Method Development For Remote Sensing of River Flow with Limited Ground-Based Measurements

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Abstract

Quantification of river flow is a significant component of water resource management. Yet, these data have often been deficient in rural regions generally dependent on smaller river systems, especially in low- and middle- income countries, and in places where no remote gaging capabilities currently exist. A relationship between river flow and width has been demonstrated in attempts to record and monitor flow with only satellite-based measurements; however, those methods have focused on rivers with a width of > 30m and have shown extreme errors when compared to historical gaging records. This new technique for monitoring river flow remotely uses Manning's equation for open channel flow coupled with satellite-measured river widths. This technique allows for the creation of a remotely-sensed historical river flow record. Cross-river depth profile, discharge, and slope are necessary for initial calibration. An estimation of flow at study sites was obtained using satellite images at transects. The primary challenge of using this method on smaller rivers is the determination of width from the satellite images. Automated techniques to delineate the water's edge are presented as recommendations to increase accuracy. This method may be used as an additional tool in river flow monitoring for water resource management.

Introduction

Water resource management requires accurate collection of water data over time, including river flow, but these data have been deficient in rural, often low- or middle- income, regions, which generally depend on smaller river systems. In the context of an ever-changing climate and growing unpredictability of global systems, the need for consistent and reliable methods for monitoring resources, such as water, has become impossible to ignore.

The purpose of this research has been to develop a method for sensing river flow in tributaries and rivers with a width of less than 30m using high resolution satellite images, and the relationship between the width and the flow of a river. The additional progress of this method development has included the discovery for the need to distinguish between water, land, and the water's "edge" as the combination of higher resolution satellite images and smaller river width demands more precision and that delineation of the "edge" of becomes more and more complex.

Study Regions

Buffalo Creek, Freeport PA

Mutale River, Limpopo ZA

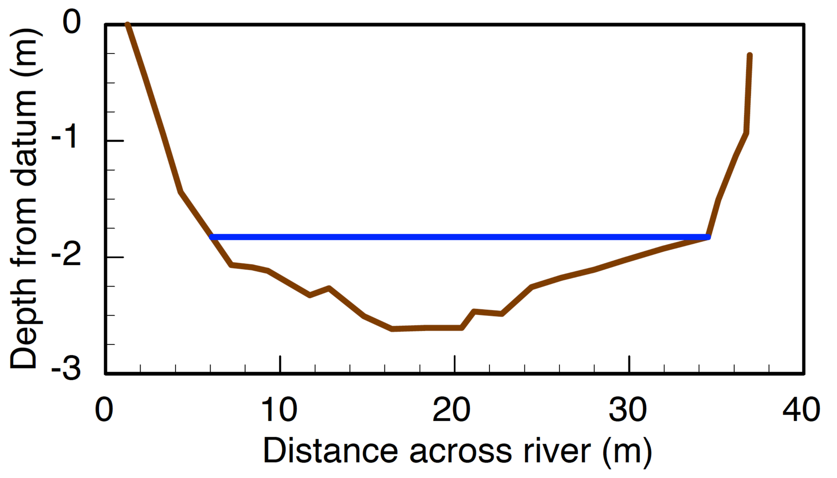
Both of the selected study regions are tributaries of much larger rivers, and are significant to the water supply of their region: **Buffalo Creek** to the **Allegheny River**, and the **Mutale River** to the **Limpopo River**.

Field Measurements and Calibration

Ground measurements including the cross-sectional bathymetry, or depth profile, of the transect location, the slope of the river at the transect location (+/-20m), and discharge were taken at least once for each transect location that would be remotely monitored. These measurements are used to develop a calibrated Manning's equation for each transect.

We can initially calibrate Manning's equation with the ground measurements and the use remotely measured widths to **calculate discharge at any satellite image of the transect location**. This includes any historical widths obtained with older images.

Using Manning's equation calibrated to any given study site, discharge can be calculated from an estimation of width.

