COMPARISON OF DISCHARGE MEASUREMENT BY CURRENT METER AND ACOUSTIC SCINTILLATION METHODS AT LA GRANDE-1

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ABSTRACT

This paper presents a comparison of discharge measurements made by the Current Meter and Acoustic Scintillation methods at La Grande-1. This low head power plant has an intake typical of those for which the acoustic scintillation method was developed; at present, the current meter method is actually the only IEC code approved method for discharge measurement in such intakes. The measurements were performed simultaneously with the two methods. The instruments were mounted on frames, which were moved to acquire data over the entire section. The measurement section was located more than 5 m downstream of the trash racks. The results clearly show the wake of the trash rack elements in both current meter and acoustic scintillation measurements. CFD flow simulations were also performed in order to investigate possible causes of the differences observed between methods. At La Grande-1, the measurements were performed at three different heads, effected mainly by changing the number of units in operation during the tests. Depending on the head, the adjacent units were operating or not and that changed the approach velocity and the turbulence level in the forebay. These changes allow studying the influence of different flow conditions on the results of the measurements.

INTRODUCTION

In the mid-1990s, ASL AQFlow developed a new method for measuring the discharge in low head, short intake power plants, the Acoustic Scintillation Flow Meter (ASFM). Originally tested in rivers and ocean channels, the method uses the scintillation of an acoustic signal transmitted along a path in a turbulent flow to measure the flow velocity. This method is well suited for short intake applications where the Current Meter (CM) method is the only alternative method.

In 1999, Hydro-Québec's testing department (HQ) acquired an ASFM Advantage system after a first comparative test at HQ's Laforge-2 power plant [1] showed its potential for making discharge measurements. Since then, HQ has made ASFM measurements whenever CM measurements have been done in a short intake. HQ's ASFM system uses only one path per bay. The transducers are mounted on a movable frame (same as CM), which is displaced along the height of the measurement section while the measurement is done continuously. ASL AQFlow generally uses a number of paths mounted on a fixed frame but which can also in some cases be displaced to increase the number of measurement paths [2, 3].

At La Grande-1, the discharge measurement was done to establish efficiency curves at different heads, which vary between 24.5 m at the full power plant discharge during winter, and 30 m, for the minimum discharge in summer. These curves are important to maximize the energy produced by the power plant.

This paper presents the results of the first comparative measurements done by HQ. It also presents some of the post processing done with ASFM data to improve the quality of the results. Some CFD flow simulations were done to identify possible sources of uncertainty.

1 DESCRIPTION OF TESTS

This section describes the tests done at La Grande-1. This generating station was built in the 1990s. The power plant has twelve 116 MW propeller turbines under 27.5 m head. The maximum flow at this head is 520 m^3/s. The intake has three short converging bays (Figure 1).

The measurements were performed on unit 6 (GEC Alsthom) and unit 7 (GE Hydro) at three net heads: 25.5, 27.5 and 30 meters. The downstream level is affected by the number of units in operation at the station, so it was necessary to start and stop some units to change the heads for the test. The 25.5 m. head was obtained with only 2 units in operation, seven units for the nominal 27.5 m head, and ten units for the 30 m head. During the measurement, the adjacent units were in operation for the 27.5 and 30 m tests but not for the 25.5 m test. Approximately 60 tests were done for each unit.

1.1 Current Meter Measurement

The discharge measurement was done with ten current meters installed on the bottom of three

