Peer Review

of

Manitoba Hydro's

SPLASH Model

May, 2005

Manitoba

Building for the Future

INTRODUCTION

During the Clean Environment Commission hearings in 2004 and the Section 35 consultation process related to the Wuskwatim hydro-electric project, questions were raised about the adequacy of the SPLASH model for estimating the impact that the additional power station would have on the water regime on the Nelson River system, and in particular at Cross Lake. To address this concern Manitoba Hydro prepared a report documenting the use of the model entitled *"Utilization of the SPLASH Computer Simulation Model to Represent Water Regime in the Manitoba Hydro System, March 21, 2005"*. Manitoba Water Stewardship then hired three experts to review the report, discuss the simulations with Manitoba Hydro staff, and to give their opinions on the adequacy of the model.

TERMS OF REFERENCE FOR THE REVIEW

The terms of reference given to the three experts are as follows:

> *The consultant is to read the report on Manitoba Hydro's SPLASH Model and participate in a one-half day session in Winnipeg, at which Manitoba Hydro representatives will present the report and answer questions from the consultants (3) pertaining to the report and model. The consultant is required to provide a written summary of his professional opinion on the adequacy of the SPLASH model.*

PEER REVIEW

The peer review took place on May 3, 2005 at the offices of the Water Science and Management Branch at 200 Saulteaux Crescent in Winnipeg. The three invited experts were:

- **Dr. Slobodan Simonovic** Dr. Simonovic is a professor of Civil and Environmental Engineering at The University of Western Ontario, and holds the position of Engineering Research Chair, Institute for Catastrophic Loss Reduction. He has thirty years of research, teaching and consulting experience in water resources systems engineering. His primary research interest focuses on the application of systems approach to, and development of the decision support tools for, management of complex water and environmental systems.
- **Dr Jay Doering.** Dr. Doering is Dean of the Faculty of Graduate Studies at the University of Manitoba and is also a Professor in the Department of Civil Engineering. He was previously Head of the Department of Civil Engineering at the University of Manitoba. Dr. Doering is an expert in hydraulics and wave mechanics. He established the hydraulics research and testing facility at the University of Manitoba.
- **Rick Carson.** Mr Carson has 35 years of experience in hydraulic engineering, hydrology, and project management for water resource projects. He has been involved in the development of and application of numerical models to assess

river flows, reservoir use for hydroelectric systems and multi-purpose developments. He is currently the Manager of Water Resources for KGS Group.

The session on May 3, 2005 was chaired by Rick Bowering, Manager of Surface Water Management in the Department of Water Stewardship.

Manitoba Hydro was represented by Harold Surminski and Bruce Hinton of Power Planning and Development and David Cormie of Power Sales and Operations. Bruce Hinton went through a presentation that summarized the use of the SPLASH model for assessing the impact of the Wuskwatim project. This was followed by questions from the three reviewers and a general discussion.

COMMENTS FROM THE PEER REVIEWERS

After the Peer Review session each of the experts provided comments on their assessment of the adequacy of the model. All three reviewers agreed that the SPLASH model is an appropriate model for assessing the impact of adding the Wuskwatim Generating Station to the Manitoba Hydro system.

- Dr Simonovic said *"In conclusion, the SPLASH model can be used for prediction of the expected water regime. The accuracy of water regime calculation is directly related to change in the amount of energy added to the Manitoba Hydro system by an alternative future power plant. In other words the larger future power plant addition will result in more dramatic change of the flow regime. The smaller future power plant addition will result in a very small change of the flow regime. Current version of the model is sufficiently accurate to represent the change of the water regime caused by the addition of the Wuskwatim power plant to the Manitoba Hydro system."*
- Mr. Carson said *"In my opinion, there are no better tools of which I am aware that could be used for a more detailed assessment of the effects of the addition of the Wuskwatim plant on the future water levels at Cross Lake. That is not to say that SPLASH is perfect, as it is not (nor does Manitoba Hydro suggest that it is). However, models used to assess incremental changes to a hydraulic system need not be perfect to enable them to accurately and adequately indicate the potential incremental effects due to that change to the system. That fact has been long recognized by authorities in the field."*
  Mr. Carson concludes with *"In conclusion, I wish to summarize my opinion that SPLASH is the best available scientific means of assessing the range of potential impacts on Cross Lake levels and flows that could be expected due to the addition of the Wuskwatim plant on the power system."*
- Dr. Doering said *"In my opinion the SPLASH model does a good job of doing what it was designed to do, i.e., simulate the long-term operation of a complex system of (predominantly hydro-) electric generation within an imposed set of constraints. I am not aware of a better decision support system software package. The SPLASH model represents many years of development by Manitoba Hydro. It is an impressive package! The model has been calibrated and verified. While*

> *there are improvements that could be incorporated in to the model ... it appears to do a good job of predicting* ***absolute*** *water levels; the hindcasting process has confirmed this. More importantly, to assess the impact of a new hydro-electric station the model need only assess the* ***incremental*** *impact. I believe the model can do this accurately."*
>
> Dr Doering concludes with "*I believe that the SPLASH model can accurately predict incremental water regime impacts on Cross Lake arising from the addition of the proposed Wuskwatim generating station to the existing power system. It is not surprising that the model predicts a small effect on Cross Lake given that Wuskwatim is a small addition to the installed system capacity."*

Each of the reviewers provided additional comments on potential future improvements to the model. Dr. Simonovic also provided comments on the model documentation report. However, each reviewer stressed that the model as it now stands is sufficiently accurate to predict the impact of the Wuskwatim project.

CONCLUSION

The peer review concluded that the SPLASH model is sufficiently accurate to represent the change of the water regime caused by the addition of the Wuskwatim power plant to the Manitoba Hydro system.

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June 10, 2005

Utilization of the SPLASH Computer Simulation Model to Represent Water Regime in the Manitoba Hydro System

March 21, 2005

Prepared By:
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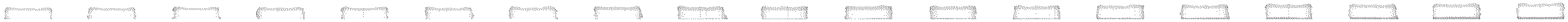

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1.0 Introduction

This document provides a description of the process that Manitoba Hydro utilizes to determine the impacts on system operations resulting from changes in characteristics of either the generating system or the demand requirements. Manitoba Hydro's system operation is affected by the variability of water flows entering the system and the demand for energy production. The hydrologic conditions within the watersheds draining into the Manitoba Hydro system result in a range of water flows that can be expected to occur in the future. Through the operation of reservoirs, diversions and generating facilities, Manitoba Hydro either utilizes the water inflows as they occur or places such inflows into storage for later use depending on demands and value of energy in the future. This operation of the system over the range of flow conditions produces a set of outflows and water elevations that define the water regime for various locations in the system.

The SPLASH (**S**imulation **P**rogram for **L**ong-term **A**nalysis of **S**ystem **H**ydraulics) computer model is used to simulate operation of the hydro-electric system under a series of flow conditions with the objective of meeting a forecast of load requirements and maximizing revenues while recognizing limitations imposed by licences and agreements. The output from this simulation produces a set of water flows and elevations that are used to define the water regime. This document describes the inputs, methodology and outputs of the SPLASH model and how the model is utilized to determine impacts on water regime.

2.0 Background

Manitoba Hydro has a mandate to supply electrical power adequate for the needs of the Province of Manitoba. This translates into planning and developing a system of generation resources that is capable of producing the required power needs in the most economical manner. The Manitoba Hydro electrical power system is primarily hydro-electric with a small proportion of its generation derived from thermal resources utilizing coal and natural gas. The system is interconnected with neighbouring Canadian and United States utilities that are a source of import energy as well as providing large markets for the export of surplus power.

The requirement for electrical power varies with the hours of the day and the seasons of the year. For example, the Manitoba demand for power is generally higher in daytime hours and during the winter months. The power supply system must be designed with the capability to increase and decrease generation according to this variation in demand. The natural water supply for hydro-electric generating plants is highest in the summer season, which is directly opposite to the annual pattern of electrical energy demand. Therefore, Manitoba Hydro utilizes several reservoirs to store water during periods of lower demand for power and draws on this storage during periods of higher demand.

The operation of reservoirs and hydro-electric generating stations results in a pattern of water flows and elevations that can be characterized as the water regime that is a consequence of Manitoba Hydro operations. This water regime is important to communities and individuals who are situated near watercourses or who depend on water based activities such as fishing for their livelihood. Consequently, water regime is a major consideration in the assessment of environmental impacts of hydro-electric developments.

In order to describe the future water regime, Manitoba Hydro utilizes the SPLASH computer simulation model as a means of analyzing system operation under a range of hydrologic conditions that may occur in the future. This computer model is utilized in determining the water regime as the Manitoba Hydro system is expanded over time to continue meeting the electrical power needs of the Province.

The Manitoba Hydro system currently consists of about 5000 MW of hydro-electric generating capability and 470 MW of thermal capability. An additional 200 MW of hydro-electric generation at the Wuskwatim Generating Station is currently proposed for an in-service date of about 2010, and a target has been set for 250 MW of wind generating capability to be in-service by about 2009 if it is economically, technically and financially viable. The remaining undeveloped hydro-electric generating potential is approximately 4800 MW. Manitoba Hydro is currently planning to develop about 2000 MW of this potential hydro-electric generation at the Gull and Conawapa sites for possible in-service in the next 8 to 12 years.

