instruments
   7. Capital Structure
   8. Shortage Pricing / Fuel Price Volatility
   9. Power Financial Instruments

C. **Environmental**
   1. Water Supply / Drought
   2. Climate Change / Kyoto Protocol
   3. Operational Impact and Infrastructure
   4. Reliability of Supply

D. **Infrastructure**
    1. Loss of Plant (all Property, all Perils)
        1. Dam and Dike Structures
    2. Insufficient Supply (Drought Peril)
    3. Prolonged Loss of System Supply
    4. System Shutdown (Short Term)
    5. System Shutdown (Natural Gas – S.T.)
    6. Technology
    7. Special Interest Groups.
    8. Emergency Response/ Business Continuity

E. **Human**
    1. Safety / Health / Workplace Violence
        1. Infectious Disease
    2. Union / Employee Issues
    3. Succession Planning
    4. Technology

F. **Business Operational**
    1. Supply Chain
    2. Operational Controls

G. Reputation

H. **Governance / Regulatory / Legal**
    1. Regulation and Licensing
    2. Export Market Access
    3. Legal Compliance
    4. Contracts and Ventures
    5. NERC/MRO Reliability Standards

I. **Aboriginal**
    1. Relationships
    2. Legal

J. Emerging Energy Technologies

K. Strategic

There is a wide divergence among the reports in terms of their coverage of risks. But a common list can be constructed, and this includes a small subset of events that have high probability of occurrence and large consequences. The following risks are included in this list:

- Volumetric / Drought Risks
- Long Term Contracts Risks
- Export Price Risks
- Congestion Price Risks

- Natural Gas Price Risks
- Transmission Risks
- Load Forecasting Risks
- Exchange Rate Risks
- Interest Rate Risks

The common theme among these risks is their association with long term contracts. A significant number of the risks listed above are correlated with the long term contracts risks.

5.2.4.1 MH Long Term Contract Risks

The risks listed above exert independent influence on many of the key variables of the system, but their main influence arises from the risks embedded in long term contracts. This issue more than any other has pre-occupied the authors of the previous reports and has received an inordinate amount of attention.

The discussion will be organized around the following questions and themes:

First, the appropriateness, from a long-term business strategy and risk exposure perspective, of Manitoba Hydro entering into long-term firm contracts 20 or 30 years into the future.

Second, the adequacy of price that Manitoba Hydro derives (or will derive) from export sale transactions in both the long-term firm and the short-term opportunity sales.

Third, the adequacy of curtailment and other measures negotiated in the new contracts to reduce the risk exposure of MH during a drought .

Fourth, the risks assumed by Manitoba Hydro in selling long-term firm energy from dependable resources considering volumetric risks and the obligation to meet domestic load.

Fifth, the extent to which Manitoba Hydro should be involved in pure merchant energy trading transactions.

5.2.4.1.1 Appropriateness of Long Term Export Contracts

MH has, by design and since its inception, installed more capacity than is needed to meet Manitoba's load. It has targeted export sales to other provinces (Ontario and Saskatchewan and Alberta) and primarily to the US. Clean, reliable hydro energy exports are a reflection of Manitoba's comparative advantage and resource endowment. Manitoba treats its hydro energy exports in a way that is no different from the way Alberta treats its oil exports.

Hydroelectric generation stations and dams are built in "chunks" and often in anticipation of larger home demand in the future. There is always a lag between installed capacity and domestic load. The latter grows gradually and takes years to reach installed capacity.

As long as installed capacity exceeds Manitoba peak load, there is always a surplus that Manitoba can sell comfortably outside the province. In 2008/09, MH had an installed capacity of 5,480 MW while Manitoba peak demand, which occurs in the winter, did not exceed 4,477 MW (KPMG, 125). MH generation of electricity was 34.5 TWh and Manitoba load was 21.3 TWH (Manitoba Hydro 2009 Annual Report). Average demand is typically lower than peak demand (50%) for most of the year and larger surpluses arise that could be exported.

MH is not capacity constrained. Even with no addition to capacity, MH has considerable installed capacity to export surplus energy. There is surplus energy in most years but this cannot be guaranteed every year. We have already noted that the abundance of water in Manitoba is only exceeded by its variability. In other words, MH is not capacity constrained, rather it is energy constrained. The variability of water, the exposure to several droughts (some of long duration and extreme severity (1937-1942)), and the overriding requirement to meet Manitoba load has forced MH to make a sharp distinction between installed capacity and firm and dependable energy.

MH defines dependable energy as the hydroelectric power that can be generated under the lowest river flow conditions in the historical record including wind energy and thermal generation as well as from firm energy imports.

Two criteria have been stipulated in MH's power resource planning in order to guarantee sufficient dependable energy for Manitoba's need (Manitoba Hydro Policy G195, Generation Planning).

Capacity Criteria:

"MH will plan to carry a minimum reserve against a breakdown of plant and an increase in demand that is 12% above the Manitoba forecast peak demand each year plus the reserve required by any export contract in effect at the time."

Energy Resource Planning:

"The Corporation will plan to have adequate energy resources to supply the firm energy demand in the event that the lowest recorded coincident river flow conditions are repeated. Planning studies, to meet the firm energy demand, may include up to a maximum of 10% of the energy demand in Manitoba to be supplied from energy reserves on interconnected utilities, provided an energy purchase contract is or will be in effect during the time being studied."

The availability of power for exports is not a sufficient condition to do so. It is also necessary that net revenues from these exports are positive. To the extent that MH may need to import energy in the winter and in time of shortages, exports provide both a financial cushion and a physical one. The financial cushion is provided on account of the foreign exchange earned that could be used to pay for imports and the second is that the transmission capacity that can take surplus power to distant markets can be used to import power in times of deficit.

ICF International has studied this issue thoroughly and has produced strong arguments in favour of long term export sales of firm energy and expanding the system through new massive investments. As a matter of fact, ICF has argued that the two are inseparable. The arguments of ICF have been accepted by and included in those of KPMG. We will present these arguments followed by the Consultants opposing views. We will summarize our findings and state our position on these issues.

The arguments of ICF in favour of this strategy are provided below. When KPMG added a new argument to the original ICF ones, it will be recognized in situ.

First, there is the issue of surplus of power. ICF argues that even without additional investment in hydroelectric power plants, MH will have surplus power for sale, and the only feasible market is the export market. Also, exports are a far larger share of generation for MH compared to other Canadian utilities exceeding those of Quebec, BC, Ontario and New Brunswick with a share of over 31% of total generation. In other words, the issue is not *whether,* but *how* to be involved in exports. The fact that hydro surplus is variable complicates the management of the MH export business, but does not change the imperative to maximize value and dispose of the surplus for revenue.

Second, the involvement of MH in the export market is a natural consequence of its early involvement in this market and the acquisition of knowledge and expertise in this market. ICF specifically argues that MH's extensive historical experience has facilitated the development of sophisticated structures and capabilities to manage exports and hydro variability. These structures continue to develop and improve and should not be wasted.

Third, success in the export market is a major reason why MH has the lowest domestic electricity rates in Canada and North America. ICF argues that export prices greatly exceed MH's embedded generation costs, and the revenues are used to decrease domestic rates and/or to provide the financial capacity to withstand droughts without rate shocks or heavy use of additional Province backed financing. In this way exports, are part of MH's risk mitigation strategy.

Fourth, ICF believes that MH's proposal to enter into new long-term firm contracts to export hydro power backed by the accelerated construction of new hydro facilities will provide several types of benefits, including lower MH rates to domestic consumers than would otherwise be the case. To the extent that the proposed prices will on average be above MH's costs and average expected spot prices, large surpluses will accrue to MH. ICF quote recent MH estimates that show that two of the three proposed long-term firm contracts will provide savings of $153 million on a present value basis by 2041.

Fifth, ICF believes that the savings reported above are very conservative in that they address only two of the three long-term firm contracts. They also do not account for the up to $2 billion (Canadian, as expended nominal dollars) in transmission costs that the buying US utilities will expend for the construction of expanded transmission between the utilities and the Canadian border. In the absence of long term contracts, MH would likely bear the majority of these costs. These transmission linkages can be crucial for the Corporation in the event of a drought that is worse than the worst-on-record, or if there are changes in reliability requirements under NERC rules. For example, Hydro Quebec is effectively paying for new DC line construction in New England to support its exports. Finally, the calculation does not factor in the benefits of lower price volatility, decreased risk of rate shocks and the decreased financial stress on MH compared to spot sales.

Sixth, – MISO can raise questions about the reliability of existing capacity and transmission capabilities of MH. Since the passage of the US 2005 Energy Policy Act and subsequent regulations, US transmission entities increasingly face enforceable centralized standards for reliability. There is a risk that MISO might conclude that the current transmission system's export capabilities are not robust enough to consider MH exports to be firm. This can lead to either a decrease in export pricing by changing their status from firm to non-firm energy or MH would have to pay for the construction of new lines. But, even if MH were willing to make these investments in transmission, it is unlikely that MH could get the necessary approvals and permits needed to have the transmission built in the US without the active support of the buying US utilities and it certainly would be much more expensive than having the US utilities paying for construction. It is clear that the construction of the new transmission lines by the buying U.S. utilities enhances MH's firm export capability.

Seventh, the expansion of hydroelectric generation capacity, combined with long-term firm contracts, is an advantage for Manitoba as it permits MH to avoid the risks involved in developing fossil fuel power plants. There has been already strong opposition to and limits on the operation of MH's single coal plant that is slated for closure in 2018. Were MH to pursue alternative capacity expansion such as fossil plant development, this could only be done subject to the legislative restriction that coal can only be used to support emergency operations, and there is a risk that opposition to and the difficulty of sitting and permitting, would eliminate the fossil fuel option entirely. Furthermore, there would be increased exposure to fuel price and environmental regulatory risk.

Ninth, – MH considers developing a sizeable retained earning cushion (equity) to help it mitigate risks of unforeseen but highly probable droughts of long duration and intense severity as a secure way to protect it against the necessity of large rate increase or having to borrow large amounts that need to be guaranteed by the province. This mitigation plan causes in part MH to accept a reasonable level of risk exposure associated with exports. It is also to be noted that MH is actively working to decrease transmission related risks, and has a mixed contract-spot sales strategy designed to limit volatility while still having exposure to market.

Tenth, MH has long term financing needs for expanding its future power generation capacity. These capital expansion plans involve long-term fixed rate debt and fixed-debt service payments. Raising this debt is facilitated by a steady and predictable flow of earnings which also help in negotiating lower financing rates. This steady and predictable stream of earnings will also be used to defray the fixed-debt service and support MH's ability to finance its capital expansion program. These capital expansion projects are undertaken now, ahead of their need, to meet Manitoba load in the hope that the surplus firm energy they produce can be used to finance these developments so that they become available for Manitobans when they will be needed at little or no sacrifice to them.

Eleventh, with large fixed costs and low variable costs, steady and less volatile revenues are needed to synchronize and match costs and revenues.

Twelfth, the export proceeds from long term export sales are in US dollars. Imports, if and when needed, have to be paid for in US dollars. Furthermore, debt obligations are primarily in US dollars. The US dollar denominated export proceeds act as a good hedge for currency fluctuations. The exchange rate changes have been very wide in the past few years and are likely to remain a feature of the future.

Thirteenth, MH sells electricity abroad in both the opportunity market and through long term firm contracts. This mixed and balanced (50% in the opportunity market and 50% in firm long term contracts) portfolio is itself a risk mitigation measure. It provides revenue stability as well as limits exposure to firm commitments. It avoids seller regrets in the event that future prices exceed the fixed contract prices.

Fourteenth, the large capital projects to be undertaken by MH will act to pre-empt further expansions in the US. With large wind projects expected in the near future, it is a strategic imperative to stake a claim in the market ahead of others plan to expand.

The arguments above make a number of claims and raise a number of issues. Are export revenues subsidizing Manitoba's rates? Are the risks embedded in these contracts sufficiently low and mitigated by MH? Can the terms of these contracts be improved in favour of MH? Is the new capital expansion program warranted and necessary? Is timing of the capital expansion program staggered enough and appropriately? Are the negotiated long term prices in the contracts high enough and above likely opportunity prices? Is the expectation of more stringent environmental measures realistic? Is MH capturing all the rents in the environmental attributes? Is the transmission capacity squandered on long term contracts instead of yielding to more profitable short term opportunity trading?

Questions of this nature have been raised by some of the reports under review and in particular, by the Consultant. More than 150 points of her 280 are devoted to long term contracts that she believes are exposing MH to risks that exceed by far the drought risks. She even claims that drought risks are exaggerated to mask the exposure embedded in long term contracts and other operational inefficiencies. A sample of her concerns (many of the claims are repeated several times) is discussed below:

1. MH has erroneously identified "Drought Risk" as the primary source of financial exposure to the Corporation. It should be "Long Term Contract Risk (Public Document, 1 and 43).

2. MH has not sufficiently addressed the market changes inherent in the US deregulation. In particular, the Contracts offered to US counterparts have been (and continue to be) priced in a manner that is no longer consistent or competitive with deregulation prices (2). MH continues to base its contract prices on stale formulas that lead to under valuing / mis-pricing its energy (3).

3. The Consultant's concern is not about the strategy to sell forward, as it is the pricing formula mechanisms and their disconnect to market prices and market risk that raise serious concerns (4).

4. The Consultant believes that MISO cash prices were higher than the contract prices, noting that FY 06/07 is a case in point (5).

5. The Consultant reports that Power Trading has verified that MH real-time losses of Export Power Marketing for the fiscal year 06/07 have been in the order of $100 million (7) and that these losses far exceed normal risk management (8).

6. The EPM contracts serve energy below market price, incur a huge financial penalty and also utilize valuable transmission access without any consideration of forward risk capital (9).

7. The Consultant estimates a half a billion dollar loss on the Long Term Contracts (LTC) that could have been used more appropriately to build risk capital (10). Export Power Marketing strategy is operating at a significant Economic Value Loss (EVL) (11, 12 and 64).

8. The Market Risk Capital and Tolerances are not being set around MH's LTC (16). Responsible risk management would mandate Market Risk Capital Adequacy prior to the execution and signing of LTC (17).

9. NYC recommended the immediate ceasing of the Export Power Market contracts until risk capital adequacy is obtained (18).

10. Contracts are signed without Middle Office review (19).

11. Risk capital needed to cover just two LTCs is approximately $846 million with 95% confidence (20). Given that MH estimates a total revenue of $4.1 billion over the next 15 years from the LTC, then the risk capital needed to cover it is $0.8 billion (21 and 86).

12. MH should reduce its forecasted revenue and allocate adequate risk capital to support the energy portion and structuring of risk associated with the LTC (23).

13. The buy-back commitment in the LTC of a single counterparty could top $700 million to support paltry revenue of less than $20 million (24).

14. While MH has built its business on "preserving long term relationships" with key business customers, it was noted that during the drought in 2003/04 none of the counterparties offered any discounts or price breaks to it. On the contrary it was

those that traded in the short term with MH that offered price discounts (26, 61 and 72).

15. The EVL of the combined firm-energy sales contracts exceeds $1.9 billion (27). Even retroactively on generation assets such as Limestone, these contracts have generated negative rates of return and have inadvertently self-incurred an exorbitant 50% of what has been considered Drought Risk to the rate payers (50)

16. Up to 2017, firm commitments should not exceed 100MW in most months (29).

17. The sale vs. no-sale scenario is incorrect and it leads to incorrect analysis of the risks and returns to Manitoba rate-payers (31).

18. MH is overselling energy in the long term that it does not have. It is already short between 400 and 600 MW (32). Because MH is in an oversold position it is exposed to import price risk over the next 25 years (33, 34). MH is overselling energy in the form of firm commitments (LTCs) and essentially on a 95% confidence basis approximately 600-700 MW until 2017 and approximately 670-800 MW past 2022 (37). In the Fiscal year 2025/26 the book under flow scenario requires an excessive 1000-2000 MW of imports (39). MH's book is oversold until new generation comes online and the book is being sold completely as non-firm and there is no new generation available to support those contracts (55).

19. Once MH starts to experience a real low-flow year in MISO and it has to import energy in excess of 900-1000 MW, even the stress tests of $4.2 billion and $7-$9 billion may be mild. The $20 billion in rate-payer increases are being used to fund overselling and inefficiencies in US markets (36).

20. The Consultant believes that MH uses the wrong components of energy in its computation of dependable energy (38).

21. The Consultant does not accept that the new generation will increase the dependable energy supply and argues it will do nothing to relieve the over sold position (40). This oversold position could lead to a misstatement in projected rate increases of 3 multiples (42).

22. Now that the US market is operating under open access, there is no longer a need to structure LTC in the same manner they were structured prior to open access (45 and 48).

23. Both energy and capacity portions of the contracts were found to be sub-optimized (46).

24. MH is incorrectly assessing the value of numerous options and benefits of how it could modernize and structure its Contracts under deregulation (49).

25. The Consultant argues that there is a misperception around MH's forward book being long and that any losses or risks due to reductions in inflows/precipitation are only taking away from "opportunity costs." The Consultant believes that this statement is factually wrong and misnomer when it pertains to Earnings at Risk (EaR) (51).

26. Losses to MH could easily exceed $310 million and be as high as $700 million in a single year just to support the LTC even when prices are mild (52).

27. The firm-commitment book contains 850 MW of export power sales to a single counterparty and this is the source of concentration of an excessive amount of the Corporation's market-risk exposure (53).

28. MH is not looking after its own interests in selling short carbon free electricity and will not pre-empt other energy expansions; it is too small to make a significant effect on capacity expansions (57 and 58).

29. Costly hedging and real exposure to risk are caused by poor structuring of LTC which necessitate imports. It is this poor structuring of LTC that exposes MH to major risks and not drought (59).

30. The Consultant wants MH to refrain from signing any new contracts unless substantial rewrites are made to the contractual provisions to eliminate risk and/or the pricing and volume terms are completely re-negotiated or the contract is restructured to the best interest of the Corporation to preserve retained earnings (63).

31. MH should note that the majority of the single year exposure under low flows of over $293 million and a high of $700 million is directly attributable to maintaining commitments to under-priced Contracts (65).

32. Since MH has not experienced volumes of this magnitude before MISO and market deregulation, the ongoing uneconomic underwriting of long term deals may have detrimental impacts on the Corporation's debt, net revenue and rate pay increases (67)

33. Diversity contracts should be renegotiated or usurped with more modern current deregulation replacements with other counterparties (68 and 69).

34. A lack of ISDA's is of detriment to price mitigation and leaves MH inefficiently positioned with a handful of select counterparties (69).

35. Some of the new contracts have disadvantageous reverse-call options (70).

36. A conservative estimate of MH's EVL and Risk Capital is greater than $1.4 billion over the next 7 years alone (71).

37. Both the RFP and Term Sheet review process needs to be overhauled to include best practice approaches (80, 82, and 84).

In summary, we identify the following questions as being deserving of further review and factual analysis:

First, should long term exports be stopped and Long Term Contracts scrapped?
Second, are rate payer increases subsidizing export sales to the US?
Third, is MH's forward book oversold?
Fourth, are the new prices, curtailment provisions and the import upset price sufficient to prevent seller and buyer regret?
Fifth, are the Consultant's estimates of risk exposure correct and warranted?

There are many other issues that were raised by the Consultant some of which we have already dealt with under risk governance and best practice. A few concerns by the

Consultant were not in our opinion valid or sufficiently serious to be considered and analyzed.

5.2.4.1.2 Should Long Term Exports Be Stopped and Long Term Export Contracts Be Scrapped?

Voluntary contracts are based on voluntary exchange and the capture of gains from exchange and transactions when the costs of transactions are low. Contracts also allocate risks between the parties. The generally accepted principle here is that contracting parties will not enter into binding agreements unless both parties feel that the agreement confers on both more gains than what they can realize in its absence. Rational parties would attempt to maximize their win-win positions and would settle their counter claims at a level where no single party can realize more than it has in the agreement.

Scrapping contracts on the presumption that MH would realize more gains in another agreement is not realistic or to be expected. A single party cannot be expected to re-contract a better deal. MH invests a great deal of effort and care on structuring these contracts in a manner that would maximize its rent (gains from trade) subject to the willingness of the counterparty to remain in the agreement. Trying to extract more benefits from the counterparty would not work; the counterparty could walk away from the agreement should it feel that it can do better without it. The Consultant seems to believe that the counterparties have had the better deal, but it would be costly and risky to test this sensitivity at a time when the energy market is becoming more volatile (large wind energy in the pipelines) and current electricity prices are extremely low (with natural gas prices at their lowest levels) and will remain so for a while. Higher fixed prices could perhaps be extracted but perhaps at the expense of the large transmission investments to be made by the counterparty. These investments are crucial for MH to remain in the firm and reliable status in MISO. In their absence firm prices of MH could easily turn into lower non-firm prices. Curtailment provisions are advantageous and a major risk mitigation measure to have. Higher prices than those negotiated may have to be compared to the opportunity of securing firm transmissions and/or curtailment clauses.

Finding 11

There are many benefits for MH to be in the export market and specifically, the long term fixed price firm exports market. The long list advanced by KPMG and ICF outlined these benefits which include: diversification of the export portfolio, matching fixed costs to fixed revenues, guaranteeing secure investment in transmission infrastructure by counterparties and qualifying for priority transmission rights, pre-empting excess capacity by competitors, guaranteeing access to long term finance on favourable terms, raising export revenues in US dollars to defray import and debt costs in the same currency (providing MH a hedge against exchange rate fluctuations), greater access to firm imports when needed, and a host of other advantages. Even the Consultant admits that the issue is not selling in forward markets; the benefits from this would outweigh costs.

5.2.4.1.3 Are Export Revenues Subsidizing Local Rates?

The main contentions of the Consultant revolve around adequate contract prices. She has advanced a number of propositions suggesting that these prices are formulated and structured in a way which is not consistent with deregulated prices, that they are below what MH could achieve, that they fall below existing market prices (RA or DA prices), that they are not high enough to match import prices and that this discount is forcing rate payers to subsidize US consumers. Most of these contentions can be settled easily by evaluating facts.

KPMG presents Exhibit 4.12 (KPMG Report, 149) that compares contract prices with MAPP and MISO on peak prices between 1997 and 2009. ICF has done the same but only for 1997 and 2008 (ICF, Exhibit 6-8, 86). Both have concluded that the contract prices are higher than historical MISO spot market prices. More specifically, [redacted]

[redacted]

Below is a summary of MH's Pricing of electricity as determined in Long-Term Export Contracts (Source: Pricing of Long-Term Export Contracts, provided by Manitoba Hydro).

"Long-term electricity price forecasts and market analyses are usually purchased annually from a group of industry consultants (for the 2008 forecast 5 expert consultants were used). The forecasts are adjusted to a common Canada-US border pricing point and are aggregated on a weighted basis following a detailed analysis."

In addition, a [redacted] to the 'on peak' price forecast for dependable energy to reflect the expectation that [redacted] will be willing [redacted] over the long-term. This [redacted] reflects MH's historical experience in selling a high value, long-term product, backed by MH's dependable energy resources.

MH's Electricity Export Price Forecast is used as a benchmark for the setting of the minimum offer prices for long-term export sales. MH's actual offer prices may be higher reflecting the customer's alternative cost of supply and perceived demand for MH product. Final contract prices may reflect additional value provided to the customer or MH following negotiation. These may include, for example, more favourable escalation terms, ownership of environmental attributes or an appropriate sharing of transmission costs.

Furthermore, in conjunction with the price forecasts as inputs into the process of contract price determination, MH uses avoided cost analysis to benchmark the long term price against the counterparty's long term marginal costs. KPMG reports that although there is some evidence that this is done at MH (excel files), it is not done thoroughly enough or documented sufficiently to be a satisfactory procedure.

The price forecast and the avoided cost procedure are coupled in benchmarking the minimum offer price for long term exports. There are also other factors that influence the outcome of the contract negotiations. These include [redacted] It would be wrong to see the price in isolation of these additional values that a lower price may have been necessary to acquire these attributes.

It is also to be noted that the contracted price is a real price (nominal price adjusted for inflation). Real price increases over the term of the contract are stipulated in order to capture real increases in electricity prices. Typical escalators include the [redacted]

Whatever the value of the final price embedded in the long term contracts, it appears to be higher than the past average in the spot market. This is a comforting result but needs to be considered against marginal cost, average total cost and import prices before generalizations can be made about which party is subsidizing the other, or that the risk exposures in long term contracts is sufficiently mitigated. We will deal here with the first issue.

According to MH's recent Cost of Service study, costs attributable to export sales constituted approximately 13% of total costs, whereas export sales contributed 32% to total revenue. This shows that if the allocation of costs to domestic sales and exports is credible and believable, exports are contributing more to revenues than to cost and therefore it is quite likely they are contributing to the sustainability of low domestic rates. This question is contingent on a proper allocation of total costs.

MH has only four choices. It can sell its energy surplus in long term contracts or it can sell the surplus in the opportunity market either in real time (RT) or in the day ahead market (DA). Of course it can store the water for another period and refrain from generating in the current period. But in order to store there should be enough storage capacity. This we will assume it is there.

The optimal generation is determined by equating the prices to marginal costs and refraining from current production whenever expected price increases minus storage costs are higher than the interest rate. If prices in the long term market are higher than long term marginal cost, more should be sold in the long term or vice versa.

We have calculated the long term marginal cost of generation for MH; it is quite low and could be declining over the relevant range given the large fixed costs involved in generation. There is no question the prices negotiated are significantly higher than marginal cost. This means that if MH has more capacity it should use it in long term export sales.

The question of total cost and average cost is different. Our calculations are heuristic but point to a higher average cost for exports than the one claimed in the Cost of Service, but our estimates are still far below price. If there is any ambiguity here, it is over the proportion of total cost defrayed by exports, and not over export revenues exceeding average cost.

Finding 12

Contract prices embedded in long term contracts are sufficiently higher than historical average spot MISO prices. These prices are carefully constructed using weighted long term forecasts and hopefully estimates of the long run marginal cost of counterparties. The export prices are higher than long run marginal cost of MH and average total cost. This suggests that export revenues can be relied upon to subsidize domestic rates when they are higher than import prices. We are not in a position to verify the claim in the Cost of Service that exports account for only 13% of total cost but we can verify that they contribute 32% of total revenue.

5.2.4.1.4 Is MH's Book Oversold?

The Consultant claims that dependable energy is incorrectly estimated by MH. While it is not explicitly stated, the Consultant is not happy about using the lowest water flow data before 1942 in estimating dependable energy. She has already voiced concern about this data. But her objection is centered on including wind and even expensive thermal energy from inefficient gas turbines and unclean coal in the calculation of dependable energy.

NYC would prefer that all surpluses be sold in the spot market. She showed some evidence over a very short period that spot prices exceeded contract prices and that even off-peak prices in some (2006/07) winters have exceeded on-peak prices. These exceptions are not sustained and the trends are of a different kind where on-peak prices are higher than off-peak. Long term contract prices exceeded spot on-peak prices for most of the years except for some parts of 2006 and most of 2007.

The real concern of the Consultant is the necessity to import in time of shortage (dependable energy below load and firm exports) at prices that have on average been quite high. During the drought in 2003/04, these prices (shortage prices) were sufficiently high that that literally devoured MH's retained earnings in one year.

The Consultant has gone on record stating that the new generation will not relieve her major concern of the high probability of dependable energy falling short of load growth and firm exports committed to in the long term contracts. The increased energy from Keeyask and Conawapa will reduce dependence on purchased imports or the need for thermal power; they represent an expanded capacity to harvest head from the same amount of water.

> ***Finding 13***
>
> The expanded capacity when Keeyask and Conawapa are completed will increase dependable energy and sales in the long term at higher prices than spot MISO prices will increase revenues. Expected declines in spot prices beyond 2011 will make these contacts more valuable. High import prices will remain a threat in time of shortages but new contract limit prices on these imports will define an upset price for MH. The inclusion of wind and out of money thermal energy in dependable energy is a stretch but they represent such a small portion of total generation that their inclusion or exclusion is not a material concern.

5.2.4.1.5 Will the Prices, Curtailment Provisions and the Import Upset Price in the New Contracts Prove Sufficient to Prevent Seller and Buyer Regret?

The new contracts are structured differently than the old ones in several respects, but primarily by the inclusion [redacted]

Contract prices are set at the expected long-term nominal price with escalators to account for inflation and other factors that affect expected prices. MH uses the [redacted]

[redacted] The latter only reflects the changes in prices in a basket of consumer goods, whereas the implicit GDP deflator reflects price changes in the entire basket of final goods and services produced over a year. The escalators are not linked to market prices of electricity because that would change the fixed price contract into a variable one which contradicts the logic of fixed price contracts.

The specifics of these escalations are clear and can be summarized as follows:

The contract with [redacted] allows the escalation of [redacted] If, however, the [redacted] then capacity and energy prices from [redacted] calculated using [redacted]

In the [redacted] contract, the capacity [redacted] until April 2022; no escalation after 2022, but the capacity price is not allowed in any year to fall below [redacted] in 2008 dollars. The [redacted] The fixed energy price in any year is not allowed to fall below [redacted] in 2008 dollars.

In the [redacted] contract, the [redacted] in 2008 dollars. The guaranteed energy price is [redacted] in 2008 dollars.

These prices are [redacted] The reasons why counterparties will pay these relatively prices are based on four factors:

A) Guaranteed access to a large pool of reliable energy.

B) Access to clean (carbon free) energy with environmental attributes transferred to them.

C) Avoided risks of price changes. They are guaranteed a firm price with certainty.

D) The major part of the volumetric risk is assumed by MH.

The new curtailment clauses are far better than those in the old contract and should prove their worth in the event that they are needed. It may be argued that better terms could have been negotiated but that is pure speculation. If that is the case, one would wonder why MH would refrain from wrestling better terms from the counterparty. The issue with this thinking is the treatment of each component of the contract separately from the rest of the components. The contract has to be seen in its entirety as it is outcome of protracted and difficult negotiations: the agreement is a set of compromises acceptable to both parties.

The exact structures of the curtailment provisions negotiated differ by contract. In the [redacted] contract the curtailment causes include:

In the event of adverse water conditions (MH unable to meet firm load), MH has the right to reduce guaranteed energy [redacted]

Curtailment can be exercised under the following circumstances:

[redacted]

MH would follow a curtailment priority criteria in which firm power delivery takes precedence over system participation power sales.

In the [redacted] (Term Sheets) these curtailment conditions are specified to include:

[redacted]

[redacted]

[redacted]

Also, MH would follow a curtailment priority criteria in which firm power delivery takes precedence over system participation power sales.

The general conditions for curtailment in the contract with [redacted]

[redacted]

MH would also follow a curtailment priority criteria in which firm power delivery takes precedence over system participation power sales.

Under adverse water conditions (MH is unable to meet firm energy commitments), MH has the right to curtail [redacted]

[redacted]

The curtailment clauses negotiated with [redacted] (contract), and binding term sheets that allow MH to curtail up to 29% (2/7 days) of its firm export commitments but would leave 71% of these commitments to be met. Total system firm commitments would only decrease by 19% given that the firm export commitments represent 68% (ICF, 123) of 2020-2025 volume (0.29*0.68). The latter is more consistent with dependable supplies coincident with the worst drought. In Chapter 4 we have estimated that the likelihood (probability) of a minimum below the one MH has chosen to define its dependable energy is quite low (about 1 in 392 years at the 95% confidence level). In other words, the actual minimum chosen by MH would define a level that is consistent with the average of all minima simulated from 100 drawings using a statistical process of 94 water flow possibilities.