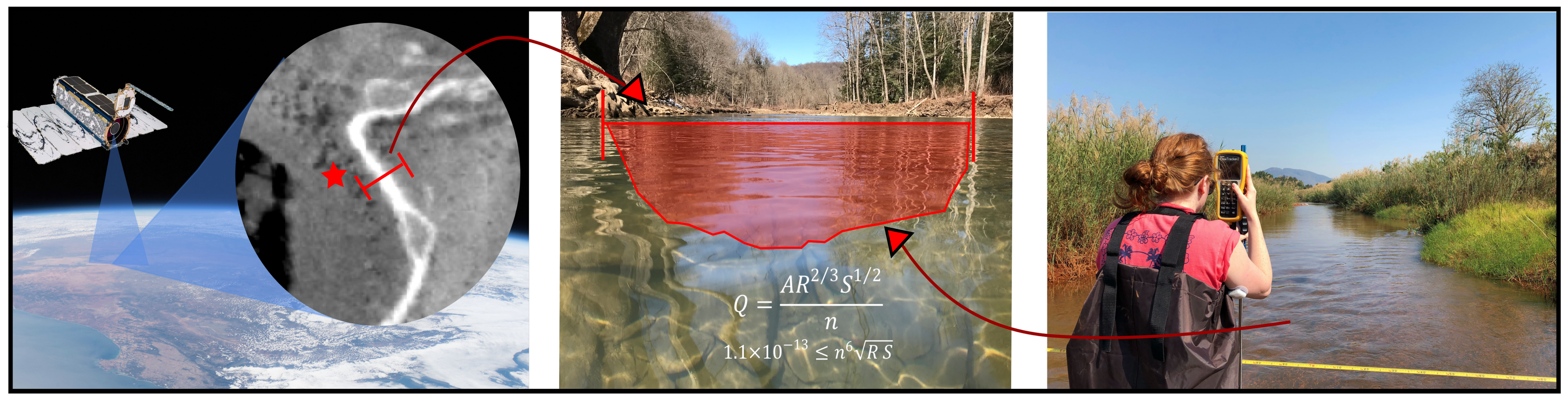


Manning's equation for discharge[8]:

$$Q = \frac{AR^{2/3}S^{1/2}}{n}$$

Method

Data Collection



Method Basics

This method requires certain quality parameters be fulfilled to accurately measure river discharge.

✓ **A study site consisting of:**

A. River transect location, free from overhanging vegetation and accessible on foot across both banks
   a. This location should have an average width of at least >2x the satellite resolution.
   b. Average widths of <30m are of interest for our purposes

B. Nearby gaging station for flow monitoring for validation of method

C. A relatively straight section of river, so that an accurate slope and a more regular bathymetry can be analyzed

✓ **Satellite images of the study site:**

A. Minimum 3m resolution, "4-band" (Red, Blue, Green, and Near-Infrared) images without cloud cover over the transect site (PlanetLabs PlanetScope Images were used here)[6]

B. Able to be adjusted to the Normalized Difference Water Index (NDWI)[5] for determination between image pixel values

Normalized Difference Water Index

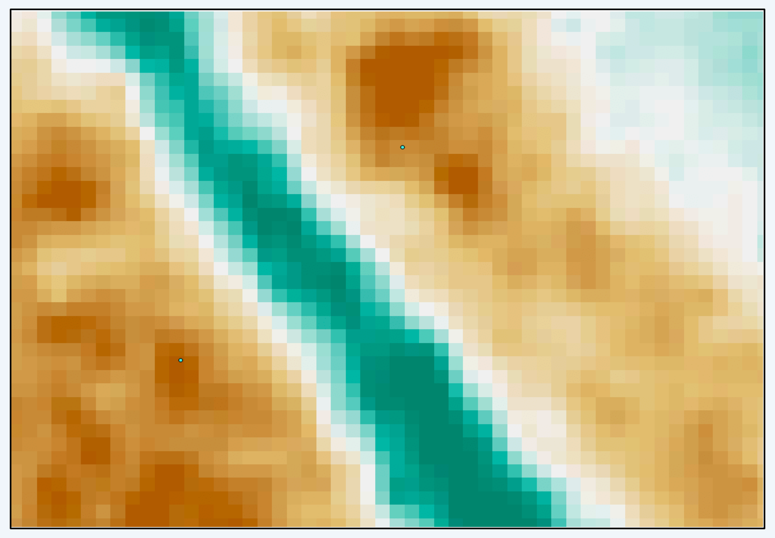
Original Image

NDWI Image

The remote sensing requires satellite images adjusted to better determine water/soil/ vegetation. The **Normalized Difference Water Index (NDWI)** enhances the presence of water features in a satellite image by accounting for the **reflectance of the Green and Near-Infrared bands**, allowing more accurate width measurement in an image.[5]

