The Appleton Wetland;
Its Decline, Cause and Recommended Action

Appendix R: Reach 18 Power Production

Report prepared by

Appleton Wetland Research Group
of the
Mississippi Valley Field Naturalists

Research Group Members:

Cliff Bennett, Chair
Joachim Moenig
Al Seaman
Mike O'Malley
Howard Robinson

March 20, 2015

Appendix R: Reach 18 Power Production

1 Introduction

The original report, *The Appleton Wetland; Its Decline, Cause and Recommended Action* dated August 11, 2014, included *Section 7.2.1 The Impact on Upstream Power Generation*. This section indicated that while the use of flashboards at the Enerdu Generator Station (GS) would be beneficial to Enerdu, it would probably reduce power output at the Appleton GS. The publication deadline for the original report precluded a rigorous quantitative analysis of this issue.

This Appendix documents subsequent work to build a mathematical model that would yield accurate estimates of power production at both of the Enerdu GS and the Appleton GS when the current flashboards are in place at Enerdu, and when they are not installed. Supplementing the Appendix is a complete working set of all of the MS/Excel spreadsheets and data used to implement the model.

2 Overview of the Model Approach

The energy produced by the Enerdu GS and Appleton GS can be calculated knowing the net head at each station, the water flow used (the lesser of available stream flow, or the upper limit of turbine flow through), and the overall efficiency of each station. Detailed historical data on daily stream flow, averaged over 95 years of flow records is available from Environment Canada. The Appleton Wetland Research Group (AWRG) has also made measurements of river level at a number of places along the river versus river flow rate, with and without flashboards in place at Enerdu. Much of this has already been detailed in the original report, *The Appleton Wetland; Its Decline, Cause and Recommended Action.* In principle, that data can be used to derive equations for headpond and tailrace water levels for every point on the average daily stream flow record and ultimately to compute the GS power output for every such point. The sections that follow detail the steps necessary to convert this principle into a working model.

3 Time Sampling Intervals

Calculation of the annual power output (in megawatt-hours) of a hydro GS is complicated by the fact that there are wide variations in the operating power level (megawatts) of the GS throughout a year. A practical approach is to divide the year into smaller segments that have a more or less stable power level that can be estimated or measured, and to compute the power output for each segment. The annual output is then the sum of the outputs of all segments.

The operating power level for a hydro GS is largely dependent on the flow rate of the associated river, and since the daily average flow rate is available, building the model with 365 segments (one for each day of the year) would be a practical limit for minimum segment size. Realistically, that would result in a large model that would be too laborious to build and manage. To simplify the analysis the year was divided into 38 segments or time blocks, with each segment representing a block of between 8 and 11 successive days. The shorter blocks were assigned to periods when flow rate was changing more rapidly, and the longer intervals for periods of more stable flow. Using the 38 block model was more manageable than using a model with 365 days, and should not significantly affect the accuracy of the end results.

4 Mean Annual Flow Data

From the Environment Canada website (http://wateroffice.ec.gc.ca) a summary of mean daily flow as recorded at Appleton for the 95 year period from 1918 to 2012 was downloaded.

A graphic display of the mean flow record is saved in the file: *AppletonStatsMean95Yr.png*.

The numeric data is saved in the file: *AppletonStatsMean95Yr.doc.*

4.1 Appleton Flow Station Daily Data

For ready reference, the graphic display of the Appleton mean flow record is reproduced below.

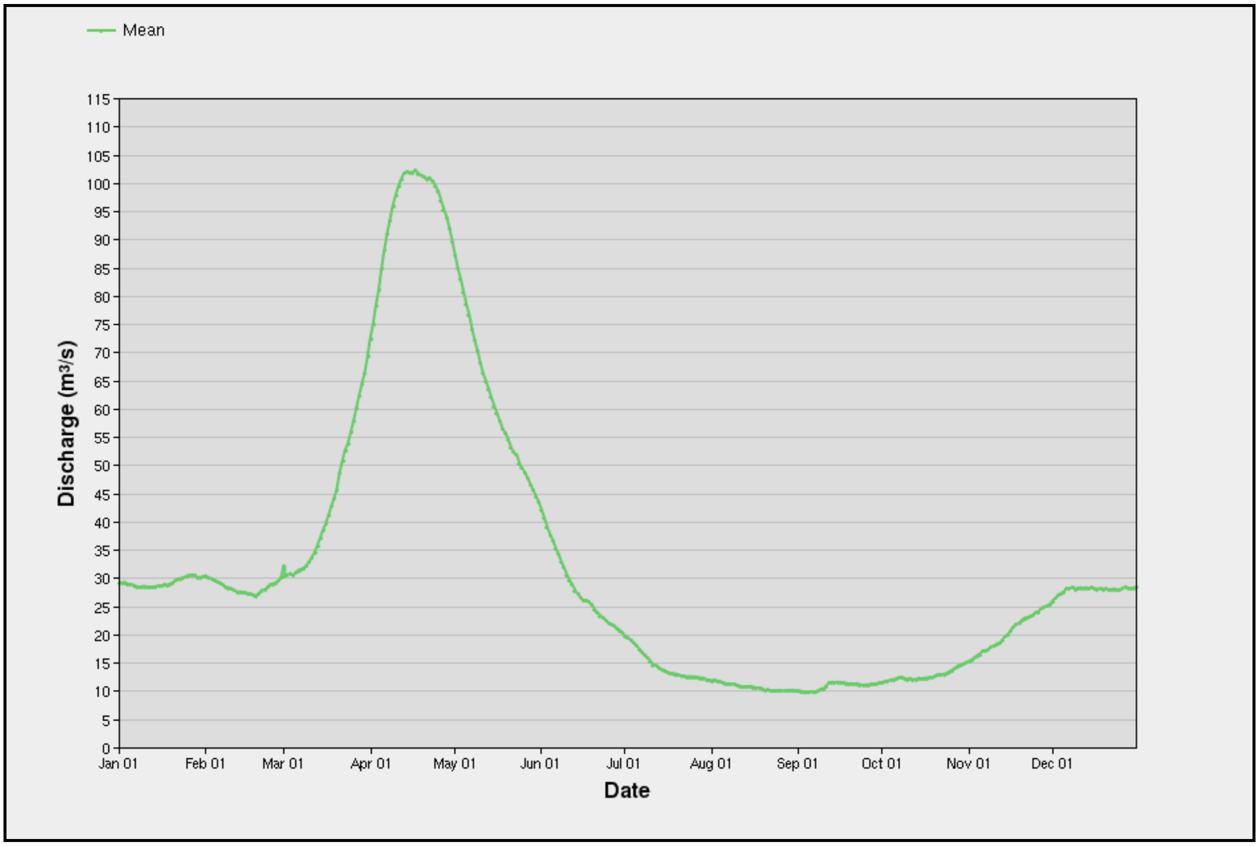

Figure 1 Mean daily flow, Mississippi River at Appleton (02KF006), 1918 to 2012

Also for reference, the numeric mean daily flow in tabular form is reproduced below.

Table 1 Daily Discharge Statistics Data for MISSISSIPPI RIVER AT APPLETON (02KF006)

This table provides mean daily values for each day over the entire record (1918 to 2012).