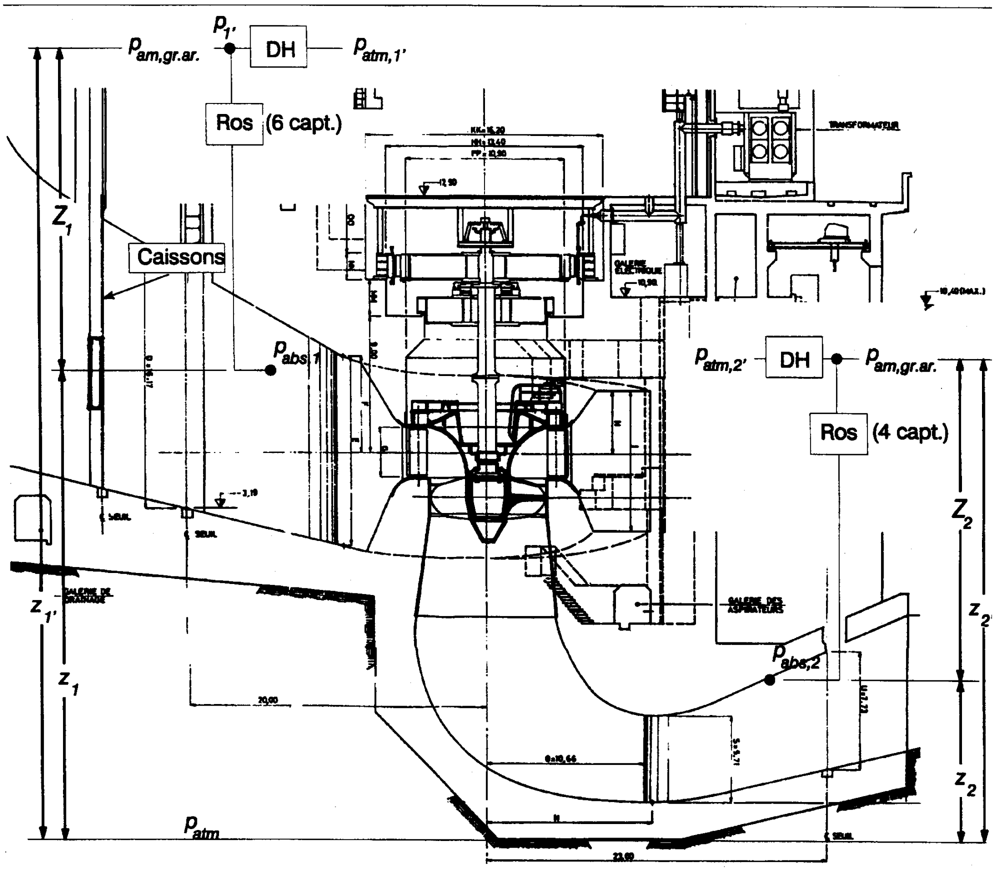

Figure 1 La Grande-1 Intake Layout

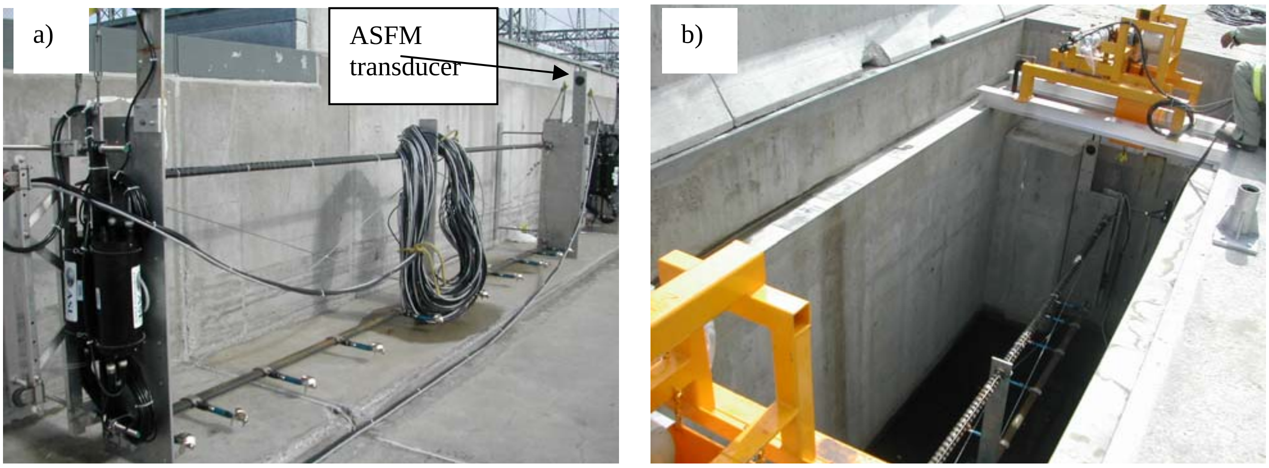

Figure 2 – La Grande-1 Current Meters and ASFM Frame (a) and hoists (b)

movable frames made of two end plates, profiled rods and steel cables (see Figure 2). The frames slide in the stop log gate slots approximately 5 meters downstream of the trash racks. Each frame was moved by means of two hoists controlled by an electronic device, which allows selection of the travel velocity. The width of each measuring section is 5.56 m and the height is 17.87 m. The theoretical flow angle is 22.3˚, so type A self-compensating Ott current meters that compensate for up to 45˚ flow angle were used. The frame velocity was set to 27 mm/s, requiring a total of 11 minutes for each measurement.

The computation of the discharge from the CM measurements was done by calculating 100 different velocities for each current meter as the frame was moving and the associated height of the frame which gives a grid of 100x10 velocity points. These data were integrated horizontally then vertically and conversely. Between the physical boundaries (walls and floor) and the first current meter, the velocity profile was assumed to be of the exponential form as described in IEC 41 and ISO 3354.

1.2 ASFM Measurement

The ASFM transducers were mounted on the top of the two end plates (Figure 2a), on the upstream edge. This location does not allow measuring the velocity all the way to the bottom of the measuring section with ASFM transducers, but avoids repeating the complete measurement. For the purpose of comparing the velocity and discharge measurements, the calculation was done for the common part of the section.

The ASFM uses a technique called acoustic scintillation drift to measure the flow velocity perpendicular to a number of acoustic paths that are placed across the intake to the turbine. Fluctuations in the acoustic signals transmitted along the paths result from turbulence in the water carried along by the current. The ASFM measures those fluctuations (known as scintillations) and from them computes the lateral average (i.e. along the acoustic path) of the velocity perpendicular to each path. Both the magnitude and inclination of the velocity are computed. The ASFM computes the discharge through each bay of the intake by integrating the horizontal component of the velocity over the cross-sectional area of the bay. The discharge through each bay is then summed to compute the total discharge.

Scintillation drift was first applied to the measurement of winds in the ionosphere and atmosphere, using light or radio waves. The first applications to water flow using acoustic scintillation signals were for measuring currents and turbulence in ocean channels and rivers [4 – 7]. Since 1992, the method has been applied in hydroelectric plants, and in some instances compared with other discharge methods [1, 8].

2 RESULTS

The results of the measurements are presented in this section. First, the results of the 2003 current meter measurement for the units n^{o} 6 and 7 are compared with the 1995 results obtained for the units n^{o} 4 and 5 shortly after the commissioning. The CM and ASFM results are then compared to each other. As mentioned before, for the purpose of comparison, the CM and ASFM partial discharges were calculated between 2 m and 17 m of elevation, since the velocity was not measured with the ASFM transducers close to the bottom of the section and to avoid possible interfering echoes (ASFM) near the top.

2.1 Current meter results

The results of the current meter measurements are shown in Figure 3. The efficiencies (results of year 2003) of the units 6 and 7 are compared to the efficiencies of the units 4 and 6 respectively measured at the commissioning of the units in 1995. The discharge measurement was done with current meters but a different approach (see [1]). The results of 1995 and 2003 agree well for each type of unit. The mean difference between the efficiency curves for the same type of unit is less than one percent. As the efficiency of one unit can differ from that of another of a similar type, this difference is well within the measurement uncertainty.

