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The Implementation Challenges Behind a Hydro Cascade Decision Support System

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ABSTRACT

The Vista Decision Support System (DSS) was implemented for Brascan Powers New York hydro system (formerly Reliant Energy) located in Northern New York State in 2003/2004. This paper describes the challenges to successfully implement Vista. The paper presents a brief description of all the DSS modules and outlines the input data quality analysis and validation methodology. The importance of historical operational, hydrological and weather data series analysis is highlighted due to the ability to identify the inadequacies and how they can lead to important operational issues such as erroneous efficiency curves or obstructed orifice gates. A detailed description of both the inflow forecast and the generation scheduling tools is presented, including the calibration process and the testing. Recommendations to ensure an efficient and safe transition from legacy scheduling methods to the new system are included.

1. Introduction

Competitive market forces are changing the way power producers view hydroelectric generation. The ability of hydroelectric facilities to store energy and respond quickly to changes in the market makes it a very powerful asset for the energy trader. Being able to optimize hydro generation in the new de-regulated market environment while taking into account all regulatory and operational constraints becomes a critical challenge.

In this context, a decision support system (DSS) like *Vista* becomes an essential and very powerful tool. Indeed, *Vista* is sophisticated energy optimizer/simulator software with highly developed hydroelectric features. *Vista* assists managers, engineers, specialists and operators in their decision making, regarding the planning and the operations of each power plant, unit, water control work and reservoir, over a long-term horizon of the next year or more, to a short-term horizon of just the next few hours, the current or the next week. Operators can optimize then simulate

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several scenarios; they can ratify and apply the most cost effective schedule, taking into account all the related impacts. *Vista* also helps to maximize profits through power contracts and spot market opportunities, while meeting all constraints.

Vista is already used by more than fifteen power generating companies in North America, including Brascan Power. Based on this experience, this paper explains the implementation challenges to accurately define the equipment characteristics, the operation process including constraints, the energy market opportunity and the watersheds & related hydrology. These tasks are mandatory prerequisites to forecasting natural inflows and preparing an optimum generation plan and detailed schedule.

2. Objectives

Brascan Power New York operates 71 hydroelectric generation stations on 6 river systems with a total of 674 MW and produces an average 2,933 GWh of electricity annually. Most of these stations are run-of-river plants and must be carefully operated with regards to fishery, flood control, recreation, environmental and navigation constraints. In September 2004, Brascan introduced its energy sales in the open market and consequently needed to adapt and improve its power plant management.

Following this objective, the company selected Synexus Global in 2003 to implement its *Vista* decision support system (DSS) to meet their growing needs with regard to efficient operation within the context of the energy open market.

Hydro system management tasks are complex and require sophisticated models to simulate with acceptable accuracy, the plant operations given their hydro and network characteristics, hydro and transmission constraints, energy load and contracts, etc. The quality of the DSS results depends greatly on the models degree of accuracy, but also on how the DSS is implemented and used.

3. *Vista* DSS Description

Vista DSS is an integrated system that includes 9 modules (see Figure 1).

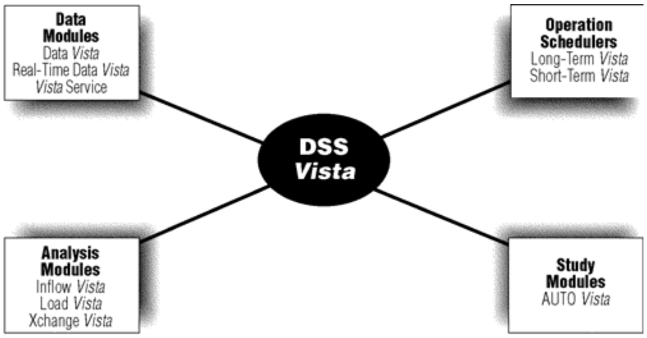

Figure 1 - *Vista* DSS Module Summary

These modules consist in the following (Ref. 1):

- Data *Vista* - provides access to all hydro system characteristics and constraints which is stored in a static database;
- Inflow *Vista* (IM)- forecasts natural inflow by watershed (at all gauged sites and/or reservoirs) for long and short term analysis;
- Load *Vista* - defines the load demand for customers;
- Xchange *Vista* - defines the market transactions;
- Long-Term Generation Scheduling (LT *Vista*) - manages the storage reservoirs, plants operations and power exchanges over a time horizon of a year or more;
- Short-Term Generation Scheduling (ST *Vista*) - schedules the hourly operations of power plants and control works over 1 or 2 weeks, including reservoir levels, unit generation, spilled flows and power exchange;
- Historic Simulator (AUTO *Vista*) - analyses past operations and optimises (combination of LT and ST) them to calculate the benefits and the cost of any new constraints or upgrading equipment. Can analyse or optimize system operations for multiple hydrologic scenarios (What-if analysis) over a 1-year or longer study period;
- Real Time Data (RT *Vista*) – access real-time data, including SCADA and hydro-meteorological data, displays and enables the editing of the data, calculates derived data like total outflow, power flow and natural inflow;
- Server Application (*Vista* Service) - acquires each hour (or smaller time step) the SCADA data (client system), river gauge data, and meteorological station data. Can fill in missing data and can automatically launch some RT, IM and ST functionalities.