> ***Finding 14***
>
> The negotiated contract prices in the new contracts or binding term sheets with [redacted] the escalation clauses are firmly structured to protect the contracts' real prices in the future. At this point in time, the contracted prices are sufficient to raise significant revenues for MH over its costs. The upset price on importing energy in the [redacted] contract will play a modest role in protecting MH from paying congestion prices in the event of a shortage. But the major achievements in these contracts are the curtailment provisions in the new contracts that could effectively decrease MH's firm export commitments by 29% and 19% of the total volume in times of adverse water conditions.

5.2.4.1.6 Are the Consultant's Estimates of Risk Exposure Correct and Warranted?

NYC claims that MH has underestimated its risk exposure in LTC and has not allocated enough or adequate risk capital to mitigate this high exposure. She also believes that MH has exaggerated its estimates of drought risk.

The Consultant has made and reported many calculations of the risk capital needed to mitigate exposure in LTC, presumably using VaR at the 95% level of confidence. The Consultant does not show her calculations (always claiming that they represent intellectual property). This may be the case, although we have not seen any evidence that her methodology is outside the commonly known methodologies of risk estimation (variance-covariance). She has been critical of Monte Carlo estimates as they typically fudge the true probabilities.

Her estimate of the probability of a severe drought as being equal to (1/93)^5 is flawed as we have argued earlier. She assumes independence among the years and she neglects the fact that there are many low flow years other than the one she singled out. Her estimate of the cost of a severe drought is also too low; the estimated order of magnitude is an average of less than $0.5 billion but there is no detail as to how this figure was calculated. The Consultant simply states that MH should note that the majority of the single year exposure under low flows of over $293 million and a high of $700 million is directly attributable to maintaining commitments to under-priced Contracts (Public Document, 65). The low estimate on the cost of the drought is not even the result of the drought. It is rather a direct effect of the long term commitments to supply firm energy that MH did not have during the drought. In the absence of long term contracts the loss would be miniscule; less energy to sell abroad and more is devoted to meeting domestic load. This argument may be valid during a drought with firm export commitments but what are the opportunity costs of not having contracts to sell surplus energy under average, median or higher flows? The Consultant believes that spot prices are always favourable and above contract prices. They were higher than contract prices for a short while in 2006/07 but far less than contract prices in other years between 1997 and 2009.

In the Public document, the Consultant presents a number of conflicting estimates of the risk exposure forced on MH by LTC that require adequate risk capital provisions. The three most relevant estimates are reproduced below:

1) Once MH starts to experience a real low-flow year in MISO and it has to import energy in excess of 900-1000 MW, the stress tests of even $4.2 billion and $7-$9 billion may be mild. The $20 billion in rate-payer increases are being used to fund overselling and inefficiencies in US markets (Public Document, 36).

The implicit prices of imports used in these calculations are quite high; more in line of congestion prices. The new upset price will dampen these estimates by a margin, but it is also assumed that no other hedging can be used and all is left for adequate risk capital. As we will argue in Chapter 6, there are many options open to MH to deal with this risk exposure.

Another estimate along the same line of reasoning is the one advanced by the Consultant arguing that losses to MH could fall between $310 million and $700 million in a single year just to support the LTC, even when prices are mild (Public Document, 52). If we were to take the low estimate of $310 million and assume it holds unchanged, (denying MH any adjustments) it would be $2.2 billion (well below the $4.2 billion above). Even the high end estimate of $4.9 billion is well below $7-9 billion. If the drought lasts less than seven years these estimates would further decline.

A third estimate in the Public Document puts the expected economic loss at $1.4 billion. “A conservative estimate of MH’s EVL and Risk Capital is greater than $1.4 billion over the next 7 years alone (71).” The credibility of these calculations falls to the extent they are not explained (the methodology or equation used is nowhere to verify), there are multiple values dealing with the same risk and no probability confidence levels are offered.

These undocumented and contradictory calculations do not detract however from her valid claim that the risks embedded in LTC need to identified, measured and mitigated.

Finding 15

The Consultant’s calculations of the probability of a severe drought and the magnitude of drought losses are glaringly low and those that may result from LTC commitments considerably higher than those that reasonable calculations would produce. The need, however, for adequate risk capital to mitigate against MH’s LTC risk exposures is a serious concern.

5.3 Conclusions

We have reviewed 14 documents in terms of five major themes. The list included the effectiveness, appropriateness and the predictive accuracy of Manitoba Hydro's suite of models in supporting optimum operations, capacity planning, financial forecasting and budgeting processes. Drought and volumetric risks were also considered given the heavy dependence of MH on good water conditions. Risk governance issues were evaluated given the newness of the Middle Office at MH and the evolving architecture. Risk governance policies, practices and personnel were evaluated against best practice in other utilities in North America. We also managed to evaluate risk identification, measurement, mitigation and long term contracts and options.

We tried to avoid the adversarial nature of the exercise. Our aim was to explore the different perspectives taken in these reports and to relate them to the issue of risk management at MH.

We have arrived at 14 findings. These are summarized below:

First, prices in HERMES are not stale; they are based on adjusted forecasts from five reputable consulting groups. Making adjustments to expert forecasts is reasonable and necessary but MH may wish to be more formal, transparent and to document the adjustments it makes. As well, MH may have to consider an alternative to purchase forecasts (this could be a complementary exercise) that uses forward price curves.

Second, the accuracy of the historical water flow data before 1942 is not high, but to discard this series is unjustified. The use of the historical series as if it is the only reliable series on which to base calculations of dependable energy is also not recommended.

Third, different production coefficients in HERMES and SPLASH are a problem. This problem pertains to the nonlinearity of the generation equation that links water flows to energy and the time strip differences in the two systems. This is why harmonizing the two systems on a common platform will iron out these discrepancies. The revenue losses due to this problem are limited and nowhere close to the exaggerated calculation of $26 million by the Consultant

Fourth, HERMES, SPLASH and PRISM are indispensable operational, planning and risk assessment tools at MH. These decision support tools represent standard systems that are currently used in many leading utilities in North America. They can be expanded, harmonized, and integrated. They should be reviewed internally and externally and upgraded and updated regularly. BC Hydro and Hydro Quebec have or are moving to dynamic and stochastic systems, MH may wish to follow suit. A hydrological sub-model to complement HERMES and even SPLASH should be considered seriously as water management issues become more complicated under possible climatic changes.

Fifth, there is wide agreement among most of the reviewers of the models (KPMG, RiskAdvisory, KM and others) that the systems require formal documentation, more staff should be trained on using and supporting the systems, that external reviews are needed, and that the Middle Office should be involved particularly in verifying and checking the results. The PRISM model should also be run in the Middle Office.

Sixth, notwithstanding the small dollar amount of discrepancy between the Generation Estimate and HERMES solutions, these discrepancies raise concern about the accuracy of the model and the reporting system. But the real problem is more profound. HERMES and SPLASH are static models and do not handle time in a manner consistent with dynamic programming. MH may wish to consider some of the existing dynamic programming systems in use at similar utilities in North America.

Seventh, HERMES is not directly linked to the trading floor and its forecasts are not used as bids on the floor. Whether HERMES is relied upon to inform decisions in the opportunity market is another matter; models are useful tools for guiding human decisions but not replacing them. It makes sense, however, to dispel this concern by streamlining and documenting trading decisions and practices in order to dispel this misconception.

Eighth, the probability of a drought occurrence is higher than those estimated by the Consultant or ICF. The costs of a 5 year drought are in the order of magnitude used by MH rather than those calculated by the Consultant and the inclusion of other risk factors increases measurably the drought costs. It is also clear that the water flow data are serially correlated and that a statistical process confirms that Manitoba Hydro is correctly using the low flow years in 1937-1942 as the basis of its dependable energy calculations.

While a more severe drought than the one experienced in 1937-1942 is possible, its probability of occurrence is 24 times in 9400 years (or 1 in 392 years).

Ninth, ICF International, Dr. Bhattachryya, KPMG, RiskAdvisory and KM all share the general appreciation that MH's Middle Office is evolving and that major progress has been made towards best practice. We all also recognize that much is needed in terms of strengthening the HR expertise set at the Middle Office, the independence of its functions, the MTM measures of all risks, the expansion of risk limits standards and process control limitations to all aspects of MH functions, the development of an Internal Responsibility Matrix, the need for quantification of risks at Middle Office, and its involvement in contract risk assessment. Most of us recognize that there is some merit in NYC's comments about risk governance issues with respect to the independence of the Middle Office and the greater need for oversight, but we all disagree with her claims of lack of competence in the CRMC, and the concealment and manipulation of data by the Front Office.

Tenth, there are many benefits for MH to be in the export market and for that matter in the long term fixed price firm exports market. The long list advanced by KPMG and ICF detailing these benefits from diversification of the export portfolio, to matching fixed costs to fixed revenues, to guaranteeing secure transmission infrastructure investment by counterparties and to qualifying for priority transmission rights, to pre-empting excess capacity by competitors, to guaranteeing access to long term finance on favourable terms, to raising export revenues in US dollars to defray import and debt costs in the same currency providing MH a hedge against exchange rate fluctuations, to greater access to firm imports when needed, and a host of other advantages. Even the Consultant admits that the issue is not selling in forward markets; the benefits from this would outweigh costs.

Eleventh, contract prices embedded in long term contracts are sufficiently higher than historical average spot MISO prices. These prices are carefully constructed using weighted long term forecasts and hopefully estimates of the long run marginal cost of counterparties. The export prices are higher than long run marginal cost of MH and average total cost. This suggests that export revenues when they are higher than import prices can be relied upon to subsidize domestic rates. We are not in a position to verify the claim in the Cost of Service that exports account for only 13% of total cost but we can verify they contribute 32% of total revenue.

Twelfth, the expanded capacity when Keeyask and Canawapa are completed will increase dependable energy and selling in the long term at higher prices than spot MISO prices will increase revenues. Expected declines in spot prices beyond 2011 will make these contacts more valuable. High import prices will remain a threat to contend with in time of shortages but new contract limit prices on these imports will define an upset price for MH. The inclusion of wind and out of money thermal energy in dependable energy is a stretch but they represent such a small portion of total generation that their inclusion or exclusion is not a material concern.

Thirteenth, the negotiated contract prices in the new contracts or binding term sheets with NPS, WPS and MP are [redacted] and the escalation clauses are firmly structured to protect the contracts' real prices in the future. At this point of time, the contracted prices are sufficient to raise significant revenues for MH over its costs. The upset price on importing energy in the NPS contract will play a modest role in protecting MH from paying congestion prices in the event of a shortage. But the major achievements in these contracts are the curtailment provisions in the new contracts that could effectively decrease MH's firm export commitments by 29% and 19% of the total system in times of adverse water conditions.

Fourteenth, The Consultant's calculations of the probability of a severe drought and the magnitude of drought losses are glaringly low and those of what may result from LTC commitments considerably higher, than those that would emerge from a reasonable calculation. The need, however, for adequate risk capital to mitigate against MH's LTC risk exposures is a serious concern.

Chapter Six

Quantification of Manitoba Hydro Risks

6.1 Introduction

Droughts of any severity and many other risks, separately or in combination, can adversely impact the net revenues of MH. To manage and protect its financial stability, MH must mitigate drought risks and simultaneously monitor all other potential risks that can threaten and prevent MH from realizing its business objectives and the optimization of its net revenues.

MH uses many different strategies to manage its risks and to mitigate their negative consequences. Risk identification is a pre-requisite to risk measurement and the latter is a pre-requisite to risk mitigation. We have already dealt with risk identification at length. In this Chapter we will deal with both risk quantification and risk mitigation strategies available to MH under many factual and constructed scenarios.

Most of the activities of MH involve minor or low risks because they are of short term durations and have limited consequences. There are, however, some major transactions and events that have high probability of occurrence and large consequences. Droughts, long term contracts, and expansions of capacity have major consequences on net revenue and have reasonably high probabilities of occurrence. Major events and therefore large risks may occur in clusters. The drought in 2004 was accompanied by high import prices. Risks must then be quantified separately and in combinations having regard for their correlations and inter-relationships.

The list of these risks has already been discussed. We move in this Chapter to quantify these risks and define both their likelihood and consequences. We use three basic techniques in this estimation: Two statistical methods that allowed us to estimate the probability of a minimum water flow lower than the actual minimum (Auto-regressive procedures and the Extreme Value Distribution) and Monte Carlo estimates of likely financial damages using @RISK (the same system embedded in PRISM) and variance-covariance estimates. A proper and comprehensive assessment of risk cannot be done without integrating these statistical techniques with the models utilized at MH. We have made a strong point of recommending the integration of statistical packages into the inner workings of SPLASH and HERMES. In the exercises to follow, we wish to demonstrate the usefulness of these risk analysis tools by applying them to data published by Statistics Canada on financial parameters of MH. This data is not totally consistent with IFF information published by MH or estimates of risk exposure undertaken by MH based on correlations embedded in HERMES and SPLASH. We have used it because it is in the public domain and is illustrative of a time series of relevant data, albeit relatively short (2001-2007).

6.2 Quantifying MH's Risk Exposure

We started with a base case defined by the financial statements for MH prepared by Statistics Canada for the years 2001 to 2007. Although the entries are not consistent with MH IFF, they are for calendar years and comparable to other utilities in Canada because Statistics Canada uses definitions that are applicable to all provinces and different utilities and as such they may not be fully applicable to any one separately. Our preference for using Statistics Canada data is motivated by our desire to avoid using sensitive and confidential data. The entries in Table 6.1 include a few calculations such as weighted prices of imports and exports. They bear little resemblance to actual MISO or domestic rates because of the embedded weights in the actual data.

The calculations of the risk exposure based on Statistics Canada data can vary from those for fiscal years in the IFF, so the absolute magnitudes of these calculations may have to be used with caution. The relative and incremental changes in these magnitudes are; however, relevant and can shed light on the interactions among the different variables.

We have prepared a large set of simulations; each one is constructed to deal with a relevant change in a variable of concern. The calculations are all probabilistic in that an embedded probability distribution was chosen to reflect the formation of these variables. Monte Carlo estimates were calculated for the final net revenue equation.

Table 6.1 – Manitoba Hydro Generation, Exports, Imports, Operating Revenues, Expenses and Debt. 2001-2007

	2001	2002	2003	2004	2005	2006	2007
Exchange Rate	1.5484	1.5704	1.4015	1.3015	1.2116	1.1341	1.0748
Load (GWh)	21,450	22,470	19,455	20,309	21,918	21,068	22,235
Unallocated Energy	3,750	4,386	1,048	1,466	1,880	2,365	2,326
Net Load	17,700	18,084	18,407	18,843	20,038	18,703	19,909
Domestic Price	4.84	4.93	4.81	4.88	4.86	4.90	5.10
Exports (GWh)	12,648	9,836	7,907	10,166	15,400	14,511	12,845
Firm	5,380	4,678	3,655	4,223	3,808	3,427	3,538
Non-Firm	4,378	2,732	587	2,494	8,291	8,886	7,525
Provincial Exports Firm	1,750	1,999	3,665	2,923	1,896	1,392	1,232
Provincial Exports Non-Firm	1,140	427	-	526	1,405	806	550
Prrovincial Imports - Total	2,890	2,426	3,665	3,449	3,301	2,198	1,782
Export Price							
Firm (US)	3.97	3.66	4.50	4.39	4.70	5.18	14.63
Non-Firm (US)	3.02	2.76	4.02	4.49	4.06	4.40	4.33
Firm (CDN)	6.14	5.74	6.31	5.72	5.69	5.88	15.72
Non-Firm (CDN)	4.67	4.33	5.63	5.84	4.92	4.99	4.65
Generation	34,098	32,306	27,362	30,475	37,318	35,579	35,080
Gross Domestic Revenue	856,703,087	891,517,142	885,365,397	919,516,928	973,853,847	916,423,088	1,015,377,462
Revenues from US Exports	535,439,197	387,288,907	263,583,469	387,027,445	624,689,571	644,733,114	906,531,354
Revenues from Other Provinces	160,688,000	133,231,700	231,261,500	197,914,000	177,008,400	122,069,000	219,245,400
Gross Revenues	1,552,830,284	1,412,037,749	1,380,210,365	1,504,458,373	1,775,551,818	1,683,225,202	2,141,154,216
Imports Total (GWh)	853	2,485	6,439	2,820	297	1,121	708
Imports from Provinces	195	342	533	266	66	302	174
Imports from US	658	2,143	5,906	2,554	231	819	534
Import Price (US)	3.97	1.92	3.05	4.83	3.44	3.94	4.57
Import Price (CDN)	6.14	3.01	4.28	6.28	4.17	4.47	4.91
Import Cost	52,421,234	74,909,250	275,268,800	177,255,497	12,380,058	50,094,897	34,772,604
Net Revenue (net of imports)	1,500,409,050	1,337,128,499	1,104,941,566	1,327,202,876	1,763,171,760	1,633,130,305	2,106,381,612
Marginal Cost ($/MWh)	1.09	1.53	3.26	1.52	1.30	0.98	1.04
Average Variable Cost	14.61	14.88	22.42	18.00	15.38	18.21	15.12
Average Total Cost	25.90	28.03	55.84	33.21	29.06	33.67	28.37
Operating Expenses	808,345,000	837,548,000	1,323,114,000	897,480,000	988,592,000	1,124,067,000	944,663,000
Wages and Salaries	247,249,000	196,265,000	276,506,000	301,733,000	312,317,000	349,038,000	348,627,000
Cost of Fuel Used	10,464,000	21,999,000	53,361,000	15,797,000	16,464,000	22,564,000	18,506,000
Cost of Material Used	23,477,000	23,815,000	23,979,000	25,384,000	27,831,000	10,120,000	16,039,000
Cost of Purchased Services	13,617,000	21,314,000	24,776,000	9,990,000	6,630,000	5,793,000	9,888,000
Cost of Repair and Maintenance	6,400,000	9,458,000	9,690,000	11,917,000	12,334,000	11,808,000	13,643,000
Royalty Expenses	112,784,000	102,856,000	71,455,000	47,542,000	68,103,000	112,497,000	13,767,000
Indirect Taxes	45,942,000	48,411,000	50,165,000	51,429,000	53,722,000	55,024,000	57,326,000
Other Expenses	-3,880,000	20,618,000	21,254,000	22,761,000	25,693,000	40,888,000	25,714,000
Electricity Purchased	108,388,000	129,171,000	515,570,000	119,659,000	162,398,000	203,648,000	115,224,000
Depreciation	243,904,000	263,641,000	276,358,000	291,268,000	303,100,000	312,687,000	325,929,000
Net Operating Income	692,064,050	499,580,499	-218,172,434	429,722,876	774,579,760	509,063,305	1,161,718,612
Long Term Debt (CDN)	7,269,896,000	6,924,890,000	7,114,613,000	7,047,576,000	7,051,016,000	6,822,361,000	7,217,181,000
Interest on L.T. Debt (CDN)	462,263,000	458,465,000	454,711,000	472,606,000	473,148,000	472,234,000	406,235,000
Effective Rate	6.36%	6.62%	6.39%	6.71%	6.71%	6.92%	5.63%
Net Operating Income (After Debt Chargers)	229,801,050	41,115,499	-672,883,434	-42,883,124	301,431,760	36,829,305	755,483,612

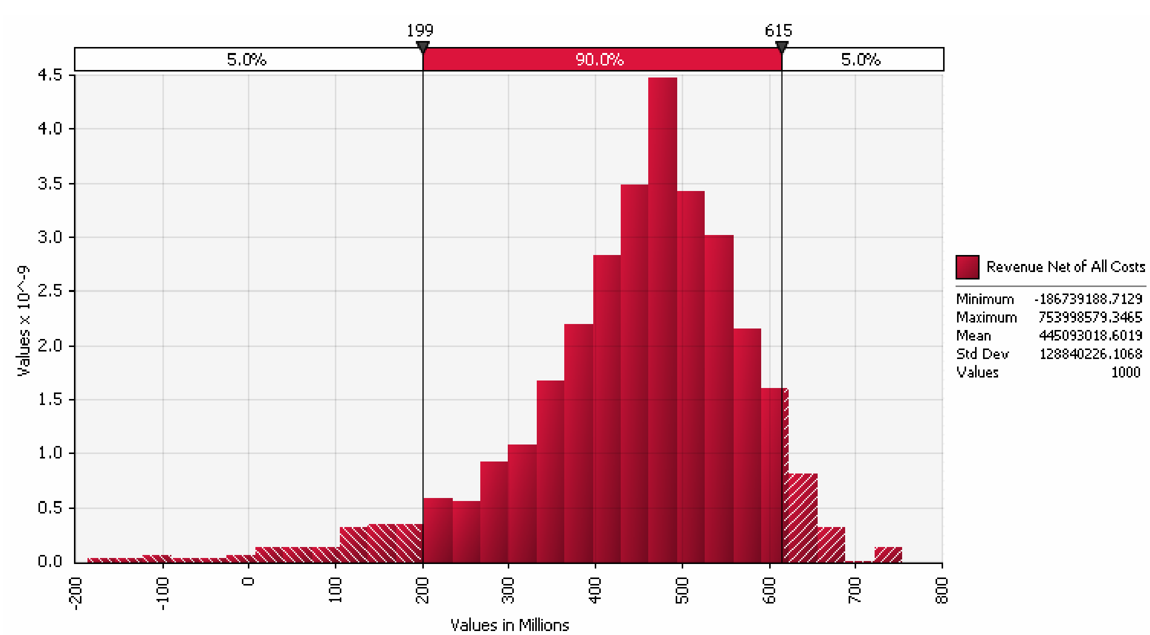
Sources: Statistics Canada, Annual Electric Power Generation, Transmission and Distribution Reports.
and http://www.bankofcanada.ca/en/rates/exchange_avg_pdf.html

Net revenues were calculated before interest costs and after as the case required, but most of our calculations except in the case where interest rate changes were analyzed, deal with net revenue without deducting interest charges.

In total we have estimated the risk exposure of 15 different variables on MH's net revenue. We started with defining a Base Case to benchmark the behaviour of the system under average conditions that prevailed between 2001 and 2007. The averages are simple averages calculated from the data in Table 6.1.

Using these averages and the selected probability distribution functions for each one of them in the calculation of net revenue, we generated using Monte Carlo simulations (1000 iterations) the mean, low and high values of net revenue at the 5% and 95% confidence levels. The choice of the appropriate probability density function was based on the Chi-Square scores of the different distributions (lower values were preferred to higher values) and their match of the actual numbers under consideration in Table 6.1. The selected density functions are presented in figures 6.17 to 6.43.

Figure 6.1 – Net Revenues, Base Case, Average Flows



The base case net revenue has a mean of about $445 million, a low of -$187 and a maximum of $754 million. The distribution is tight around the mean but not symmetrical with a thick left tail. Net revenue is positive with $199 million at 5% confidence level and $615 million at the 95% confidence level.

This base case is for one average year and sets the stage for evaluating losses from major and simple events. The first case is that of a drought that is representative of the actual minimum of water flows over the period between 1912 and 2005. When this minimum is introduced it drives generation lower and necessitates adjustments to meet firm exports and the Manitoba load.

The low flow (drought) scenario results show a drastic loss in net revenue; the mean losses are in the order of $343 million, but when compared to the base case this represents a loss of $788 ($343 million plus $445 million) million and this is the first year (Table 6.2 and Figure 6.2). We did not examine the results of a five or seven year drought as we did not have and did not think that the actual series would produce the best correlation given that our estimate came from a statistical simulation exercise. We could use our estimates of a five year drought from Chapter 4 but for comparison purposes we calculated these losses only for the representative year.

Table 6.2 – Quantification of Manitoba Hydro Risks (Millions of Dollars)

Scenario	Impact on Net Revenue Without Interest Costs	Net Impact
Base Case	$445	
Drought (1940 Flows)	-$343	-$788
Drought (More Severe than 1940) (Minimum at 2.5% Quantile, with Curtailment)	-$277	-$722
Drought (1940 Flows, High Import Prices)	-$755	-$1,200
Drought (1940 Flows, High Export Prices)	$114	-$331
Base Case with Wind Variation	$445	$0
10% Increase in Load with Average Import Prices	$448	$3
10% Increase in Load with High Import Prices	$48	-$397
10% Increase in Wage Costs	$416	-$29
10% Increase in Fuel Prices	$442	-$3
10% Increase in Purchased Materials Costs	$443	-$2
10% Increase in Cost of Purchased Electricity	$425	-$20
10% Exhange Rate Depreciation of Canadian Dollar	$478	$33
10% Exhange Rate Appreciation of Canadian Dollar	$412	-$33

Source: Table 6.1 and @Risk Model

It is interesting that the mean losses almost approximate the actual losses in 2003/04 but this resemblance is coincidental. The next scenario involved constructing a case with lower water flows (we used the water flows from our statistical series at the 2.5% quantile of all minima). But we also allowed curtailment of exports (reduced by 29%); all other variables were left at their average values and the appropriate distributions. It is highly interesting that the mean losses are lower than those associated with actual minimum. The mean losses are $227 million and at an opportunity cost of $722 million. This is lower than the actual minimum costs by over $66 million (Table 6.2 and Figure 6.3).

Figure 6.2– Net Revenues, Actual Minimum

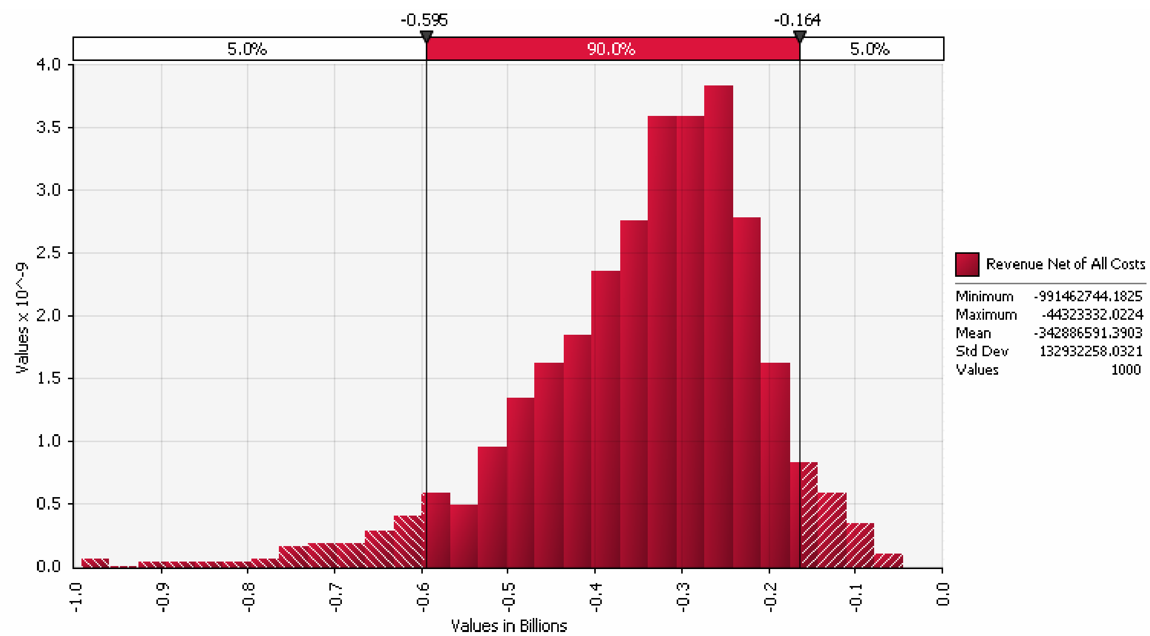
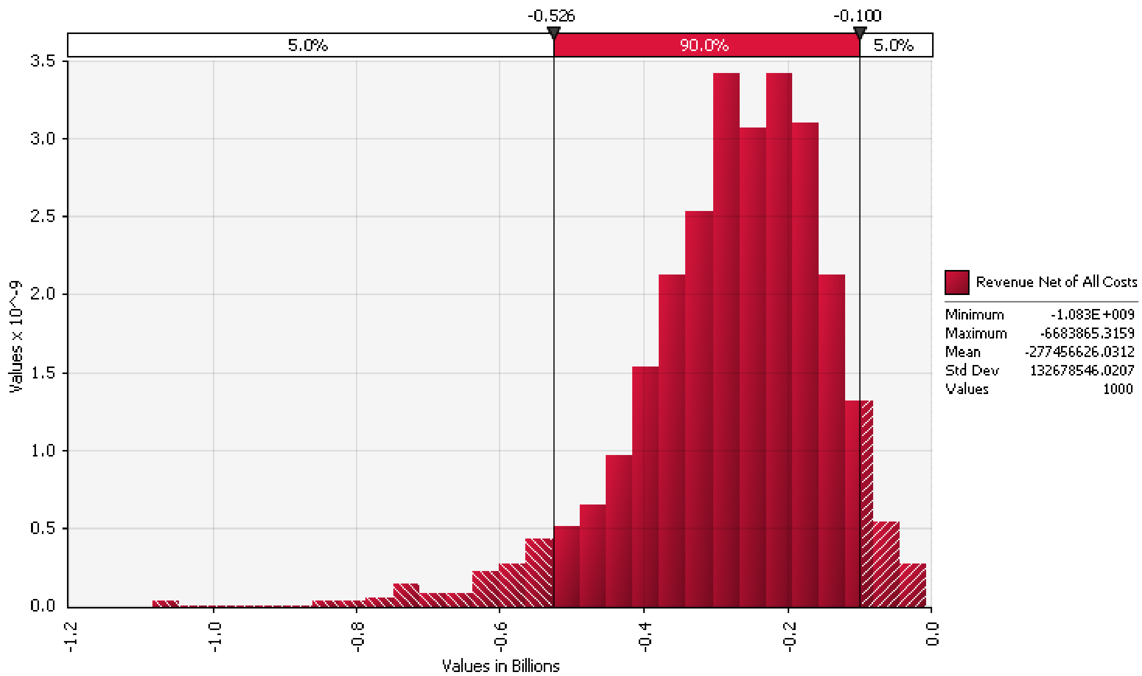
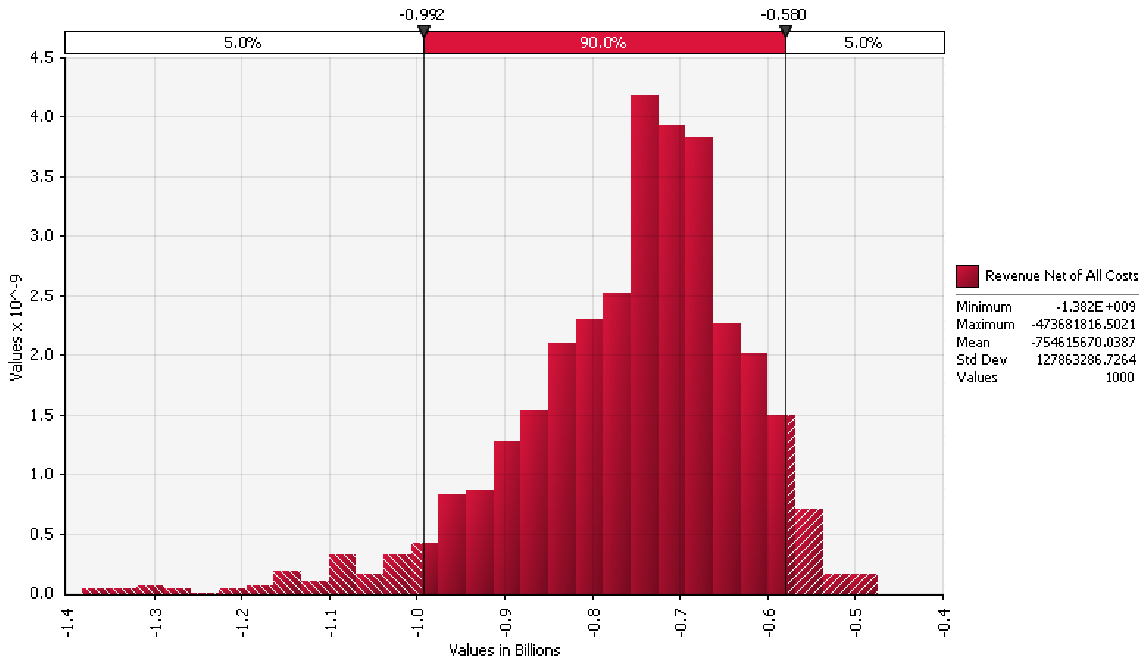


Figure 6.3 – Net Revenues, 2.5% Quantile Minimum with Export Curtailment



Risks can be expected to be compounded, that is one risk is augmented by another. In the next scenario we address the costs of a drought equal in severity to the one in 1940 but also impose high import prices (at about $120 MWh). The mean losses rise quickly to $755 million and the opportunity losses to $1.2 billion (Table 6.2 and Figure 6.4)

Figure 6.4 – Net Revenues, Actual Minimum, High Import Prices



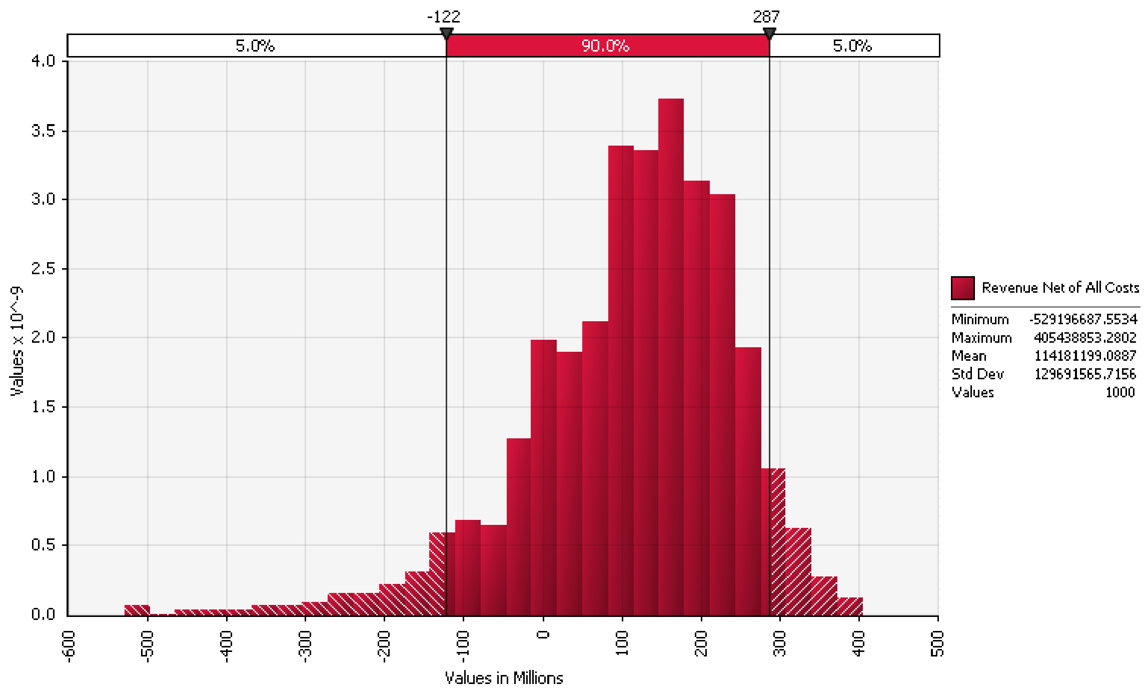
If we examine the higher risks embedded in this scenario, at the 5% confidence it is likely that the losses would rise to $992 million. This is not the total loss as we need to subtract the base case expected net revenues. If this done, the losses would mount to over $1.4 billion (Figure 6.4). Even at the 95% level of confidence losses are still over $580 million under this scenario.