Day	Statistic	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	MEAN (m^3/s)	29.4	30.2	30.3	72.6	87.4	42.2	19.2	11.7	9.9	11.3	15.2	25.9
2	MEAN (m^3/s)	29.3	29.9	30.4	75.1	85.1	40.7	18.9	11.8	9.85	11.6	15.5	26.5
3	MEAN (m^3/s)	29.4	29.7	30.7	78.4	83.2	39.2	18.6	11.6	9.68	11.7	15.9	26.9
4	MEAN (m^3/s)	29.1	29.3	30.4	81.1	81.1	37.9	18.1	11.5	9.67	11.9	16.3	27.2
5	MEAN (m^3/s)	29.0	29.1	30.8	84.9	78.9	36.8	17.6	11.3	9.76	12.0	16.5	27.4
6	MEAN (m^3/s)	28.9	28.8	31.3	88.3	77.1	35.5	17.1	11.2	9.79	12.1	17.1	28.1
7	MEAN (m^3/s)	28.7	28.7	31.5	91.2	74.5	34.4	16.4	11.1	9.71	12.3	17.0	28.1
8	MEAN (m^3/s)	28.5	28.1	31.7	93.6	72.4	33.0	16.0	11.1	9.97	12.3	17.3	28.2
9	MEAN (m^3/s)	28.6	28.1	32.3	96.2	70.6	31.9	15.5	11.1	10.3	12.2	17.7	28.0
10	MEAN (m^3/s)	28.7	27.9	32.8	98.0	68.5	30.7	14.9	10.8	10.4	12.0	17.9	28.1
11	MEAN (m^3/s)	28.5	27.6	33.7	99.7	66.6	29.7	14.3	10.8	10.8	12.2	18.2	28.2
12	MEAN (m^3/s)	28.5	27.4	34.6	101	65.2	28.8	14.1	10.6	11.3	12.0	18.4	28.1
13	MEAN (m^3/s)	28.5	27.3	35.7	102	63.8	27.7	13.8	10.6	11.5	12.0	18.9	28.2
14	MEAN (m^3/s)	28.5	27.2	37.0	102	62.3	27.1	13.4	10.7	11.4	12.2	19.6	28.0
15	MEAN (m^3/s)	28.6	27.2	38.4	102	60.8	26.3	13.3	10.7	11.5	12.1	19.9	28.3
16	MEAN (m^3/s)	28.6	27.0	39.5	102	59.5	25.8	13.1	10.6	11.4	12.2	20.6	28.0
17	MEAN (m^3/s)	28.7	27.0	41.0	102	58.1	25.8	12.9	10.4	11.3	12.3	21.3	28.0
18	MEAN (m^3/s)	28.7	26.7	42.6	102	56.7	25.5	12.8	10.5	11.3	12.4	21.6	28.1
19	MEAN (m^3/s)	28.8	26.7	44.1	101	56.1	25.0	12.6	10.4	11.2	12.4	22.0	28.0
20	MEAN (m^3/s)	29.0	27.2	45.7	101	54.9	24.1	12.5	10.1	11.2	12.6	22.5	28.0
21	MEAN (m^3/s)	29.5	27.7	48.6	101	53.4	23.6	12.4	10.2	11.1	12.9	22.8	27.8
22	MEAN (m^3/s)	29.6	27.8	50.8	101	52.6	23.0	12.3	9.94	11.2	12.8	22.9	27.9
23	MEAN (m^3/s)	29.8	28.2	52.8	101	52.1	22.5	12.2	9.96	11.0	12.9	23.2	28.0
24	MEAN (m^3/s)	29.9	28.8	54.0	99.6	50.6	22.2	12.3	9.94	10.9	13.1	23.4	27.8
25	MEAN (m^3/s)	30.2	28.9	56.0	98.6	49.7	21.7	12.2	10.1	10.9	13.4	23.8	27.8
26	MEAN (m^3/s)	30.3	29.0	58.0	97.1	48.9	21.3	12.3	9.98	11.0	13.7	24.0	28.1
27	MEAN (m^3/s)	30.3	29.5	60.3	95.5	47.9	21.1	12.2	9.9	11.1	14.0	24.6	28.4
28	MEAN (m^3/s)	30.4	29.9	62.5	94.1	46.8	20.6	12.1	10.0	11.1	14.5	24.8	28.2
29	MEAN (m^3/s)	30.0	32.2	64.6	92.1	45.8	20.2	12.1	10.1	11.1	14.5	25.0	28.1
30	MEAN (m^3/s)	30.0	-	66.6	89.8	44.7	19.9	11.9	10.1	11.4	14.7	25.3	28.2
31	MEAN (m^3/s)	30.1	-	69.4	-	43.6	-	11.7	9.93	-	15.0	-	28.4

4.2 Time Block Flow Data

The spreadsheet *AppletonStatsMean95Yr.xls* was used to convert the above daily data into the format of mean flow data for the 38 time blocks used in the analysis. Several validity checks were included to ensure that no errors were made in this editing process. The table below shows the resulting time blocks and average flow rate in each block:

Table 2 Time Block allocation with associated average flow rate

Block No.	Start Date	Days	Av Flow cms	Block No.	Start Date	Days	Av Flow cms	Block No.	Start Date	Days	Av Flow cms
1	Jan 01	10	28.960	14	Apr 28	8	86.463	27	Aug 29	11	9.860
2	Jan 11	10	28.640	15	May 06	8	69.838	28	Sep 09	11	11.127
3	Jan 21	10	30.000	16	May 14	9	57.156	29	Sep 20	11	11.091
4	Jan 31	9	29.322	17	May 23	9	47.789	30	Oct 01	10	11.940
5	Feb 09	9	27.411	18	Jun 01	9	36.844	31	Oct 11	10	12.240
6	Feb 18	9	27.889	19	Jun 10	9	27.489	32	Oct 21	10	13.650
7	Feb 27	9	30.533	20	Jun 19	9	22.722	33	Oct 31	10	16.350
8	Mar 08	9	35.078	21	Jun 28	9	18.911	34	Nov 10	10	19.840
9	Mar 17	9	48.400	22	Jul 07	10	14.480	35	Nov 20	10	23.700
10	Mar 26	9	67.500	23	Jul 17	10	12.450	36	Nov 30	10	27.160
11	Apr 04	8	91.625	24	Jul 27	11	11.736	37	Dec 10	11	28.091
12	Apr 12	8	101.75	25	Aug 07	11	10.773	38	Dec 21	11	28.064
13	Apr 20	8	99.350	26	Aug 18	11	10.093				

5 Flow vs. Level Regimes

In order to develop a model relating levels at the locations of interest versus the flow rate at given sample times, it is necessary to understand what is happening that will in any way alter the flow vs level relationship. There are four regimes that need to be modeled separately. These are discussed below.

5.1 Regime 1 – No Enerdu Flashboards

This is the base state of the river, it provides the lowest possible water levels, and the prior AWRG measurements yield equations for this regime relating water level to river flow. The entire one year period of the "No Flashboards" model is governed by these equations. For the "Flashboards In" model, there is a no flashboards period for part of the year, and the same equations apply to this segment. This is the period immediately after the spring flood, when the prior year's flashboards have all been broken off, and extends up to the time when new flashboards are installed. This includes model block 13 through 19 (20 Apr to Jun 18) based on observation over several years of flashboards breaking and being replaced, with the principles applied to the historical average river flow. That is, all flashboards are broken after the spring flood peak approaches 100 cms, and flashboards are replaced as flow rate diminishes below 25 cms.

5.2 Regime 2 – Enerdu Flashboards Installed and Flow Exceeding 17 cms

There are three periods during the year when this condition occurs:

- From the beginning of the year through to the beginning of Regime 4 – for model blocks 1 through 8 (Jan 1 to Mar 16).
- From the point of replacing the flashboards to the beginning of Regime 3 – for model blocks 20 and 21 (Jun 19 to Jul 6).
- From the end of Regime 3 to the end of the year – for model blocks 34 through 38 (Nov 10 to Dec 31).