4. Data Input Quality

Data input quality is the most important factor that affects the results and accuracy in a DSS implementation. Mainly, this applies to:

4.1 Data Integrity (Ref. 1)

The successful implementation of such a DSS system tends to improve the data integrity taking into account:

- The uniqueness: It is important that data be defined only once within the system, even though the information may be needed in different forms by more than one function. This is often not the case prior to a DSS implementation, as each of several existing stand-alone functions tend to have their own data set, in their own format;
- The consistency: Often, the data set is not up-to-date or applied adequately (ex. the modelling of operating rules); and
- The security: an integrated DSS supports privileges, as various levels of users are not allowed to change the data. It is also very important to distinguish between the Official and Study (What-if analysis) data sets.

4.2 Physical Modelling of the Hydro System

The various hydro system components and characteristics must be accurately defined, such as:

- Reservoirs: level-storage rating curves;
- Generating Units:, efficiency curves, head losses, operating limits;
- Spillways and gates: discharge rating curves in free and/or controlled conditions, as a function of gate openings, maximum spill;
- Tailwaters: rating curves with or without downstream water level if they have an impact;
- River Reaches: time delay and/or routing effect using Muskingum method, when applicable.

However, it is common to find that the data is not ready for the immediate implementation within a DSS, both in terms of accuracy and format. A significant effort is required to obtain the best and coherent information (Ref. 1).

4.3 Modelling of the Operating Rules (Ref. 1)

Operators may have a number of un-written rules that need to be formalised. Very often, rules are not really optimal and must be analysed or changed prior to their integration in the DSS. A typical example would be the use of reservoir rule curves based on a few extreme inflow years. The use of optimal results as generated by a stochastic optimisation model within the DSS (using all historical inflow series) is generally preferable.

4.4 Historical Data Quality

The schedule results and inflow forecast will be only as good as the historical data. Reservoir water level, unit generation, spillage, river gauge measures and meteorological data are used to calculate the current hydraulic conditions and to produce the inflow forecast.

Firstly, hourly operational data must be validated for a historical period of a few recent years before the natural inflow series calculation is done. Efficiency curves of old turbines, undocumented flashboard operations, tailwater data effected by downstream pond level, erroneous head loss calculations and wrong fish constraint, are some of the most important sources of uncertainty affecting the model's accuracy. If these inaccuracies are not investigated and corrected, the model calibration can be wrong. For the *Vista* implementation, missing and erroneous data are corrected with the help of spreadsheets and macros. Then, these historical data are loaded in *Vista* to make a water balance analysis. *Vista* calculates the outflows and natural inflows based on coherent characteristics and reliable data sources. More precisely, the turbined flow is calculated based on the net head and unit generation. The natural inflow is calculated from the water balance principle, considering reservoir storage variation, total outflow and upstream controlled inflow (which corresponds to the upstream reservoir total outflow).

In order to identify the suspicious data, the analysis consists mainly in making a water balance study, considering the following:

- Comparison of provided historical inflows with non-perturbed river gauges data. The Table 1 presents a few incongruities (CAR, STK and SOC) when compared to two neighbouring river gauges (PCF & SOC). The PCF and SOC gauges have similar specific flow of 1.90 and 1.93 cfs/mi2 respectively, hence the average specific flow in the region should be in the range of 1.92 cfs/mi2

Table 1 Calculated Average Inflow Compared with River Gauges Average Data

Subbasin	Area	Mean inflows *(1953-2001)*	Specific inflows	Comments
	(Mi^2)	(cfs)	(cfs/mi^2)	
PCF River gauge	**723**	**1377**	**1.90**	**Reference**
PCF calculated	idem	1378	1.91	Good /PCF river gauge
CAR calculated	135.7	230	1.69	Too low
STK calculated	9.7	91	9.38	Too high
FIF calculated	3	6	2.00	Good
SOC calculated	13.3	10	0.75	Too low
SOC River gauge	**942**	**1820**	**1.93**	**Reference**

- Comparison of calculated daily flows with river gauged daily flows at a same location. This helps to identify suspicious data based on a reliable gauge. For example, the Figure 2 shows an underestimation of the calculated flow at PCF by 15 to 20% for the high flow range. We see that this offset was not observed in Table 1 due to the compensation effect of averaging over a long period.