Manitoba Hydro currently has sufficient generation to supply domestic demand to the year 2020, and therefore the Wuskwatim plant is being proposed for development earlier in order to capture economic opportunities in the export market with neighboring utilities. Similarly, the Gull and Conawapa developments are being proposed with early in-service dates to take advantage of export opportunities.

The SPLASH computer model was developed to enable the Corporation to make sound decisions on the various options for system expansion. This document describes the model objectives, capabilities, and how the model represents the Manitoba Hydro system in order to determine costs and benefits of various long-term system expansion alternatives. The determination of water regime is also described since the same model is used for both economic analysis studies and for determination of water regime impacts.

3.0 Model Objective

The primary objective of the SPLASH model is to determine the expected long-term operation of the Manitoba Hydro system under various resource options and under a range of flow conditions that are representative of the future. Some examples of resource options include the following:

- new hydro-electric generating stations
- supply side efficiency improvements of existing resources (i.e., turbine replacement)
- new thermal generating stations
- new inter-jurisdictional transmission interconnection capability
- new internal major transmission lines
- additional demand-side management
- development of wind generation

The objectives of the SPLASH model are as follows:

- ensure sufficient energy is available to meet all firm forecast demands

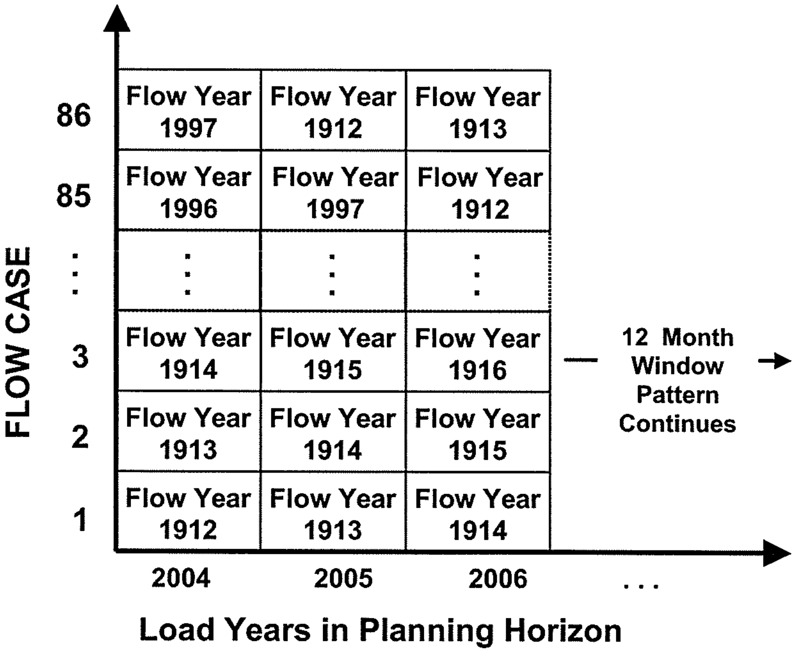
- manage reservoirs within licence and agreement limitations
- maintain an acceptable level of system reliability
- operate economically

4.0 Model Capabilities

The SPLASH model has the capability of representing the physical characteristics of the hydraulic, thermal and transmission systems, the constraints imposed on the physical system by licences and agreements, and the practical operating limitations. As part of the representation of the system, the model also requires a definition of the external opportunity energy markets through a user-defined pricing structure, and the costs associated with energy generation (thermal fuel costs and water rental rates). This representation of the integrated system for the SPLASH model is required in order to undertake a detailed production costing simulation by incorporating the use of a linear programming optimization methodology. The objective of the optimization is to maximize the net outcome of revenues after they are offset by costs for all components that are influenced by water conditions (i.e., maximize net flow related revenue). The resulting output of a SPLASH simulation provides the capability to define the water regime resulting from operation of the Manitoba Hydro system.

Since Manitoba Hydro produces its electric power predominantly by water, the variations in hydrologic conditions play a significant role in system expansion. The model has the capability of representing this variation by utilizing 86 historical years of monthly inflows that have been modified to represent present day regulation. Each of the 86 flow years is chronologically cycled through the simulation period (typically 40 load years) such that every flow year occurs in every load year. This results in a series of 86 different 'flow cases' that are utilized to represent hydrologic variability. Figure 1 illustrates the cycling of 86 historical flow years from 1912 to 1997.

Figure 1: Chronological Cycling of Historical Flows



FLOW CASE	2004	2005	2006	. . .
86	Flow Year 1997	Flow Year 1912	Flow Year 1913	
85	Flow Year 1996	Flow Year 1997	Flow Year 1912	
⋮	⋮	⋮	⋮	
3	Flow Year 1914	Flow Year 1915	Flow Year 1916	— 12 Month Window Pattern Continues →
2	Flow Year 1913	Flow Year 1914	Flow Year 1915	
1	Flow Year 1912	Flow Year 1913	Flow Year 1914	

In each flow case, an initial flow year is used to correspond to the first load year, and the chronological flow record is maintained for each successive load year to the end of the planning horizon. For example, 'Flow Case 1' corresponds to 'Flow Year 1912' occurring in 'Load Year 2004' and 'Flow Year 1913' occurring in 'Load Year 2005'. The chronologic flow pattern is maintained in this way to the end of the planning horizon. The initial flow year is shifted by one year to create successive flow cases such that all 86 possibilities are modeled. For example 'Flow Case 2' begins with 'Flow Year 1913' and continues with the chronologic flow record. When the last flow year is reached in the historical sequence, the first flow year is then used to form a continuous cycle.

The model has the ability to simulate system operation for long periods; typically 40 load years are used as an appropriate long-term planning horizon. The period to the planning horizon for each case is not modeled as a single continuous entity, but rather it is modeled in small time increments called 'windows'. Windows are typically of one year duration and are further broken down into variable lengths called 'time-steps' (typically one month). The SPLASH model simulates the operation of the system for each of these time steps.

Within each time-step the user can further subdivide the period to describe periods used for energy consumption. Typically, Manitoba Hydro users of the SPLASH model have utilized two periods as representative of the load (on-peak and off-peak strips on the load duration curve). The value of energy within each strip must be defined in order to optimize the system energy allocation throughout each load year.

5.0 Model Representation of the Manitoba Hydro System

The simulation of operation of the Manitoba Hydro system requires modeling of energy requirements, energy supply resources, transmission capabilities, and opportunity market conditions along with physical and licensing constraints. The objective of the simulation is to ensure energy availability and to maximize revenues from energy production over the range of water flow conditions while recognizing limitations imposed by licences and agreements. The following sections will briefly describe how each of the components are defined and modeled within the SPLASH environment.

5.1 Energy Requirements

Domestic Load

The domestic load forecast to the planning horizon is defined by monthly energy (GWh) and peak capacity (MW) requirements for the system. Each time step (month) is separated into an on-peak and off-peak period during which energy requirements must be met.

Export Energy Demand

The SPLASH model has the ability to model both long-term and opportunity (spot) export transactions. Firm export energy is similar to domestic load since contractual obligations require that specific quantities of energy must be supplied during a specific time period. The quantity of contractual firm energy for on-peak and off-peak periods for each month must be provided as input to the model. This export energy requirement 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.

5.2 Energy Supply Resources

Hydro Generation

The SPLASH model defines the hydraulic network through a configuration of reservoirs, rivers and hydro-electric generation sources. The model is extremely flexible in being able to represent the hydraulic network that is being modeled. Hydro-electric generating stations are defined using power versus discharge relationships based on forebay and tailrace rating curves during open water and under winter ice conditions. The power-discharge relationship considers turbine and generator efficiency as well as design parameters of the units. Maintenance and other forced outages are modeled by reducing the number of units operating in specific months throughout the planning horizon.

The range of water conditions is represented by the input of 86 years of unregulated present use flows at various locations in the hydraulic network. The inflow record since 1912 was modified to be representative of consumptive uses and regulation by upstream entities as they are forecast to be in the future. The major inputs for streamflows consist of monthly average flows from the Winnipeg River (28% of system inflow), the Saskatchewan River (17% of system inflow) at the border entering Manitoba, and the Churchill River Diversion (27% of system inflow). The remaining inflows are defined as local flows at various locations in the network, the largest being the local inflow available for outflow from Lake Winnipeg.

Initial conditions and system constraints are used to specify license and operation ranges for reservoirs and river reaches, starting elevations of controlled reservoirs, specific flow sequences, and operating rules such as storage and outflow capabilities of both controlled and uncontrolled reservoirs. Water rental costs are also defined and used during production costing simulations.

Thermal Generation

The SPLASH model defines the thermal generation capabilities by specifying the maximum and minimum output on a monthly basis for each thermal station. The minimum output reflects the requirement to test and maintain units on an annual basis, while the maximum output considers planned maintenance, forced outages, and licence restrictions. Fuel cost and heat rate information is also defined and used during production costing simulations.