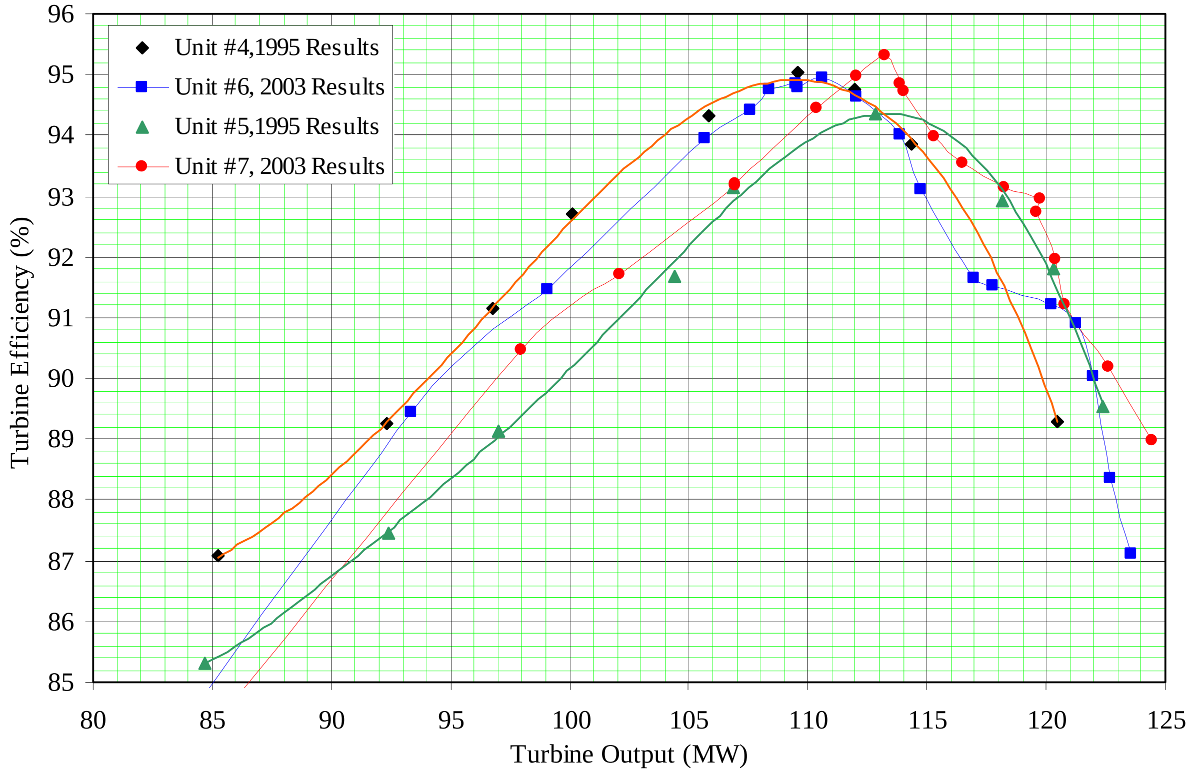

Figure 3 – Unit efficiency curves, 1995 and 2003 tests.

In 2003, more measurements were done since the method was faster than the method used in 1995. Some points were repeated to investigate possible discrepancies but the curves were found to have some real irregularities. These results give a good comparison basis for the ASFM.

2.2 ASFM vs. CM

For the purpose of comparing the ASFM and CM discharge measurements, the velocity data were used to calculate the discharge between the elevations 2 m and 17 m. This allows comparing the same results for the ASFM since the transducers were mounted on the top of the frame. Some typical data that were obtained from ASFM and CM are shown in Figure 4. It represents the laterally averaged (CM) or measured (ASFM) horizontal component of the velocity profile. Each ASFM data point represents a single 4.1-second sample; with a fixed-path ASFM installation, between 8 and 30 such samples are averaged together to produce the velocity for each path. Scintillation drift is a statistical measurement of a randomly varying process, and the stability of the result depends on the length of the sample. The profiles in Figure 4 show all the raw samples, without averaging or the rejection of outliers, and therefore exhibit much more variability than would the data from a fixed-path installation.

The profiles in Figure 4 clearly show the wake of the trash rack's main structural members on the horizontal component of the velocity profile (see Figure 6 for a general view of the main trash rack members) for both measurement methods. The ASFM also gives the angle of the flow (right-hand panel in Figure 4) at the measuring section. While the velocity profile variation can be explained by the wake of the trash racks, the oscillation of the flow angle seems to be much larger than expected. Some flow angle differences of 20 to 30 degrees in a short distance seem to be inconsistent with the general flow and the distance from the trash rack. Such variations in flow angle would indicate rapidly converging or diverging flow, which is not found with the CFD simulations (see below). It is likely that the turbulence level in the wake of the trash rack varies rapidly, causing some errors in the flow angle calculation.

