RIVER INFLOW CHARACTERISTICS FOR HYDROKINETIC ENERGY CONVERSION

V. Neary[1], D. Sale[2], B. Gunawan[1],

[1] Oak Ridge National Laboratory, Oak Ridge, TN 37831; Mechanical Engineering Department, University of Washington, Seattle, WA

1. Background

River inflow characteristics, including spatial-temporal distributions of mean velocity, Reynolds stresses, and turbulence intensities over the energy extraction plane of a hydrokinetic machine are needed to quantify a site's annual energy production, machine loads, machine performance and levelized cost of energy.

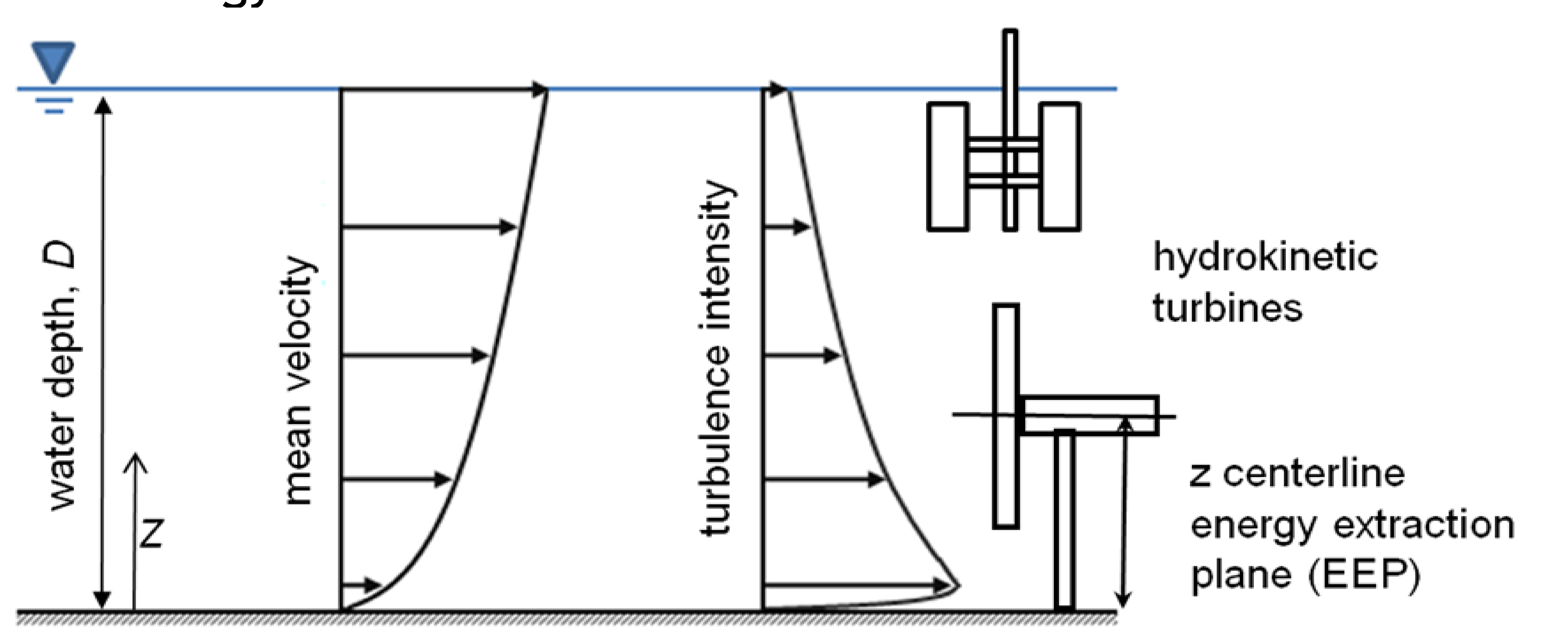

Figure 1. Typical distributions of velocity and turbulence and sketch of (a) surface mounted vertical axis turbine; and (b) bottom mounted horizontal-axis turbine.