Import Energy Reserves

Manitoba Hydro has been able to access a unique category of import energy while negotiating long-term export contracts. Since Manitoba Hydro's energy supply is dependent on water conditions, the supply of energy becomes critical in low flow years. It is advantageous for Manitoba Hydro to obtain a source of energy that can be drawn on only during low water conditions instead of relying on a purchase over all flow conditions. Manitoba Hydro has obtained a commitment during low flow conditions for specific quantities of import energy over a year from neighbouring utilities that generate energy from thermal resources. This energy has no particular terms and conditions related to dispatch since it is intended to be derived from reserve capacity whenever it is available.

The modeling of import contracts assumes that as much energy as possible is imported during the low cost off-peak period before utilizing any high cost on-peak period imports. During a critical flow period, nearly 100% of the import contract energy may be utilized to ensure system firmness. During years of higher flows, the import of energy in the off-peak is undertaken if it provides an economic benefit to the operation of the system.

5.3 Transmission Losses

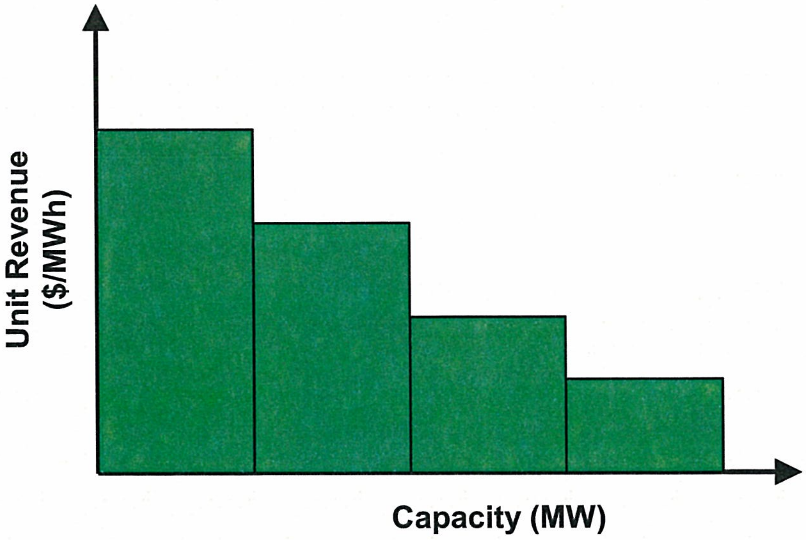
The transmission losses in the model are accounted for by referencing all energy production to a common point in the system. This common reference point is selected to be at the generation level. Therefore, the domestic load forecast, DSM and export commitments are adjusted to ensure that they include transmission losses to the common reference level at generation. Due to this convention, exports at generation must be 10% higher to account for losses to the border. Imports at the border are given a credit of 5% since this energy has less transmission losses than energy at generation.

5.4 Opportunity Market

The objective of a SPLASH simulation of system operation from the production costing perspective is to maximize the net flow related revenue by taking advantage of available opportunity exports. Opportunity exports are limited to either tie-line or market limits.

The opportunity energy markets are represented by piece-wise linear unit costs (import) or revenue (export) functions for each month in a simulation. The modeling must provide a price-volume relationship for both the on-peak and off-peak periods. A price-volume export market function is shown in Figure 2. As more opportunity export energy is delivered into the market, the market becomes more saturated and the result is a lower value for the product. Alternatively, an increasing market function used for imports represents the escalating value of imports as the quantity of import energy increases.

Figure 2: Representation of Opportunity Export Market



6.0 Model Methodology

The simulation of system operation is normally undertaken in three distinct steps: 1) dependable energy determination, 2) rule curve determination, and 3) production costing. Steps 1) and 2) must be undertaken first since they provide the constraints that are input into the production costing simulation.

6.1 Dependable Energy Requirements

Manitoba Hydro determines its resource requirements utilizing the dependable energy criterion which requires that sufficient energy must be available to meet all firm demand requirements should the lowest flows on record occur at any time in the future. The lowest flow period (critical period) in the Manitoba Hydro system corresponds to the sequence of historical low flows that occurred from approximately August, 1939 to March, 1941. The dependable energy is defined as the maximum energy that the Manitoba Hydro system can produce during the critical period. This energy is derived from water inflow as well as water removed from storage during this period. Any available dependable energy above the total firm demand requirements is called 'surplus dependable energy'.

To calculate the dependable energy of the Manitoba Hydro system, a simulation of system operation is undertaken during the critical flow period. The simulation leading up to the critical flow period is required to store as much water in reservoirs as possible such that the storage in controlled reservoirs (i.e., Lake Winnipeg and Cedar Lake) is at a maximum. This requirement is created by proportionately increasing the load demand throughout the period to the point of firmness becoming critical. Figures 3 and 4 illustrate sample lake level trajectories during the critical period for Lake Winnipeg and Cedar Lake, respectively. The last month in which it is possible to maintain full reservoirs is determined to be the beginning of the critical drought period. This usually corresponds to flows of August, 1939 as shown in Figure 3. The load growth in the years corresponding to flow years 1938, 1939 and 1940 is the factor that determines the pattern of the trajectory.

During the critical period, reservoirs are drawn down until they either reach minimum supply level or until the outlet rating curve limits the quantity of hydraulic energy that can be produced in the month. Lake Winnipeg, the largest reservoir in the Manitoba Hydro system, has a limited outflow capability at low elevations and also under ice conditions. Consequently, it is not possible to use the entire storage range in the determination of dependable energy because sufficient water cannot be released from Lake Winnipeg at low elevations.

Since Cedar Lake is not limited by outlet constraints as described for Lake Winnipeg, the trajectory for Cedar Lake indicates that water levels are able to be drawn down to minimum supply level during the critical period. In general, Cedar Lake is kept at full supply level (FSL) as long as possible. This release policy reduces the required storage in Lake Winnipeg during the winter months, and allows for instant load following capability since the storage of Cedar Lake is available immediately to produce energy at the Grand Rapids Generating Station.

Figure 3: Lake Winnipeg Critical Period Trajectory

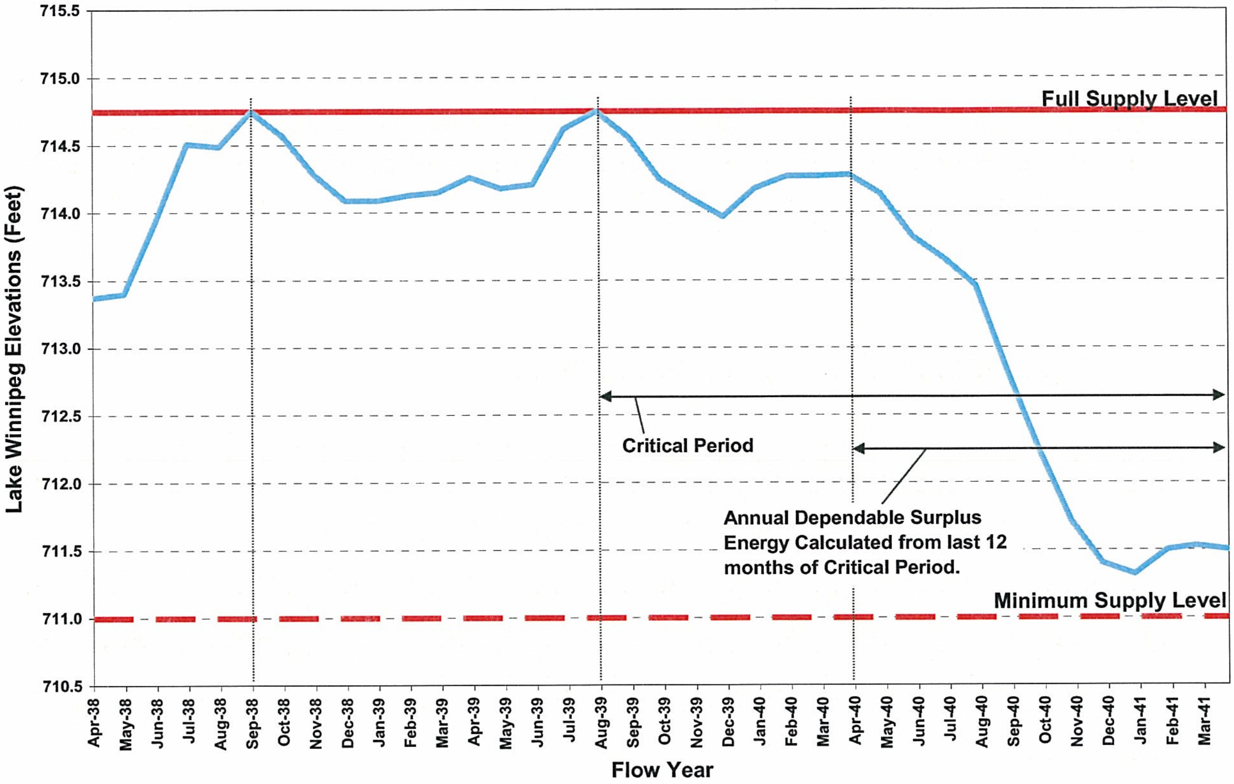
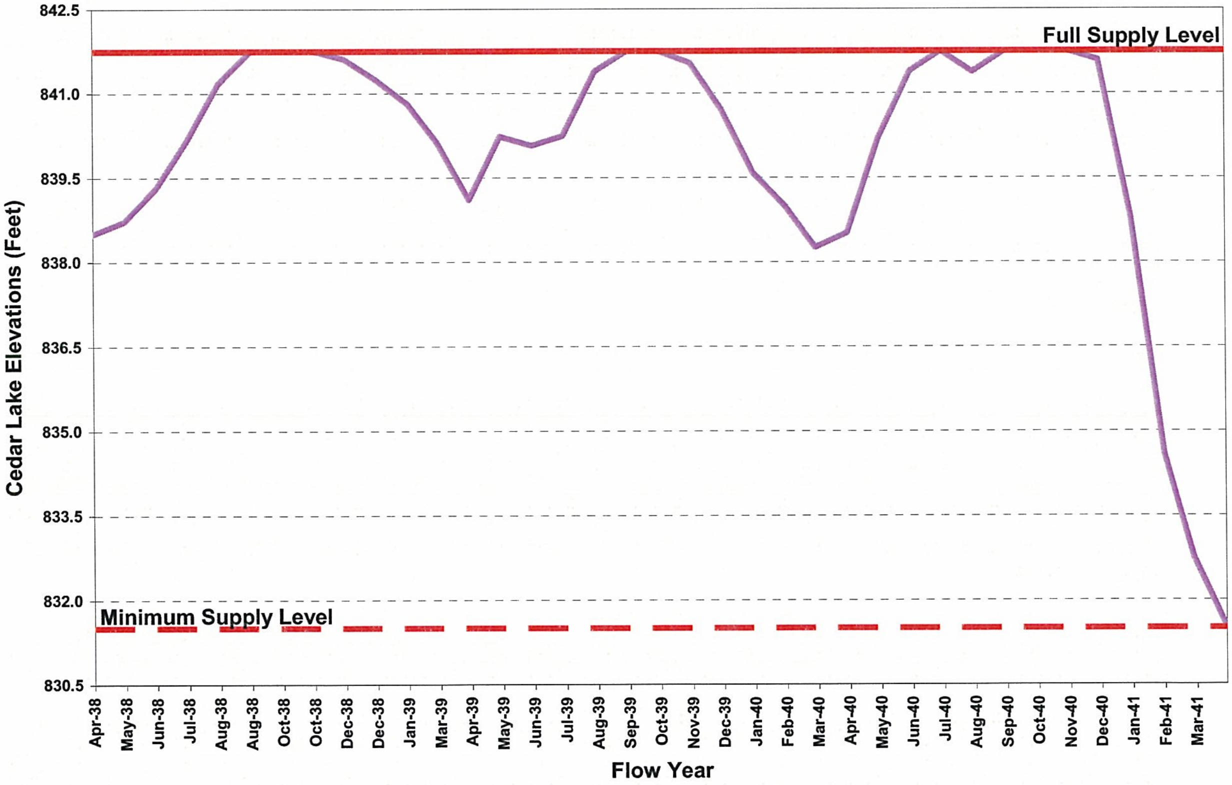