A less severe scenario postulates higher export prices almost matching long term contract prices. If this was assumed, the impact of a drought as severe as that of 1940 on net revenue will be substantially cushioned (Table 6.2 and Figure 6.5).

Mean net revenue is positive with $114 million. The opportunity losses are still relatively high at $331 million, but this is substantially below the situation when average export prices (over the period 2001 and 2007) are used.

At the 5% confidence level losses are $122 million and at the 95% confidence the net revenue will not exceed a positive $287 million.

Figure 6.5 – Net Revenues, Actual Minimum, High Export Prices



MH has accumulated a large long term debt, of which 35% is owed to the US. This debt is expected to rise substantially in the future if and when the new capital expenditure program is implemented. The average actual interest payment over the period 2001 and 2007 is $457 million and the debt stood at $7.2 billion in 2007. There is an interest in knowing the impact of interest rate increases on MH's net revenue. The current interest rates are quite low (actually at historical lows) and these levels cannot be expected to remain at their current levels. In the next two simulations we rebuilt the base case but deducted average interest payments from net revenue. The Base Case results with net revenue after deducting interest payments are displayed in Figure 6.6. Long term debts are typically for extended periods of times at fixed rates, but parts of these debts mature and have to be refinanced. The changes in interest rates in this simulation are imposed on all of the debt and do not take into account that possibly only a fraction at any given period of time may have to be refinanced.

Mean net revenue is a negative of $12 million and when interest rates are increased by a single 1 % this leads to an additional loss of $71 million in one year. This is a major increase and could be quite consequential if interest rates were to start rising at particularly the same time debt is accumulating under the influence of major capital expansions slated for the near future.

The results of these two simulations are in figures 6.6 and 6.7 and the results of losses are in Table 6.3.

Figure 6.6 – Net Revenues with Interest Payments, Base Case

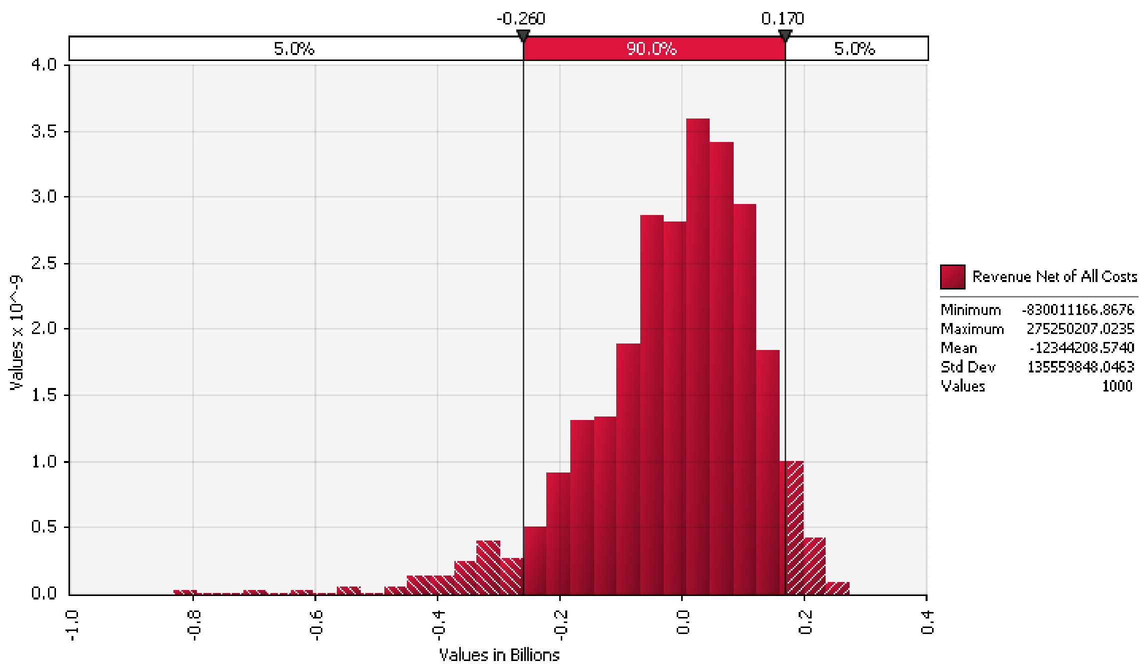


Figure 6.7 – Net Revenues with Interest Payments + 1%

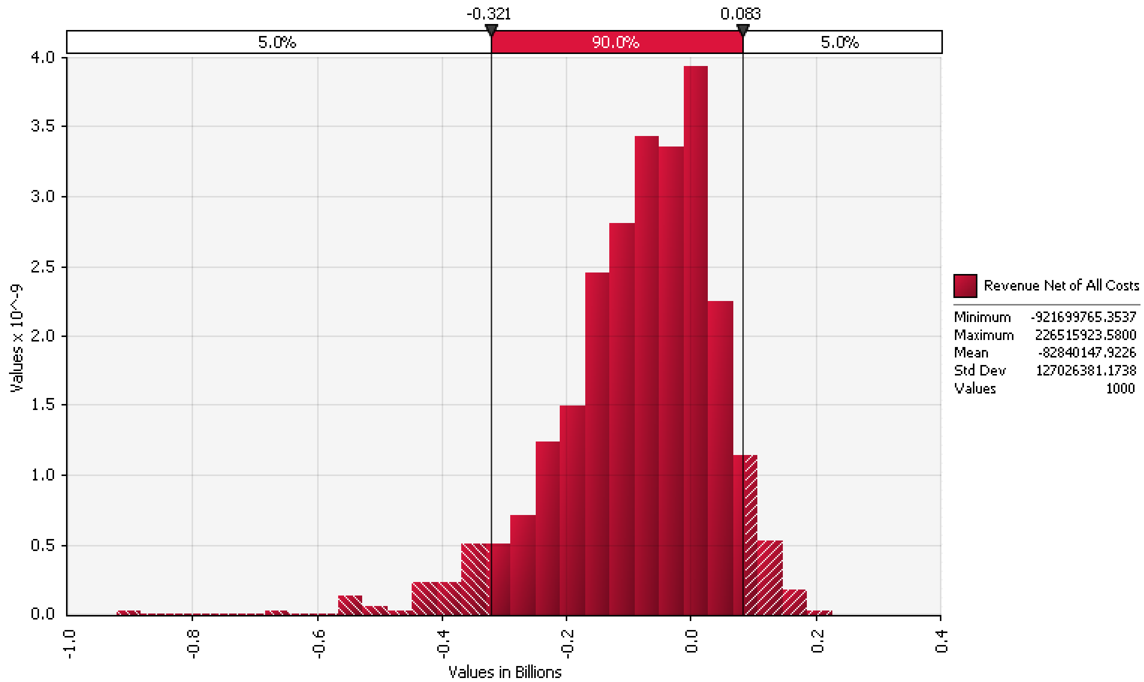


Table 6.3 – Net Revenue Sensitivity to Higher Interest Rates (Millions of Dollars)

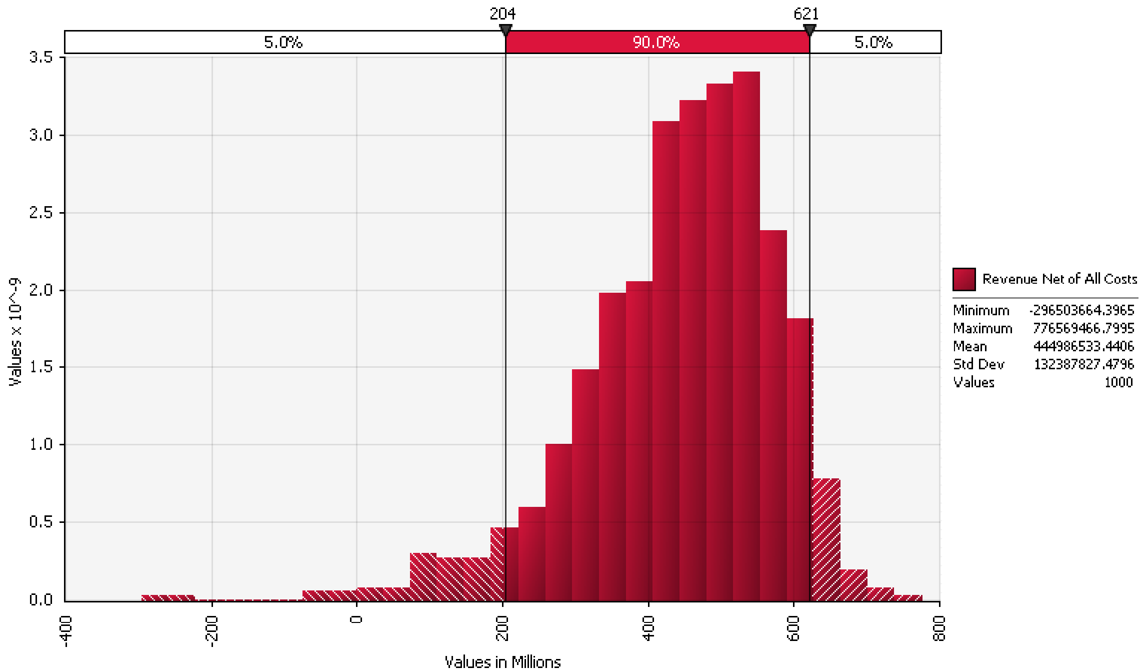
Scenario	Impact on Net Revenue With Interest Costs	Net Impact
Base Case	-$12	
Increase of Interest Rate of 1%	-$83	-$71

Source: Table 6.1 and @Risk Model

In what follows we have constructed a number of simulations to gauge the sensitivity of net revenues to a host of factors; some of which are of minor consequences and others are not.

Varying the amount of wind energy available did not show any material impact on net revenues. We changed wind by 10% and mean net revenue almost stayed the same (Table 6.2 and Figure 6.8)

Figure 6.8 – Net Revenues Without Interest, Wind Variation



We simulated the system with an increase in load that was financed by increasing imports, but we could have decreased exports. First, we increased the load by 10% and increased imports by an equivalent amount holding prices of imports at their historical average. The results are quite interesting, net revenue increased as prices of domestic electricity was higher than the average import prices between 2001 and 2007.

Mean net revenue increased to $448 million or $3 million above the base case (Figure 6.9 and Table 6.2). The story changes quickly if we were to use high import prices. In this case net revenue losses approximate $48 million and opportunity cost is $397 million when compared to the base case (Table 6.2 and Figure 6.10).

Figure 6.9 – Net Revenues Without Interest, 10% Increase in Domestic Load Supplied by Imports at Average Prices

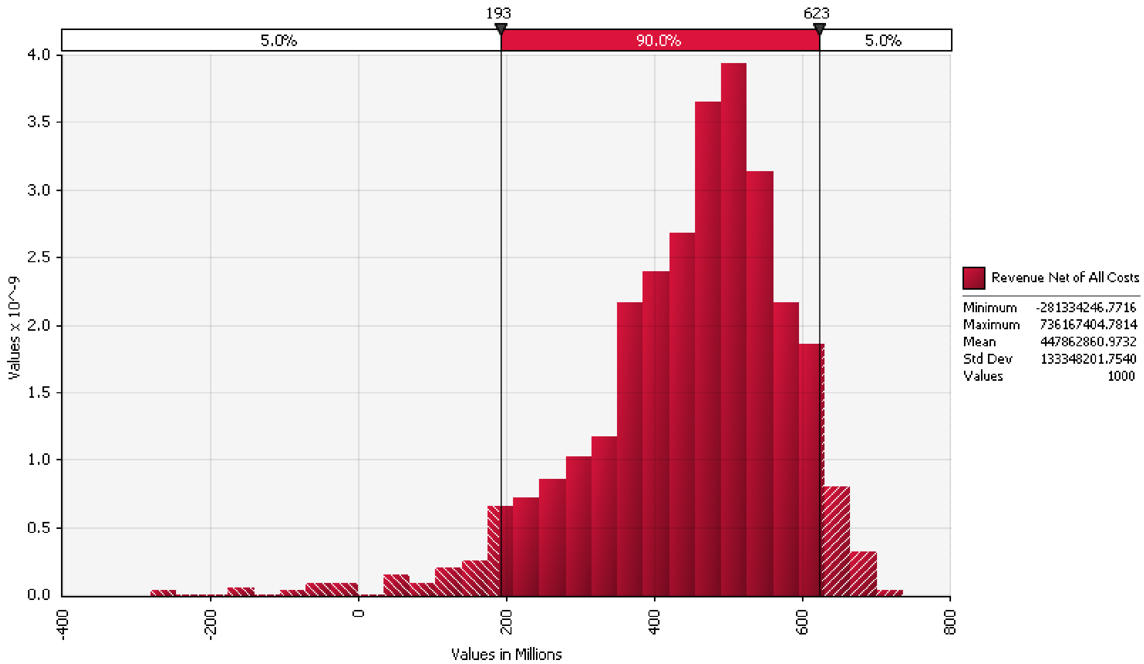
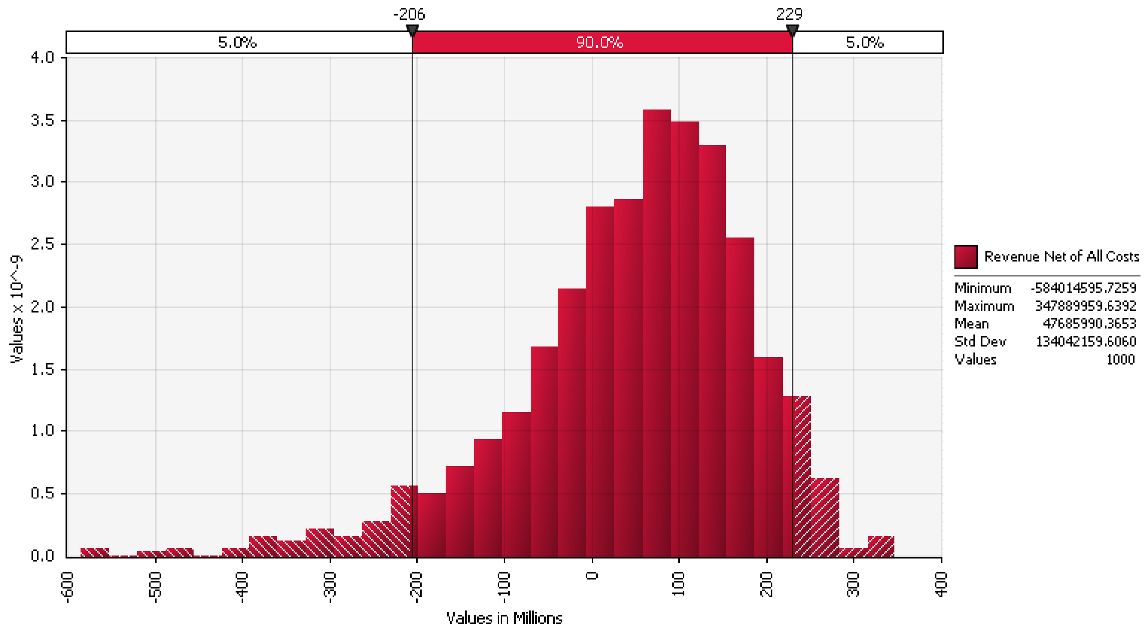


Figure 6.10 – Net Revenues Without Interest, 10% Increase in Domestic Load Supplied by Imports at High Prices



We experimented with a number of scenarios by increasing by 10% the cost of fuels, the impact on net revenue was minimal of about $3 million (Figure 6.11 and Table 6.2). The same is true when we raised the cost of purchased materials by 10%, net revenue declined by $2 million (Figure 6.12 and Table 6.2). Surprisingly raising the cost of purchased electricity by 10% had a much lower impact on net revenue than is expected. Mean net revenue declined to $425 million or a loss of only $20 million (Figure 6.13 and Table 6.2).

Increases in labour cost have a higher impact on net revenues than other operating costs, but the increases are moderate by any standard. Net revenues decline by about $29 million for a 10% increase in wages (Table 6.2 and Figure 6.14)

When the Canadian dollar appreciates or depreciates it is expected that major changes would be experienced in the financial performance of MH. This is not the case because any change in the value of the Canadian dollar has a number of offsetting entries. The US dollar is used to pay for imports and pay interest on debt raised in the US. When the Canadian dollar appreciates, MH gets less in revenue in Canadian dollars for its exports but has to pay less for its imports and debt. These relationships are borne out in the simulations where we appreciated and depreciated the Canadian dollar. There is a gain of about $33 million from a 10% depreciation of the Canadian dollar and an equal loss for an appreciation of 10% in the Canadian dollar (Table 6.2 and figures 6.15 and 6.16).

Figure 6.11 – Net Revenues Without Interest, 10% Increase in Cost of Fuel

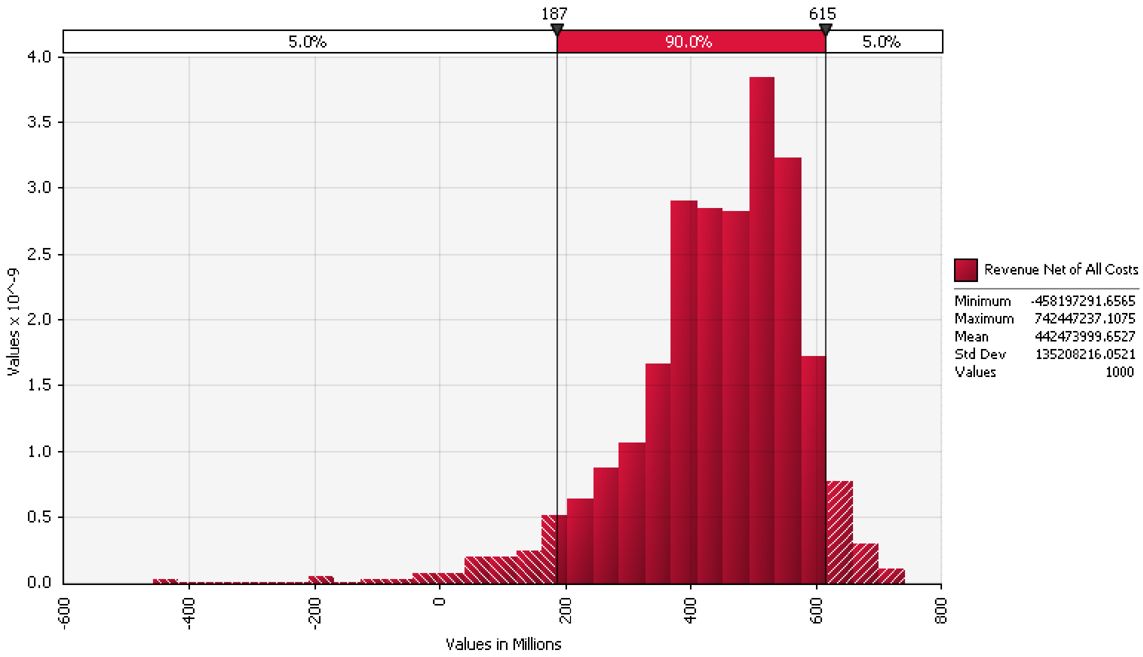


Figure 6.12 – Net Revenues Without Interest, 10% Increase in Cost of Materials

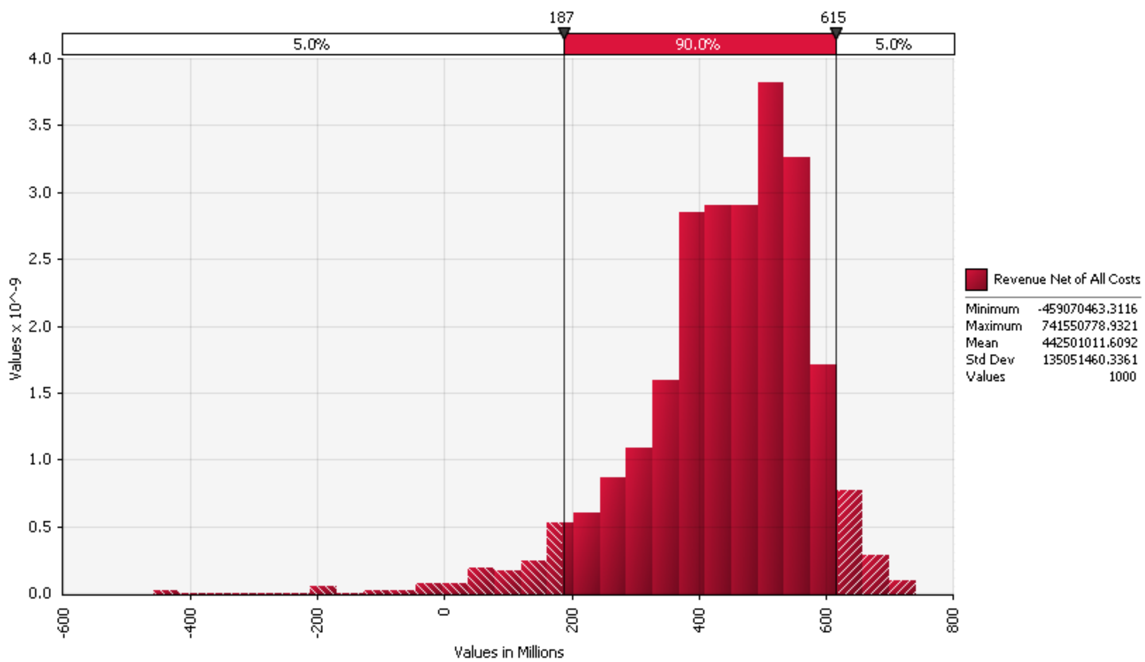


Figure 6.13 – Net Revenues Without Interest, 10% Increase in Cost of Electricity Purchased

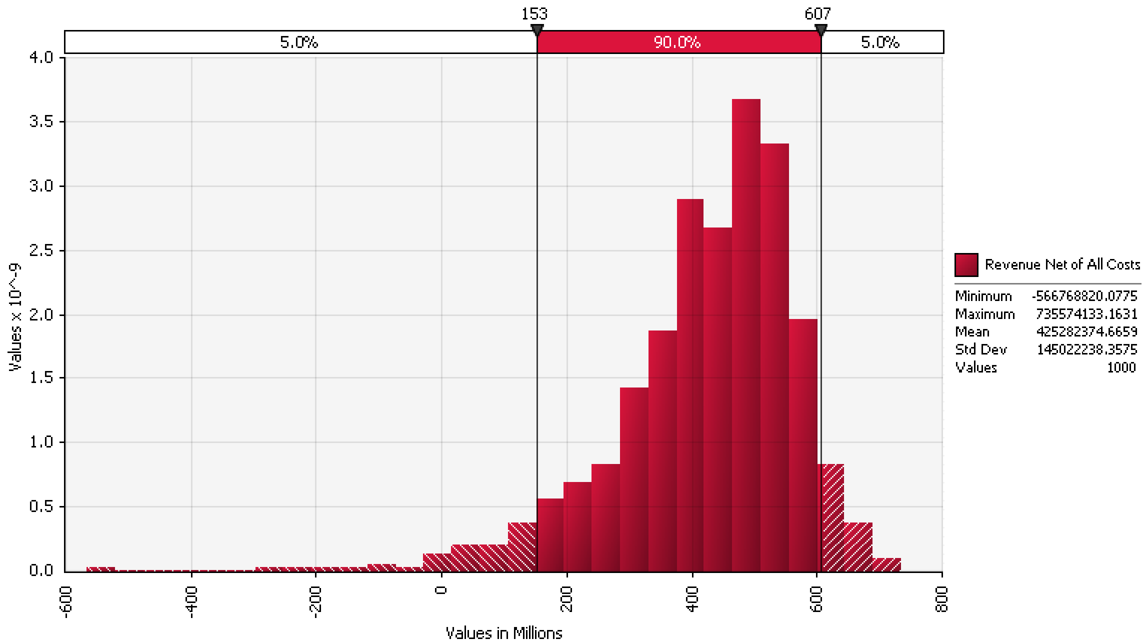


Figure 6.14 – Net Revenues Without Interest, 10% increase in Wages

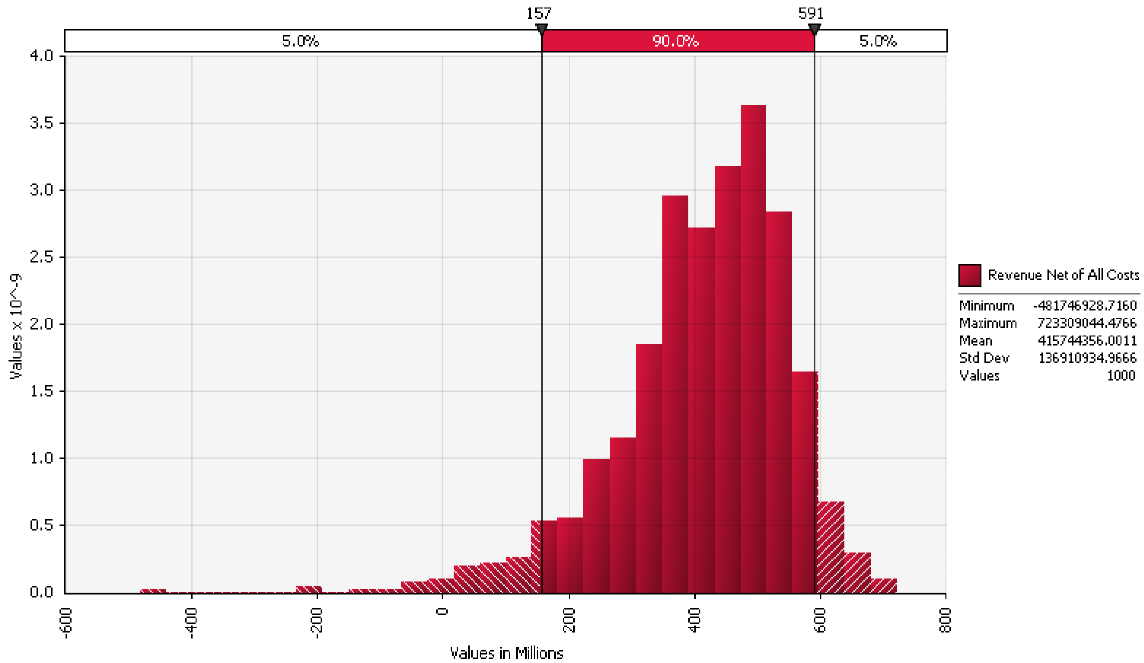


Figure 6.15 – Net Revenues Without Interest, 10% Depreciation in the Canadian Dollar

