

# **Turbine flow measurement in low-head plants – Hydro-Québec's and Corps of Engineers' experience with ASFM: continuous flow monitoring**

## **Gilles Proulx**

Essais spéciaux de production  
Expertise de centrale  
Hydro-Québec,  
5655 de Marseille, Montréal, QC, H1N 1J4  
Canada

## **David Lemon,**

ASL AQFlow Inc  
1986 Mills Rd. Sidney, BC V8L 5Y3  
Canada

## **Luc Martell**

Expertise - Mécanique, métallurgie et civil  
IREQ (Institut de Recherche d'Hydro-Québec)  
HQ Technologie et développement industriel  
1800, boul. Lionel-Boulet, Varennes, QC J3X 1S1  
Canada

## **Introduction**

Hydro-Quebec has undertaken a program at LG-1 power plant to test methods to provide continuous, real-time flow monitoring for low-head turbines. LG-1 was chosen because the performance of its units has been tested extensively, and as a result their characteristics are well-known. Acoustic scintillation is one of the methods being tested. A 3-path ASFM Monitor system was installed in the scroll case of Unit 5 in June, 2006, with its sampling paths oriented vertically. The ASFM Monitor operates continuously and autonomously, and is equipped with a real-time, remote connection to Hydro-Québec's laboratory in Montreal.

The initial results show good agreement between the ASFM velocities and those predicted by a CFD model of the scroll case flow field, and a consistent relationship between the ASFM velocities and the discharge computed from the unit operating characteristics. Data are being collected under a variety of conditions, as they arise during normal plant operations. These data permit an analysis of the performance of the ASFM Monitor in the scroll case installation to be made as a function of the unit and plant operation, and an evaluation to be made of its performance as a real-time flow monitoring instrument.

Hydro-Quebec has also installed an ASFM Monitor system to measure to discharge that passes through a bottom outlet of the control structure for the partial diversion of the Rupert River.

In December 2004, US Army Corps of Engineers installed a 5-path ASFM Monitor in the intake of Unit 4 at the Lower Granite powerhouse on the Snake River in Washington State. This installation was part of a coordinated effort to investigate absolute and relative flow measurements in large short intakes of Kaplan turbines and included the ASFM Advantage, ASFM Monitor, acoustic time-of-flight and Winter-Kennedy methods. The ASFM Monitor remained in operation for a month after the completion of the turbine testing, operating unattended and providing the opportunity for real-time flow monitoring.

## **1. ASFM Monitor**

Low-head power plants often witness large variations of turbine discharge over a period of a year and even during a single day because of the open market or demand variations. Head losses can also vary greatly during a year because of trash accumulation. During winter, ice cover in the fore bay and tailrace or frazil ice can also change the net head. It may also be necessary to assess the efficiency of the turbine operating under special condition such as with air admission or fish screens.

To evaluate the turbine efficiency under these different conditions, it is sometimes necessary to monitor the discharge of the unit on a permanent basis, as using the hill chart and gate opening or power output can lead to large errors in the turbine setting and cause loss of revenue. A better way to calculate the efficiency is to measure the discharge but this measurement is known to be difficult, particularly in low-head plants. Whether

