Performance Assessment Manual

Appendix 2.04 – Examples of Results from Hydrologic Analyses

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Introduction

Appendix 2.04 provides an example of results from the hydrological analyses for a three-unit hydro plant. This includes the hydrological background information about the plant site, the discussions of approaches and methods used for hydrology-based assessment, and results for the metrics of Long-Term Stream Power (LTSP), Long-Term Production Potential (LTPP), and Average Power Production (APP). These performance metrics enable benchmarking and trending of performance across many facilities in a variety of river system, power system, and water availability contexts.

Site Hydrological Characteristics

Rhodhiss hydropower plant is situated on the Catawba River with a contributing watershed of 697,600 acres. Stream flow data from the USGS stream gauge 02140991, located on a tributary (John's River) to the Catawba River, was used to identify the hydrological trends in this watershed area for the period from 2007 through 2011. Other stream gauges on the main river did not have the full record of data for this time period. For the purpose of identifying hydrological variation trends in the area as opposed to absolute values, using a stream gauge in the vicinity of the dam is considered as appropriate. The gauge flow variations are trended (shown as the blue curves in Figure 2.04-4 and Figure 2.04-5).

Long-Term Stream Power (LTSP) Analysis

The calculation of the annual and Long-Term Stream Power (LTSP) is to determine the power potential at the plant site based on the historical gross heads and flows passing through the site. This total flow (so-called plant site flow or plant flow) includes turbine flows, spill flows, measurable leakages, bypass flows, etc. Ideally, the flows measured immediately downstream of a hydropower plant would be used for this calculation as they would represent the total flows actually passing through the plant site. However, many hydropower plants do not measure the flows, and often there are not any nearby USGS gauge measurements that can be utilized for historic site flows. In this case, the plant operations data would be used to retrieve the historic plant flows.

For the Rhodhiss hydropower plant, the historical records of unit operations with 15 minutes intervals are available, from which the time series of gross heads, the corresponding powerhouse flows (i.e., the flows passing through all the turbine units for energy generation), as well as the spill flows, can be obtained or retrieved. The sum of powerhouse flow and spill flow is used as plant flow to calculate the stream power potential at the plant site.

Long-Term Production Potential (LTPP) Analysis

Since the LTPP is a measure of power production for the three different performance levels of IPL, CPL, and PPL, a series of plant performance curves corresponding to each of these performance levels are needed. The performance curves relating the powerhouse flows to the plant efficiencies are discussed in Appendix 2.05. For the Rhodhiss case, four different performance curves under each performance level are provided, corresponding to gross heads of 55 ft, 60 ft, 65 ft, and 70 ft, respectively. These curves serve as the basis from which the values of plant efficiencies corresponding to other gross heads and powerhouse flows are interpolated. The plant efficiency curves are shown in Figures 2.04-1, 2, and 3 for the IPL, CPL, and PPL, respectively.