Figure 4: Cedar Lake Critical Period Trajectory



The SPLASH model has an operating mode that can automatically undertake a series of iterations in order to calculate the dependable energy during the critical period. The dependable energy is defined as the maximum hydro-electric energy that the system can produce under the lowest water flow condition. The objective in the series of iterations is to increase either the export energy or the domestic load until the system is just about to fail in meeting the total energy demand. This is accomplished by using either a long-term export sale contract that has a uniform shape over the months or a load adjustment that is shaped based on the Manitoba load demand. In either scenario, a starting value of increased demand is used for the first iteration, and then factors are determined and applied automatically to the demand (domestic or export) in subsequent iterations until the system is at the point of incipient failure in meeting one of the constraints. At this point, the system produces the maximum quantity of hydro-electric energy, while at the same time no system constraints are being violated.

The dependable hydro energy over a year is utilized in expansion planning studies to determine when load or export sales have grown to the point at which additional resources will be required or export sales must be terminated. The choice of whether load should grow in the monthly shape of the domestic load or the shape of export sales is dependent on the objective of the planning exercise. If the objective is to maximize the quantity of long-term export sales, the dependable energy is determined by growing the load in the pattern a uniform export sale. This provides input to the simulation of system operation by determining the quantity of annual surplus dependable energy that is available for long-term export sales for each load year.

6.2 Rule Curve Operation

The objective of the rule curve simulation is to determine operational guidelines that will ensure that the system will have an adequate supply of hydro energy over all water flow conditions. These guidelines consist of target end of month reservoir levels that will provide the required storage in system reservoirs and will ensure adequate generation to meet forecasted firm demand requirements during critical low flow periods.

The methodology for determining rule curve can be thought of as a simulation of system operation executed in reverse order, starting with the last months of the critical flow period and 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 calculation of hydro requirements includes consideration of the maximum available non-hydro energy which would be available during the critical period. Following this logic, the required storage is determined by stepping back one month at a time through the sequence of low flows until the entire low flow period has been considered.

A windowing pattern for determining the rule curve is utilized to ensure that all possibilities of the sequence of low flows are considered for each load. By simulating all possible sequences of the low flow, an envelope of highest required reservoir elevations is determined (rule curve elevations). If the controlled reservoirs are kept at or above these rule curves in a production costing (forward) simulation, the system will be able to meet all firm energy demands even if the lowest flows on record should be repeated.

6.3 Production Costing

The production costing simulation is the final step in the process and is used to determine the operation of the system over the entire range of flow conditions and over all of the load years to the planning horizon. This simulation utilizes a deterministic linear programming procedure to maximize the revenues resulting from the operation of the integrated Manitoba Hydro system using chronological sequences of water flows derived from the 86 historical flow years of record over a 40 year planning horizon. The goal of this process is to maximize the export revenues and minimize operating costs while ensuring system firmness.

The annual dependable surplus energy and rule curve elevations for controlled reservoirs are both used in this multi-period optimization simulation. The dependable surplus energy that was determined in the first step in the process is usually converted into a 5x16 long-term export contract because this is the export product that currently provides the greatest value to Manitoba Hydro. This 5x16 sale consists of a uniform distribution of energy over all of the months of a year with energy provided during the 16 on-peak hours for the Monday to Friday days of the week. It is assumed that this contracted export energy must be supplied in all water flow conditions. The rule curve elevations are input to the production simulation as a guide to the lower bound above which reservoirs should be operated to ensure system firmness over the entire range of flow conditions.

In order to determine optimal system operation, a value must be assigned to all export energy, and costs must be assigned to the use of Manitoba coal and gas-fired generation as well as for the import of energy. In addition, water rental costs, which must be paid to the Province of Manitoba, are assigned to all hydro generation. Because thermal and import energy are the most costly energy sources, use of these sources will be minimized. In general terms, the optimization determines the best allocation of hydro generated energy over the year based on the value of the energy in each month while considering constraints that may be physical or the result of licences and agreements. The optimization consists of maximizing export revenue through opportunity sales and minimizing costs by avoiding the use of costly non-hydro energy resources.

One of the factors that must be considered in optimal operation of hydro systems is consideration of whether water should be carried over into subsequent years versus use of the water in the current year. The rule curve provides guidance as to the minimum amount of water that must be carried over into that next year in order to ensure system firmness, but does not indicate whether it may be more economic to carry more water forward. The decision to store water in reservoirs for future energy demands in the next year will reduce the risk of requiring expensive non-hydraulic energy should a low flow cycle begin, thus lowering the cost of overall system operation. However, if a high flow cycle occurs in the next year, reservoirs will reach full supply level quickly which may result in a potential for spillage of water with no generation, tie-line limits being exceeded, and export markets becoming saturated resulting in little or no value to the stored energy.

The issue of water carryover is simplified in the Manitoba Hydro system because it does not have reservoirs of sufficient size to be able to carry forward large quantities of water without significant risk of spill. Therefore, the target elevation of reservoirs at the end of the year for economic operation cannot be very high because of this risk of spill. This would tend to indicate that the economic guide for reservoir elevations should be near the mid-point of the operating range. The current mode of utilizing the SPLASH model results in rule curves generally being at about the mid-point of the operating range on a consistent basis over the load years to the planning horizon. This is the consequence of converting any dependable energy surplus into export contracts and having a significant quantity of thermal and import energy. Therefore, the rule curve elevation as it is currently determined is a good proxy for the optimal year end reservoir elevations. This has been verified by analysis of different levels of end of year targets for reservoir elevations.

The SPLASH model provides the user with flexibility relating to the stepping through time and formulates the optimization problem automatically in each time step. Given the above observations about the carry over of water in storage, Manitoba Hydro currently formulates the optimization problem for a window of one year from April 1 to the following March 31. The only guide as to end of year storage is the rule curve elevation for system firmness. This guide elevation along with the physical and economic constraints is sufficient to address the issue of carryover of water.

Given that the window of the optimization has been determined to be one year, the next decision that must be made relates to how the monthly decisions within the one year window should be made. In order to reduce running time, the current problem formulation used by Manitoba Hydro consists of solving the 12 month operating mode all in one step by assuming perfect knowledge of water flows over the period. Further discussion on the consequences of using a perfect forecast is provided in Section 8.3.