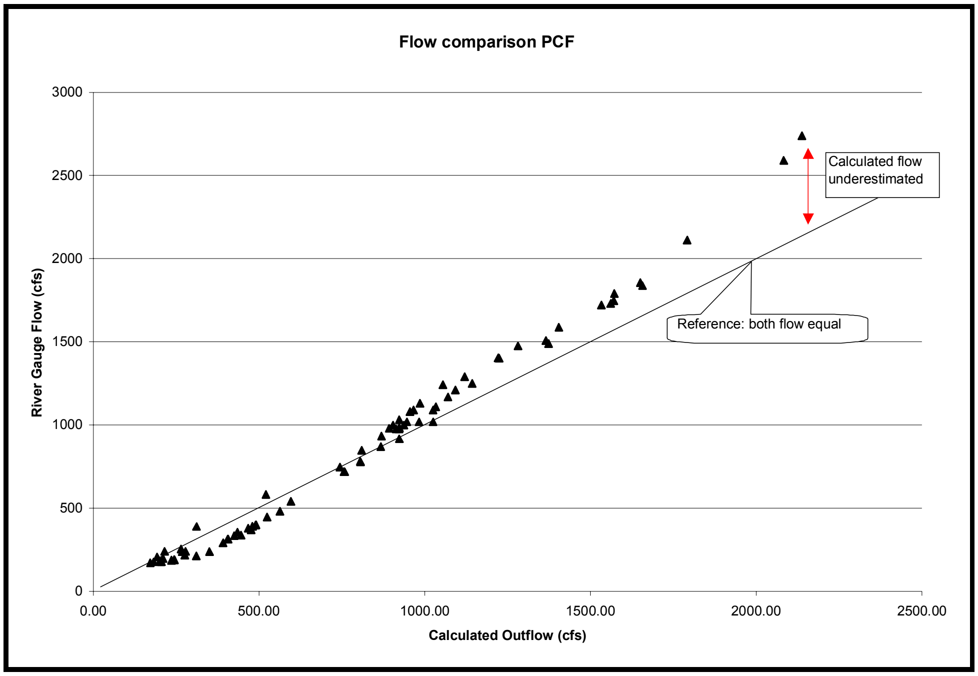

Figure 2 - Calculated Daily Flows Compared to River Gauge Daily Flows

- Comparison of total flows from upstream plants to downstream plants. The total outflow calculation along the river system should be increasing going downstream if the downstream plants are all run-of-river. Figure 3 shows that in this case, the total outflow calculation along the river system is not coherent, having the first upstream reservoir (Carry) outflow higher than some of downstream plants. The big arrow shows the corrected flow (30 % reduction) for that plant.

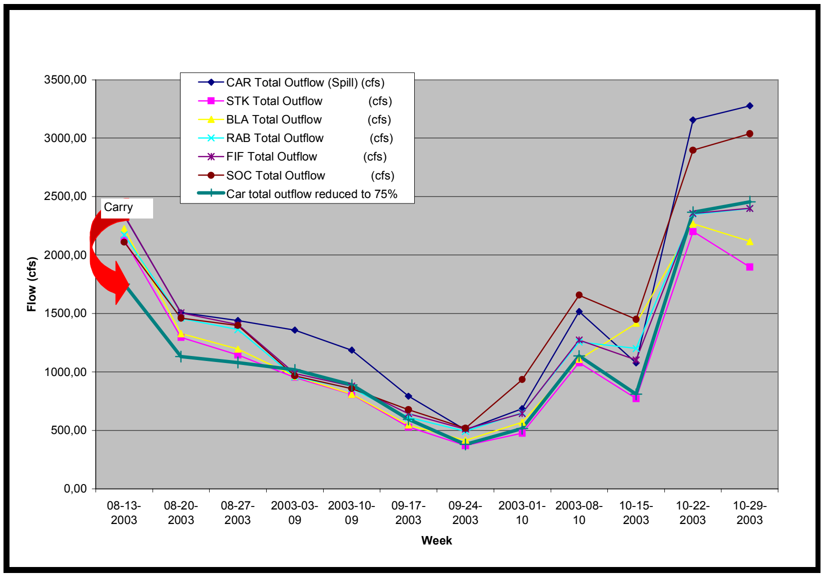

Figure 3 - Total Weekly Outflow Verification For Run-of-River Plants

- Spill curve validation. From the observations of Figure 3, the spill flow rating curves at Carry were analysed. They appeared to be correct. From on-site investigation, it was found that the gate orifice was progressively obstructed during the last 3 years by debris, causing presently a 30 % flow restriction and therefore the overestimated total outflow.
- Efficiency curve validation. This effect is partly caused by the inaccuracy of the generation measurement (possible error of 5 %) based on the current turbine efficiency curve (possible error in the range of 10 % to 20 % for very old turbine due to a lack of recent information). Adjustments were made to some generating unit efficiency curve to have more consistent data.