2. Objectives

Review published turbulent flow data from large rivers, a canal and laboratory flumes to:

1. Evaluate the validity of classical models that describe the depth variation of the time-mean velocity and turbulent Reynolds stresses
2. Determine the range of velocities and longitudinal turbulence intensities acting on EEP

Table 1. Bulk flow properties of reviewed open channel flow data

investigators	site	Q_m	Q*	D_{avg}*	W*	Re**	Fr**
		(m^3/s)	(m^3/s)	(m)	(m)	(10^6)	
McQuivey (1973)	Mississippi	19000[a]	7900-9200	7.4-16	570-890	3-9	0.06-0.17
McQuivey (1973)	Missouri	910[b]	890-920	2.9-3.1	200-210	4-38	0.19-0.35
Holmes & Garcia (2008)	Missouri	2200[c]	1400	4.9	350-400	5-9	0.13-0.17
McQuivey (1973)	Rio Grande canal	NR	14-26	0.85-0.91	21-22	0.8-1.3	0.36-0.49
Nikora & Smart (1997)	Hurunui	NR	250	1.2	85-90	1-5	0.70-0.79
Carling et al. (2002)	Severn	NR	100	NR	NR	3-6	0.10-0.16
McQuivey (1973)	CSU flume	NR	1-2	0.33-0.53	2.44	0.4-0.8	0.69-0.74

NR = not reported
* reported by original investigators at time of measurement
** derived by authors, using depth averaged velocity and local water depth
[a] mean annual discharge from nearest USGS station #07289000, record period: 2009
[b] mean annual discharge from nearest USGS station #06610000, record period: 1953-2009
[c] mean annual discharge from nearest USGS station #06935965, record period: 2001-2010

3. Results

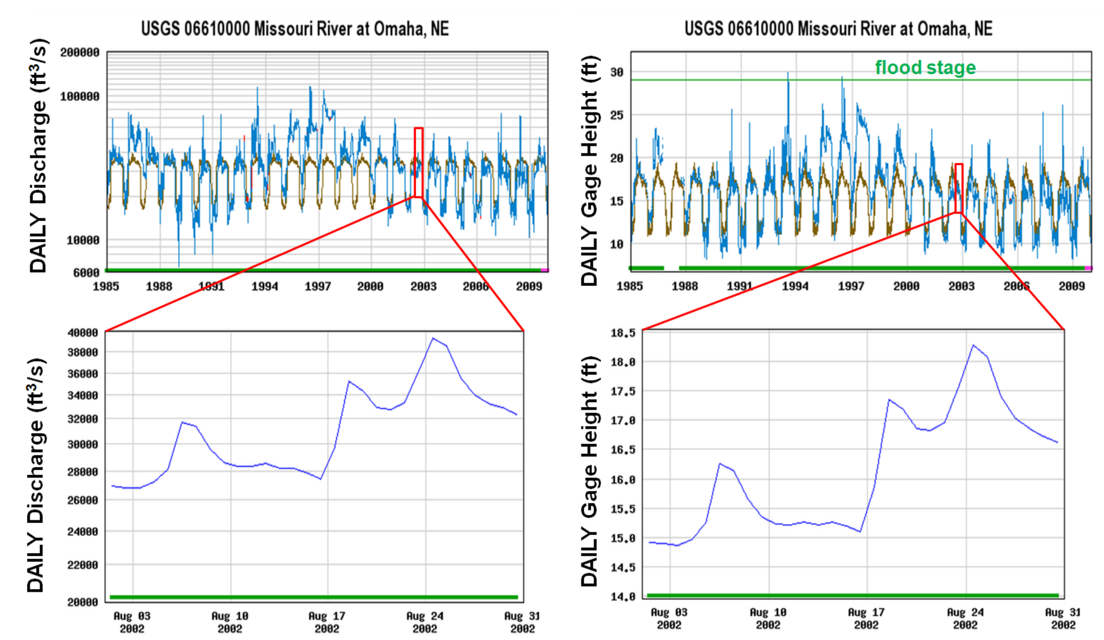

Figure 3.1. Daily flow and depth time-series record on the Missouri River, Nebraska (USGS 06610000). Blue indicates the daily values. Brown indicates the daily mean values for the (POR). The inset plots show the flow and depth time series during field measurements by Holmes and Garcia (2009).