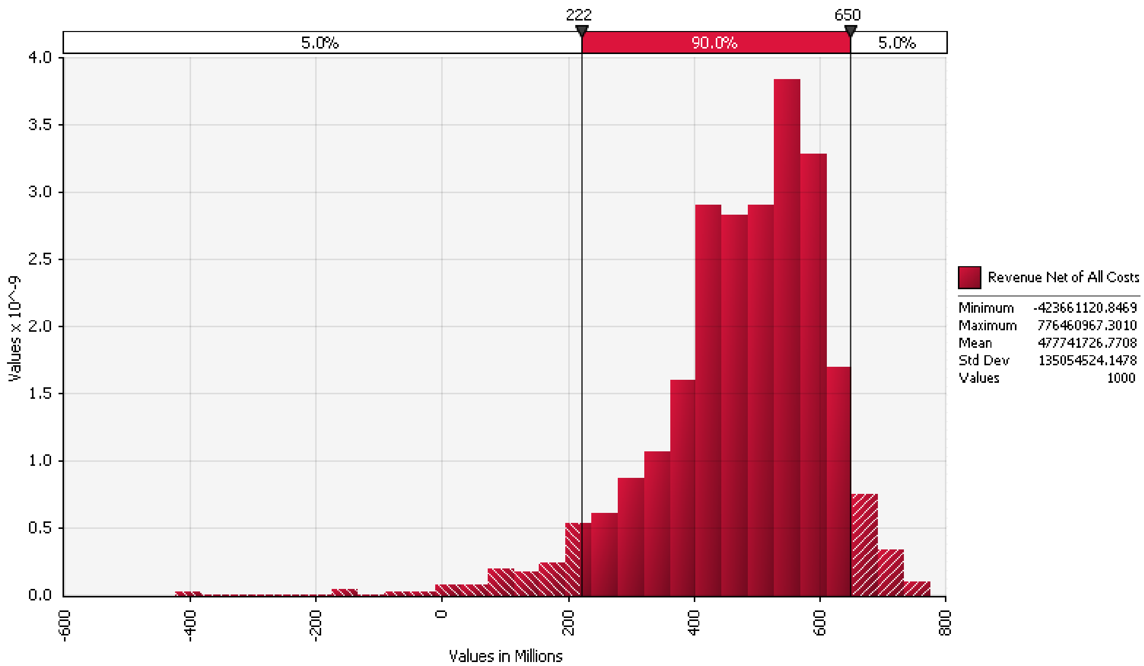
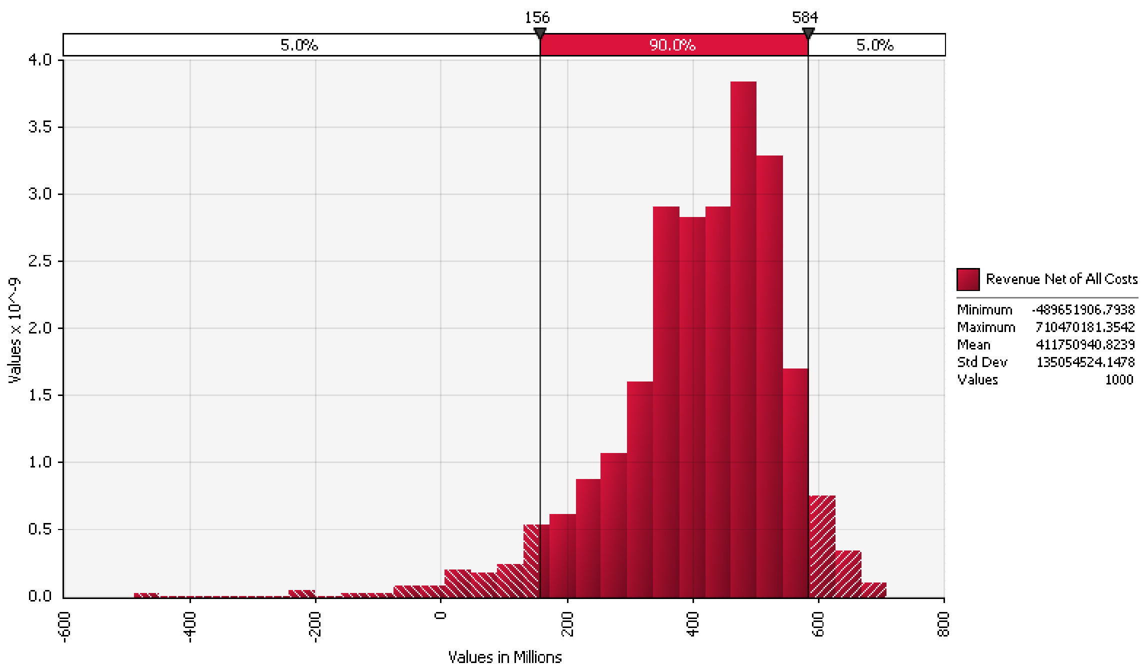
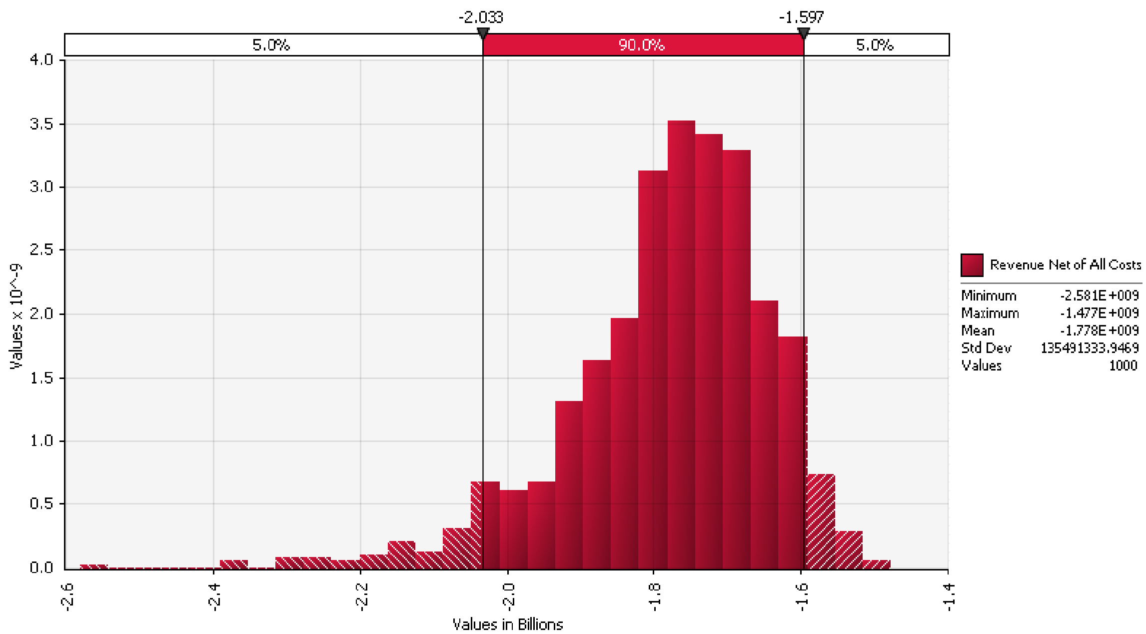


Figure 6.16 – Net Revenues Without Interest, 10% Appreciation in the Canadian Dollar



A worst case scenario is constructed to include a low water flow (at the worst drought on record), high import prices at the upset price, average export prices, an interest rate that is 200 basis points above average interest and the dollar at parity. This scenario results in $1.8 billion loss in Net Revenue (Figure 6.17). The opportunity losses rise to $2.2 billion. This means that accumulates net revenues of MH could be wiped out in one year. This scenario has a very low probability of occurrence, especially if it can be argued that these events are independent. Even when some of these events are not independent, the joint probabilities are low.

Figure 6.17 – Worst Case Scenario



6.3 Summary of the Findings

Major losses can be expected from low water flows and a rise in import prices or a decline in export prices. Volumetric, price changes and interest rate changes are the major causes of risk for MH. Changes in labour cost, material cost, purchases of electricity costs and wind have only limited Impacts.

Summarizing our findings above, we have the following key results:

First, low water flows have the largest impacts on net revenue of MH. A total of $788 million can be lost on account of a repeat of the worst drought on record.

Second, a more severe drought than the worst on record would trigger the Force Majeure clause in the contract. A lower flow than the worst drought on record with curtailment will have lower impacts than the worst historical drought. Losses are large but only $772 million compared to $788 million.

Third, a low flow year at the same level of the worst drought coupled by import prices at the upset price 120/MWh results in a drastic loss of $1.2 billion in one year.

Fourth, a severe drought with high export prices (at future contract levels) and an average import price will result in positive expected net revenue, but a loss of $331 million from the base case.

Fifth, a 10% variation of wind generation has very low impacts on net revenue (less than $1 million).

Sixth, a 10% increase in wages and benefits' cost will reduce net expected revenue by $29 million.

Seventh, 10% increases in purchased inputs, materials and fuel prices have limited effects on net revenue (less than $3 million each).

Eighth, a rise of 10% in load met by an equivalent rise in imports, with no change in import prices, leads to a rise in net revenue of $3 million.
Ninth, a 10% increase in load met by imports that are priced at $120/MWh, will lead to a loss of $397 million in revenue.

Tenth, surprisingly changes in the exchange rate are not particularly high. A 10% appreciation in the Canadian dollar (moving towards parity), results in a loss of $33 million.

Eleventh, the worst case scenario with very low probability of occurrence would result in a $1.8 billion loss in net revenue.

6.4 Risk Mitigation Strategies for MH

Risks can be mitigated. Risks can be shared through insurance internally or externally, can be minimized by constraining the activities that gives rise to them, by hedging against their occurrence by acquiring derivatives and other hedging instruments, by diversifying the sources of the risk exposure, by staggering obligations and commitments or by allocating sufficient and adequate risk capital or other assets to cover the exposure.

The current mitigation of risks at MH is based on a collection of measures including:

1) Accumulation of retained earnings and an expanded borrowing capacity.

2) Mix of export sale types and contracts.

3) Multiple counterparties, diverse terms and staggered times.

4) Contact provisions that allow MH to decrease long term sales in a drought of a severity that exceeds the worst on record.

5) Financial risk management instruments.

6) Domestic demand management.

7) Contract provisions to reduce transmission risks.

8) Drought Preparedness Plans.

9) Adequate Risk Capital.

These measures appear to be eclectic and have not been arranged into a coherent package totally devoted to dealing with expected losses from severe droughts or any other adverse event. The development of a plan to deal with drastic events with large consequences and low probabilities would be desirable and necessary.

Droughts will diminish earnings from net exports, and can end up in losses if import prices were to exceed export prices. Non-firm exports would disappear and MH may have to arrange for replacing power through book-out deals.

Retained earnings have been accumulated and short term liquidity have been arranged to help MH mitigate the adverse financial consequences of the drought. It is difficult to estimate fully and accurately the full cost of a five or seven year drought. MH estimated this cost to be approximately $2.7 billion for a five year drought and $3.5 billion for a seven year one. If high import prices were to accompany the drought, this number can rise very quickly. The worst case scenario developed above showed that losses can be compounded and retained earnings can be blown in one year.

The target level for retained earnings should perhaps approximate the upper bound of the drought losses, but this amount of retained earnings should not be totally devoted to this mitigation. A minimum amount of retained earnings will be needed for other purposes. This minimum must be determined by MH's Board and the difference between the upper exposure and the minimum reservation value of retained earnings must be covered using other sources of funds. This could be through acquiring derivatives or other financial hedging instruments, or through "insurance riders" added to rate-payers' rates, or by drawing on water in storage, or if totally necessary through borrowing.

Water in storage is an asset. MH should think of keeping a storage level each year as a hedge against a major drought. This amount can be thought of an "insurance premium payment." There is a minimum level that should remain in storage consistent with dependable energy targets; the level above that minimum should be part of the mitigation strategy and should be adjusted in proportion to deviation of retained earnings from their targeted minimum. The closer the retained earnings are to their minimum desirable value, the higher the water that should be left in storage for drought mitigation purposes.

Retained earnings and water in storage should be complemented by an additional rider on domestic rates totally devoted to a specially created fund to be used in the event of a drastic drought. This additional rider should also be treated as insurance premium paid by domestic consumers of electricity to be used in emergencies to save the rate-payers from rate shocks and the province from having to guarantee additional debt.

The manner in which all these variables can coalesce into a coherent equation is given below:

$$a_1\left(RE - \overline{RE}\right) + a_2\left(WS - \overline{WS}\right) + a_3\left(r - \bar{r}\right) + a_4\left(B - \overline{B}\right)$$

RE = Retained earnings above the targeted minimum
WS = Water level in storage above the minimum determined by dependable energy targets.
r = Is the premium rider added to rate payers bills.
B = Borrowing target above the existing level.
a = These are the weights that MH will negotiate with its Board and PUB.

Of course all other qualitative components of the strategy remain valid—multiple counterparties, staggered contracts, mixed portfolio of export sales, stronger provisions for curtailment under Force Majeure conditions and import upset prices, a portfolio of financial hedging instruments, more stringent and wider demand management programs, a Drought Preparedness Plan, and priority transmission rights.

6.5 Probability Distributions of Financial Variables Defining Net Revenue

Figure 6.18 – Triangular Probability Distribution of the Exchange Rate

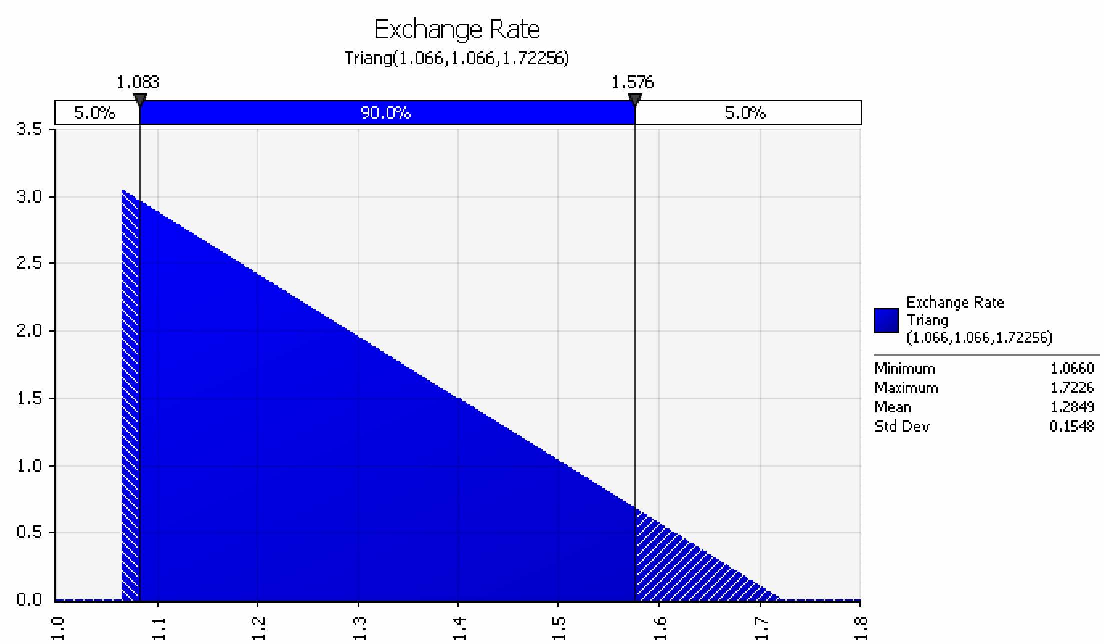


Figure 6.19 – Normal Probability Distribution of Load

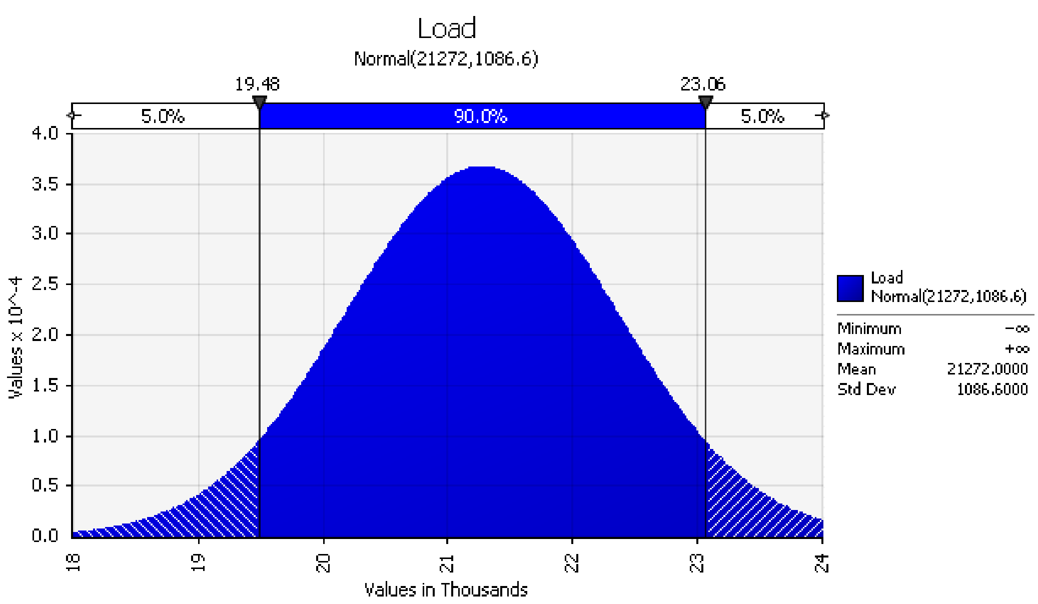


Figure 6.20 – Triangular Probability Distribution of Unallocated Energy

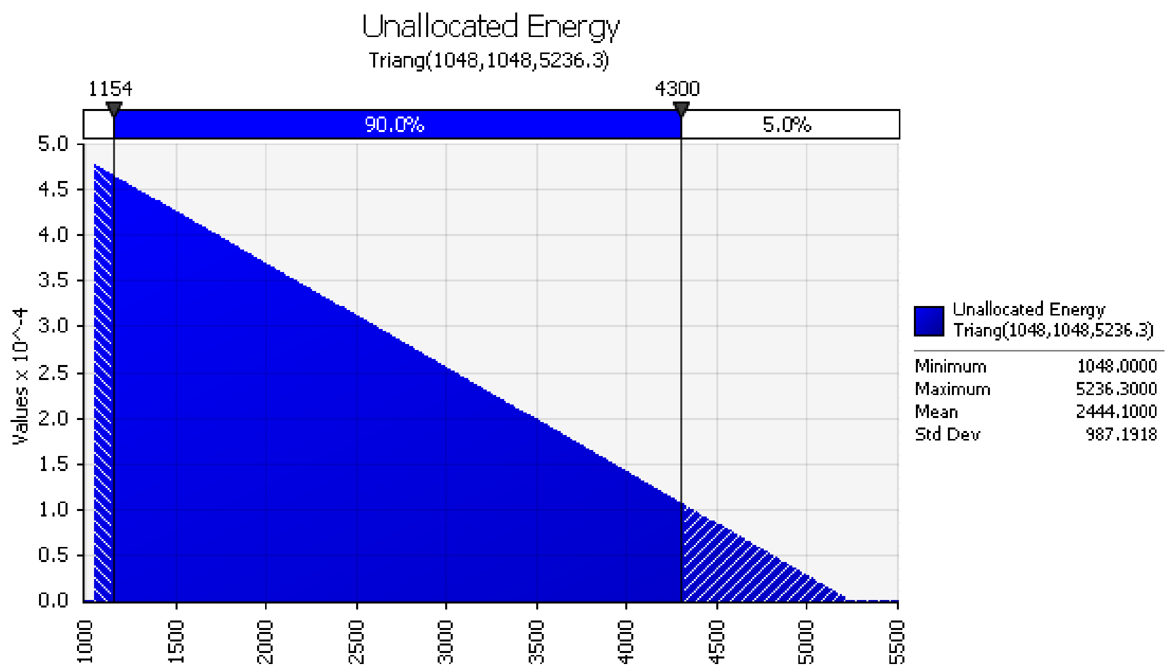


Figure 6.21 – Inverted Gaussian Probability Distribution of Domestic Price

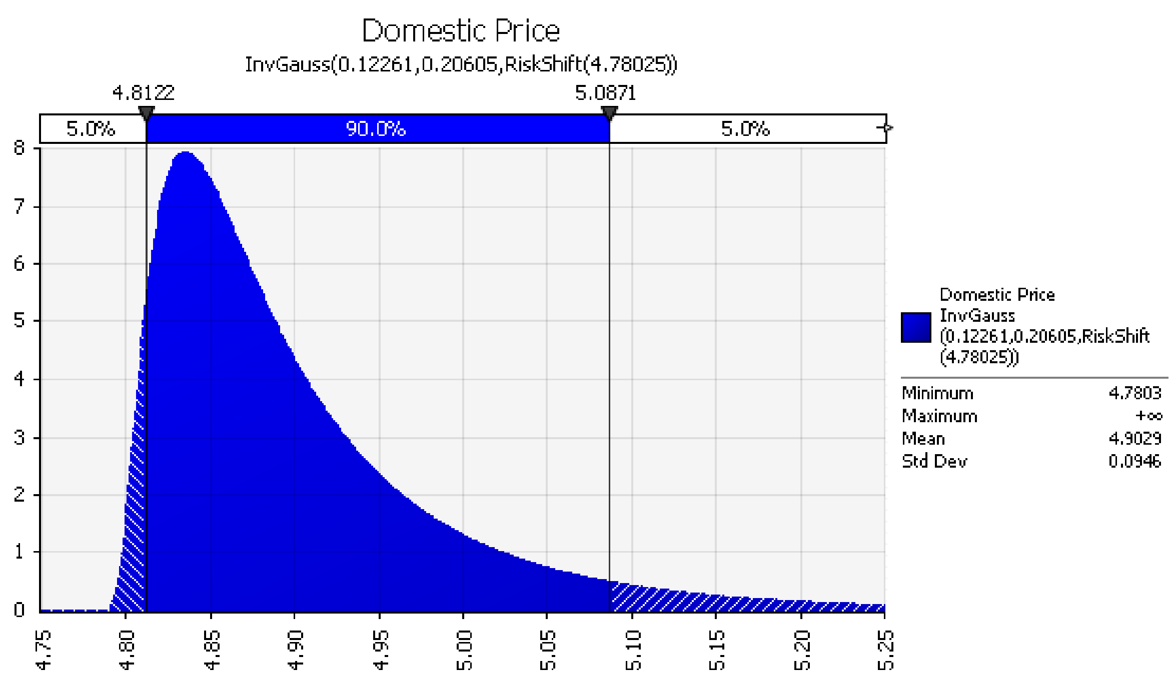


Figure 6.22 – Extreme Value Probability Distribution of Exports to US (Firm)

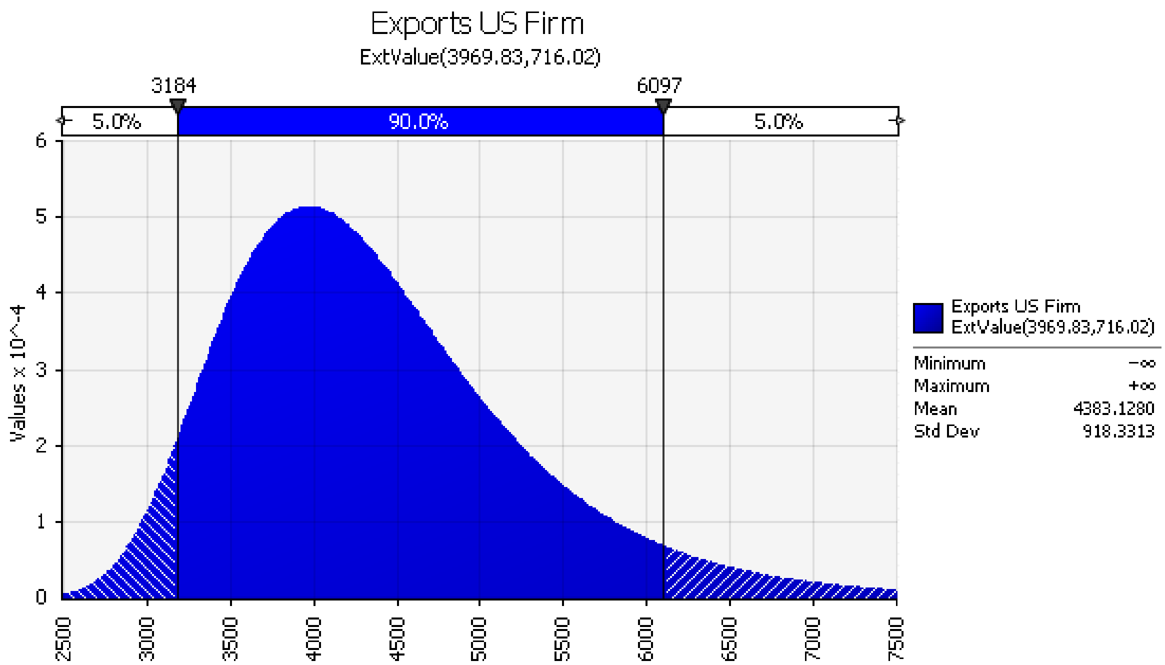


Figure 6.23 – Weibull Probability Distribution of Exports to US (Non-Firm)

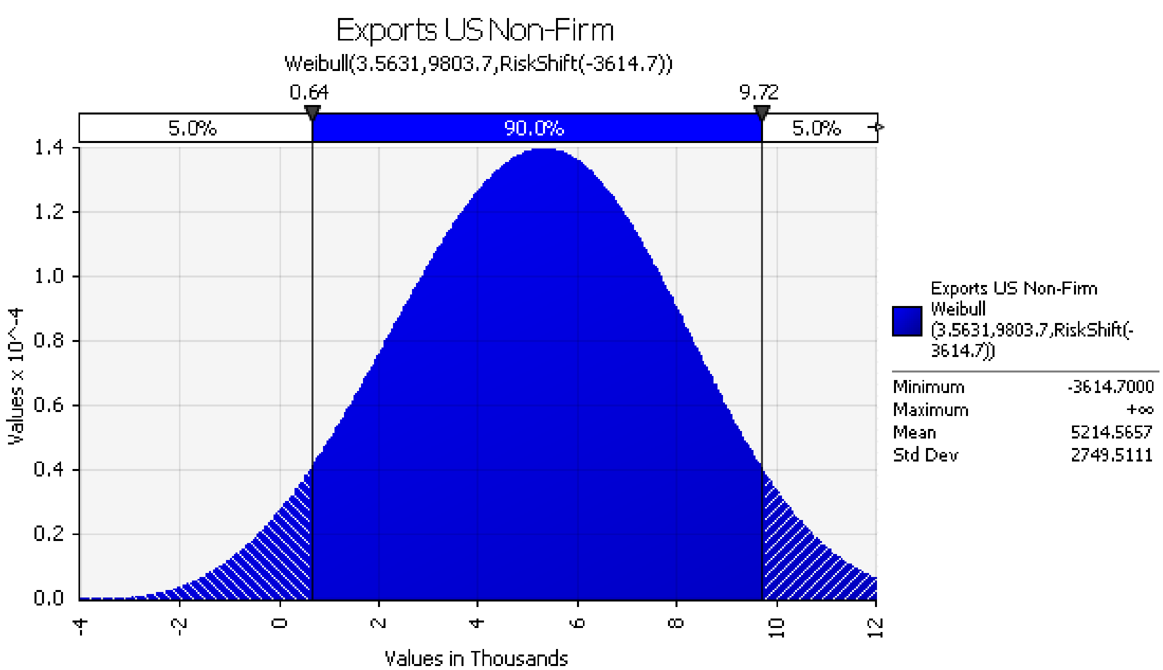


Figure 6.24 – Triangular Probability Distribution of Exports to Other Provinces (Firm)

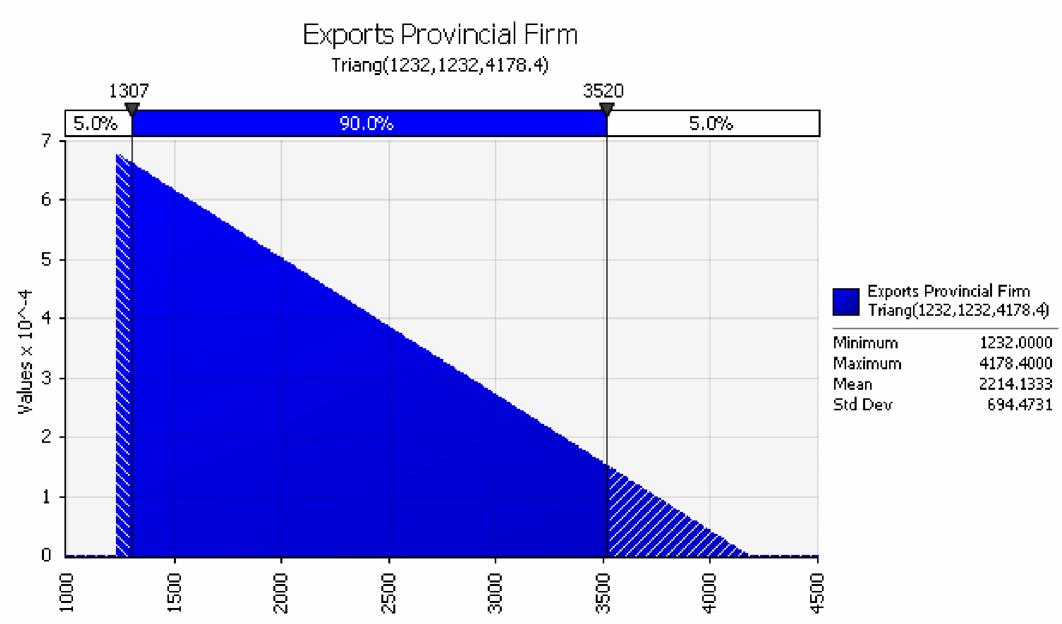


Figure 6.25 – Triangular Probability Distribution of Exports to Other Provinces (Non-Firm)

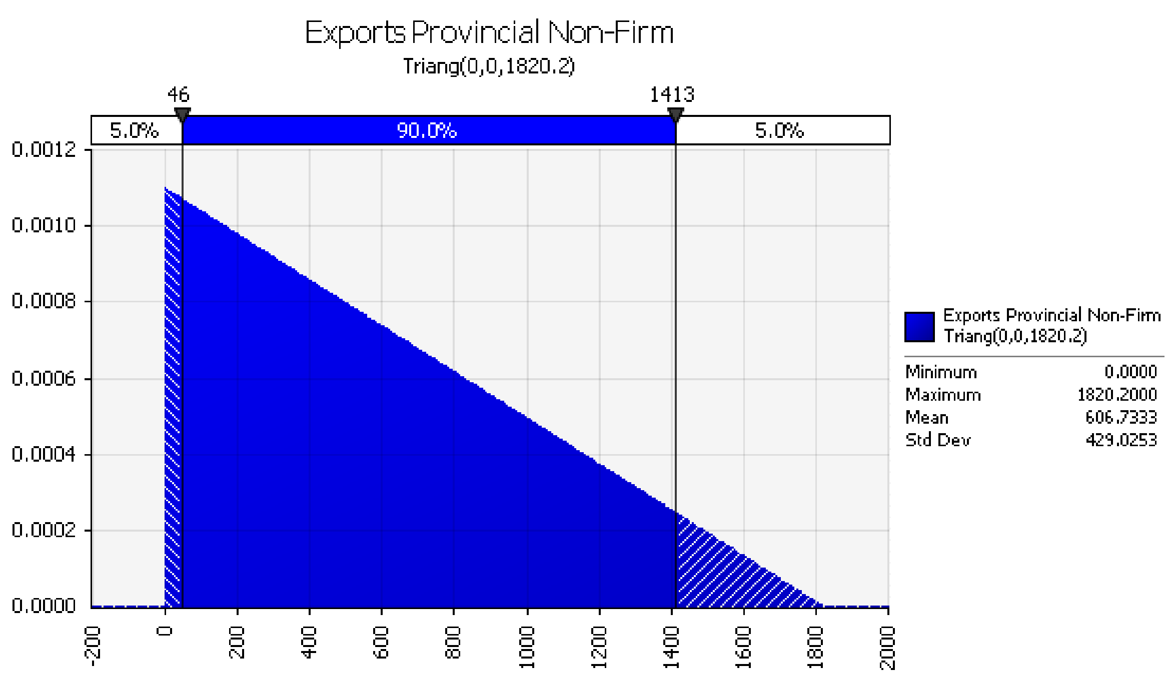


Figure 6.26 – Exponential Probability Distribution of Prices for Exports to US (Firm)

