Characterization of Biases in Culvert Flow Measurements by Acoustic Doppler Flow Meter (ADFM) due to Gate-Induced Complex Flows and Meter Placement

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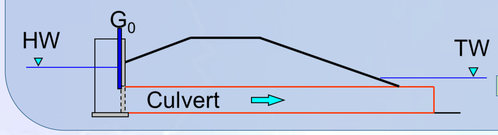
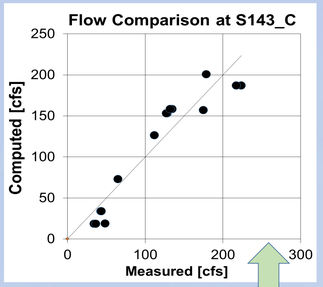
How much water flows through cells in the STAs?

Computed discharges are needed for compliance

Flow is conveyed through the cells of the STAs via gated culverts, for which upstream and downstream stages are monitored continuously, and used to compute discharges.



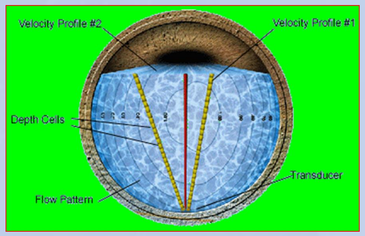
In order to provide accurate estimates, the discharge rating equations are calibrated using field flow measurements.

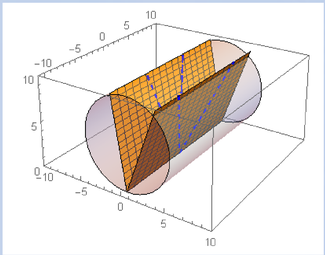


$$Q = CA_0\sqrt{\frac{2g(H-T)}{\left(\frac{A_0}{A_G}\right)^2 + 2C^2\left[1-\frac{A_0}{A_G}+\frac{gn^2L}{k_n^2R_0^{4/3}}\right]}}$$

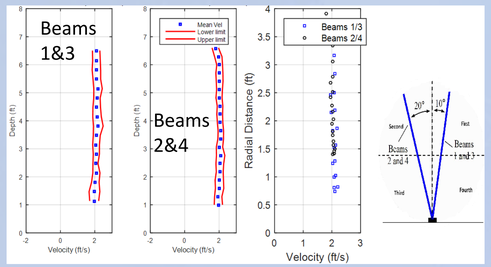
What are ADFMs? What challenges come with their use?

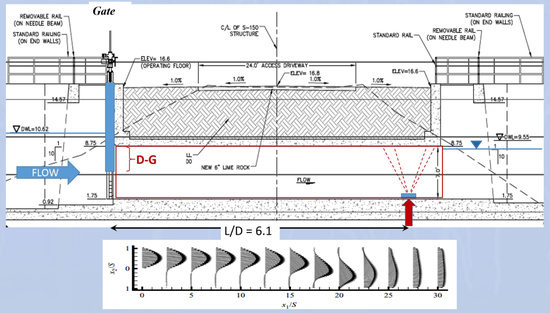
Acoustic Doppler Flow Meters (ADFMs) are the instruments used most frequently to measure the flow needed to calibrate flow ratings for culverts. ADFMs incorporate a transducer, mounted in the culvert, which emits and measures the return signal of sound waves from particles moving through water.





ADFMs incorporate a transducer, mounted in the culvert, which emits and measures the return signal of sound waves from particles moving through water. Using the Doppler principle, ADFMs develop a profile of the velocities in the culvert from the acoustic signals.



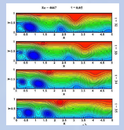


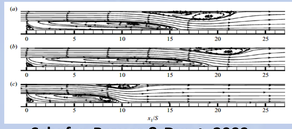
Gates controlling the flow in the STAs' culverts induce a complex flow field consisting of a jet below a hydraulic jump, or a submerged jet with a recirculating eddy, depending on whether the flow is free or pressurized.

ADFM challenges (continued)

ADFMs are suitable for measurements in well-developed flows. However, best-measurement guidelines regarding ADFM placement for flow measurements in gated culverts are not available.