6.4 Formulation of the Linear Programming Problem

The optimization of a set of operating decisions for the Manitoba Hydro system is a problem that can be solved by a mathematical programming technique called linear programming. This technique maximizes the value of an objective function subject to a set of constraints. Both the objective function and the constraints must be represented by linear equations in order to be able to utilize the technique. Since many of the constraints in the Manitoba Hydro system are not linear, it is necessary to use piecewise linear segments to represent such relationships. The user must have knowledge of the limitations of the technique in order to ensure that the problem being formulated has a feasible solution.

Manitoba Hydro uses the CPLEX linear programming software package that has been purchased from an external vendor. This solution technique can become computer intensive once the problem size reaches many variables with many constraints and if the number of times the optimization must be repeated is large. For the Manitoba Hydro system, it is necessary to undertake several iterations of any one time step because of the complex relationship between power output and reservoir elevation. The power is dependent on reservoir elevation, which is not known in advance, and therefore requires iterations to achieve convergence. These iterations greatly increase the computer time required for a simulation. Therefore, it is advantageous to reduce the number of time steps in any simulation in order to achieve a reasonable running time. SPLASH is a complex model incorporating the technical aspects of the hydro-electric system as well as the qualitative elements of operational policies. Because of its inherent flexibility and complexity, the quality and accuracy of the output depends on the experience and technical competence of the user.

6.5 Development of the SPLASH Model

In the late 1980s Manitoba Hydro investigated the replacement of a previous simulation model that was developed in the late 1960s. The modeling requirements had changed with the export market playing a significant role in system operations, and specific consideration of economic operation was necessary. It was found that there were no “off the shelf” models that could be utilized and consequently the models utilized by major hydro-electric utilities in North America were investigated. It was found that each hydro-electric system has unique characteristics that require customized models and it was not practical to modify any of these models for use in the Manitoba Hydro system.

Manitoba Hydro initiated development of the SPLASH model in 1990 using in-house staff from both resource planning and information services. It was decided this new model should be consistent with Manitoba Hydro’s newly developed HERMES operations planning model which utilized optimization in determining short-term operating decisions. The project consumed approximately 30 person-years of staff time over a five year period. Project guidance was provided by an executive-level management committee and a steering committee consisting of department managers. These committees brought together all relevant interest groups, such as long-range resource planning, operational planning, export marketing, hydraulic engineering and information systems.

Implementation of SPLASH began in 1995. Initial runs focused on the compatibility of SPLASH with respect to the previous Simulation Model. Using the inherent flexibility of the SPLASH model, SPLASH could be run in a manner similar to the previous Simulation Model. Results indicated compatibility between these models. In order to incorporate the new capabilities of SPLASH, a calibration and verification exercise was undertaken to assure that SPLASH results were consistent with system operation. Section 7.0 below describes such a verification exercise using more recent operating experience.

During years 1995 and 1996, the Simulation Model and the SPLASH model were run concurrently in order to fine tune the operational and economic output of the SPLASH model. Full implementation began with the 1997 Power Resource Plan and the delivery of generation costs and interchange revenue forecasts for corporate planning reports. Since 1997, all long-range resource planning studies have been based on results obtained with the SPLASH model. These studies have included: annual power resource plans, integrated financial forecasts, marginal cost analysis, review of candidate generating plants and proposed long-term export sales.

Structurally, the SPLASH model consists of the following three major components:
- SPLASHEM: Graphical user interface which allows the user to view and edit data contained in the input data base.
- GPS: System simulation program, utilizing the CPLEX linear programming solver.
- SPLASHVIEW: Graphical user interface which allows the user to display output data. SPLASHVIEW allows full flexibility for the user to extract and summarize all output data from a specific run. The selected data may represent an aggregation of several physical components and/or of several time periods.

For a full 40-year long-range production costing simulation run, the computational requirements of the SPLASH model are significant. The Manitoba Hydro hydro-electric system operation is simulated for 86 flow cases (current historic flow record 1912/13 to 1997/98) for each of the 40 load years with a monthly time step. Data is stored for on-peak and off-peak monthly time periods for each reservoir (elevation and discharge) and generating station (power production and discharge) and for each tie-line (import and export energy). Typically, a single run consists of 100 megabytes of computer storage.

The UNIX platform was used to develop SPLASH because of the need for high speed workstations. Currently, a typical long-term production costing run takes approximately three hours. The SPLASH model incorporates the following software packages: FORTRAN 77 and C programming languages, PV-Wave, CPLEX, UIMX, amongst others. Two Hewlett-Packard UNIX workstations are dedicated to SPLASH simulations. The corporate database is used to store input and output data (5 gigabytes of available storage space for SPLASH data).

For each of the above run modes, the system operation is controlled by user-defined costs or values for each energy type, including water storage. These costs are termed as "hard" or "soft". Hard costs reflect defined costs for fuel as well as for import and export energy. These costs are included in the calculation of net revenue. Soft costs or values are incorporated into the overall cost structure for optimization but are not included in the calculation of net revenue. The value of stored water is an example of a soft cost or value. These soft costs incorporate user preferences which also guide system operation in conjunction with hard costs.

6.6 Input to the SPLASH Model

Input data for the SPLASH model is accessed through a customized graphical user interface (GUI) called SPLASHEM. The data is physically stored in Manitoba Hydro's database. All input data may be categorized as either 'Constant', 'Annual', or 'Run Specific'. 'Constant' input data refers to data that doesn't normally change from one year to the next (e.g. hydro station power curves). 'Annual' input data refers to data that normally changes, or gets updated, each year (e.g. Manitoba domestic load). 'Run Specific' input data refers to data that may change from one SPLASH run to the next (e.g. event schedule defining in-service dates of plants). Data is stored in terms of objects within specific database tables. Each separate SPLASH run is denoted with a separate object in the 'Run Configs' table. This 'Run Configs' object contains a list of all relevant objects for the SPLASH run. Input data may be grouped as follows: planning horizon data, hydrology data, reservoir data, thermal station data, hydro station data, outlet data, load forecast data, capacity grouping data, interconnection data, market data, network data, and miscellaneous data. Table 1 in Appendix I indicates the various types of input tables, a definition of the input data stored, and the input data category (Constant, Annual or Run Specific).

6.7 Output from the SPLASH Model

Output data for every SPLASH run is accessed through a customized graphical user interface (GUI) called SPLASHVIEW. The data is physically stored in Manitoba Hydro's database. There is no specific report that summarizes the output from the SPLASH runs. The user has complete flexibility in identifying output data requirements and extracting the data from SPLASHVIEW. There is approximately 100 to 150 megabytes of computer memory used to store the output for each run in the database. Common output data extracted includes monthly and annual energy supply or demand values (GWh), and monthly and annual revenue or cost values (in constant year dollars). In addition, there is complete flexibility in extracting and summarizing information relating to reservoir elevations and river flows at various locations in the system. Output results can also be transferred to spreadsheets to produce customized table and graphs.

7.0 Calibration and Verification of the SPLASH Model

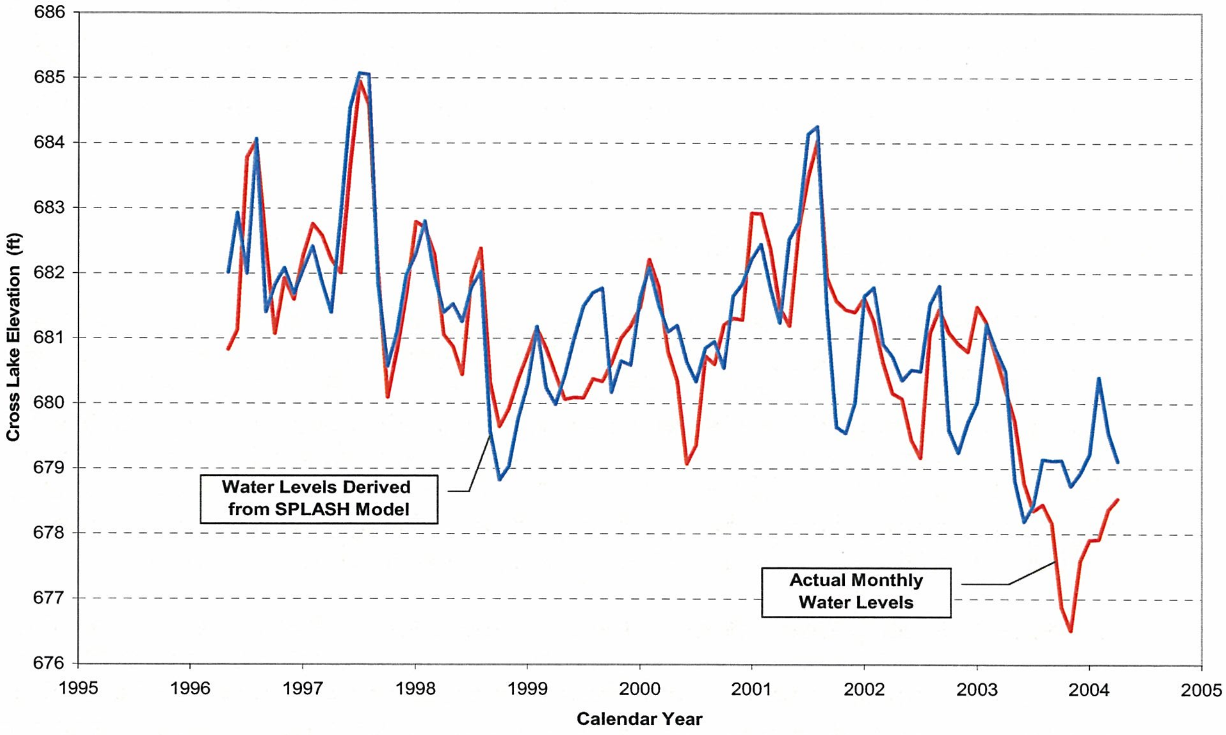
An objective in developing the SPLASH model was to utilize a methodology that is consistent with actual system operation. A calibration or verification exercise was undertaken in order to illustrate that the SPLASH model provides a reasonable representation of actual system operation. Since Lake Winnipeg is the dominant reservoir in Manitoba Hydro operations, a location immediately downstream of the outlet of Lake Winnipeg (Cross Lake) was used as a representative sample to verify the simulation process. Elevations at Cross Lake are directly influenced by the operational decisions to increase or decrease the outflows from Lake Winnipeg.

