B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

2009 Resource Program

Wind Reserves Impact Study

March 2009

Wind Reserve Impact Study
(Columbia Vista - Auto)

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Purpose

The purpose of this analysis is to evaluate the effects on the Federal Columbia River Power System (FCRPS) under the increasing reserve requirements associated with growing wind penetration in Bonneville Power Administration (BPA) balancing authority area. This is a single-issue study that isolates the incremental impact of additional reserve requirements. It analyzes the effects on FCRPS operation of providing all wind integration reserves solely from FCRPS resources.

BPA is experiencing very fast, significant growth of wind power in its balancing authority, and has been and continues to work with the wind community on ways to facilitate the rapid growth of the wind power resource. The reserve levels used in this study are based on the *Regulation, Load Following and Generation/Load Imbalance* report prepared by the BPA Wind Integration Team (WIT) and presented on September 10, 2008. The installed wind capacity shown for each scenario year from 2009 – 2013 is based on actual interconnection requests received by the date of the WIT report. BPA Wind Integration Team actions, improvements in wind power scheduling accuracy, and changes in interconnection requirements since that date may lower the reserve requirement for a given installed capacity level.

The study seeks to identify the level of reserves where it appears that the hydro system is no longer functioning in an acceptable manner and reliability, hydro operation or non-power operating requirement violations may be expected to occur. Indicators of situations that could cause violations:

- Inability to hold downward regulation without violating system minimums (low flow).
- Inability to hold upward reserves without violating downstream spill constraints (high flow). This could result in failure to meet the Biological Opinion (BiOp) and Total Dissolved Gas (TDG) spill caps and/or other non-power requirements.
- Unreliable allocation of reserves – Grand Coulee (GCL) and Chief Joseph (CHJ) dams holding a larger proportion of reserves.

Note that the level of reserves associated with identified volumes of wind capacity is based on actual operations of the initial wind fleet interconnected at the time of the study. This relationship is likely to change as a result of the recently released Large Generation Interconnection Agreement (LGIA). Improved scheduling will reduce the regulating reserve requirement needed to manage a particular level of wind fleet. Thus the timing of the reserve effects may be extended to a larger wind fleet but the effects will be the same. Therefore, the model results shown in this report should be used for reference only.

Results Summary: The results of this study are consistent with expectations:

As the reserve requirements rise:

- The ability to peak the system declines.
- The wholesale market opportunity goes down; i.e. generation moves from on-peak to off-peak filling the trough.
- Spill increases and unit efficiency decreases causing generation volumes to decline.
- The number of operational violations increases, reaching unacceptable levels by the 2011[1] level of wind reserves.
- The additional reserve requirements are held mainly at GCL, which may cause reliability concerns.

These impacts are magnified as flow levels move away from the median. As can be seen in the following graphs the effects are seasonal, driven by flow, flood control, and spill requirements. Each of these points is expanded following the methodology section.

Methodology: The Columbia Vista (CV) Auto Vista module was used to perform multiple year-long hourly simulations of the Federal hydro system with varying reserve requirements and flow levels. Analyses were run for 21 sample cases; three flow levels (low, median, and high) combined with seven levels of reserve requirement. CV Auto studies enable a year long simulation of the hydro system at a finer resolution than has previously been available.[2]

The reserve levels used in this study are based on the *Regulation, Load Following and Generation/Load Imbalance* report prepared by the BPA Wind Integration Team (WIT) and presented on September 10, 2008. These reserve levels assume the wind facilities schedule with the equivalent of a two-hour persistence forecast for the projected installed wind fleet capacity. The installed capacity at the end of each scenario year is based on actual interconnection requests received by the date of the WIT report. It should be noted that improvements in scheduling accuracy and changes in interconnection requirements may lower the reserve requirement for a given installed capacity level. Therefore, the model results shown in the balance of this report are for the given reserve requirement levels and the years and installed capacity are subject to the assumptions in the WIT report and should be used for reference only.

Scenario Wind	Base 0 MW	2008 1425 MW	2009 2105 MW	2010 3155 MW	2011 4330 MW	2012 5570 MW	2013 6670 MW
Up Reg	679	757	894	1179	1414	1693	1983
Down Reg	837	884	1048	1453	1773	2174	2542

For this first set of studies the only variables are the reserve requirements representing the level of wind penetration and specific constraints that match the inflow volume. All of the studies are running against 2007 historical loads. The wholesale purchase market has a limit of 4000 MW in any hour and the sales market is effectively unlimited.

[1] Because this analysis does not include load growth, 2011 refers only to the level of reserves modeled not the actual operating year. Additionally, improved forecasting of wind energy is expected to reduce the quantity of necessary reserves, allowing the assimilation of more Wind generation before operations become acceptable.

[2] To get results in a timely fashion the simulation used a 7-period blocking rather than hourly for these studies. Each blocked, year-long study takes approximately 24 hours to complete. Each year long hourly study takes nearly three weeks to complete and a small sample comparison indicated that the results were not substantially different from the blocked studies.

Results

Peaking Capability Declines

The extra reserves required to follow the variability of wind resources decrease the flexibility of the hydro system. Hydro flexibility is available because there is not enough fuel (streamflow) to use all of the system capacity in every hour. While operations that provide flood control and protect fish have limited the operational flexibility to some extent there is still opportunity to generate more energy during the peak load hours and less in the off-peak load hours.

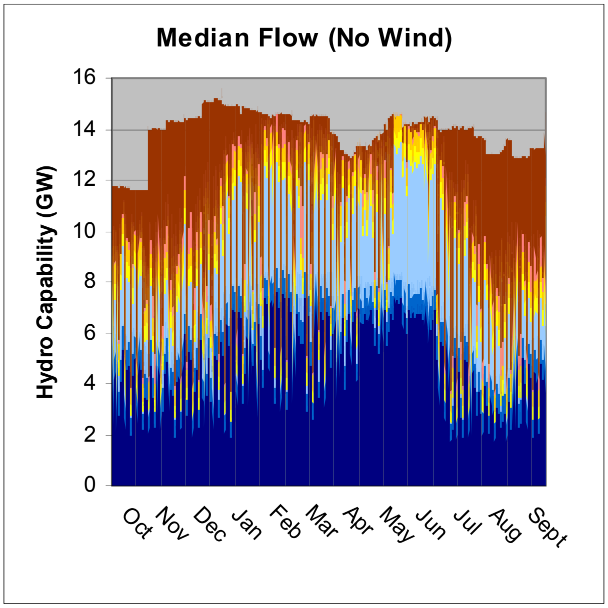
The increased reserve requirement needed to manage variable resources like wind power further limits the system flexibility. The **downward regulating margin** (*down reg*) increases the low end of the operating range while the **upward regulating reserves** (*up reg*) decrease the upper end of the operating range.

