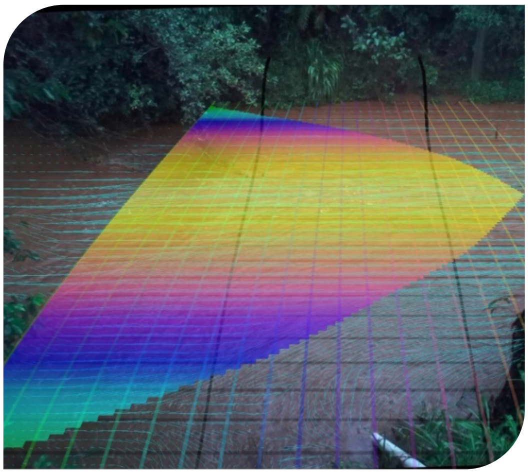
Optical flow monitoring in complex hydraulic conditions



1. Introduction

Efficient flow monitoring networks are a fundamental component of water resource and flood management, and this has become more evident with the impacts of climate change and significant flood events that Australia is experiencing. The development of accurate stage-discharge relationships requires a series of stream flow gauging's over the entire stage range at a monitoring site. An initial stage-discharge relationship at a monitoring site is normally based on 7 or more flow measurements performed over the entire stage range. The stage-discharge relationship is then further developed over time by performing additional stream flow gauging's throughout the stage range and can take several months to years.

This process is highly dependent on available resources, catchment characteristics, rainfall events, monitoring site and hydraulic conditions. Several flow monitoring sites within Australia, especially in remote areas and catchments prone to flash flooding have insufficient flow measurements for the development of an accurate rating curve due to challenging conditions. The use of the same high flow measurements over consecutive stage-discharge rating curves is common due to the lack of high flow measurements to define the top end of the stage-discharge rating curve.

An in-depth research of the optical surface velocimetry methods developed over the past 20 years was performed and it was decided to deviate from the common techniques used. The Farneback algorithm was adopted for its relatively high accuracy, dense flow field and lower sensitivity to noise (Farnebäck, 2002, 2003). A cost-effective noncontact flow measurement solution, Computer Vision Stream Gauging (Hutley et al. 2023). was developed by Xylem Water Solutions Australia and Fluvio that incorporates Farneback algorithm with innovative techniques in integrating surface velocity and stage-discharge model development with machine learning.

The Computer Vision Stream Gauging (CVSG) system makes use of stereo cameras for the remote sensing of surface velocity and water level to develop an adaptive stage-discharge rating curve. The real-time monitoring of surface velocity changes within a channel reach allows the system to develop an accurate rating curve within an exceptionally short timeframe. The stage-discharge rating curve is continuously assessed from instantaneous discharge, surface velocity and water level measurements over consecutive flow events to provide an accurate flow record within the flow monitoring site and hydraulic conditions.

The efficiency of the overall stage-discharge development process is directly related to machine learning that is performed on the point cloud, surface velocity model and stage-discharge rating development. Each of the real-time optical flow measurements are quality coded based on a comprehensive quality matrix for the internal stage-discharge rating development.

2. Methodology

The CVSG is a complete integrated solution from raw data collection to optical flow analysis, the development surface velocity models fitted at each water level increment, machine learning on the processed data sets and real-time stage-discharge development.

The learning applied during the computation process comprises of analyses of all new measurements at different stages of the system operations, with cross-section, surface velocity distribution and discharge rating making up the three main learning stages.

In the first steps of analysing a video, the system checks if the global lighting conditions are satisfied and only the data points that has adequate illumination are used in the computation process.

Cross Section

Point cloud is developed of the near bank and water elevation using stereophotogrammetry technique based on data from the stereo camera, inertial measurement unit (IMU), elevation of camera, camera orientation and cross-section analysis boundaries shown in Figure 1. The point cloud developed is used to analyse the camera elevation, cross section profile and water surface elevation entered.

