LAKE WINNIPEG REGULATION
Manitoba Hydro Report in Support of a Final Licence under *The Water Power Act* (Manitoba)

Review of Hydrologic and Operational Models

Prepared for:

Manitoba Clean Environment Commission

Prepared by:
George F. McMahon, Ph.D., PE, D.WRE, PH

ARCADIS
Infrastructure · Water · Environment · Buildings

2410 Paces Ferry Road, Suite 400
Atlanta, Georgia, USA 30339

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1.0 INTRODUCTION

This report documents comments and recommendations made on behalf of the Manitoba Clean Environment Commission (CEC) regarding models and data developed by Manitoba Hydro (MH) in support of its Lake Winnipeg Regulation (LWR) final licence application under *The Water Power Act* (Province of Manitoba, 1988) Issues, comments and questions raised in this review are based on the report prepared by Manitoba Hydro (MH) in support of the licence application (Manitoba Hydro, July 2014a), Information Requests (IRs) and subsequent MH responses, and other issues identified during the licencing process.

Comments provided herein are made with the acknowledgement that operational modeling in support of the current license application focused on the historical impacts of LWR, i.e. quantification of effects of LWR on historical Lake Winnipeg pool levels and the Nelson River flow regime downstream of Lake Winnipeg. The 'region of interest' designated by MH in the July 2014 Report is shown in Figure 1.1 and includes Lake Winnipeg, Jenpeg power station and the Nelson River downstream through Stephens Lake and the Kettle, Long Spruce and Limestone Dams.

The purposes of this review are to (1) assess the adequacy of assumptions, models and data developed by MH in support of its licence application, and (2) provide recommendations to the Commission on needed modifications or improvements to the current models, as well as studies and tools that may be needed in the future to address various aspects of LWR implementation. This review may also generate issues for discussion during the Final Licence Hearings in Winnipeg.

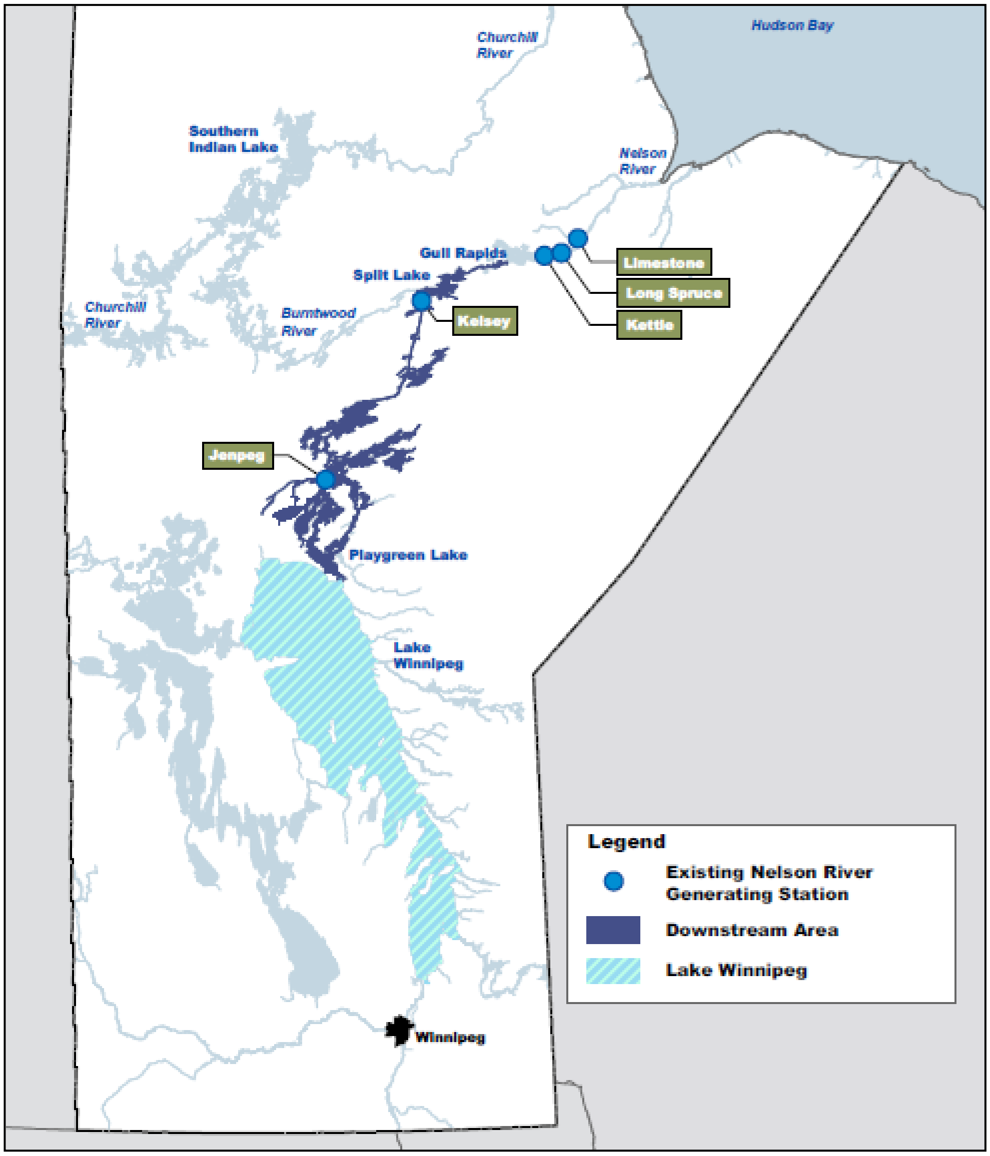

Figure 1.1: LWR Final Licence Application region of interest (from MH July 2014 Report)

2.0 MANITOBA HYDRO FINAL LICENCE REPORT

The focus of the Report is assessment of impacts of LWR on Lake Winnipeg levels, and to a lesser extent the downstream flow regime. The main conclusions of the report are that (1) LWR has not increased Lake Winnipeg's average water levels, and moreover has effected an overall reduction in flood pools compared to without-LWR conditions, and (2) LWR is not the principal source of other basin problems including shoreline erosion, water quality, fisheries and the ecology of the Netley-Libau Marsh. Due to inherent model limitations and other reasons these conclusions are generally but not strongly supported by the MH operational models developed for this purpose.