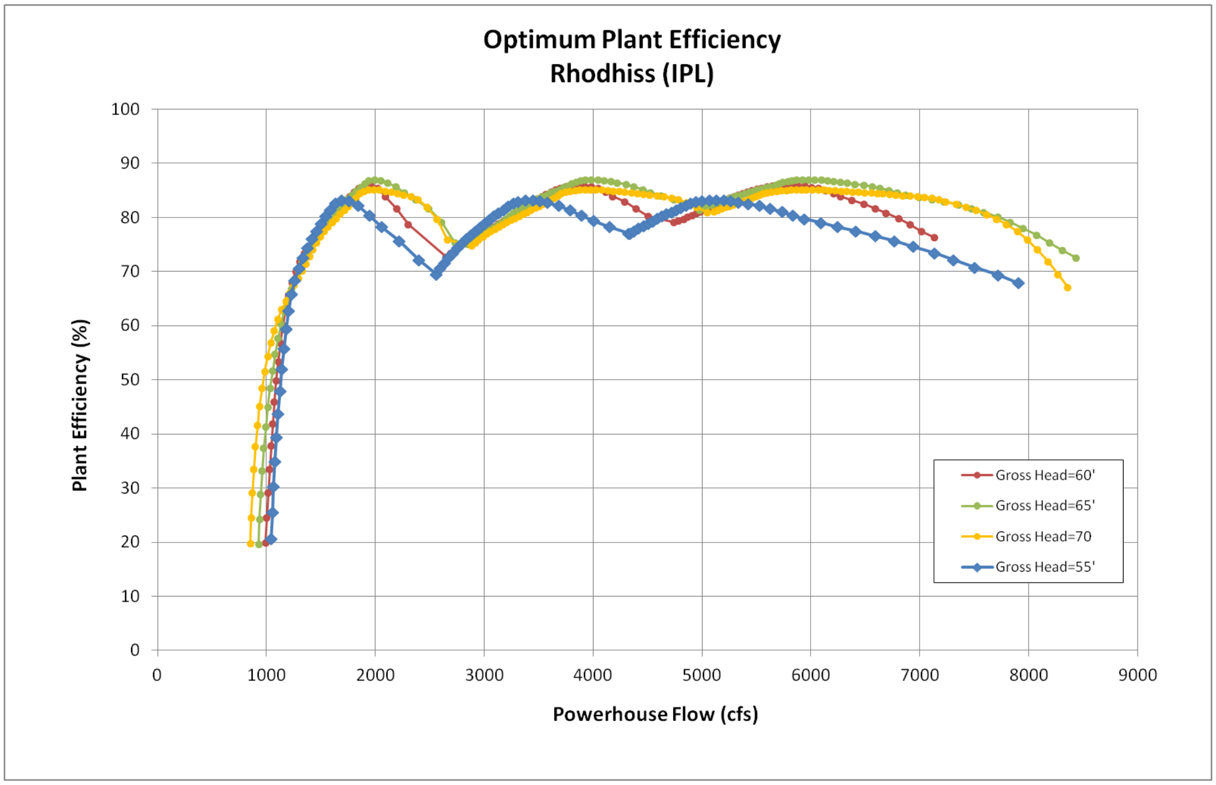

Figure 2.04-1: Powerhouse Flow versus Plant Efficiency (IPL; U1, U2, U3)

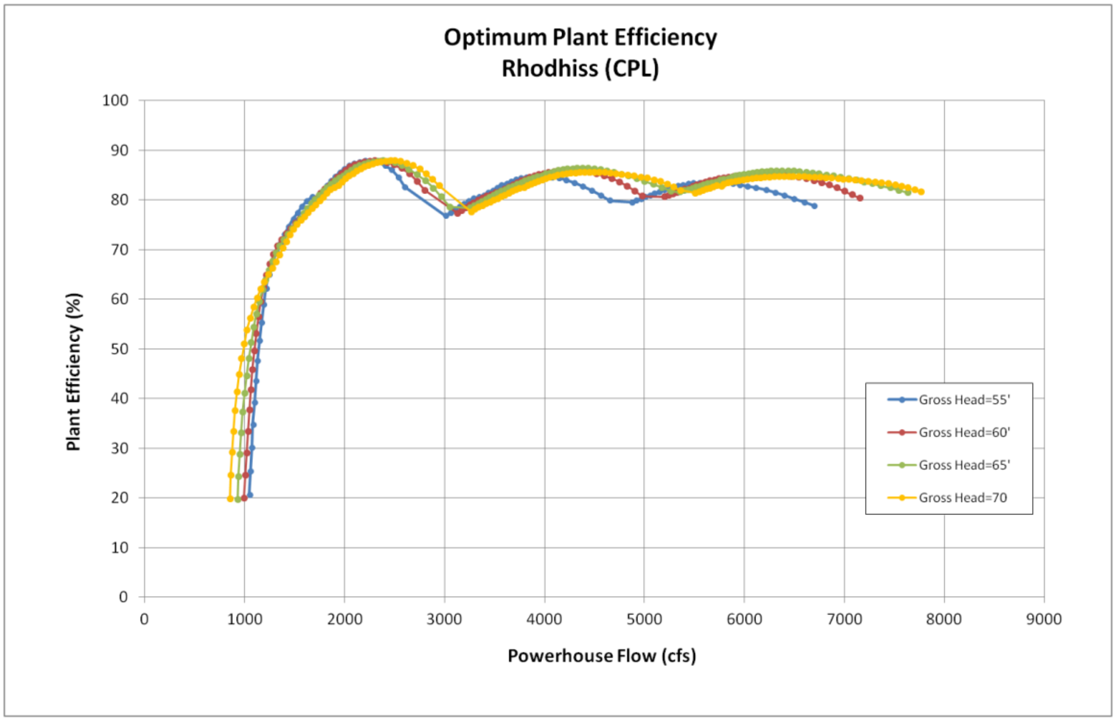

Figure 2.04-2: Powerhouse Flow versus Plant Efficiency (CPL; U1, U2, U3)