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$$

Delineation of Water Edge



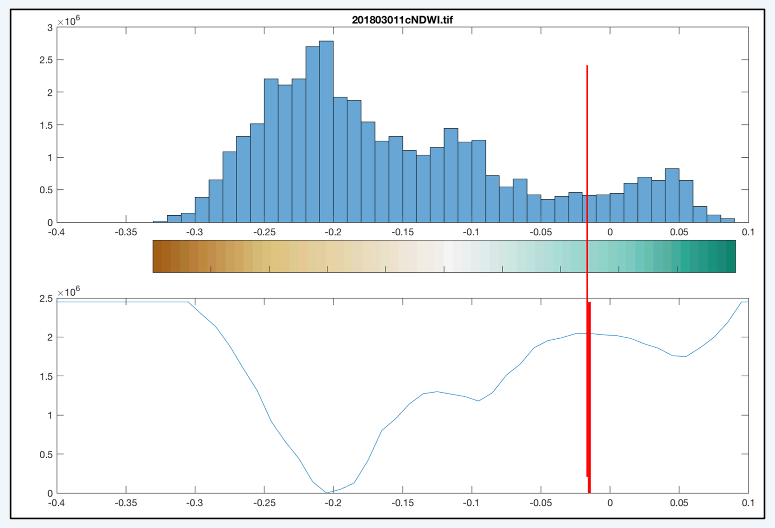


Fig 1. As river width decreases and satellite image resolution increases, it becomes more significant to determine where the true difference between "water" and "soil" or "vegetation" lies in the distribution of pixel values.

A typical distribution seems to show a pattern of three peaks: vegetation, soil, and water, from [-1,1]. This research has determined that the true edge of a river, where water ceases to contribute to flow or is not present, lies somewhere between the true pixel value of "water" and the true pixel value of "soil". In this way here, pixels valued with the color associated with the red line delineate the waters "edge" for this river.

Motivations for Method Development

The Mutale River, a small tributary of the Limpopo River, is the source of water for 32 communities fed by a municipal water plant, and is also a source of water for agricultural use, though that use may go unmonitored or regulated by any party. Because a true accountancy of the water availability in this area has not been made, the need to perform this kind of monitoring is significant because of the number of communities and individuals this river supplies resources for. Particularly, in poorer communities where municipal money may not be free for use for monitoring or fixing any existing gages, being able to perform this kind of monitoring remotely will drastically increase the availability of data, and the accessibility by community and workforce members who may be able to make improvements to these water supplies using these data.

In addition, technological advances that allow higher resolution satellite images are ever-increasing, yet the ability to distinguish between components of those satellite images remains at the 30m resolution level. Without an increase in ability to distinguish between those factors, the availability of hydrologic data will continue to decrease, instead of improving. However, understanding the ways we can distinguish between these components using both advanced technology and also advances in programming increases our ability to easily monitor our water resources.