Appendix 4 to the MH Report describes in detail modeling performed to assess LWR effects on Lake Winnipeg (Manitoba Hydro, July 2014b). Appendix 10 (Manitoba Hydro, July 2014c) documents application of the MH models to analysis and comparison of effects of two alternative Lake Winnipeg power ranges – 711-714 and 711-716 feet above sea level (fasl) – to the existing 711-715 fasl power range on Lake Winnipeg, Cross Lake, Sipiwesk Lake and Split Lake levels, and Jenpeg flows and power generation. Model limitations, however, precluded application to two other important studies performed by MH to support of the licence application. Appendix 3 (Manitoba Hydro, July 2014d) assesses LWR based on hydrometric data, but because the model lacked capacity for reconstitution of regulated and unregulated flow regimes over the full 1915-2013 period of record, the assessment compared two different flow periods (pre- and post-LWR). Appendix 7 (Manitoba Hydro, July 2014e) addressed the potential effects of climate change on the water regime associated with LWR. In this instance as well the MH models are not capable of application using climate-adjusted hydrologic time-series, and consequently effects of climate change and long-term climate cycles on LWR could not be assessed.

2.1 MODELING APPROACH

Appendix 10 of the LWR documents development and application of two Excel spreadsheet models – a water balance model for Lake Winnipeg (the Lake Winnipeg Routing Model) and a downstream Nelson River routing model (the Nelson River Routing Model). The models were coupled and used to compare effects of the existing 711-715 fasl Lake Winnipeg operating range to alternative operating ranges (711-714 fasl and 711-716 fasl) on Lake Winnipeg levels, Jenpeg station releases and power generation, and Nelson River flows and lake levels downstream of Jenpeg. As shown in Figure 2.1, there are fewer components and a significantly smaller combined domain of the two spreadsheet models (both upstream and downstream of Lake Winnipeg) in comparison to the area of interest shown in Figure 1.1.

In addition to information presented in the Report and Appendices 4 and 10, Manitoba Hydro provided a half-day workshop on the models and provided copies of the model for review and testing. It is clear from this review that the models were designed in a practical sense only to track occasional deviations from historical Jenpeg releases from 1977 to the present. Deviations are determined by trial-and-error adjustments to maintain Lake Winnipeg elevations within the allowable operating range under consideration, subject to constraints of maximum station discharge capability, channel rating curves, hydraulic head, allowable ramping rates, etc. Page 14 of Appendix 10 states:

The regulation of Nelson West Channel outflows with different power production ranges used the above [historical 1977-2013] water balance, except in this case Jenpeg outflows may be different from historical outflows with existing LWR. In this case, Jenpeg outflows were chosen manually using the rule set described below. Manual re-regulation was used over computer algorithm re-regulation because it was judged to be the simplest while still being representative of operator decision making, thus comparable to historic operations.

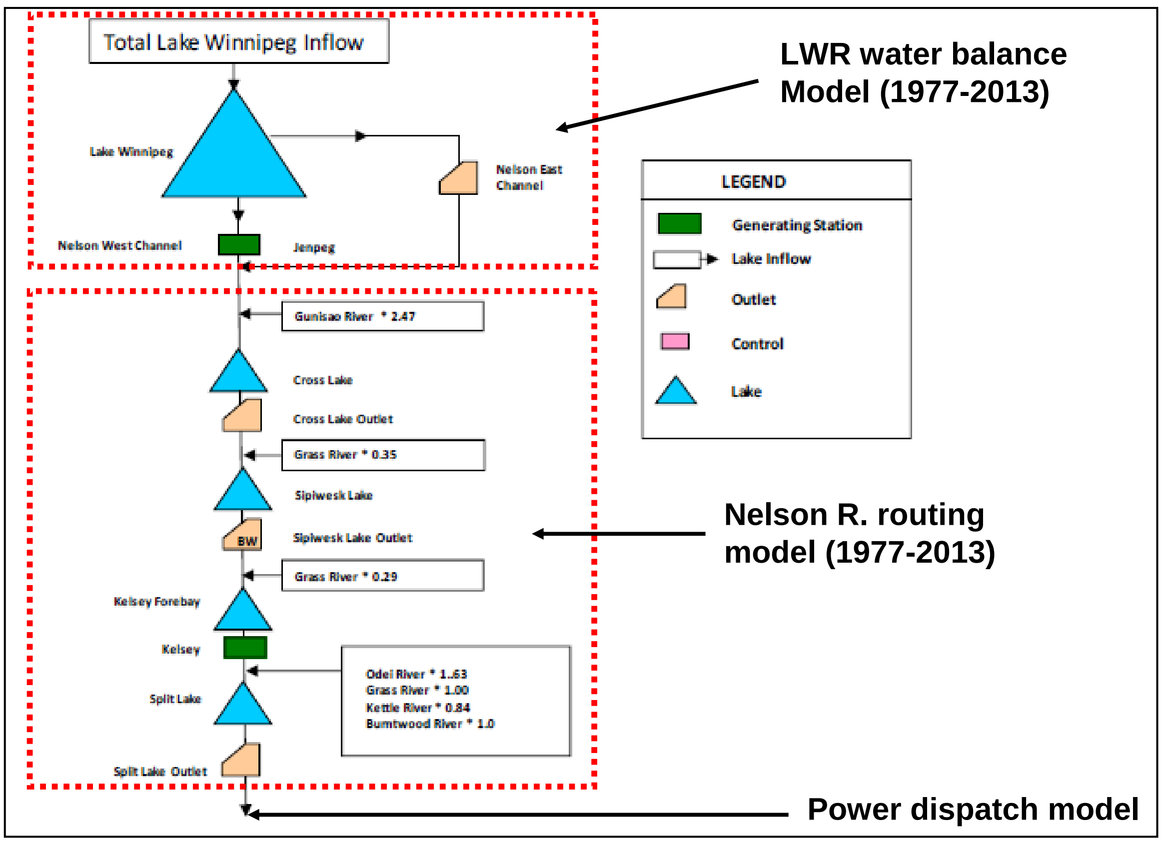

Figure 2.1: Domains and components of MH Lake Winnipeg and Nelson River spreadsheet Routing Models

2.2 MODEL LIMITATIONS

The use of manual adjustments for re-regulation of Jenpeg releases, as opposed to algorithms for simulation of Jenpeg release decisions following logical and conditional operating rules, constitutes the models' most serious limitation relative to the following applications:

- System analysis, i.e. simulation of coordinated operation of all major MH system components upstream and downstream of Lake Winnipeg, both existing and planned, including Grand Rapids, Jenpeg, Kelsey, Keeyask, Kettle, Long Spruce and Limestone, to balance system storage for multiple flood and conservation purposes

- Analysis of more complex and systemwide operational alternatives than the two at-site constant-pool power range alternatives considered for Lake Winnipeg

- Reconstitution of natural flow regimes and lake levels throughout the MH system by removal of effects of system regulation under LWR, enabling a uniform 1915-2013 period of record for assessment of LWR effects based on hydrometric data (Appendix 3 to the MH Report); this approach was recently used to synthesize continuous 70-year periods of daily naturalized flows in multiple river basins for statewide water planning in Georgia (ARCADIS, 2010).