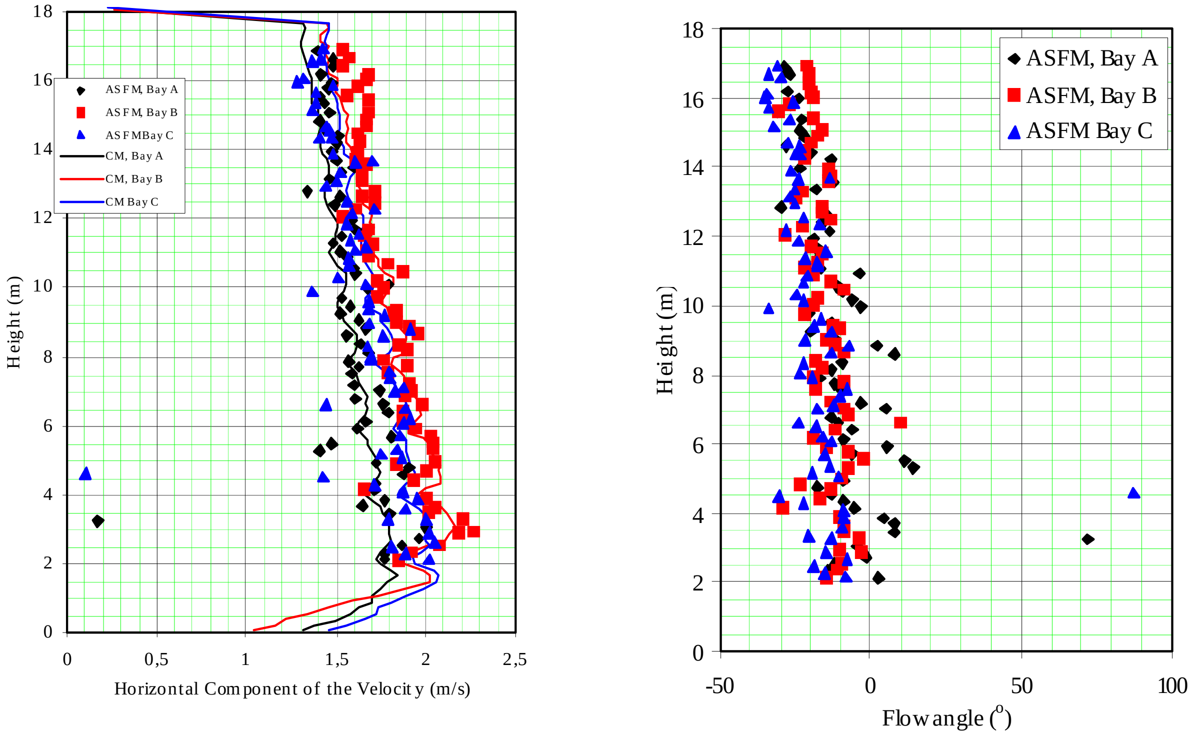

Figure 4 – Left panel: Typical velocity (ASFM and CM); Right panel: flow angle (ASFM only) profiles.

From the data obtained directly on site by the ASFM measurement system, the partial discharge was calculated and compared with the CM partial discharge. The discharge was calculated with a simple trapezoidal integration of the velocity profile. The result of this comparison is shown in Figure 5a. A least square curve of the form $Q_{asfm}=K*Q_{cm}$ was calculated and gives a coefficient K of 0.9823 which means an under reading by the ASFM of 1.8 %. The standard deviation was around 1%, which means an uncertainty of a sample of 2 %, which is considered to be on the high side. Some research was done to find possible causes of errors and to decrease the difference with the CM results. These included a comparison with CFD simulations and reprocessing of the data using some filtering techniques, different velocity calculation methods, and removal of outlying results. These results are presented in the following sections.

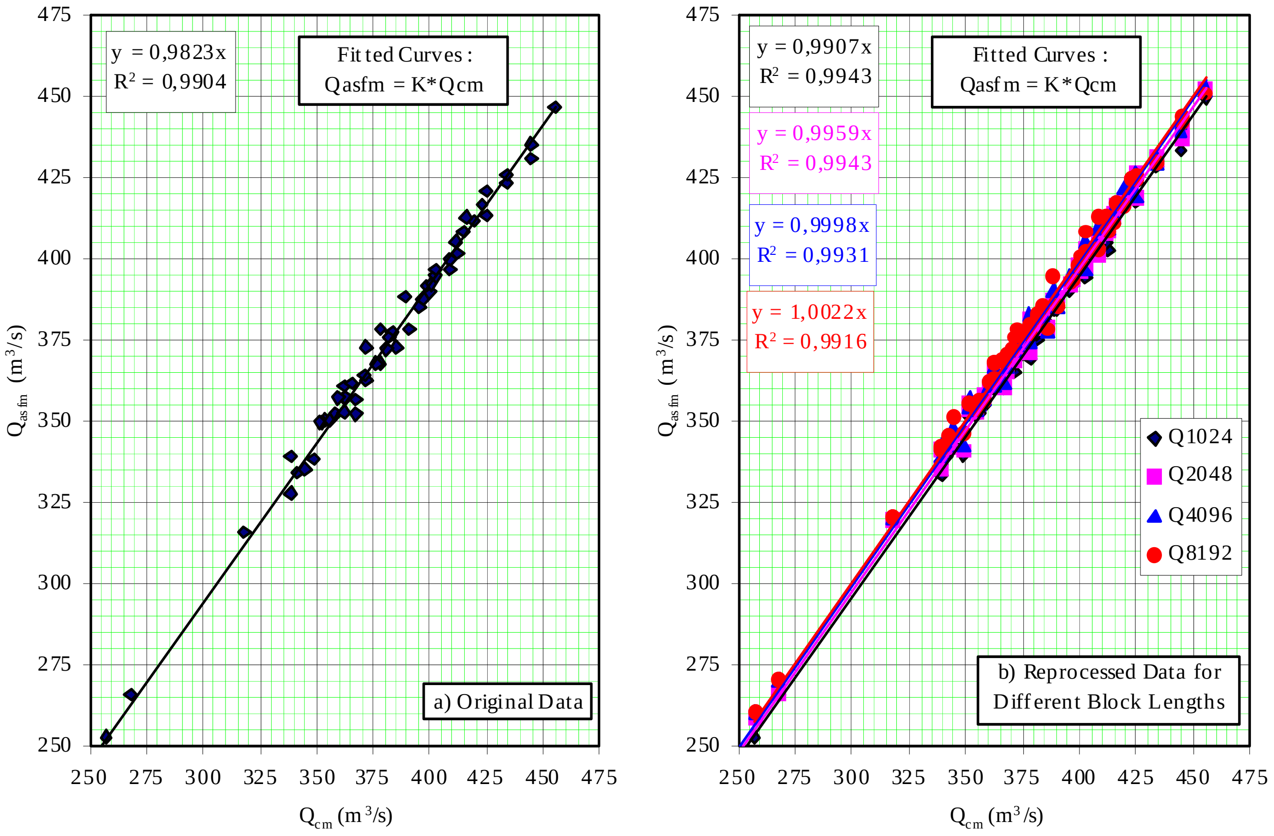

Figure 5 - Comparison of ASFM and CM results for the original data (a) and for reprocessed data with filtering and various block lengths (b)

2.3 Reprocessing of ASFM data

The reprocessing of the data was carried out for three different aspects of the ASFM measurement: filtering of the ASFM signal, varying the block length for individual velocity calculations and eliminating outlying results before the integration of the velocity profiles.