5.3 Regime 3 – Enerdu Flashboards Installed and Flow Less Than 17 cms

This is the period during the summer and early fall when Reach 18 in-flow is less than maximum out-flow (maximum generator demand of 14 cms plus total 3 cms flow of flashboard leakage plus Thoburn Mill bypass flow). Water levels are set by controlling the water demand of the Enerdu GS; reduced demand raises the water level to nearly the top of the flashboards, then increased demand drops the level to around 117.5 masl, and the cycle repeats. The records clearly show continuous cycling of the water level at Almonte within the range of 117.5 to 117.7 masl during this period. The river is also very flat during this period and the level in the wetland (and at the Appleton tailrace) is identical to that in Almonte. For this period a mean value of 117.6 masl has been used for both locations. This period in the model extends from block 22 to block 33 (Jul 7 to Nov 9).

5.4 Regime 4 – The Transition Stage

This is the period leading up to the spring flood when the flashboards start breaking under the pressure of rising water levels, and continues until they are all broken. It starts when the river flow increases to 40 cms and the level in Almonte reaches 118.0 masl, and continues until the all flashboards are gone around a flow of 100 cms. Throughout this period average levels in Almonte stay close to 118.0 masl – as the flow increases the level rises a bit above 118.0 masl, then more flashboards break bringing the level just below 118.0 masl. This cycle repeats as flood flow increases until eventually all flashboards are broken. The Enerdu headpond level during this regime averages 118.0 masl. Levels in Appleton below the dam on the other hand make a continuous change over this period, from the level with 40 cms flow with all Enerdu flashboards in place, to a final level for 100 cms flow with no flashboards at Almonte. That is 118.02 masl at the start to 118.36 masl at the end of this period. For the model, this Transition Stage covers blocks 9 through 12 (Mar 17 to Apr 19). At the end of this period, with the flashboards all broken, flow reverts to Regime 1.

6 GS Efficiency

The overall efficiency of a hydro GS has a direct effect on its ultimate power output. The efficiency is reduced by factors such as hydraulic flow losses, turbine losses, friction and windage losses in the rotating machinery, and electrical losses in the generators and transformers. The AWRG does not have any of this information for the Enerdu and Appleton stations. The best information available suggests that for small hydro installations typical efficiencies are in the range of 70 to 80%. The efficiency value of 75% was used in the model for both stations. If better data becomes available this parameter is easily changed in the model and will enable more exact results. Since it is a constant factor in both cases, any error in the efficiency estimate will have only a secondary effect on the power comparison between the *No Enerdu Flashboards* case and the *Enerdu Flashboards Installed* case.

7 Flow Rate versus Water Level Data

As noted in Section 2, a fundamental requirement of the model is establishing the exact relationship between the published mean flow rate and corresponding actual water levels at the Enerdu GS and the Appleton GS. The AWRG is not aware of any prior published data that would satisfy this requirement. However, the AWRG has made measurements in 2013 and 2014 of river level at a number of places along the river versus river flow rate, with and without flashboards in place at Enerdu. Most of this data has already been detailed in the original report, *The Appleton Wetland; Its Decline, Cause and Recommended Action.*

7.1 2013 Data Set

The data recorded in the summer of 2013 as reported in *Appendix H: Coordinated Level Measurements*, included Appleton Stream Gauge data along with simultaneous water level measurements at:

- the staff gauge under the Bridge Street bridge in Almonte,
- a flat rock shelf in the river bed at 222 Spring Street in Almonte, and
- a benchmark at the rear of 521 River Road in Appleton.

Although not used in *Appendix H*, the original measurements also included a water level measurement at the mid-span of the RiverWalk bridge adjacent to the Almonte Old Town Hall parking lot.

This series of measurements recorded the changes in flow and water level during the summer and fall period, and provided the data for deriving the relationship between flow rate and water levels without and with Enerdu flashboards.

7.2 2014 Data Set

The data recorded in the summer of 2014, as reported in *Appendix P: Further Flow and Level Measurements,* included Appleton Stream Gauge data along with simultaneous water level measurements at:

- the mid-span of the RiverWalk bridge adjacent to the Almonte Old Town Hall,
- the staff gauge under the Bridge Street bridge in Almonte,
- a flat rock shelf in the river bed at 222 Spring Street in Almonte, and
- a benchmark at the rear of 521 River Road in Appleton.

Although not used in *Appendix P*, the original measurements also included a water level measurement behind the Almonte Post Office directly across from the Enerdu tailrace.

This series of measurements recorded the changes in flow and water level from the spring highwater period to the point where Enerdu flashboards were reinstalled, and provided the basis for deriving the relationship between flow rate and water levels without Enerdu flashboards.

7.3 Analysis of Flow and Level Data Sets

The details of this analysis are contained in the MS/Excel spreadsheet *CompLvl-2013-14.xls* that accompanies this Appendix. The initial table in this spreadsheet, with the heading *With NO Flashboards*, is a replication of the spreadsheet *CompLvl-2013.xls* that was the foundation for Appendix P. Columns A and B record the Date and Time of each observation.

Columns C through H contain the water levels recorded at six stations along the river with the values converted to metres above sea level. The respective column headings identify the location as:

- Gauge – a direct reading in masl from the staff gauge on the Bridge Street bridge pier.
- Rail-A – the water level in masl at the mid-span of the RiverWalk bridge adjacent to the Almonte Old Town Hall computed from the railing reference level and the recorded distance in cm to water surface from the railing in column K.
- Rail-B – the water level in masl at the west end of the RiverWalk bridge adjacent to the Barley Mow Pub computed from the railing reference level and the recorded distance in cm to water surface from the railing in column L.
- PO-Lvl – the water level in masl at the waterfront railing behind the Post Office computed from the railing reference level and the recorded distance in cm to water surface from the railing in column M.
- SpringSt – the water level in masl at 222 Spring Street in Almonte computed from the riverbed rock shelf reference level and the recorded distance in inches to water surface from the rock shelf in column N.
- Appleton – the water level in masl at 525 River Road in Appleton from the benchmark reference level and the recorded back sight to the benchmark (Appl-BS in mm) in column O, the fore sight to the water surface (Appl-FS in mm) in column P, and the level rod extension (Appl-Add in mm) in column Q.

The remaining columns in the first table are Column I recording the river flow in cms as reported by the Appleton Stream Gauge, and Column J recording flashboard status (in the first table all values are None).

The second table in this spreadsheet, with the heading *Transition Stage – flashboards partly broken*, tabulates any data recorded in 2013 or 2014 during the period when high water level was breaking flashboards. The table columns have the same meaning as those described above for the first table. Many columns are blank since the complete range of data items was not recorded during this period. It is noted that no Appleton data was recorded in 2013, and there is only one Appleton observation in 2014. There were also icing problems in 2013 and many of these values are based on best estimates as noted in column L. The flashboard status for all entries in this table is shown as Trans.

The third table in this spreadsheet, with the heading *With ALL Flashboards Installed*, tabulates any data recorded in 2013 or 2014 during periods when all Enerdu flashboards were in place. The data for 2013 is extracted from the data tabulated with *Appendix H* for those entries with all flashboards in place, and entered directly to columns A through D and G through J. The Rail-B and PO-Lvl data was not recorded in 2013 and that section of the third table is blank as a result. The 2014 data for this table was recorded in identical fashion to that in the first table, but for later dates after the installation of flashboards.

The fourth table in this spreadsheet, with the heading *Flow vs Level Model with No Flashboards - Regime 1*, copies and reorganizes data from the first table for the case of all Enerdu flashboards missing. Since there was no data available for flows less than 26.10 cms, some estimated values were added for the low end of the flow range. In the case of Rail-A with generators operational the level should drop to the top of the weir (117.20 masl) for a flow of 15 cms or less. For the Appleton data, with zero flow the level should be the same as the top of the weir – 117.20 masl.

The Flow, Rail-A and Appleton data was then used to generate a chart showing the variation of Enerdu headpond level and Appleton tailrace level versus flow rate. In this case, the Rail-A data is the closest level measurement to the Enerdu intake and represents the best estimate of headpond level for power generation calculation. Best fit trendlines were added to the chart, and the equations for the trendlines were also displayed on the chart. See Figure 2 below.