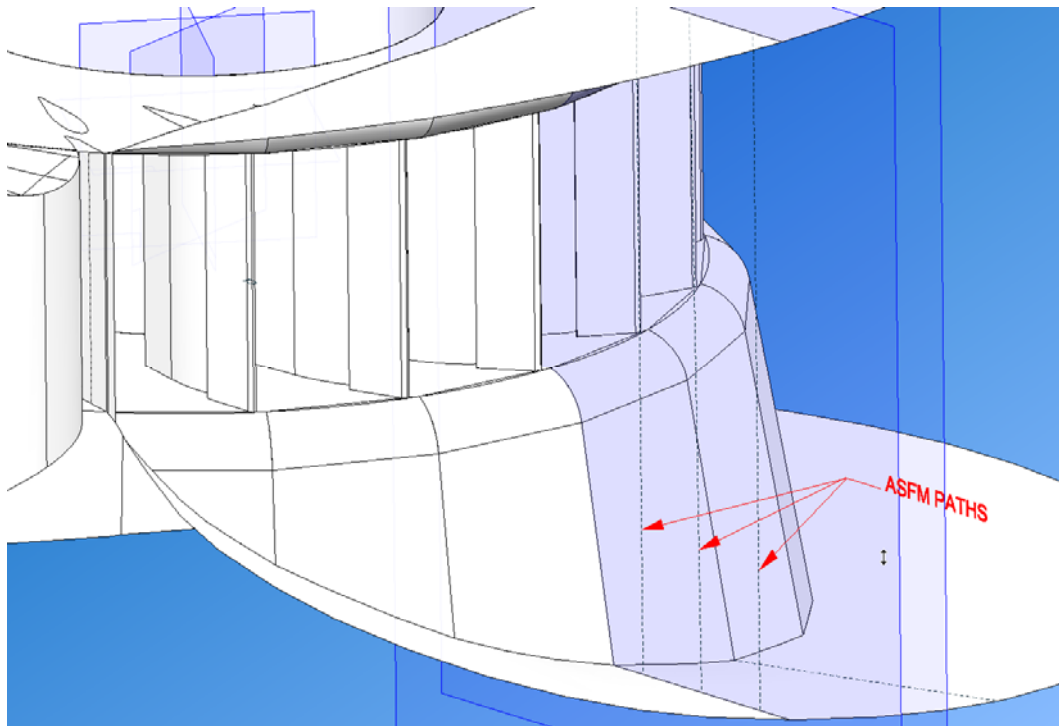
absolute or relative, the discharge measurement is subject to many types of perturbation that can affect the results. The trash racks can be easily obstructed, which can change the velocity profile in the intake, penstock and scroll case. This velocity profile can also change when the operation of adjacent units is changed (start, stop, load variation, etc.). The Winter Kennedy index method is one method that may be used but in some cases can be inaccurate.

The Acoustic Scintillation Flow Meter (ASFM) has been developed specifically for flow measurements in short intakes of low-head plants [1]. The ASFM Monitor is, designed to provide continuous, real-time flow data in such plants at reasonable cost. It is intended for permanent installation, to produce a relative measure of discharge with a limited number of paths,. It may be calibrated using other methods, such as the ASFM Advantage, temporarily installed in the intake [2].

The ASFM Monitor was tested in the unit #5 of La Grande-1 powerhouse, unit #4 of Lower Granite powerhouse and the Rupert Control Structure.

## 2. La Grande-1 power plant

Various flow measurement methods have been compared in the fronto-spiral case of a group of LG1, a northern Quebec power facility. A special version of the ASFM Monitor has been used with three paths installed vertically at the end of the spiral case (Fig. 1). This location has been chosen because it is the farthest from the intake and thus can limit the influence of any velocity profile changes. The other methods tested were Acoustic Time of Flight (one path), Acoustic Doppler (one vertical path and one horizontal path) and various pressure difference sensors on the stay vane.



*Fig. 1. Location of the ASFM paths*

For the ASFM Monitor, three 8400 mm long vertical paths, separated from each other by 500 mm, have been installed. Tx sensors are deployed on the ceiling, while Rx ones sit on the floor (Fig. 2). Due to the local geometry and to the angle of the flow related to the path ensemble, each of the sensor localisations presents a different angle with respect to the flow. Therefore, special sensor brackets have been designed, ensuring that all sensors faces are horizontal. Accurate alignment and levelling have been obtained using electronic inclinometer and laser level tools. Instrumentation cables, first attached to the structure with stainless steel clamps, have afterwards been protected with a rubber membrane for preventing flutter caused by the water flow, and finally covered by a stainless steel profile ensuring mechanical protection. Those cables are exiting the casing through

the structure surrounding the access door: water tightness is ensured using 150 psi sealed connectors, additionally covered with a polysulfide and mechanically protected with a strong steel deflector. Electronic modules processing the signals are installed in a cabinet 100 meters away.