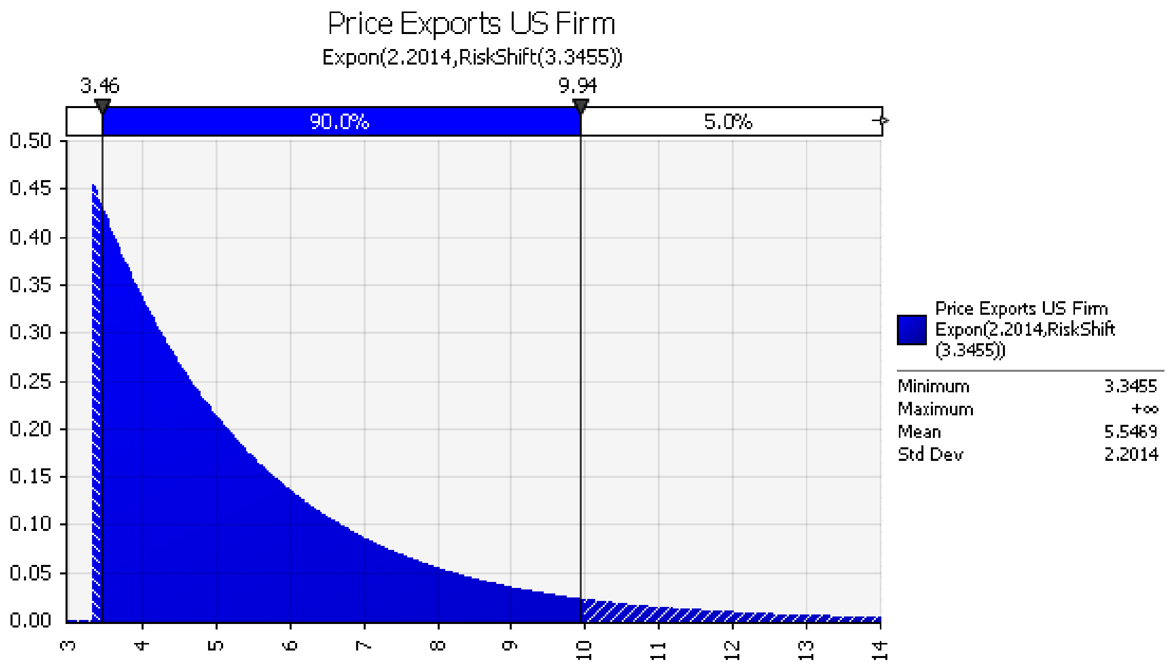


Figure 6.27 – Logistic Probability Distribution of Prices for Exports to US (Non-Firm)

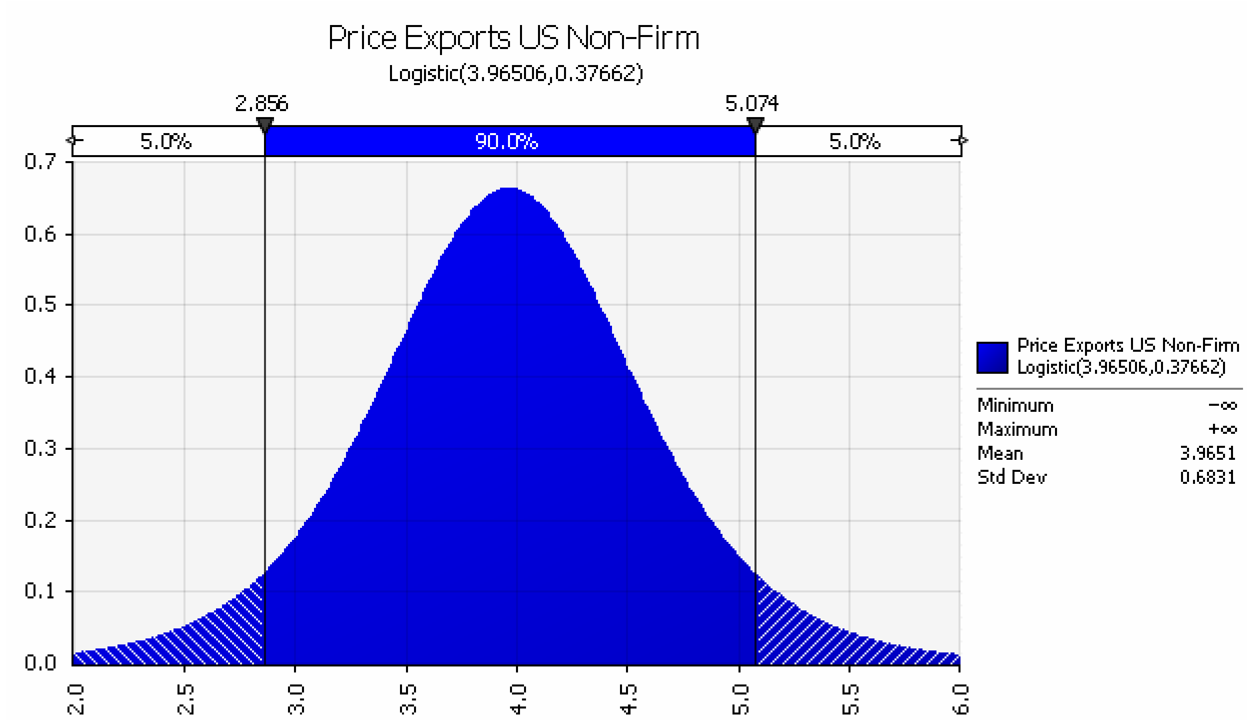


Figure 6.28 – Pareto Probability Distribution of Prices for Exports to Other Provinces (Firm)

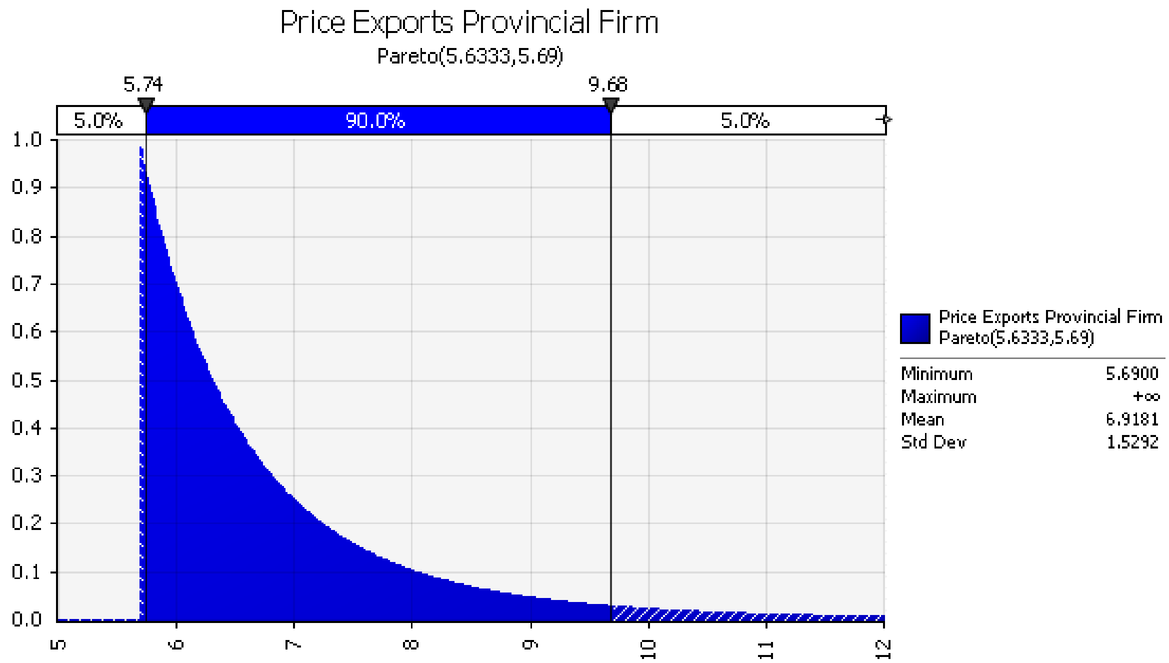


Figure 6.29 – Inverted Gaussian Probability Distribution of Prices for Exports to Other Provinces (Non-Firm)

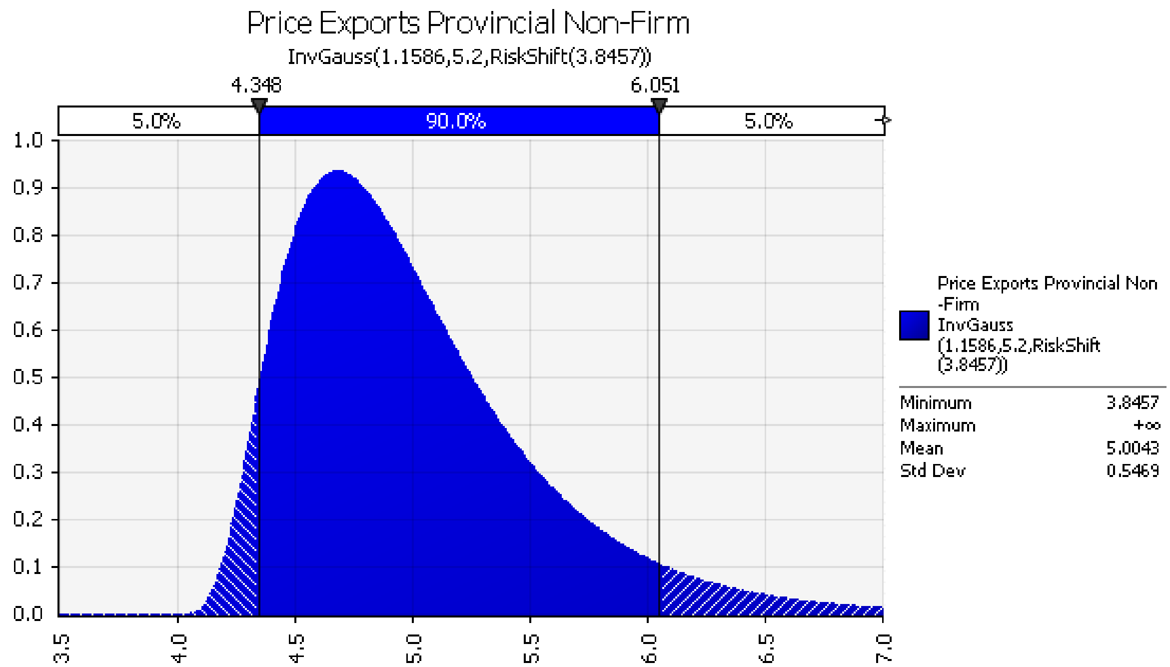


Figure 6.30 – Weibull Probability Distribution of Imports from Other Provinces

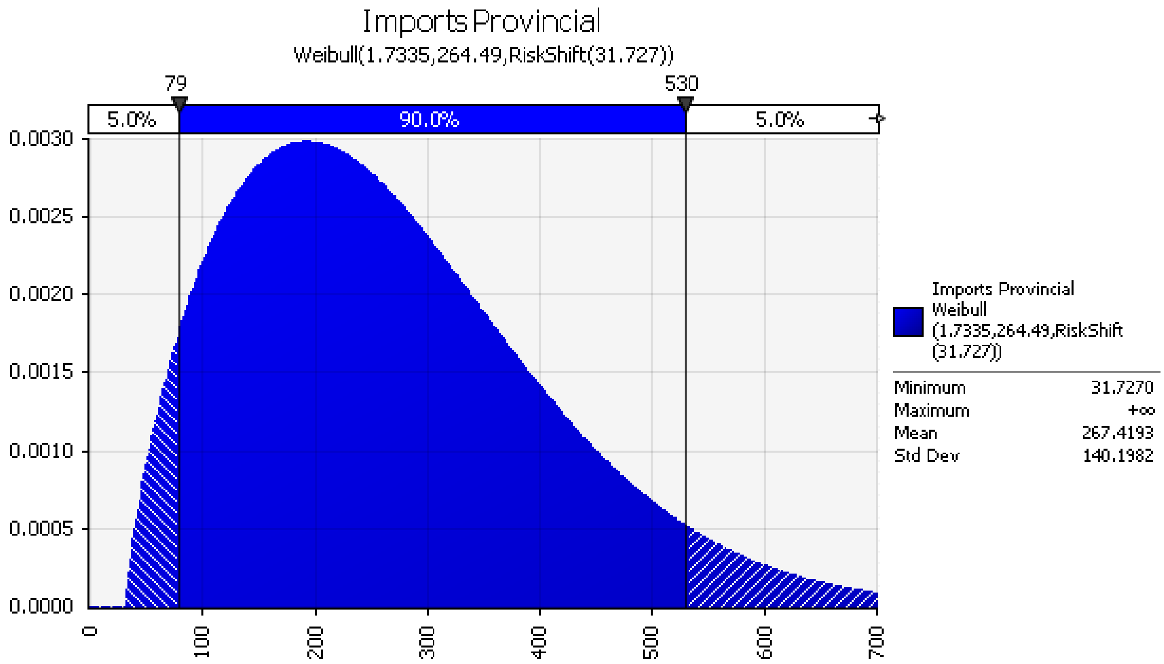


Figure 6.31 – Extreme Value Probability Distribution of Imports from US

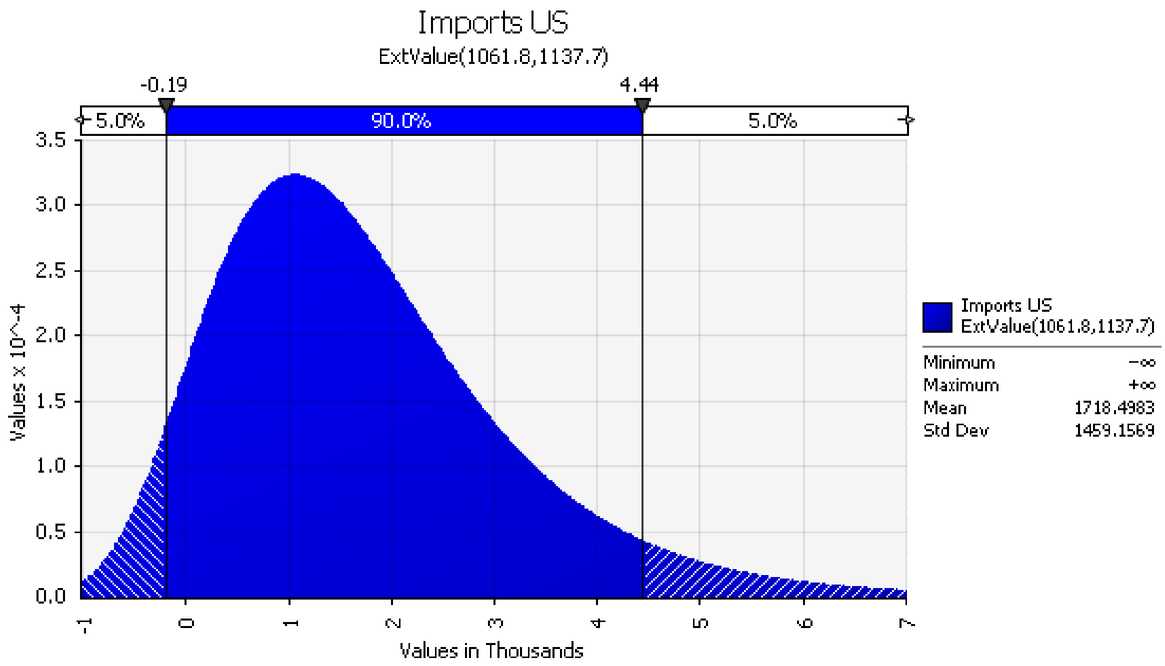


Figure 6.32 – Weibull Probability Distribution of Prices for Imports from Other Provinces