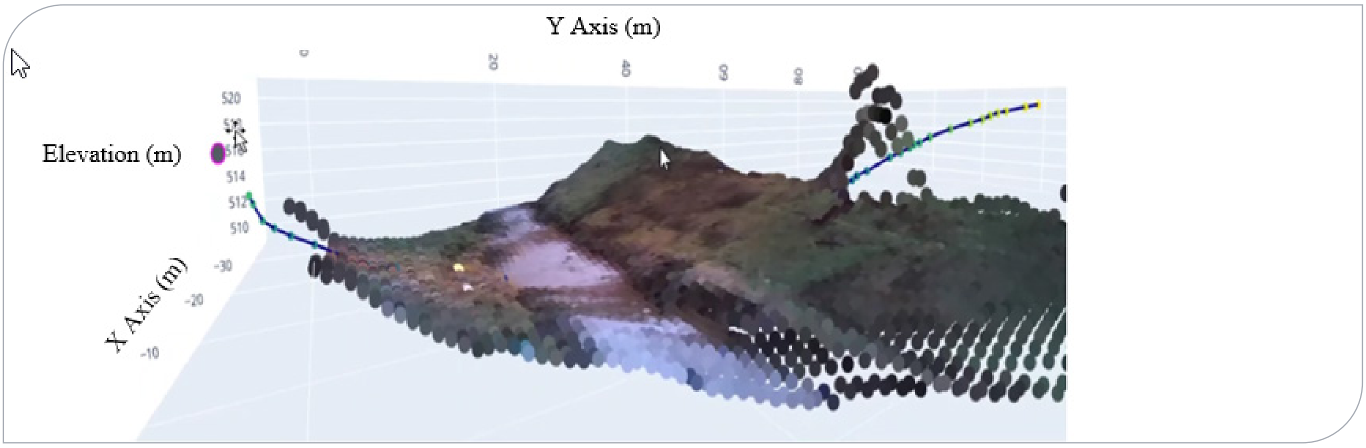


Figure 1: Stereophotogrammetry of cross-sectional profile and water elevation.

Velocity Distribution

The nett optical flow displacements between adjacent frames are processed using the Farneback optical flow algorithm, resulting in a dense flow field with high accuracy and low sensitivity to noise. Raw planar surface velocity rectification is performed at 0.1m resolution across the analysis domain using data from water level elevation relative to camera, inertial measurement unit (IMU), camera orientation, flow direction and surface velocity analysis boundaries. An adaptive database of measured learning surface velocity distribution and surface velocity profile model are developed for each 1cm water level increment shown in Figure 2.

New data is continuously assessed against global lighting conditions and lower and upper surface velocity envelopes to determine if suitable to further improve surface velocity profile model.

