McCULLOUGH RESEARCH

ROBERT F. MCCULLOUGH, JR.
MANAGING PARTNER

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To: McCullough Research Clients

From: Robert McCullough

Subject: September 29, 2008 New York Risk Consultant - Hydraulics Report

On September 29, 2008, Manitoba Hydro's New York risk consultant provided a preview of a larger study to Bob Brennan, Manitoba Hydro's Chief Executive Officer, which connects export policy, drought risk, and hydro operations.[1] Since it has been Manitoba Hydro's position that the hydroelectric construction program and the export of its generation to the U.S. will not affect hydro operations, the existence of this confidential high-level memo is quite significant. The technical sophistication of this document is so considerable that we have prepared our memo as a translation for the ordinary reader.

The confidential memo was released by Manitoba Hydro apparently in violation of a confidentiality agreement between Manitoba Hydro and the New York risk consultant as part of Manitoba Hydro's legal filing asking for authority to break the confidentiality agreement.[2]

The report is significant for two reasons:

1. It provides insights into the planning process including the relationship of the venerable SPLASH model with the even more vintaged HERMES.[3]
2. It directly ties reservoir levels and reservoir operations to exports and drought risk.

[1]September 29, 2008 New York Risk Consultant - Hydraulics Report; it is also Exhibit 48 of the Affidavit of Andrew David Cormie sworn the 18th day of February, 2010.
[2]Queen's Bench Application CI-09-1-64372.
[3]Utilization of the SPLASH Computer Simulation Model to Represent Water Regime in the Manitoba Hydro System; March 21, 2005. SPLASH was developed in the 1990s. HERMES dates from the 1980s.

6123 REED COLLEGE PLACE • PORTLAND • OREGON • 97202 • 503-777-4616 • ROBERT@MRESEARCH.COM

By comparison, the discussion in Manitoba Hydro's recent filing with the Manitoba Public Utilities Board is both shorter and less sophisticated.[4]

The memo opens with a frank discussion of the New York risk consultant's concerns after discovering critical differences in the predictions of SPLASH and HERMES. After some discussion of the scale of the discrepancies, the author focuses on three key errors in Manitoba Hydro modeling. First, the assumptions between the two models differ significantly; second, the use of an arbitrary historical sequence of water years allows SPLASH to "see the future"; and third, the optimization of HERMES is significantly less efficient than that of SPLASH.

The Hydraulic Report to CEO Brennan makes nine major points:

1. **The HERMES 1940/1941 drought case overstates reliability and revenues – primarily due to the assumption that the historical record will guarantee a rapid recovery of streamflows to average levels**

The HERMES 1940/1941 case represents a computer study reflecting the worst case exposure of Manitoba Hydro to drought. If errors exist in this study, then Manitoba Hydro's public statements concerning drought risk will be incorrect. This concern is addressed more fully in point 4 below.

2. **The value of hydro storage in HERMES is overstated – leading to unrealistically high release levels during periods of low inflows**

The New York risk consultant notes that in discussions with Manitoba Hydro's Chief Financial Officer it is clear that the storage in Lake Winnipeg is viewed as "money in the bank."[5] The New York risk consultant's own analysis indicates that drawing down Lake Winnipeg by one foot will actually cost Manitoba Hydro $208.3 million on an expected basis. This is a surprising conclusion, since it indicates that the risk of drought is significant enough to offset the benefits of current sales.

An easy way to think about this is to consider the investment decision faced in the game of Monopoly. If one invests all of one's cash in new houses, and then lands on the opponent's hotel, one is forced to sell the houses back to the bank at half price.

[4]Corporate Risk Management, Tab 12, 2010/11 & 2011/12 General Rate Application.
[5]September 29, 2008 New York Risk Consultant - Hydraulics Report, page 2.

Obviously, one makes more income by buying houses. If one is about to throw the dice facing a long line of hotels owned by the opponents, one will probably not invest in more houses, since the risk of a major payment of rent is greater than the immediate return.

The New York risk consultant's conclusion, backed by detailed analytical results on pages 8 and 9 of the report, is that the risk of emergency purchases is great enough to overwhelm the prospects of immediate revenues from additional export sales.

3. High inflow cases indicate that higher reservoir levels are considerably better than lower reservoir levels

The New York risk consultant's computer modeling indicates that drawing down Manitoba Hydro's reservoirs below a certain level is inadvisable even if current inflows are high.

Continuing the Monopoly example, most players would not spend their cash to buy new houses if they were facing hotels on Boardwalk and Park Place. They might invest if they had passed the dangerous hotels and were not facing large rents on their next throw of the dice.

The calculations on pages 10 and 11 indicate that it is prudent to maintain reservoir levels above minimum levels even when there is no prospect of a drought in the immediate future.