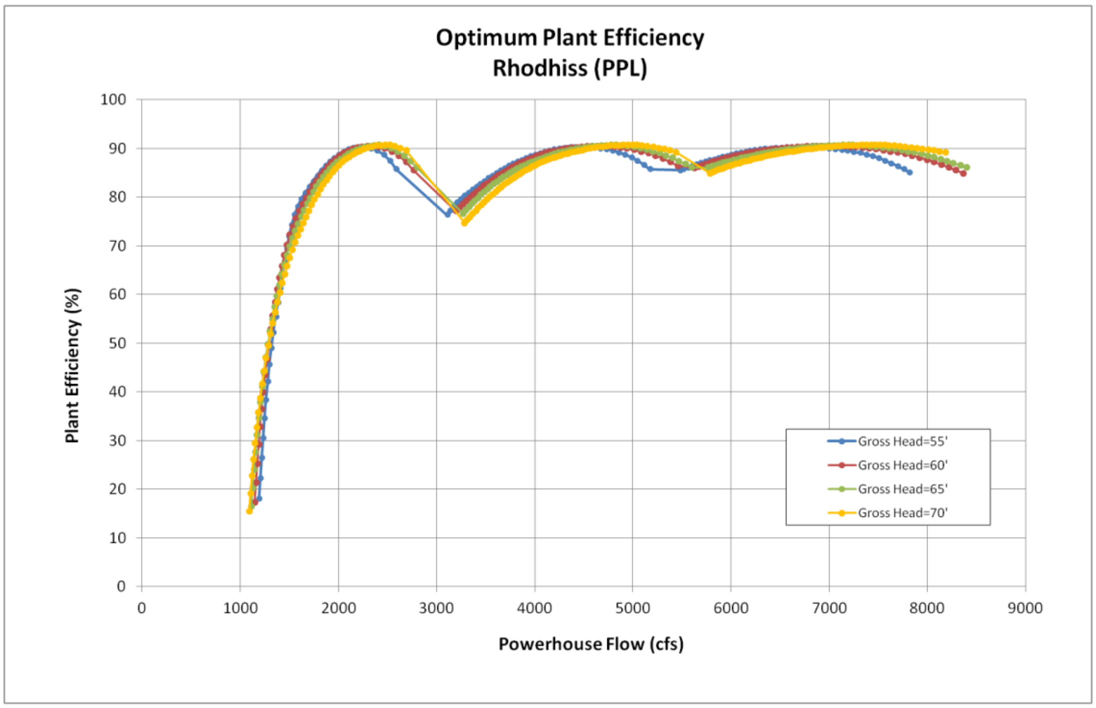

Figure 2.04-3: Powerhouse Flow versus Plant Efficiency (PPL; U1, U2, U3)

Based on the optimized efficiency curves provided in Figures 2.04-1 through 2.04-3, the method used to determine the plant efficiency for a given powerhouse flow assumes that the plant is operated at the peak efficiency point within each of the three curvatures on the optimized efficiency curves for the dispatch of one unit, two units, or three units. This is accomplished by "shifting" the actual time increment (15 minutes in this case) of a flow to a shorter or longer time period while conservation of water is maintained by allowing the same volume of water to be released for generating over different time durations with a higher efficiency. This method assumes that the total of the "extra" time resulted from this flow shifting does not exceed what is physically allowable over the course of the day, and hence any net changes of reservoir storage and water levels resulting from this flow shifting are negligible.

For the efficiency curve corresponding to the last unit dispatched (in this case – the third curvature), the powerhouse flows that exceed the peak efficiency point are not shifted to the peak efficiency. Instead, the actual flows and their corresponding efficiencies are used in the calculation of annual and long term production potentials. This reflects a hydropower facility's typical operation during the periods where flows at this large magnitude may represent the passage of a flood. The priority of passing the flood must be considered and the shifting of flows towards smaller ones to gain better efficiency values would not be appropriate in this case.