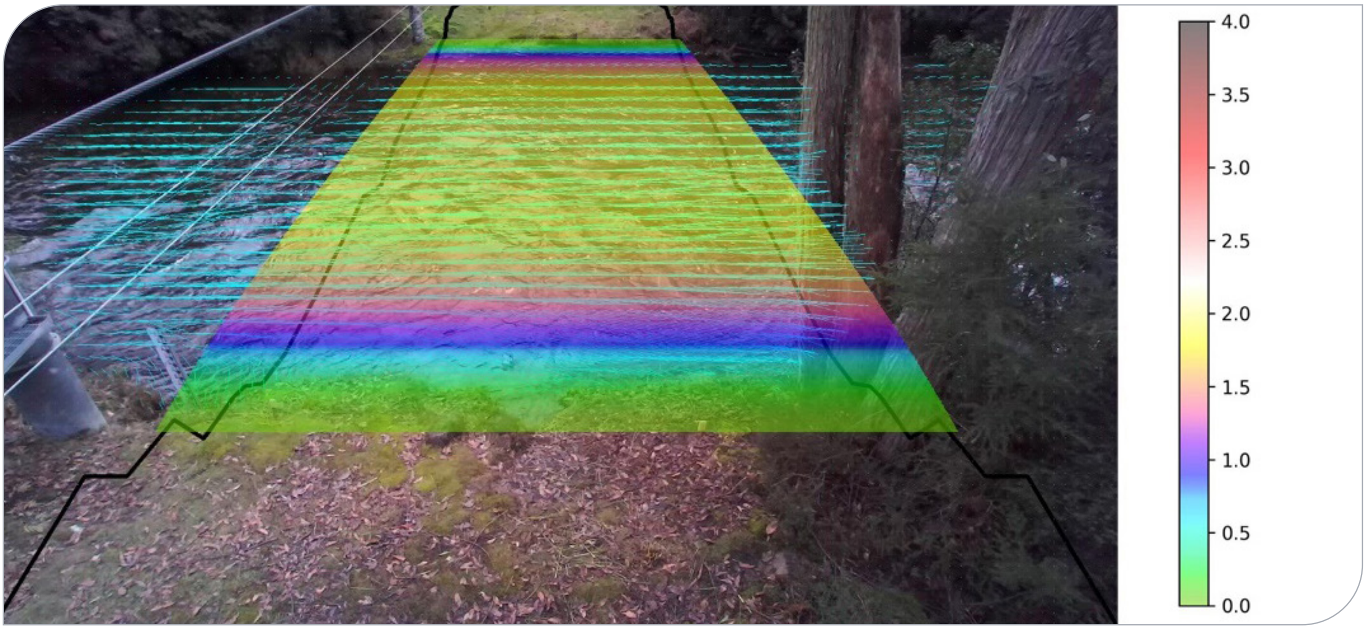


Figure 2: Site learning velocity distribution.

Discharge Rating

Raw discharge is calculated across the analysis domain from the rectified raw planar surface velocity, local water depth and alpha coefficients (Hauet et al. 2018) at 0.1m step size, with the total discharge the sum of all the step sizes across the measurement section. An adaptive learning discharge rating is produced based on adaptive learning surface velocity distribution and surface velocity profile model shown in Figure 3.

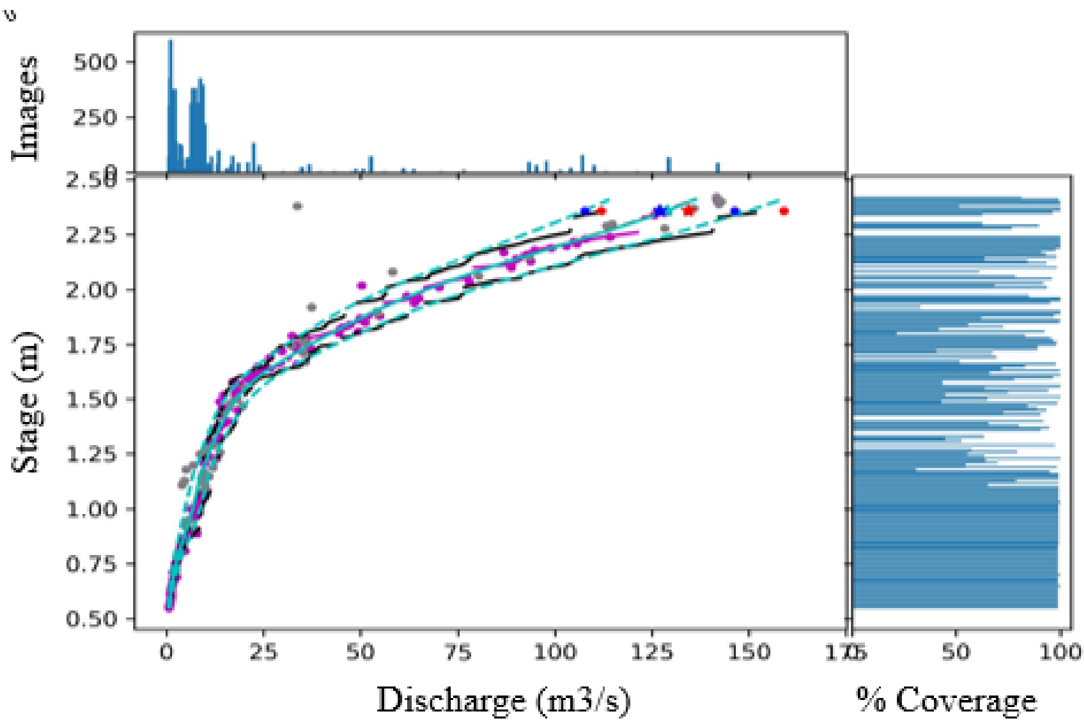


Figure 3: Development of adaptive learning discharge rating.

3. Case Study

The performance of computer vision stream gauging (CVSG) system has been verified at various flow monitoring sites with a range of hydraulic flow conditions. The results from the case study at Upper Creek is presented due to the complex flow conditions that exist at the flow monitoring site.