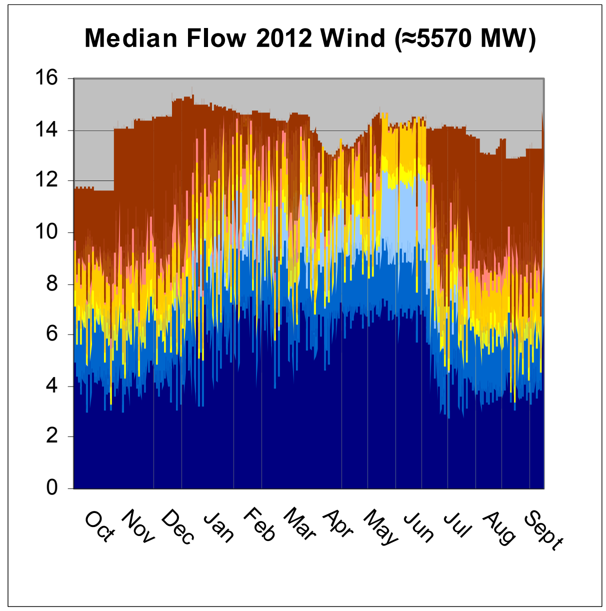
Down reg effectively increases the minimum operating level from the minimum flow level to a generation level that would allow the system to back off to minimum flow levels if the wind resource is greater than expected. *Up re*g is the regulating margin, in excess of the contingency reserves, that must be spinning with enough headroom to quickly replace wind resources that suddenly decline below the expected level. *Up re*g has a triple impact. First, the available capacity is decreased by the amount of the reserve requirement. Second, since these reserves must be spinning, more spinning units are required and the combined minimum generation increases. And finally, more units spinning reduce the plant efficiency, reducing the total energy that can be produced with the available streamflow.

The graphs on the following two pages provide a visual display of the hydro operations modeled using Auto Vista, with and without the increased reserves required to manage wind resources. The first page includes an example of the hourly optimized annual operation of FCRPS projects as modeled with and without the additional reserve requirement. On second page the detail is expanded to more clearly show the details of the changing operation for a typical week in each of the four seasons.

On each page the graphs on the left are from the study with no additional reserves for wind and the graphs on the right are the operations that require enough reserves to support the 2012 level of wind (about 5570 MW). In these graphs the three shades of blue areas represent generating resource including the generation that could be decreased without violating non-power constraints. The yellow and red areas are the unused available hydro capacity identified as different types of reserves.

Annual Hourly Hydro Operations – Model Results





Operations Category

- Total Hydro Capacity Available - NonSpinning Reserves
- Spinning Reserves Available
- Spinning Reserves - Identified for Reg Up
- Contingency Reserves - 50% Spinning
- Operating Generation Flexability
- Operating Generation - Reg Down Required
- Operation Generation - Minimum Levels

These graphs are examples of the hourly optimized annual operation of FCRPS projects as modeled with and without the additional reserve requirement. In these graphs the dark orange area represents the available capacity of the federal hydro system. The other colors are laid over the top to display how the capacity is used by the modeled operation. The three blue areas represent the generating resource:

- **dark blue** is the minimum generation for each hour,
- **medium blue** is generation required for *down reg*, and
- **light blue** area is the portion of the hydro generation that is operating to maximize the value of the hydro system generating capacity; i.e., the discretionary (flexible) portion of the optimized hydro operation.

The yellow to orange colors represent the non-generating system capacity including both spinning and non-spinning reserves in various state of readiness.

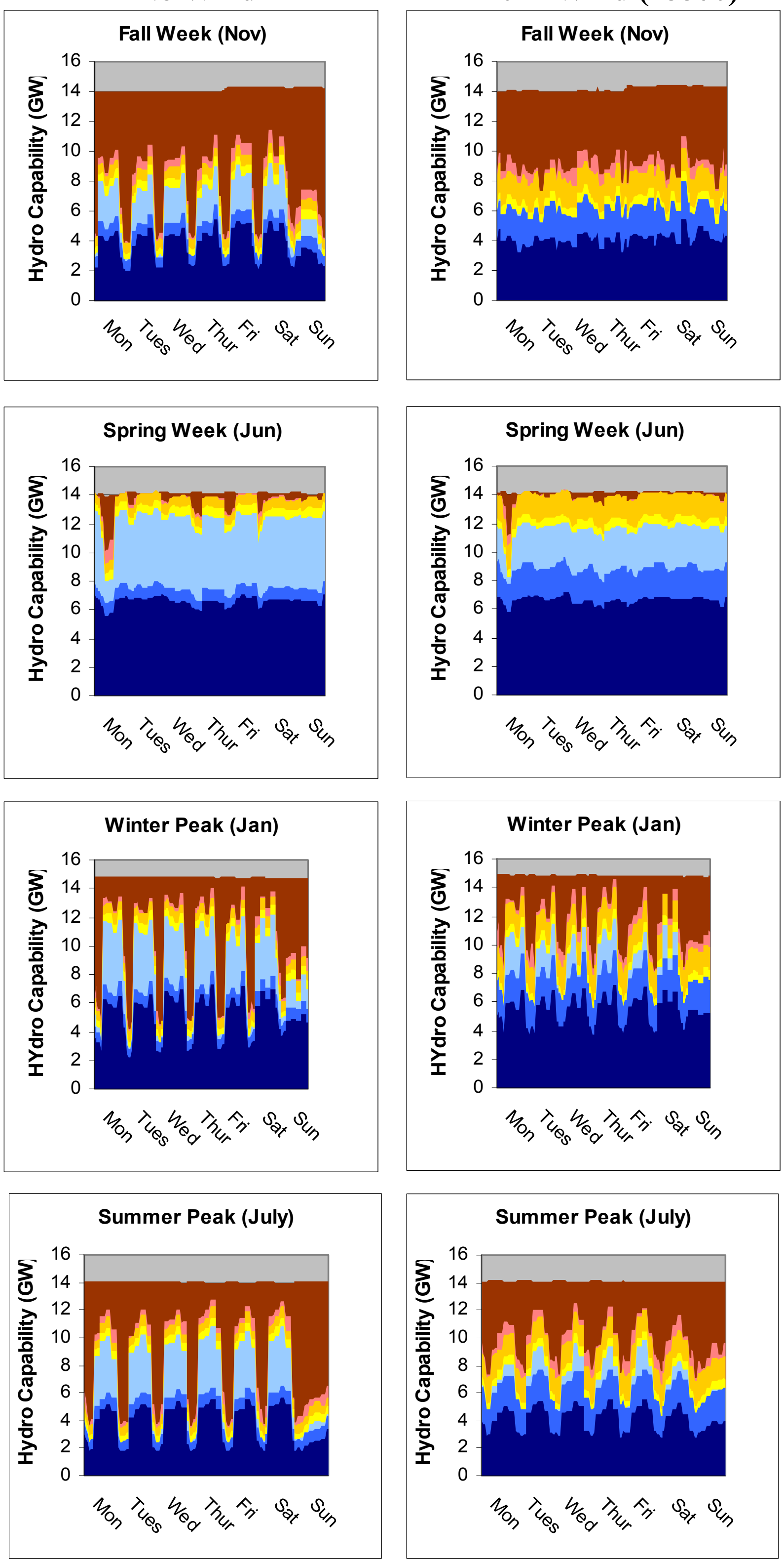
- **bright yellow** is the contingency reserve required by WECC (half spinning),
- **light orange** is the *up reg* that is used to manage load following and generation imbalance and, in the graph on the right, to balance wind resources.
- **peach color** is spinning resource that is in excess of the reserve requirements and
- **dark orange** is capacity that is available but not spinning in the given hour.