A period from 1996 to 2004 was selected for the "backcasting" or verification process because it is a period during which many system characteristics remained relatively constant. This period contains a sample of extremely high and extremely low flow years as well as average flow years. The verification process utilized the best estimate for major factors as they are known at the time that decisions are made. These include estimates of inflows into the system, the Manitoba domestic load forecast, the long-term export contracts and the generation facilities in service. The SPLASH modeling for this verification process did not attempt to calibrate input information that was specific to those particular years if such information was not known in advance and could not be utilized in decision making. Examples of specific factors that may vary from year to year or month to month, but are not known exactly in advance, are characteristics of the winter ice effects, specific environmental considerations, and the specific knowledge of the availability of energy from neighbouring jurisdictions. It is possible to obtain a better verification of the SPLASH simulation for this specific case by utilizing more of the after-the-fact information, but this was not done since it would require much more analysis of the conditions that prevailed at the time. Furthermore, this after-the-fact information would not be useful in simulating future operation because it would likely not be know at the time of decision making. A simulation of future operation must be based on a best estimate of the various factors that are uncertain at the time of decision making.

The comparison of actual system operation and simulated operation is illustrated in Figure 5 below. It is observed that the modeling is a good representation of actual operation in most periods. It was found that it is difficult to duplicate the decisions of system operators in some cases because operators may have additional information or they may be considering additional factors unique to the specific time period. An analysis of the differences between model and actual operation concluded that there are many reasons for these differences, but they were not the result of modeling deficiencies. For example, the particularly large difference between model and actual operation in the year 2004 is due to the operators' concern that the drought may persist, and therefore releases from Lake Winnipeg were minimized in actual operation. The operators had specific knowledge that additional energy could be purchased in order to conserve water in storage. The simulation did not have knowledge of the additional energy that may be available or concern about drought persisting. Further information on factors that may cause differences between model and actual operation is provided in Section 8.3 "Model Limitations".

Figure 5: Verification of Simulation - Cross Lake Elevations

SPLASH Simulation Results vs. Historic Data



8.0 Applications of the SPLASH Model

8.1 Economic Evaluation

The primary use of the model is to provide support for economic evaluations used in major decision making efforts for long-term system expansion projects. These major decisions are usually based on an in-depth business case analysis that results in a formal recommendation on the choice and timing of future projects. The SPLASH production costing simulations provide detailed cost and revenue estimates associated with the future operation of a project that are used in a comprehensive economic evaluation

It is common to evaluate various alternatives of system expansion by analyzing the difference in long-term operation between two scenarios of development – a base case versus an alternative scenario case. The 'base case' includes current operating system supply and demands, approved future development projects, forecasted demands, expected retirements and/or license extensions of specific generation, and potential new energy supply developments that ensure firm energy demands are continually met into the future. The base case is then compared with the 'alternative scenario case', which contains all the same information as the base case, plus the added system expansion information associated with the alternative. Taking the difference between the net operating costs from each case provides the incremental economic benefit required for the business case analysis.

An example of the application of the model to economic evaluations is the justification of the Wuskwatim Generating Station for an in-service date of 2010. The base case consisted of Wuskwatim G.S. having an in-service date of 2020 for domestic load purposes and this was compared to advancing the facility to 2010 for export sales. The SPLASH model simulated system operation for each of the scenarios, and the difference in production costs and revenues over all of the years were compared in undertaking the economic evaluation.

8.2 Water Regime Evaluation

The SPLASH model is used to determine the expected water regime resulting from operation of hydro-electric facilities by Manitoba Hydro under the various possibilities of water inflows into the system. The current record consists of 86 years of monthly average inflow and this will soon be increased to 92 years. A record of this length provides a good representation as to what may be expected in the future with respect to hydrologic variability. Therefore, the model is utilized to define the envelope of water regime characteristics that can be expected with changes in the composition of the system in the future or changes to the operating rules or licence constraints.

Because the model operates on a monthly time step, it must be recognized that the characteristics of water regime over shorter time periods are not represented in this model. For example, the cycling of flows at a hydro plant over the hours of a week is not modeled in SPLASH, and consequently the model should not be relied on to supply information relating to water fluctuations within the hours of a day and the days of a week. However, the average monthly operation of the plant is represented well, as is the seasonal and annual representation of system operation. The water elevations over a month for large reservoirs such as Lake Winnipeg and Cedar Lake are represented very well since they react very slowly to regulation changes.

The impacts on water regime due to changes in the system such as addition of expansion alternatives can be evaluated by determining the difference between SPLASH simulations for the base case and the alternative scenario case. The advantage of comparing two simulations is that it is not critical that the variables being studied are perfectly represented because any approximations will be treated similarly by each simulation and will not be detectable in the difference. This approach of comparing the difference between two scenarios is most often utilized in determining impacts resulting from new hydro developments or changes in operation rules or constraints.

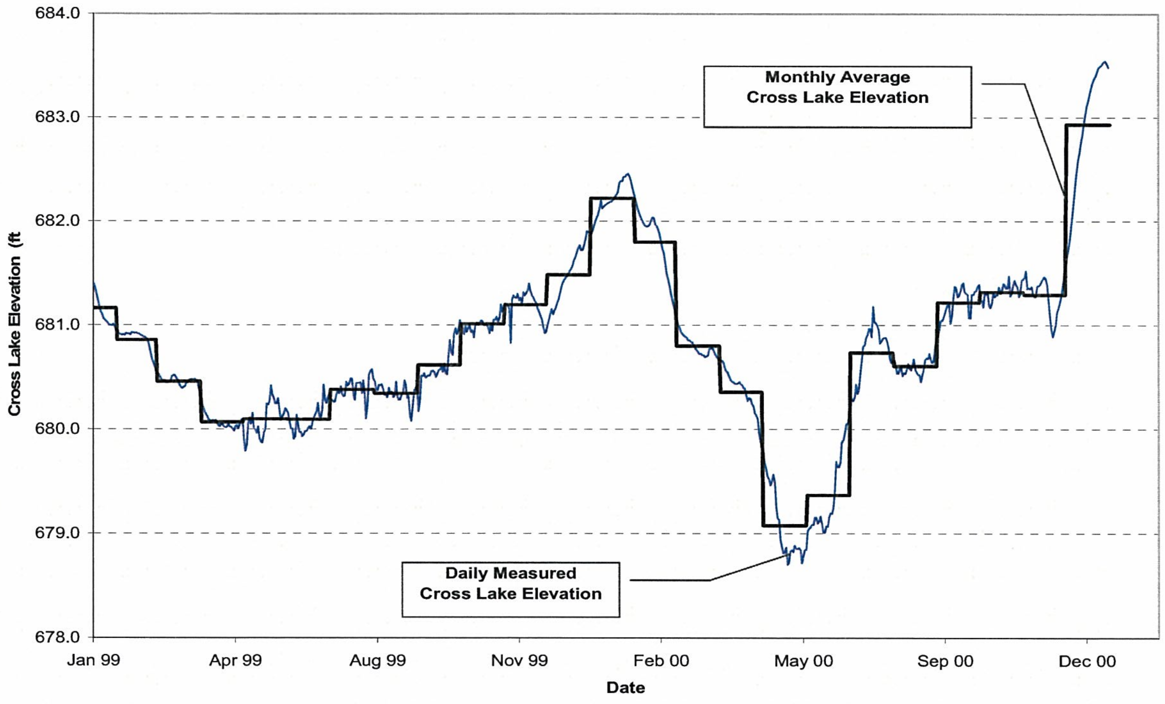
8.3 Model Limitations

Monthly Time Step

Because the model operates on a monthly time step, it must be recognized that some system characteristics such as water regime over shorter time periods are not represented in this model. For example, the cycling of flows at a hydro plant over the hours of a week is not modeled in SPLASH, and consequently the model should not be relied on to supply information relating to water fluctuations within the hours of a day and the days of a week. The primary purpose of the model is to simulate the long-term operation of the system and to provide long-term patterns of system operation rather than operational changes within a month.

The use of monthly time steps is sufficient for determining the most economic operation because the primary purpose of the model is to determine the optimal allocation of energy over the year through the operation of reservoirs and generating stations. Since the inflows to the system do not change dramatically over a month, a monthly time step is adequate for operation of large reservoirs. Furthermore, Manitoba Hydro must provide advance notice of up to two weeks for water releases from its largest reservoir, Lake Winnipeg. Therefore, major changes in reservoir releases from Lake Winnipeg are not made in time periods of hours and days, and a monthly time step is adequate for the simulation of system operation.