Even with a lot of effort done to identify the possible sources of error, to validate and modify the characteristics and the dynamic data, some actions are still needed to be done as they take more time to be put in place. Until all corrections are completed, the quality of the model's results won't be at its best. The main impact of the inaccuracy is on the water balance and inflow estimations, which is the basis of inflow forecasting and scheduling. Nevertheless, with this historical data analysis, the quality of the information was significantly improved and certainly, after one or two years of utilisation, the system set-up will be far more accurate.

4.5 Modelling of the Dynamic Data (Ref. 1)

Dynamic data is received from automatic data acquisition systems. The accuracy and availability of such input parameters as reservoir water levels, unit status and power generated, spill flows, etc. is critical. Indeed, errors may lead to serious miscalculations in natural inflow (backrouting calculation) and in short-term scheduling. Consequently, the RT *Vista* module warns the operator of any suspicious or missing data. A pre-determined rule such as interpolation or repeating the last value can be set in the *Vista* Service for the missing values. As for the suspicious values, at the present time they can only be corrected by the user, but enhancement on this issue are to come. The model results remains within acceptable range, allowing schedulers to rely on *Vista*. Nevertheless, the users must stay vigilant with all of the inputs and outputs of the DSS. The incoming data (SCADA, weather, hydrological) must regularly be validated and corrected. If the system is not used for a certain period, a data validation is again required to get it up to date, due to frequent suspicious or missing input data.

5. Inflow Model Calibration and Performance

5.1 Model Description

The Inflow *Vista* Module is the inflow forecasting component of *Vista*. It translates actual and forecast hourly values of precipitation (rain or snow) and temperature into runoff entering the river at a specified watershed defined by the presence of river gauges or monitored reservoirs. Inflow forecasts are required by all the generation scheduling modules of *Vista* (ST, LT, and AUTO). The forecasting features are summarized in Table 2.

Table 2 Inflow *Vista* Features

Feature	**Short-Term**	**Long-Term**
Typical time horizon	1 – 2 weeks	1 – 2 years
Data Format	hourly	daily
Calculation Methodology	- National Weather Service River Forecast Model (NWSRFM)	- univariate time series model - multivariate time series model - National Weather Service River Forecast Model (NWSRFM)); Extended Streamflow prediction (ESP)
Operation	- manual (run by the user); or - automatic (run by *Vista* Service)	- manual (run by the user).

Additionally, Inflow *Vista* offers the following features:

- capability to import user-defined forecasts;
- displays for viewing, editing, and graphing both historic and forecast meteorological data;
- displays for viewing and graphing both historic and forecast inflow data.

In the Brascan implementation, the inflow calculation methodology is a modified version of the National Weather Service River Forecast System (NWSRFS). More precisely, it is based on the Sacramento Watershed Model, Parameters model (soil moisture accounting and runoff) and the HYDRP-17 model (snow accumulation and ablation) (Ref.2). The model includes over 20 parameters per watershed. In-depth knowledge of the model and its numerous applications to the watersheds are required to achieve a good calibration. The calibration of the coupled Sacramento and snow models is work intensive and has to be approached very methodically. In theory, most of the parameter values of the NWS models can be derived from hydrologic field and time series data. Based on the project team experience, however, only some are derived from observing historic streamflows and meteorological conditions and the remainder are manually derived from adjustments of reasonably standard values so that parameter values stay within physically realistic limits.

5.2 Model Set-Up

The watershed inflow forecast is related to the hydro system by the inflow arc. To produce the watershed inflow forecast, the watershed, the meteorological stations and the meteorological forecast region must be defined, as presented in Figure 4.

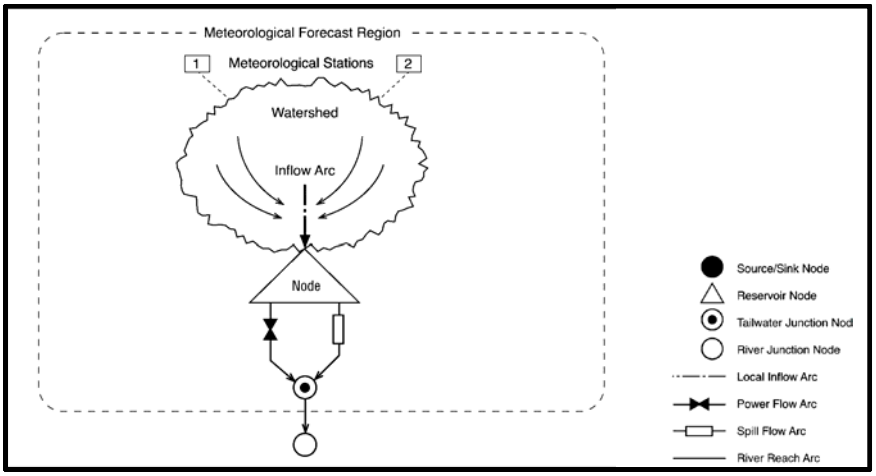

Figure 4 - Inflow Module Components

To ensure that real-time meteorological data is available, each watershed is typically related to multiple met stations. The met stations are defined in several groups in a way to ensure that some data can be processed even if some met stations do not report at a particular time. To take into account the accuracy of the met stations within a group, the data from each met station is weighted differently based on Thiessen polygon and/or Isohyetal methods (Ref.3). Also, temperature data are corrected based on the laps rate, considering the average elevation of the watershed and the station elevation.