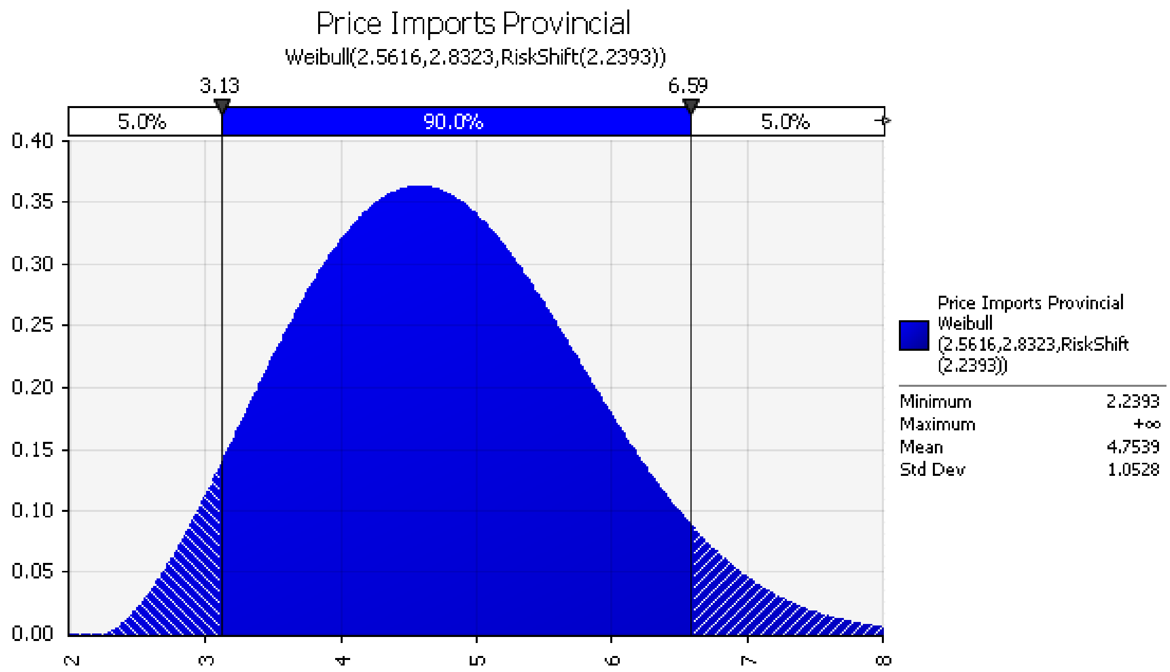


Figure 6.33 – Weibull Probability Distribution of Wages

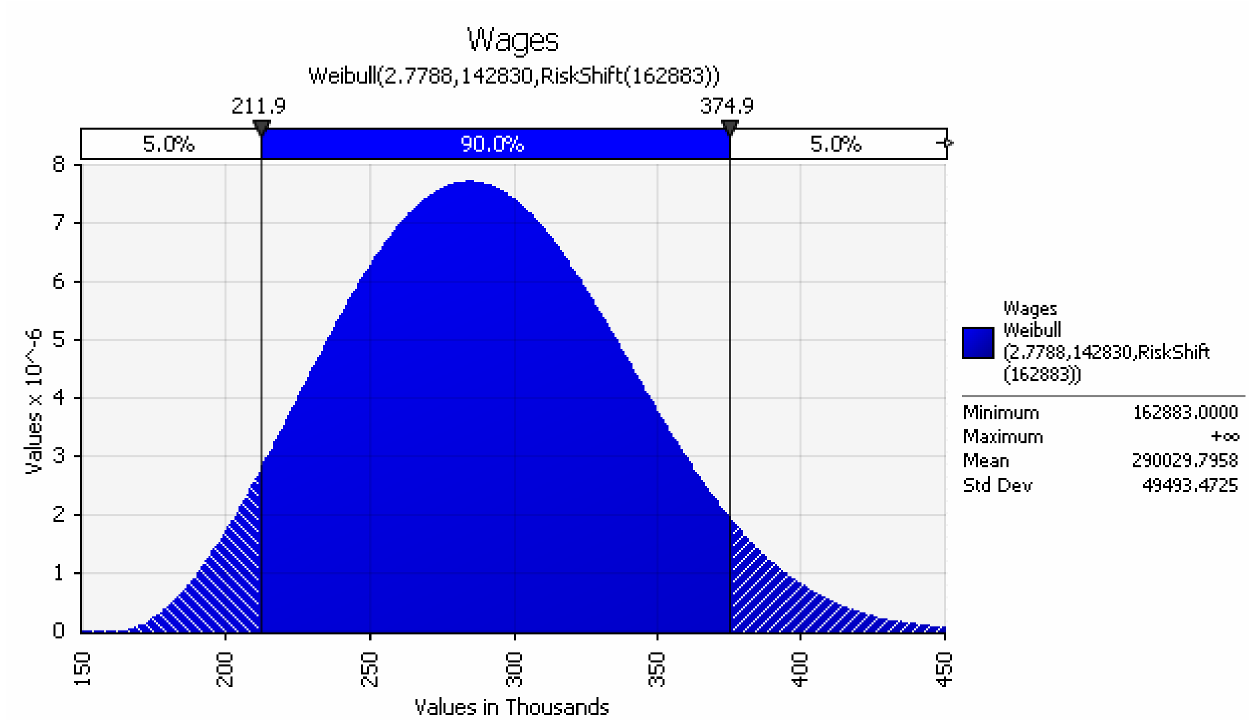


Figure 6.34 – Inverted Gaussian Probability Distribution of Cost of Fuel

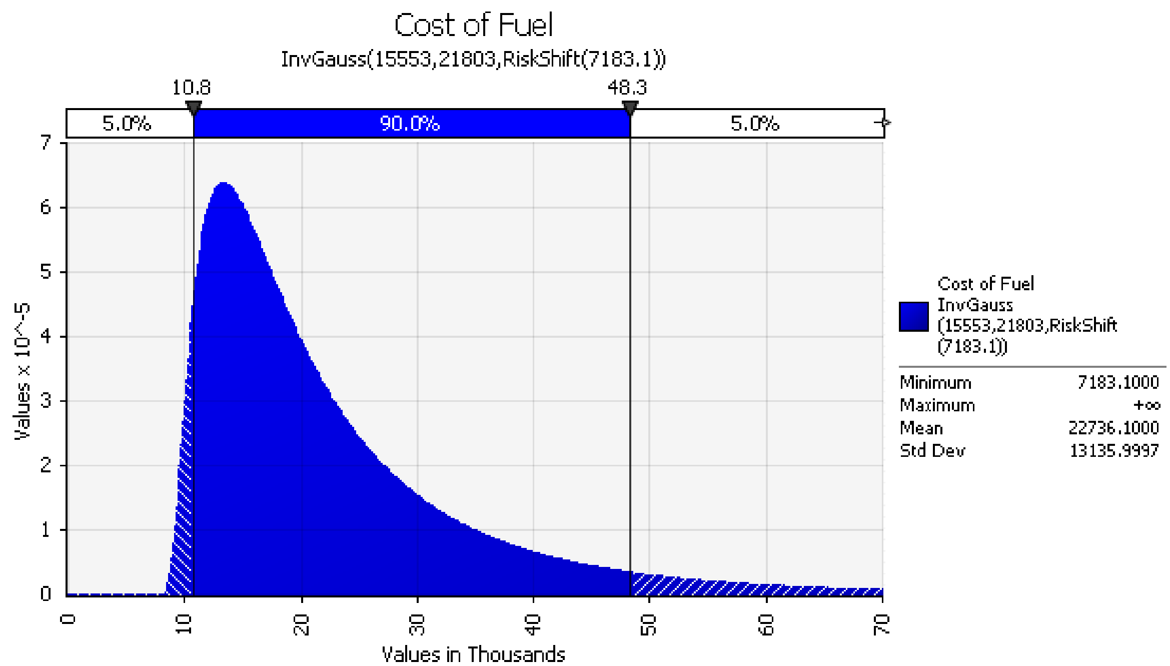


Figure 6.35 – Logistic Probability Distribution of Cost of Material

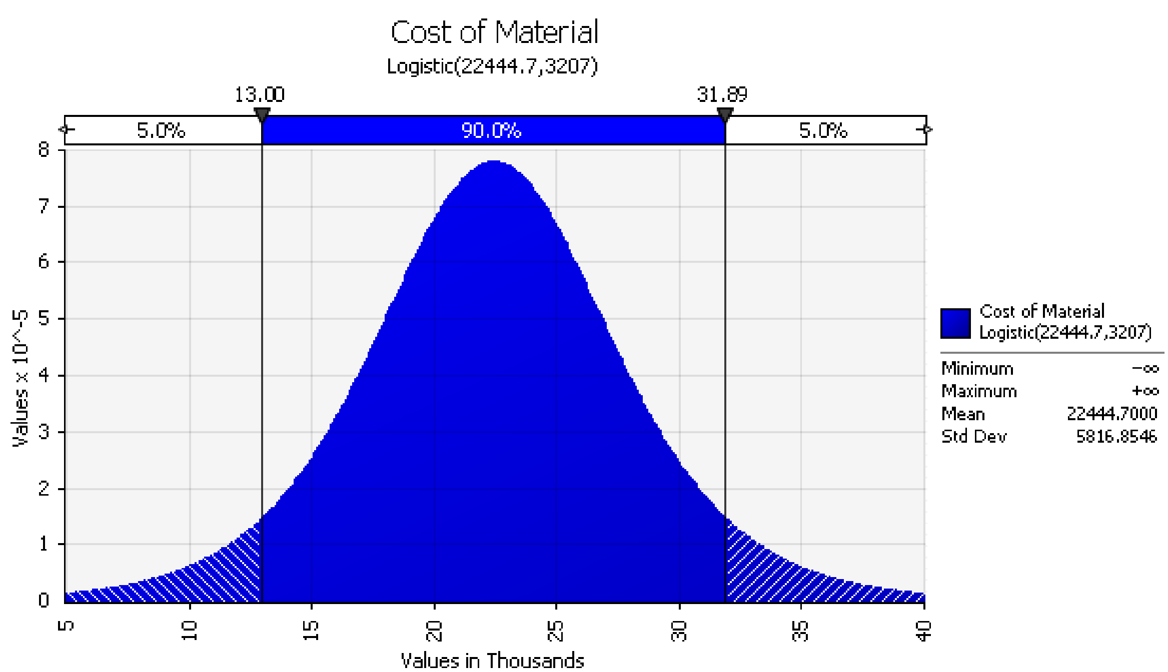


Figure 6.36 – Triangular Probability Distribution of Cost of Purchased Services

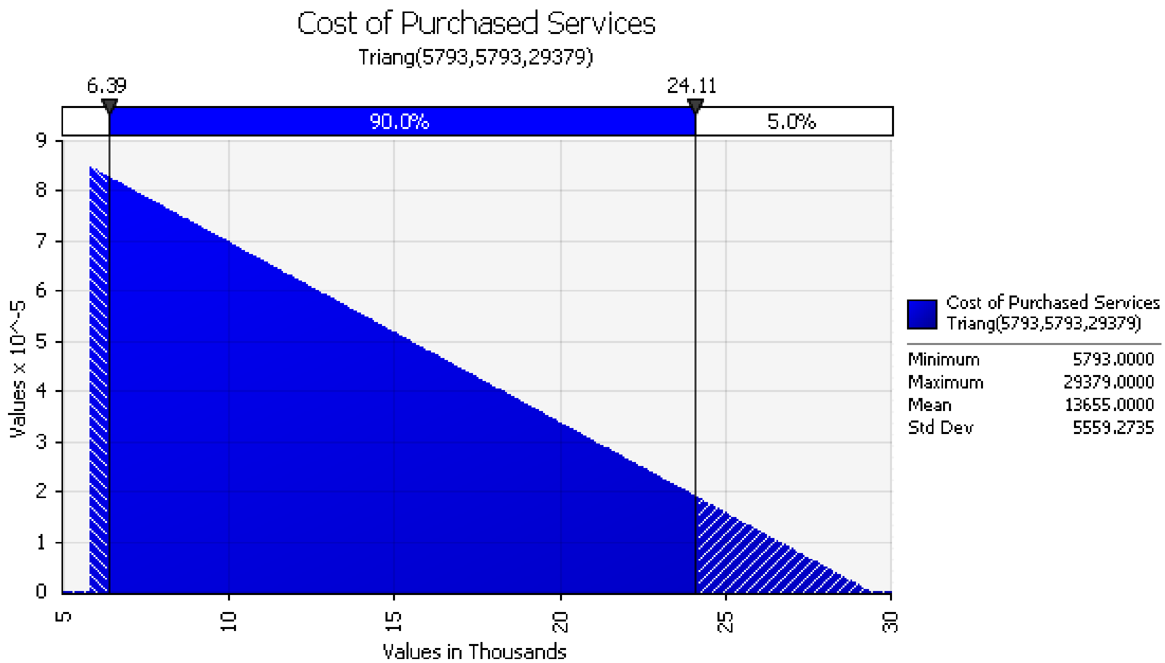


Figure 6.37 – Triangular Probability Distribution of Cost of Repairs

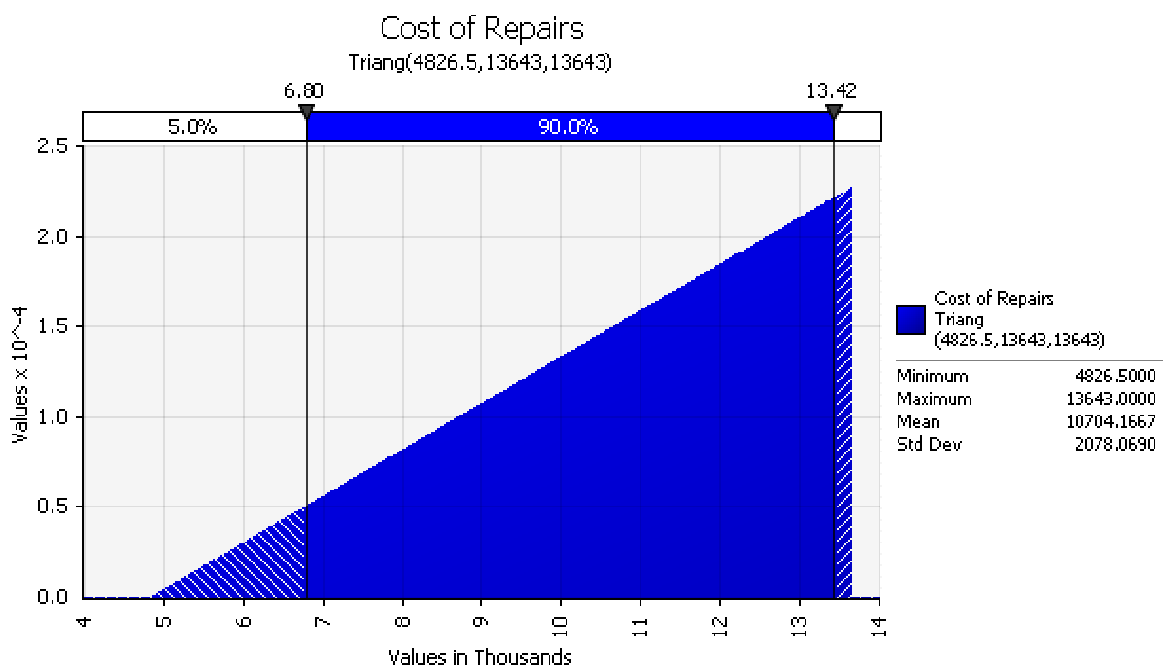


Figure 6.38 – Weibull Probability Distribution of Cost of Royalties

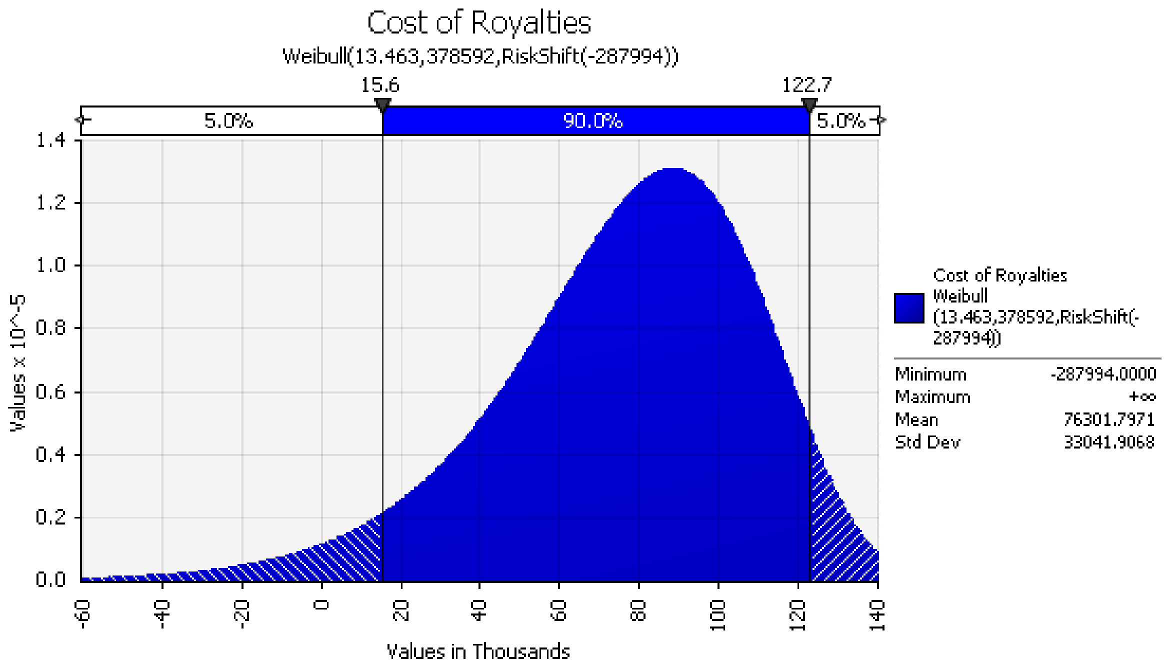


Figure 6.39 – Weibull Probability Distribution of Cost of Indirect Taxes

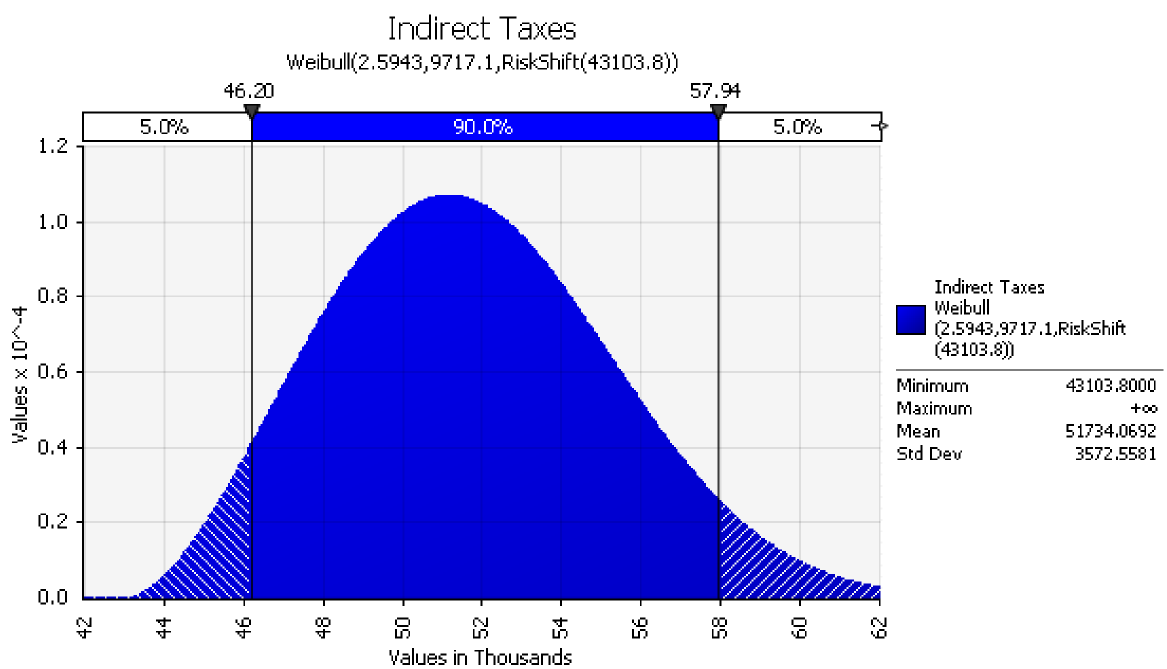


Figure 6.40 – Log Normal Probability Distribution of Cost of Other Expenses

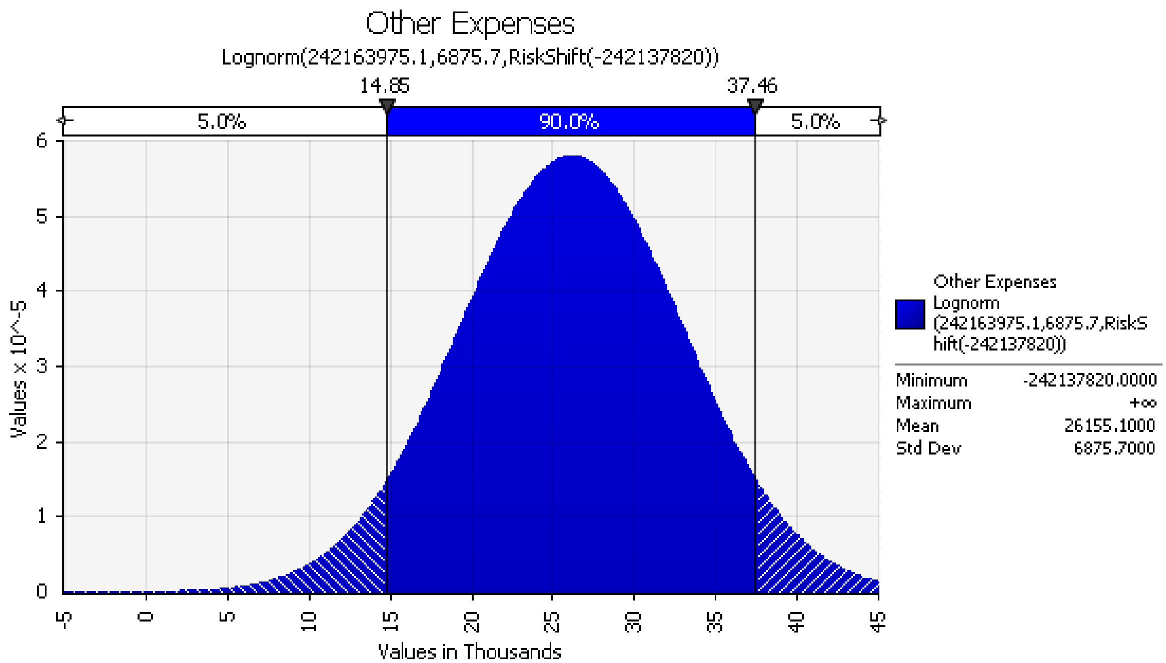


Figure 6.41 – Weibull Probability Distribution of Cost of Electricity Purchased

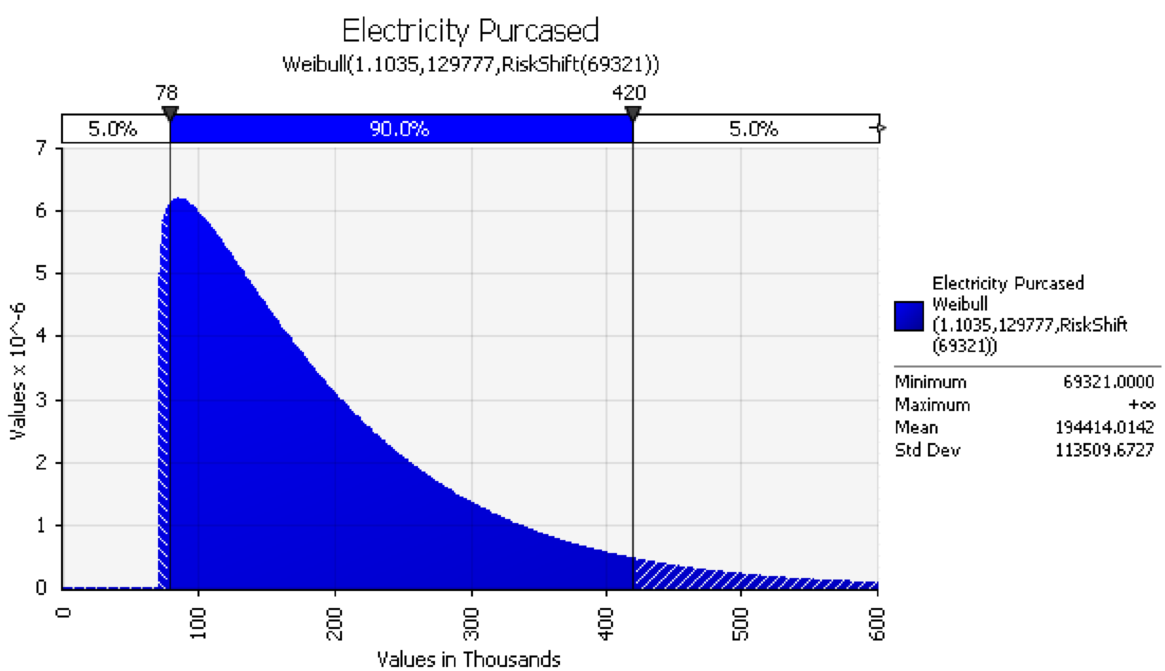


Figure 6.42 – Logistic Probability Distribution of Cost of Depreciation

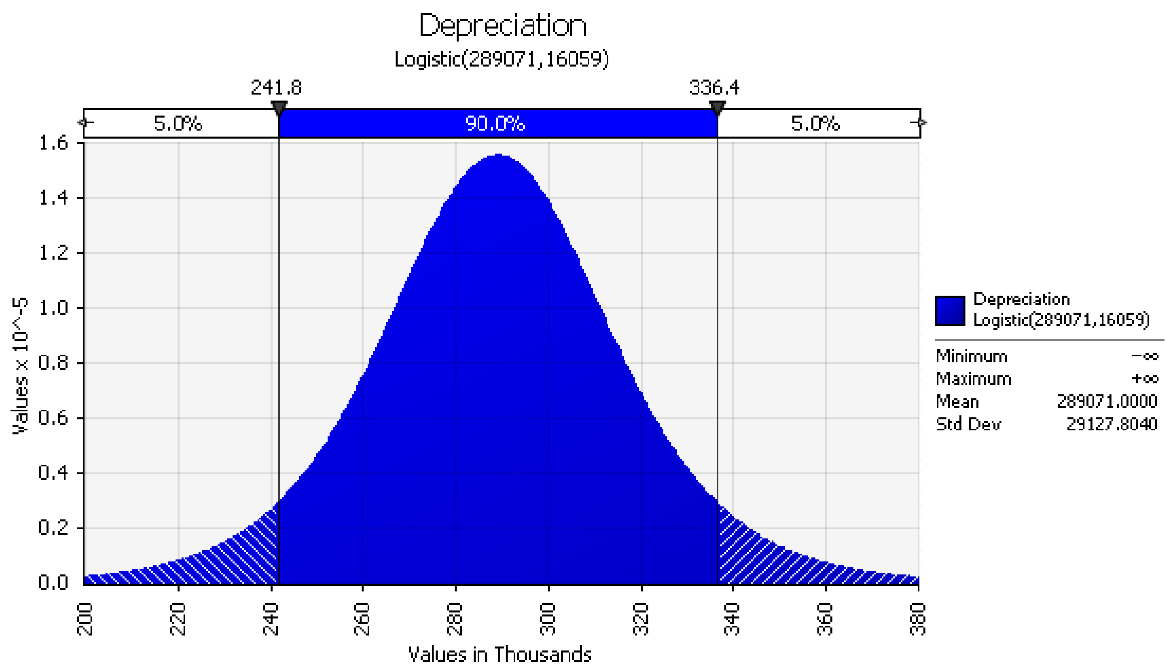


Figure 6.43 – Weibull Probability Distribution of Cost of Indirect Taxes

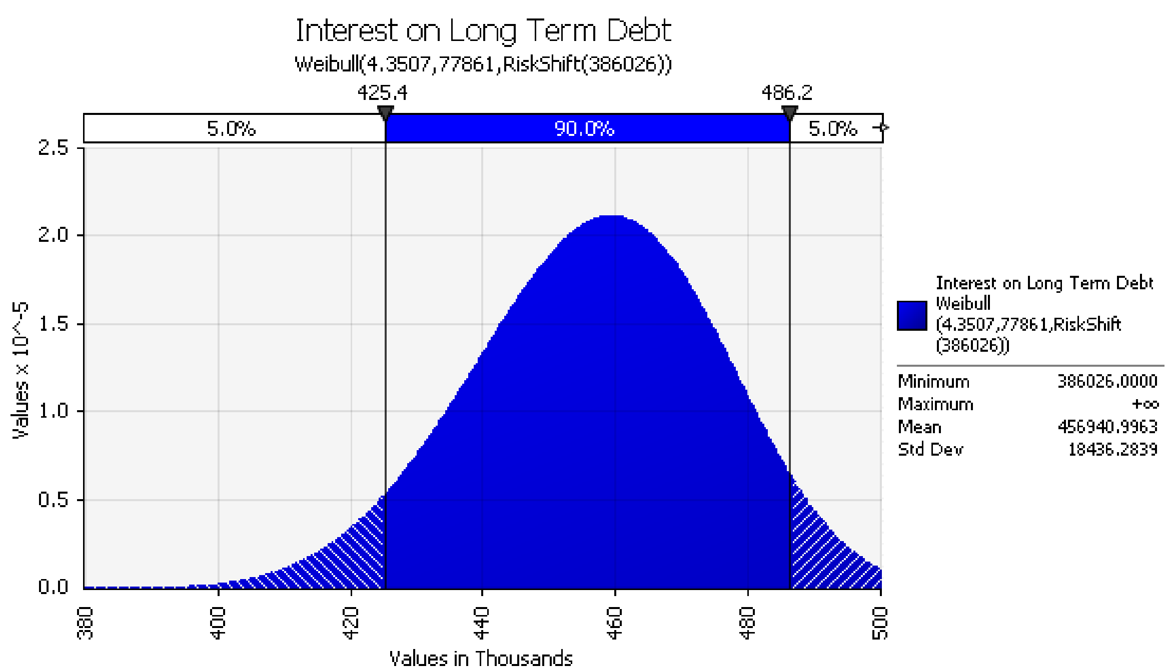
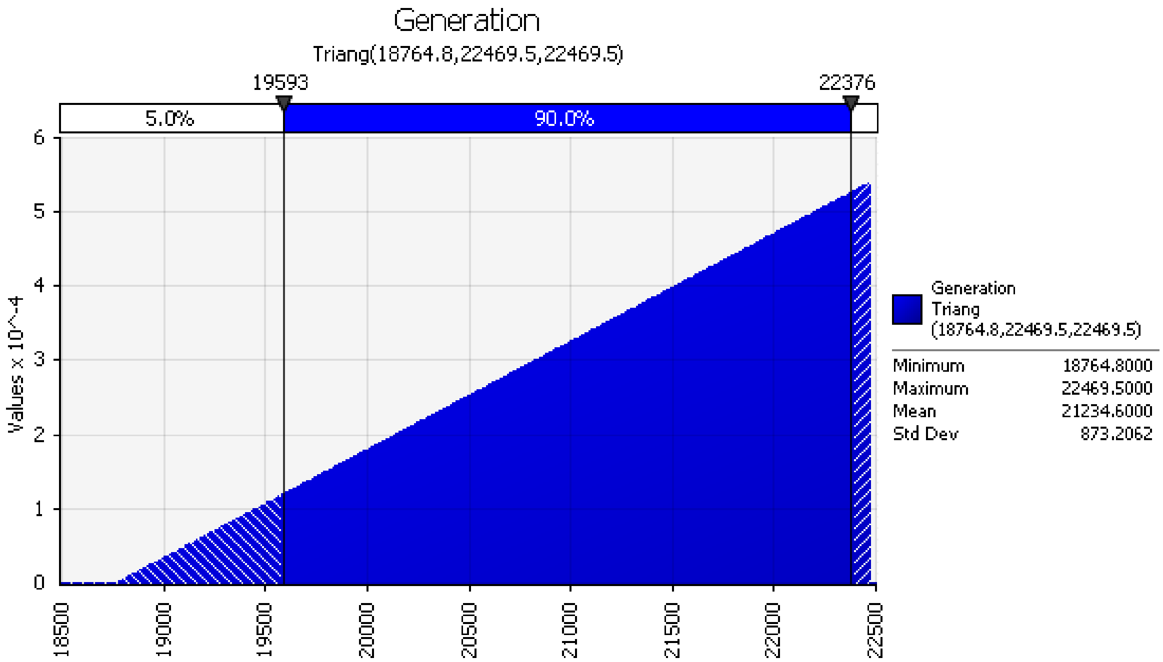


Figure 6.44 – Triangular Probability Distribution of Generation



6.6 Conclusions

The different simulations above provide tentative estimates of the sensitivity of the net revenues of MH to some key volumetric and financial variables. The impacts of water flow shortages are drastic on their own and would be more so if compounded by high import, escalation in interest rates, appreciation of the Canadian dollar and high growth in domestic load. The net contribution of each to the financial performance of MH has been estimated in order to illustrate the extent to which MH net revenue is responsive to changes in these separate variables.

Chapter Seven

Conclusions and Recommendations

7.1 Introduction

On March 26, 2010 the Public Utility Board of Manitoba (also referred to in this report as "PUB ") issued Order No. 30/10 in which it appointed Dr. Atif A. Kubursi and Dr. Lonnie Magee ("KM') to provide an independent assessment of Manitoba Hydro (also referred to in this report as "MH")--its risk management practices, policies, quantification, identification, tolerance, mitigation, governance structure and a host of other related matters as part of its 2010/11 & 2011/12 General Rate Application (GRA).

Specifically, PUB requested that KM provide comments and conclusions and complete the tasks detailed in 10 items contained in the Terms of Reference ("TOR") for the assignment in Schedule "C" of Order No. 30/10. The assignment includes:

XXI. Identify and explain general enterprise risk management concepts and best practices.

XXII. Review and evaluate all relevant available reports and supporting data, systems, models and analyses which address risk management or contain information affecting risk management for MH and report on findings arising from this review.

XXIII. Review and evaluate MH's water supply data and management models for impact upon identified risk factors, opportunities and risk mitigation options.

XXIV. Obtain any relevant information required from MH or other participants to the GRA process pertaining to risk management issues and impacts on MH's 20 year Integrated Financial Forecasts (IFF).

XXV. Identify all material operational and business risks for MH and MH's 20 year IFF.

XXVI. Prepare statistical analyses, quantification of risks and provide other analytical reports to consider the probabilities of all material operational and business risks of MH.

XXVII. Provide recommendations for risk mitigation measures to be considered by MH and future reporting requirements for regulatory purposes.

XXVIII. Be available through counsel for Consultants, as resource on general risk management inquiries, as reasonably required, to any Party to the GRA and receive input on possible relevant risk issues from any Party to the GRA (but not bind the Consultants). Any additional costs are subject to PUB approval.

XXIX. Provide a written report covering matters in items 1-7 herein with supporting data for use in the current MH GRA and any related applications before the PUB.

XXX. Participate as independent witnesses before the PUB in the current MH GRA and all related Applications before the PUB, including pre-hearing processes, responding to Information requests and testifying/attending for cross examination at oral hearings of the MH GRA and all related Applications before the PUB.

7.2 Unique Features of Manitoba Hydro

The general context within which MH operates is complex, given the inherent difficulties of being a public utility--both a business entity seeking positive, if not maximum, net income, and a public organization serving the best interests of the residents of Manitoba. Compared to other Canadian public power generators, MH is very hydro-oriented and export-oriented. As a major hydro generator it is critically dependent on weather and the environment. MH is a monopoly selling power without competitors in the domestic market but faces stiff competition in the export market where it is generally a price taker. These characteristics have proven crucial for our understanding of the conditions, challenges and risks faced by MH.

MH being a public utility, means it is an industry that provides the public with what are considered necessary services and that has, either through a relatively large initial investment or other unique operational conditions, the traits of a natural monopoly - traits which from early times inevitably tended to bring it within some form of public control, judicial or administrative or both. The public control takes many forms, but typically includes the supervision of rates and service by a public utility board, public ownership and oversight over operations and expansions by public bodies. Significantly, public ownership and oversight imply that the residents served by the utility are both shareholders and consumers. They are the main “clients” of MH and are at the same time the owners of the enterprise, and bear the final responsibility and consequences of its financial viability and success.

The provincial government exercises vital direction over the entire hydro-electric system in Manitoba as it guarantees its loans for expansion, underwrites its losses, appoints its regulatory Board, and ensures that MH management is accountable to responsible cabinet ministers, public bodies (e.g., Provincial Auditor) and the legislature (Standing Committee of the Legislature). MH is also subject to a broader network of regulation from the Federal Government (National Energy Board, Department of Fisheries and Oceans, etc.), and must comply in the US market with US regulatory bodies such as FERC and NERC, and has a contractual relationship with MISO.

Utility services are characterised by large capital investments, economies of scale in service, and high barriers (technical, legislative, financial) to entry. Some utility activities (e.g. network operation, system control, etc.) can be carried out only by a single entity, and others (e.g., power generation, water production, customer service, metering and billing) have such economies of scale that it is unlikely that there will be more than one supplier of these services in a small market. Public regulation is premised on simulating competitive market conditions that force the natural monopoly to moderate its market power and charge prices reflective of marginal costs. This is often done through a hard budget constraint imposed on the utility where it has to explain and justify any rate change by justifiable cost increases and where it has to demonstrate that its cost of service is minimal and all efficiency requirements are met.

The Crown Corporation structure in Canada places MH, as seen above, in two categories at the same time. Firstly, it has a business operating structure like any other business, even though it does not own its assets. Secondly, its shareholders are the people of Manitoba, and it is subject to a complicated governance regime with many overlapping jurisdictions. These special characteristics set it apart from the general run of Canadian business. It is also important to note that the workability of the competitive market place, which is relied upon to set the terms of trade in other businesses, is generally absent in the case of public utilities. This duality of character creates a principal agent problem because of information asymmetries between the principal (the public) and the agent (MH). The government or its agencies and bodies are interested in overcoming information asymmetries with the operator and in aligning the operator’s interest with those of the public. The information asymmetry arises in the context of utility regulation because the operator knows far more about its abilities and effort and about the utility market than does the regulator or the public.

The dual structure of the utility in Manitoba presents challenges and difficulties for MH but it also confers some critical advantages. MH is able to borrow at preferred interest rates, to expand its operations with greater access and ease to capital markets, to pursue environmental and social objectives, and to be liberated from an undue short term focus in favour of long term objectives (creating jobs, maintaining balanced relationships with First Nations, taking environmentally friendly initiatives, and so on). However, this structure also insulates MH from strict and direct shareholder scrutiny and it may constrain it to compromise business objectives in favour of social and environmental goals.

The public guarantees of debt can tempt a public utility to undervalue risk and behave more recklessly than if it were to bear alone the consequences of its risky behaviour. This temptation is further complicated by a regulatory regime that may set rates to cover the public utility costs and errors and that allows it to pass the costs of its mistakes, inefficiencies and risks to domestic consumers.

Profit optimization is not necessarily consistent with revenue optimization. The former would require higher prices, lower output, and lower employment. Socioeconomic and environmental concerns can trump some efficiency criteria. The fact that the residents of Manitoba are the owners of the utility and that the government guarantees the utility's loans may prompt MH to tolerate more risks than the shareholders would like it to or are willing to support. This proclivity to engage in risky behaviour or to accept different tolerance for risk between the residents of Manitoba and MH is a crucial problem for the regulators as they attempt to align the two interests and dispositions and minimize the tolerance differential between them.

Put differently, the real issue is for the regulators to align the risk exposure and tolerance of MH to match that of the citizens on behalf of whom the government and/or the Public Utility Board typically act. Citizens, in general, are risk averse, and Manitobans are likely no exception. Roughly speaking, this means that they would prefer to take on financial risk only if the probability of gain outweighs the probability of loss. MH tolerance and acceptance of risks may be (and generally is) different from that of the public. The issue is, then, one of a potential lack of alignment between the two and the extent to which regulators are forced to govern the risk tolerance and appetite of MH to match that of the shareholders (the people of Manitoba). This misalignment in risk tolerance arises not only because of different appetites for risk but also from the fact that the public assumes the costs of any losses either in higher electricity rates (if PUB allows it) or through debt payment charges, whereas the rewards of the risk-taking are internalized within MH.

A number of characteristics of MH set it apart from other power generating utilities:

- The heavy dependence of MH on hydrology exceeds 93% of total supply coming from hydro sources. If imports were not considered, this share would rise to 98%.
- MH has one of the lowest electricity rates in Canada.
- Net exports accounted for 31% of total generation of electricity in Manitoba.
- The historical record of water availability in Manitoba shows an obvious tendency towards drought recurrence.
- Water flow variability between 1912 and 2008 shows that the water flow rate in 1940 was 40% of the average flow and reached 160% of this average in 2007.
- Droughts do not only create volumetric shortages, they also create financial challenges. MH suffered major losses in 2003-04, as retained earnings declined by $436 million.
- Power generation has exceeded domestic load in all but 2003 during the decade 1998-2007 in Manitoba.
- The prominence of MH as a leading economic node in the province is quite recognizable and any development affecting this key export oriented sector is of serious interest and concern for Manitobans.

7.3 Enterprise Risk Management: Best Practices and MH Procedures

Plato is credited with stating that “The problem with the future is that more things might happen than will happen”. There are many potential events that may or may not occur. The range of possibilities is wide and it is costly and difficult to configure every possibility that may occur. In such circumstances it would make more sense to assign two measures to narrow the range of the potential set of events and to assign some parameters to their probability of occurrence and a magnitude of their expected consequence.

Risk management occurs on a daily basis and involves all aspects of business operations and the entire organization. With pro-active risk management we look at events and processes in a comprehensive manner and assess ***and document*** risks and uncertainty. The list of these best practices includes the following key elements:

First, risk management is not a one time event or a window dressing exercise. It is a serious on-going process. It is a systematic process based on feasible options and choices to optimize results and outcomes.

Second, it is about prioritizing risks in terms of probabilities and consequences and segregating risks in areas of specific concern.

Third, it is not sufficient, although it is important, to recognize, identify and link risks to business operations and objectives. This qualitative assessment must be backed by quantitative calculations.

Fourth, risk assessment is done with a purpose. It is not sufficient to know what the risks are: it is equally important to devise strategies and procedures to deal with them and reduce their threat to the realization of the objectives of the enterprise.

Fifth, individual responsibilities for these risks must be assigned. Individual responsibility must be backed by authority, resources, expertise and oversight.

Sixth, monitoring and tracking are essential components of the best practice system of risk management.

Best Practice Risk Governance Recommendations

The drastic events and the significant financial losses caused by the drought in 2003/04 drove home the need for instituting a comprehensive risk management plan to identify, assess and mitigate possible recurrence of drought. The plan has since been extended to cover a broader spectrum of anticipated risks.

When the best practice structure defined earlier is super-imposed on the current practices of MH a number of gaps emerge that MH can easily deal with in a manner that will increase and strengthen its resiliency and capacity to manage risks.

First, the Risk Map and the Control Map are clearly in place at MH. There may be some questions about how comprehensive is the list of identified risks and the extent to which the probabilities and expected values of outcomes and consequences are the products of objective criteria but this is a separate issue and we will offer some suggestions to deal with it later. What is conspicuously needed at MH is an Individual Responsibility System where responsibilities for identification, assessment, quantification, mitigation and avoidance are clearly spelled out and where these responsibilities are assigned clearly and unequivocally to specific managers and staff. This process ensures that each risk requiring a response has an "owner" and that responsibilities are segregated.

Second, the CRMR will be more complete if there is attached to each risk identified and colour coded, a component of the Organization identified as responsible for it. In the absence of this responsibility matrix, it will be difficult to define and implement a risk accountability structure for the Organization. It is only when responsibility is clearly identified that we can hold specific offices and people accountable for their actions or inactions. Surely a system of rewards and penalties is also needed to avoid a culture of impunity and moral hazard that is often endemic to public organizations. Furthermore, a superstructure is needed to evaluate, validate and verify different assessments. At each level a dual structure is needed; one to undertake the assessment in situ at the operation level and another to validate it at a management level. The function of the Middle Office here is critical for the success of the management of risk function.

Third, the qualitative aspects of risk management are well in place at MH. Unfortunately, this is not the case when it comes to the quantitative areas of risk management. There is hardly a mention of the word "quantitative" in the CRMR. Risk management is ultimately about quantification of exposure and calculation of the magnitudes of losses and threats. It is about statistical density functions, confidence intervals, expected values and variances. Quantification of risk and expected values are calculated at MH. There exits a number of models (particularly PRISM) and systems that are used as part of the operations of MH particularly at the Front Office – but these are not part of the function of risk management at the Middle Office. Their use and their numbers should be part and parcel of the risk management plan that needs to be verified by the Middle Office. Depending on a single risk tool is not advisable. There exits many commercially viable risk analysis tools (software) that may be worth evaluating and adopting to complement the existing system @RISK at MH.

Fourth, the quantification of financial exposure should use fair market values (replacement costs). The Mark to Market (MTM) measures shall take precedence over other benchmark evaluations of financial risks. This preferred measure of value in the energy market is premised on calculating the true exposure (taking account of unrealized losses and gains of the portfolio) as current prices differ from forward settlement prices. In this respect MTM prices gauge the true value of the financial risk exposure and can be compared to stop loss provisions and other risk tolerance rules. The MTM measures also define the requisite financial hedges and their effectiveness. The use of MTM may have to be limited, however, to financial risks. MH may use MTM to value future contracts. If it does so it opens MH to the exposure of new risks but it also avails MH the opportunity to use hedging instruments.

Fifth, it would make a great deal of sense to organize specialized teams to assess major identified risks for their probability of occurrence and their impact on business objectives. Risk teams should elicit assistance from "Subject Matter Experts (SME)" or functional units to assess the risks in their respective fields, but they should all funnel their expertise and calculations to the Middle Office. The Organization can surely benefit from greater visibility and use of statisticians and actuarial experts and from instituting these expert committees, especially when they are all linked and integrated to the risk management function and the responsible body (Middle Office) for it within the Organization. The Middle Office can surely benefit from recruiting specialized experts in statistics and risk analysis; at present it appears to be under staffed.

Sixth, the governance structure of risk management at MH can benefit from some needed restructuring and alignment. The CRMC is now part of Finance & Administration Division and reports to the Senior VP of the Division. It is now on the Organizations' Organogram at the lowest slot. Perhaps unintentionally, this placement conjures an image of lack of importance and lack of centrality of its stature, functions and contributions. Being at the Middle Office is the appropriate place for the CRMC, but it has to be part of the SVP Office, maybe in the first slot. At this time the CRMC is only an advisory body and is without any executive powers.

Seventh, there is an evident multiplicity of bodies dealing with risk (EPRMC, PSOMC, and CRMC, etc.). In itself, this is not a problem, but it becomes a problem in the absence of a well defined integrated and centralized structure that can harmonize the lines of authority, obligations and accountability. In the final analysis all of the risks must be combined and integrated. Dealing with all of them simultaneously is critical for the success of the Organization. Quantitative assessments of risks are based on a simultaneous evaluation of the impacts of all identified and quantified risks on a coherent basis with a focussed approach and integrated administrative structure. This can best be achieved through Joint Risk Management Committees organized and supervised by the Middle Office through CRMC.

Eighth, Risk Preparedness Plans and manuals are needed for all costly risks. A Drought Preparedness Plan is a critical necessity. It must be completed and instituted in the working mechanisms of the organization immediately. The preparedness plans should not stop at the Drought Plan. There are many other emergencies and drastic events that may occur that need to be expected and plans made to deal with them. A broad preparedness plan can make substantial contributions to the effectiveness of risk management services and plans at MH.