Figure 6: Daily versus Monthly Water Levels at Cross Lake



As an illustration of the difference between daily and monthly average, the water levels at Cross Lake are shown in Figure 6 above. This indicates that the use of a monthly time step in the simulation can be expected to provide a good representation of elevations at Cross Lake.

Perfect Forecast of Annual Inflow

As discussed in Section 6.3, the current problem formulation used by Manitoba Hydro consists of solving the 12 month window from April to March in one step by assuming perfect knowledge of water flows over the period. In order to test the sensitivity of this approach, Manitoba Hydro has experimented with stepping through on a monthly basis and using a forecast of future inflows to simulate uncertainty as it exists in the operating environment. It was found that the production costing was not significantly different for this sensitivity analysis. Therefore, it was deemed that solving all 12 months in one step is adequate for purposes of production costing.

Although the use of perfect forecasting in the simulation does not impact production costing greatly, this approach may not result in the best representation of water regime relative to actual operation. This was one of the factors that would cause differences in the model verification process that was discussed earlier. The simulated operation may be different than actual operation of reservoirs in some flow cases since perfect foreknowledge will alter operating decisions relative to the case where system operators do not have a perfect forecast. However, this shortcoming would not be expected to influence the validity of using the model to detect changes between two simulations since each simulation would have the same assumption on perfect forecasting.

Historic 86 Year Period Representative of Future Water Variability

It is assumed that the 86 year period derived from the historic period from 1912 to 1997 is representative of the future water regime. It is possible that future flows may be higher or lower on average and the extremes may be greater or less than that indicated by the existing record. For example, climate change may be a factor that increases variability and extremes such as drought. Therefore, one of the limitations of the model is the use of this specific flow record as a representation of the future. However, it is judged that use of this record is appropriate since there is a wide range of flows in this long record, and there is no evidence that there is a trend of either increasing or decreasing flows over time. Even if the 86 year record was not the best representation of the future, it is still appropriate to use the model to detect changes between two simulations since each simulation would have the same assumption on water inflows.

Simulating Real-Time Operator Decisions

The simulation of system operation will match actual operations only if all the factors that influence operation are modeled and the operator is consistent in making decisions based on knowledge of these factors. However, it is usually the case that some additional information is available to the operator in actual operations, and consequently a different decision is made compared to the simulated decision that is based on information available to the simulation model. In addition, decision making based on human behavior cannot always be modeled. This is not a strictly a shortcoming of the model but a realization that it is not possible to incorporate all factors of human behavior in a simulation model. In spite of being unable to fully model human behavior, it is still appropriate to use the simulation approach to detect changes between two simulations since each simulation would have the same shortcoming.

Difference Between Two Simulations Overstated

It is possible that the difference between two simulations with slightly different inputs may be overstated because of the methodology used for the analysis. The SPLASH model utilizes a linear programming technique to determine the optimal allocation of water in reservoir storage over the months of the year. The Manitoba Hydro system has reservoirs at Lake Winnipeg and Cedar Lake that can be utilized for seasonal storage. It is possible that there are several solutions to the optimization problem on allocating water between Lake Winnipeg and Cedar Lake. This can occur because both reservoirs have similar roles and both are capable of providing storage for the major generating facilities on the Lower Nelson River. It is possible that storage in one reservoir or the other can produce very similar economic results in the long run. However, the impacts on water regime as derived from the difference between two simulations in any one month may be overstated because there may not be a consistency between simulations in utilizing each of the reservoirs. This phenomenon is discussed further in Section 9.2.

9.0 Water Regime Impacts

9.1 Wuskwatim Impacts on Cross Lake

As part of the environmental licensing process for the proposed Wuskwatim G.S., Manitoba Hydro assessed the impacts that the new facility may have on outflows from Lake Winnipeg and consequently on downstream lakes such as Cross Lake. The output of the SPLASH model was used to determine the water regime with and without the Wuskwatim facility added to the system. Manitoba Hydro submitted a document to the Clean Environment Commission process on October 9, 2003 that described the effects of Wuskwatim on the water regime at various locations in the system. The document titled "Updated Information Regarding Effects of Wuskwatim on Operation of the Churchill River Diversion (CRD) and Lake Winnipeg Regulation (LWR)" was provided in a response to the Department of Fisheries and Oceans (DFO) in Appendix B from the Environmental Impact Statement report[1] as a revised response to DFO-S-39 which was originally filed on August 8, 2003.

This October 9, 2003 document provided a detailed description of the various factors that affect hydro operations and how future operation of LWR and CRD may be influenced by the addition of Wuskwatim. In addition, a detailed analysis of water regime impacts on Cross Lake was also provided since this was an area of particular interest. It was found that the degree of impact on water regime was greatly dependent on how the energy from Wuskwatim would be utilized in the future. It is the mismatch between the pattern in which Wuskwatim energy is generated and the pattern in which it is utilized that will result in system effects. The analysis consisted of two scenarios for the utilization of Wuskwatim energy: 1) the dependable energy sold as a long-term sale and 2) a sensitivity analysis with all energy made available to the opportunity export market or for domestic use in Manitoba. It was found that the change in water regime was greater for scenario (2) since the utilization of energy did not match the pattern of Wuskwatim energy production as well as it did in scenario (1). Whenever the timing of the utilization of energy from Wuskwatim does not match the time in which it is produced, the Manitoba Hydro reservoir system is utilized to store water for release when it is most valuable.

The SPLASH analysis consisted of utilizing the simulated monthly outflows from Lake Winnipeg from all 86 historical flow years for a sample load year (2012). The chronologic monthly outflows were converted to monthly elevations using a series of stage-discharge rating curves for various periods in the year to reflect ice restrictions and weed growth as well as actual performance of the Cross Lake weir compared to design performance. As an example of output for scenario (1), the Cross Lake water elevations for each month of the 86 historical flow years are shown a chronologic time series in Figure 7 below for the period 1912 to 1997. This enables a direct monthly chronological comparison between the two SPLASH simulations on a month by month basis. The monthly data can also be summarized in many different ways such as duration curves for months or seasons.

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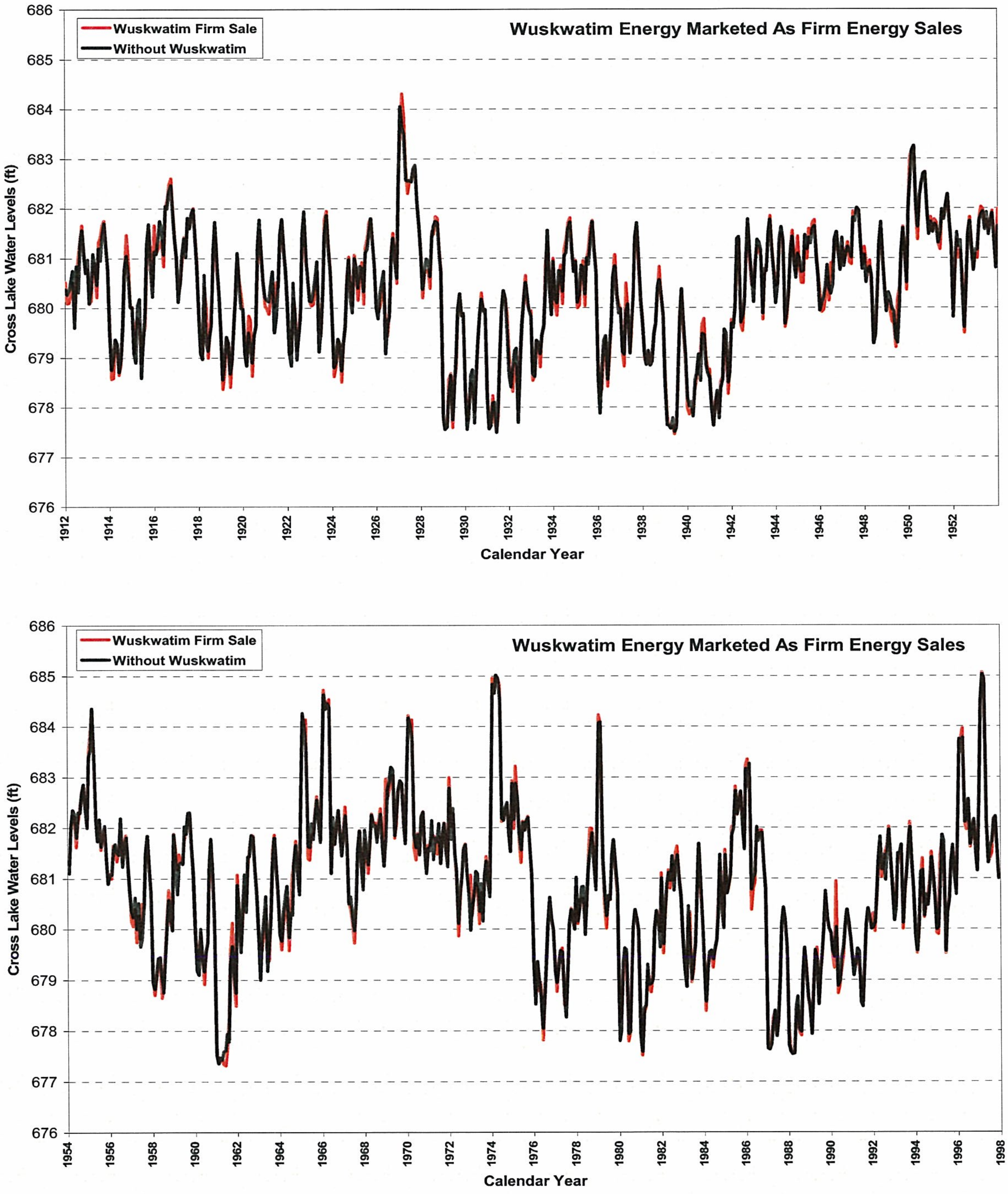
[1] Supplemental Filing, Environmental Impact Statements: Wuskwatim Generation and Transmission Projects, Response to Technical Advisory Committee, August 8, 2003. Appendix B: Attachments for Responses to DFO Comments.