5.3 Model Calibration

The IM calibration process is done in two steps. Firstly, the calibration of regionalized parameters based on historical daily values (5 to 10 years) of observed flow, precipitation and temperature. Mean area precipitation (MAP) and Mean area temperature (MAT) are calculated for each watershed based on the meteorological station groups. Figure 5 presents the calibration of the Newcomb watershed.

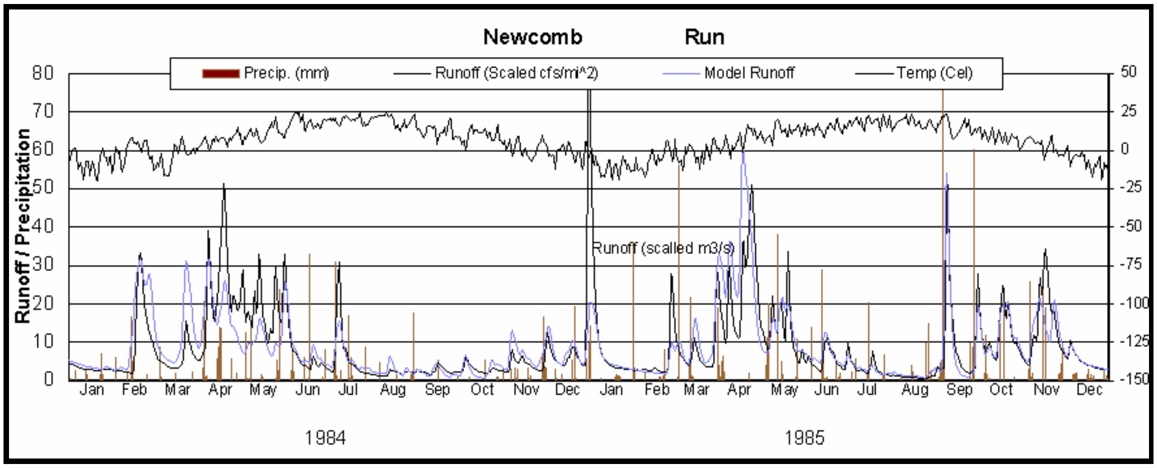

Figure 5 - Newcomb Watershed Daily Calibration

Secondly, the calibration is fined-tuned with hourly historical data (at least 1 year) to define the watershed routing of total channel inflow by using a dimensionless unit hydrograph of the form:

$$Q(t) = Qp\ (t/tp)n * exp((t/tp-1)*(n-1))$$

Where Qp is the peak flow rate (m3/s or ft3/s), tp is time to peak in hours and n is a dimensionless shape parameter. The final calibration result by comparison with observed flow is shown in Figure 6.

