# Hydro-Québec Experience with Acoustic Scintillation Flow Measurement Method in Low Head Power Plants

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ABSTRACT

*The flow is one the most difficult parameters to measure in determining the efficiency of a hydraulic turbine. For low head power plants, it is even more difficult because the measurement is normally done in a short converging intake. Few methods exist for performing the flow measurement under these conditions; one of them is the Acoustic Scintillation Flow Measurement (ASFM) method. After a first comparative test with a Current Meter (CM) measurement at Laforge-2 power plant, HQ acquired an ASFM system and has gone through a series of comparative tests in five other power plants. For some power plants, the agreement between both methods (CM vs ASFM) was good while for some others, difficulties were encountered which lead to a greater difference. These results will be used to illustrate the accuracy achievable with the ASFM under various intake hydraulic conditions.*

## Introduction

In order to improve the accuracy of the discharge measurement of low head power plants, Hydro-Québec has decided to explore different methods. Given the short converging intake form or often a very irregular layout, the only method that can be used actually according to the IEC 41 test code is the Current Meter (CM) method. The ASME PTC-18 test code does not recognize any method as valid for flow measurement in these conditions.

Among the new methods was the Acoustic Scintillation Flow Measurement method. Initially developed for measurement in the ocean and rivers, ASFM have been adapted for measurement in low head power plant. Among other advantages of this method is that the instruments can be installed outside of the main flow since they are generally installed in the stop log gate slots. Also, the transducers do not require any calibration. This method can also be used for permanent measurement.

The first test done with the ASFM method in one of HQ's power plant was at Laforge-2 during the discharge measurement made by the CM method. Following the tests performed by ASL-AQFlow in one of the three bays, HQ acquired an ASFM system. HQ performed its first test at the Coteau-1 spillway, which is not a typical case for this method. Other tests were done in the intake of low head power plants. The ASFM measurements were compared with the CM results in four power plants.

The technique used by HQ for the measurement by both ASFM and CM methods was the sweeping technique. For most of the tests, one or two rows of current meters and one pair of ASFM transducers were mounted on movable frames which are moved vertically to record the velocity profile along the entire height of the measurement section. The velocity profile was then integrated numerically. The sweeping technique was chosen for the ASFM method compared to a fixed path method mainly to reduce the time to perform the test since the current meters are already mounted on those frame.

## Principles of Acoustic Scintillation Measurement Method

Acoustic scintillation drift measures flow by utilizing the effects of naturally-occurring small-scale turbulence on underwater sound signals sent across a water passage [1-7]. The variations of refractive index caused by the presence of the turbulence produce random fluctuations in the amplitude of the received sound signal. If two propagation paths are placed across the passage, and are sufficiently closely spaced that the turbulence does not evolve significantly during the time required for the mean flow to carry it form the upstream to the downstream path, then the pattern of fluctuations observed at the downstream receiver is the same as that observed at the upstream receiver, except for a small time delay (Figure 1). The time delay may be measured by recording both received signals and computing the time-lagged cross-correlation between them. The position of the peak of the cross-correlation function gives the time delay, $\Delta t$. If the spacing between the paths, $\Delta x$, is known then $V = \Delta x/\Delta t$ is the along-path average of the component of the velocity perpendicular to the propagation paths. For typical hydroelectric intakes, $\Delta x$ is 35 mm.

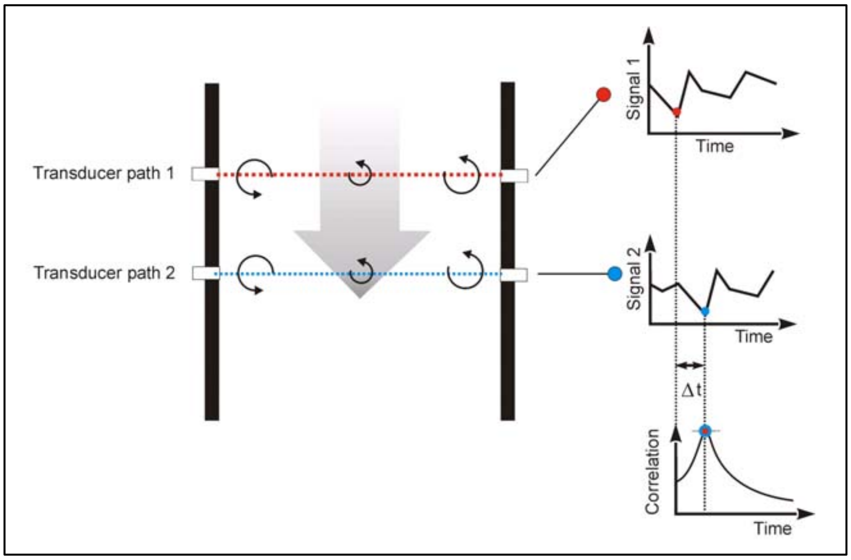

**Figure 1 - Illustration of acoustic scintillation drift principle**

Using three propagation paths arranged in a triangular array allows both the magnitude and the inclination of the laterally-averaged flow to be measured. Placing a number of paths over the height of a turbine intake bay and integrating the horizontal component of the velocity over the height of the bay results gives the discharge through the bay, and the sum of the discharges in all bays gives the total turbine discharge. For a typical Kaplan turbine intake, the transducers are mounted on removable frames installed in the stop-log slots. With 10 paths per intake, measurement accuracy of ± 1.5% can normally be achieved [8,12].