Elizarova & Shilnikov, et al, 2004



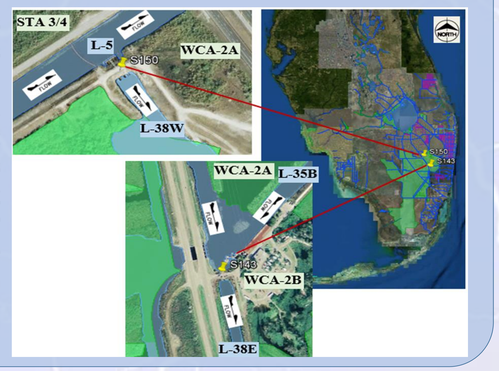


Schafer, Breuer & Durst, 2009

Neither a characterization of the distance from the gate where well-developed flow occurs, nor an assessment of the biases in ADFM measurements while measuring partly-developed flows are available in the literature.

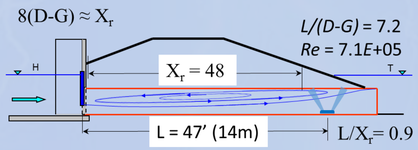
How can ADFM biases be assessed?

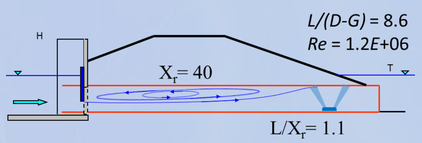
ADFM data from 3 sites were analyzed to assess bias due to placement: S143, S150 and G441 (not shown). At the first two sites, bias was assessed by comparing concurrent ADCP measurements; in the third, an upstream ADFM was used.

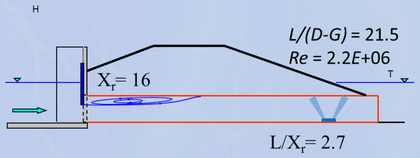


What biases exist due to ADFM placement?

At S150 and S143, the reattachment length was varied by adjusting the gate setting. ADFM measurements were made with a fixed placement at 47' DS of the gate. Independent measurements were made with Acoustic Doppler Current profiler (ADCP) to provide an un-biased reference.



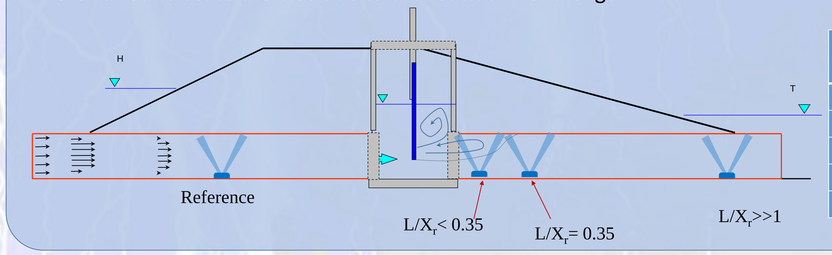




$Q \pm U_Q$ (95%) [cfs]		Relative Difference	Reattachment length, Xr = 8(D-G) [ft]
ADFM[1]	ADCP	ΔQ	
147.5 ± 2.8	148.2 ± 7.3	0.5%	24
127.4 ± 6.1	128.4 ± 7.4	0.8%	32
132.3 ± 2.1	134.9 ± 4.5	1.9%	32
164.0 ± 4.3	175.1 ± 4.9	6.3%	20
217.5 ± 5.5	223.7 ± 6.7	2.8%	12
178.8 ± 2.5	186.6 ± 4.7	4.2%	29
34.5 ± 1.1	36.8 ± 3.9	6.2%	44
42.9 ± 0.9	43.7 ± 2.9	1.8%	42
52.1 ± 1.0	53.5 ± 2.8	2.6%	40
45.4 ± 1.2	46.2 ± 3.0	1.7%	36
65.1 ± 1.7	67.2 ± 4.7	3.1%	32

Maximum biases ~6.4%

At G441, three ADFM meter placements were analyzed, with a fourth ADFM placed upstream used as the unbiased reference. Gate openings were varied to asses the bias due to the reattachment length.



$Q \pm U_Q$ (95%) [cfs]		Relative Difference	Reattachment length, Xr = 8(D-G) [ft]
ADFM[1]	ADCP	ΔQ	
176.6 ± 5.2	175.9 ± 24.3	0.4%	48
629.4 ± 12.3	672.8 ± 12.3	6.4%	16
317.8 ± 8.4	298.8 ± 12.4	6.3%	40
659.8 ± 10.9	702.9 ± 33.8	6.1%	2

Conclusions

- Good-quality data could not be collected for **L/Xr < 0.35; this seems to be the limit for the proximity of the sensor with the gate**.
- **Bias appears to weakly increase with increasing Xr.**
- Bias is also likely highly dependent on a scaled velocity called Reynold's number (Re = Vel*(D-G)/v)
- **Data with very low bias (0.4%) is possible with L/Xr as low as 0.35!**

References

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