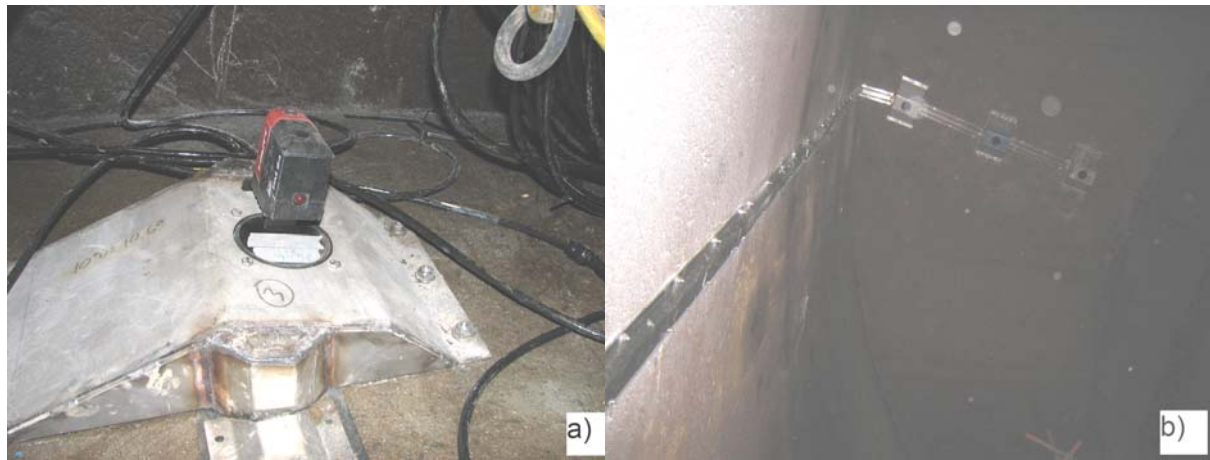


Fig. 2. Transducers installation at bottom (a) and top (b)

The first series of tests has been performed immediately after the installation of the transducers. The goal was to compare and calibrate the ASFM Monitor measurements with previous results obtained in 2005 with the Current Meter method [3]. The ASFM Monitor measurements have also been compared with standard Winter Kennedy measurements taken at the same time. Other measurements such as servomotor stroke, power, scroll case inlet pressure and tailwater level have been recorded during these tests.

Each point was measured for 5 minutes, after the hydraulic stable conditions have been obtained. The first set of points was taken at different servomotors strokes. During all these measurements, the two adjacent units were kept at fixed gate opening.

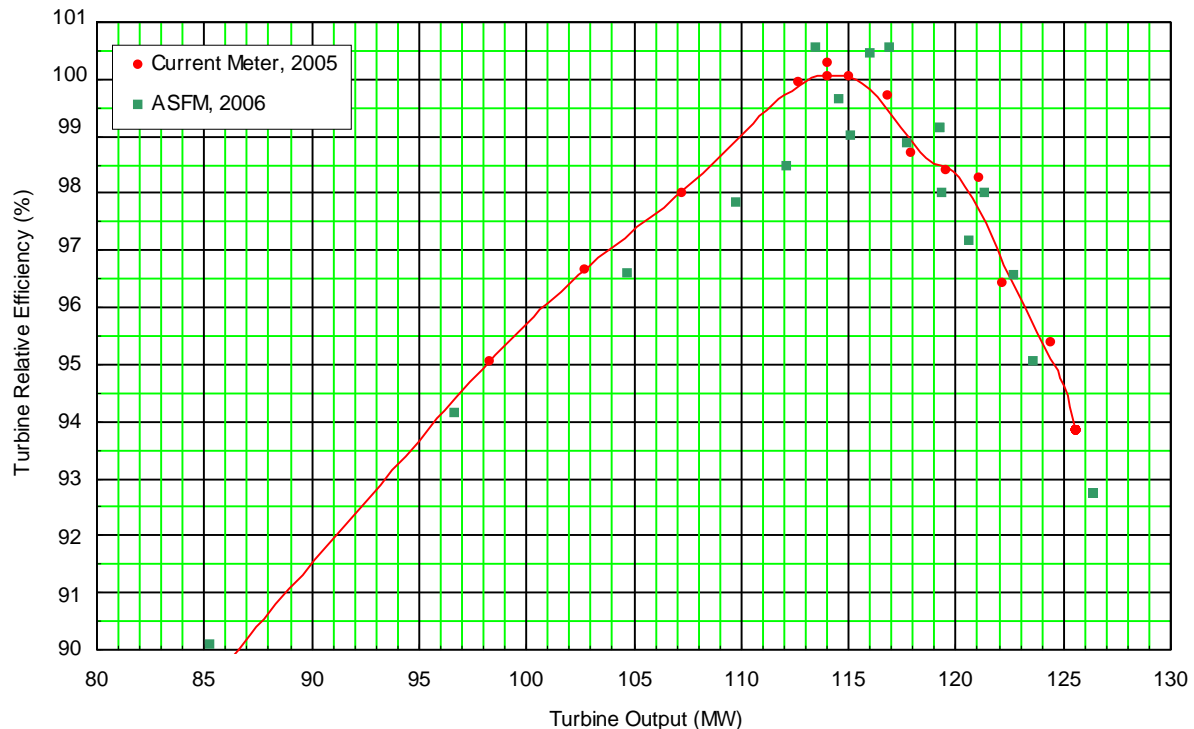
With only one path in service at the time of the test, the ASFM discharges generally agree within  $\pm 2\%$ . It is likely that the agreement would have been better with all three paths in service. Long term measurement has shown a random variation of  $\pm 1.5\%$  (Fig. 3).