## Coteau 1 spillway

The Coteau 1 spillway is part of the Beauharnois development on the St-Lawrence river near Montreal. It is used to control the flow going to Les Cèdres powerplant situated slightly downstream. As this plant has a lower head than the Beauharnois plant, operating parallel to it, a minimal flow is maintained throughout the year towards the Les Cèdres powerplant. Model tests were performed to determine the spillway flow. However, a better accuracy was required for the plant operation.

The Coteau 1 spillway has twenty (20) gates, that are 42 feet wide and have an upstream water level of 5,4 m (Figure 2). Hydro-Quebec chose to try the ASFM method at this site, after at first considering the use of the current-meter method. The latter was not retained as the water velocity at the location where the current meters would have been used, i.e in the upstream gate slots, was high and the flow was strongly inclined.

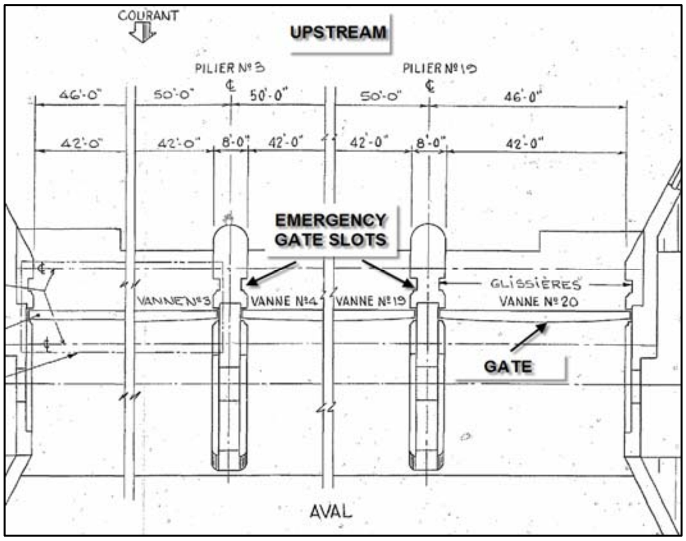

**Figure 2 - Coteau-1 spillway layout**

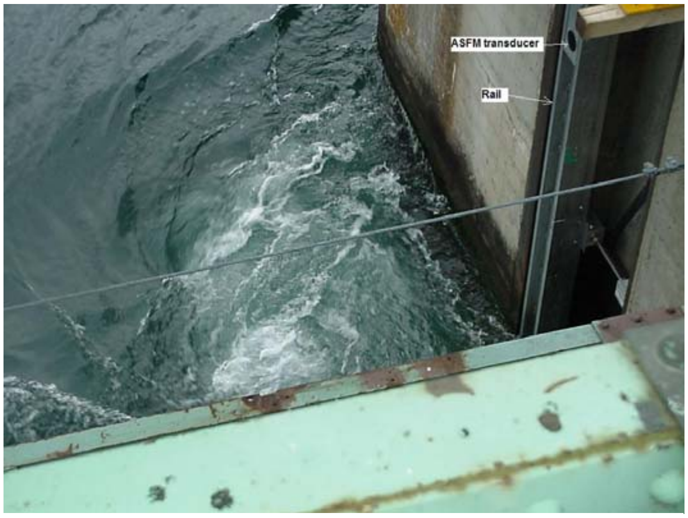

**Figure 3 - Typical vortex in front of the ASFM transducer at Coteau-1**

The ASFM transducers were installed on rails specifically fabricated for the tests (Figure 3). The transducers could be positioned at any chosen height using two electronically synchronised hoists. During the tests, the measurements were made while a continuous sweep of the gate section was performed with the transducers.

The measurements were made at heights comprised between full opening and 0.55m from the sill. From 0.75 m and beyond, air was entrained in the flow as can be seen in Figure 3. The air bubbles were responsible for signal loss and a reduction in the quality index of the acoustic signal. Only at the 0.55 m position were the results satisfactory. The measured flow at this opening is 47.0 $m^3/s$ as compared to the model test value of 46.0 $m^3/s$, thus a 2.1% difference.