- Analysis of implications of climate change to LWR and evaluation of adaptive responses.

- Analysis of effects of LWR and alternatives to LWR under stationary-climate and climate-adjusted hydrologic conditions outside the range of those experienced during the 1977-2013 period of LWR implementation.

- Analysis of combined LWR operational and structural strategies to address other water management issues raised during the licencing process that could affect the operation of the MH system but are not addressable using the current MH models, including flow control for ice management, the Lake Manitoba drainage channel, protection/restoration of the Netley-Libau Marsh, and others.

My review of the MH Report and Appendices has generated additional observations related to the underlying models, data and assumptions, subsequently described.

2.2.1 LWR operating rules

The MH Report identifies fixed (seasonally constant) operating ranges for Lake Winnipeg, Playgreen, Kiskittogisu and Kiskitto Lakes. Other than these, constraints imposed on LWR operation are minimal:

- A requirement for maximum Jenpeg release when Lake Winnipeg exceeds 715.0 fasl;
- A 25000 cubic feet per second (cfs) minimum total Lake Winnipeg outflow requirement;
- No specific low-level support requirements when Lake Winnipeg falls below 711.0 fasl other than imposed ad-hoc by the Minister of Conservation and Water Stewardship; and
- A maximum allowable rate of change (plus or minus) of total Lake Winnipeg outflow of 15,000 cfs.

The LWR operating rules are simple, generalized and only minimally prescriptive. Rules for maximum and minimum releases are neither adjusted seasonally nor in response to hydrologic conditions within the basin. The most significant gap, however, is the fact that no targets, priorities or conditions govern Jenpeg release decisions relative to system power, instream flows or distribution of storage within the MH system. Consequently, when Lake Winnipeg is within its normal power range, which is most of the time, Jenpeg release decisions are largely based on operator discretion, informed by past practice and judgement. While these are legitimate and essential elements of reservoir system operation, they are not easily reduced to sets of logical operating rules that can be replicated in a true operational model.

Given the lack of specificity in the operating rules, the spreadsheet water-balance accounting models developed by MH constitute a reasonable approach to analysis of historical LWR operations and incremental changes to historical operating constraints. The major weaknesses of this approach, however, are its inability to (1) re-create historical releases under a given set of rules (to investigate how well the rules were followed), and (2) simulate release decisions under different and more complex rules outside the historical hydrologic record. The spreadsheet water balance models are not operational models in the traditional sense because they lack operational logic and do not consider some of the important complex physical constraints on release decisions, e.g. wind setup, ice formation, flow conveyance, etc. The water balance models would necessarily be incapable of analysis LWR as an integrated system, with complex operating rules and with individual system components subject to both system and at-site operational requirements.

2.2.2 Period of analysis

The MH modeling approach necessarily restricts analysis of LWR effects to a unique set of hydrologic and climate conditions occurring during the 37-year period (1977-2013) LWR has been in operation. This limitation does not invalidate MH's overarching conclusions that (1) LWR has not increased Lake Winnipeg's average water levels and (2) LWR is not the principle cause of a variety of downstream problems to which it may be attributed. However, these assertions would be more strongly supported by a century-long statistical record generated by a model able to utilize the additional 62 years of hydrologic record prior to LWR implementation. Comparison of pre- and post-LWR conditions for different flow records, shown in Figure 2.2, would not statistically isolate effects of LWR from the influence of climate change or long-term climate cycles (multi-year wet and dry periods).

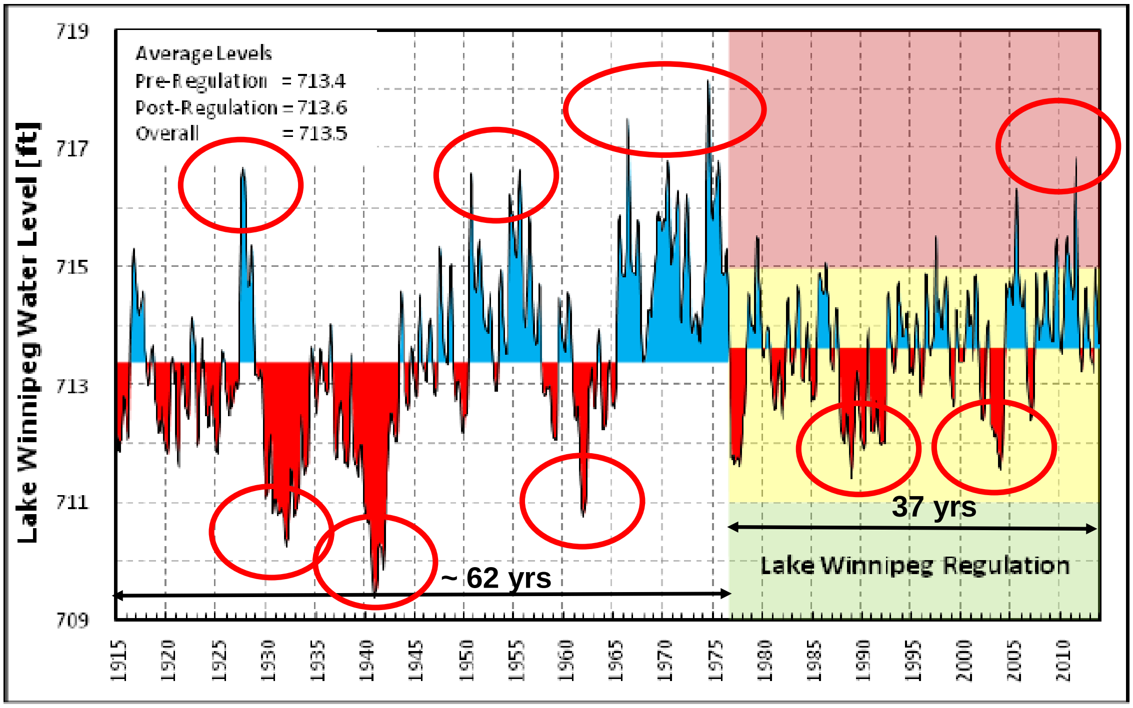

Figure 2.2: Comparison of pre- and post-LWR Lake Winnipeg levels (from MH Report Appendix 3)