A second series of tests has been performed to verify the influence of the operation of adjacent units. Unit no 5 was operated at a fixed gate opening near the peak efficiency. Unit no 4 was also kept at fixed gate opening while the unit no 6 output was varied between 50 % and 100 % gate opening. The measurements were repeated with unit no 6 at fixed gate opening while unit no 4 gate opening was varied. Again with only one path in service, the discharge has shown some deviation depending on the unit that was operated. The maximum deviation was less than  $\pm 2\%$ . The permanent measurement with all three paths in service shown that the deviation improves to  $\pm 1.5\%$ . It can be noted that deviation of the same magnitude or even greater has also been observed for many of the other methods tested at the same time as the ASFM method. We can thus say that the change in the velocity profile is real and the deviation of the ASFM is not necessary due to a measurement error of the method

The velocity profile in the region of the ASFM Monitor measurement section has been compared with CFD simulations and showed a difference of about 3.5 %. The flow angle obtained by the ASFM Monitor differs by  $3^\circ$  compared to the CFD simulation.

Table I - Comparison of velocity profile between ASFM and CFD

	Relative Velocity		Flow angle $^\circ$ (normal to section)	
	ASFM	CFD	ASFM	CFD
Exterior (wall)	0,907	0,874	-9,7	-13,7
Midle	0,990	0,990	-13,4	-17,5
Interior (stay vane)	1,103	1,136	-19,7	-21,3
		Mean	-14,3	-17,5



*Fig. 3. Relative efficiency of unit 5 with load variation*

### 3. Lower Granite Unit 4

US Army Corps of Engineers have been investigating absolute and relative flow measurement methods in the large short intakes of Kaplan turbines for over 20 years. Of particular interest to them are methods which can provide reliable measurements both without and with fish diversion screens that the Corps is obligated to install in the Columbia and Snake River plants during specified periods during the year. The December 2004 field testing performed index test both without and with fish screens installed. Figure 4 shows the location of the fish screens in the intake.