The flow monitoring site is situated on the Upper Creek in Northern Queensland. The flow in the channel is flashy due to the presence of steep bed slopes in the surrounding mountainous areas. Performing accurate and reliable flow monitoring is challenging due to high-water velocities associated with rapid flow conditions. CVSG system was installed on the right bank and a complete channel cross section was surveyed with the camera position and elevation.

The water surface roughness during medium to high flows at the monitoring site was ideal for optical flow measurements shown in Figure 4, with the CVSG system able to resolve nett optical flow displacements accurately based on the dense flow field shown in Figure 5.

Figure 4: Water surface roughness of Upper Creek.

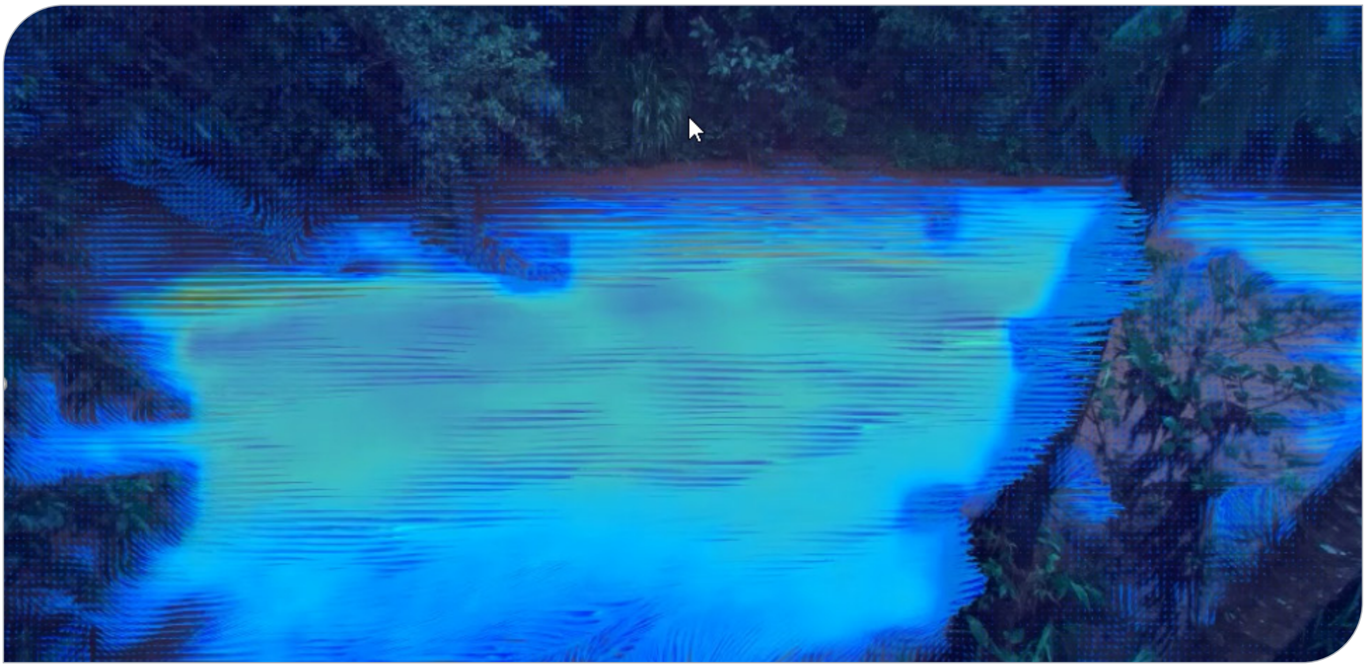


Figure 5: Nett optical flow displacements of Upper Creek.

During the first flow event from Cyclone Jasper the CVSG system was able to develop a adaptive database of measured learning surface velocity distribution and surface velocity profile model shown in Figure 6.
It became evident during consecutive flow events that the flow conditions at the flow monitoring site is very complex and that traditional stage-discharge rating would not be sufficient to accurately define the flow present at the flow monitoring site.