2.2.3 Regulation effects on Lake Winnipeg

Appendix 4 of the MH Report documents the development of a naturalized water-balance model for re-creation and comparison of Lake Winnipeg outflows, levels and hydraulic residence time without LWR to those observed following LWR implementation. The LWR historical operation spreadsheet model was adapted to this purpose by (1) replacement of outlet rating curves in the model with computed natural rating curves, and (2) routing of historical Lake Winnipeg inflows through the Lake with unregulated outlet releases. Time-series outputs of the re-created natural flow and lake level regime were analyzed and compared with those produced by the MH spreadsheet water-budget model with LWR and the current 711-715 fasl power range. While this approach does avoid the need for comparison of pre- and post-LWR conditions, the period of analysis is limited by the water budget model to 37 years (1977-2013), and the statistical inferences drawn as a result are not as strong as would be the case with a century-long period of record for comparison of natural and LWR conditions.

2.2.4 Climate change effects

Because application of the MH spreadsheet models is limited to the post-LWR implementation period (1977-present) hydrology, they could not be applied to analysis of climate-adjusted hydrologic or demand (hydropower, flood protection, drought management, etc.) conditions. In the long term, system operational models capable of assessment of LWR response and adaptability to climate change will be needed.

2.2.5 Alternative power ranges

Appendix 10 of the MH Report describes modifications to the Lake Winnipeg and Nelson River routing models (domains shown in Figure 2.1) to accommodate reduced (711-714 fasl) and expanded (711-716 fasl) power range alternatives to the historical 711-715 fasl operating range. Each alternative operating range was implemented in separate Winnipeg and Nelson River routing model pairs, and because the changes were incremental (1 foot lower or higher, constant throughout the year), the major differences between the alternative and baseline models were the times requiring manual adjustments to re-regulate historical Jenpeg releases as needed to maintain the lower or higher operating ranges associated with the alternatives.

As in the other model applications previously discussed, the spreadsheet routing models are very limited in their ability to explore slightly more complex operational improvements. Analysis results presented in Appendix 10 shows lake levels predictably shifted higher or lower depending on the alternative, but with little seasonal redistribution of outflows. Seasonal redistribution of flows could be extremely important to water management strategies designed to maximize multiple competing and complementary objectives while reducing or not unduly increasing flood and droughts. At minimum, evaluation of seasonal lake level management and environmental flow alternatives requires a model capable of simulation of effects of seasonal power ranges on multiple purposes upstream and downstream of Jenpeg, and ideally throughout the MH system. Given the degree of manual intervention and statistical post-processing of simulation results required, evaluation of alternative seasonal power ranges using the existing MH water-balance models might be possible but, due to proliferation of models, impractical.

2.2.6 System operation, storage balance and power generation

The physical domain of the MH Lake Winnipeg and Nelson River routing models shown in Figure 2.1 does not allow for simulation of LWR operation outside the 1977-2013 historical period or with new or modified water control structures. Lake Winnipeg inflows could be influenced, for example, by Grand Rapids station operations and proposed changes to Lake Manitoba drainage channel(s). Jenpeg releases, river flows and lake levels can all be affected by operation of the existing four and the planned Keeyask power station on the Nelson River downstream. Because many of these MH system components are not included in the spreadsheet water balance models, and the models lack an operating rule base, they cannot as a practical matter be configured to analyze effects of LWR operational alternatives on system storage balance or system power generation.

2.2.7 Physical and hydrologic detail

In addition to the lack of operating rules, several important physical and hydrologic constraints to LWR operation cannot be captured by spreadsheet-based water balance models as a practical matter. These include wind setup, ice jamming, turbine-generator performance data, gate-limited spillway and outlet rating curves, and river reach flow routing characteristics – to name but a few. Some of these are fixed, some are time-varying, and some may be conditioned by time-varying model variables and/or user-defined (internal or external) state variables. Without this physical detail, operational models may be significantly limited in their ability to account for and analyze effects of major factors influencing reservoir releases – wind setup on Lake Winnipeg or flow controls needed for ice management as two prominent examples. Most comprehensive river/reservoir system models in use around the world do accommodate detailed physical description of system components and provide the necessary structure for accommodation of constant, variable or conditional paired-data relationships (e.g. rating curves), routing parameters, etc. to allow significant flexibility and realism for rule-based operational simulation. Example characteristics of multipurpose reservoir system models capable of addressing issues discussed above are subsequently discussed in Section 5 of this report.

On December 19, 2014, the Manitoba Infrastructure and Transportation (MIT) Department responded to a November 3, 2014 inquiry by the CEC regarding the potential impacts of a new Lake Manitoba drainage channel to Lake Winnipeg. Specific areas of CEC inquiry were as follows:

- Quantity of water exchanged between Lakes Manitoba and Winnipeg
- Timing of water transfers
- Impacts on Lake Winnipeg levels
- Local and lake-wide environmental impacts

The December MIT letter noted that the configuration and operating rules for the drainage project have not been finalized and as a result the information provided based on the analysis is subject to change. An operating regime was described whereby the Lake Manitoba outlet would be opened "…whenever the lakes exceed their desirable lake levels." It is unclear whether or not this rule allows for two-way operation, i.e. drainage from Lake Winnipeg when its level exceeds its normal operating range relative to Lake Manitoba's. The MIT letter asserted that the drainage channels will "…not change the total volume of water flowing to Lake Winnipeg but rather the timing of the flows." However, because the timing of high lake inflows and high lake levels in both lakes will often coincide, timing may be a more important measure of impact than inter-annual flow volume. Additional inflows to Lake Winnipeg caused by accelerated drainage of Lake Manitoba have the potential to diminish the capacity for balancing lake and downstream Nelson River flood risks during large regional floods, and to complicate ice cover or shoreline erosion management efforts as well.