Figure 7: Monthly Chronologic Time Series of Cross Lake Water Levels



9.2 Water Regime Impacts at Cross Lake Overstated

As described in Section 8.3 above, it is likely that comparing two simulations overstate the impacts of Wuskwatim on water regime at Cross Lake because of the methodology used for the analysis. This is due to the possibility of several solutions to the optimization problem on allocating water between Lake Winnipeg and Cedar Lake. This possibility of several alternative solutions creates some difficulty in assessing water regime impacts on a month by month basis because differences in water flows in some months may be due to these modeling characteristics and not purely due to the effect of Wuskwatim on system operations.

Thorough analysis of output data for several specific cases has found that whenever there are large discrepancies in Lake Winnipeg outflows between two simulations, much of the difference can be attributed to the random choice of which reservoir is utilized first. This phenomenon is not likely to distort results over longer periods such as seasons because water releases from Cedar Lake must eventually flow through Lake Winnipeg and on to Cross Lake. Therefore, it is judged that the SPLASH model provides a reasonable representation of water regime changes on a seasonal basis and may overstate impacts on a monthly basis.

10.0 Summary and Conclusions

This document has described the inputs, outputs and methodology associated with the SPLASH model that is utilized by Manitoba Hydro for the analysis of the long-term operation of the hydro-electric system. More specifically, this document has focused on the utilization of the model to analyze changes in water regime that can be expected with the addition of a generating station to the system. The results of a model verification or "backcasting" exercise were provided by comparing actual system operation with simulation results. This verification exercise confirms that the SPLASH model is representative of actual system operation. Therefore, it appropriate to utilize the SPLASH model to derive information on long-term changes in water regime. In addition, model limitations were discussed and it was concluded that these limitations would not be expected to affect the analysis of water regime for a location downstream of Lake Winnipeg.

APPENDIX

SPLASH INPUT DATA SUMMARY

SPLASH Table Name	Description	Data Type
Planning Horizon Input Data		
event_schedule	Defines the events and the inservice dates for these events.	Run Specific
lp_iter_control	Contains the data necessary to control the number of LP iterations for a particular window and the convergence.	Run Specific
win_load_flow_sc	Defines for each window: the number of time periods, length of each time period and Manitoba load demand scenario to be used within the times step.	Run Specific
win_pattern_def	Defines the windo pattern(s) to be used across the plannig horizon of the SPLASH run.	Run Specific
flow_prediction	Defines the uncertainty of uncontrolled inflows into the reservoir system.	Run Specific
Hydrology Data		
rsvr_gauge_fac	Defines the net local inflow into a particular reservoir to be based on the inflows from one or more gauge stations.	Constant
inflow_record	Contains all hydrologic data for all gauge stations.	Constant
flowcase_schemes	Defines the number of flow cases and flow year range to be used for these flow cases.	Run Specific
statistic_range	Defines the range of years in which the representative flow ranges (i.e., normal, flood or drought) are calculated.	Run Specific
flow_accum	Defines the accumulation periods over which historic inflow data is summed in order to classify the flow range.	Run Specific
flow_stat_flags	Defines the flow ranges - normal, flood or drought for flow prediction.	Run Specific
Reservoir Data		
rsvr	Contains the initial/final reservoir elevations and calibration/gauge datums to be used for each reservoir.	Constant
rsvr_bnd	Contains the normal full supply water levels, maximum an dminimum water levels for each reservoir.	Constant
rsvr_elev_stor	Contains the stage-storage curve for a reservoir.	Constant
rsvr_ttl_flow	Contains the inflow and outflow constraints for reservoirs with two or more inlets or outlets (i.e. the total inflow and/or total outflow from Lake Winnipeg).	Constant
rsvr_elev_valuep	Contains the elevation-value curve for a reservoir (Dependable and Production runs only).	Run Specific
rsvr_elev_valuer	Contains the elevation-value curve for a reservoir (Rule Curve run only).	Run Specific
rsvr_endw_el_vap	Contains the end-of-window elevation-value curve for a reservoir (Dependable and Production runs only).	Run Specific
rsvr_endw_el_var	Contains the end-of-window elevation-value curve for a reservoir (Rule Curve run only).	Run Specific
setup_elev_value	Contains data for the segmentation of the reservoir storage volume, which are placed within the input table (rsvr_elev_valuep).	Run Specific
setup_endw_el_va	Contains data for the segmentation of the reservoir storage volume, which are placed within the input table (rsvr_endw_el_vap).	Run Specific
Thermal Station Data		
therm_stn	Defines general data related to the thermal stations.	Constant
fuel_cost	Defines fuel cost for thermal stations.	Annual
therm_stn_cap	Defines generating capacity for thermal stations.	Constant
therm_stn_maxgen	Defines maximum thermal generation during a specified time frame.	Constant
Hydraulic Stations Data		
Inservice_sched	Defines the number of turbine-generator units at a particular hydraulic station with respect to the inservice date for the plant.	Constant
hyd_stn	Defines general information for the hydraulic generating stations	Constant
hyd_stn_cap	Defines the generating capacity for hydraulic stations.	Constant
hyd_stn_bnd	Defines the bounds on the spillway and powerhouse flows for hydraulic stations.	Constant
pwhs_min_flow	Defines rating curve for the minimum station flows.	Constant
pwhs_max_flow	Defines rating curve for the maximum station flows.	Constant
hstn_pwr_rating	Defines the energy/discharge curve with respect to the forebay and tailrace elevations.	Constant

SPLASH Table Name	Description	Data Type
Outlet Data		
ctrl_outlet	Contains basic information about the controlled outlets	Constant
nat_outlet	Contains the calendar date in which the natural outlet is changed to a controlled outlet.	Constant
nat_outlet_flow	Defines the rating curve for natural outlets.	Constant
ctrl_o_min_flow	Defines the rating curve for minimum flow at controlled outlets (i.e., West Channel Outlet of Lake Winnipeg).	Constant
ctrl_o_max_flow	Defines the rating curve for maximum flow at controlled outlets (i.e., West Channel Outlet of Lake Winnipeg).	Constant
Load Forecast Data		
load_forecast	Defines daily load forecast data for Manitoba.	Annual
load_scenario	Defines the number of strips contained within each load scenario.	Contstant
load_adjust	Defines the load adjustment data which is added to the Manitoba load forecast.	Run Specific
load_bus_factor	Defines the bus factor to adjust the Manitoba load forecast data to the common bus.	Constant
Capacity Grouping Data		
slack_goal	Defines the goal constraint.	Constant
str_cap_mem	Defines all members which are related to a particular goal constraint.	Constant
str_cap_grp_con	Defines the goal constraint.	Constant
str_cap_grp_blk	Defines various blocks of relaxation for the slack goal.	Constant
str_mem_fctr	Defines membership factors for all members within a specified goal constraint.	Constant
Interconnection Data		
tieline	Defines general information for the tielines (maximum/mimimum import/export capacity).	Constant
contract_tieline	Assigns import/export contracts with specific tielines.	Annual
contract_descr	Defines the characteristics of the import/export contracts.	Constant
Market Data		
intrup_market	Defines maximum number of price blocks for interruptible markets.	Constant
onpk_imp_market	Defines price blocks for the interruptible on-peak import energy market.	Annual
offpk_imp_market	Defines price blocks for the interruptible off-peak import energy market.	Annual
onpk_exp_market	Defines price blocks for the interruptible on-peak export energy market.	Run Specific
offpk_exp_market	Defines price blocks for the interruptible off-peak export energy market.	Annual
Network Data		
hydro_network	Contains the hydraulic network, including all reservoirs, hydraulic generation stations, controlled outlets and uncontrolled outlets.	Constant
thr_network	Contains listing of thermal generating stations.	Constant
Miscellaneous Data		
output_flags	Defines the output flags which are used to control debug output from a SPLASH run.	Run Specific
contract_deficit	Defines the initial contract defecit for various contracts.	Constant
datum	Defines all datum (i.e., forebays, reservoirs, etc.)	Constant
deficit_blk	Defines cost for deficit energy	Constant
economics	Defines the interest rate which is used ot calculate present worth within a window	Constant
sink_el	Defines the elevation of the sink, i.e., the last reservoir in the network.	Constant