One of the possible sources of error encountered in the acoustic scintillation measurement arises from vibration of the structure that supports the transducers. The vibration can produce interfering noise in the signal. It can often be removed by using band-pass digital filters. This filtering was done by the ASFM Pro Plus software, provided by ASL-AQFlow. Based on user selectable parameters, the software selects a filter that gives the best quality index for the velocity measurement.

Because of the nature of the turbulent flow in a low head, short intake, immediately downstream of a trash rack with large supporting members, some non-linear effects due to the variation of the turbulence can introduce some variation in the velocity calculation. To attempt to decrease these variations, the block length for the calculation of local velocity was increased from 1024 samples (4 seconds or 100 mm in height) to 8192 samples (32 seconds or 800 mm in height). For the longer block length, the local velocity calculation covers more than one half of the distance between two wakes from the trash rack's main structural members.

The elimination of outlying results was performed using a procedure similar to the one presented in Annexe B of the IEC 41 test code. This procedure was necessary to eliminate some evident bad results as shown in Figure 4. These data come either from a wrong evaluation of the velocity or the flow angle. All local velocities falling outside of a band of 3.7 times the standard deviation from a third degree polynomial fitted curve were rejected.

The results of filtering the data are shown in Figure 5b for each of the different block lengths. The results of all the reprocessing are summarized in Table 1. We see that filtering the data increased the calculated discharge by 0.5 %, so the difference between ASFM discharge and CM discharge decreased by 0.5 % for all block lengths. Increasing the block length also had a significant effect, since the difference in the discharge varies by 1 % from 1024 samples per block to 8192 samples. With this block length, the filtered data agrees within 0.2 %, now an over reading for ASFM discharge.

In contrast to what was anticipated, the standard deviation has increased slightly from 0.75 % for the shortest block length to 0.89 % for the longest block. The standard deviation did not vary greatly with the filtering.

Table 1
Results of Reprocessing the Data: Comparison of ASFM Results for Different Block Lengths and With or Without Filtering of The Acoustic Signals (all outliers were removed)

	Block Length	1024	2048	4096	8192
Filtered	K (Q_{asfm}=K*Q_{cm})	0.9907	0.9959	0.9998	1.0022
	Std. Deviation	0.0075	0.0077	0.0083	0.0089
Not Filtered	K (Q_{asfm}=K*Q_{cm})	0.9851	0.991	0.9929	0.9944
	Std. Deviation	0.0075	0.0084	0.009	0.0095

2.4 Comparison with the CFD Model

Reprocessing the ASFM data improved the overall discharge agreement with the CM data to within 0.5% for analysis block lengths of 2048 or more points. The standard deviation of the comparison yields an expected agreement of ±1.5% in an individual comparison at the 95% confidence level. That indicates that, while there is no significant bias in the ASFM discharges, compared with the CM discharges, there is significantly higher variability than has been found in the majority of low-head intakes [9]. The variation of the observed flow angle suggests that the wakes from the major horizontal trash-rack members may be the cause of the increased variability.

To investigate this possibility, the turbulent flow in La Grande-1 power plant intake was simulated with a Computational Fluid Dynamics (CFD) model. The mean horizontal velocity and flow direction are compared to the current meter and ASFM data at the measuring section, and the distribution of mean flow and turbulence downstream of the trashrack are illustrated.

The unstructured and parallel code CFX 5.6 is used to solve the three-dimensional Navier-Stokes equations with a shear stress transport (SST) based k-ω turbulence model. This model was designed to give a highly accurate prediction of flow separation under adverse pressure gradients. All the solid walls are treated with the scalable wall functions. The simulations were performed on ASL's parallel computing facility. A discharge equal to 156 m^3/s was set through the intake to match one of the measured ASFM and current meter discharges as closely as possible. The flow direction is assumed to be normal to the inlet section of the computational domain. This condition can be easily changed in the model if the inlet flow direction is known. The computational domain of one of the three bays composing a Unit is shown in Figure 6 and includes a small part of the upstream reservoir. The trash rack shown in the same Figure consists of twelve 12.5 cm x 76 cm horizontal beams and four 7.6 cm x 61 cm vertical members. The intake is about 24 meters high at the entrance.

The distribution of the mean horizontal velocity at selected longitudinal and lateral sections is shown in Figure 7; the corresponding distributions of turbulent kinetic energy are shown in Figure 8. The presence of the trash rack clearly disturbs the flow far downstream in the intake. The flow coming down to the intake from the top upstream part of the domain, is slowed down by the first beams, where large wakes are produced, because of the large angle of attack. In the middle and bottom sectors, the flow approaches the intake in a progressively straighter fashion, and is therefore more accelerated past the trash rack. Note the relatively large re-circulation region produced by the upstream bottom step. The measurement plane is located at the first gate slot in its middle section. The signature of the wakes produced by the horizontal and vertical beams are clearly visible in this plane, in both the velocity and turbulence. The vertical members at the sides produce recirculation zones and significant wakes along the side walls.

