Flow Discharge Measurements Using Small Unmanned Aerial Systems

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First things first…

What is a small unmanned aerial system (sUAS)?

- It's a drone!

What is flow discharge?

- The amount of water that flows through a river during a given amount of time

What's the point of this project?

- To measure river discharge with drones using a remote method of estimating the velocity index

Problem Solving

Problem Solving

- Main problem: obtaining accurate and safe measurements of river discharge during a flood event
- Floods are the most common natural disaster in the world
- A key component in mitigating the damage to structures and human life caused by flooding is knowing the max discharge that could occur in a given river
- Knowing the peak discharge allows for the proper design of hydraulic structures such as bridges, dams, spillways, culverts, etc.

https://www.greenmatters.com/p/hawaii-floods-march-2021

https://www.hawaiinewsnow.com/2021/03/12/hawaiis-rains-floods-cited-examples-climate-change/

- We know that measuring the discharge during peak flow events critical when it comes to flood management planning.
- The issue is that measuring discharge during high flow events is exceedingly difficult and dangerous in the Southwest U.S. since floods are flashy and full of suspended load
- Current flowmeters, Acoustic Doppler Sensors, and other probes often perform poorly in suspended sediment laden flows and mobile bed scenarios that frequently occur during flooding events in arid environments

How drones could help solve the problem

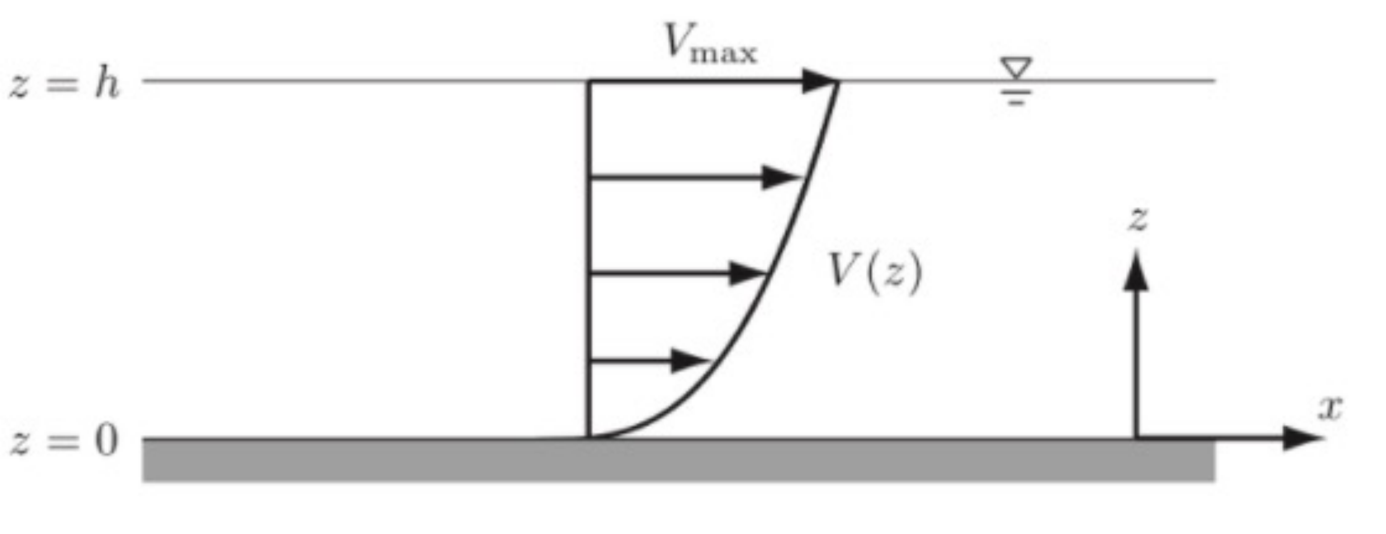
- In recent years, drones have become increasingly affordable, stable, and reliable
- sUASs provide a unique opportunity to obtain surface flow velocity data at rivers without compromising the safety of field technicians
- Can be easily deployed in hard-to-reach areas
- Can Collect high resolution video during flight that can be processed to obtain a detailed surface velocity distribution.

https://www.amazon.com/Parrot-Foldable-Quadcopter-Autonomous-vertical/dp/B07D5R2JKL

But there's a caveat…

- Using Large Scale Particle Image Velocimetry, the surface velocity distribution can be obtained
- The surface velocity is not the same as the depth-averaged velocity which is a key component in the discharge calculation.
- **The surface velocities must be converted to depth-averaged velocities in order to estimate the river discharge using a *velocity index* (often referred to as α)**

$$Discharge = v_{average} * Area$$



https://www.chegg.com/homework-help/questions-and-answers/open-channel-flow-depth-h-velocity-profile-v-z-shown-figure--channel-width-b-normal-page-v-q20176317