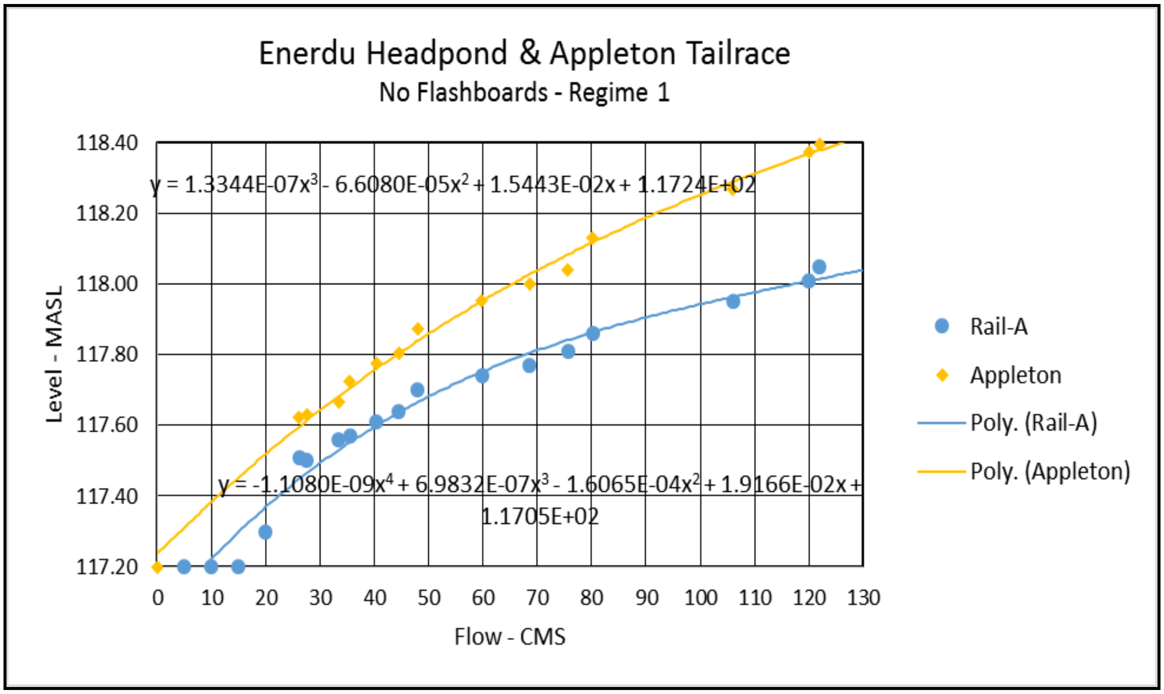

Figure 2 Chart of Enerdu headpond and Appleton tailrace levels for Regime 1

The fourth table also includes data for PO-Lvl which is a good estimate for Enerdu tailrace level. Since this level is primarily driven by river flow rate and is not particularly affected by the presence or absence of flashboards it can be used to derive a chart showing the variation of Enerdu tailrace level versus flow rate for all Regimes. The best fit trendline has been derived and the trendline equation is displayed on the chart. See Figure 3 below.

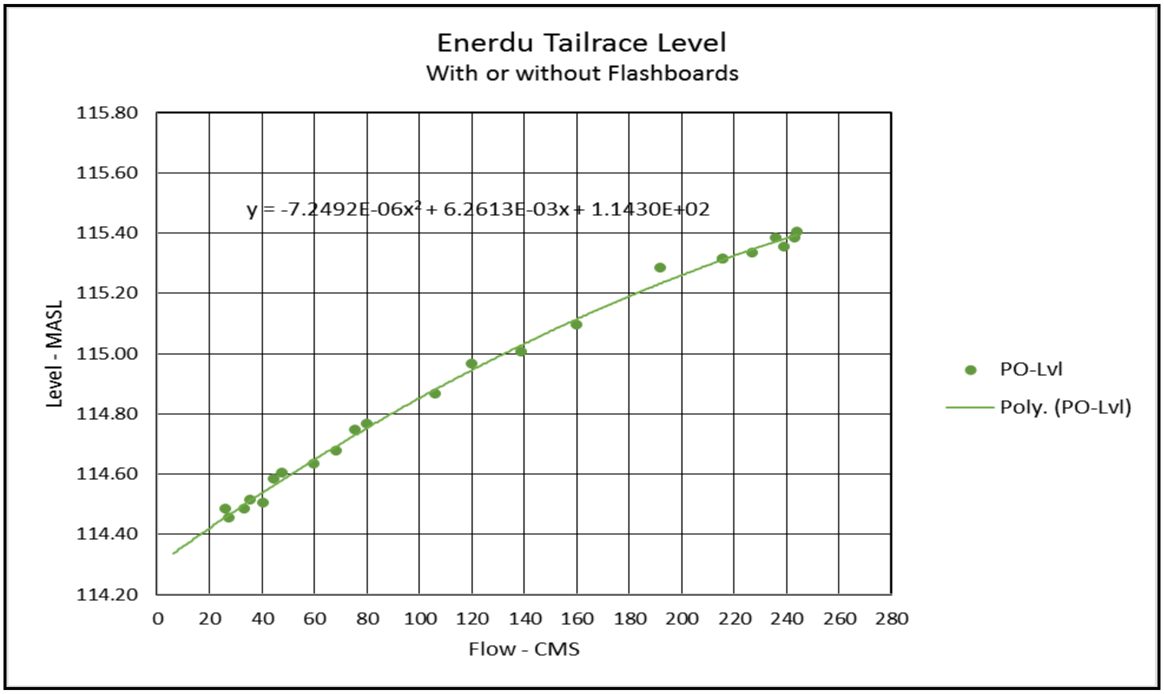

Figure 3 Chart of Enerdu tailrace levels for all Regimes

The fifth table in this spreadsheet, with the heading *Flow vs Level Model with Flashboards and Flow Over 17.0 cms – Regime 2*, copies and reorganizes data from the third table for the case of all Enerdu flashboards installed. The data of interest is Rail-A and Appleton. Any point with a flow of 17 cms or less was deleted from the table and marked Null in column J. This data was used to generate a chart showing the variation of Enerdu headpond level and Appleton tailrace level versus flow rate for Regime 2. Some plotted points had excessive scatter, presumably because levels had not reached equilibrium, the result of greater storage with flashboards in place and a resulting longer settling time. Some of these were also deleted and marked Null. The final chart with trendlines and trendline equations is shown below as Figure 4.