The MIT letter provided time-series comparisons of Lake Manitoba outflows and Lake Winnipeg levels with and without the drainage channel. The letter does not indicate whether the existing MH Lake Winnipeg routing model was used to make the comparison or a simple storage routing was performed using historical Winnipeg outflows. In any case, neither approach allows the potential influence of alternative drainage channel configurations or Grand Rapids controlled releases on Lake Winnipeg inflows, lake levels or Jenpeg releases to be analyzed.

2.2.8 Drought management

A major shortcoming in the current LWR rules is the lack of rules governing drought response and drought management. This is not a deficiency of the models per se, but if evaluation of system reliability under low-inflow conditions and alternative LWR rules were desired, the existing MH water-balance models would be inadequate for this purpose; the existing models are driven by historical releases mandated by higher authority as opposed to rule-based release decisions. Future LWR operational planning should involve formulation and testing of drought management rules due to (1) the Province's high reliance on hydropower, which carries more than 95% of the MH system load, (2) the need to conserve water in storage to make hydro energy and capacity dependable during extended critical low-flow conditions, and (3) the potentially serious impacts of water shortages on human uses and the water environment. System operational simulation models with capabilities previously discussed will be essential for this purpose. Moreover, real-time drought management can be enhanced by real-time adaptation of the planning models, and further enhanced by pre-emptive response enabled by robust drought indicators and special-purpose drought forecasting decision support systems.

Letters were exchanged between the CEC and the Manitoba Province Water Use Licensing Section (WULS) in November 2014 regarding operational and compliance monitoring procedures should Lake Winnipeg fall below its usable power range (elevation 711.0 fasl). As previously indicated, the current LWR operating rules do not prescribe Jenpeg releases other than a minimum of 25,000 cfs when Lake Winnipeg is within the normal operating range, and releases as ordered by the Minister of *The Water Power Act* when below the normal operating range.

Without prescribed rules (e.g. seasonal at-site and system energy generation requirements, releases to maintain downstream lake levels, control downstream flooding, or support downstream power generation, etc.) the current MH models are not readily adaptable to rule-based operational simulation. In its November 21, 2014 response to the CEC, WULS largely re-affirmed ministerial control of Jenpeg releases below elevation 711.0 fasl, indicating specific concerns for marinas and vessel grounding but not any concerns specifically related to power generation or availability of water for other purposes. While MH is responsible for 90-day forecasts of Nelson River flows and water levels in Lakes Winnipeg, Playgreen and Kiskittogisu, no specific drought initiation/response protocols involving Jenpeg releases or power generation during low-water conditions were identified in the WULS letter, nor in the current LWR rules.

The WULS response confirms the lack of a concrete drought management plan, which, coupled with the lack of prescribed operating rules for the Lake Winnipeg conservation pool (within the 711-715 fasl power range) disclose gaps in the MH modelling to date and the utility in general of the current models for conservation and drought management planning.

3.0 INFORMATION REQUESTS AND OTHER ISSUES

Comments and observations posted in this section focus on Information Requests (IRs), correspondence and issues discussed in community hearings related to the water-balance models and data developed by MH in support of the final licence application.

3.1 INFORMATION REQUESTS (IRS)

Information requests related to MH water-balance models and data are listed in Table 3.1. Participant-generated IRs pertaining to other than hydrologic and operational models (e.g. hydrodynamic or water quality models) are addressed only to the extent needed to clarify their relevance to the major conclusions of the MH Report regarding impacts of LWR on Lake Winnipeg levels or the downstream Nelson River water regime.

Table 3.1: IRs related to LWR hydrologic and operational models

Identifier	Subject
CAC_0001	Choice of modeling approach (2.1)
CAC_0002	Model uncertainty
CAC_0003 CAC_0004	Historical model inflow reconstruction
CAC_0005	Alternative lake models
CAC_0009	Methodology for elimination of wind effects (2.2.7)
CAC_0014	Evaluation of alternative power ranges (2.2.4 – 2.2.6)
CAC_0015 CAC_0016 CAC_0017	Climate change effects (2.2, 2.2.4)
CAC_0018 CAC_0019 CAC_0020	Appropriateness of manual reregulation in water-balance models (2.1, 2.2, 2.2.1)
CAC_0026	Flood control benefits of LWR (2.2, 2.2.2, 2.2.3)
CAC_0032 CAC_0033	Alternative Lake Winnipeg power ranges (2.2.5)
CAC_0037 CAC_0038	Adaptive management (2.2)
CAC_0040	Downstream Nelson River impacts of LWR (2.2, 2.2.5, 2.2.6, 2.2.7)
CAC_0046	LWR effects on Netley-Libau Marsh (2.2)
CEC_0003	Study area/model domain, system power analysis (2.2, 2.2.6)
CEC_0010	LWR operation under climate change (2.2, 2.2.2, 2.2.4)
CEC_0012	Modeling approach (2.1, 2.2)
MB_0058	Effects of climate change on LWR (2.2, 2.2.2, 2.2.3, 2.2.4)

Table 3.1 entries shaded in grey are considered highly relevant to issues addressed in Section 2 of this report, and are cross-referenced accordingly. Unshaded entries are related to operational modeling to a lesser degree and not within the scope of issues addressed in this review.

The MH responses to several of the grey-shaded IRs listed in Table 3.1 tended to be more qualitative than quantitative, confirming some of the limitations (discussed in Section 2) of the spreadsheet water-balance models relative to quantitative analysis of system operations outside historical LWR hydrologic conditions or operational practice. While acknowledging, for example, the fact that climate change would affect LWR operations, MH provided few quantitative measures of its effects on Lake Winnipeg and downstream lake levels, the Nelson River flow regime, ice management procedures, system power generation, flood or drought risks operating under LWR. Neither do the MH models permit evaluation of operational responses to climate change or adaptive LWR modifications to address other multipurpose water management issues raised in the IRs, among them flood risks, lake levels, system power generation, Netley-Libau Marsh, ice management, shoreline erosion, and others. While fully answering these questions may not be essential to the present licence application, these issues should be addressed in the future using more comprehensive reservoir system operational models.

3.2 COMMUNITY ISSUES

Many of the issues raised in community hearings around the Province relate to various types of models. Some areas of concern specific to hydrologic and operational models are listed as follows:

- Effects of water quality and water currents on commercial fisheries; special-purpose models that might address these issues may rely on operational models to provide simulated boundary conditions for extreme hydrologic events, seasonal or inter-annual flow regimes.