Two general approaches of estimating the velocity index

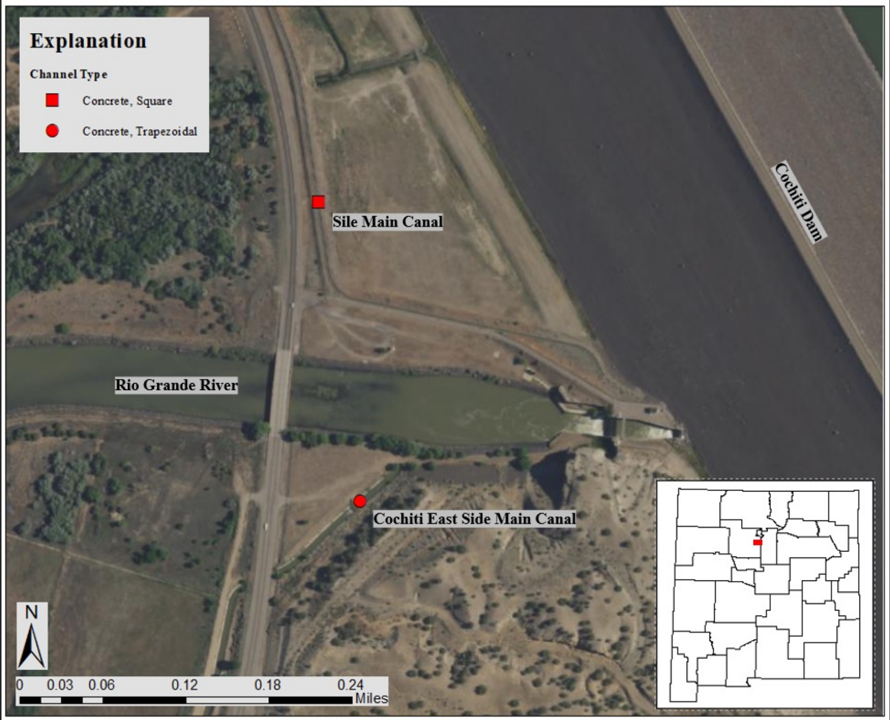
- Qualitative
  - Past flow data
  - Channel type (natural, earthen, concrete, etc.)
  - Flow properties (flow depth, aspect ratio, hydraulic radius, etc.)
- Quantitative
  - Entropy method
  - Turbulence properties

General Approach

- Record video of water surface
- Track features on water surface to estimate the surface velocity distribution
- Use that velocity distribution to calculate turbulence properties
- Leverage the turbulence properties to calculate the velocity index
- Calculate the channel discharge using the velocity indices.

Study Sites

Channel Name	Location	USGS Gage Number	Date Measured	Manning's n	Type
Agua Fria River	Rock Springs, AZ	9512800	3/13/2020	0.041	natural
Reservation Main Canal	Yuma, AZ	9523200	7/7/2020	0.030	earthen
Gila River	Dome, AZ	9520500	7/7/2020	0.019	natural
Wellton-Mohawk Main Outlet Drain	Yuma, AZ	9529300	7/6/2020	0.016	concrete
Coachella Canal Above All-American Canal Diversion	Felicity, CA	9527590	7/8/2020	0.015	concrete
Cochiti East Side Main Canal	Cochiti, NM	8313500	8/17/2020	0.019	concrete
Sile Main Canal (At Head)	Cochiti, NM	8314000	8/17/2020	0.016	concrete
Androscoggin River	Auburn, ME	1059000	5/1/2019	0.050	natural