Historical powerhouse flows that are less than the minimum flow point on the plant efficiency curves are neglected for the calculation of plant production potential. The minimum flow point is associated with the turbine operating limits to avoid turbine vibration and cavitation. In addition, shifting these small flows to those corresponding to the peak efficiencies would result in extremely small and unrealistic periods of run-time. Historical powerhouse flows greater than the maximum value exceeding the endpoint of the plant efficiency curves utilize the endpoint efficiency on the curve.

For the case of Rhodhiss, none of the historical gross head values fall outside of the 55 ft and 70 ft envelope of gross heads.

Average Power Production (APP) Calculation

The calculation of the Average Power Production (APP) simply requires the time-series of historical generation data. For the Rhodhiss data, only positive values of reported generation are used in this computation. Generation values of zero within the time-series are also included in the average.

Summary of Results

The actual productions in megawatt-hours (MWh), in addition to the average hourly MW for each of the years, are calculated. Table 2.04-1 summarizes the annual generations (in MWh) through the years from 2007 to 2011, respectively, for the historical recorded plant production, the plant production potentials at IPL, CPL and PPL, and the stream hydropower potential.

Table 2.04-2 summarizes the annual power potentials (in MW) for each year from 2007 to 2011, respectively, for historical recorded production, plant production potentials at IPL, CPL and PPL and the stream hydropower potential. The bottom array shows the long-term power potentials (in MW) over the years from 2007 to 2011.

Table 2.04-3 summarizes the absolute and relative increases in annual generation (MWh) at each of the IPL, CPL, and PPL levels, potentially gained from optimization of plant operations.

Table 2.04-1: Summary of Results for Annual Generation

	Actual Annual Generation	Optimized Annual Generation (IPL)	Optimized Annual Generation (CPL)	Optimized Annual Generation (PPL)	Annual Stream Power Potential
	(MWh)	(MWh)	(MWh)	(MWh)	(MWh)
2007	32,866	34,067	34,573	36,315	40,650
2008	35,398	36,507	36,651	38,685	42,821
2009	67,517	69,896	70,442	74,446	83,232
2010	63,360	65,921	66,923	70,212	78,270
2011	29,768	30,695	31,063	32,515	36,799

Notes:

1. The 2007 results include generation and flow from January 1, 2007, through June 30, 2007, only.
2. The 2011 results include generation and flow from January 1, 2011, through August 31, 2011, only.
3. Some missing hours were found on the first and last day for the year 2008 and 2011. These values account for less than 0.25% of the entire yearly data.

Table 2.04-2: Summary of Results for APP, LTPP and LTSP

	APP	LTPP IPL	LTPP CPL	LTPP PPL	LTSP
	(MW)	(MW)	(MW)	(MW)	(MW)
2007	7.57	7.85	7.96	8.37	9.36
2008	4.04	4.16	4.18	4.41	4.89
2009	7.72	7.99	8.05	8.51	9.51
2010	7.24	7.53	7.65	8.03	8.95
2011	5.31	5.48	5.54	5.80	6.57
All Years	6.32	6.55	6.62	6.97	7.78

Notes:

1. The 2007 results include generation and flow from January 1, 2007, through June 30, 2007, only.
2. The 2011 results include generation and flow from January 1, 2011, through August 31, 2011, only.
3. Some missing hours were found on the first and last day for the year 2008 and 2011. These values account for less than 0.25% of the entire yearly data.

Table 2.04-3: Summary of Generation Increases for Optimized IPL, CPL, and PPL Performance Levels

	Improvement (IPL)	Improvement (CPL)	Improvement (PPL)	Improvement (IPL)	Improvement (CPL)	Improvement (PPL)
	(MWh)	(MWh)	(MWh)	(%)	(%)	(%)
2007	1,201	1,707	3,449	3.65	5.19	10.49
2008	1,109	1,253	3,287	3.13	3.54	9.29
2009	2,379	2,925	6,929	3.52	4.33	10.26
2010	2,561	3,563	6,852	4.04	5.62	10.81
2011	927	1,295	2,740	3.11	4.35	9.20

The monthly averaged actual power production (APP), plant production potential, and stream power potential are plotted in Figures 2.04-4, 2.04-5, and 2.04-6, respectively. These monthly variation trends are compared across the years from 2007 to 2011, which shows the overall production and power potential were the lowest in 2008 and the highest in 2009, the same finding as indicated in Table 2.04-2. As expected, the APP calculated from historical generation records (Figure 2.04-4) trended consistently with the stream power potential that is calculated from the plant site flows (Figure 2.04-6). This is because at the Rhodhiss site there was little spill and no releases other than for power generation purposes. Also as expected, the monthly variations of plant production potential for each year (Figure 2.04-5) follow the similar pattern and trend of stream power potential (Figure 2.04-6). The major difference between the two plots is that plant production potential takes the plant efficiency into account.