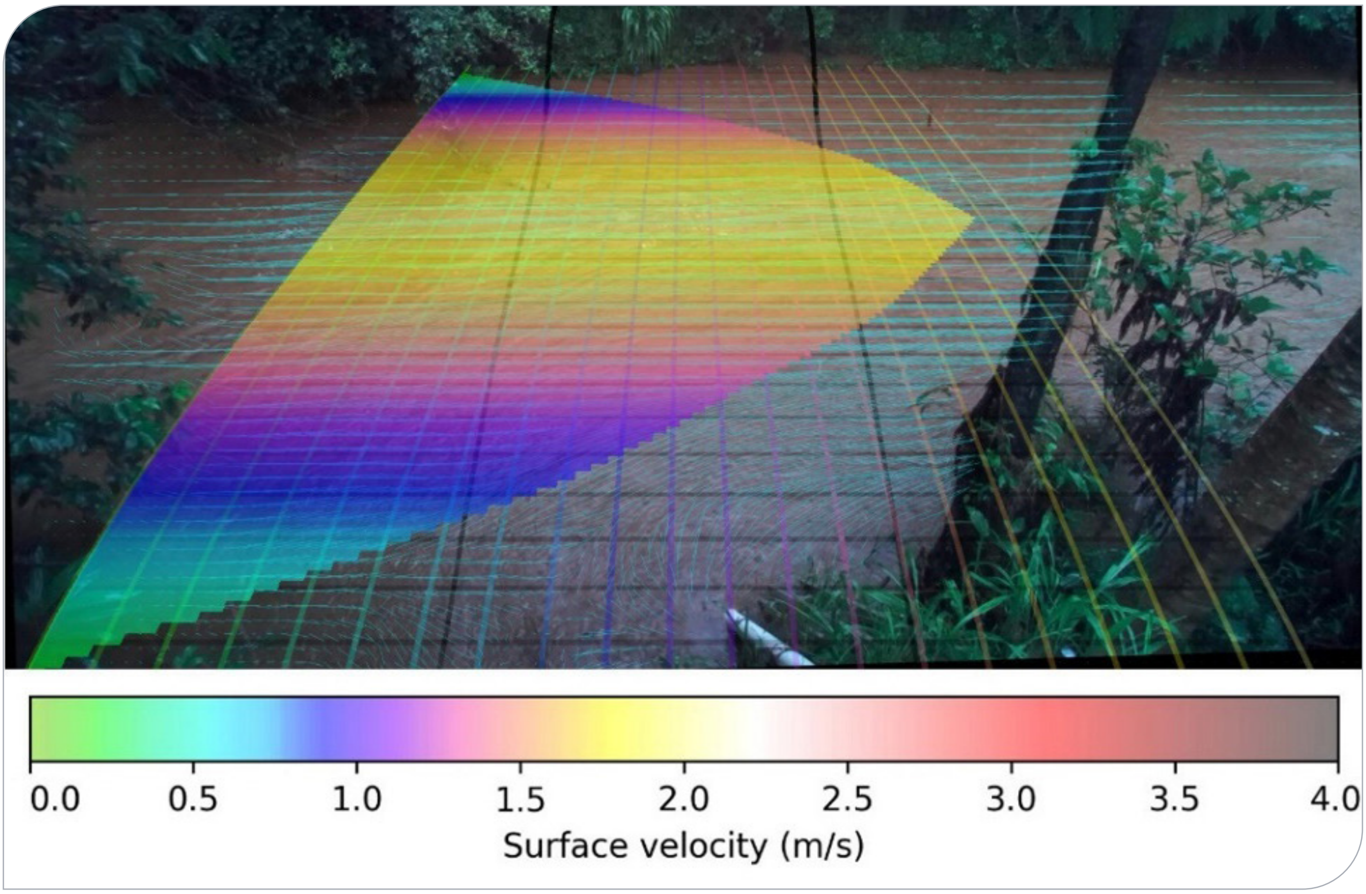


Figure 6: Surface velocity profile model of Upper Creek.

Review of the flow hydrograph on the 15th December has revealed that there is a good correlation between the raw instantaneous discharge estimates (black) and adaptive discharge estimation (green) based on internal stage-discharge rating development. During the second flow hydrograph on the 16th December a significant deviation was present between raw instantaneous discharge estimates and adaptive discharge estimation shown in Figure 7.