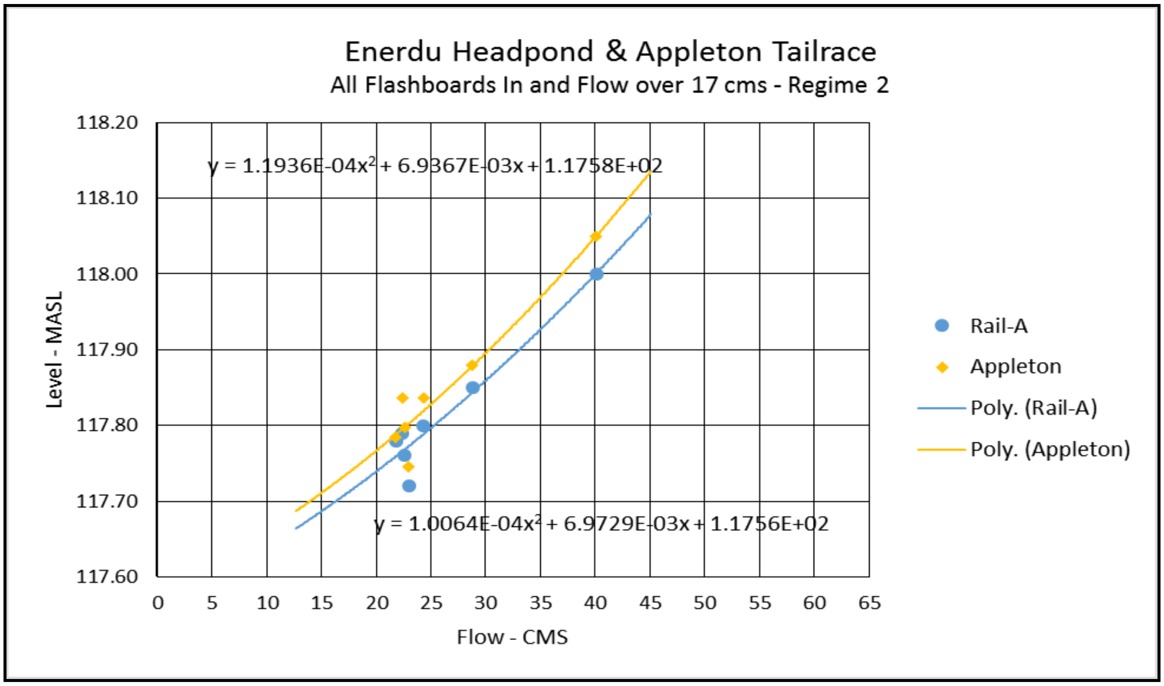

Figure 4 Chart of Enerdu headpond and Appleton tailrace levels for Regime 2

The sixth table in this spreadsheet, with the heading *Flow vs Level Model for Transition Stage - Regime 4*, copies and reorganizes data from the second table for the Transition Stage - flashboards partly broken. The data of interest is Rail-A and Appleton. Unfortunately, during the period of interests there were serious icing problems at the staff gauge and under the RiverWalk bridge with the result that readings were best estimates. As plotted on a chart, it was clear that they were too inaccurate to be of value, consequently the readings from Jan 30 through Mar 9 were deleted from the sixth table and marked Null in column I. On Jan 18 icing prevented any reading at Appleton, so that entry has been estimated on the basis that at the start of the transition stage, with few flashboards broken, levels would have been comparable to any record with all flashboards in and a similar flow rate to 38.7 cms. In the third table, the record for Aug 26, 2014, with a flow of 40.1 cms, shows Rail-A at 118.00 masl and Appleton at 118.05 masl, a differential of 0.05 m. Adding that amount to the sixth table entry for Rail-A on Jan 18, 2013 (117.97 masl) provides the Appleton estimate for that date of 118.02 masl. The remaining data points are quite sparse, but they to provide plausible end points for the period of interest. The final chart with trendlines and trendline equations is shown below as Figure 5.

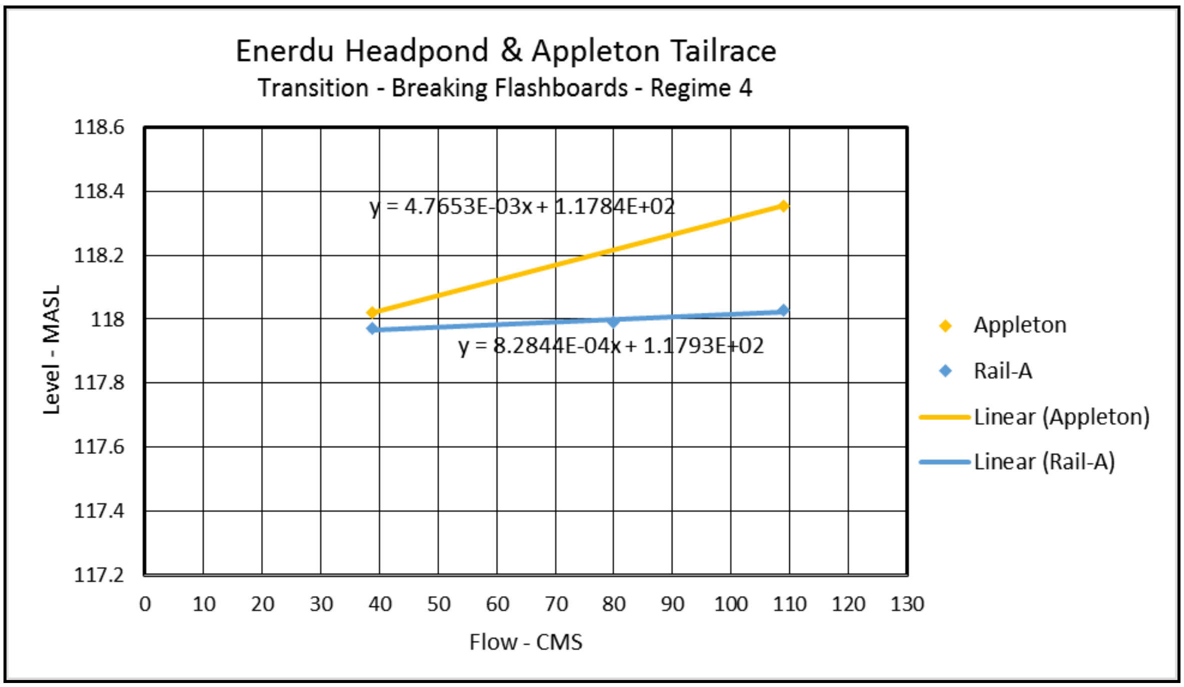

Figure 5 Chart of Enerdu headpond and Appleton tailrace levels for Regime 4

.

The seventh table in this spreadsheet, with the heading *Appleton Headpond Estimate*, provides a basis for a plausible estimate of the flow versus headpond level. What we know from the MRWMP is that the Appleton weir height is 123.00 masl, flashboards of 0.30 m are added to the weir in the summer, and that currently their Permit To Take Water requires them to “maintain a measurable flow over the spillway during ice free periods”, that would probably amount to 2 cm, and the total of 123.32 masl represents the normal minimum headpond level. Whenever river flow is below the turbine design maximum of 35 cms the headpond level will be held to a constant level of 123.32 masl by controlling the flow rate to the turbine. Under peak flood conditions the MRWMP indicates that “waters levels will be kept at or below 123.80 masl by the use of the mechanical gate or stop logs”. For an average spring high water a level slightly below that may be appropriate, hence the estimated maximum is 123.70 masl at a flow of 110.0 cms. With those values as tabulated in the seventh table, the chart in Figure 6 was plotted along with the trendline and trendline equation.