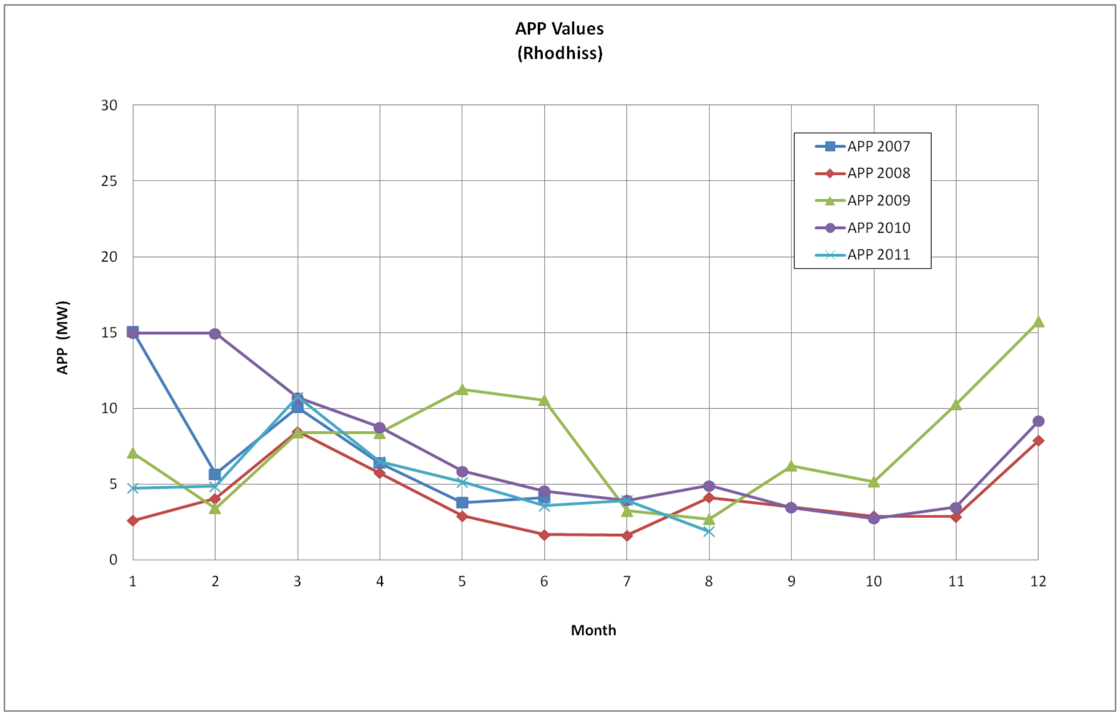

Figure 2.04-4: Monthly averaged APP trend for 2007-2011

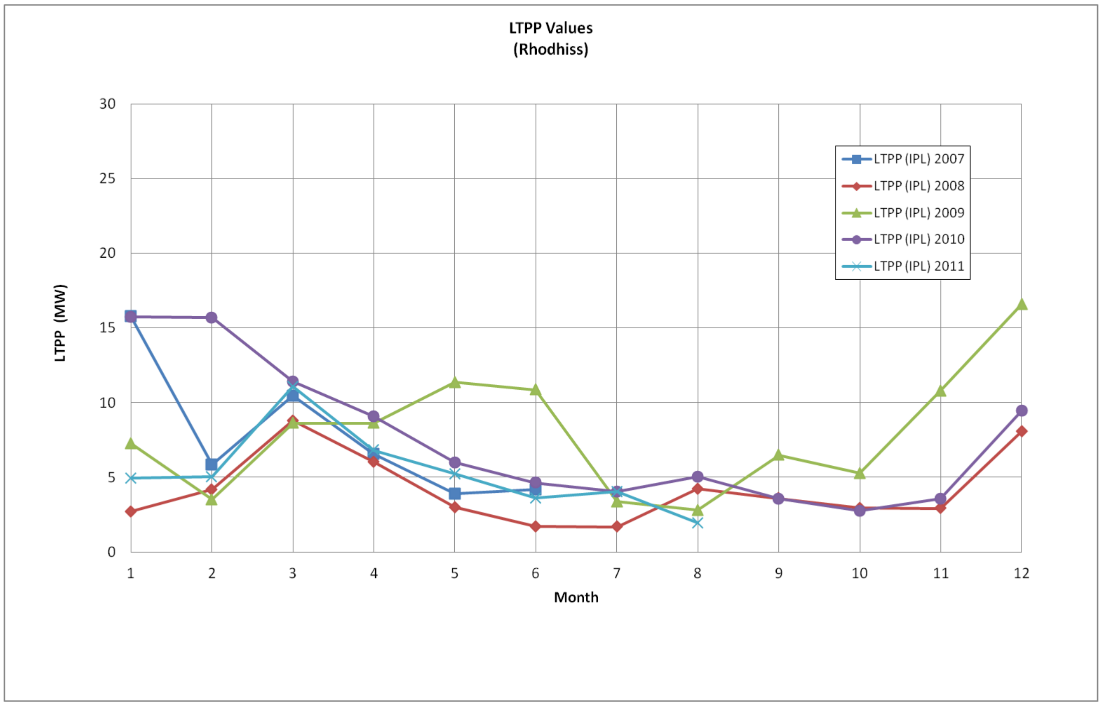

Figure 2.04-5: Monthly averaged plant production potential trend for 2007-2011

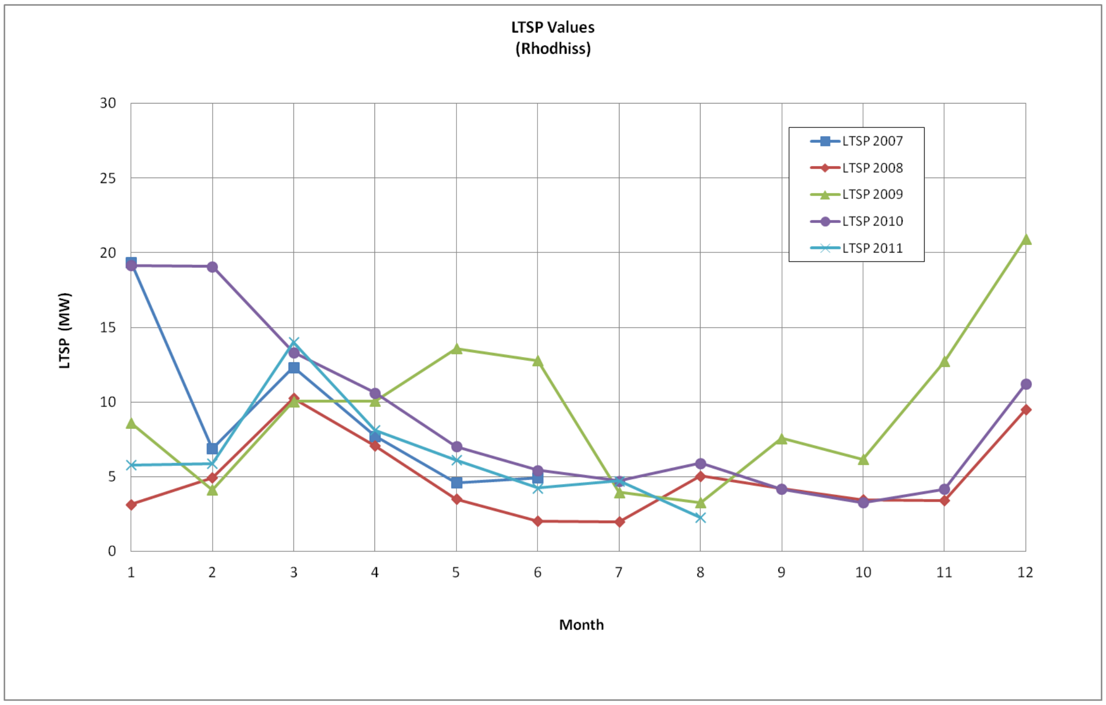

Figure 2.04-6: Monthly averaged stream power potential trend for 2007-2011

Discussion of Results

The increasing trend in the results for the annual optimized generation in Table 2.04-1 from IPL to CPL and to PPL is as expected. This is also reflected in the LTPP values in Table 2.04-2. An indication that the plant was not operated at an optimized schedule is reflected in the comparatively smaller values for the actual annual generation as compared to the optimized annual generation. Optimized generation for all of the years indicate an average performance increase over actual generation of about 3.5%, 4.6%, and 10.0% at the IPL, CPL, and PPL levels, respectively. This corresponds to average increase in annual generation by about 1635 MWh, 2149 MWh, and 4651 MWh for the five year period at each of the respective performance levels.