Notice that in the graph on the right, the base load generation (the two darker blue areas) increases and the system flexibility decreases. The reason is three fold: (1) The *down reg* requirement takes over some of the flexible generation; (2) The additional *up reg* requirement causes the model to bring on more hydro units increasing the minimum generation[3]: and (3), the required *up reg* reduces the maximum operating capacity for available for discretionary operations.

[3] Minimum generation is a function of the number units in operation for the hour as well as down stream flow requirements and changes depending on the number of units in operation.

Using the same color scheme as the previous page, these graphs show the detail of the reserve effect using typical weeks from each season. Even though both scenarios have the same load input, notice the flattening of the generation profiles when more reserves are required. In all seasons the higher reserve requirements force generation out of high load hours into the light load hours.

No Wind | **2012 Wind (~5570)**



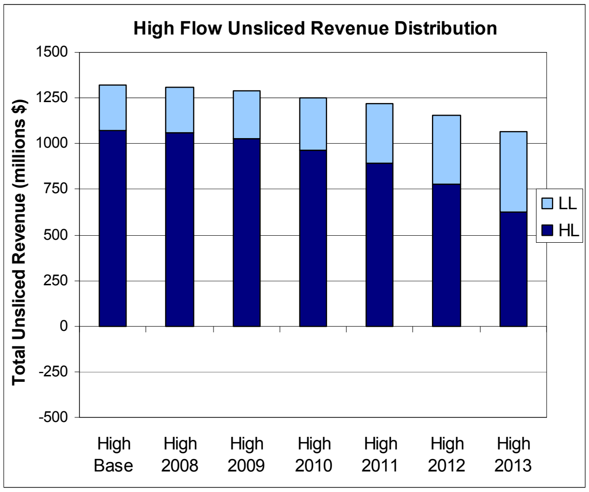
The fall season (with the lowest streamflow) is the most dramatic. In the right-hand graph, the required *down reg* leaves no room for any discretionary generation shaping. In fact, detailed analysis shows that many hours are violating the high *down reg* reserve requirement.

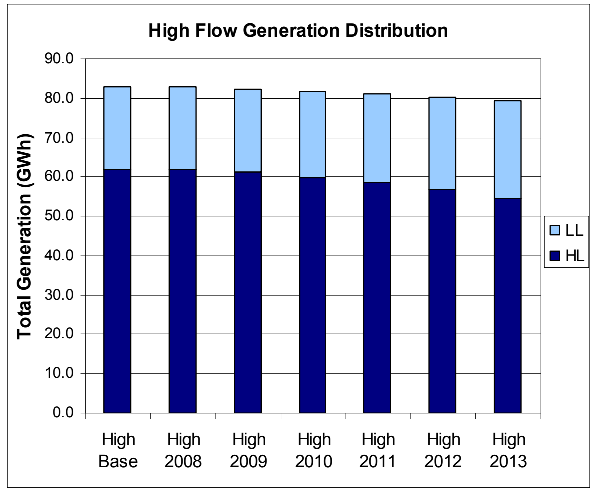
In the spring example, total generation has declined in the right-hand graph. At this time of year, high streamflows are being spilled to maintain the *up reg* requirement. While there is plenty of discretionary generation, any reduction in generation will result increase the amount of spill. The spill would result in lost energy and often violate the total dissolved gas limits.

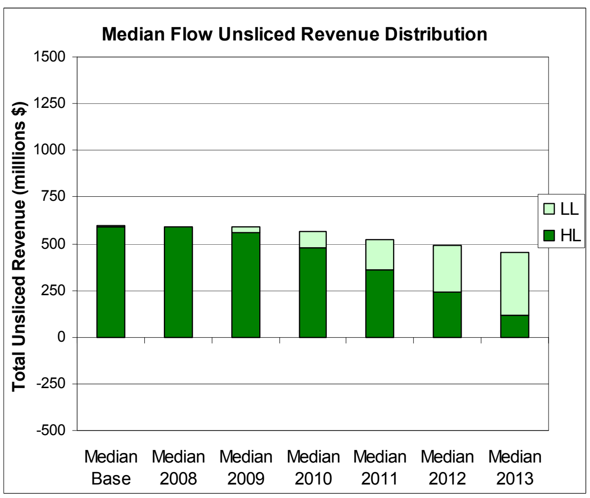
There are similar consequences during the summer and winter peak periods. Comparing the left and right diagrams, it is apparent that a significant portion of the generating capability is devoted to managing the reserve requirement. Water that is used, in the base case, to generate during high load hours is forced into the light load hours to maintain the *down reg*.