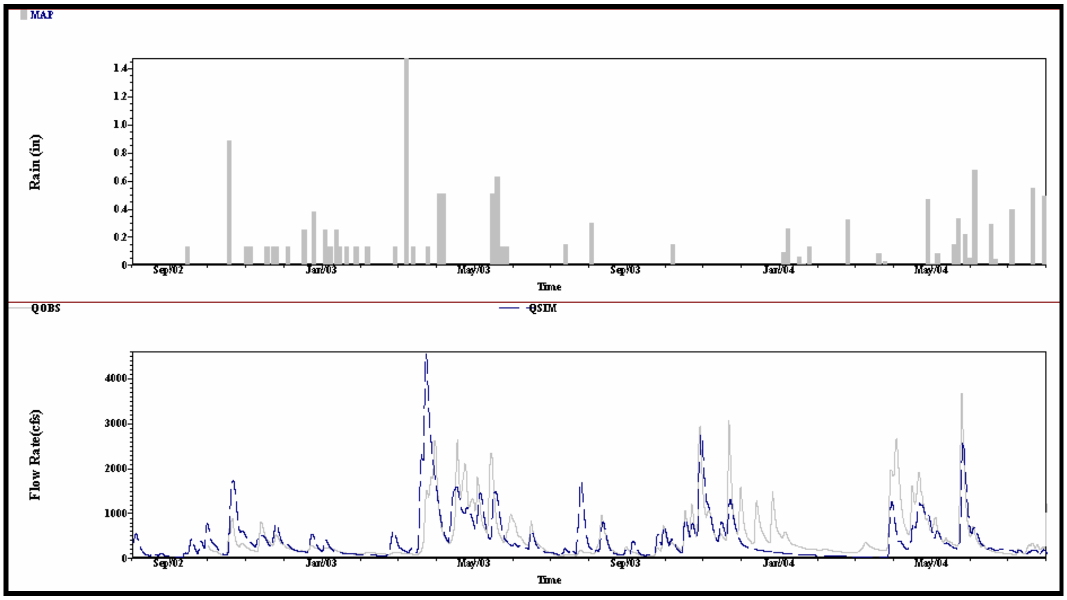

Figure 6 - Newcomb Watershed Hourly Calibration

The calibration of the Newcomb watershed has a Nash coefficient of 72.4 %. Figure 7 illustrates an example of an inflow forecast for the period from September 25th to November 7th 2003.This example is based on a past period so that an appreciation may be gained regarding the model accuracy excluding meteorological forecast uncertainty. The exact MAP and MAT are used as a forecast and, having the observed inflow, it can be compared with the simulated one.

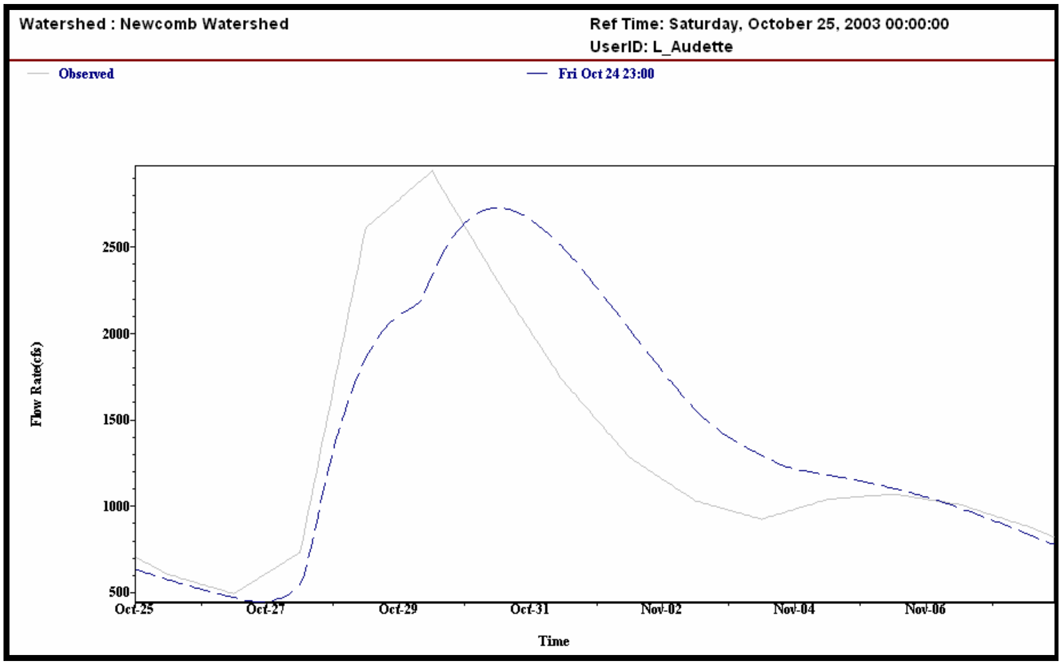

Figure 7 - Inflow Forecast Example on Newcomb Watershed

5.4 Inflow Model Calibration Challenges

Observed inflows are calculated by water balance at the gauge (outlet) or at the reservoir based on operational data. As discussed in section 4.4, the inaccuracy of the operational data has an impact on the calculated inflow series. Basically, a watershed that has a lack of accuracy in the data is almost impossible to calibrate if there are no river gauges nearby. When operational data are inaccurate, it is indeed preferable to use gauged data to build the inflow series. The challenge here is the availability of the gauges and the reliability of the data series. USGS gauge information appears to be quite good and easily accessible, although in winter conditions they sometime freeze within the ice and stop reporting the information. Field follow-up can then be required, if possible. Otherwise, there might be a significant gap between real conditions and simulated conditions without knowing it, as the observed flow won't be available for comparison with simulated one.

The most frequent challenge for watershed calibration encountered is the availability and reliability of the meteorological stations both for historical and real-time data, and their consistency with the hydrological data. Indeed, stations that are best located for most of the watersheds are the "Co-operative" (COOP) stations that can often be unavailable or at their best, data comes in a day later and consists of daily average value. ASOS stations, available in real time and on an hourly step, are therefore most likely to be used although in the present case, they are less accurate considering their distance from most of the watersheds.

Finally, keeping the watershed state variable up-dated and having the simulated flow reasonably similar to the observed one remains a continuous challenge, in the operational phase. Indeed, when there is an important difference between simulating and forecasting streamflow, the observed streamflow (for most watersheds) can provide the opportunity to monitor the model performance. There are several ways to update forecast models that vary in level of complexity. Most agencies that utilize conventional watershed models for forecasting, update their models in real-time by systematically adjusting estimated precipitation inputs and/or some of the model parameters until model performance is in-line with the most recently observed streamflow data. This can be a major task that may have to be repeated frequently during major events and requires the constant attention of an expert (Ref.4).