Ninth, MH has set limits and tolerance levels quantitatively in the areas of Merchant Transactions and Customer Credit. The setting of quantitative targets and rules should be extended to all areas of operations particularly power trading and export sales. The exposure versus limits reports should cover all aspects of operations with financial implications for MH. Variance and Exception reports should be all encompassing and produced routinely.

Tenth, best practice requires that any business transaction should be evaluated on its own but particularly for all the risks that it may encounter. This should be done by the business unit directly involved (Front Office) but an independent review must be undertaken by the Middle Office. Before a business opportunity is approved the Middle Office should validate the appropriateness of the market research, models, curves used to value the opportunity. But more importantly, the Middle Office should independently identify and quantify the various risks involved in accepting the new business. We urge

MH to direct the Middle Office to undertake such an assessment with every business opportunity above a certain dollar limit but particularly all Long Term Contracts.

Eleventh, many functions and activities in the organization are operating with deterministic models and frameworks. This is not particularly helpful for an organization that has taken the challenge to manage and control effectively and proactively all of its risks.

Twelfth, a detailed training program with simulation games dealing with risk occurrences and plans should be developed for the organization. These training programs and learning by-doing practices have helped other organizations in dealing with their risk exposures and threats.

7.3 Manitoba Hydro Models

Manitoba Hydro uses a large set of models to predict and optimize its operations, evaluate transmission options, quantify risk, forecast domestic load, and as tools for short term operations ranging to long term planning of operations and expansions. In this regard Manitoba Hydo is not different from BC Hydro which uses HYSIM (Hydrological Simulation) and SO (System Optimizer) models. HYSIM uses historical data on hydrological variables and system constraints to generate operational forecasts for generation and costs and these feed into SO which calculates the optimal expansion path given the forecasts of HYSIM.

We have reviewed a number of MH models including MOST, HERMES, SPLASH, PRISM, Domestic Load Forecast and the Economic Outlook. Below are the results of our evaluation.

In Manitoba hydrology, power generation, and financial systems are subsystems of a broader politico-technical system of which Manitoba Hydro is a key component. More precisely, three basic systems comprised of hydrology, power and finance interact with one another to define a complex underlying reality.

The number of variables within each of the three systems above is very large and is exceeded only by the number of equations that balance the complex interactions among these variables. The variables and equations are basically quantitative and technical in nature. No expert can be expected to know fully and deeply how these relationships work and unfold. It is necessary to construct models to represent, understand, explain and predict the outcome of changes in these complex systems. MH has developed a family of such models, each with its own unique objectives and structure, to deal with operational and planning purposes.

Generally models have two characteristics. First, they are a simplification of and an abstraction from observed data. It is impossible to include and represent the entire complex reality. Abstraction and generalization are necessary. Second, they are a means of selection of data based on the purpose for which the model is built. Choice of what is pertinent is crucial; otherwise the task of explaining and predicting a phenomenon will become impossible. Even with the largest and fastest computer there are limitations on what can be included in the focus set.

The details of model construction vary with type of model and its application, but a generic process can be identified. Any modelling process has three steps: First, one constructs a logically consistent model (heuristically making sure that the number of relationships is equal to the number of variables). Second, one checks the model for accuracy and validates its tracking of the observed data. Third, one uses the model for explaining and predicting the underlying reality.

The validation of the model accuracy is important because a model is useful only to the extent that it accurately mirrors the relationships that it purports to describe. Creating and diagnosing a model is frequently an iterative process in which the model is modified (and hopefully improved) with every iteration. Once a satisfactory model is found, it should be double-checked by applying it to a different data set and using it to predict within the sample (observed data) the values in the sample not used to estimate it (Back testing or intra-sample validation).

There are other criteria to use in evaluating a model besides its logical consistency and accuracy. These include:

- Its overall structure (linear or non-linear).
- Type (deterministic or stochastic).

- Complexity, completeness, and ease of use and interpretation.
- Its designers' skills.
- The competence of the backstopping technical and professional staff.
- Its flexibility and capacity to integrate with new subsystems.
- The ease with which it communicates with other models in the Organization.
- Its contribution to improving the overall performance and efficiency of the Organization.
- The documentation of its procedures for other users and for institutional memory.
- The training and support from within the Organization and outside it available on demand.
- The sophistication of the "solvers", their vintage and those that support them.
- The vintage and computational capacity and ratings of the hardware used to process the model.
- The nature and extent of "ownership" exercised by the Organization over the system.

These criteria were used to evaluate the MH model family. Below is a summary of our findings and recommendations, organized by model.

7.3.1 MOST

First, we would like to see the MOST model cast in a stochastic framework given the many uncertainties that are embedded in the system. It is possible to re-solve the Linear Programming Problem (LP) several times under different specifications of the parameters to take into account possible variations in these variables, but this is not necessary if other systems at MH (for example, PRISM) can be used to generate distributions of the exogenous forecasts.

Second, it is clear that a few price forecasts are embedded in the MOST system; it would make more sense to represent these as probability densities using @RISK in PRISM or any other probability generating system.

Third, we would like to see more than one or two skilled persons responsible for the model. It would make more sense to train a designated group of the staff to work on any given model: this will guarantee that a pool of skilled staff is always available to support the model.

Fourth, we recommend that the system be continuously subjected to validation and verification to improve its forecasting accuracy. Stressing the system (stress tests of the model) should be a regular and routine operation and reports about these tests should be funnelled to the Risk Management Committee.

Fifth, it will be useful to formalise the integration of Vista with other models and bring together those supporting and maintaining the system as part of a formal Modelling Committee at MH that meets regularly with a sufficient budget and that is entrusted with the task of internal oversight, review, upgrading, documenting and internalizing the ownership of the models.

Sixth, internal audits are necessary but not sufficient. This function should also be augmented by arms length verification, review and evaluation by an external Model Audit Committee comprised of experts from outside MH with no commercial connections to any of the models. These experts will be involved on a needs basis and granted consulting assignments.

Seventh, we would like to see that every effort is made to establish full ownership of the model systems within MH and that MOST is not seen or perceived as being a "black box" that was developed generically outside the full control and mandate of the Organization.

Eighth, we would like to formulate the objective function wherever possible to minimize cost of generation and delivery rather than maximizing net revenues.

7.3.2 HERMES

First, by any standard HERMES is an impressive system; it developed over time and grew in complexity and utility.

Second, its developers are on staff and the source code is home stored.

Third, we are satisfied that the technical staff that support and run the model are competent and committed.

Fourth, we have seen a couple of demonstrations of the system and have seen its objective function and constraints as well as solution runs and outputs.

Fifth, it is a large system with over 8000 constraints and bounds and a larger number of variables. It is capable of generating a rich set of bases (linearly independent vectors) that define feasible solutions for the objective function to choose from among them the optimal one.

Sixth, we have seen forced solutions which reflected assigning huge costs to particular objective function coefficients. This is a standard practice in large LP systems but is still worrisome. There is always the fear that users select optimum solutions close to actual operations or desired solutions.

Seventh, being an internally developed and maintained system it has advantages and disadvantages. Among the advantages is the ease and flexibility of changing and upgrading the system. This seems to be a continuous process at MH. But being a home grown product it may not be documented sufficiently or regularly. We have not seen a User Manual or a Technical Manual which are typical products of commercially developed systems. Home grown products are also protected and defended with zeal by their developers. It makes sense to subject the system to an external audit by an External Committee of Experts in a similar way to what was suggested above. The need for this validation and audit is doubly important when it is home grown.

Eighth, the deterministic nature of the model calls for more thorough adjustment and upgrades. It makes sense to move to a stochastic system or at least add a few stochastic modules. The system is flexible enough to accept new modules. This feature can be exploited here to add the stochastic framework.

Ninth, the same goes for some non-linear modules in the system. Since the underlying structure is nonlinear and new solvers (GAMS or AIMMS) can easily solve large nonlinear and stochastic systems, it is worth considering these upgrades. Successive optimization may reduce this need, but in our opinion this will be a poor substitute.

Tenth, the availability of PRISM and its subordinate @RISK at MH should facilitate using stochastic forecasts instead of the arbitrary optimistic and pessimistic variants.

Eleventh, HERMES is one of many systems within the general class of LP system. It is for a short to a medium term horizon. It sits between MOST and SPLASH. We would like to urge the model builders and users to fine-tune their models' integration and collectively work on synchronizing their work and improving their communication with one another.

Twelfth, we note with satisfaction that HERMES incorporates weather variables. This is a crucial advantage given the sensitivity of load to this variable and the extent to which it is expected to vary in the future.

Thirteenth, the forecasting accuracy of HERMES is not very high, particularly on the first round, but it improves on the second round. A thorough review of where the forecasting accuracy of the model can be improved on the first round is necessary. Continuous forecasting should be adopted. We noticed that in the regression equations only the first lag is adopted. Surely incorporating a more sophisticated lag structure could help in this regard.

7.3.3 SPLASH

SPLASH is a critical component of the model family at MH. It plays a crucial role in simulating future alternatives and is dependent upon to plan the system requirements for expansion in the future. Given this critical role any weakness or gap can have serious

implications for decisions based upon it, or alternatively any improvement and upgrades can yield high returns.
A number of issues are noted below that need to be addressed before this system can deliver on its promises.

First, the system relies heavily on linear approximations to deal with a basically nonlinear underlying structure. There are grounds to ask whether a nonlinear specification might now be necessary to deal directly with this problem. Given the major advances in computer languages in the optimization field, this consideration is not far fetched.

Second, the model is fully deterministic. Uncertainty is recognized but not dealt with directly. There are a number of areas where the simple introduction of some elements of PRISM can be relied upon to broaden the probabilistic base of the model. This will also increase and improve on the integration of the models at MH and add value to both models. We see a number of areas where SPLASH can use PRISM or simply @RISK particularly to represent a probabilistic structure for export and import prices, water flows and reservoir elevation levels.

Third, SPLASH is an extension of HERMES and the two could sit on the same platform. At the moment they are not fully integrated. There is more room for linking more explicitly the two systems to benefit from their commonalities.

Fourth, SPLASH is an in-house developed system which can benefit from both internal and external audits.

Fifth, we have seen some good documentation covering the components of the system but have seen nothing formal. Again, we would like to suggest careful and formal documentation of the system in User and Technical manuals.

Sixth, although the staff supporting the system are qualified this group should be formalized and expanded to be an identifiable group that is continuously trained and integrated in the overall model community at MH.

Seventh, we have not seen a real demonstration of the model and did not have the opportunity to get to look at the gear work of the model, its forecasts and their accuracy. This was not offered despite our interest in seeing an actual demonstration. We were

readily and openly allowed to examine and see the guts of HERMES and its forecasts but not SPLASH. This is another reason for formal external audits.
Eighth, we are not convinced that the integration of the past 94 flows is a sufficient procedure for taking account of water volumetric risks. There may be situations where a more severe or a longer drought that could take place, besides the recourse to an average or median flow is simply dismissing the embedded deviations of the system from central tendencies.

7.3.4 PRISM

PRISM fills a gap at MH. The aftermath of the 2003 drought highlighted the need for probabilistic models that can map a wide set of possibilities and introduce uncertainty into decision making and planning at MH, avoiding arbitrary specifications of pessimistic and optimistic forecasts. Besides, it enriches the set of what-if runs to a large magnitude from randomly generated values, replacing the limited number of possibilities typically used.

The following recommendations and comments about PRISM are tendered:

First, as an in-house system it allows staff at MH to customize the model to the specific needs of the Organization. We met the staff responsible for PRISM and we are convinced that they have the required computer and engineering skills to deal with its extensions and use. But we are also convinced that the staff can be beefed up to include statisticians who are competent to make informed selections and representations of the underlying probability distributions available in PRISM and @RISK. We have already alluded to the sensitivity of the results in PRISM to the choice of the underlying probability distributions. The competent choice of these distributions is of crucial importance to the usefulness and relevance of the results to risk management.

Second, some of the concerns we have about PRISM are in fact associated with the adoption by PRISM of results and vectors from other systems. The concern is that problems or errors in one system may be propagated through the entire family of models.

Third, while @RISK is a standard industry tool for dealing with uncertainty, it is a coarse system that requires customization and sophisticated knowledge of statistics and other related skills to become more flexible and produce genuine and useful results. There are other systems in the field and there is no substitute for detailed and painstaking analyses of the individual risks and the use of standard Value at Risk calculations (VaR). The two systems when used judiciously can be complementary to one another.

Fourth, we are happy that PRISM draws on other models at MH. It is our belief that the various and separate models that MH uses should all be integrated and should be adjusted to operate on a common platform (in Appendix B we present a simplified version of a fully integrated system for MH). Although there is always a concern that errors could be propagated throughout the system, having separate and disjointed models that do not conform to a consistent set of operations is also problematic. In this regard, it would be helpful if @RISK were used in the other models too. The relationships between these models are two-way streams of interdependence in which the outputs of one system become the inputs to another.

Fifth, some of the noted and preferred uses of @RISK have coupled it with other statistical models where it comes into play after other sources of uncertainty have been identified and exploited. For example, in the context of a specific application at MH, the model parameters of the Electric Load Forecast can be represented by their distributions using the standard errors of the coefficients. It is then that @RISK could be used to model the exogenous variables' distributions. The ultimate outcomes would represent the combined influence of parameter imprecision and uncertainty about forecast values of exogenous (independent or determining) variables.

Sixth, a few minor but important issues for improving PRISM would include freeing it from the seasonal and annual structure and allowing it to deal with intra-year issues. Also a richer and a better statistical anchor could be used to model water variability than the SPLASH characterization. More than a 5 year time horizon can be adopted to highlight results. Furthermore, as it stands now PRISM is only an energy model; it may be worth considering augmenting it so that it can become as well an energy capacity model. Price volatility modeling can be enhanced. The simple inert acceptance of external forecasts may be supported by a firmer probabilistic approach. There is also a need to contrast and compare @RISK calculations with other quantitative risk calculations. Greater integration and harmonization of the PRISM model with other MH models should be initiated quickly. Documenting the system explicitly in User and Technical manuals on a regular basis is essential. Equally relevant is subjecting the system to external audit and verification. Finally, adding statisticians/econometricians to the model support team is a critical necessity.

7.3.5 Load Forecast Model

The load forecast also plays a central role in the running of all MH models and contributes to both operational efficiency and future expansion plans. Errors in these forecasts can be costly and could result in faulty decisions and plans.

The following is a short list of our comments on and recommendations for improving the system:

First, the combination of survey results, technical and engineering information and regression techniques results in a rich base for the forecasts.

Second, the forecasting accuracy of the load forecasts is deemed reasonable for the 5 year term and the move to integrate probabilistic forecasts is encouraging.

Third, the staff responsible for maintaining and running the model is competent, enthusiastic about their work and dedicated. We were impressed with their knowledge and expertise.

Fourth, the structure of some of the regression equations can be strengthened. The use of one dependent variable may not suffice for future forecasts. Since the main objective is to forecast future values with accuracy, some experimentation with other variables and specifications should be encouraged.

Fifth, the use of standard deviations of the explanatory variables is a good step but more sophisticated integration of probabilistic structures is advisable. Some of the advanced uses of econometric models for risk analysis combine the use of the standard errors of the coefficients with different probability distributions for the independent variables and then a final Monte Carlo simulation to define the probabilistic range of the key variables of the system. MH could easily develop a similar framework to the one suggested above given that all of the pieces are available in-house for such an analysis.

Sixth, it will make sense that those responsible for the load forecast become official members of the model community group at MH and that integration of their model with the rest of the models at MH be made seamless and interactive.

Seventh, the inclusion of weather related variables is explicit in only one equation. It would make sense to have this key variable in most of the equations given its high significance in the equation in which it was included. But the question remains as to what procedure will be used to forecast this variable in the future. It may be worth considering developing in-house, or adopting, weather related forecasts from Environment Canada.

7.3.6 The Economic Outlook

A number of recommendations are made with regard to the preparation and use of the Economic Outlook beginning with adding both human and financial resources to the EAD and ending with expanding the mandate of the Department and changing some of its operating procedure. The centrality and pervasive uses of the EO necessitates elevating this function from a purely eclectic assembly of others' forecasts to a more nuanced and effective function.

First, the Department can benefit from the addition of economists and econometricians with quantitative skills and experience in forecasting to its staff.

Second, there is a serious need to revisit the forecasting role of the Department. At this time the eclectic selection of forecasts and forecasters is simplistic and driven by the commercial availability of the forecasts, while untested assumptions about their relevance and accuracy are accepted. Far more productive procedures would include in-house development of a forecasting model and/or cooperation with a Manitoba university department of economics for the development of selection criteria based on track record of forecasting accuracy.

Third, the forecasts adopted should abstract from the arbitrary specification of low (pessimistic) and high (optimistic) forecasts and move to generate probabilistic forecasts from standard risk tools available at MH.

Fourth, it is important that the EO group become part of the modeling family at MH and that their procedures be scrutinized and jointly developed with those who use their forecasts in their respective models.

Fifth, the terms of reference of this group should be expanded to involve serious contributions and evaluations of all economic matters at MH.

Manitoba Hydro supports and uses a number of models beside those discussed above, including PROMOD and others. The focus on the subset above is justified given its centrality and wide use.

7.4 Water Flows: Statistical Modeling, Prediction of Droughts, and other Issues

Manitoba is blessed with water abundance, but this abundance comes with the price of high variability. Over the past 98 years since records began to be kept for water flows in the Manitoba hydro system, this water was in critical shortage (drought) at least three times, and has varied by about 200% around the average recorded flow. In 1940 it was 40% of the average flow and in 2005 it exceeded the average flow by 152%.

We wish to emphasize our view that for MH's forecasting challenges, as in many others involving complex systems, it is not possible to show conclusively that any one prediction method is better than any other. Our goal in this chapter has been to describe some alternative approaches to the ones that MH has used, and apply them to MH's aggregate water flow data. These approaches involve different statistical models, varying the number of lags in AR models, suggesting the use of other variables in AR models, and using variable transformations.

Our main focus, in keeping with the risk management element in our terms of reference, was on predicting the frequency and severity of low water flow events. We use simulations based on estimated AR models, and an entirely different method that uses results from extreme value theory (EVT) in which the observed low water flow events are used to fit the tail shape of that extreme end of the distribution.

We are then able to simulate the distribution of the minimum annual water flow that would be observed over a 94-year period. This is more informative than simple historical simulation. We find that the actual minimum lies roughly in the middle of our 95% intervals, and the means and medians of our simulated minima are greater than the actual minimum. On the one hand, this reassures us that the use of the actual minimum as a kind of benchmark worst-possible-case scenario is not unduly optimistic or pessimistic. On the other hand, because we find that the 95% intervals are fairly wide, we wish to caution that an over-reliance on the actual minimum could result in a mind-set in which it is not necessary to consider the possibility of even worse outcomes, or indeed more beneficial water flow conditions.

The totally-different AR and EVT approaches provided very similar 95% intervals, which we consider to be an important check on the sensitivity of the results to the choice of model.

The same AR simulation method produces simulated five-year water flow minima within the same 94-year periods. Again, we find that the actual minimum is very close to the mean of the simulated minima, which is again reassuring, but we note that the 95% intervals are still fairly wide. The lowest five-year event in the next 94-year period may be very different from the one observed in the previous 94 years – the averaging-out effect in switching the outcome from one year to five years makes the outcome less severe, but no less variable.

We also suggest an AR model for monthly data that accommodates the strong seasonal patterns in monthly flows. We found a square-root transformation resulted in a model with better residual diagnostics tests, and found that the actual minimum is a worse outcome than the average of the simulated minima.

When the AR method was used for longer-run (20-year) predictions for the 2006-2025 period based on the record up to 2005, we find the predictive power of the model rapidly ebbs, which is typical of AR models and reflects the inherent difficulty of long-run predictions.

Our review of the climate change implications for MH water flows suggests that while precipitation patterns may not change a lot, fairly large temperature changes are predicted.

7.5 Review of Risk Reports: A Critical Evaluation

Our terms of reference stipulate that we review and evaluate all relevant reports and supporting data, systems, models and analyses which address risk management or contain information affecting risk management for MH and report on findings arising from this review. In this Section we have reviewed most of the reports that dealt directly and almost exclusively with the identification, measurement, control, mitigation and management of risks that we were able to obtain. Our review relied on our analysis and findings in the previous chapters.

The reports that were reviewed included the following:

1) MH. Corporate Risk Management Report, October 2008.

2) The NYC's June 20, 2010 Public Document (Appendix A).

3) NYC Power Point Presentation on Manitoba Hydro. Risk Management Presentation. January 10, 2008 (Appendix G).

4) MH's March 2007 Comments on NYC's December 4, 2010 Report (Appendix B).

5) MH's May 2007 Comments on NYC's December 4, 2006 Report (Appendix C).

6) MH's 2008 Middle Office Review of the NYC's Reports (Appendix D).

7) MH's October 2008 Middle Office Comments on NYC's Long Term Contracts Risk Report (Appendix E).

8) MH's May 2008 Review of NYC's January 2008 and December 2006 Reports (Appendix F).

9) MH's December 2008 Export Power Sales Risk Management Issues (Appendix G).

10) Nalinaksha Bhattacharrya. Report on Risks Faced by Manitoba Hydro in Power Exports. July 4, 2007.

11) Alan Peretz. MH Corporate Risk Management. Deloitte. January 26, 2004.

12) ICF International. Independent Review of Manitoba Hydro Export Power Sales and Associated Risks, September 11, 2009.

13) KPMG. April 2010 Reports and Appendices (Appendix H).

14) T. Simard and J.R. Joyce. 2002-2004 Drought Risk Management Review, Risk Advisory, January 18, 2005.

We did not succeed in obtaining all of the NYC's risk reports. NYC insisted that any review of her reports will constitute an infringement on her intellectual property rights. NYC was quite adamant in her request that we do not read any of her work and not even other reports that referenced her work. Obviously we could not comply with her requests fully and implement PUB's terms of reference. We opted instead to review exclusively her public document but complemented it with a face to face interview with her in New York City, as well as reviewing the reports prepared by MH and KPMG that dealt with her work and responded to her allegations. We did not want; however, to rely exclusively on secondary sources about her work. We tried again and again to meet her face to face for another time. The initial visit with her took place in New York City over a two day period between June 6 and 8, 2010 involving Dr. Kubursi, accompanied by Mr. Gavin Wood our counsel. We have tried subsequently to initiate another discussion following the release of her Public Document, June 20, 2010, but failed. Another meeting with her would have given her and us the chance to ask questions and for her to explain her logic, methodology, calculations and implications of her statements in the public document.

There was more than one way of meeting the request of PUB to review and evaluate these documents. It was possible to take each of the 14 documents separately, summarizing its findings and analysis and critically evaluating its methodology, calculations and recommendations. We opted not to do so for a number of reasons. First, there is a good deal of repetition in these reports within and between them. Second, there is a wide area of overlap in coverage and content that would have made our evaluation tedious and repetitive. Third, the risk reports are not of equal quality or relevance. Fourth, some are old and their findings have been overridden by developments and changes at MH and by recent events.

We defined a small set of themes each comprising a set of issues. These issues were considered from the various perspectives of the different authors and parties. We tried to abstract from the adversarial positions of the authors of these reports and simply dealt with the gist of the issues of risk raised and singled those we considered to be particularly relevant and critical for risk management at MH.

We have arrived at 14 findings. These are summarized below:

First, prices in HERMES are not stale; they are based on adjusted forecasts from a reputable forecast provider. Making adjustments to expert forecasts is reasonable and necessary but MH may wish to be more formal, transparent and to document the adjustments it makes. As well, MH may have to consider an alternative to purchase forecasts that uses forward price curves (this could be a complementary exercise).

Second, the Consultant claims that the accuracy of the historical water flow data before 1942 is not high. However, in our opinion, to discard this series is unjustified. The use of the historical series as if it is the only reliable series on which to base calculations of dependable energy is also not recommended.

Third, different production coefficients in HERMES and SPLASH are a problem. This problem pertains to the nonlinearity of the generation equation that links water flows to energy and the time strip differences in the two systems. Harmonizing the two systems on a common platform will minimize these discrepancies. The revenue losses due to this problem are limited and nowhere close to the exaggerated calculation of $26 million by the Consultant.

Fourth, HERMES, SPLASH and PRISM are indispensable operational, planning and risk assessment tools at MH. These decision support tools represent standard systems that are currently used in many leading utilities in North America. They can be expanded, harmonized, and integrated. They should be reviewed internally and externally and upgraded and updated regularly. BC Hydro and Hydro Quebec have or are moving to dynamic and stochastic systems: MH may wish to follow suit. A hydrological sub-model to complement HERMES and even SPLASH should be considered seriously as water management issues become more complicated under possible climatic changes.

Fifth, there is wide agreement among most of the reviewers of the models (KPMG, RiskAdvisory, KM and others) that the systems require formal documentation, more staff should be trained on using and supporting the systems, that external reviews are needed, and that the Middle Office should be involved (particularly in verifying and checking the results). The PRISM model should also be run in the Middle Office.

Sixth, notwithstanding the small dollar amount of discrepancy between the Generation Estimate and HERMES solutions, these discrepancies raise concern about the accuracy of the model and the reporting system. The real problem is more profound. HERMES and SPLASH are static models and do not handle time in a manner consistent with dynamic programming. MH may wish to consider some of the existing dynamic programming systems in use at similar utilities in North America.

Seventh, the predictive accuracy of HERMES can be improved. The antecedent forecasts need to be reviewed. Back-testing should be used. The practice of continuous forecast reviews has definite benefits.

Eighth, HERMES is not directly linked to the trading floor and its forecasts are not used as bids on the floor. But whether HERMES is relied upon to inform decisions in the opportunity market is another matter; models are useful tools for informing users' decisions, not replacing them. It makes sense, however, to dispel this concern by streamlining and documenting trading decisions and practices in order to dispel this misconception.

Ninth, the probability of a drought occurrence is higher than those estimated by the Consultant or ICF. The costs of a 5 year drought are in the order of magnitude used by MH rather than those calculated by the Consultant and the inclusion of other risk factors increases measurably the drought costs. It is also clear that the water flow data are serially correlated and that a statistical process confirms that Manitoba Hydro is correctly using the low flow years in 1937-1942 as the basis of its dependable energy calculations. While a more severe drought than the one experienced in 1937-1942 is possible, its probability of occurrence is 24 times in 9400 years (or 1 in 392 years).

Tenth, ICF International, Dr. Bhattachryya, KPMG, RiskAdvisory and KM all share the general appreciation that MH's Middle Office is evolving and that major progress has been made towards best practice. We all also recognize that mush is needed in terms of strengthening the HR expertise set at the Middle Office, the independence of its functions, the MTM measures of all risks, the expansion of risk limits standards and process control limitations to all aspects of MH functions, the development of an Internal Responsibility Matrix, the need for quantification of risks at Middle Office, and its involvement in contract risk assessment. Most of us recognize that there is some merit in NYC's comments about risk governance issues with respect to the independence of the Middle Office and the greater need for oversight, but we all disagree with her claims of lack of competence in the CRMC, and the concealment and manipulation of data by the Front Office.

Eleventh, there are many benefits for MH to be in the export market and specifically, the long term fixed price firm exports market. The long list advanced by KPMG and ICF outlined these benefits which include: diversification of the export portfolio, matching fixed costs to fixed revenues, guaranteeing secure investment in transmission infrastructure by counterparties and qualifying for priority transmission rights, pre-empting excess capacity by competitors, guaranteeing access to long term finance on favourable terms, raising export revenues in US dollars to defray import and debt costs in the same currency (providing MH a hedge against exchange rate fluctuations), greater access to firm imports when needed, and a host of other advantages. Even the Consultant admits that the issue is not selling in forward markets; the benefits from this would outweigh costs.

Twelfth, contract prices embedded in long term contracts are sufficiently higher than historical average spot MISO prices. These prices are carefully constructed using weighted long term forecasts and hopefully estimates of the long run marginal cost of counterparties. The export prices are higher than long run marginal cost of MH and average total cost. This suggests that export revenues can be relied upon to subsidize domestic rates when they are higher than import prices. We are not in a position to verify the claim in the Cost of Service that exports account for only 13% of total cost but we can verify that they contribute 32% of total revenue.

Thirteenth, the expanded capacity when Keeyask and Conawapa are completed will increase dependable energy and sales in the long term at higher prices than spot MISO prices will increase revenues. Expected declines in spot prices beyond 2011 will make these contacts more valuable. High import prices will remain a threat in time of shortages but new contract limit prices on these imports will define an upset price for MH. The inclusion of wind and out of money thermal energy in dependable energy is a stretch but they represent such a small portion of total generation that their inclusion or exclusion is not a material concern.

Fourteenth, the negotiated contract prices in the new contracts or binding term sheets with [redacted] and the escalation clauses are firmly structured to protect the contracts' real prices in the future. At this point in time, the contracted prices are sufficient to raise significant revenues for MH over its costs. The upset price on importing energy in the [redacted] contract will play a modest role in protecting MH from paying congestion prices in the event of a shortage. But the major achievements in these contracts are the curtailment provisions in the new contracts that could effectively decrease MH's firm export commitments by 29% and 19% of the total volume in times of adverse water conditions.

Fifteenth, the Consultant's calculations of the probability of a severe drought and the magnitude of drought losses are glaringly low and those of what may result from LTC commitments being considerably higher than those of that a reasonable calculation would produce. The need, however, for adequate risk capital to mitigate against MH's LTC risk exposures is a serious concern.

7.6 Quantification of MH Risks

Major losses can be expected from low water flows and a rise in import prices or a decline in export prices. Volumetric, price changes and interest rate changes are the major causes of risk for MH. Changes in labour cost, material cost, purchases of electricity costs and wind have only limited Impacts.

Summarizing our findings above, we have the following key results:

First, low water flows have the largest impacts on net revenue of MH. A total of $788 million can be lost on account of a repeat of the worst drought on record.

Second, a more severe drought than the worst on record would trigger the Force Majeure clause in the contract. A lower flow than the worst drought on record with curtailment will have lower impacts than the worst historical drought. Losses are large but only $772 million compared to $788 million.

Third, a low flow year at the same level of the worst drought coupled by import prices at the upset price 120/MWh results in a drastic loss of $1.2 billion in one year.

Fourth, a severe drought with high export prices (at future contract levels) and an average import price will result in positive expected net revenue, but a loss of $331 million from the base case.

Fifth, a 10% variation of wind generation has very low impacts on net revenue (less than $1 million).

Sixth, a 10% increase in wages and benefits' cost will reduce net expected revenue by $29 million.

Seventh, 10% increases in purchased inputs, materials and fuel prices have limited effects on net revenue (less than $3 million each).

Eighth, a rise of 10% in load met by an equivalent rise in imports, with no change in import prices, leads to a rise in net revenue of $3 million.
Ninth, a 10% increase in load met by imports that are priced at $120/MWh, will lead to a loss of $397 million in revenue.

Tenth, surprisingly changes in the exchange rate are not particularly high. A 10% appreciation in the Canadian dollar (moving towards parity), results in a loss of $33 million.

Eleventh, the worst case scenario with very low probability of occurrence would result in a $1.8 billion loss in net revenue.

Appendix A - Risk Aversion[31]

Consider the following simple experiment. Flip a coin once and you will be paid a dollar if the coin comes up tails. The experiment will stop if it comes up heads, but if you win the dollar on the first flip you will be offered a second flip, where you can double your winnings if the coin comes up tails again but lose all your winnings if the coin comes up heads. The game will thus continue, with the prize doubling at each stage, until you come up heads. How much would you be willing to pay to partake in this gamble?