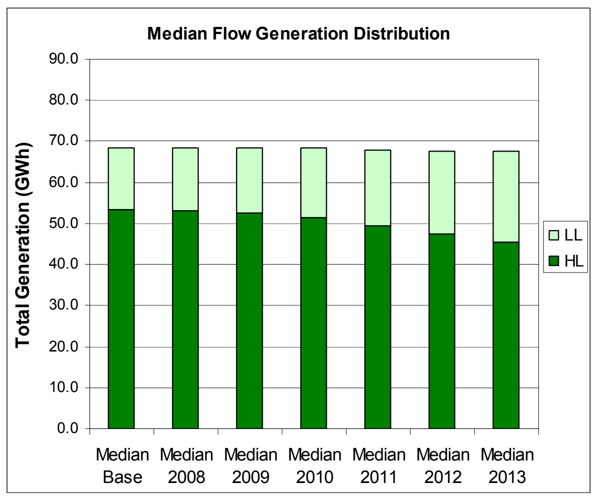
Secondary Market Opportunities Decrease

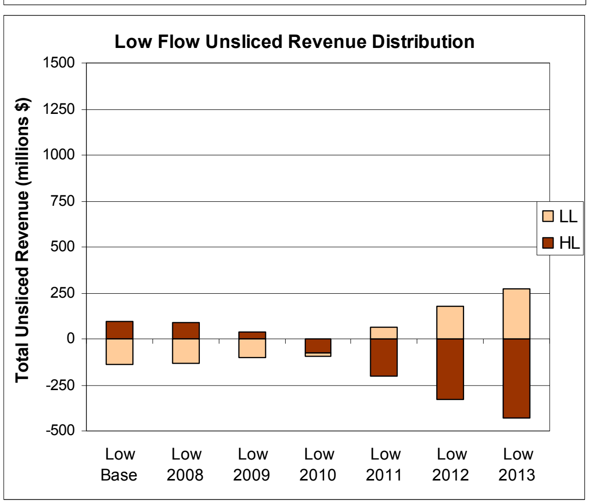
These graphs illustrate the effect on BPA power sales inventory and revenues as the wind fleet in BPA's balancing authority increases, assuming BPA provides all generation imbalance, load following and regulation from the Federal hydro power system. As the system is limited by the need for more regulating reserves due to the increase of variable resources, generation moves from on-peak to off-peak and wholesale market opportunity goes down.

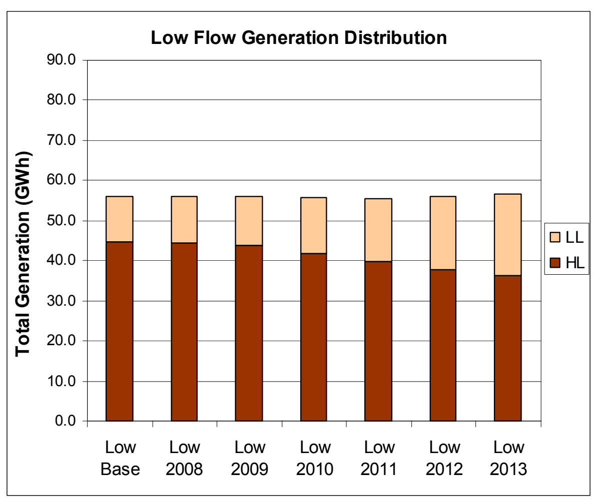








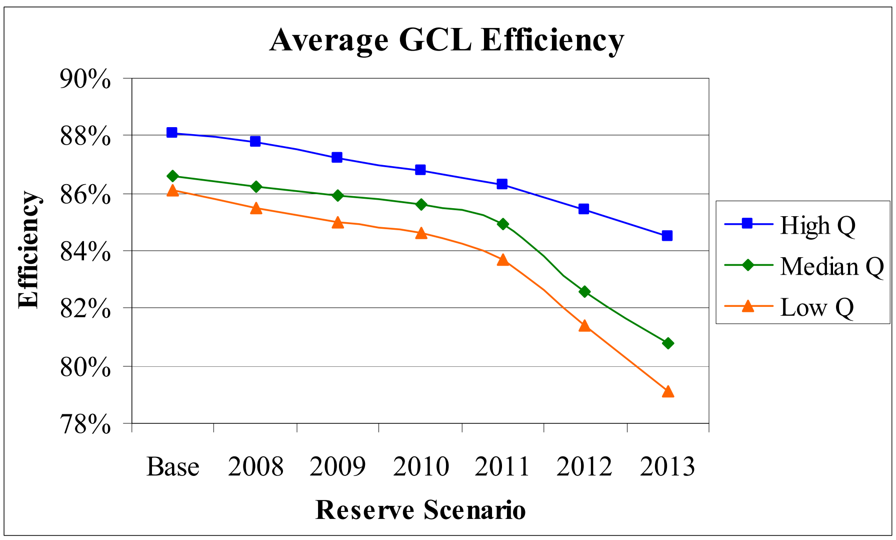




Unit Efficiency Decreases and Spill Increases:

The increased reserve requirement results in a reduction in generation and in some cases a need to bring more units on line. This effect is measured as a reduction in unit efficiency; i.e., the same volume of water produces less energy Grand Coulee (GCL), Chief Joseph (CHJ), McNary (MCN), John Day (JDA), and The Dalles (TDA) dams were modeled as plants capable of holding regulating reserves. The units of three lower river plants were limited by the 1 percent efficiency operating range prescribed by the Biological Opinion.

The graph below shows that GCL plant efficiencies decrease with the increasing reserve requirement. Efficiency on the lower river plants did not greatly change from the base scenario because the majority of the incremental reserve requirements ended up at GCL. To accommodate reserve obligations, the model brings more units online particularly when the regulating up reserve is the controlling factor. As units are brought online plant efficiency drops causing a reduction in generation. Costs associated with additional unit activity (e.g., breaker costs and unit wear and tear) were not addressed in this study.



The table below shows spill increases under higher hydrologic conditions and incrementally with higher reserve requirements. Regulation up reserves will induce additional spill when units cannot increase generation to meet increasing reserve requirements but are also required to meet elevation requirements. Consequently water that cannot be generated must be spilled.

Average spill during fish operations for high hydrology (kcfs)

FY	GCL (kcfs)	CHJ (kcfs)	MCN (kcfs)	JDA (kcfs)	TDA (kcfs)	Total (kcfs)
Base	13	14	183	134	135	***479***
2008	14	15	184	137	136	***485***
2009	15	15	186	139	136	***491***
2010	17	16	187	146	142	***507***
2011	19	17	187	151	144	***519***
2012	21	19	192	159	151	***542***
2013	24	21	196	166	156	***563***

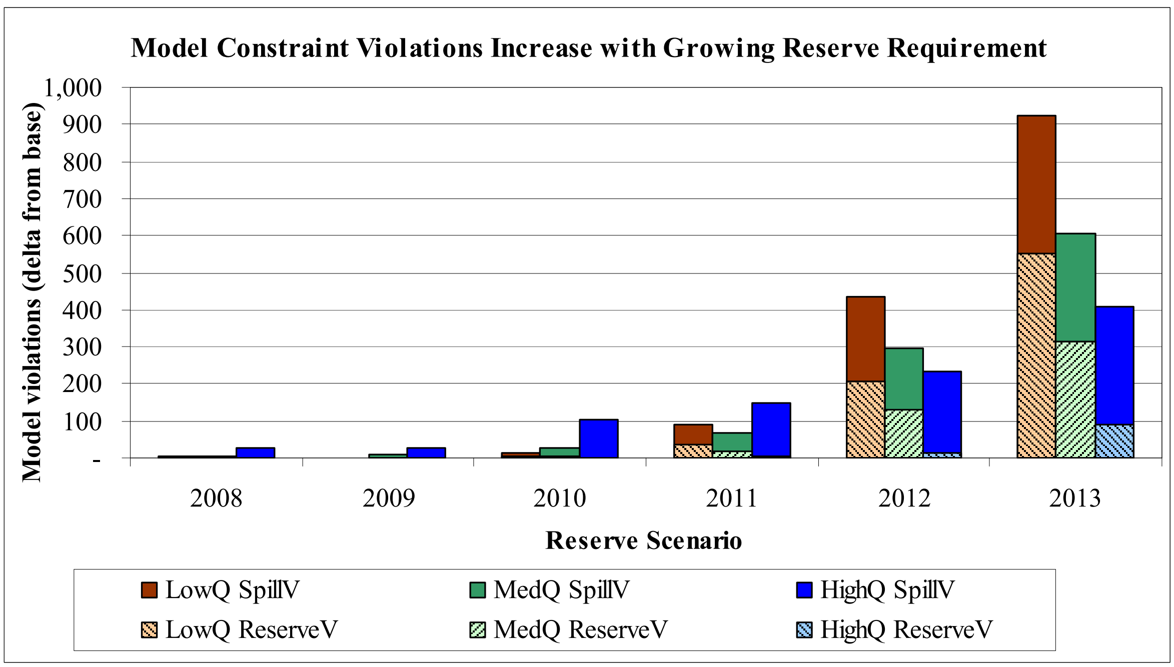
**563-479/479 = 17.5 percent increase in spill during fish operations for the 10 percent water year. These values will change based on flow volume and timing of spring runoff.