Flow Example

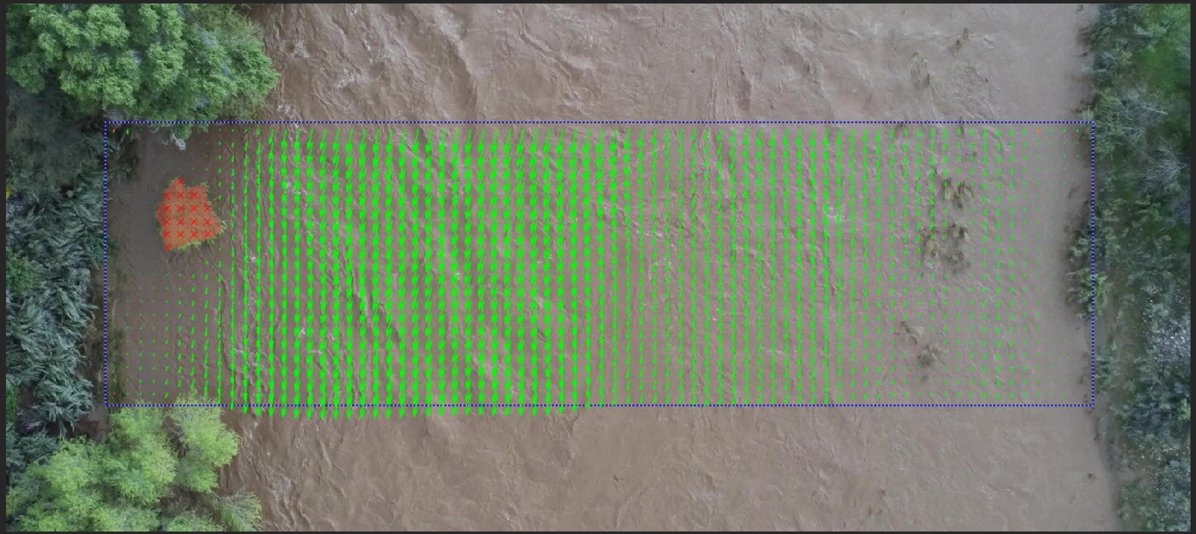
Seed dispersion *apparatus*

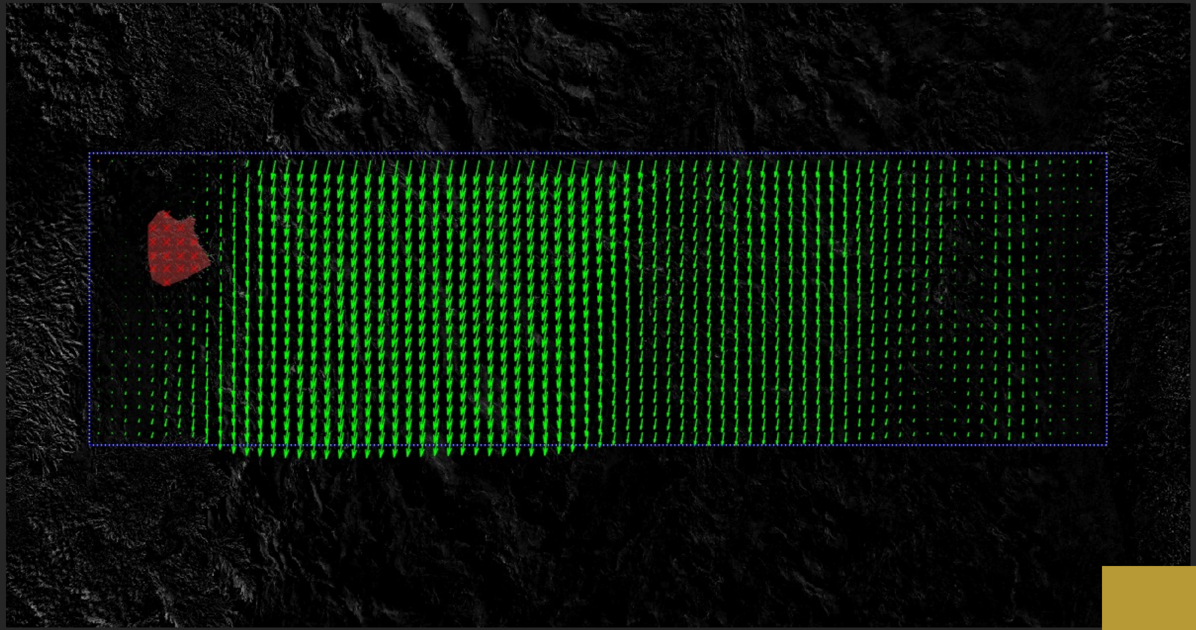
https://www.youtube.com/watch?v=QiwHsI4YGKI

Flow Example after “seeding”

Extracting Velocities From Videos

- The first step is to split the video into individual consecutive pictures.
  - A 20 second video shot at 30 frames per second creates 600 pictures
- The frames were stabilized and enhanced to improve feature tracking
  - Frames were enhanced by performing a "background subtraction"
- Frames were loaded into PIVlab where surface features were tracked, and velocities were calculated using Large Scale Particle Image Velocimetry