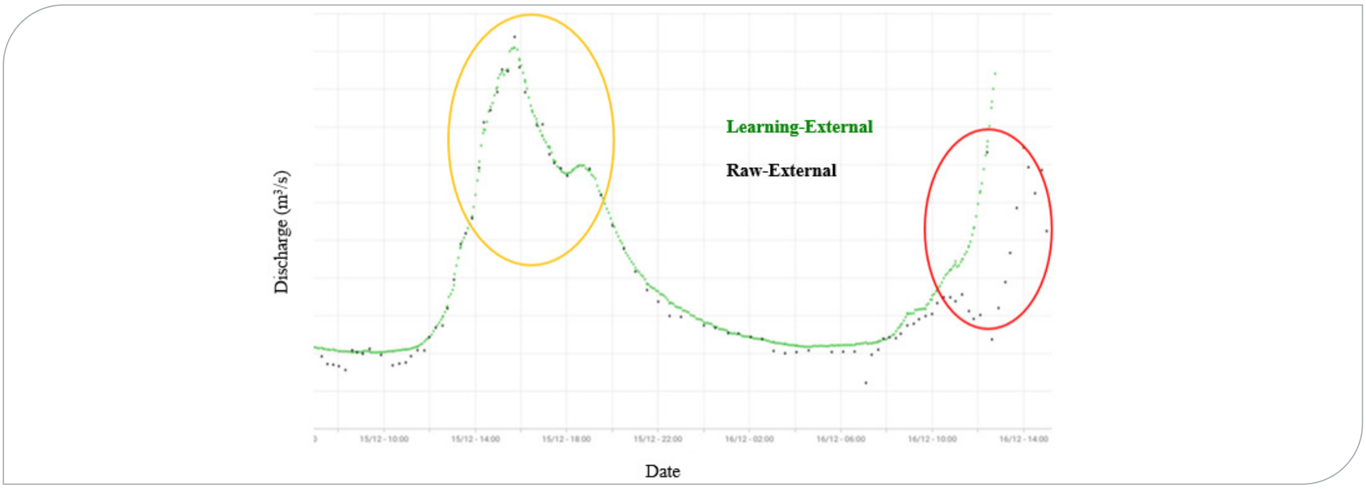


Figure 7: Timeseries of flow hydrograph of Upper Creek.

The deviation between the raw instantaneous discharge estimates (black) and adaptive discharge estimation (green) required a more in-depth assessment of the potential factors that may impact the overall accuracy of the flow estimation at the flow monitoring site. A detailed review of the catchment identified potential impact from the confluence with the main tributary downstream of the flow monitoring site.

Water surface (purple) and cross-section (red line) elevations at Upper Creek flow monitoring site was compared against water surface (brown line) elevations at the main tributary downstream shown in Figure 8.

It was identified that Upper Creek flow monitoring site was impacted by variable backwater effects during the flow hydrograph on the 16th December and successive hydrographs that followed based on the interception of water surface elevation at main tributary and cross-section elevation.