Model Constraint Violations Increase:

The graph below shows reserve and spill violations increasing as the size of the wind fleet grows, again, assuming BPA provides all reserves for the wind fleet in BPA's balancing authority from the Federal hydro power system. We developed a model constraint violation index[4] that combines probability and magnitude of reserve and spill violations. The index is for comparative purposes and does not have any physical meaning.

There are two types of spill violations that occur in the model results. In the low streamflow scenarios, the spill violations occur due to violating minimum spill requirements. In the median and high water year scenarios, spill violations are caused by exceeding the spill caps, which results in excess nitrogen saturation (TDG) levels in the water. During median and high flow base cases (no wind), variances in spill operations occur and spill priorities are used to manage high flow during spring runoff.

Incremental changes in spill and reserve violations increase between the 2010 and 2011 regulating requirement. As the reserve requirement increases, spill is used to try to manage the reserve requirement. This leads to increasing spill violations during spring runoff, indicating difficulty meeting BiOp operations. Also, the model increasingly cannot hold the reserve requirements needed to integrate the growing wind fleet.

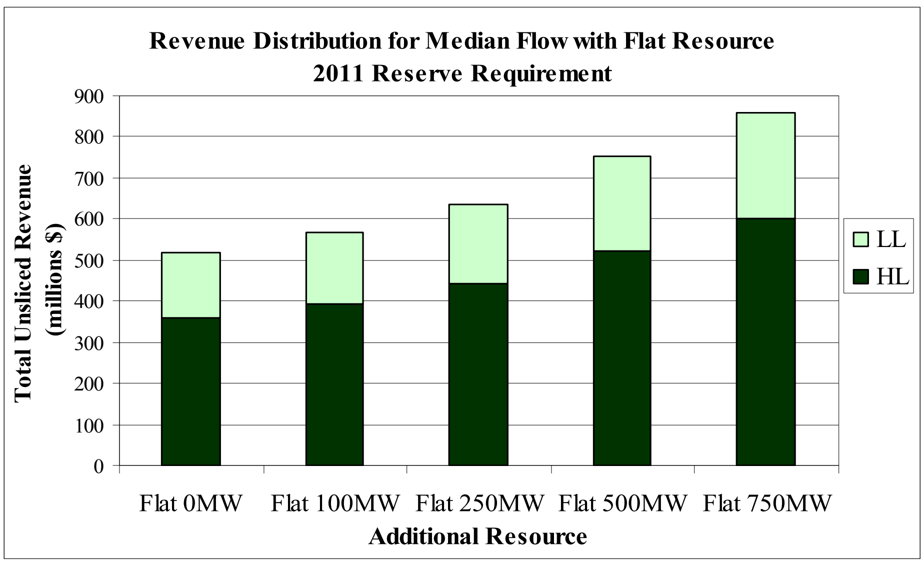


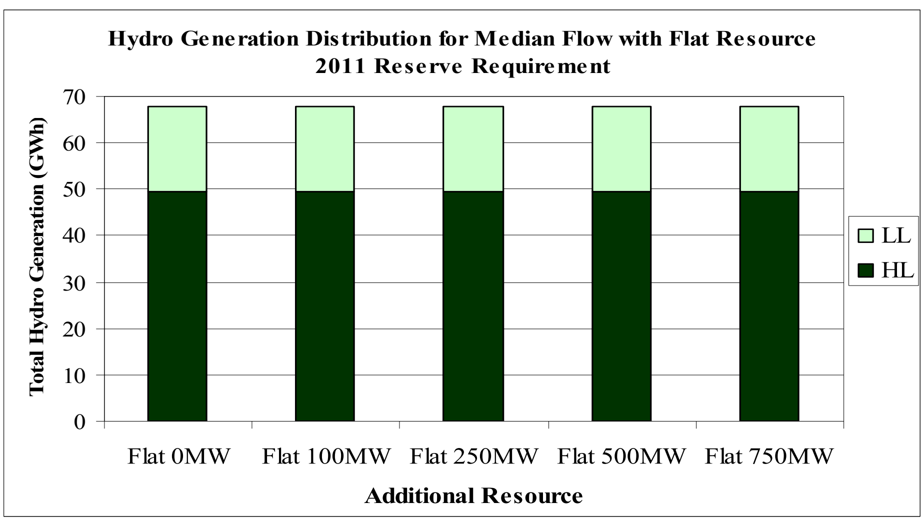
Many BPA analysts suggested that, since FCRPS has an installed system capacity of 22,000 MW that is energy constrained, if more energy could be supplied from another source, the freed up water in the FCRPS could be used in a more shaped, responsive manner to supply ancillary services rather than meet load on an hour. To test this theory, we added new energy resources to our system model, reran the analyses and calculated the operations violations. However, no

[4] The violation index was calculated by multiplying the percent of hours the metric was missed by the magnitude of the violation. The spill metric was calculated at TDA and JDA and converted using an average energy to flow ratio for each of the projects. Spill violations at other projects are still being examined.

significant change in the calculated violation index resulted from adding a flat 500 MW resource to the median flow scenarios at the 2009 and 2011 wind (future) reserve requirement levels and to the high and low flow cases at the 2011 level.