6. Results Validation and Benefits

6.1 Long-Term Basic Concept (Ref.5)

Long-Term (LT) *Vista* employs an optimization process that determines the optimum water release with the objective of maximizing water use benefits over the long term. The optimization process considers the optimum water use for each of a number of hydrologic scenarios, independently. More precisely, for one defined hydrology, it considers all the operational and physical constraints, the customer load and the contract scenario. Taking into account the possible future hydrologies, LT *Vista* uses a rigorous optimization methodology considering the probability distribution of all parameters over the long-term, to define for the next time step, the best water release, for each storage reservoir. LT *Vista* will also compute the marginal value of water in storage for each reservoir. Along with this marginal value of water, the output includes a schedule of releases and expected reservoir trajectories for the whole study period (usually at least one year). The first period optimization (1 or 2 weeks) is undertaken in order to pass on to the Sort-Term scheduling module, its end-of-period target (marginal value of water and/or water levels). LT should normally run on a weekly basis, but more frequently when the estimates of future value of generation and/or purchased power is changing.

The LT module is a significant improvement to the state-of-the-art in annual storage management, because it goes beyond determining a single hydrology optimum and beyond a 'optimum' storage uses for a set of possible hydrologic forecasts, since it rigorously convolves those results to yield a true optimum weekly water release in the ensuing time period.

6.2 Short-Term Basic Concept (Ref.5)

Short-term (ST) *Vista* is a flexible, interactive tool to assist operators in defining their generation scheduling for a short-term (days, 1 or 2 weeks) period. Based either on LT target (marginal value of water and/or water levels) or user-defined end-of-period targets (water levels), ST will dispatch on an hourly time step (or grouping hour), the plant outputs and storage releases. A key feature of this module is the ability of the dispatcher to carry out optimization analysis and to manually fine-tune (simulate) the optimum schedule to adjust for small changes in operations.

6.3 Validation and Benefits (Ref.6)

The long-term and short-term optimisation models do not have parameters to calibrate. The task here is to make a post-audit of the model calibration. This consists in validating the results and reviewing, if required, the characteristics, constraints and market conditions in order to have a first feasible operation that is consistent with the historical operation. Then a comparison between optimum and real operations is made to evaluate the benefits related to the optimization.

More precisely, the post-audit, is done in two steps. Firstly, an hourly simulation of the historical operation during a typical period (one week) is done and compared with the real data. As the initial and final reservoir levels and the total outflow at the upstream controlling reservoir are the same, normally the generation and revenues calculated from the simulation should be quite similar to the real values. A generation gap of 4 % was observed for the 1st week of February 2004 period. This is found to be acceptable taking into account the source of errors mentioned in the section 4. In other *Vista* implementations, this gap is more in the range of 1 %. This step allows to fine tune some of the inadequate power efficiency data or erroneous spillage data.

Secondly, an optimisation run is done for the same week as in step one, but where *Vista* increases the generation during the peaking hours. The Figure 8 shows the optimum generation compared to the current one. An increase in revenues of 5 % is observed along with an optimum peaking generation profile. On an operational point of view, such peaking operations are not easy to schedule considering that most of the plants are run-of-river and operations are not all remote controlled.