The velocity profile is shown in Figure 4. It can be seen that the velocity variations are large even in the absence of any upstream obstacle, such as trash racks. It is possible that this is caused by the

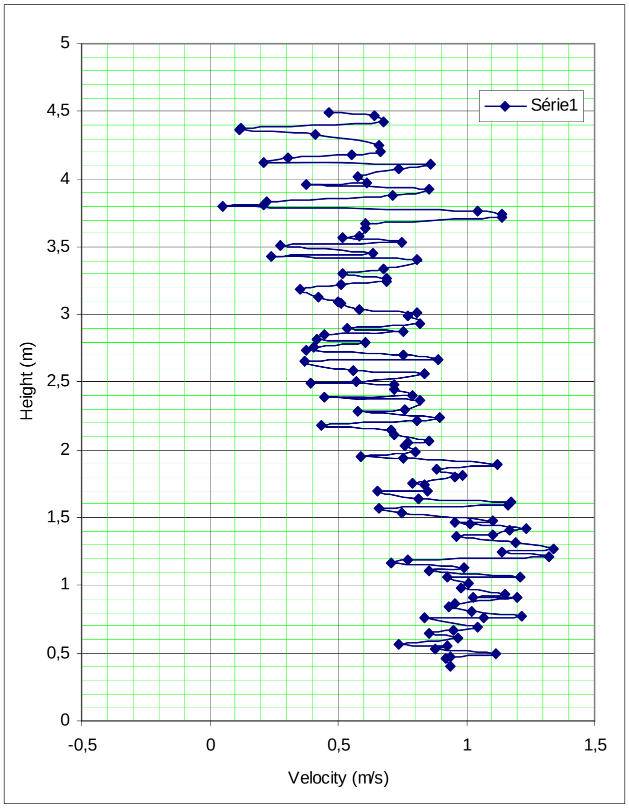

**Figure 4 - Velocity profile at the Coteau-1 spillway**

sizable turbulence downstream from the nose of the piers.

This turbulence combined with the presence of air bubbles in the water may have led to a bias in the flow measurements done at other openings. Indeed, this strong turbulence, which moves more slowly than the rest of the flow, might have caused the flow to be strongly underestimated as the results have pointed out. As was observed during the measurements done at Les Cèdres powerplant, the amount of turbulence can be very low in the absence of an obstacle, such as a frame, that promotes water mixing.

## Les Cèdres

Les Cèdres powerplant is situated on the original river bed of the St-Lawrence. Power is generated from the water coming from the Coteau 1 spillway and which therefore does not pass through the Beauharnois powerplant. The geometry of the water intake of each of its 17 units corresponds well to the typical shape for which the Acoustic Scintillation method was developed (Figure 5), i.e. short and irregular in form. The intake comprises three separate entrances, each of which are divided in two vertical sections by a two foot thick horizontal pier. For a number of years, the lower gate has been left in place on a permanent basis. A first set of measurements was done using both the Current-Meter and the Acoustic Scintillation methods. The measuring instruments were placed in the gate slots upstream of the trash racks and moved to various positions along the vertical axis in order to properly sample the velocity profile in the measurement section. To avoid having to cross the wake of the horizontal pier, the lower part of the intake was temporarily

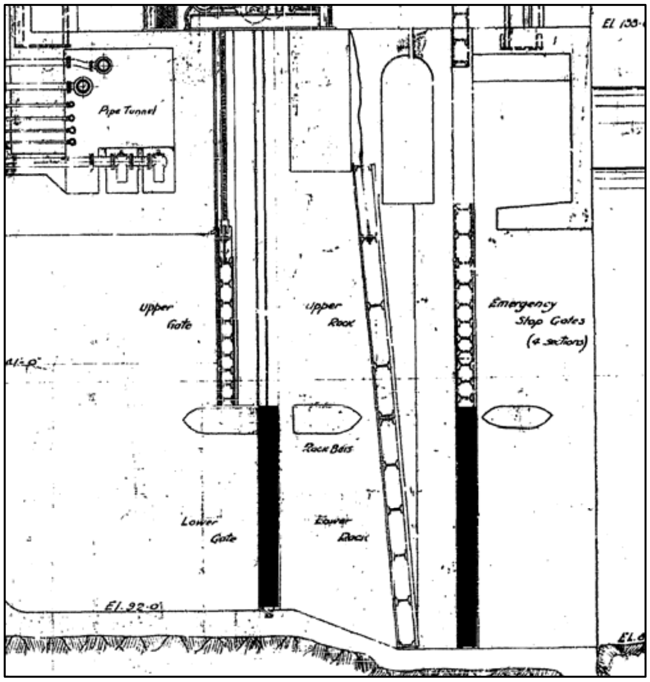

**Figure 5 - Les Cèdres intake layout**

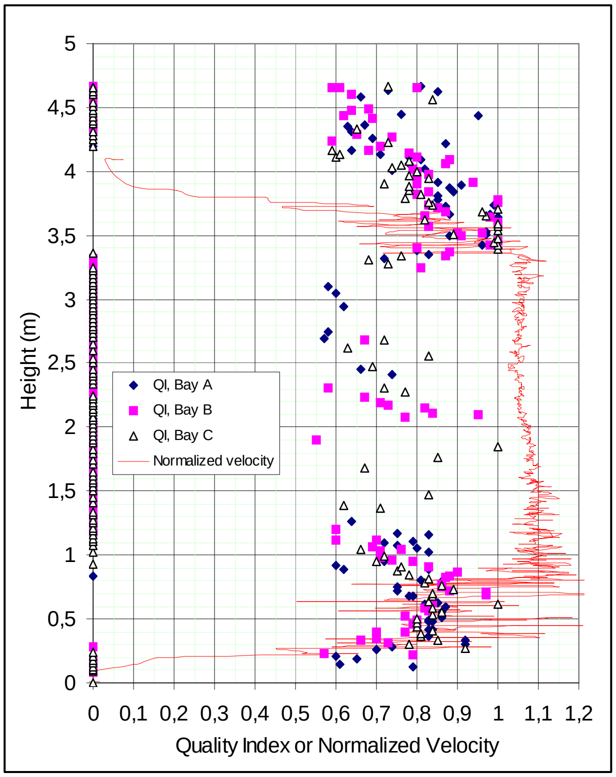

**Figure 6 – Les Cèdres, quality index (QI) and normalized volecity of a current meter**

blocked. The flow was therefore temporarily confined to the upper section of the intake, as was already the case in the area of the intake gate.

