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Monitoring flow and suspended sediment in challenging field conditions: successes, failures, and lessons learned along the way

Surveillance du débit et des sédiments en suspension dans des conditions de terrain difficiles : retour d'expérience sur les succès et les échecs

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RÉSUMÉ

Une surveillance précise du débit est essentielle pour les études de l'hydrologie et des charges polluantes en zone urbaine et périurbaine. Nous avons surveillé le débit et les concentrations de sédiments en suspension sur quatre sites périurbains, dans le but de comprendre comment le développement urbain affecte la production de sédiments. Nous avons déployé des déversoirs à seuil de précision et des sondes de pression pour calculer le débit, ainsi que des échantillonneurs automatiques pour prélever des échantillons de MES. Nous avons rencontré de nombreux défis pratiques sur les sites, y compris (i) des conditions de hautes eaux résiduelles changeant la relation hauteur-débit en amont du seuil, (ii) l'évolution rapide des conditions du bassin versant et du site, et (iii) des interférences biologiques avec l'équipement. Face à ces défis, nous partageons certains de nos succès et échecs, ainsi nos perspectives pour améliorer la qualité des données. Nous espérons que notre expérience sera utile à d'autres.

ABSTRACT

Accurate flow monitoring is critical for studies of urban and peri-urban hydrology and pollutant loads. We monitored flow and suspended sediment concentrations at four peri-urban sites, for the purpose of understanding how urban development affects sediment production. We deployed precision thin-plate weirs and pressure sensors to calculate flow, and autosamplers to take TSS samples. We encountered numerous practical challenges at the sites, including high tailwater conditions changing the relationship between flow and water level upstream of weirs, rapidly changing catchment and site conditions, and biological interference with equipment. We share some of our successes and failures in responding to these challenges, and the next steps we plan to take to improve data quality. Based on our experience, we offer recommendations for addressing similar challenges elsewhere.

KEYWORDS

Flow gauging, monitoring, weir equation, data acquisition, experience sharing

Mesure de débit, suivi hydrologique, formule de seuil de déversoir, acquisition de données, partage d'expérience

1 INTRODUCTION

Monitoring of pollutant loads carried by water relies on accurate flow data, which in turn relies on careful site selection and design. We monitor sediment production from peri-urban catchments using flow gauges and autosamplers. Despite implementing best practice flow gauging methods which include a precision weir with a standard flow equation, we encountered challenging conditions which required novel responses to ensure the data we collected was of adequate quality and fit for purpose. Three major challenges are explored in this paper: (1) high tailwater conditions; (2) rapidly changing peri-urban landscape; and (3) biological interference.

2 STUDY AREA AND EXPERIMENTAL DESIGN

We installed four flow and sediment load monitoring stations in outer eastern Melbourne, Australia. Urban development in the study catchments was in progress when sites were installed and has progressively expanded since then. The study catchments are small (1 to 5 km²) with intermittent flow. The experimental design was based on paired upstream-downstream stations on two streams (Quirks Creek and Officer Creek) to isolate inputs from urbanizing areas.

Each site included a pressure level sensor and precision thin-plate weir to measure flow, an autosampler to collect samples for laboratory TSS analysis, and an Arduino-based system for remote control, logging and telemetry. A turbidity monitoring system consisting of a pump and flow cell sensor inside a dark cabinet is currently under testing at one site and planned for implementation at other sites. The site design was reliable and the open-source Arduino systems have allowed great flexibility in how we manage and visualise monitoring data. However, we faced many practical challenges in implementing flow and TSS monitoring stations in a low-gradient and rapidly changing peri-urban environment.