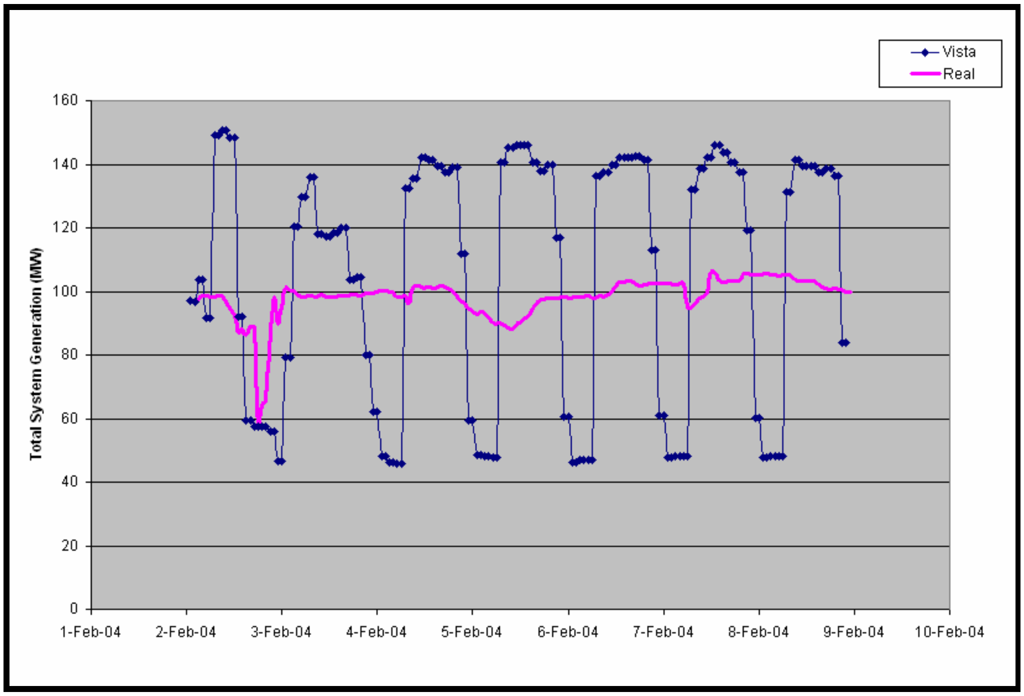

Figure 8 - Optimum generation compared with current generation

7. Utilisation Challenges

7.1 General Observations (Ref.1)

Implementing a DSS within the actual work process is a challenging task that should not be underestimated. Indeed, schedulers & operators who are used to their own home-made DSS (spread sheets) are often found to be reluctant to change their way of scheduling and operating. Training to use the DSS, combined with close support to users, are the keys to a successful DSS implementation. Changes to the work process can be difficult for the user and a constant follow-up during the initial stage following implementation, and even in later stages, reduces the project risks. Also, new users often find the training activity a heavy burden when combined with their normal work activities. Adaptability for both the corporation and the user is required for any successful DSS implementation.

7.2 Specific *Vista* Training & Implementation at Brascan Power

Considering this training effort, it is found preferable to split the *Vista* implementation phase into a number of smaller, separate deliverables, so that the client can exert better control over the project and limits its risks. More precisely, the *Vista* DSS implementation at Brascan Power was done with on-site visits & training effort, working mainly one river system at a time. In this case, the Raquette River was the first river system where the on-site work included data validation and *Vista* training as follows:

- General *Vista* training: *Vista* environment (modules and databases), LT-ST & RT modules;
- Data & configuration validation and site visits;
- LT/ST/RT review and General Inflow module training: presenting watershed calibration and preliminary Inflow forecasting procedure;
- Detailed Inflow module training when meteorological data was made available in real-time and calibration procedure completed.

Two additional on-site visits were made for Beaver/Black and Hudson/Sacandaga river systems covering the data and configuration validation, inflow forecasts and respective LT/ST training. Further, a Step-by-Step documentation was developed to accompany the operators on an everyday use, combined with telephone/e-mail support. Essentially, the support team assists the scheduler in doing their daily scheduling with *Vista*, in parallel with their usual scheduling tools. The results are discussed and analysed with the schedulers and the *Vista* team in order to detect how to improve the system representation and to eventually integrate new constraints or conditions if required. After a few weeks of testing, the schedulers are able to run *Vista* on their own. The *Vista* support team is always available for any assistance. Reference guides are also provided for more details on the *Vista* modules functionalities.

The *Vista* DSS implementation challenge within Brascan Power New York's hydro system was increased with the recent changes in the company administration. Indeed, the former Reliant Energy Company was bought by Brascan Power in fall 2004, with the consequence that significant changes were required within the company to adapt all of their system to the new owner's platform. This caused a significant delay for the operators to integrate the *Vista* system to their regular work.

8. Conclusion

In this paper, the *Vista* Decision Support System (DSS) and its 9 modules have been presented. The challenges of data validation and of the model calibration, as well as the implementation and integration of the DSS within the hydro plants regular working process, have been highlighted.

The implementation experience revealed that a key determinant to a successful project is the data input quality. One must not underestimate the importance of having good data (operational, hydrological, weather, contract, constraints, etc.). Water balance analysis is a simple and efficient way to identify erroneous data. USGS river gauges are found to be a very good reference for the water balance analysis as well as important or mandatory information for watershed calibration and inflow forecasting. On the other hand, the meteorological stations required for the inflow forecasting represent certainly a challenge to the hydrologists, due to their often poor availability and reliability.

On-site training and post-training support are essential to encourage the operators to work with the new tool, and bring it into everyday use. The support team must work closely with the operators to identify incorrect behaviours and fine tune the systems calibration. A successful implementation and an appropriate follow-up concerning training and support enable the client to fully make use of the potential of its DSS system. This includes not only the optimization of operations, but also the ability to have an easier access to the information, to easily update the system (new constraints, new contracts, unit upgrades, etc.) and to evaluate the impacts of these changes. The DSS will assure the uniqueness of the data and therefore uniformity of all the systems information, thus reducing incoherence with data processing within the entire company.

Finally, implementing the *Vista* DSS requires certainly an important effort in terms of data validation, model calibration and staff training. The effort undertaken by both Brascan Power and Synexus Global reported herein contribute significant positive impacts on the actual operations, including an increase in generating revenues and overall hydro system management, both extremely important in a competitive open market context.

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