The CM measurements were done using mobile frames (Figure 9, 12). Ten current meters were mounted on the lower horizontal support rod of each frame. A number of these current-meters were of the Ott self-compensating type and were therefore able to measure directly the horizontal component of the velocity for flow angles up to 15°. Siap and in house made current-meters completed the set up. Neither of these was of the self-compensating type.

The flow was anticipated to be horizontal at the current-meter measurement section. However, the Acoustic Scintillation measurements show a significant upward component of the velocity. The flow angle was around 25° at the lower part of the section and 45° in its upper part. This would likely have been seen had CFD simulations been done prior to the tests. The flow angle values were much higher than the maximum angle for which the current-meters are designed for. As the orientation of the current-meters was not possible for this test, a correction of the velocity, based on calibrations done at different angles, was calculated. This however resulted in an increased measurement uncertainty.

The first set of measurements made using the ASFM method were done using the same type of rails and transducers as were used for the Coteau 1 tests. These rails were placed in the same slots, upstream of the trash racks, as the current-meter frames. As a result the current-meter and Acoustic Scintillation methods were not done simultaneously.

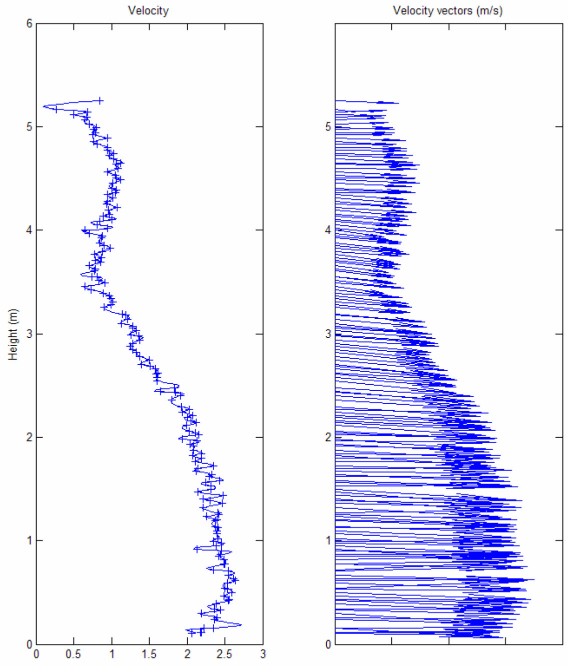

**Figure 7 – Les Cèdres velocity profile downstream of the trash racks**

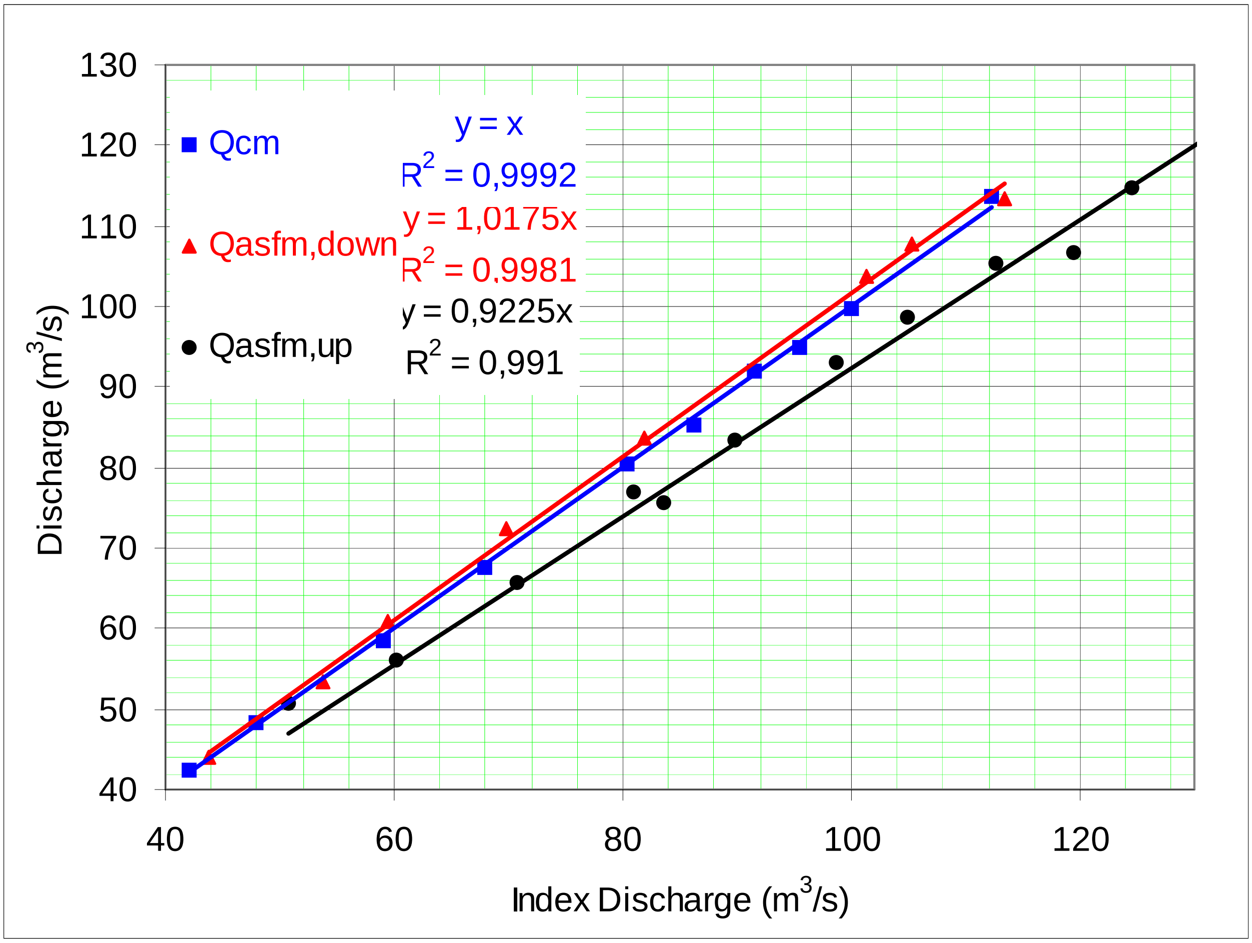

**Figure 8 - Comparison of discharge measurement at Les Cèdres**

Another set of Acoustic Scintillation measurements were done with the transducers installed downstream of the trash racks in the lower headgate slots. This was done as the measurements made upstream of the trash racks showed a very low turbulence level over a large part of the measurement section. This caused the quality index (QI, Figure 6) to be poor and some velocity measurements were not possible (QI equal to 0). In effect, a look at the instantaneous velocity measurements from a typical current-meter (Figure 6) shows that the turbulence level for those heights between 1.5 m and 3.2 m was very low compared to that of the upper and lower part of the section.

The velocity profile measured by the ASFM (Figure 7) was found to be fairly smooth considering that large structural components of the trash racks were very close upstream of the measurement section.

A comparison of the discharge measurements was made by using an index measurement as the reference since the other discharge measurements (CM, ASFM upstream and downstream of the trash racks) were not done at the same time. The index measurement was based on the pressure difference between the headrace level and the pressure in the scroll case and was calibrated using the CM discharge (Qcm).