- Lake level fluctuations, shoreline erosion, ice formation and navigation safety, analysis of which would rely to a significant degree on hydrologic and operational models.

- Influence of Lake Winnipeg levels and Jenpeg releases on flood risk.

As discussed in Section 2 of this report, future LWR operational planning to address the above-listed and related issues will require rule-based system simulation models. Due to their limitations (described in Section 2.2 of this report), the current MH spreadsheet water-balance models will not be adaptable to these purposes

4.0 EXPERT REPORTS

Comments and observations provided in this section address reports prepared by experts working independently or on behalf of participants in the LWR licencing process. Only reports pertinent to the models and data developed by MH in support of the licence application were reviewed.

4.1 LAKE WINNIPEG EROSION AND ACCRETION PROCESSES (BAIRD 2015)

The Baird report concludes in Section 2.2.2 that LWR has substantially reduced Lake Winnipeg water level fluctuations in comparison to natural conditions, based on the MH comparison reproduced in Figure 2.2 of this report. As discussed in Section 2.2.2 of this report, the period of analysis using MH water-budget models was limited to the post-LWR period (1977-2013), and as a result the fluctuation ranges cited by Baird are based on two sequential (1915-1976 and 1977-2013) sample periods of different lengths. The conclusions of the Baird report related to extreme low and high-flow events are thus less reliable than if based on comparison of with- and without-LWR conditions throughout the 1915-2013 period of hydrologic record, which a rule-based operational simulation model (as previously described in Section 2.2 of this report) would allow. The with-and without-LWR comparison shown in Figure 2.12 of the Baird report is accurate, however, presumably comparing historical regulated Lake Winnipeg levels with natural lake levels reconstituted as described in Appendix 4 of the MH Report (Op. Cit.).

4.2 CLIMATE IN THE LAKE WINNIPEG WATERSHED AND THE LEVEL OF LAKE WINNIPEG (MCCULLOUGH 2015)

The McCullough report documents seasonal, annual, multi-decadal patterns and long-term trends in precipitation and tributary discharge in the Lake Winnipeg and Red River Basins, which combined supply more than half the inflow to Lake Winnipeg. These patterns and trends were analyzed using approximately a century's worth of compiled or synthesized meteorological and hydrologic records. However, as discussed in Section 2 of this report, the MH water-balance models are incapable of rule-based operational simulation, and as a result the more interesting questions of (1) climate change effects on LWR, and (2) potential adaptations of LWR to climate change, cannot be answered at this time.

4.3 CLIMATE CHANGE REPORT, FISCAL YEAR 2012-2013 (MANITOBA HYDRO)

This document summarizes Manitoba Hydro's actions and initiatives related to climate change and its effects on hydrology and GHG emissions. Discussion of issues pertinent to LWR is limited to presentation of the ensemble ranges of Winnipeg Basin seasonal inflows, predicted for the 1950s based on downscaled global climate model (GCM) simulations. Application of rule-based operational simulation models in the future would allow investigation of LWR alternatives for adaptation to climate change to meet demands on water, storage and hydropower. Adaptive LWR management would be a valuable and tangible initiative from any perspective.

4.4 THE ECOLOGY OF COASTAL WETLANDS AROUND LAKE WINNIPEG AND VEGETATION LOSS IN NETLEY−LIBAU MARSH (GOLDSBOROUGH 2015)

Among management strategies suggested in the Goldsborough report potentially benefitting from future rule-based operational modeling are (1) alteration of the Lake Winnipeg regulation protocol to permit two-year, low-water periods with a frequency of roughly ten to twenty years, (2) construction of a flow-regulation structure at Netley Cut, and (3) resumption of dredging at the Red River outlet to Lake Winnipeg.

The first recommendation above presents a set of complex issues that would greatly benefit from future study, (1) to validate the need for bringing the Lake down 2 feet for two years out of 10 or 20 years, and (2) to devise the least impactful means to achieve the objectives of the periodic draining. At minimum, implementation of this proposal would require long-term streamflow forecasting to manage flood and drought risk. Modifications to the current LWR rules may also be needed to trigger operational responses to forecasts and enable induced drawdown and refill of Lake Winnipeg while maintaining requirements for power generation, lake levels and instream flows elsewhere throughout the MH system. The level of model sophistication and integration needed for operational planning for this purpose would be considerable, requiring powerful system operational models linked to forecasting tools. Alternatives to this proposal could also be investigated using the operational models, including construction of water control structures, prototypes of which could be tested in conjunction with alternative management strategies to assess feasibility in comparison to lowering the entire Lake for such an extended period of time. The potential impacts of implementation of this proposal as is on all LWR management objectives could be severe, lending impetus for investigation of other less drastic approaches to improve the Netley Marsh or mitigate its deterioration.

The other Goldsborough recommendations could be studied relatively easily using operational models by incorporation of rating data and operating rules for the Netley Cut regulation structure (recommendation 2), and use of dredging-adjusted rating curves for determination of Red River inflows to Lake Winnipeg (recommendation 3).

4.5 DEVELOPMENT OF A NUMERICAL MODEL FOR PREDICTING ICE CONDITIONS ON THE UPPER NELSON RIVER (BIJELJANIN AND CLARK 2010)

This report is identified only for purposes of illustration of potential opportunities for integration of rule-based reservoir system operational models with numerical models, in this case for prediction of ice conditions downstream of the Jenpeg power station. Operational models now in widespread use and subsequently described in Section 5.2 of this report have capabilities for user-scripting of state variables. Jenpeg release decisions could be informed in such models by state variables, programmed around time-series outputs of numerical hydrodynamic models of the kind described by the authors, run using historical or synthetic hydrologic and other inputs corresponding to the operational model time-series inputs. A similar approach could be used to develop state variables for wind adjustment of lake levels, which then could likewise inform release decisions.

5.0 CONCLUSIONS AND RECOMMENDATIONS

My overall observation, based on reports, IRs, models and data reviewed is that the focus of studies undertaken by MH are generally adequate to support the current licence application. However, their focus is more hindsight (attempting to show that LWR hasn't greatly exacerbated problems or altered historical conditions) than foresight (investigation of opportunities to improve LWR to mitigate future problems and meet forecasted/emerging needs). A notable exception to this observation is the investigation of two alternative Lake Winnipeg power ranges (711-714 and 711-716 fasl). However, the results of this analysis by MH are somewhat inconclusive in view of the limited capabilities of the MH routing models for analysis of more complex operational alternatives relative to a comprehensive set of water management objectives, and in an integrated system context. These additional capabilities will be needed in the future, however, to address known, forecasted and emerging issues of concern related to LWR implementation.