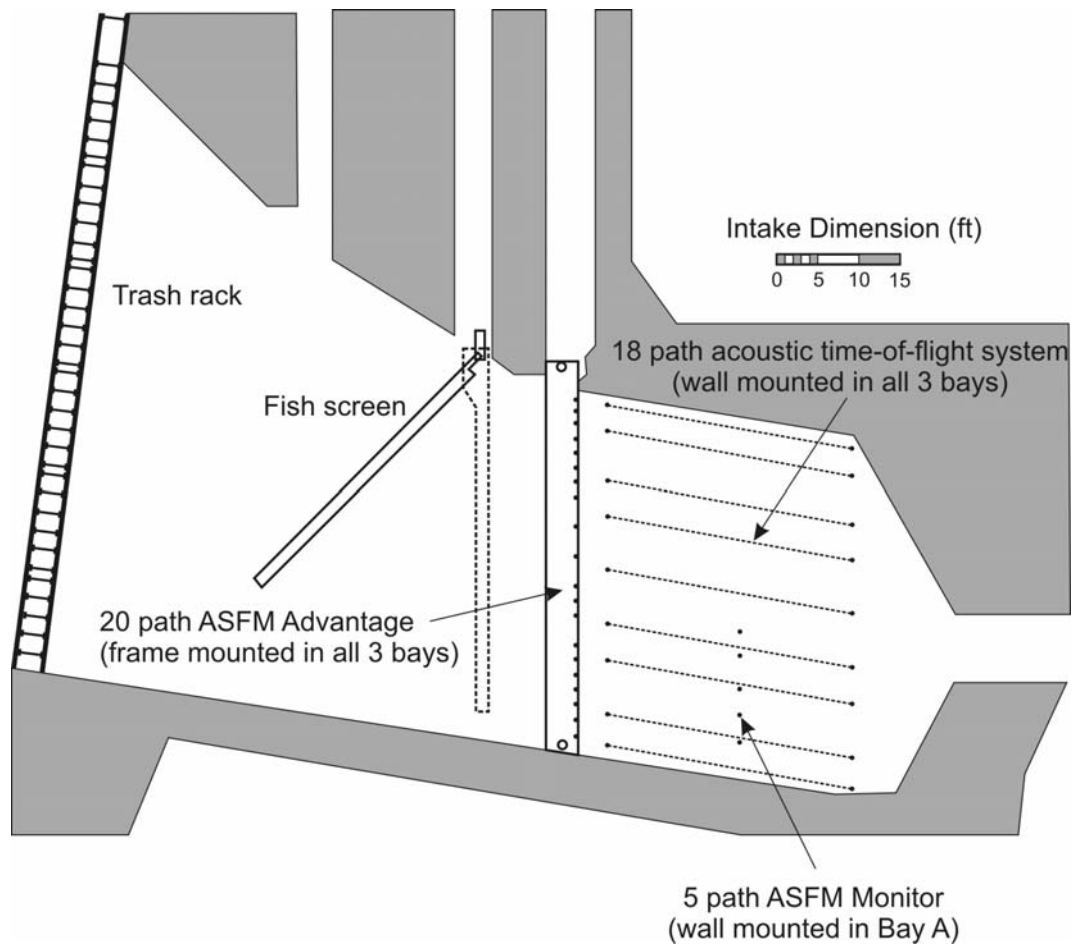
To test whether satisfactory relative flow data could be obtained with a greatly reduced number of acoustic paths, a 5- paths a prototype ASFM Monitor was installed in the lower region of Bay A, downstream of the full ASFM (also shown in Fig. 4). The 5-paths configuration, with all paths in the lower region, followed the recommendations of a 2003 USACE Report (4), which investigated flow data from the ASFM Advantage measurements at The Dalles Unit 9 (no screens), John Day Unit 9 (fish screens in place) and Bonneville Unit 6 (fish screens in place).

With the fish screens in place, the Lower Granite ASFM Monitor recorded discharges within 1.5% of the reference 20-path frame mounted ASFM Advantage values with Unit 6 operating and within 1.0% with no other unit in operation (5). Without the fish screens in place, however, the flow difference ranged as high as 5%, caused by the increased variability in the velocity profile relative to that seen by the 20-path ASFM Advantage when the fish screens were in place.

Subsequently, using other paths configurations selected from the 20-paths ASFM Advantage, the performance of a number of simulated 'monitors' was constructed, with the following results:

- Discharge measurement agreement within 1.5% can be achieved under all plant configurations (with and without fish screens) and unit operating patterns with a 5-paths ASFM Monitor, installed in each intake bay and sampling the full height of the intake.
- Agreement within 2% can be achieved with a smaller number of acoustic paths.

These findings are consistent with the results of an earlier study of flow data from Little Goose Units 3 and 4, Lower Monumental Unit 6 and Wells Unit 3 (4).



*Fig.4. Lower Granite – intake flow measurement methods*

While these results are encouraging, as they indicate that reliable flow monitoring could be achieved with the ASFM Monitor cost-effectively in relative terms and, after calibration, potentially in absolute terms, further field testing is required to test the hypotheses.

#### **4. Rupert Control Structure**

The Rupert Control Structure is part of the river partial diversion project (28% of the mean discharge is maintained at the control structure and 48 % at the river mouth) that will bring water to three existing power plants as well as to a new plant (La Sarcelle). The Rupert Control Structure was built to maintain a minimum flow of water in the river bed for environmental purposes. Due to the importance of this discharge, Hydro-Québec has decided to monitor the discharge with two methods: the Acoustic Time of Flight (ATF) and the Acoustic Scintillation Flow Monitor (ASFM Monitor).

The two flow meters are installed in the central control spillway (Fig. 5). The transducers are embedded in the concrete so that they are completely out of the flow (Fig. 6). For the ASFM Monitor, eight paths (16 transducers) are installed about 9 m upstream from the gate. The position of the measurement section has been chosen after an analysis of the flow from CFD simulation and model tests. It was a balance between the need to be as far as possible from the fore bay in order to get enough turbulence and flow uniformity as well as avoiding flow recirculation close to the gate when it is partially opened.