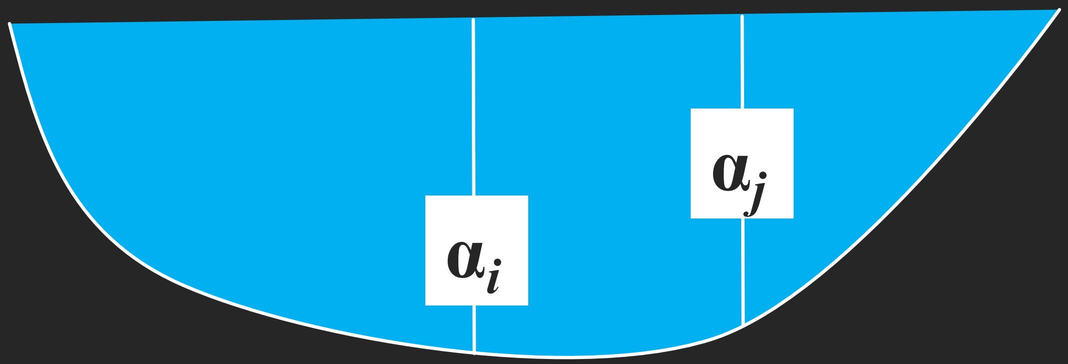


Theory

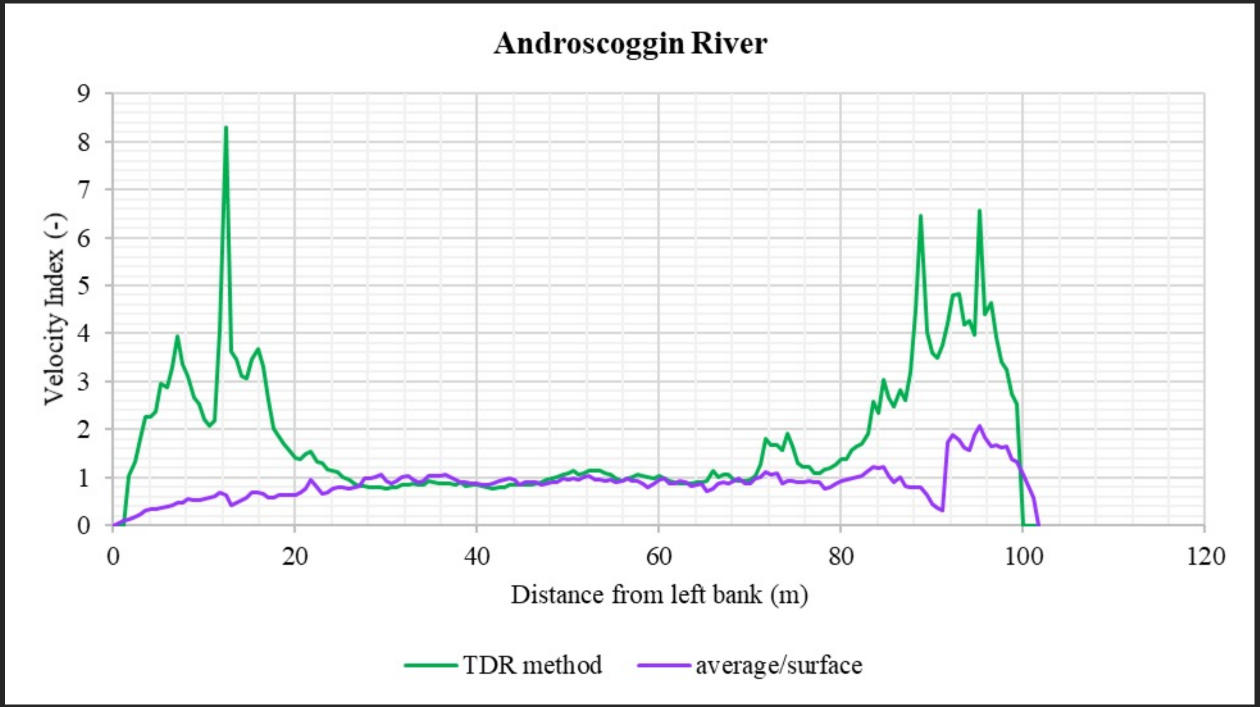
- **For fully developed open channel flow and assuming flatbed surface, the Law of Wall is valid so that the vertical distribution of turbulence energy dissipation rate is inversely proportional to the flow depth as:**
  - $\varepsilon(z) = \frac{u_*^3}{\kappa z}$
    - **Where:** $\varepsilon(z)$ **is the turbulence dissipation rate at flow depth** z, u_* **is friction velocity, and** κ **is the von Kármán constant**
- **Manning's equation is:** $V_{average} = \frac{1}{n} H^{2/3} S_f^{1/2}$
  - **Where** $V_{average}$ **is depth averaged velocity,** n **is Manning's roughness, and** S_f **is the friction slope**