4. Vintages of drought

This argument is difficult to follow without having access to the Manitoba Hydro reports the New York risk consultant is criticizing. "Vintage" is not a term of art in hydroelectric planning, nor is the term in common use elsewhere in the industry. The ICF report contained an odd argument breaking drought risk out by starting year which may reflect the same analysis, but the presentation was very unclear.[6]

5. Optimization problems

[6] Independent Review of Manitoba Hydro Export Power Sales and Associated Risks, September 11, 2009, pages 19 through 21.

Closely related to the New York risk consultant's concerns about using the original historical sequence of inflows, rather than the correct statistical tools, is a similar workaround developed for Manitoba Hydro in the 1980s. A common problem in finding exact optimal solutions for hydroelectric systems is the availability of good optimization algorithms. Manitoba Hydro has used a sequential linear programming approach for the past twenty-five years. While this was an acceptable approximation in the 1980s, current approaches are vastly more sophisticated.[7]

At its heart, the problem is simple. To get the best view in a city like Montreal, one would advise a tourist to keep walking uphill until reaching Mount Royal Park. This is a solid algorithm for Montreal, because Mount Royal is the highest point in Montreal. However, it is a poor algorithm for Portland, Oregon, since the terrain climbs steeply out of the city toward the Cascades to the east and the Coastal Range to the west. An inadvertent tourist given the same instruction might even find that the walk leads to a not-so-dormant volcano on the outskirts of Portland. Unfortunately, multi-reservoir hydroelectric systems are more like Portland than Montreal. In other words, more complicated problems require better algorithms.

The sequential linear programming algorithm is no longer required to save computational time. With computers thousands of times more efficient than those it was designed for, more precise and reliable tools are the standard today.

6. Unusually high losses in the 2003/2004 drought compared to model results

In 2003/2004, Manitoba Hydro suffered very low inflows. These inflows contributed to an extremely adverse level of earnings in 2004. The New York risk consultant's analysis of operations in 2003/2004 indicates that a major cause of the poor financial results involved poor business decisions at Manitoba Hydro.

7. The 2009 and 2010 financial forecasts are incorrect

From the discussions above, this conclusion is not surprising. The Integrated Financial Forecast – the basis of Manitoba Hydro's financial and regulatory reporting – is likely to be wrong if the drought assumptions and modeling are wrong.

[7] The use of this algorithm was even questioned in the 1980s. See, for example, Practical application of successive linear programming for reservoir operations at Manitoba Hydro, K.K. Reznicek and S.P. Simonovic, May 1989, for a critical comparison of approximate optimization algorithms.

8. The five-year drought criterion used in Manitoba Hydro's annual reports and PUB filings is not nearly conservative enough

As noted above, the computer systems used to develop SPLASH and HERMES were very different from those used today. In the mid-1980s, when HERMES was developed, a top-of-the-line IBM workstation had a 32 bit processor running at 6 MHz. The workstation now on my desk has four processors, each of which is running at 3.9 GHz – roughly 2,000 times as fast as my 1985 workstation. Hydroelectric operations are often complex, so the use of a time-saving "workaround" was the custom until the 1980s. Instead of creating a statistical distribution of possible stream flows, planners used the historical sequence, with the calendar years repeated in the original order.[8]

Again, we can turn to the business problem in the children's game Monopoly. At some point during each game every player faces the question whether to spend money on buying more houses and hotels or to hold it to pay the high rents on the Boardwalk and Park Place. Smart players will count the different possibilities of landing on the high rent properties. If the odds are high, they will keep money in reserve. Otherwise, they will invest in more houses. Manitoba Hydro's models, by contrast, assume that the sequence of rolls of the die is always repeated. Example: a player throws a 7 on the last turn around the board, followed by a 4 on the next turn. Manitoba Hydro's models *always* assume that the 7 will be followed by a 4. Because the Manitoba Hydro approach is readily calculated, this approach was adopted in the early 1900s.[9] Today, of course, hydro planners (and Monopoly players) employ more sophisticated approaches.

The New York risk consultant's point is straightforward assuming that the worst cases – 2003/2004, for example, will always be followed by the inflows from 2004/2005 is very optimistic and likely to lead to dangerously optimistic planning.

Again, this follows directly from the New York risk consultant's previous arguments. The "worst case" is depending on the unrealistic assumption that the sequence of in-

[8]It is worth noting that ICF recently recommended a similar improvement in Manitoba Hydro's modeling in Independent Review of Manitoba Hydro Export Power Sales and Associated Risks, September 11, 2009, page 109.

[9]See, for example, Hydro-Electric Practice, H.A.E.C. von Schon, Chapter 5, J.B. Lippincott, 1908.

flows must always follow the historical record. In addition, the modeling problems have understated the downside during drought periods.

9. The 2009/2010 forecasted reservoir operations are not conservative enough

The New York risk consultant draws upon the analyses above to warn CEO Brennan that current operations will remain risky until the construction of Conawapa in 2022. Moreover, the proposed operational levels will not provide protection against a 2003/2004 drought.