The measurement should take place in December 2009 and cover the full gate opening. Three important discharges will be tested, two of them being the compensation water that reproduce the fall and spring floods.

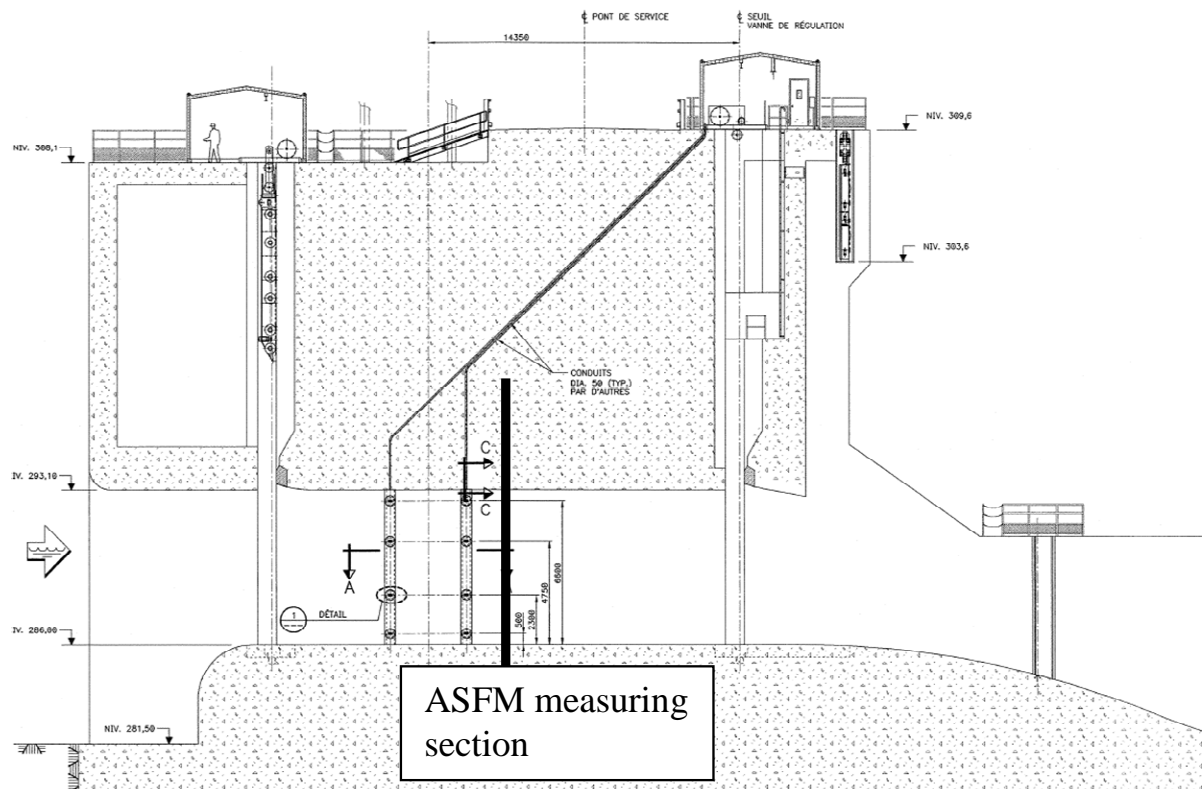


Fig. 5. Cross section of Rupert control structure

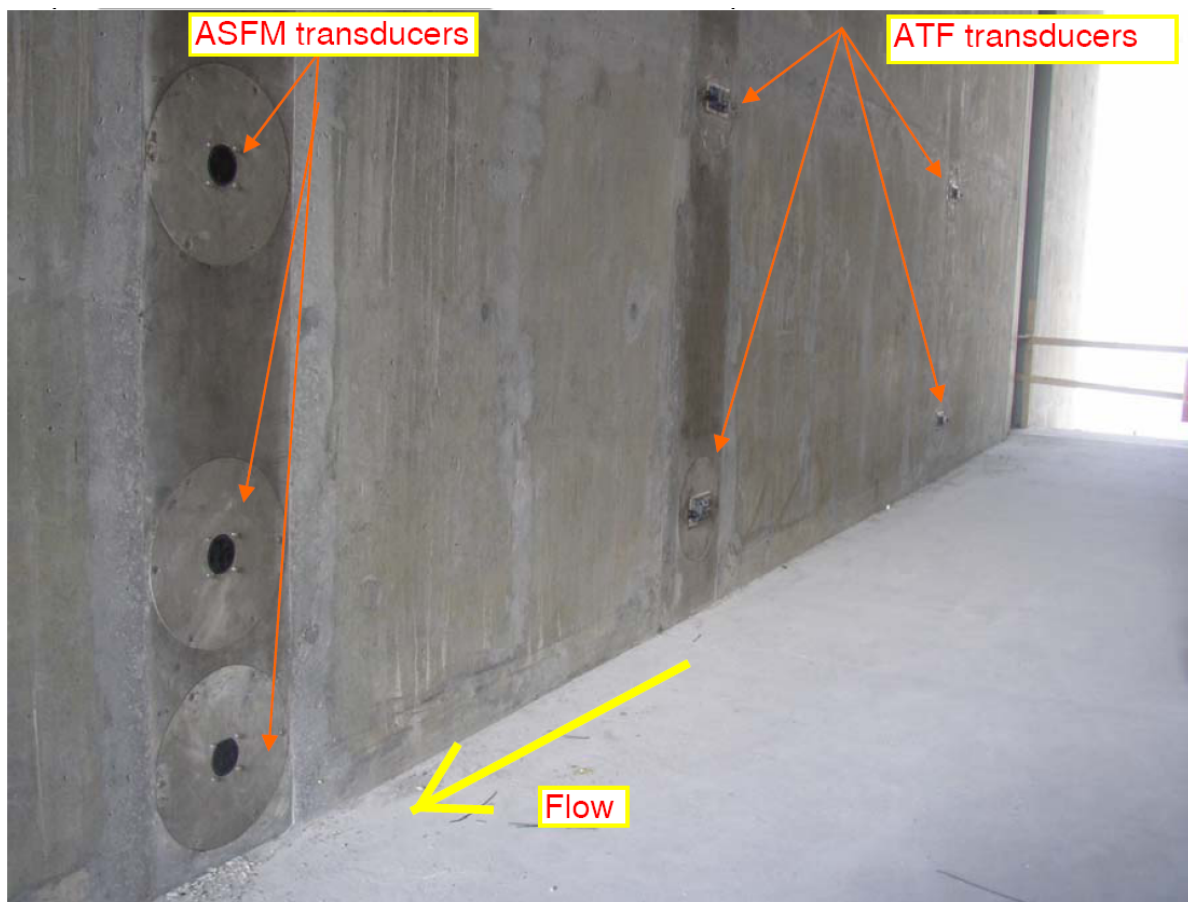


Fig. 6. Rupert control structure, ASFm and ATF transducers

## **Conclusion**

The Monitor version of the Acoustic Scintillation Flow Meter have been used to implement permanent flow monitoring in various situation, from the classical version in the intake of a low head power plant like at Lower Granite to a measurement in a fronto-spirale case at La Grande-1 and finally to a measurement in the Rupert control structure. Although somewhat preliminary in nature, all indicate that ASFM Monitor appears to have the potential to provide a flow monitoring tool sufficiently reliable, accurate and cost effective to justify further field applications. Balance should be made between these three aspects of any measurement methods that oppose each other.

## **Acknowledgements**

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## **Authors:**

**Gilles Proulx,** P. Eng., graduated in Mechanical Engineer from the École Polytechnique de Montréal, in 1989 and has worked for Hydro-Québec test department since then. He has worked on the commissioning of Hydro-Québec's major power plant. He has performed many performance tests using different method and is responsible of the R&D team of the testing department.

**Luc Martell,** graduated as a Physical Technologist from CEGEP de La Pocatière in 1977 and as worked for 20 years in instrumentation of rotating machinery, mainly applied to wind turbines. Since the last 10 years, he worked in the fields of hydrologic measurement in rivers with the Doppler method and of flow measurement in hydraulic power plants.

**David Lemon,** M.Sc., graduated in Oceanography from the University of British Columbia, Vancouver, in 1975 and has worked for ASL Environmental Sciences since 1978. He has worked extensively on the application of acoustics to measuring flow, and has been responsible for the development of the ASFM. He is currently President of ASL's subsidiary, ASL AQFlow Inc., with responsibility for internal research and development.