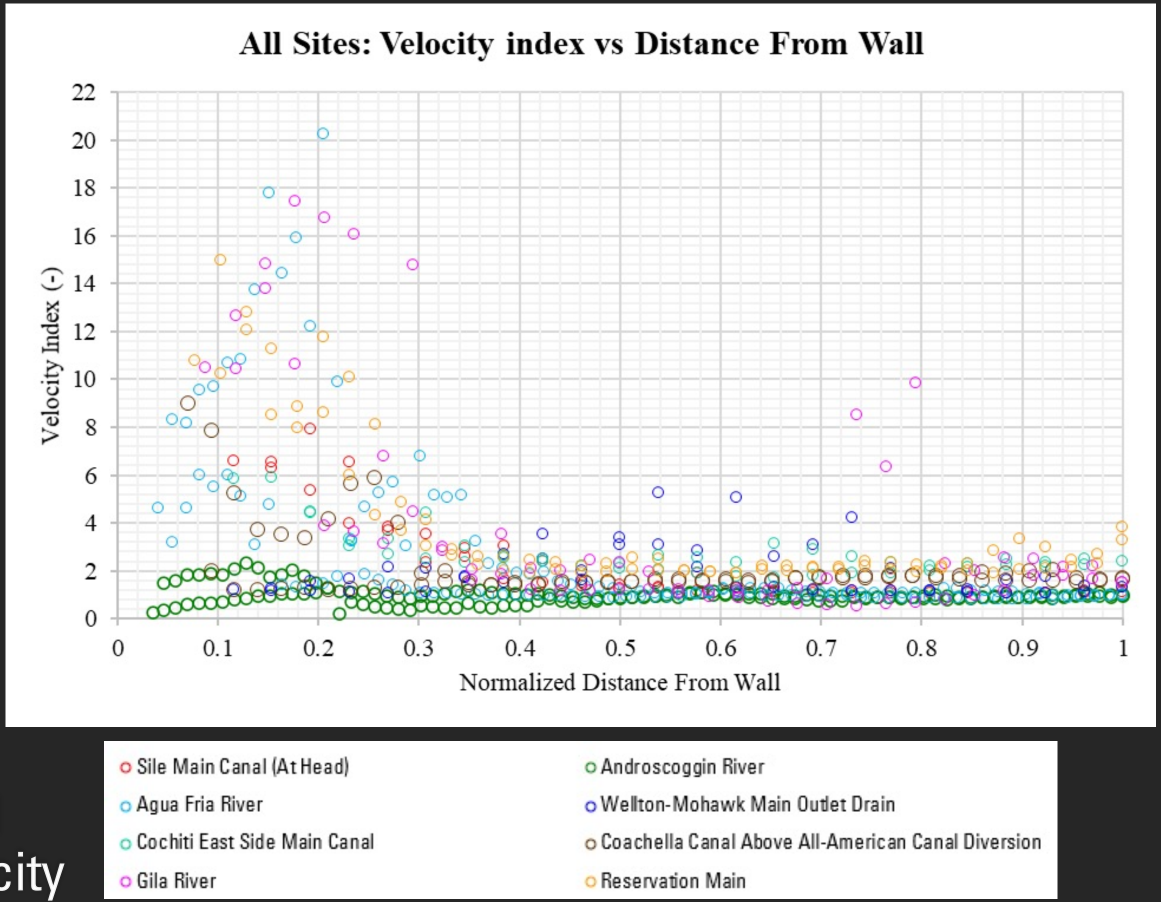
Theory

- **Since friction velocity (u_*) is related to flow friction (S_f,) slope by $u_* = \sqrt{gHS_f}$, the Manning's equation can be rewritten as:**
  - $V_{average} = \frac{k_n(\kappa\varepsilon_s)^{1/3}H^{1/2}}{ng^{1/2}}$
    - **Thus, making the depth averaged velocity a function of the turbulence dissipation rate, depth, and Manning's n.**
- **The velocity index can then be calculated as:**
  - $\alpha = \frac{V_{average}}{V_{surface}}$