Manitoba Hydro's assessment of the overall effects of LWR on Lake Winnipeg and downstream lake water levels, as well as the Nelson River flow regime, relies to a large extent on spreadsheet water balance models – Lake Winnipeg Routing models that include Lake Winnipeg inflows and Jenpeg Power Station releases, and Nelson River Routing models for routing of Jenpeg releases through Cross Lake, Sipiwesk Lake, Kelsey forebay and Split Lake. The models were developed and applied for the following purposes:

- Without-LWR flow routing to reconstitute and compare unregulated lake level and flow conditions with historical 1977-2013 conditions, for assessment of the overall effects of LWR on the Lake Winnipeg water regime; the intent of this effort was to create a natural water-balance model capable of isolating the effects of LWR from other influences on the water regime, including climate cycles and climate change, and changes in upstream regulation, water use and land use. This analysis is documented in Appendix 4 of the Manitoba Hydro Report (Manitoba Hydro Report, Appendix 4, July 2014b).

- Simulation of effects of alternative Lake Winnipeg power ranges (elevations 711-714 fasl and 711-716 fasl) and comparison with lake levels and water regime with current (711-715fasl power range) LWR operation (Manitoba Hydro Report, Appendix 10, July 2014c).

While the scope of the water balance model applications is generally appropriate and supportive of the Final Licence Application under *The Water Power Act*, some refinements are warranted. In the near term, the models and data should be enhanced to (1) address information gaps identified by the MH report, and (2) supplement and clarify MH responses to IRs submitted subsequent to the report. In the long term, more comprehensive water resource system analysis capabilities will be needed to meaningfully address interdependent and cumulative effects of climatological, hydrological, physical and operational changes during the term of the next licence. Each of these changes has the potential to create significant tradeoffs between competing and complementary project purposes, require structural alterations, changes in operating rules, or some combination of all of these. These aspects of LWR will need to be considered in an integrated fashion in the formulation of a sustainable plan for system operations and to ensure that associated costs, benefits and environmental impacts are equitably allocated.

5.1 NEAR-TERM RECOMMENDATIONS

The most significant potential improvement to the MH Lake Winnipeg routing models would be conversion from manual intervention and input of deviations from historical (1977-2013) Jenpeg releases to rule-based operation, by which the model simulates Jenpeg releases based on logical operating rules and constraints. Conversion of the Lake Winnipeg routing models to rule-based operational simulation models would allow (1) merger of the Lake Winnipeg and Nelson River routing models and (2) analysis of multiple operational alternatives within a single model. Currently there are three Winnipeg and three Nelson River routing models, paired by the three Lake Winnipeg power-range alternatives considered (711-714 fasl, 711-715 fasl, and 711-716 fasl). The conversion would offer the following benefits:

- Allow a longer period of analysis for reliable determination of effects of LWR on lake levels and river flows; because the current spreadsheet models rely primarily on historical releases rather than simulation of rule-based release decisions, the 36-year period of analysis (1977-2013) to which they are limited may not be adequate to (1) reliably isolate LWR operational effects from long-term climate, hydrologic, fluvial geomorphology, and land-use changes within the 380,000 square-mile watershed draining into Lake Winnipeg, or (2) assert with confidence that LWR has not increased average Lake Winnipeg water levels – a central contention of the MH Report.

- Permit analysis of more complex and system-wide operational improvements than the two seasonally-constant power range alternatives considered for Lake Winnipeg alone; seasonally-varying operating ranges could benefit both conservation and flood management objectives related to magnitude and timing of Nelson River flows, Lake Winnipeg and downstream lake levels, system-wide power generation, flow control for ice management, and wind setup.

- Provide limited capabilities for accommodation of drought triggers and simulation of drought management strategies; these are largely non-existent in the current models, defaulting to control by the Minister responsible for *The Water Power Act* (Manitoba WULS, November 2014).

The utility and practicality of model conversion in the short term should be weighed against the need for additional quantitative data to support the Final Licence application, and whether the spreadsheet modeling framework is in fact suitable for addressing some of the more complex and challenging issues subsequently described.

5.2 LONG-TERM RECOMMENDATIONS

The focus of models and data developed for future LWR operation should not be a comparison of Lake Winnipeg water levels and flow regime with and without-LWR, as is the case in the current licence application, but on system operation to maximize and equitably allocate the benefits of multipurpose regulation while minimizing basinwide flood risks, drought risks and environmental impacts. Several complex water management issues have been raised in the LWR licensing process, some of which may not directly pertain to the current licence application and would not in any case be amenable to analysis using the present generation of MH spreadsheet water balance models. Nonetheless these issues are likely to assume greater importance in the future and others may emerge that will require detailed analysis in support of future licence applications. These issues will require a new generation of decision-support tools to comprehensively address, with the following capabilities:

- Incorporation of, at minimum, the major existing and planned components of MH's LWR and Nelson River power system outlined in Figure 5.1 for integrated analysis and assessment of systemwide storage balancing and coordinated operation for flood protection, hydropower, environmental and drought management objectives; consideration should be given to incorporation of all MH system components that are hydraulically connected to Lake Winnipeg and the Nelson River and currently included in its HERMES decision-support system for energy operations planning.

- Consideration of wind setup effects on rating curves, and river routing to account for lag and storage of reach inflows.

- Testing operational responses to ice conditions on the Nelson River (Bijeljanin and Clark, 2010; Tuthill, 1999).

- Analysis of effects of major inflow changes, for example the Lake Manitoba drainage channel, into the LWR plan.