The mean horizontal velocity component is compared to the current meter and ASFM data shown in Figure 9 (left column) while the flow direction is compared to the ASFM data only (right column), since the current meters do not measure the flow angle. The velocity profile confirms the conclusions made earlier: a reduced velocity at the top section and accelerated at the lower part of the profile as well as visible velocity deficits produced by the trash rack wakes. The overall agreement with the measured data is close although some discrepancies appear at the floor when comparing the profiles in the three bays. This can be explained by the fact that the bottom region of the intake is strongly influenced by the large flow re-circulation taking place past the bottom upstream step. Because the upstream bottom floor may have been modified over the years by sediment or debris deposits, the size of the flow re-circulation and the bottom section of the velocity profile could be modified as well.

The comparison of the simulated flow direction with the ASFM data shows systematic differences in Bay A and B. Note however that the flow angle calculated by the numerical model is closer to the measured flow angle in Bay C. In all three bays, however, the measured flow angles have large variations with elevation, which are not present in the simulation. The turbulence associated with the wakes from the trash-rack appears to have introduced errors in the flow angle calculated by the ASFM, although the effect on the discharge is small.

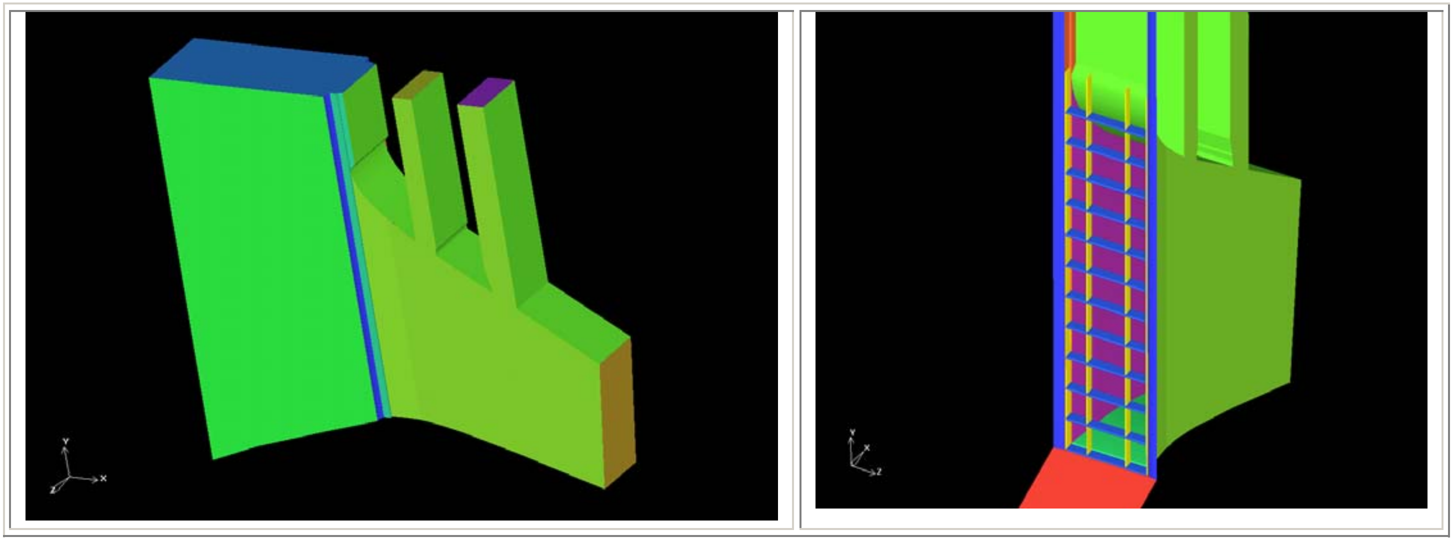

Figure 6 - Three-dimensional computational domain of La Grande-1 intake and trash rack.