Velocity Index Calculations

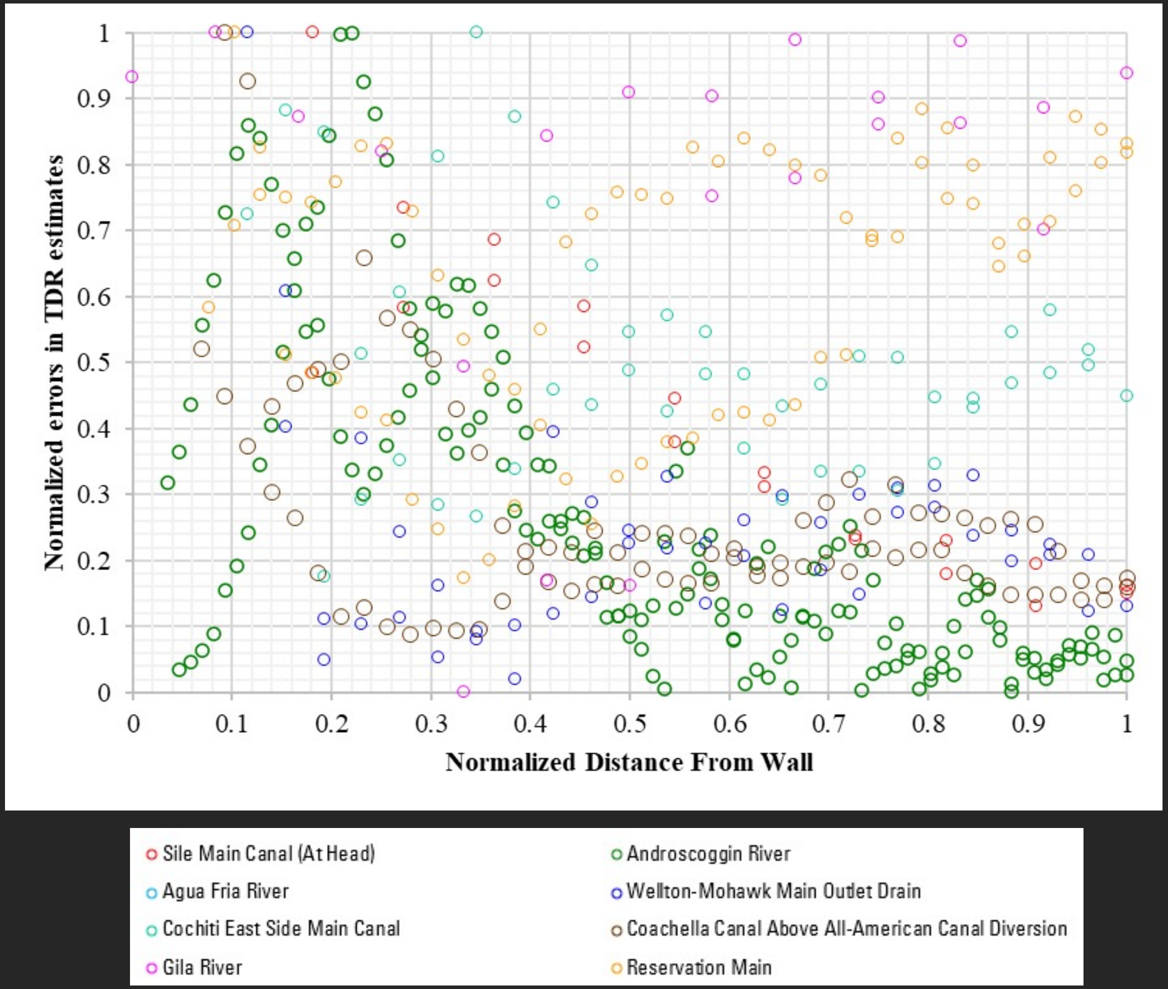




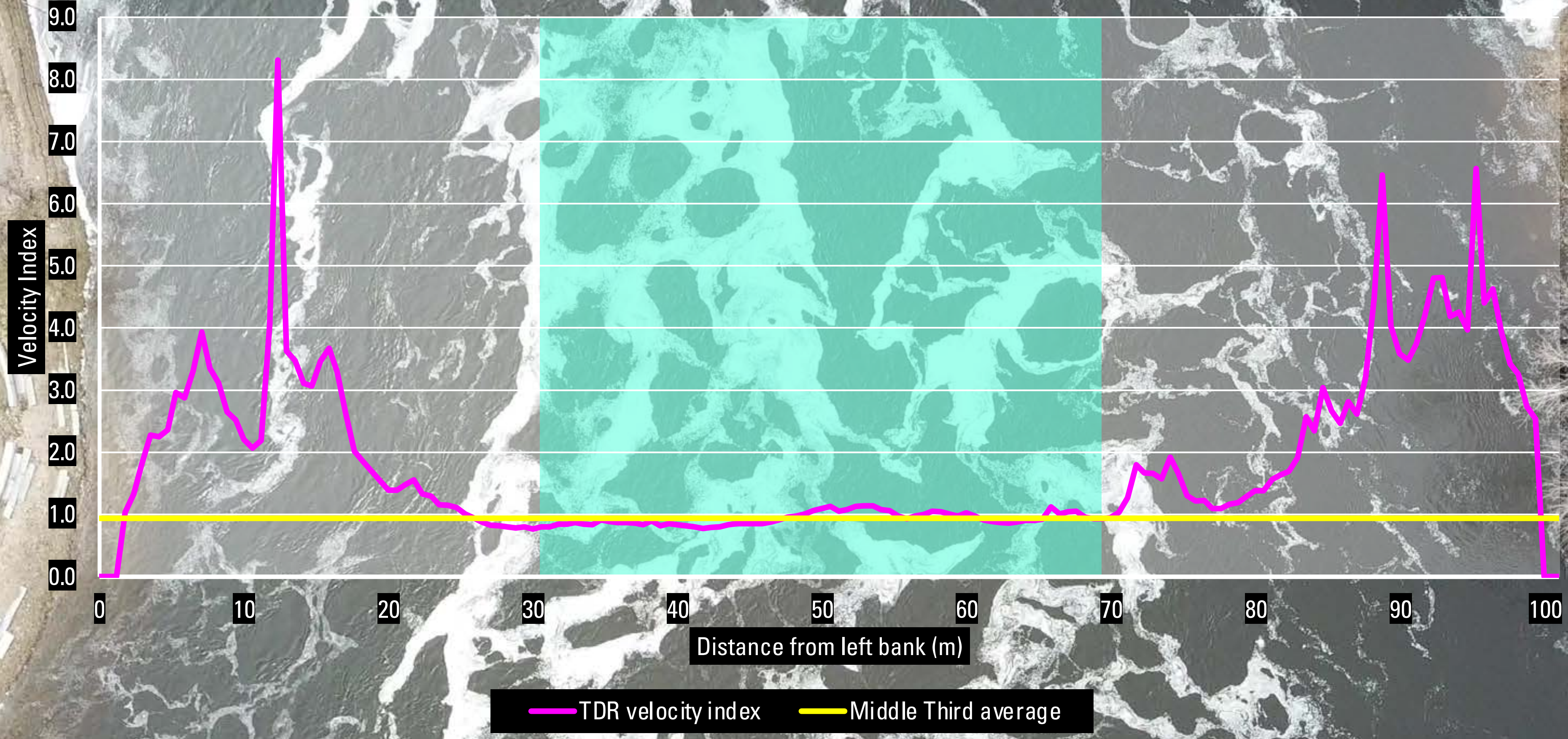
- The velocity index was calculated using the TDR method described earlier and compared against the known velocity index calculated using USGS measurements
- It was found that the TDR method of estimating α often produces large estimates near the riverbanks

Factors Affecting Velocity Indices

- The TDR errors were plotted against normalized distance to the wall, and it was found that TDR errors also increase near the riverbanks
- There are two exceptions to this phenomenon:
  - Reservation Main: high winds created small waves causing an increase in measured turbulence
  - Gila River: very shallow depth (0.28 m) and variation in bathymetry could have influenced the turbulence