Nicholas Bernoulli proposed this game almost three hundred years ago, and he did so for a reason. This gamble, called the St. Petersburg Paradox, has an expected value of infinity, but most of us would pay only a few dollars to play this game. It was to resolve this paradox that his cousin, Daniel Bernoulli, proposed the following distinction between price and utility:

"...the value of an item must not be based upon its price, but rather on the utility it yields. The price of the item is dependent only on the thing itself and is equal for everyone; the utility, however, is dependent on the particular circumstances of the person making the estimate."

Bernoulli had two insights that continue to animate how we think about risk today. First, he noted that the value attached to this gamble would vary across individuals. Certain individuals would be willing to pay more than others, with people's difference a function of their risk aversion. His second insight was that utility from gaining an additional dollar would decrease with wealth: he argued that "one thousand ducats is more significant to a pauper than to a rich man, although both gain the same amount." He was making an argument that the marginal utility of wealth decreases as wealth increases, a view that is at the core of most conventional economic theory today. Technically, diminishing marginal utility implies that utility increases as wealth increases, and at a declining rate.

---

[31] This section is based on Aswath Damodaran. Strategic Risk Taking: A Framework for Risk Management. Upper Saddle River: New Jersey: Pearson Education Inc., 2008. pp. 11-15.

Another way of presenting this notion is to graph total utility against wealth. Figure A.1 presents the utility function for an investor who follows Bernoulli's dictums and contrasts it with utility functions for investors who do not.

If we accept the notion of diminishing marginal utility of wealth, it follows that a person's utility will decrease more with a loss of $1 in wealth than it would increase with a gain of $1. Thus, the foundations for risk aversion are laid because a rational human being with these characteristics will then reject a fair wager (a 50% chance of a gain of $100 and a 50% chance of a loss of $100) because she will be worse off in terms of utility. Bernoulli's conclusion, based upon his particular views on the relationship between utility and wealth, is that an individual would pay only about $2 to partake in the experiment proposed in the St. Petersburg paradox.

While the argument for diminishing marginal utility seems eminently reasonable, it is possible that utility could increase in lock step with wealth (constant marginal utility) for some investors or even increase at an increasing rate (increasing marginal utility) for others. The classic risk lover, used to illustrate bromides about the evils of gambling and speculation, would fall into the latter category. The relationship between utility and wealth lies at the heart of whether we should manage risk, and if so, how. After all, in a world of risk-neutral individuals, there would be little demand for insurance, in particular, and risk hedging, in general. It is precisely because investors are risk averse that they care about risk, and the choices they make will reflect their risk aversion. Simplistic though it may seem in hindsight, Bernoulli's experiment was the opening salvo in scientific analysis of risk.

Mathematics meets economics: von Neumann and Morgenstern

In the bets presented by Bernoulli and others, success and failure were equally likely, although the outcomes varied. That is a reasonable assumption for a coin flip but not one that applies generally across all gambles. Whereas Bernoulli's insight was critical to linking utility to wealth, Von Neumann and Morgenstern shifted the discussion of utility from outcomes to probabilities. Rather than think in terms of what it would take an individual to partake in a specific gamble, they presented the individual with multiple gambles or lotteries with the intention of making him choose between them. They argued that the expected utility (this is utility multiplied by the probability of occurrence of the lottery win) to individuals from a lottery can be specified in terms of both outcomes and the probabilities of those outcomes, and that individuals pick one gamble over another based on maximizing expected utility.

The Von Neumann-Morgenstern arguments for utility are based on what they called the basic *axioms of choice*. The first of these axioms, titled *comparability or completeness*, requires that the alternative gambles or choices be comparable and that individuals be able to specify their preferences for each one. The second, termed *transitivity*, requires that if an individual prefers gamble A to B and B to C, she has to prefer A to C. The third, referred to as the *independence axiom*, specifies that the outcomes in each lottery or gamble are independent of each other. This is perhaps the most important and the most controversial of the choice axioms. Essentially, we are assuming that the preferences between two lotteries will be unaffected if they are combined in the same way with a third lottery. In other words, if we prefer lottery A to lottery B combining both lotteries with a third lottery, C, will not alter our preferences. The fourth axiom, *measurability*, requires that the probability of different outcomes within each gamble be measurable with a probability. Finally, the *ranking axiom* presupposes that if an individual ranks outcomes B and C between A and D, the probabilities that would yield gambles on which he would be indifferent (between B and A&D and C and A&D) have to be consistent with the rankings. What these axioms allowed Von Neumann and Morgenstern to do was to derive expected utility functions for gambles that were linear functions of the probabilities of the expected utility of the individual outcomes. In short, the expected utility of gamble outcomes $10 and $100 with equal probabilities can be written as follows:

$$E(U) = 0.5U(10) + 0.5U(100)$$

Extending this approach, we can estimate the expected utility of any gamble, as long as we can specify the potential outcomes and the probabilities of each one.

We cannot underestimate the importance of what Von Neumann and Morgenstern did in advancing our understanding and analysis of risk. By extending the discussion from whether an individual should accept a gamble or not to how he should choose between different gambles, they laid the foundations for modern portfolio theory and risk management. After all, investors have to choose between risky asset classes (stocks versus real estate) and assets within each risk class (Google versus Coca Cola) and the Von Neumann- Morgenstern approach allows for such choices. In the context of risk management, the expected utility proposition has allowed us not only to develop a theory of how individuals and businesses should deal with risk, but also to follow up by measuring payoff to risk management. When we use betas to estimate expected returns for stocks or Value at Risk (VaR) to measure risk exposure, we are working with extensions of Von Neumann-Morgenstern.

Summarizing the findings of the risk quantification simulations and the mitigation strategy to deal with them we include the following:

First, low water flows have the largest impacts on net revenue of MH. A total of $788 million can be lost on account of a repeat of the worst drought on record.

Second, a more severe drought than the worst on record would trigger the Force Majeure clause in the contract. A lower flow than the worst drought on record with curtailment will have lower impacts than the worst historical drought. Losses are large but only $772 million compared to $788 million.

Third, a low flow year at the same level of the worst drought coupled by import prices at the upset price 120/MWh results in a drastic loss of $1.2 billion in one year.

Fourth, a severe drought with high export prices (at future contract levels) and an average import price will result in positive expected net revenue, but a loss of $331 million from the base case.

Fifth, a 10% variation of wind generation has very low impacts on net revenue (less than $1 million).

Sixth, a 10% increase in wages and benefits’ cost will reduce net expected revenue by $29 million.

Seventh, 10% increases in purchased inputs, materials and fuel prices have limited effects on net revenue (less than $3 million each).

Eighth, a rise of 10% in load met by an equivalent rise in imports, with no change in import prices, leads to a rise in net revenue of $3 million.

Ninth, a 10% increase in load met by imports that are priced at $120/MWh, will lead to a loss of $397 million in revenue.

Tenth, surprisingly changes in the exchange rate are not particularly high. A 10% appreciation in the Canadian dollar (moving towards parity), results in a loss of $33 million.

Eleventh, the worst case scenario with very low probability of occurrence would result in a $1.8 billion loss in net revenue.

Twelfth, an eclectic strategy is suggested to deal with these risks that involve a linear combination of four variables with different weights that can be adjusted to fit the target of minimizing losses in net revenue. The components of this equation include retained earnings above a stipulated minimum, storage of water, rate adjustments that include an explicit insurance rider and maximum borrowing limit.

Appendix B – An Integrated Model for MH

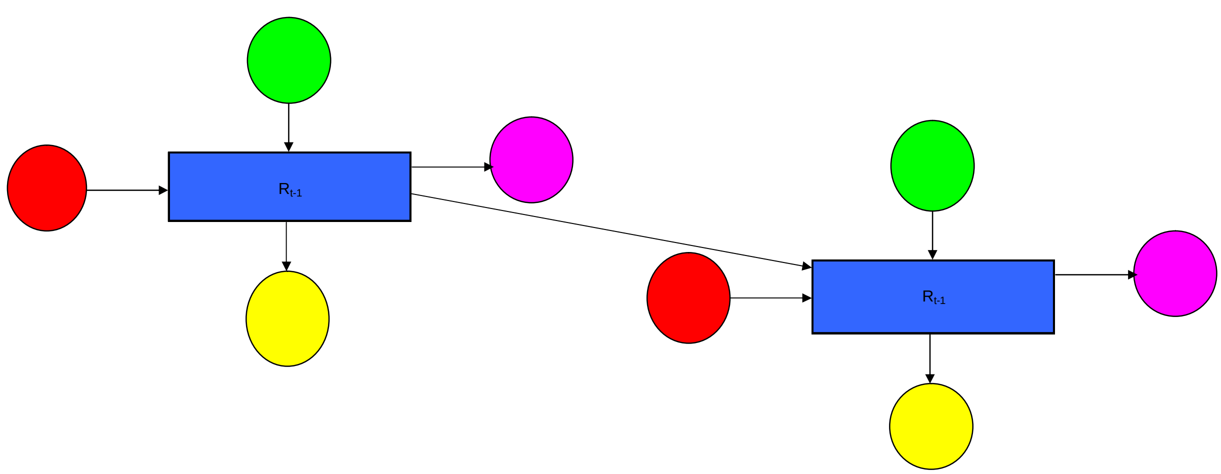
The Manitoba Hydro system involves issues of hydrology, power generation, and financial matters. These three subsystems are embedded within a broader politico-technical system of which Manitoba Hydro is a key component. More precisely, the three basic systems: hydrology, power and finance can be modeled separately and be placed on a common platform.

We have developed a very simplified accounting framework that combines all of the three sub-systems. Our objective is to demonstrate that the system can be integrated. The structure of the relationships is such that this integration is seamless and simple. We have called for a full integration of the system in our recommendations and that is why we have developed this simple presentation.

We begin first with the hydrological system; we then connect it to power generation and, finally, to the financial system. The direction of interaction runs both ways. The system, in essence, is a simultaneous system of equalities (or inequalities).

The Hydrology System

Figure B1 – Water Balances



Reservoir balance is defined by equation (1).

$$R_t = R_{t-1} + P_t - E_t + WI_t - WO_t \tag{1}$$

Where R_t is the reservoir volume at time t

P_t is the precipitation at time t

E_t is the evaporation at time t

WI_t is the water inflow at time t

WO_t is the water outflow at time t

A change in reservoir volumes is expressed in (2).

$$\Delta R = (P_t - E_t) + (WI_t - WO_t) \tag{2}$$

If net precipitation exceeds net outflow the reservoir increases in elevation; otherwise it loses elevation.

$\Delta R > 0$ if $(P_t - E_t) > 0$ and $(WI_t - WO_t) > 0$ (2a)

$\Delta R > 0$ if $(WI_t - WO_t) < 0$ but $(P_t - E_t) > 0$ and $|P_t - E_t| > |WI_t - WO_t|$ (2b)

Or if $(WI_t - WO_t) > 0$ but $(P_t - E_t) < 0$ and $|P_t - E_t| < |WI_t - WO_t|$

The hydrology system in Manitoba is a complex one with several reservoirs, many rivers and lakes. HERMES and even MOST have a more thorough and complicated hydrological structure, but the water balances are multiples of what is captured in equation (1) or equation (2).

Power Generation System

Manitoba Hydro generates power from a portfolio of sources. Hydro is the main generating source, representing over 95% of the total. But at any time Hydro can resort to Wind, Thermal, Coal and Diesel sources.

Hydro

$$WO_{it} * H_{it} * \theta_{it} = hE_{it} \quad (3)$$

Where

H_{it} is head at location i and time t
θ_{it} is the capacity coefficient at location i and time t
hE_{it} is hydro electricity generated at location i and time t

Gas

$$GE_{jt} * \lambda_{jt} = gE_{jt} \quad (4)$$

Where

GE_{jt} is gas power generating capacity of type j and time t
λ_{jt} is the efficiency factor of gas turbine of type j and time t
gE_{jt} is the gas generated electricity by turbine of type j and time t

Diesel

$$DE_{kt} * \delta_{kt} = dE_{kt} \quad (5)$$

Where

DE_{kt} is the diesel power generating capacity at location k and time t
δ_{kt} is the efficiency factor of diesel power generation at location k and time t
dE_{kt} is the diesel generated electricity at location k and time t

Coal

$$CE_{rt} * \Phi_{rt} = cE_{rt} \quad (6)$$

Where

CE_{rt} is the coal power generating capacity at location r and time t
Φ_{rt} is the efficiency factor of coal power generation at location r and time t
cE_{rt} is the coal generated electricity at location r and time t

Wind

$$WE_{pt} * \Psi_{pt} = wE_{pt} \quad (7)$$

Where

WE_{pt} isthe wind power generating capacity at location p and time t
Ψ_{pt} is the efficiency factor of wind power generation at location p and time t
wE_{pt} is the wind generated electricity at location p and time t

Total Power Generation

$$TP_t = \sum_i hE_{it} + \sum_j gE_{jt} + \sum_k dE_{kt} + \sum_p wE_{pt} \quad (8)$$

Total Power Supply

It is interesting to note that DSM is part of supply of electricity. Its value is a target of policy.

$$TS_t = \sum_i hE_{it} + \sum_j gE_{jt} + \sum_k dE_{kt} + \sum_p wE_{pt} + \sum_m IE_{mt} + \sum_n DSM_{nt} \quad (9)$$

Where

IE_{mt} is imports of electricity from market m at time t
DSM_{nt} is demand supply management program n at time t

Total Delivered Power

$$TD_t = \left(\sum_i hE_{it} + \sum_j gE_{jt} + \sum_k dE_{kt} + \sum_p wE_{pt} \right) (1 - h - m - e - a) + \sum_m IE_{mt} (1 - j) + \sum_n DSM_{nt} \qquad (10)$$

Where

η is the percentage of transmission losses

μ is the percentage of distribution losses

ε is the percentage of transformation losses

α is the percentage of HVDC conversion losses

` φ is the loss on imports of electricity

Total Demand for Electricity

Manitoba Load

$$MED_t = \sum_s mED_{st} \qquad (11)$$

Where

mED_{st} is the power demand of sector s at time t

Export Demand

$$EED_t = \sum_q eED_{qt} \qquad (12)$$

Where

eED_{qt} is the power export demand of market segment q at time t

Firm Supply

$$TFE_t = \left(\sum_i h^* E_{it} + \sum_j gE_{jt} + \sum_k dE_{kt} + \sum_p wE_{pt} + \sum_r cE_{rt} \right)(1 - h - m - e - a) + \sum_m IE_{mt}(1 - j) + \sum_n DSM_{nt} \qquad (13)$$

Where

> h^*E_{it} is the hydro power generation associated with the minimum flows at location i and time t.

It is to be noted that equation 13 includes power generated from coal, which can only come on stream in emergency situations where flows are deemed to be at exceptionally low levels.

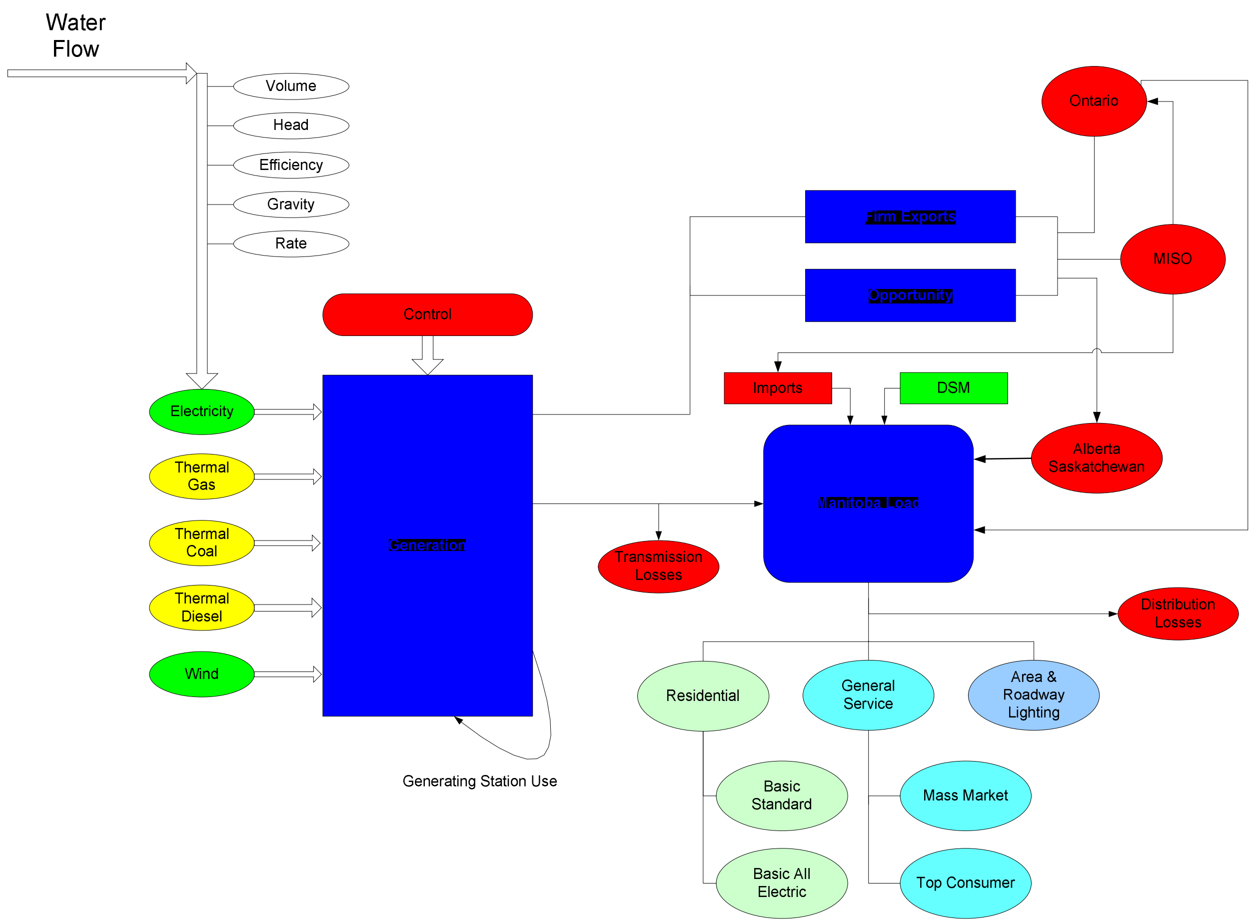
Energy Balances

$$TFE_t \geq MED_t \qquad (14)$$

The above relationship states that the firm supply is reserved for meeting Manitoba load and that no exports will be made unless total deliverable power exceeds Manitoba load at time t.

$$TD_t - TFE_t \leq EED_t \qquad (15)$$

Figure B2 – The Power Generation System



The Financial System

Gross Revenues

Revenues are derived from domestic sales and from exports.

Domestic Revenues

$$GRD_t = \sum_s P_{st} * mED_{st} \tag{16}$$

Where

P_{st} is the price charged to domestic market segment s at time t

It is possible to differentiate the price by off-peak/on-peak prices and by season. At this stage we are limiting the distinction to market segment (i.e. Residential, General Service as well as Area and Roadway lighting, etc.)

Export Revenues

$$GRE_t = \sum_q p_t P_{qt} * eED_{qt} \tag{17}$$

Where

P_{qt} is the price charged to export market segment q at time t

π_t is the exchange rate of the Canadian Dollar in terms of US dollars

Again, we can distinguish between opportunity markets and firm exports. We can also distinguish between real time prices and day-ahead market prices as well as between on-peak and off-peak prices.

Total Revenues

$$TGR_t = GRD_t + GRE_t = \sum_s P_{st} * mED_{st} + \sum_q p_t P_{qt} * eED_{qt} + OR_t \tag{18}$$

Where

OR_t is other revenues derived from selling ancillary services and other services in time t

Total Costs

Operating Costs

$$OPC_t = \sum_i w_{it} * hE_{it} + \sum_j w_{jt} * gE_{jt} + \sum_k w_{kt} * dE_{kt} + \sum_p w_{pt} * wE_{pt} + \sum_r w_{rt} * cE_{rt} + \quad (19)$$

$$\sum_m p_t p_{mt} * IE_{mt} + \sum_n w_{nt} * DSM_{nt} +$$

$$tc_t * \left(\sum_i h^* E_{it} + \sum_j gE_{jt} + \sum_k dE_{kt} + \sum_p wE_{pt} + \sum_r cE_{rt} \right) (h + m + e + a) +$$

$$\sum_m t_{mt} * IE_{mt} * j + \sum_n t_{nt} * DSM_{nt}$$

Where

w_{it} is the operating cost per unit of hydro energy at location i at time t

w_{jt} is the operating cost per unit of gas electricity using turbine type j at time t

w_{kt} is the operating cost per unit of diesel electricity at location k at time t

w_{pt} is the operating cost per unit of wind electricity at location p at time t

w_{rt} is the operating cost per unit of coal electricity at location r at time t

p_{mt} is the import cost from market segment m at time t

w_{nt} is the operating cost per unit of DSM of program n at time t

tc_t is the cost of transmission and other losses at time t

t_{mt} is the cost of import transmission and other losses from market segment m at time t

t_{nt} is the delivery cost of DSM program n at time t

Other Costs

$$\mathrm{OC_t} = \sum_{\mathrm{i}} \mathrm{wr_{it}} * \mathrm{WO_{it}} + \left(in^{ds}{}_t * Debt^{ds}{}_t + in^{dl}{}_t * Debt^{dl}{}_t\right) +$$
$$p_t\left(in^{fs}{}_t * Debt^{fs}{}_t + in^{fl}{}_t * Debt^{fl}{}_t\right) +$$
$$\left(\sum_k Dep_{kt} * Assets_{kt}\right) + CC_t + HC_t + IG_t + Oc_t \qquad (20)$$

Where

wr_{it} is the water rental rate at location i at time t
$in^{ds}{}_t$ is the domestic short term interest rate at time t
$Debt^{ds}{}_t$ is the domestic short term debt at time t
$in^{dl}{}_t$ is the domestic long term interest rate at time t
$Debt^{dl}{}_t$ is the domestic long term debt at time t
$in^{fs}{}_t$ is the foreign short term interest rate at time t
$Debt^{fs}{}_t$ is the foreign short term debt at time t
$in^{fl}{}_t$ is the foreign long term interest rate at time t
$Debt^{dl}{}_t$ is the foreign long term debt at time t
CC_t are congestion charges at time t
HC_t are hedging costs at time t
Oc_t are other charges at time t
in_t is the interest rate at time t
Dep_{kt} is the depreciation rate of asset class k at time t
$Asset_{kt}$ is the un-depreciated value of asset class k at time t
IG_t is the government debt guarantee charge at time t:

$$IG_t = f * \left(Debt^{ds}{}_t + Debt^{dl}{}_t + p_t\left(Debt^{fs}{}_t + Debt^{fl}{}_t\right)\right) \qquad (21)$$

where

f is the government guarantee charge of Manitoba Hydro’s debt

Net Revenues

$$\mathrm{NR_t = TGR_t - OPC_t - OC_t} \qquad (22)$$

Present Value of Net Revenue

$$\sum_t \left(\frac{1}{1+in_t} \right)^t * NR_t \qquad (23)$$

Net Foreign Balance

The net foreign balance is expressed in US dollars. It measures the shortfall, balance or excess foreign exchange earned or dispersed by the Utility. Exports represent an inflow of US dollars while imports and debt payments represent outflows of US dollars.

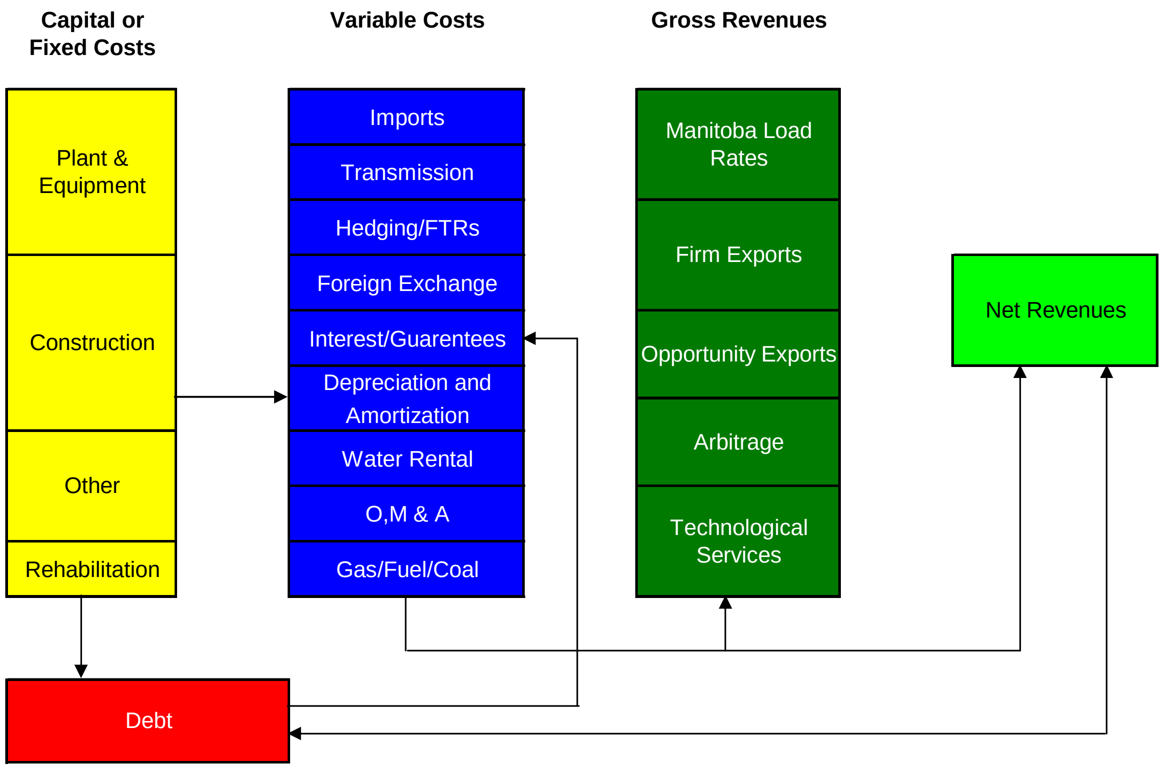
$$NFB_t = \sum_q P_{qt} * eED_{qt} - \sum_m p_{mt} * IE_{mt} - \left(in^{fs}{}_t * Debt^{fs}{}_t + in^{fl}{}_t * Debt^{fl}{}_t \right) \qquad (24)$$

where

$NFB_t > 0$ means that Manitoba earns more foreign exchange through exports of electricity than what it needs to pay for imports and interest on foreign debt.

$NFB_t < 0$ means that Manitoba earns less foreign exchange through exports of electricity than what it needs to pay for imports and interest on foreign debt.

Figure B3 - The Financial System



Appendix C – Statistical Processes of Water Flows

C.1 Description of Algorithms: Annual Data

AR(p)-based simulations

This estimated model was then used in two closely related simulation exercises “A” and “B”. Each exercise works like this:

GENERATE 1000 REPLICATIONS:

1) The sampling distribution of the coefficients (which is used to give the coefficient estimates and standard errors in the above table, but which also incorporates the co-variances between these estimates) is used to simulate a set of coefficient estimates similar to the above ones. This is done in order to account for the fact that the above coefficients are only estimates, so we want to take into account the sampling error in these estimates when simulating. This will have the effect of adding more variation to the results across replications.

2) Generate error terms using the normal distribution (in “A”) or using re-sampled residuals from when the model (with the coefficients from step (1)) is applied to the original data set (in “B”)

3) Using the coefficients from step (1) and the error terms generated from step (2), construct a data set containing 94 simulated observations. In order to control for the effect of starting values, we generated 188 values and took the last 94 as our data set. (The first 94 could be called “burn-in” values that assure that we have reached the stationary or equilibrium distribution by the time we take our sample.)

4) From this simulated 94-year period, find the consecutive 5-year period that has the smallest average water flow, and save that number.

4a) To examine the one-year minimum, replace step 4 with one where the minimum of the 94 simulated water flows is saved.

5) Repeat steps (1) to (4) 1000 times, leaving us with a collection of 1000 simulated 5-year minima. These can be interpreted as a set of 1000 possible alternatives to the 5-year minimum that was actually observed in the data.

CREATE A 95% CONFIDENCE INTERVAL FOR THE 5-YEAR (OR ONE-YEAR) MINIMUM

6) Sort the 1000 numbers collected in step (5).

7) Report the 25th and 975th largest ones. These can be interpreted as the lower and upper bounds of the 95% confidence interval for the minimum 5-year average (or for the minimum single year, depending on step (4) or (4a)) that one would observe over a randomly-observed 94-year period. Also take the mean of the 1000 numbers and report that.

Extreme Value Theory Approach

To estimate a 95% confidence interval like the above one, but in a totally different way, use extreme value theory (EVT) as follows:

A1) Select a "u" value which determines the size of the left-tail area of the distribution of annual numbers, to be fitted.

A2) Use maximum likelihood to fit a "Type-II Pareto" distribution to the tail, using only the data that lies in the tail.

A3) Use this estimated distribution to get an estimated probability distribution of the minimum that would be observed over a 94-year period.

A4) Use that distribution from step (4) to get 2.5% and 97.5% quantiles of the one-year minimum over a 94-year period. (NOTE: This requires assuming that the data are not auto-correlated, but because this is also assumed when the model is estimated, I think it does not create much of a problem unless the sample is really small.) We cannot get the mean of the distribution like we do in step (7) of the AR procedure, but we can get the 50% quantile, or median.

C.2 Box-Cox Transformation

The Box-Cox transformation[32] is a convenient and popular transformation family that has been used in a variety of ways (dependent variable, independent variables, combinations of these). The transformation is defined by the function

$$y^{(l)} = \frac{y^{l} - 1}{l} \quad \text{if} \quad l \neq 0$$

$$= \ln(y) \quad \text{if} \quad l = 0$$

Despite appearances, the $y^{(\lambda)}$ function transitions smoothly between the modified power transformation when $l \neq 0$ and the natural logarithmic transformation when l =0. The transformation parameter l can be chosen by maximum likelihood, which also allows for testing for the plausibility of using simpler null hypotheses such as l =0 (natural log), l =0.5 (square root) and l =1 (no transformation). In an AR(p) context, a convenient and natural formulation is

$$y_t^{(l)} = a + r_1 y_{t-1}^{(l)} + r_2 y_{t-2}^{(l)} + ... + r_p y_{t-p}^{(l)} + u_t$$

where u_t is assumed to be normally distributed with mean 0, constant variance s^2, and no autocorrelation. In standard practice, the parameters $\{a, r_1, r_2, ..., r_p, l, s^2\}$ would be estimated by maximum likelihood. The error term u_t is assumed to be normally distributed, and the likelihood function must incorporate a Jacobean term due to the nonlinear transformation of y_t.

Simulations such as the ones based on the model using the square root transformation reported in subsection 4.5.3 can just as easily be based on this estimated model. First, the $y_t^{(\hat{l})}$ values can be simulated using the other parameters in the usual way. Then the

[32] Box, George E. P.; Cox, D. R. (1964). "An analysis of transformations". Journal of the Royal Statistical Society, Series B 26 (2): 211–252.

simulated y_t values (i.e. the simulated water flow values rather than their transformed values) can be recovered using the inverse Box-Cox transformation:

$$y = (1 + \hat{l}\, y^{(\hat{l})})^{\frac{1}{\hat{l}}} \quad \text{if} \quad \hat{l} \neq 0$$

$$= \exp(y^{(\hat{l})}) \quad \text{if} \quad \hat{l} = 0$$

The simulations carried out in subsection 4.5.3 can be viewed as being based on this transformation with $\hat{l} = 0.5$. Instead of estimating l by maximum likelihood, we settled on 0.5 due to the satisfactory properties of the residuals.

Table C1 – MH System Uncontrolled Inflow (Kcfs)

[redacted]