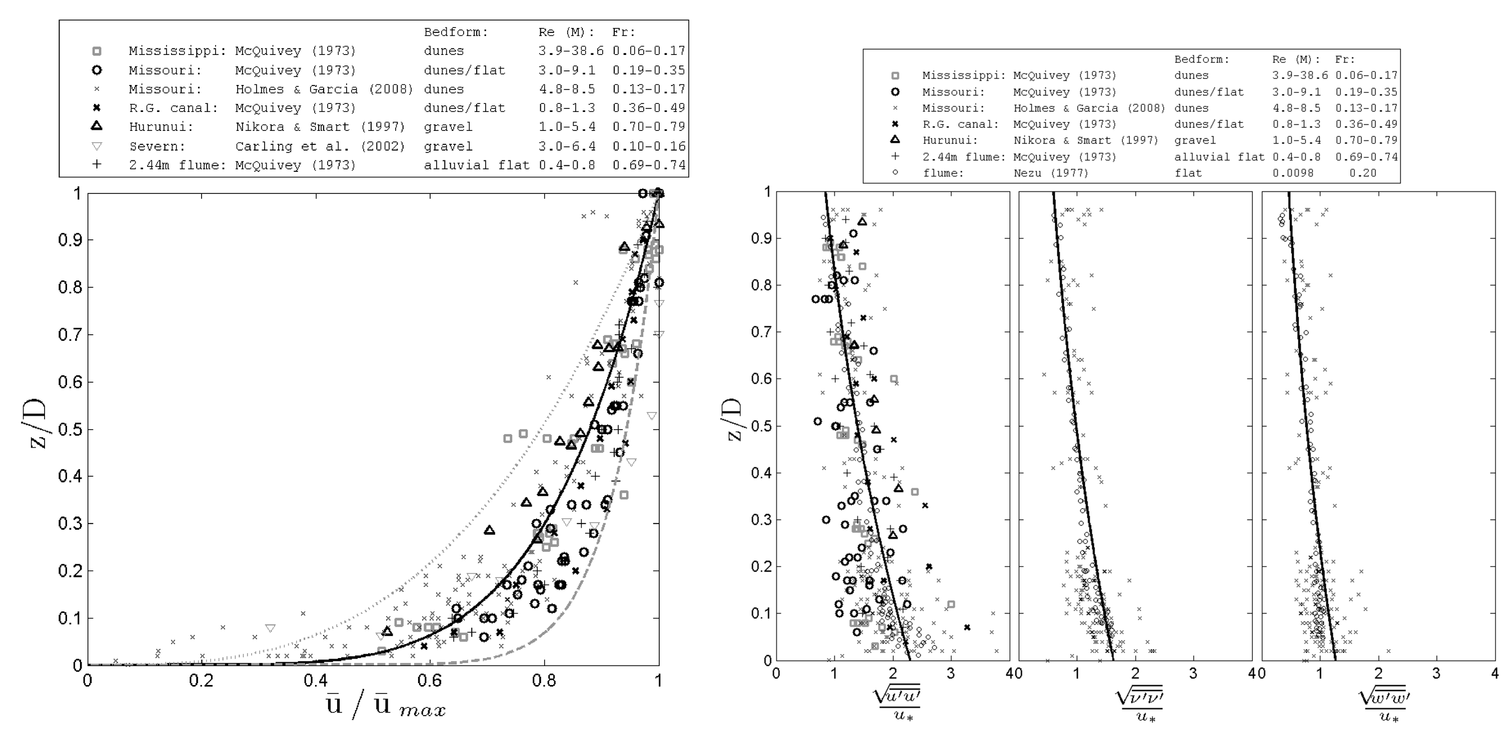

Figure 3.2 (a) Power law velocity profiles with *z* normalized by *D* and mean velocity normalized by maximum mean velocity. The solid black line represents the best fit of the power law with exponent *1/a* through the data, and the resulting best fit $a = 5.4$ ($R^2 = 0.999$). The dotted and dashed lines represent the power law with exponent 1/3 and 1/12, respectively; (b) Exponential decay law profiles by Nezu and Nakagawa (1993) compared to field measurements, with *z* normalized by *D* and normal stresses normalized by shear velocity.