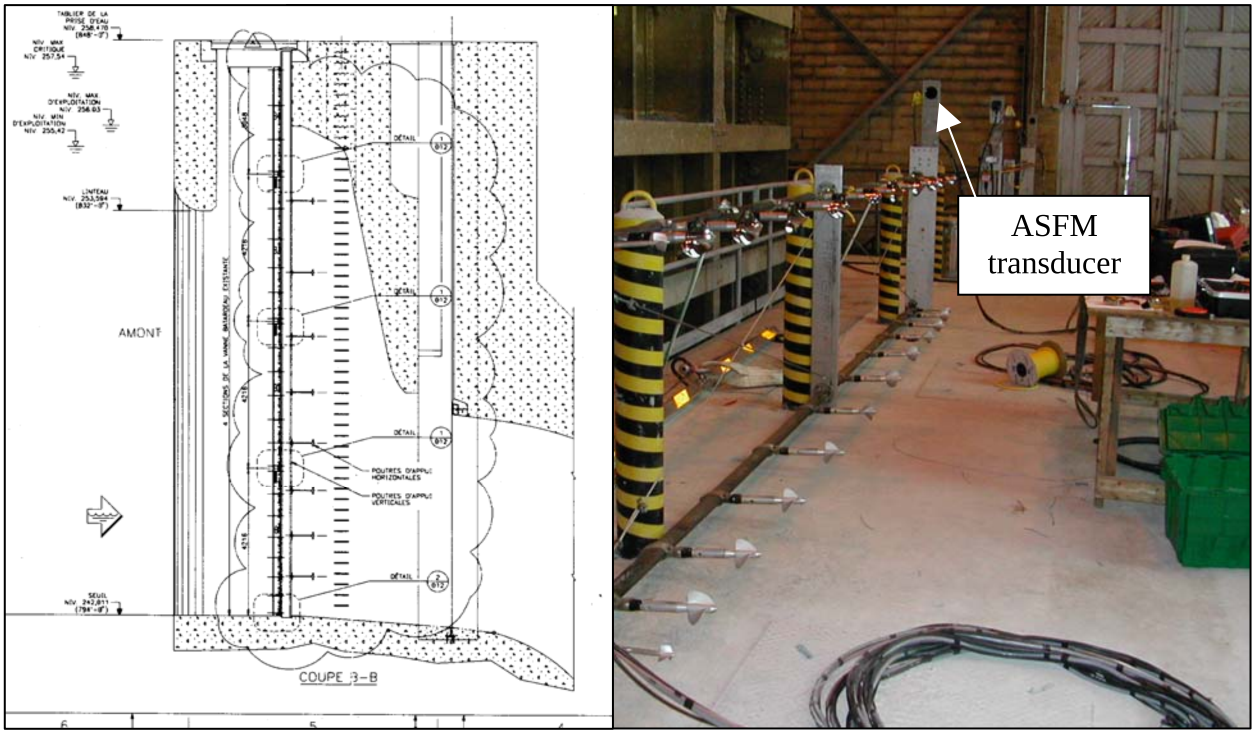

Figure 9 - Rapides-des-Quinze intake layout and CM and ASFM frame

The mean difference between CM and ASFM downstream discharge results is 1,75 % (Figure 8). We can say that the difference is within the measurement uncertainty of the CM results which is estimated to be 2%. Even if a great portion of the velocity profile was not sampled with the ASFM installed upstream, some discharge calculation was done by assuming a linear profile for the missing data based on the analysis of the CM measurement.

## Rapides-des-Quinze

Rapides-des-Quinze is not a typical low head power plant because the two intake bays converge to a single penstock and a standard scroll case. As most of the Gibson pressure taps were almost all blocked, it was decided the use the CM method in the intake. The CM frames (Figure 9) were placed in the stop log gate slots which are close to the upstream side of the trash racks. The ASFM transducers were placed on top of the frames.

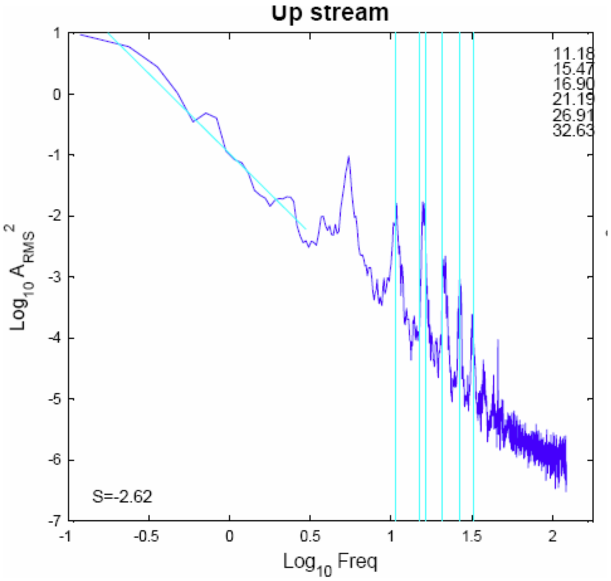

Figure 10 - Rapides-des-Quinze spectral analysis of the acoustic signal