Figure 2.04-7 depicts and compares the trends of monthly average stream flows and monthly average plant production potential at IPL, CPL, and PPL. Because the majority of the stream flow passing Rhodhiss is used for power generation, the variation of plant production potential over time trended consistently with the hydrological variation in the vicinity. This comparison also helps to identify significant periods of plant outage or periods for which plant operations data are missing (e.g., July-Dec. 2007). In addition, the variation of yearly average stream flows, as shown in Figure 2.04-8, clearly explains why the annual power potentials for the year of 2008 and 2011 are significantly lower than those of 2007, 2009, and 2010 (see in Table 2.04-2). Observation of the annual variation of stream flows indicates that 2008 and 2011 are "dry" years, while the 2009 is a "wet" year which provides a power potential 92% higher than that of 2008 and 46% higher than that of 2011.

Corresponding to the highest peak of hydrological flow (see the blue curve in Figure 2.04-7) for the period from April to July in 2009, the significantly higher actual production can be found for the same period in Figure 2.04-4. The second highest hydrologic peak in Figure 2.04-7 for the time period from November 2009 to May 2010 also corresponds to the relatively higher production in Figure 2.04-4.

Comparison of results from Appendix 2.04 and Appendix 2.05 reveals an overall difference is less than 1% in IPL, CPL, and PPL related optimized annual generation values over the five Calendar years. The slight differences in both results are attributed to subsequent refinement of methods associated with filtering the 15 minutes data and inputting flows as compared to the calculations reported in Appendix 2.05.

Some of the turbine flow data extracted from the time-condensed data files provided by the plant owner appear erroneous (e.g., some reported generation values exceed what is possible to achieve by the reported flows, and in some instances non-zero generation amount is reported during periods of zero flow). Thus, the turbine flows used for these hydrological analyses are based on the reported plant generation.