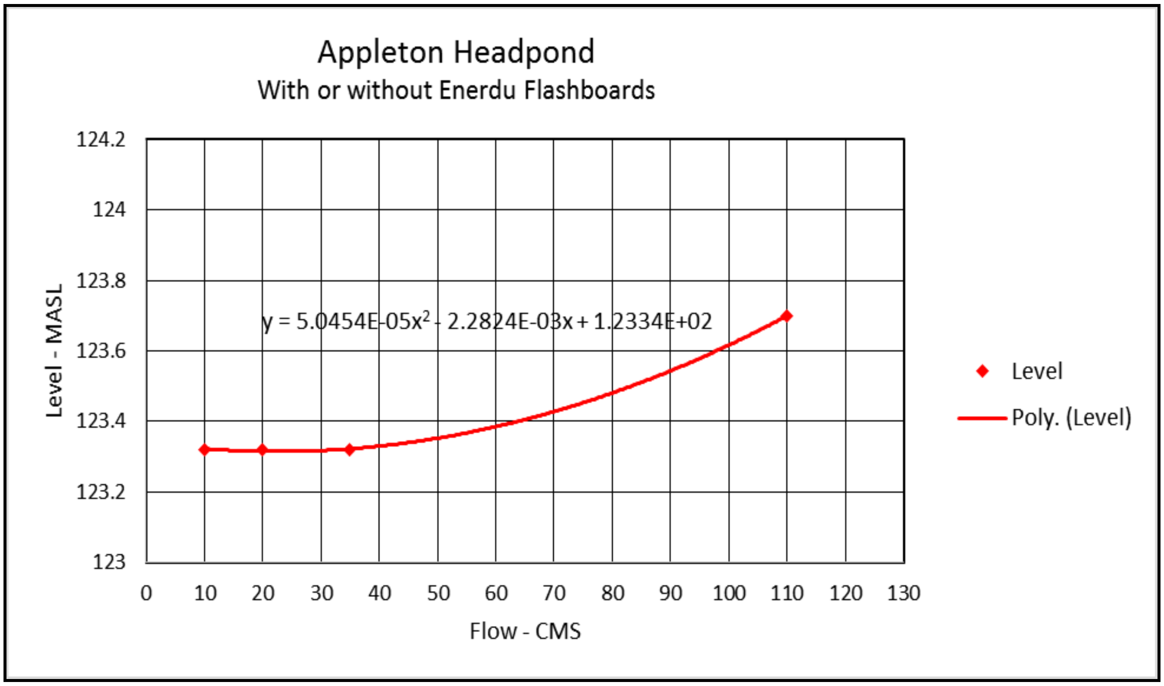

Figure 6 Chart of Appleton headpond levels for all Regimes

.

As noted in Section 5.3, for Regime 3 with flashboards installed and flow less than 17 cms, the records indicate that water levels for the Enerdu headpond and Appleton tailrace fluctuate continuously between 117.50 and 117.70 masl in response to varying water demand by the Enerdu turbines. This case does not need a plot and trendline analysis. The mean value of 117.60 masl for both locations is the simple solution for Regime 3.

7.4 Flow Rate vs. Level Equations

The sections below tabulate the equations relating river flow rate to headpond and tailrace levels at the Enerdu GS and the Appleton GS in an ordered fashion for the flow regimes applicable to each case.

7.4.1 Enerdu Headpond Levels

- *Regime 1 – No Flashboards:*

  Level = -0.000000001108(flow)^4+ 0.00000069832(flow)^3 - 0.00016065(flow)^2 + 0.019166(flow) + 117.05

- *Regime 2 – With flashboards and flow exceeding 17 cms:*

  Level = + 0.00010064(flow)^2 + 0.0069729(flow) + 117.56

- *Regime 3 – With flashboards and flow less than 17 cms:*

  Level = 117.60

- *Regime 4 – With flashboards during the transition stage:*

  Level = +0.00082844(flow) + 117.93

Note that Regime 1 occurs throughout the *No Flashboards* case, and also in the *Flashboards Installed* case during the time blocks from the point where the spring flood has broken all flashboards (block 13) until they are reinstalled when the flow drops to approximately 25 cms (block 19).

7.4.2 Enerdu Tailrace Levels

- *For all flow regimes, and with or without flashboards:*

  Level = - 0.0000072492(flow)^2 + 0.0062613(flow) + 114.30

Note that the Enerdu tailrace level is controlled primarily by the flow rate of the river. Any variation that may be introduced by flow regime or flashboard changes was too small to be measured.

7.4.3 Appleton Headpond Levels

- *For all flow regimes, and with or without Enerdu flashboards:*

  Level = + 0.000050454(flow)^2 - 0.0022824(flow) + 123.34

Note that actual level measurements were not available, and estimated values were used. Since changes in Enerdu flashboards and flow regimes will not have any effect on Appleton headpond levels, this approximation will not affect the accuracy of the estimated changes in power output due to the Enerdu flashboards.

7.4.4 Appleton Tailrace Levels

- *Regime 1 – No Enerdu flashboards:*

  Level = + 0.00000013344(flow)^3 - 0.000066080(flow)^2 + 0.015443(flow) + 117.24

- *Regime 2 – With Enerdu flashboards and flow exceeding 17 cms:*

  Level = + 0.00011936(flow)^2 + 0.0069367(flow) + 117.58

- *Regime 3 – With Enerdu flashboards and flow less than 17 cms:*

  Level = 117.60

- *Regime 4 – With Enerdu flashboards during transition stage:*

  Level = + 0.0047653(flow) + 117.84

Note that Regime 1 occurs throughout the *No Flashboards* case, and also in the *Flashboards Installed* case during the time blocks from the point where the spring flood has broken all flashboards (block 13) until they are reinstalled when the flow drops to approximately 25 cms (block 19).

8 Water Flow to Turbines

For a run of river GS the flow through the turbines, or water demand, is subject to some practical limitations. Regardless of how much the river flow increases, the maximum water that can be used is the turbine design maximum. In addition, to the turbine flow, the river flow may go in part to a bypass flow: any flow over the weir or to adjacent water using operations. There is a balance at all times that is defined by:

Turbine Flow = River Flow - Bypass Flow

The power generation model takes into account the turbine flow under various flow conditions.

8.1 Enerdu GS Water Demand Rules

For the Enerdu GS, the maximum turbine design rating is 14 cms. When flashboards are present the minimum bypass flow is estimated to be around 3 cms, the sum of flashboard leakage (1 cms) plus weir leaks and Thoburn Mill bypass (2 cms). When flashboards are not present there is no flashboard leakage and the minimum bypass flow is 2 cms. This is based on consistent observations that 17 cms seems to be a break point – with flashboards in place and generators operating, a flow of 17 cms or greater will provide a water level at the top of the flashboards or higher, and a flow of less than 17 cms will give water levels below the top of the flashboards. The applicable rules are:

- For flashboards installed and for
  - River Flow less than 17 cms, Turbine Flow = River Flow - 3, or for
  - River Flow exceeding 17 cms, Turbine Flow = Turbine Rating = 14
- With no flashboards installed and for
  - River Flow less than 16 cms, Turbine Flow = River Flow - 2, or for
  - River Flow exceeding 16 cms, Turbine Flow = Turbine Rating = 14

8.2 Appleton GS Water Demand Rules

For the Appleton GS, the maximum turbine rating is 35 cms. There is a clause in their *Permit To Take Water* that requires a small flow over their weir at all times. This bypass flow is estimated to be around 1 cms. The presence or absence of Enerdu flashboards does not enter into the demand rules for the Appleton GS, and a simple rule set results:

- River Flow less than 36 cms, Turbine Flow = River Flow - 1, or
- River Flow exceeding 36 cms, Turbine Flow = Turbine Rating = 35

9 Hydro Power Generation Equations

A hydro GS converts the energy in water falling through a defined head under the influence of gravity into electrical energy. The basic equation is well established, and is adapted below to define energy production for the multi-day time block model.

9.1 Basic power level equation

$$P = e\ d\ Q\ g\ h$$

Where:

P is power in watts
e is plant efficiency as decimal fraction of 1 (0.70 to 0.80 for small plants typical)
d is density of water in Kg per M^3 (1000 Kg per M^3)
Q is flow of water in cms (M^3/sec)
g is acceleration of gravity (9.81 M/sec^2)
h is net plant head in metres (headpond level - tailrace level)

9.2 Energy production per day equation

$$E_d = P \times 24 \times 10^{-6}$$

Where:

E_d is total energy per day in Megawatt-Hours (MWHr)
P is power in watts as defined previously
24 is hours per day
10^{-6} is conversion to MW

9.3 Energy production equation for multi-day time block model

$$E_b = e\,(H_{pond} - T_{race})\,Q\,b \times 0.23544$$

Where:

E_b is total energy per block in Megawatt-Hours (MWHr)
e is plant efficiency as decimal fraction of 1
H_{pond} is headpond level in masl (metres above sea level)
T_{race} is tailrace level in masl
Q is block average flow through turbines in cms
b is number of days in the block
0.23544 is a constant combining ($1000 \times 9.81 \times 24 \times 10^{-6}$)

10 Block Energy Production Model

The energy production model is implemented in the accompanying MS/Excel spreadsheet, *PowerComparisonRev01.xls*. There are two main tables in this spreadsheet, the *No Flashboards Case* and the *With Flashboards Case*. Except for using input data appropriate to the specific case, both tables are identical in organization. All tables are organized vertically with a row for each Time Block from 1 through 38 and a bottom Total row. The first group of four columns plus the final column show the basic information about each Time Block:

- the Time Block number,
- the Start Date of the Time Block,
- the number of days in the Time Block,
- the average river flow throughout the Time Block, and
- the Flow Regime that applies to the Time Block.