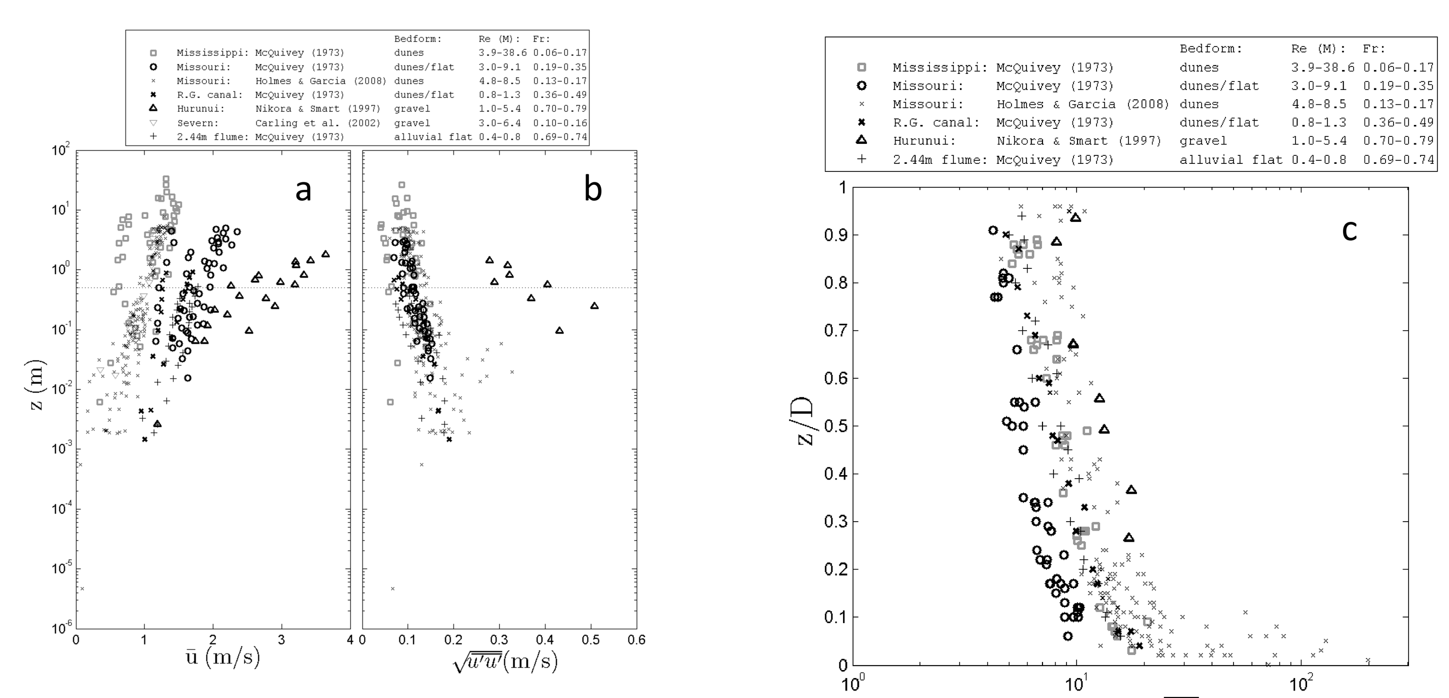

Figure 3.3 (a) Mean longitudinal velocity profiles. (b) Longitudinal turbulence intensity profiles. The dashed horizontal line indicates $z = 0.5$m. Machines will typically operate at depths greater than 0.5m off the bed. (c) Longitudinal turbulence intensity profiles with z normalized by the flow depth .