The graphs below show that, as expected, adding a flat resource of increasing size increases secondary revenues. However, because the generation distribution remains the same with the addition of the flat resource, the inability to peak the system still occurs and spill increases and unit efficiency decreases with the high reserve requirement. This indicates that the hydro system is already load factored to the maximum extent to move a given volume of water. The model has already determined the most optimal operation for the hydro resources. Therefore the addition of a flat resource does not free up hydro capability for other uses. The inability to hold downward regulation without violating system minimums also remains a problem. To change the model results, the resource added would need to reduce the reserve requirement on the hydro system. This could be a dispatchable resource that is able to hold reserves or an ancillary product from a third party supplier. Only a dispatchable resource capable of providing incremental and/or decremental capability, or that can otherwise carry a portion of the regulation, following and imbalance reserve requirements, can reduce the reserve amount carried by the hydro sources and make that capacity available for other uses.

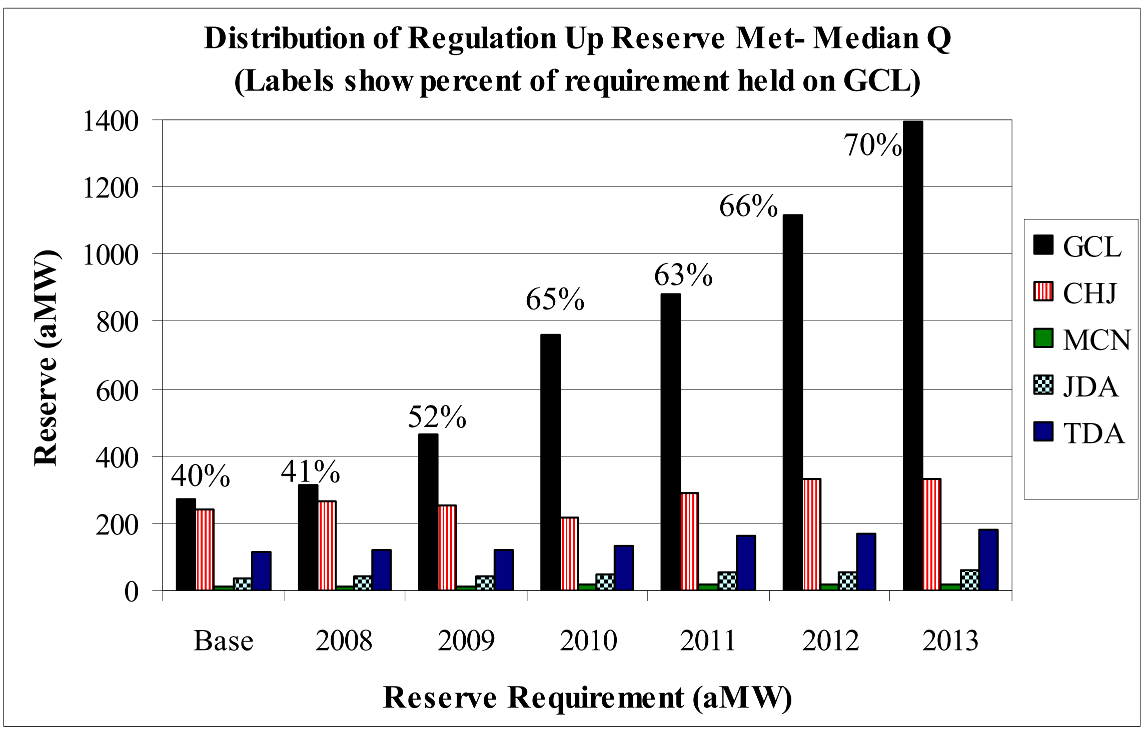


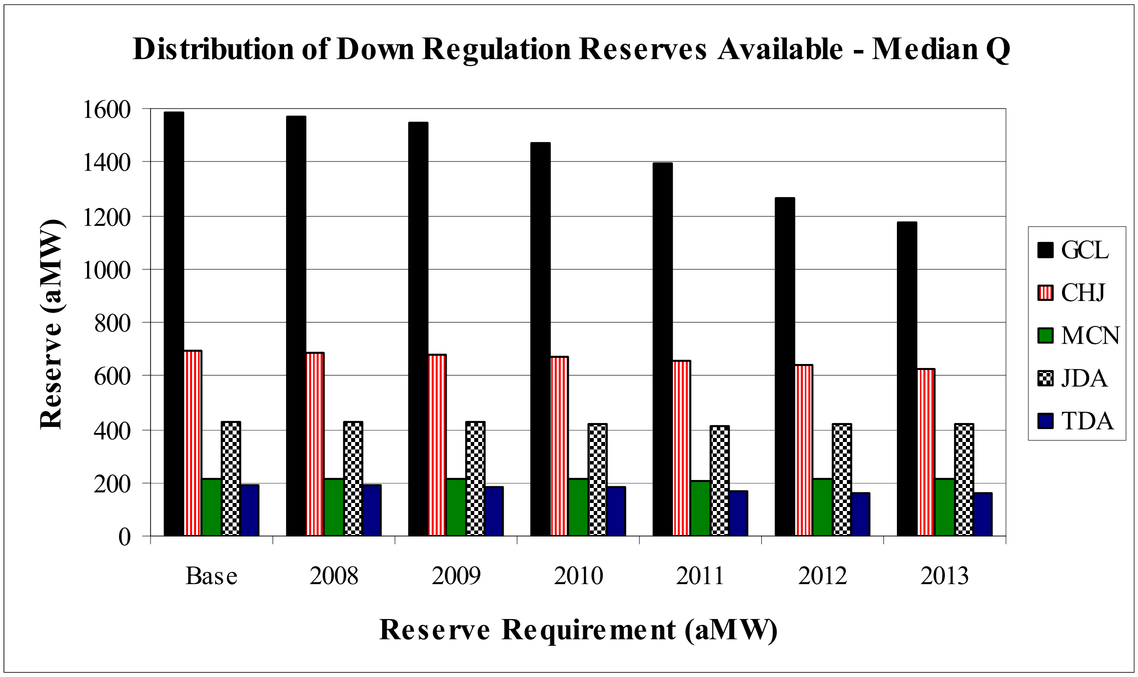


Reliable Allocation of Reserves:

Due to the existing power and non-power requirements on the system, the increasing reserve requirements needed to integrate wind are held at projects that currently operate with fewer constraints. The graph below shows that allocation of reserves on the Lower Columbia increases only slightly throughout the scenarios. The constraints on the Lower Columbia limit the ability of those plants to hold regulating reserves and any future fisheries requirements that further limits their flexibility (e.g. increased spill or requirements that limit reservoir content) would decrease the amount of regulating reserves and load following response on those projects.

The percentages in the chart below indicate the percent of total reserve requirement being met at Grand Coulee. In the base scenario, Grand Coulee holds approximately 40 percent of the regulation up reserves with the combination of Grand Coulee and Chief Joseph being 75 percent. The BPA transmission system has internal constraints and GCL and CHJ are predominantly on the "wrong" side of these constraints. Transmission was not modeled in this study so the increasing allocation of reserves onto GCL and CHJ may create transmission reliability concerns that are not captured in the results.