- Analysis of effects of LWR operational alternatives on wetlands, particularly Netley-Libau marsh and feasibility assessment of operational and/or structural alternatives

- Testing and evaluation of operational and structural alternatives to better control Cross Lake levels and flow regime
- Testing and evaluation of operational and structural alternatives for shoreline management and improvements to Nelson River flow regime relative to flood protection, environmental, water quality, and bank erosion objectives
- Analysis of LWR operational alternatives using climate-adjusted streamflow, precipitation and evaporation ensembles (as opposed to averaging of multiple downscaled climate model predictions)
- Formulation and testing of drought-management alternatives

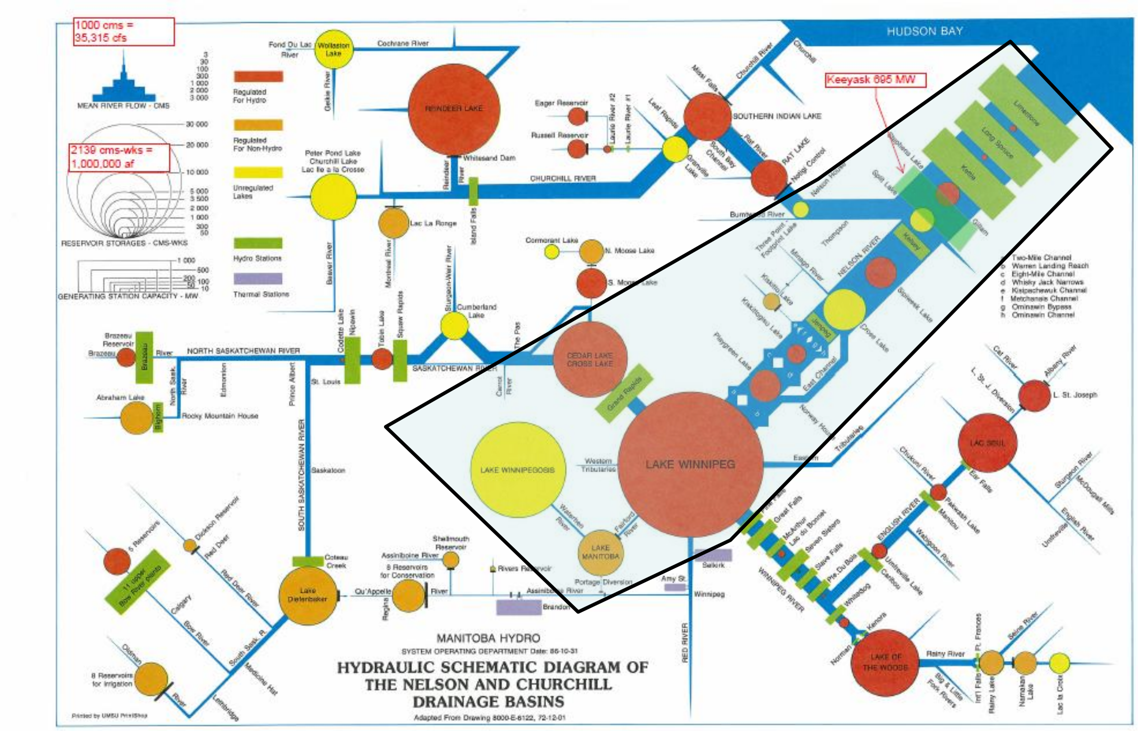

Figure 5.1 Recommended domain of future LWR system operational model (shaded area)

Spreadsheet models will not be capable of analyzing these aspects of LWR, and consequently a more robust water resource systems modeling platform will be needed, with the following capabilities:

- Geo-referenced configuration of river basins, stream alignments and reservoir networks;
- Flexibility for addition and removal of elements from reservoir networks;

- Multiple reach routing methods;

- Detailed description of physical components of reservoirs and hydraulic controls, e.g. elevation-area-storage curves, multiple controlled and uncontrolled outlet works, diversion structures, and release allocations (e.g. sequential, balanced, stepped);

- Detailed description of powerplants, including turbine-generator performance data for multiple units, station service units, etc.;

- Definition of storage zones and logical, conditional and user-scripted operating rules for each zone, for each reservoir;

- System storage-balancing rules for one or more system reservoirs within zones, for tandem and parallel operation;

- User-scripted state variables incorporating model-generated and external time series to enable complex conditional release decisions, e.g. wind-adjusted rating curves, drought triggers, remaining storage, system storage balance, seasonal or conditional environmental flow requirements;

- Interaction with or incorporation of database management utilities for input, output, pre- and post-processing, graphical and tabular display, and mathematical/statistical analysis of time-series data; linkage, using the time-series data system, of the operational model with hydrologic, hydrodynamic, water quality or other numerical models potentially involved in multipurpose system operation;

- Capabilities for simulation and side-by-side comparison of multiple alternatives (using the database management utilities); and

- Ensemble simulation capabilities for routing of multiple streamflow excursions per alternative

The above-listed performance specifications, with the exception of ensemble simulation capabilities (pending), apply to the current public-release version of the HEC-ResSim model (USACE 2013), the reservoir system simulation component of the USACE Water Management System (CWMS). Other commercially available river and reservoir modeling systems (e.g. CADSWES RiverWare) likewise satisfy many of these requirements, and some open-shell modeling platforms (e.g. Deltares Delft-FEWS) enable dynamically linked integration of river system, hydrodynamic and water quality models as well.

Other important characteristics of the recommended system operational planning model described above are (1) transparency and accessibility of physical and operational data incorporated within the model to stakeholders, (2) flexibility and adaptability for modification of operating rules and addition of new projects to the system, and (3) adaptability to real-time water control of the LWR system.

As a final observation, stakeholder participation in the licencing process could potentially be made more effective, and prospects for studying and resolving stakeholder concerns improved, by integration of stakeholder issues into the licencing process from the start, rather than addressing stakeholder concerns after studies have been scoped and performed by the applicant (MH in this case). An example framework for participatory licencing applications is the Federal Energy Regulatory Commission (FERC) Integrated Licensing Process (ILP), information for which can be found at http://www.ferc.gov/industries/hydropower/gen-info/licensing/ilp.asp. The basic ILP steps are as follows:

- Early issue identification and resolution of studies needed to fill information gaps;
- Integration of applicant and stakeholder permitting process needs;
- Establishment of time frames to complete process steps for all stakeholders and the licencing authority;

One difference between the ILP and the current LWR process is stakeholder collaboration from start to finish, by (1) identification of issues needing to be addressed in the application, (2) definition of stakeholder priorities and performance measures, and (3) scoping of studies to be performed to address these issues. Adaptation of the ILP process to LWR could occur in a variety of ways or re-sequence existing LWR elements, e.g. undertake IRs first, select and prioritize issues relevant to the licence, collaboratively scope studies to address these issues, and compare study results with previously developed stakeholder performance measures.

The overall goal of the ILP is to provide a predictable, efficient, and timely licencing process that ensures adequate protection of economic, environmental and cultural resources. As a practical matter, whether or not it could be adapted to LWR licencing under *The Water Power Act* is outside the scope of this review.

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