The next set of five columns applies to the Enerdu GS and shows the calculation of four input parameters, and the last column of the set provides the calculation of energy generation. This includes:

- Efficiency that is for now set at 0.75, a typical value for a small hydro plant. When and if better efficiency data becomes available these entries can be changed easily and the model will yield updated result.
- Headpond Level in masl that is calculated from the Average Flow using the Flow versus Level equation as appropriate for the Enerdu GS and the Flow Regime of the Time Block.
- Tailrace Level in masl that is calculated from the Average Flow using the Flow versus Level equation as appropriate for the Enerdu GS and the Flow Regime of the Time Block.
- Generator Water Flow in cms as derived from the Average Flow using the GS Water Demand Rules as previously defined.
- Energy Output in MWHr calculated using the previously defined equation for multi-day time blocks and the calculated entries from the previous four columns.

The next set of five columns applies to the Appleton GS, and is identical in function to the previous Enerdu set except that data relevant to Appleton is used in all cases.

These two tables provide a comprehensive set of power outputs for every Time Block through the year, for both Enerdu and Appleton, and with flashboards both installed and not present at Enerdu.

11 Energy Generation Comparison

The last step in the spreadsheet model *PowerComparisonRev01.xls* is the completion of the *Summary* table, and the generation of graphic charts, showing the changes in power output when flashboards are in place.

11.1 Summary Table

This table takes the power output data from the previous tables in the spread sheet; a) the *No Flashboards Case* for Enerdu and Appleton, and b) the *With Flashboards Case* for Enerdu and Appleton, and summarizes it in a form that shows the change resulting from the use of flashboards at Enerdu. There are four columns that identify each Time Block and the associated Flow Regime. The next group of three columns show the previously computed Enerdu block power output without Enerdu flashboards and with Enerdu flashboards, then the computed change resulting from the use of flashboards. The next group of three columns shows similar block data for the Appleton GS. The final group of three columns shows the computed total block power production for both Enerdu and Appleton without Enerdu flashboards, with Enerdu flashboards, and the change resulting from the use of flashboards. In all Change columns positive values indicate an increase of power output with use of Enerdu flashboards, and negative values indicate a loss of power output with use of Enerdu flashboards.

At the bottom of each Change column the block outputs are summed to show a total annual change of power production. The total annual change for Enerdu is an output increase of 160 MWHr. At the same time Appleton has an annual loss of 235 MWHr, and the net total power for Enerdu and Appleton has an annual loss of 75 MWHr.

For easy reference the *Summary* portion of the spreadsheet is tabulated below.

Table 3 Block Generation Change

Summary – Power Generation Changes with Enerdu Flashboards													
Block No.	**Start Date**	**Days**	**Flow Regime**	**Enerdu MWHr**			**Appleton MWHR**			**Net Total MWHr**			
				No FB	With FB	Change	No FB	With FB	Change	No FB	With FB	Change	
1	Jan 01	10	2	74.44	83.34	8.90	280.49	268.35	-12.14	354.93	351.68	-3.25	
2	Jan 11	10	2	74.40	83.28	8.89	277.46	265.48	-11.97	351.85	348.76	-3.09	
3	Jan 21	10	2	74.58	83.52	8.93	290.33	277.62	-12.70	364.91	361.14	-3.77	
4	Jan 31	9	2	67.04	75.06	8.02	255.52	244.42	-11.10	322.57	319.48	-3.08	
5	Feb 09	9	2	66.80	74.77	7.97	239.20	228.98	-10.22	306.00	303.75	-2.24	
6	Feb 18	9	2	66.86	74.84	7.98	243.29	232.86	-10.43	310.15	307.70	-2.45	
7	Feb 27	9	2	67.19	75.25	8.06	265.82	254.12	-11.70	333.01	329.37	-3.64	
8	Mar 08	9	2	67.69	76.04	8.35	304.14	289.84	-14.30	371.83	365.88	-5.95	
9	Mar 17	9	4	68.71	75.29	6.58	305.92	293.53	-12.40	374.63	368.82	-5.82	
10	Mar 26	9	4	69.28	73.34	4.06	300.00	292.25	-7.75	369.28	365.59	-3.69	
11	Apr 04	8	4	61.38	63.15	1.77	264.60	260.95	-3.65	325.98	324.10	-1.88	
12	Apr 12	8	4	61.15	62.34	1.20	265.13	262.30	-2.82	326.27	324.65	-1.63	
13	Apr 20	8	1	61.21	61.21	0.00	264.93	264.93	0.00	326.14	326.14	0.00	
14	Apr 28	8	1	61.48	61.48	0.00	264.63	264.63	0.00	326.11	326.11	0.00	
15	May 06	8	1	61.60	61.60	0.00	266.25	266.25	0.00	327.84	327.84	0.00	
16	May 14	9	1	69.08	69.08	0.00	302.74	302.74	0.00	371.82	371.82	0.00	
17	May 23	9	1	68.68	68.68	0.00	306.17	306.17	0.00	374.85	374.85	0.00	
18	Jun 01	9	1	67.86	67.86	0.00	311.40	311.40	0.00	379.26	379.26	0.00	
19	Jun 10	9	1	66.81	66.81	0.00	239.87	239.87	0.00	306.68	306.68	0.00	
20	Jun 19	9	2	66.12	74.13	8.01	198.70	190.38	-8.32	264.82	264.51	-0.31	
21	Jun 28	9	2	65.50	73.69	8.19	165.25	158.29	-6.96	230.75	231.98	1.23	
22	Jul 07	10	3	61.94	65.09	3.15	139.66	136.09	-3.57	201.60	201.18	-0.42	
23	Jul 17	10	3	52.09	53.78	1.69	119.23	115.64	-3.59	171.33	169.42	-1.90	
24	Jul 27	11	3	53.47	54.77	1.30	123.20	119.28	-3.91	176.67	174.05	-2.62	
25	Aug 07	11	3	48.28	48.82	0.54	112.42	108.61	-3.82	160.71	157.42	-3.28	
26	Aug 18	11	3	44.61	44.60	0.00	104.79	101.06	-3.72	149.39	145.67	-3.72	
27	Aug 29	11	3	43.34	43.16	-0.18	102.16	98.48	-3.68	145.51	141.64	-3.87	
28	Sep 09	11	3	50.19	51.01	0.81	116.39	112.53	-3.86	166.58	163.54	-3.04	
29	Sep 20	11	3	50.00	50.78	0.79	115.99	112.13	-3.85	165.99	162.92	-3.07	
30	Oct 01	10	3	49.61	50.93	1.32	114.07	110.50	-3.57	163.67	161.43	-2.25	
31	Oct 11	10	3	51.07	52.61	1.54	117.11	113.52	-3.59	168.18	166.13	-2.05	
32	Oct 21	10	3	57.93	60.48	2.55	131.33	127.73	-3.60	189.26	188.21	-1.05	
33	Oct 31	10	3	72.26	75.42	3.17	158.31	154.94	-3.38	230.57	230.36	-0.21	
34	Nov 10	10	2	72.95	81.99	9.04	192.72	184.63	-8.09	265.68	266.62	0.95	
35	Nov 20	10	2	73.64	82.51	8.87	230.22	220.57	-9.65	303.86	303.08	-0.78	
36	Nov 30	10	2	74.18	83.04	8.85	263.39	252.16	-11.23	337.57	335.20	-2.37	
37	Dec 10	11	2	81.75	91.51	9.76	299.47	286.61	-12.86	381.22	378.12	-3.10	
38	Dec 21	11	2	81.75	91.50	9.76	299.19	286.34	-12.85	380.93	377.85	-3.09	
	Total					159.85			-235.29			-75.44	