3. Results (continued)

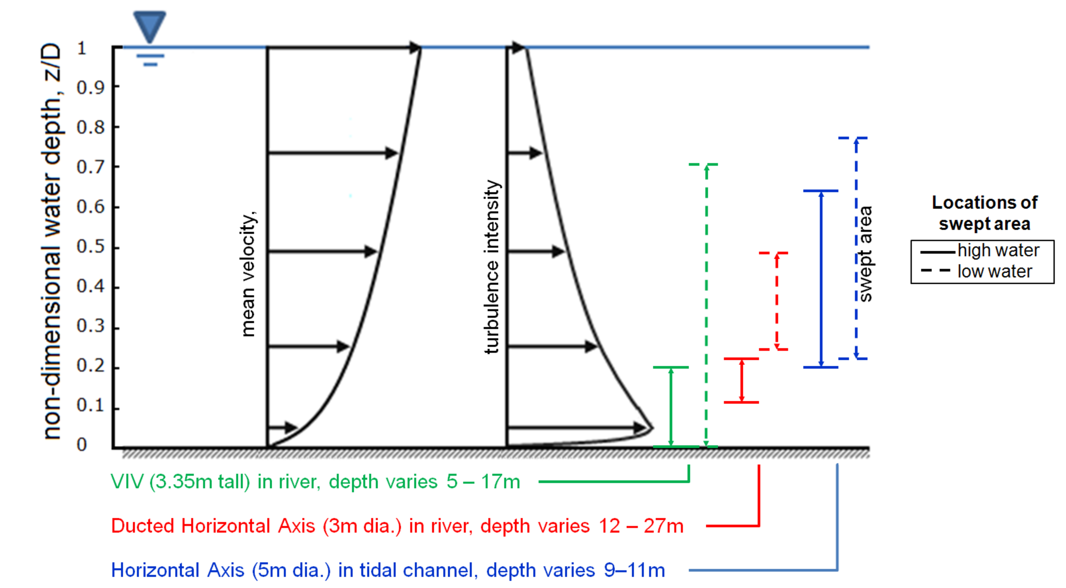

Figure 3.4 Effects of large depth variability on the location of the swept area (energy extraction area) relative to the velocity and turbulence profiles.

4. Conclusions

1. Classical models generally perform well in describing river inflow characteristics.
2. Maximum longitudinal turbulence intensities near the bed are approximately between 10 to 20% of the local mean velocity, similar to atmospheric boundary layer flows.
3. River inflow characterization is challenging due to the high variability of depth and flow, which causes significant variations of inflow mean velocity and turbulence intensity over the design life of the machine.

5. References

1. Carling, P. A., Z. Cao, M. J. Holland, D. A. Ervine, and K. Babaeyan-Koopaei (2002), Turbulent flow across a natural compound channel, *Water Resour. Res.*, *38*(12), 1270.
2. Holmes, R.R. and Garcia, M.H. (2008). Flow over bedforms in a large sand-bed river: A field investigation. *Journal of Hydraulic Research*, 46(3): p. 322-333.
3. McQuivey, R.S., *Summary of Turbulence Data from Rivers, Conveyance Channels, and Laboratory Flumes.* USGS Report 802-B Turbulence in Water, 1973.
4. Nezu, I. and Nakagawa, H. *Turbulence in Open-Channel Flows*, A.A. Balkema, Rotterdam, 1993.
5. Nikora, V.I. and Smart, G.M., (1997). Turbulence characteristics of New Zealand gravel-bed rivers. *Journal of Hydraulic Engineering*. 123(9): p. 764-773.

6. Acknowledgements

This research was funded by the U.S. Department of Energy under Contract DE-AC05-00OR22725. The authors also thank Bob Holmes of the United States Geological Survey for providing data he collected on the Missouri River.

7. Point of Contact

Vincent Neary, Ph.D., P.E., Sr. Research Engineer & MHK Technology Lead, nearyvs@ornl.gov