3 MONITORING CHALLENGES

3.1 High tailwater conditions

Our preferred method of streamflow measurement employs a water level sensor combined with a thin-plate weir to provide a stable relationship between water level and flow. Advantages of this method are high accuracy, low maintenance and reliability over time. The validity of a standard weir equation depends on the tailwater having no influence on upstream levels, requiring the weir crest to be above the normal range of water levels. However, this can be problematic in low relief areas, where high flows are forced out of the stream channel and onto the floodplain resulting in a breakdown of the weir rating. Weir design is critical in this situation to minimize both unnecessary floodplain engagement (the larger the total opening area, the better), and risk of drowning by high tailwater (the higher the crest above the downstream water level, the better). In very low-gradient streams, an acceptable balance between these competing objectives becomes difficult to achieve.

The Quirks Creek downstream site (Figure 1A) was located in a low-gradient reach, with significant in-channel vegetation growth. We undertook a site inspection and identified a site where the channel was well-defined. Given access challenges and vegetation conditions, there were no better location options. We installed the weir during low flow conditions in 2019 when it appeared tailwater would be low enough to ensure a reliable flow control (Table 1). In 2020 and beyond, prevailing high flow conditions resulted in the weir becoming submerged and the floodplain becoming inundated for extended periods. We installed two water level sensors at the site, one upstream and one downstream of the weir, in order to use a submerged weir equation for flow estimation (Villemonte 1947):

$$Q_s = Q_f \left[1 - \left(\frac{H_b}{H_a} \right)^{1.5} \right]^{0.385} \quad (1)$$

Where Q_s is submerged flow, Q_f is flow with free overfall conditions (i.e., calculated using a standard weir equation), H_b is downstream head level (above crest elevation) and H_a is upstream head level. We validated the approach and equation in a laboratory flume before deploying it at the site. We also removed in-channel vegetation and a ford crossing downstream of the weir. Despite these solutions, tailwater levels were elevated for an extended period from April to December 2021, as sediment and vegetation built up in the swamp (Figure 2). The second site was installed upstream of a culvert crossing. The culvert had low capacity and sedimentation in the waterway and culvert led to the weir being drowned by high tailwater under high flow conditions (Figure 1B).



Figure 1: Quirks Creek flow monitoring weirs (A: downstream site; B: upstream site) showing low and high tailwater conditions.

Table 1: Site improvements at Quirks Creek downstream site and resulting effects and issues.

Date	Site improvements	Effect and issues
June 2019	Weir installed	Tailwater was low and floodplain was dry. Weir provided good flow control under these conditions.
September 2019	Site instrumented. Upstream water level sensor and downstream float switch installed	High tailwater conditions became more and more frequent, occurring around 51% of the time in February 2020.
March 2020	Downstream ford crossing removed	There was only a slight and temporary reduction in the frequency of high tailwater conditions, lasting around one month. Dense vegetation grew in channel due to reduction in water level.
October 2020	In-channel vegetation removed downstream of weir	Temporary reduction in frequency of high tailwater conditions, which only persisted for approximately one month.
December 2020	Second water level sensor installed downstream of weir and submerged weir equation used to estimate flow.	Flow estimates were improved under most conditions, but had high uncertainty when water surface slope was extremely low (e.g. recession limb of events as swamp slowly drained). Overtopping of weir and bypass of flow through floodplain became commonplace from June to November 2021, meaning that the weir equation did not account for significant portions of the total flow.
February 2021	Automatic camera installed to confirm site conditions	Photos provided useful corroboration of flow data on some occasions. Clear sightlines were difficult to maintain and quantitative validation (e.g. reading gauge board from photos) was not possible.
December 2020 to present	Frequent manual site observations and maintenance, and post-processing of data to correct sensor drift and weir blockage effects, and estimate floodplain flow during high flow events.	All methods still have high uncertainty when floodplain is inundated and when water surface slope is extremely low.