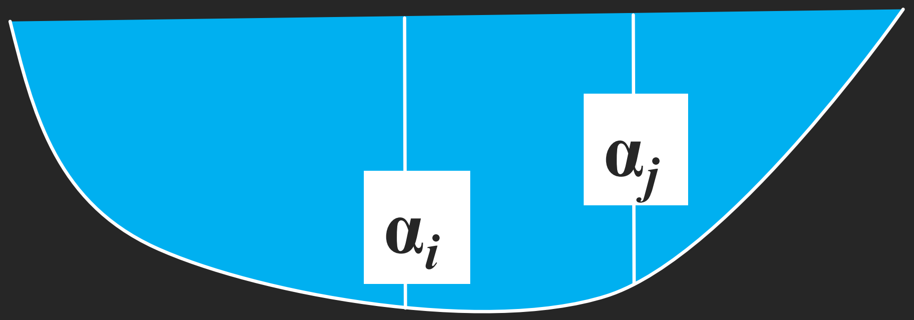
Calculating Discharge



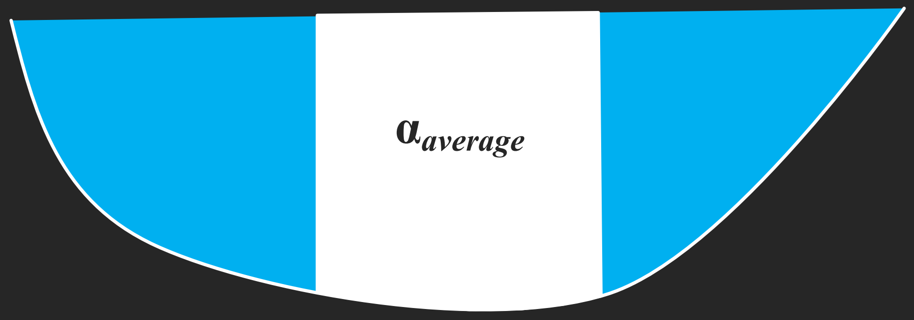
- **So, the problem is that the TDR is overestimating velocity indices near the riverbanks.**
- **To overcome this issue, the velocity index values were averaged in the center third of the channel and applied to the entire channel**

Calculating Discharge

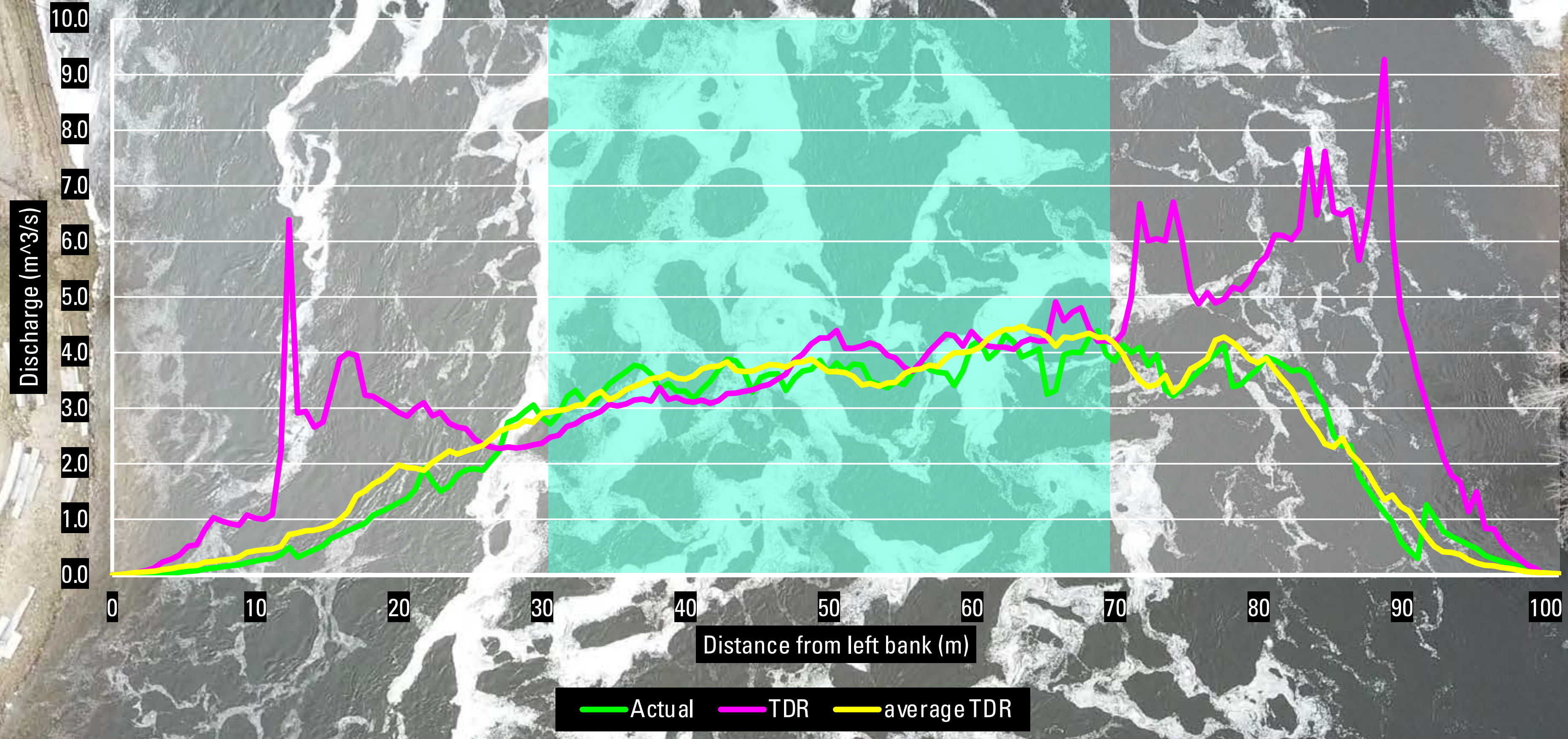
- **Original discharge calculation using the velocity indices, α, from the TDR method:**
  - $Q = \sum_{i=1}^{n} \alpha_i * v_{surface_i} * A_i$