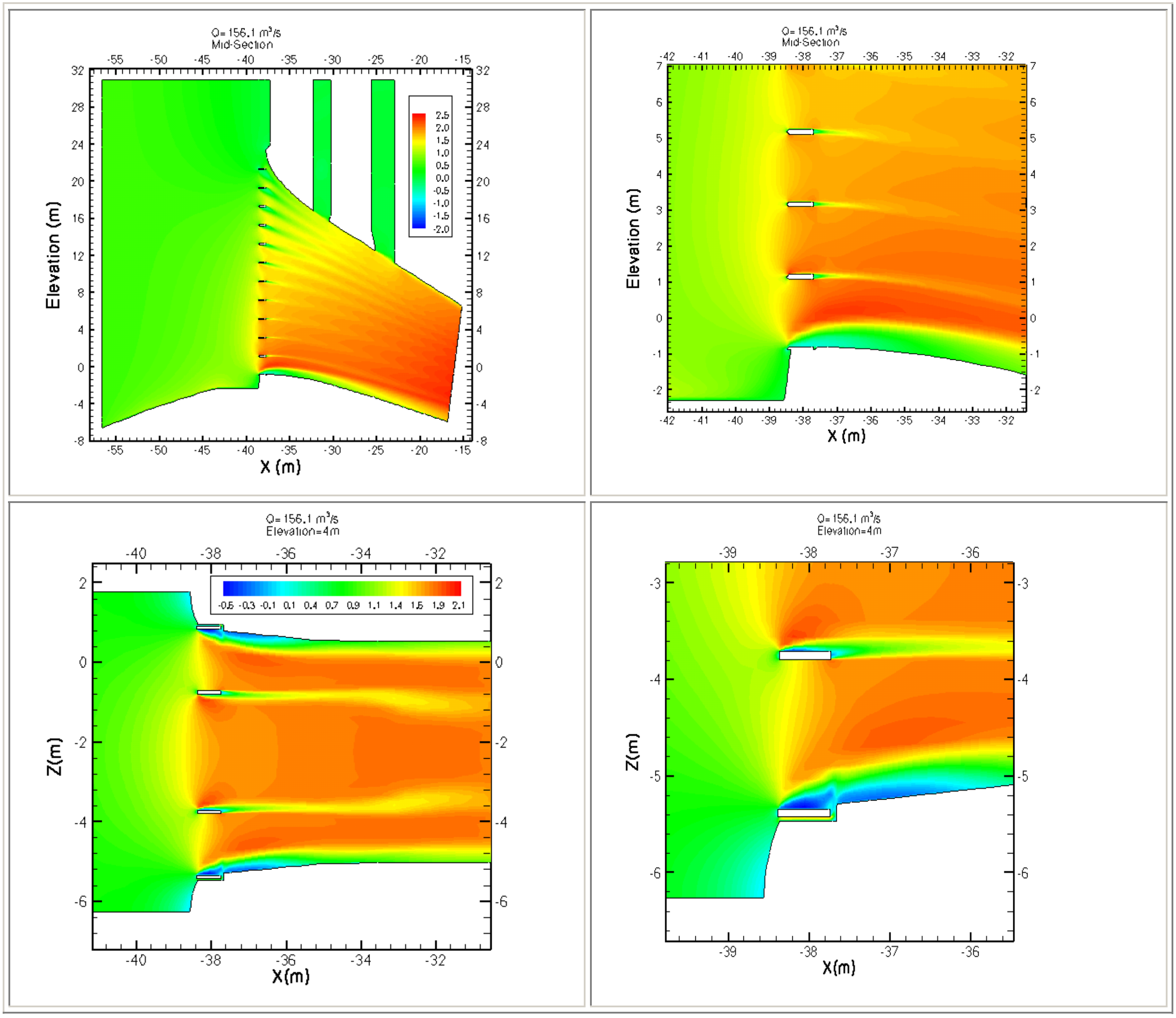

Figure 7 - Mean horizontal velocity component distribution: in the middle cross section of the intake (top) and in a lateral selected section (bottom).

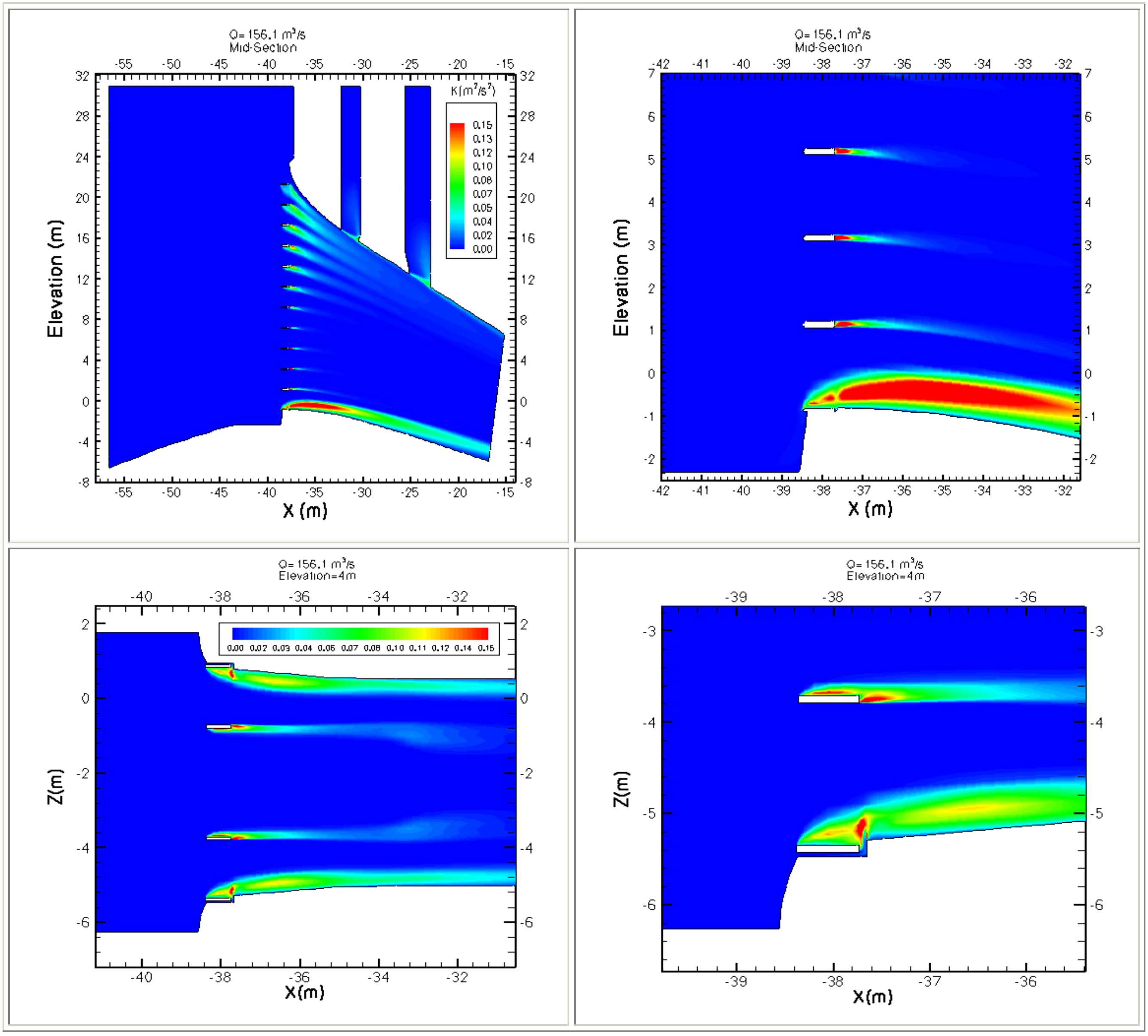

Figure 8 - Mean turbulent kinetic energy distribution: in the middle cross section of the intake (top) and in a lateral selected section (bottom).