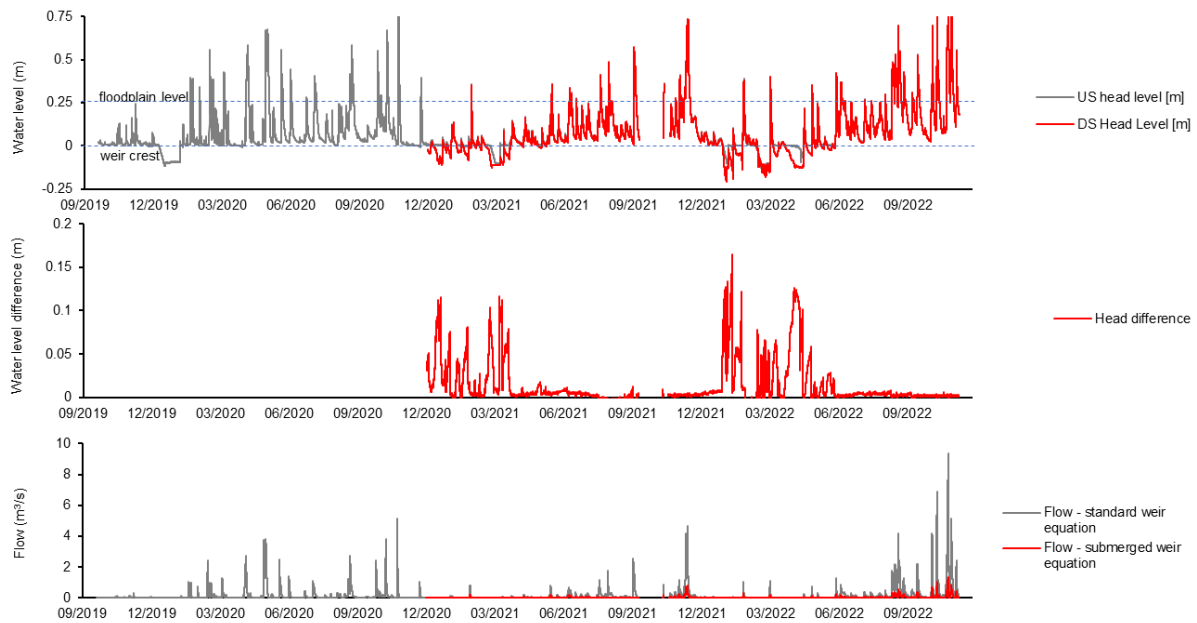


Figure 2: Changing water level and flow conditions at Quirks Creek downstream site, 2019-2022.

3.2 Rapidly changing peri-urban landscape

Part of our site selection challenge was to select sites that would not be altered (e.g. excavated) or have access cut off as urbanization proceeded. Urbanizing landscapes change very quickly and the timing and sequencing of development and drainage works can be unpredictable. We liaised with local authorities and developers to select sites, mostly in public reserves, that were least at risk. None of the sites were destroyed by development, but local changes did impact the sites. At Quirks Creek upstream site, sedimentation and then channelisation resulted in changing tailwater behaviour which affected our flow gauging. At Officer Creek, road sealing resulted in lower local sediment input to our site. These kinds of changes are important to monitor in the context of peri-urban and developing areas, but frequent inspection is needed to keep track of timing and impact of changes.

3.3 Biological interference

Biological action was the major cause of maintenance problems at our sites. We discovered repeated ant colonization of electronic equipment and samplers (Figure 3). We initially used ant killers containing bifenthrin at the sites. However, bifenthrin is environmentally persistent and causes ecosystem degradation (e.g., macroinvertebrate toxicity). Additionally, our collaborators were monitoring bifenthrin concentrations at each site, and our actions may have interfered with their data. In environmental monitoring programs, the need to protect equipment from insect invasion needs to be balanced against the ecological harm chemical agents can cause. We changed to using Fipronil, which was not being monitored but is still a harmful ecotoxicant (Tingle et al. 2003). Therefore, we used it in a targeted way, and focused on manual inspection and removal of ants and larvae as our main control method.

Other pests at our sites included mice and lizards, which were discouraged from settling in equipment cabinets by removing all nest materials on each visit. Birds perching on antennae caused damage and data dropouts. We created a decoy perch at a higher elevation than the antenna to encourage birds to perch there instead. Biofouling of turbidity sensors (e.g., algal growth) was minimised by placing the sensor inside a dark cabinet and leaving the sensor dry between each reading.