- **Revised discharge calculation using the middle third average velocity index, α, from the TDR method:**
  - $Q = \sum_{i=1}^{n} \alpha_{average} * v_{surface_i} * A_i$

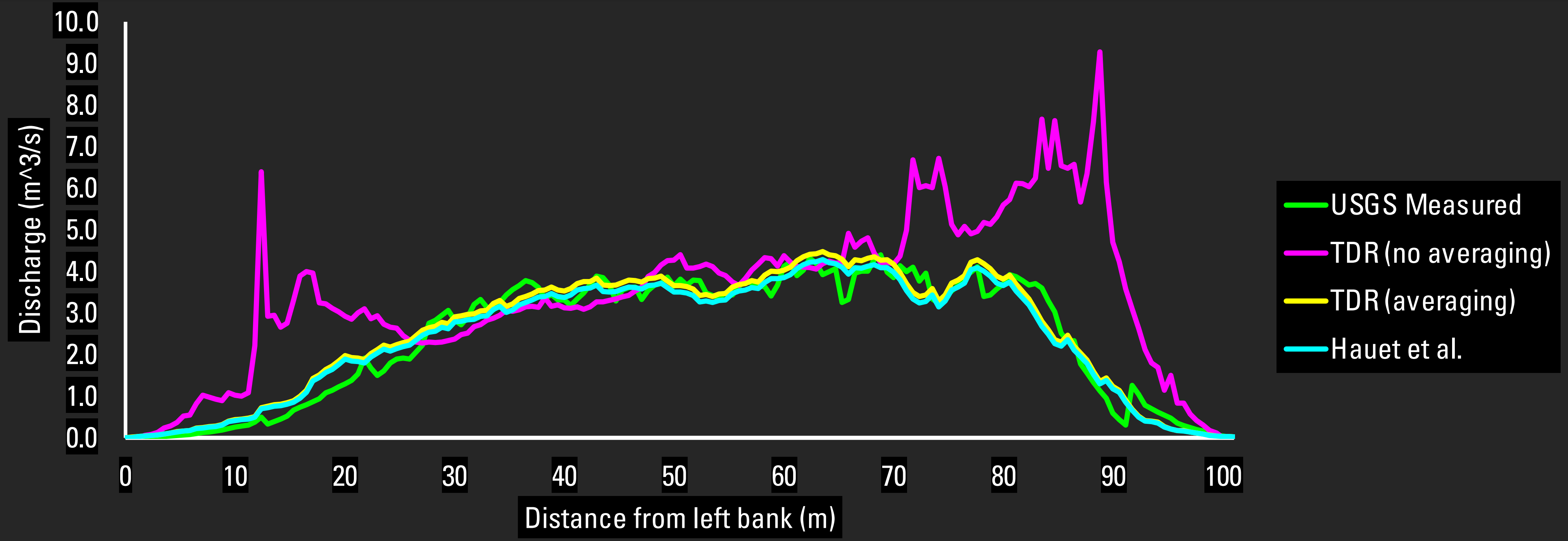


Calculating Discharge



The discharge estimates using the middle third average velocity index is much more accurate, especially near the riverbanks.

Discharge Results



Channel Name	Location	Type	Measured USGS Discharge	TDR method Discharge (no averaging)	TDR method discharge (averaging)	Discharge (Hauet et al. velocity index)
Agua Fria River	Rock Springs, AZ	natural	255.5	418.8	292.8	265.72
Reservation Main Canal	Yuma, AZ	earthen	1.7	3.3	3.2	1.19
Gila River	Dome, AZ	natural	0.2	0.3	0.3	0.11
Wellton-Mohawk Main Outlet Drain	Yuma, AZ	concrete	4.1	7.1	5.7	3.29
Coachella Canal	Felicity, CA	concrete	21.4	24.5	23.3	11.97
Cochiti East Side Main Canal	Cochiti, NM	concrete	2.9	5.9	5.5	2.20
Sile Main Canal (At Head)	Cochiti, NM	concrete	1.4	2.6	1.6	1.26
Androscoggin River	Auburn, ME	natural	410.2	587.6	428.2	409.67

Discharge Results

Channel Name	Average Velocity Index (from TDR method)	Velocity index (from Hauet et al.)	TDR method Percent Error (no averaging)	TDR method Percent Error (averaging)	Hauet et al. Velocity Index method Percent Error
Agua Fria River	0.992	0.90	64%	15%	4%
Reservation Main Canal	2.084	0.90	93%	86%	-30%
Gila River	2.322	0.80	53%	87%	-36%
Wellton-Mohawk Main Outlet Drain	1.573	0.90	72%	39%	-20%
Coachella Canal	1.749	0.90	14%	9%	-44%
Cochiti East Side Main Canal	2.242	0.90	105%	91%	-23%
Sile Main Canal (At Head)	1.110	0.90	83%	9%	-12%
Androscoggin River	0.943	0.90	43%	4%	0%
Average			66%	42%	-20%

Take-Home Messages

1. You can estimate discharge from a drone
2. The TDR method of estimating the velocity index works, especially for rivers where discharge is high
3. The discharge estimates using the TDR velocity indices are less accurate (on average) than selecting a velocity index based on depth and channel type (Hauet et al. 2018)

What I’ve Learned

Questions?