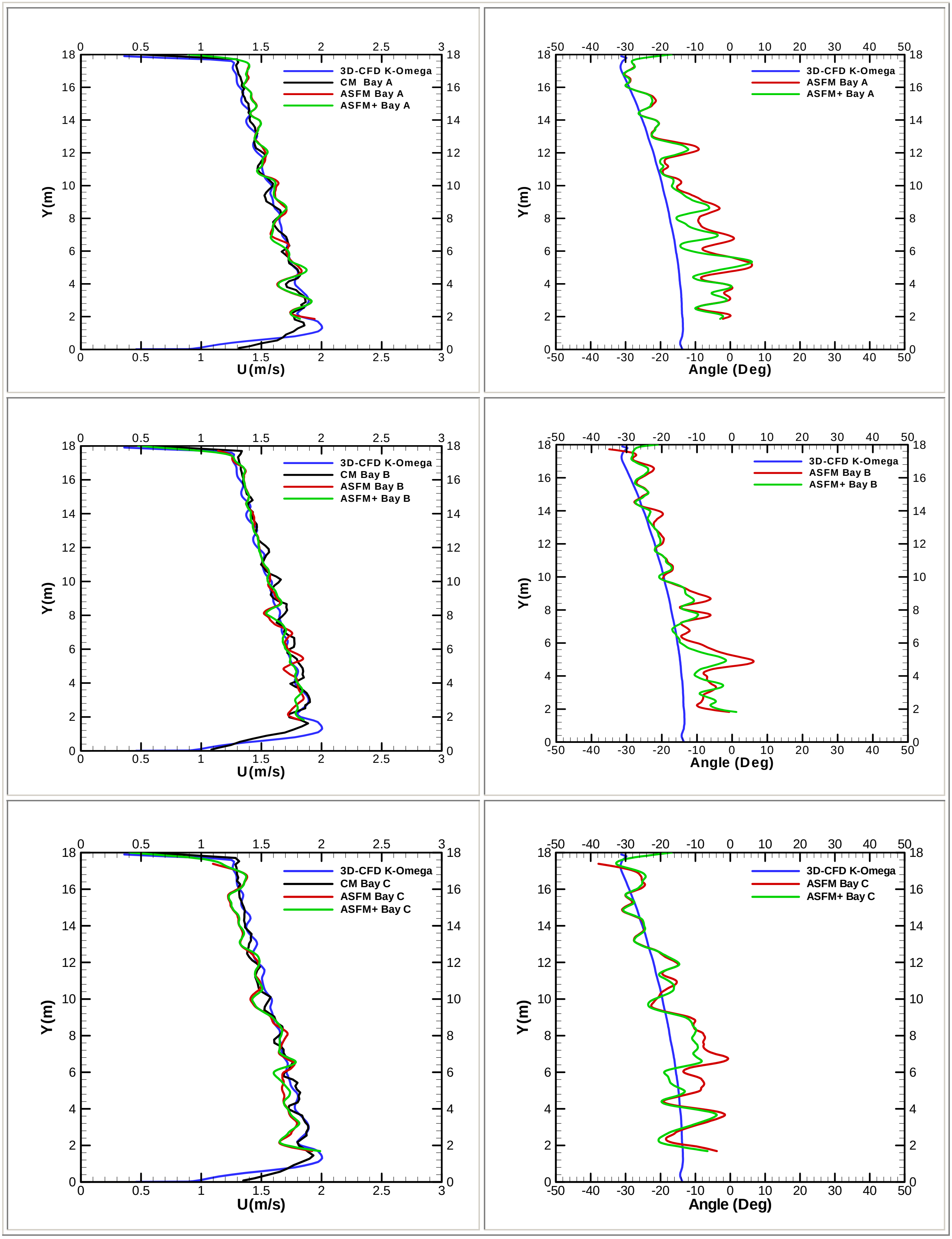

Figure 9 - Comparison of the CFD results with the current meter and ASFM data (before (red) and after (green) applying ASFM Pro Plus) in the three bays. The mean horizontal velocity and flow direction are displayed.

3 DISCUSSION

Simultaneous measurements taken with current meters and an ASFM in the La Grande-1 powerhouse have allowed comparisons of the discharge measured by the two methods to be compared over a large number of flow conditions. The data were collected on a profiling frame, which was moved continuously over the height of the intake. After application of data reprocessing methods to the ASFM data, the overall agreement between the two methods was within 0.5%. The standard deviation of the differences was ±0.8%, equivalent to an expected difference in any single comparison of ±1.6% at the 95% confidence level.

Velocity profiles from both methods showed the presence of significant wakes from the major horizontal members of the trash-rack. The flow angle measured by the ASFM showed large variations through the wakes, to a much greater extent than would be expected at the 5m downstream distance. A CFD model of the flow in the intake was developed to simulate the distribution of flow and turbulence in the intake and assess its probable effect on the ASFM velocity measurement. The model results show that the effects of the wakes in both the turbulence and the mean velocity are clearly significant at the measurement location, but the simulated flow angle does not show the variations through the wakes seen in the ASFM results.

The greater variability in the ASFM results is therefore likely caused by the proximity of the measurement location to the trash-rack. The disturbances in turbulence and velocity associated with the wakes from its elements introduce variability in the flow angle and to a much lesser extent in the discharge, but do not produce any systematic difference. A measurement location further downstream, where the wakes had merged, would have produced less variable results. The use of the profiling version of the instrument may also have contributed somewhat to the variability in the discharge, in that it does not allow for as long a sequence of data to be used for computing velocity at a particular elevation, as would a fixed-path installation. Increasing the analysis block size results in spatial variations being included in the velocity calculation, which may have prevented it from reducing the variability. Moving the frame at a slower rate, or measuring the velocity at a series of fixed elevations might result in some variability improvement.

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