No useful results were obtained from the ASFM measurement. Indeed, a very low quality index or even no velocity was measured for the major part of the section. This is probably due to, in part, to the low turbulence level caused by the absence of turbulence generation upstream of the transducers. Another reason could be from the vibration of the frames. The spectral analysis of the acoustic signals shows evidence of structural vibrations in the range of interest. This is clearly apparent in Figure 10.

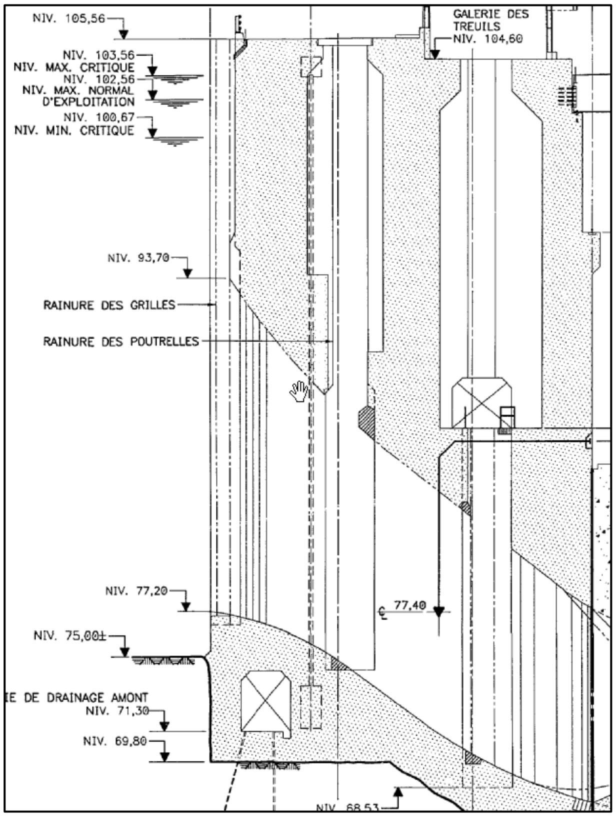

**Figure 11 - Rocher-de-Grand-Mère intake layout**

## Rocher-de-Grand-Mère

The Rocher-de-Grand-Mère is a newly commissioned powerplant on the St-Maurice river. The intake has two bays and the layout is typical of a modern design with a relatively smooth converging form (Figure 11). The ceiling angle is very important and close to 45°. The discharge measurement method used for the performance test was the CM method. Again, the current meters (28 for each of the two bays) were installed on a movable frame. Due to the high flow angle near the ceiling, self-compensating type current meters (up to 45° angle) were used. The ASFM transducers were mounted near the bottom upstream edge of each end plate, around 30 cm above the lower row of current meters (Figure 12).