11.2 Generation Change Chart

The charting function of MS/Excel was used to plot graphs from the *Summary* table showing power output changes through the year for Enerdu, Appleton and Net Total versus Block Number. The charts include separate bar charts for each of Enerdu, Appleton and Net Total, and a line chart showing all three data sets on a combined chart. Note that the Y axis has positive values for increases in power output with use of Enerdu flashboards, and negative values for losses in power output with use of Enerdu flashboards. The visual presentations make it even more obvious than the tabulated data, that with flashboards Enerdu gains throughout the year, Appleton experiences a greater loss, and there is a net loss in total power production for both plants.

For easy reference, the line chart combining the three power output changes is shown below.

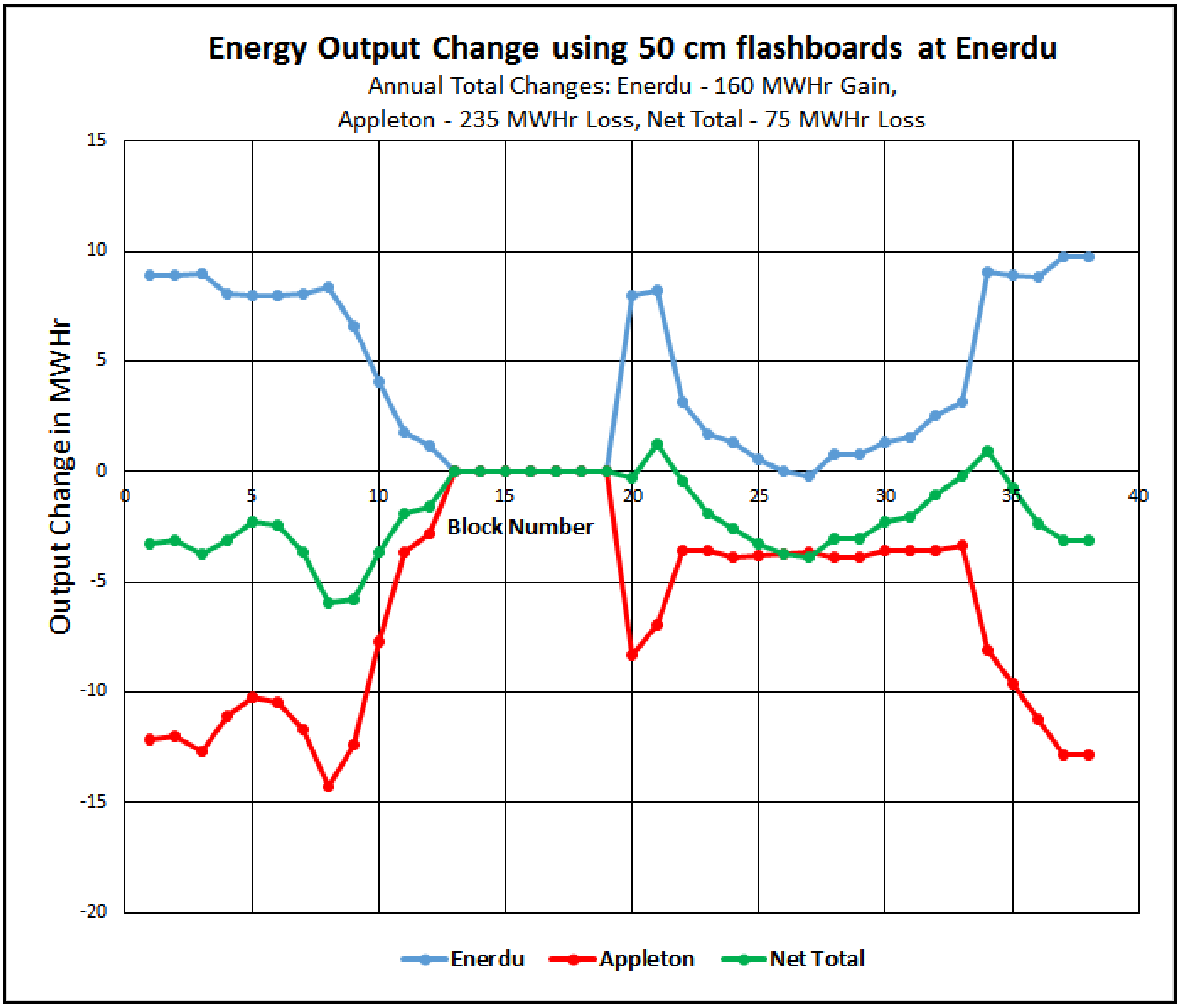

Figure 7 Block output change with use of Enerdu flashboards

The changes through the year are driven by seasonal flow changes, with consequent changes in Flow Regime, as follows:

- Block 1 through 8 (Jan 1 to Mar 16) – High winter flows and water levels over the flashboards (Regime 2).
- Block 9 through 12 (Mar 17 to Apr 19) – Spring flood period when flashboards are breaking and water levels are returning to the no flashboards state (Regime 4).
- Block 13 through 19 (Apr 20 to Jun 18) – All flashboards broken and flushed away and all results go to zero change (Regime 1).
- Block 20 and 21 (Jun 19 to Jul 6) – Flashboards reinstalled and flow rate is high enough to raise level above flashboards (+117.70 masl) (Regime 2).
- Block 22 through 33 (Jul 7 to Nov 9) – Low summer flow period involving intermittent operation and average level around 117.60 masl (Regime 3).
- Block 34 through 38 (Nov 10 to Dec 31) – Return to high winter flows and water levels over the flashboards (Regime 2).

12 Conclusion

The results of the Power Production Model clearly show that block by block, throughout the year, Enerdu receives an increase in power output through the use of the existing flashboards as permitted by the MRWMP. At the same time, the flashboards cause even larger losses in power output throughout the year at Appleton, and the net total output of both plants shows a loss throughout the year. The annual total power changes as a result of using flashboards at Enerdu show a gain for Enerdu of 160 MWHr, a loss for Appleton of 235 MWHr, and a loss in net total power for both plants of 75 MWHr. On a Reach 18 system basis the total power delivered to the Provincial grid can be maximized when there are no Enerdu flashboards in place throughout the year.

The results from the Model are for a year with *an average flow*. The flow profile for any actual individual year will not follow the average profile exactly, and there will be corresponding variations in the output for individual time blocks and for the total output for any particular year. It can be expected that any increases in flow over the average will further increase the Enerdu gains, and will also further increase the losses for Appleton and the net total output. A reduction in flow will reverse those outcomes. Although output variations are to be expected, the numbers forecast by the average Model do remain as constant indicators of what can be most probably expected.

The analysis as shown applies to the current Enerdu operation with manually installed flashboards. The question of exactly what will happen if the planned Enerdu upgrade proceeds, with controllable Obermeyer weirs, cannot be answered at this time since all of the operational parameters for that plant are not publicly available. The expectation is that Enerdu will get an even higher production gain if the variable weir is operated according to the current MRWMP terms. At the same time Appleton will probably see an increased loss of output and the net total output will also show a probable loss. The conflict of interests involved will clearly continue.