Regulation up reserves met at Grand Coulee increases according to the requirement associated with increasing wind penetration. At the same time, the down regulation reserves available are decreasing. This occurs as flow, which originally went through one unit, is dispatched through two units. The maximum generation under two units thereby gets reduced, increasing the regulation up but decreasing the regulation down capability.

Conclusion:

The ability of the hydro system to support increasing reserve requirements for integrating wind is limited by existing power and non-power constraints. As the reserve requirements rise, spill increases and unit efficiency decreases, causing generation volumes to decline. This decreases the wholesale market opportunity or causes load obligations to be met by other resources.

The incremental changes in operating violations increase noticeably between the 2010 and 2011 reserve requirement specified in the September 10, 2008, WIT study (INC range from 1,179 – 1,414 MW and DEC range from 1,453 – 1,773 MW), depending on inflow levels. This would indicate a system condition where meeting the reserve requirements and satisfying other power and non-power requirements would be extremely difficult.

The model results show that adding a flat energy resource does not significantly affect the amount of operating violations. To increase the system flexibility, the added resource would need to provide reserves in addition to energy; e.g. a dispatchable resource or ancillary product. The point of delivery should be selected to balance the increasing dependence on GCL for reserves.

This study uses actual loads from 2007 and does not incorporate load growth in the analysis. In addition, new obligations for Resource Support Services and Forced Outage Reserve requirements resulting from Regional Dialogue contracts were not modeled. Nor were transmission impacts modeled. Incorporating transmission constraints, increased load growth and increased requirements in these studies can be expected to exacerbate the complications created by rising reserve requirements for wind integration.

Risks:

This analysis is a single issue study that isolates the incremental impact of holding additional reserve requirements on the Federal system. This study does not capture any risks associated with deploying Federal reserves to balance a variable wind profile such as: managing forebay bounces, navigation issues, transmission redispatch and reliability if GCL is disproportionately responding to large swings, and unit operational cycling costs.

It is important to note that these reserve requirements are functions of the assumptions in the September 10, 2008, WIT report. The reserve requirements assume a particular level of forecasting accuracy. Sensitivity analyses show the reserve requirement to be very sensitive to this assumption. To the extent forecasts are demonstrated to be more accurate, or other provisions to limit BPA's reserve exposure are put in place (e.g. through Large Generator Interconnection Agreements and a new Dispatch Standing Order), these reserve requirements can be reduced for a given wind fleet size. However, the reserve carrying capability of the current FCRPS does not change from the values above.

The fish protection and other operating constraints on the Lower Columbia limit the ability of those plants to hold regulating reserves. Any future fisheries requirements that further limit the flexibility of these projects (e.g., increased spill or requirements that limit reservoir content), would decrease the amount of regulating reserves and load following response available from those projects. Allocating the response to fewer projects could risk the ability to manage transmission overloads (redispatch) and the ability to respond to wind imbalances and inflow uncertainties. Also, a reduction in generation available for load service would transfer that load service obligation to other projects, including projects that could otherwise have flexibility to follow wind movement.

Appendix: Technical Details for Wind Reserves Impact Study.

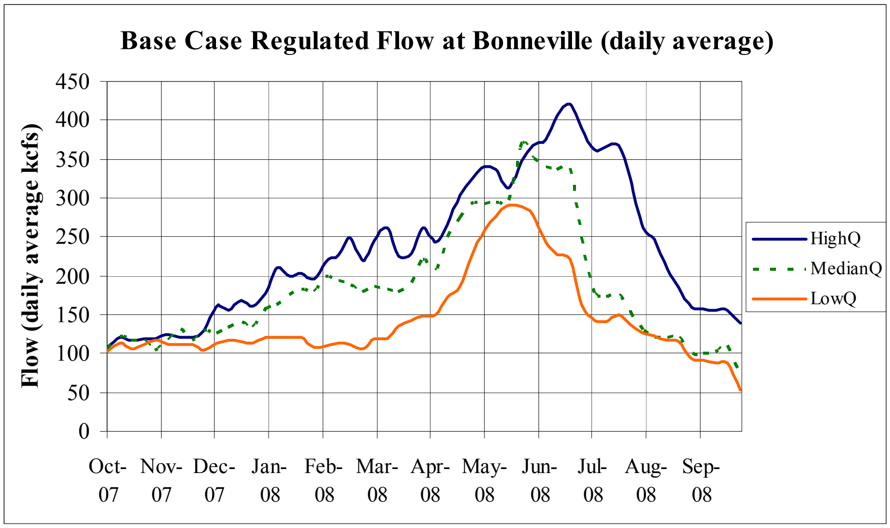
System Components Modeled: Only the "Big 10" federal projects were modeled to manage the run times and study scope. The non-federal Mid-Columbia projects were hydraulically modeled to pass inflow. The hydro regulation from projects upstream of GCL included the Willamette dams, Libby, Hungry Horse, Albeni Falls, and Dworshak generation.

Grand Coulee and Lower Granite dam inflows: The hydrologic years were selected from a set of ESP water years. The objective was to find a fair representation of the 90 percent, 50 percent, and 10 percent exceedence levels. The selection methodology broke out the year into four periods; Oct-Sep, Dec-Mar, April-Jul and Aug-Sep. The first period represented the transition into the new water year, the second period represented the winter, the third represented the majority of the freshet season, and the last represented the transition to lower summer flows. For each of these periods, the average flows were considered for The Dalles, Grand Coulee, and Lower Granite. In looking at the different cases (90 percent, 50 percent, 10 percent), it was difficult to find a consistent year across all three forecast points and in all periods. Consequently, the selection process placed more emphasis on the total volumes during the winter and freshet seasons, and less consideration on the fall and late summer. Based on this, the following years were selected:

Water volume at The Dalles for hydrology selection

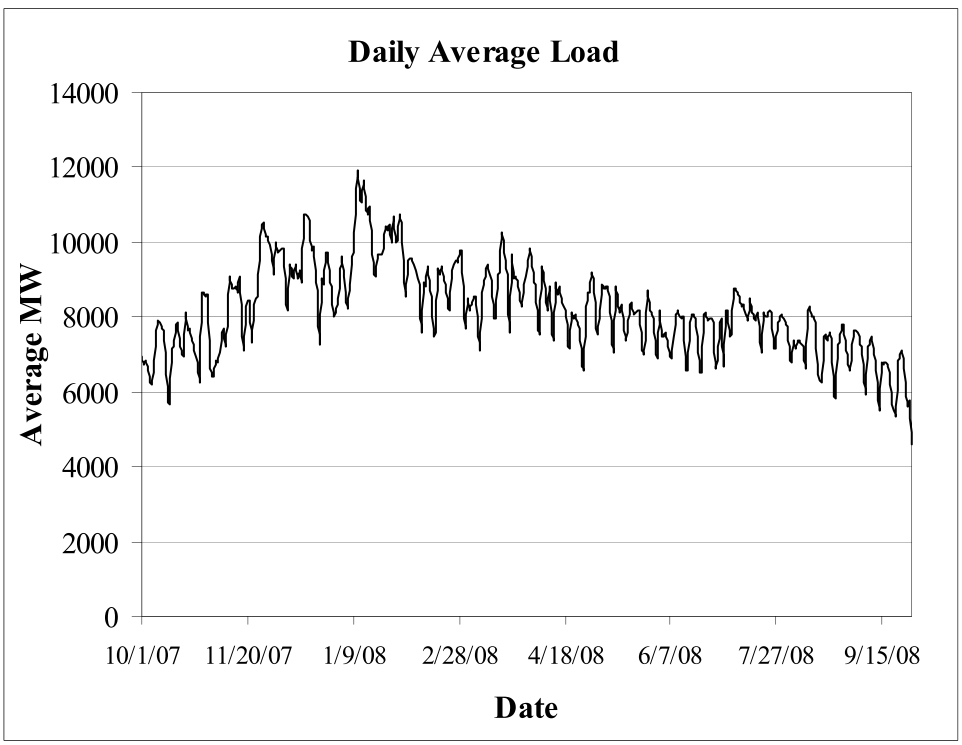
	Year	**Case**	**Jan-July Vol. at TDA**	**Oct-Sep Volume**
90%	1992	Low	77 maf	99 maf
50%	1958	Median	104 maf	129 maf
10%	1982	High	130 maf	167 maf

The average regulated discharge at Bonneville for the three water years selected is shown below.



Average Regulated Flow at Bonneville

Loads: The load profile used in the study was defined on an hourly basis and remained the same through each hydrologic sequence and reserve requirement scenario. The load was calculated by taking the generation from FY 2007 (adjusted for wind) and subtracting out the trading floor deals.



Average daily load profile

External Energy Sources: External energy sources included hydro independent, Willamette and non-hydro sources. These energy contributors were loaded as external energy sources on the BPA Bus. As a note, the external energy values were taken from the 8/21 Data Center. The Willamette generation and the generation values for LIB, HGH, ALF, and DWR are from the HYDSIM FY08 Study #2.

Markets: In all of the studies the wholesale purchase market has a limit of 4,000 MWh and the sale market is effectively unlimited. The prices came from the Aurora pricing model based off of the generation from the HYDSIM FY08 Study #2.

Availabilities: Operational conditions were based on plant availabilities defined in HYDSIM FY08 Study #2 adjusted for how reserves are treated in HYDSIM. These plant availabilities were then translated into unit outages. Because of the expected overhaul of the 3rd powerhouse units at Grand Coulee, one 805 MW unit was out of service the entire study period.

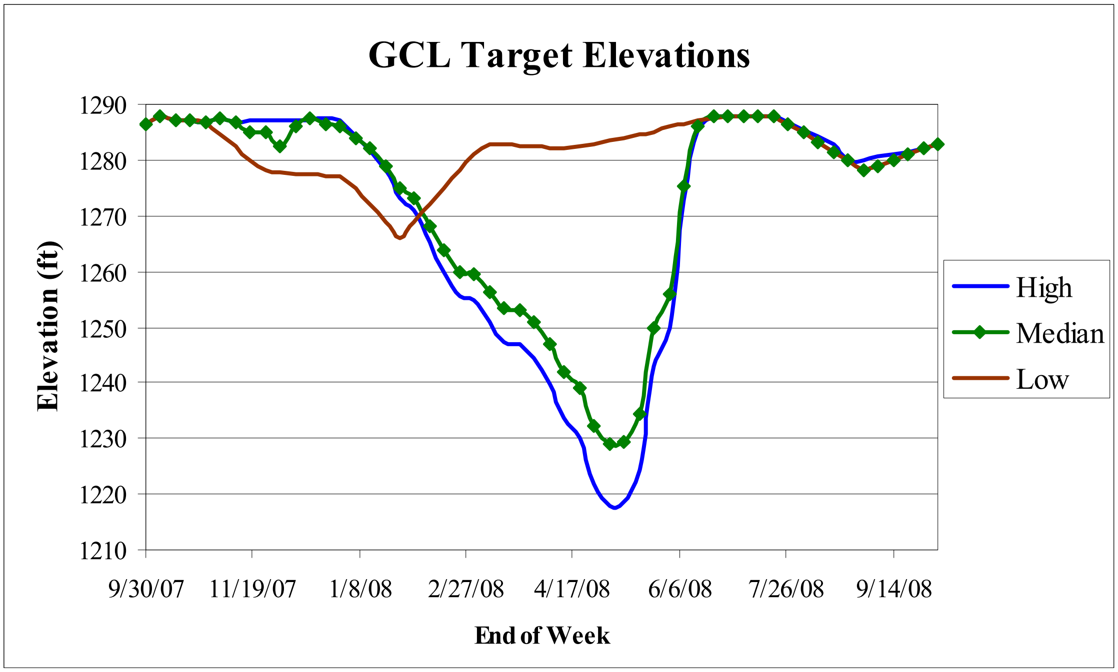
Hourly Blocking: To get results in a timely fashion, a seven-period blocking rather than hourly time steps were used for these studies. Even blocked, the year long studies took approximately 24 hours to complete. Over a long holiday weekend, test runs of a 2 hour grouping took approximately 3 days to complete. The hourly time step took a few weeks of computation time.

Regulating Reserves: Grand Coulee, Chief Joseph, McNary, John Day, and The Dalles were eligible for regulation, spin and non-spin reserve types. All other projects were eligible for spin and non spin only. The reserve levels used in this study are based on the *Regulation, Load Following and Generation/Load Imbalance* report prepared by the BPA Wind Integration Team (WIT) and presented on September 10, 2008, an average summary of the requirement is listed below.

Average Regulation Reserve Requirement

FY Wind	Base 0 MW	2008 1425 MW	2009 2105 MW	2010 3155 MW	2011 4330 MW	2012 5570 MW	2013 6670 MW
Up Reg	679	757	894	1179	1414	1693	1983
Down Reg	837	884	1048	1453	1773	2174	2542

Run Scenarios: Run scenarios included a base case and several future reserve cases. The evaluation and calibration of operations under existing conditions was performed over a 1 year period for the three flow cases. Operation constraints were adjusted during the spring runoff season to accommodate the different flow volumes and form the base case condition. Grand Coulee water level constraints were supplied to guide operations for each of the hydrologic years. The results were compared as incremental changes from the base to represent the additional operating costs associated with the additional wind integration reserve requirements



Grand Coulee target water levels

BONNEVILLE POWER ADMINISTRATION

DOE/BP-4000 • March 2009