**Figure 12 - Rocher-de-Grand-Mère frame**

The comparison of the discharge measurement is shown in figure 13. Overall, the mean difference between the CM and ASFM discharge is very low. However, large differences are observed as a function of the discharge value in the left or right bay. The analysis of the velocity profile from the current meters measurements (Figure 14) shows evident signs of asymmetry with more velocity on one side of the bays and a nearly a dead zone at the

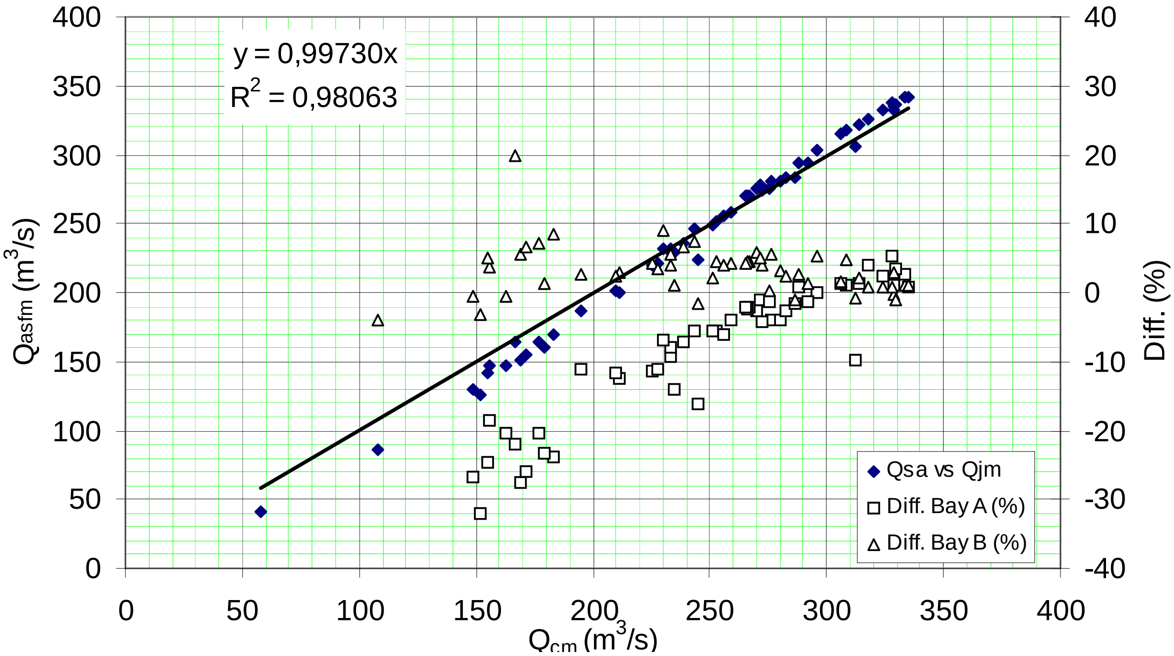

**Figure 13- Comparison of discharge measurement by M and ASFM at Rocher-de-Grand-Mère**

bottom of the section. The horizontal asymmetry is due to flow in the forebay arriving with a 50° angle to the intake upstream face. This can cause a non-uniform turbulence level that can lead in an over-weighted of the velocity of some the portion of the measurement section. This has been observed in other tests by ASL [11]. The FFT analysis have also shown sign of vibration, not as evident as Rapides-des-Quinze measurement but important enough to create some errors.

## Laforge-2

The comparison of the discharge measurement by the ASFM and CM method at Laforge-2 was presented in [9]. The ASFM transducers were mounted on one of the three current meter frames. They were placed on the downstream edge of the end plate. Thus, the ASFM path was crossed by the wake of parts of the CM frame. For the purpose of the tests, the trash racks were removed. This lowered the turbulence level to around 50 % of the normal value.

The results show a difference of 1.5 %, with the ASFM under estimating flow. The analysis of the acoustic signal shows harmonic and coherent fluctuations which likely contributed to causing errors and increasing the standard deviation of the difference between the CM and ASFM discharges.