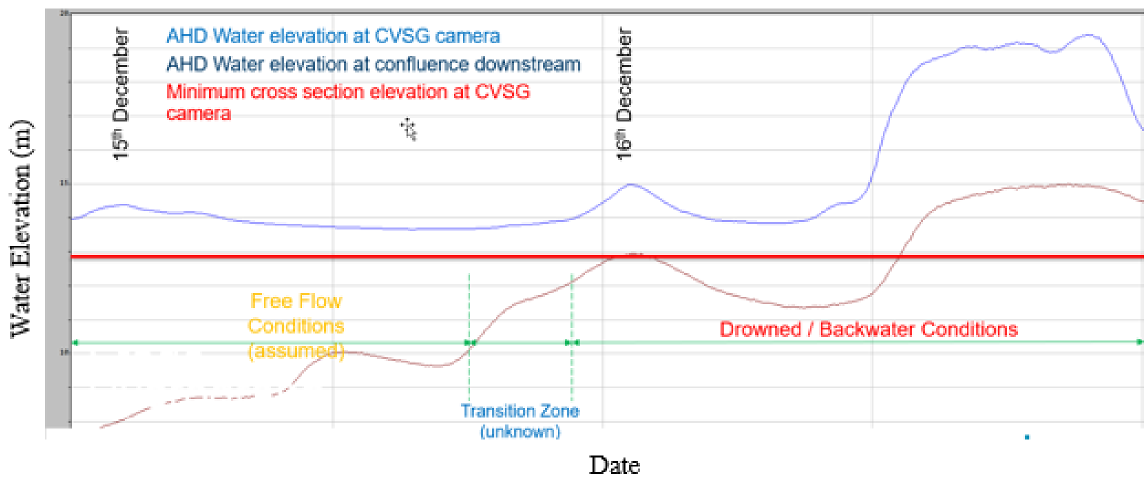


Figure 8: Timeseries of stage hydrograph of Upper Creek.

The adaptive learning discharge rating confirmed the different flow conditions present during the two successive flow hydrographs shown in Figure 9.
The flow hydrograph on the 15th December was the first measurements performed by the CVSG system at Upper Creek and was able to accurately define stage-discharge relationship for the recorded stage range.

The second flow hydrograph on the 16th December had similar optical flow conditions and the CVSG system was able to accurately develop surface velocity profile and raw instantaneous discharge estimates.
The surface velocity profile and raw instantaneous discharge estimates were well outside the lower and upper surface velocity envelopes used to qualify measurements for the enhancement of adaptive database of measured learning surface velocity distribution and adaptive learning discharge rating.

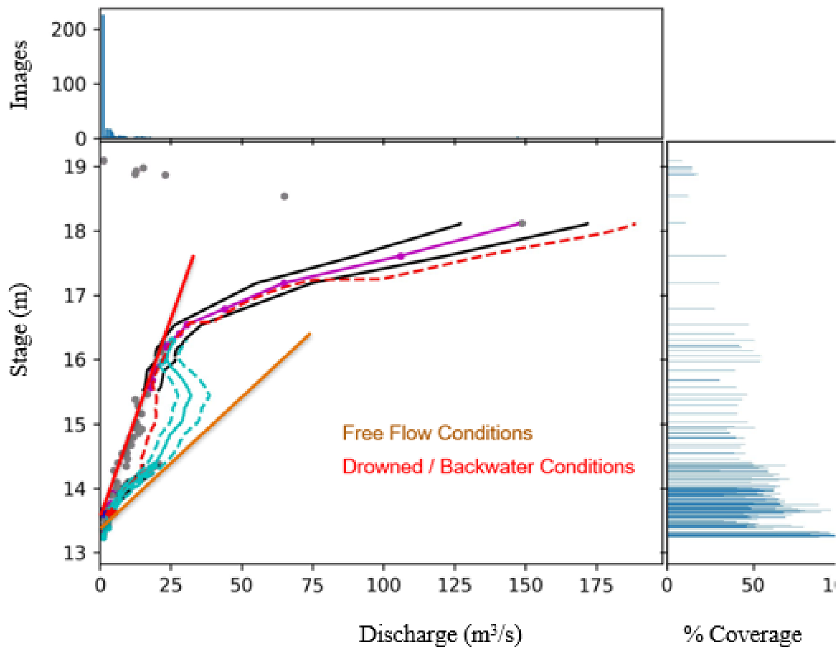


Figure 9: Adaptive learning discharge rating of Upper Creek.

4. Conclusion

Continuous flow monitoring at monitoring sites governed by unsteady flow or variable backwater conditions are complex and can be extremely costly. Most if not all Hydrological Information Management Systems can only develop traditional stage discharge ratings with version control, shifts and period of applicability. Consequently, Hydrological Information Management Systems are not equipped to develop complex stage-discharge ratings such as loop ratings due to unsteady flow or variable backwater conditions and alternative techniques must be used for continuous flow monitoring.

Although CVSG stage-discharge rating development is based on similar principles, the operator can define period of applicability, thus developing a stage-discharge rating for a specific flow event or condition. The development of a stage-discharge rating for each flow event or condition is dependent on the global lighting conditions being satisfied during each event.

The development of a stage-discharge rating for a for specific flow event or condition can be automated by firstly determining if real-time optical flow measurements are outside the velocity envelopes and secondly if there are any relationship present between the data points.

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