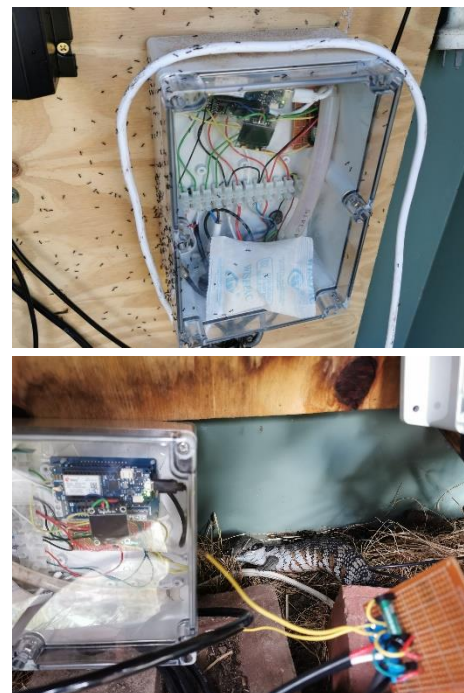


Figure 3: Biological interference with electronic equipment

4 RECOMMENDATIONS AND WAYS FORWARD

Our experiences monitoring flow and sediment at challenging peri-urban sites give rise to recommendations for others planning similar monitoring programs (Table 2). While our sites remain challenging, we have planned approaches to addressing our major challenges which will maximise the quality and usefulness of our data for the purpose of sediment monitoring in peri-urban environments.

Table 2: General recommendations for addressing challenges, and planned approach at our sites.

Challenge	Recommendations	Planned approach at our sites
High tailwater conditions	<p>Understand flow behaviour at the site over a range of flow conditions</p> <p>Predict how conditions might change due to sedimentation or human actions</p> <p>Select the best location, where channel slope and capacity are both high</p> <p>Design the weir profile for the location, anticipated flow conditions and purpose</p> <p>Consider a second water level sensor downstream of weir, or a flume with dual water level sensors</p> <p>Consider direct measurement of velocity (e.g. ADCP)</p> <p>Use multiple data sources including hydraulic and hydrologic models and directly monitored data to increase confidence</p>	<p>At Quirks Creek downstream, a combination of flow modelling and direct water level monitoring appears to be the best solution for us to move forward with flow estimation. Installation of velocity sensors would be technically feasible, but would not solve the problem of flow bypassing the channel and flowing over the floodplain.</p> <p>At Quirks Creek upstream, observations of the weir under drowned conditions indicate that a downstream water level sensor and submerged weir equation would help to estimate high flows (currently in progress). Data for high flow periods to date will be estimated using a simple hydraulic model accounting for the characteristics of the culvert and downstream channel.</p>
Rapidly changing peri-urban landscape	<p>Select locations least likely to be disturbed, in consultation with local authorities and developers (e.g. consider road reserves)</p> <p>Minimise delays between planning experimental design and deploying stations</p> <p>Be flexible to continue monitoring opportunistically as different disturbance processes occur in catchment</p>	<p>Continuing to monitor sites over a multiple-year period captured further waves of development beyond the initial development we were targeting, and we plan to continue to monitor to opportunistically capture future disturbances.</p> <p>Our final two sites were installed in a catchment where development was less advanced (Officer Creek), allowing us to compare early and late-stage development impacts on sediment loads.</p>
Biological interference	<p>Frequently inspect sites and remove pests</p> <p>Consider ecotoxicity of insect control agents and minimise use</p> <p>Use manual removal and deterrence methods wherever possible.</p> <p>Provide a dark environment for sensors to minimise biofouling</p>	<p>Focus on manual removal, with targeted use of chemical agent (Fipronil) where required.</p> <p>Undertake turbidity monitoring in a dark cabinet using a pump.</p>

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