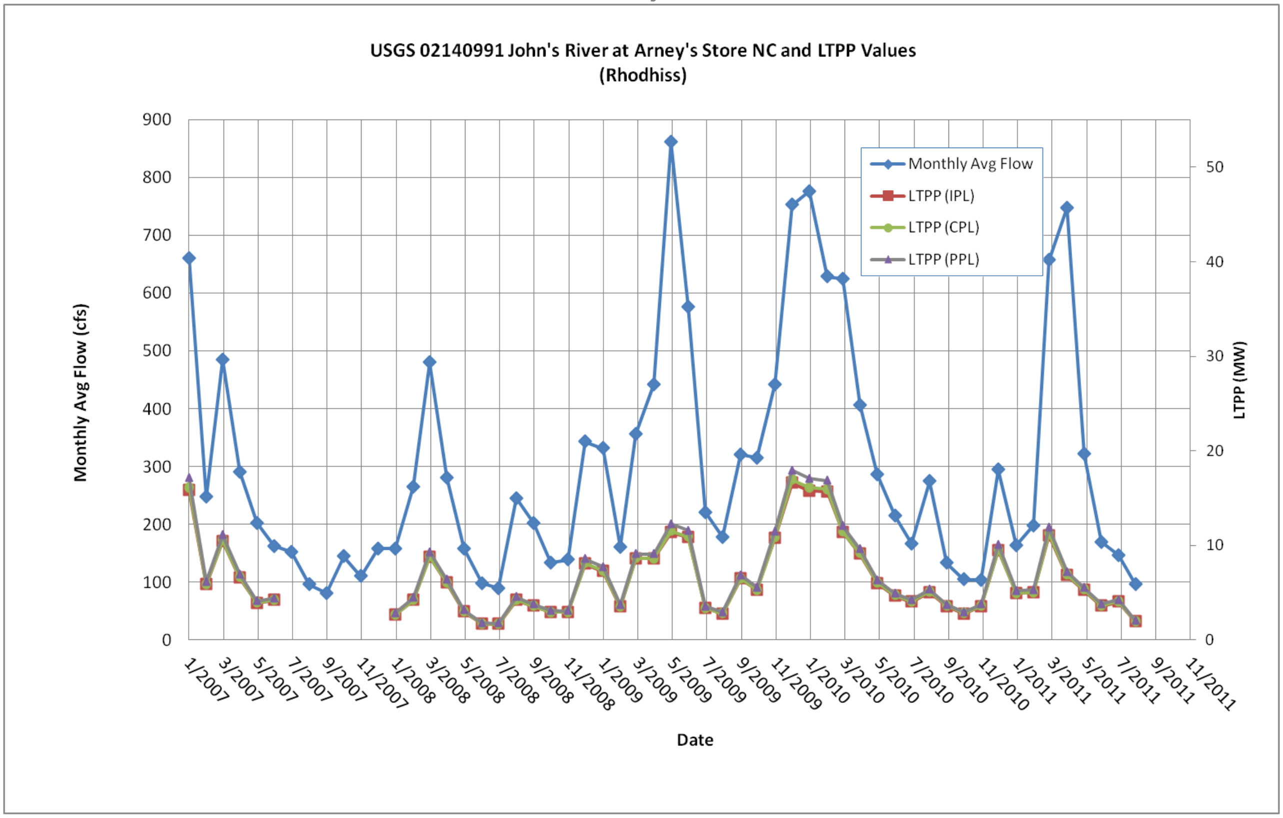

Figure 2.04-7: Monthly average hydrological flow and plant production potential trend for 2007-2011

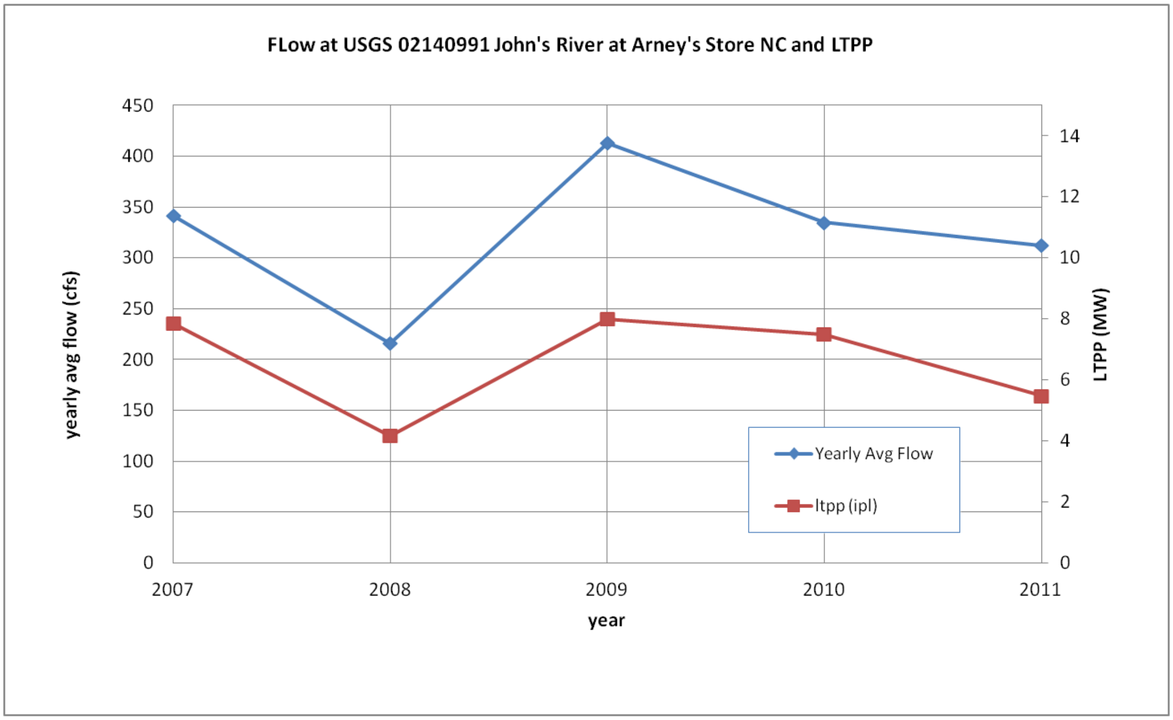

Figure 2.04-8: Yearly average flow and LTPP trend for 2007-2011

For overall questions
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