## La Grande-1

The comparison between the CM and ASFM discharge measurements at La Grande-1 was presented in Lucerne [10]. The ASFM transducers were mounted at the top of the

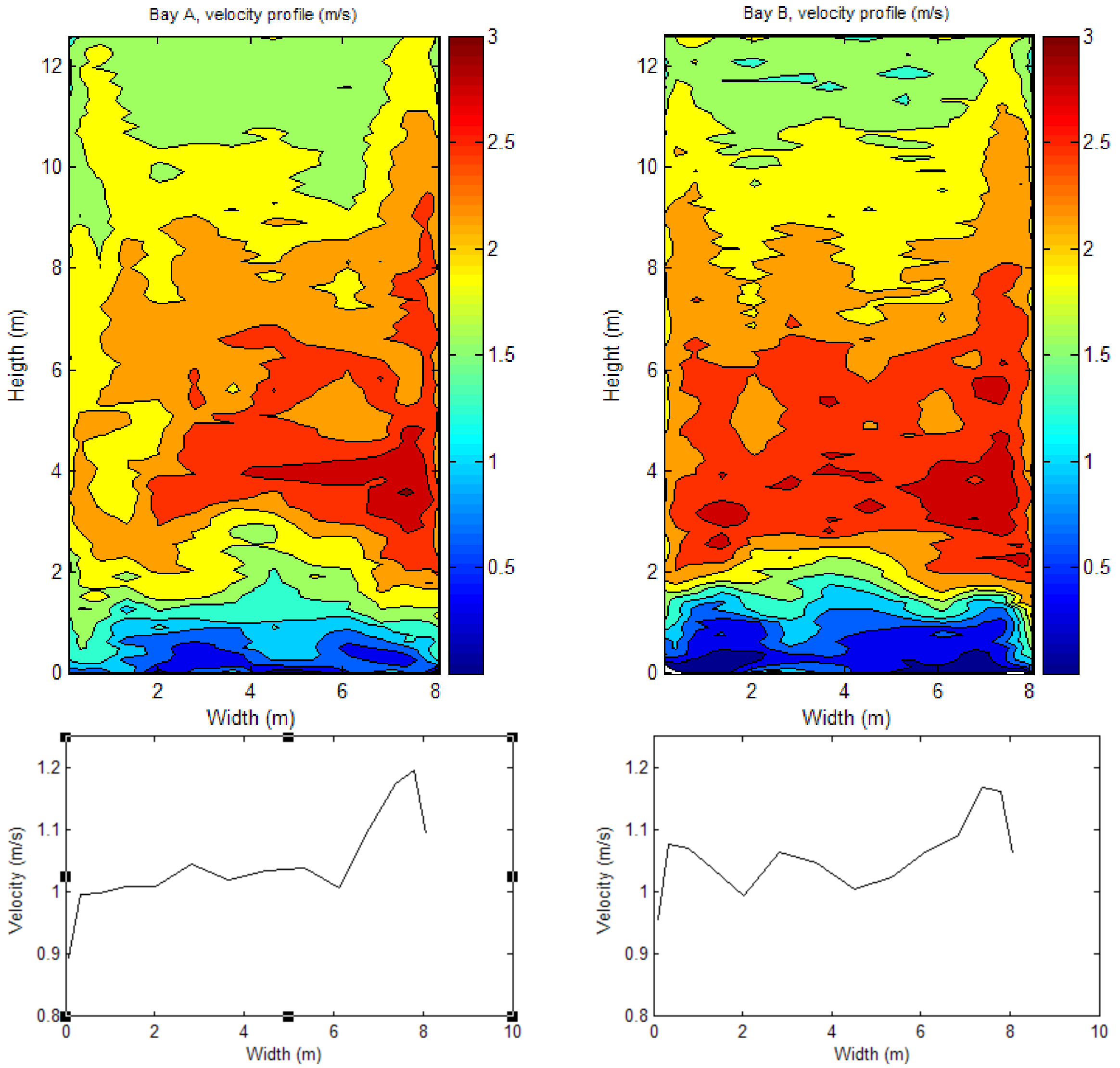

**Figure 14 : Rocher-de-Grand-Mère 3D velocity profile (upper) and horizontal velocity profile (lower)**

frame, so the velocity profile was only partially sampled. The results show a difference of around 1.8 % between the two methods, with the ASFM under estimating. By using some filtering technique to account for some possible vibration of the frame and by changing the number of samples for each individual velocity calculation, the difference was reduced to less than 0.5 %.

CFD simulations of the flow in the intake showed some significant velocity variation due to the wake of the main structural members of the trash racks, as it was detected by both the ASFM and CM method. Unlike the flow simulations, the flow angle measured by the ASFM showed large variations.

## CONCLUSION

Hydro-Québec has performed a number of tests with the ASFM flow measurement method. For some of these tests, the comparison of the results with the CM method shows a good agreement that is within the measurement uncertainty. For other tests, the difficult measurement conditions have lead to greater differences. Among other reasons that have been encountered is air entrained in the flow which as caused a cut off of the acoustic signal, a very low turbulence level when the measurement has performed upstream of the trash racks and oblique flow in the forebay which caused an asymmetric velocity and turbulence distribution in the measurement section. Other difficulties are related to the instruments setup itself. In effect, the ASFM method can be affected by vibrations of the structure on which the transducers are installed.

Like any other measurement method, the ASFM method requires a careful analysis of the measurement conditions that are anticipated in terms of the proximity of any upstream disturbance (trash racks, oblique flow, etc), structural vibrations of the transducer support, etc.

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