Results

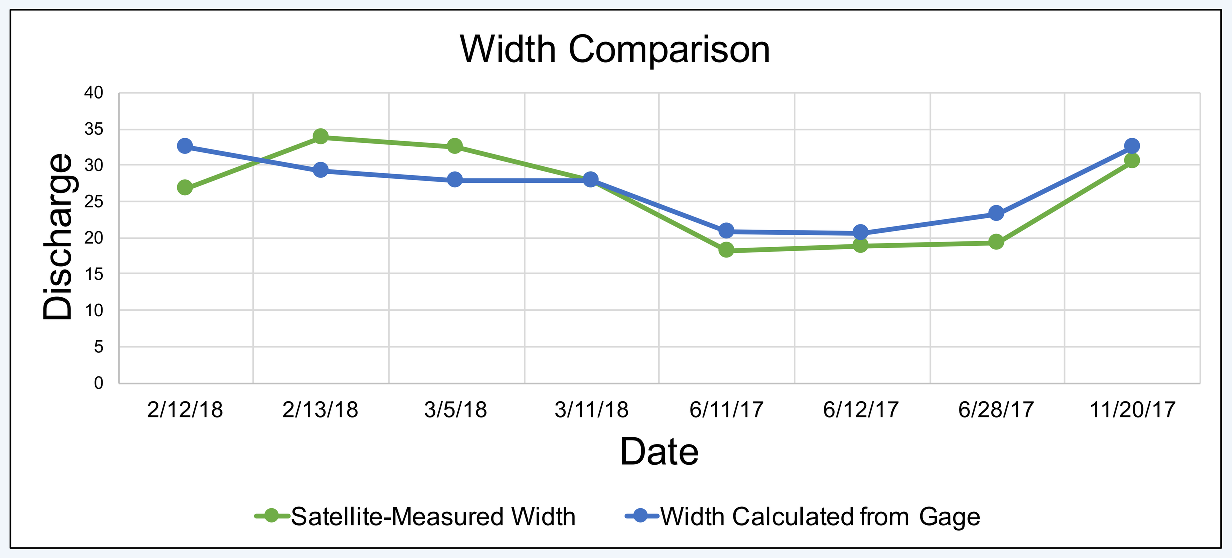


Fig 2a. A comparison of satellite-measured width data from several dates from the Buffalo Creek site to an estimation of expected width based on USGS gage measured discharge. The largest discrepancy exists on 2/12/18, with a percent error of 18.1%.

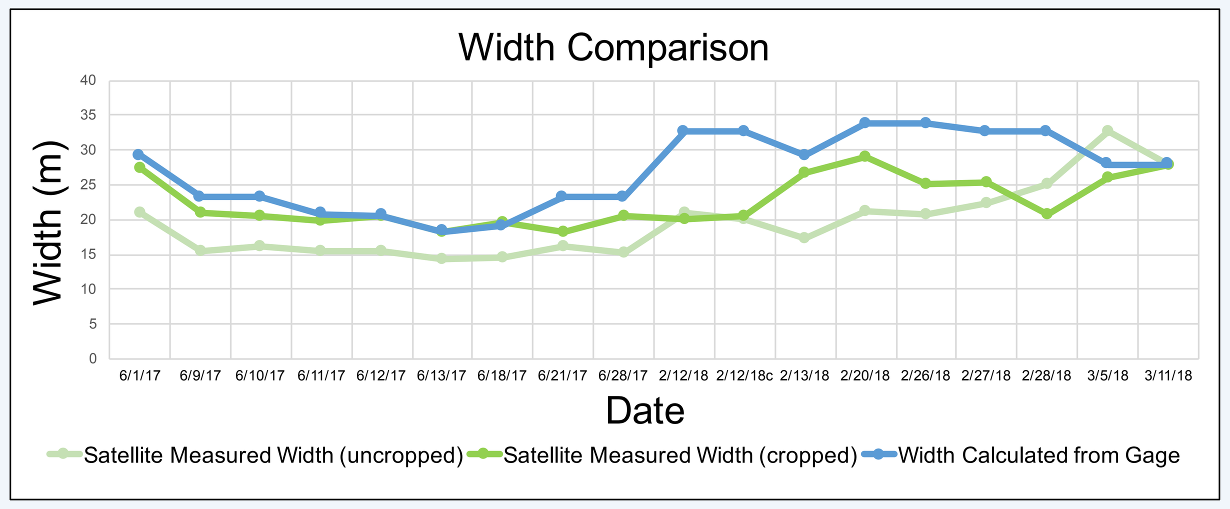


Fig 2b. A comparison of two methods of satellite-measured width data from many dates from the Buffalo Creek site to an estimation of expected width based on USGS gage measured discharge.

Conclusions

Remote sensing of river flow using high resolution satellite images coupled with a small number of field expeditions, ensures hydrologic data availability for many types of rivers, and is not limited by widths of greater than 30m. This methodology is beneficial for small and/or rural communities who use smaller rivers or tributaries for their water resources. It also improves the composition of the full collection of global hydrologic data, and approaches the issue of delineation of the three main qualities that compose satellite image data: vegetation, soil, and water. As we approach an understanding of the distinction between "water" and the "edge" of water at higher and higher resolution satellite imagery, the usefulness of these images and accuracy of any methods that utilize those data, such as remote sensing of the composition of a particular landscape, increase drastically. In order to create the most accurate collection of these data, the authors recommend a continued effort to automate this method using a computer program to measure width, as this decreases bias from the researcher.

This method is particularly of significance for one of the study locations used for this methodology development; the Mutale River. As mentioned in the motivation section of this presentation, this kind of remote sensing directly applies to communities that rely on small river tributaries for their water sources and yet have no consistent way to monitor or account for removal of water from that system. In light of the sand and sediment that are slowly filling the dam location where water for the municipality is pulled, adjustments to this system and monitoring of further affects demand an accountancy of the discharge of the river in order to have any success in their repairs, where a methodology like this which can be done with minimal field work, will both be more cost effective and efficient than traditional gaging methods, especially where money or accessibility are issues.

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