Assessing the impacts of infrastructure and development on streams

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Key Points

- Tools and a methodology for geomorphic assessment are described.
- The application of geomorphic assessment to impact assessment is illustrated.
- The impacts of improvements to Winmalee wastewater system are assessed in a case study.

Abstract

Geomorphic assessment is often required to determine the likely changes in stream form or impacts on infrastructure. The assessment can be used to inform design and understand the impacts of infrastructure and development on streams. Assessments typically relate the soil erodibility to the erosive potential caused by stream flow and investigate the stability of banks. Shear stress, flow velocity and unit streampower may be used to inform the assessment. Erosion occurs when the erosive potential created by the stream flow exceeds the ability of the material.

Parameters are typically calculated using hydraulic modelling software such as HEC-RAS. Bank stability can be tested in the Bank Stability and Toe Erosion Model (BSTEM) module of HEC-RAS.

A geomorphic assessment was undertaken for a stream at Winmalee, in the Blue Mountains. The stream receives flows from the Winmalee Waste Water Treatment Plant, operated by Sydney Water. The assessment techniques are presented, including in-situ soil testing, hydrologic calculations, HEC-RAS and BSTEM analysis.

Applications of these techniques in other locations are also outlined.

Keywords

Winmalee, geomorphology, infrastructure, impact assessment, hydraulic, BSTEM, erosion

Introduction

This paper uses a case study of a geomorphic assessment of a stream at Winmalee in the Blue Mountains to demonstrate a method of assessing the impact of infrastructure and development on fluvial geomorphology.

Background

To inform design and understand the impacts of infrastructure and development on streams, a geomorphic assessment is often required to determine the likely changes in stream form or impacts on infrastructure. The application of such assessments includes options assessments, environmental impact assessments, permits and approvals. The outcomes of the assessment may be used to guide future work to mitigate impacts or amend proposed designs.

Assessment Techniques

Assessments may include site investigations, desktop investigations, soil investigations, in-situ and off-site soil testing, hydrologic and hydraulic modelling and bank stability calculations. Typically, geomorphologists assess the soil erodibility and compare this to the erosive potential caused by stream flow. Shear stress, flow velocity and unit streampower may be used to inform the assessment. Quantitative assessment of erosion impacts is a matter of defining the creek channel response to existing and updated inputs.

The dominant drivers to channel change are:

- The hydraulic forces (shear stress) applied by the water flowing along the channel boundary that tends to erode materials particle by particle; and
- The gravitational forces that are exerted on creek banks that tend to cause failure of the bank mass.

The size and weight of the sediments will determine the resistance of the surface materials to hydraulic forces (critical shear stress); either on the bed or bank face.

The resistance of the banks to gravitational mass failure (bank slump) is dependent on the geotechnical properties of the bank materials and is termed 'shear strength'.

The interaction of the driving and resisting forces determines whether a channel will erode under given flows. If the driving forces exceed the resisting forces for a given set of conditions, channel change will occur. The rate of change will reflect the magnitude of the excess forces and the duration for which that excess force occurs.

To assess erosion potential, we can adopt a tiered approach:

- Firstly, assess relative channel stability using Rapid Geomorphic Assessments (RGAs);
- Secondly, quantify the driving and resisting forces; and
- Thirdly, conduct numerical modelling of potential bed and bank erosion using the information on driving and resisting forces.

Site Investigations

Assessing the physical properties of the creek and their resistance to erosion is a method of predicting the likely impacts of development. By collecting field data we can quantify various geomorphic parameters (such as soil type, particle size, cohesion and critical shear strength in the creek banks). We can reduce the amount of inferred or arbitrary data used in later models by quantifying these parameters to gain a clear understanding of the creek behaviour.

Rapid Geomorphic Assessments: RGAs

An RGA is an assessment of the channel evolution. RGAs were developed to classify channel stability conditions using diagnostic features of channel inform to infer dominant channel processes.

RGAs rely on the knowledge that alluvial streams are continuously adjusting to altered flows and sediment. Once disturbed, the streams go through a systematic sequence of processes and forms (Simon, 1989). There are six stages of channel evolution as identified by Simon and Hupp (1986) and Simon (1989).

RGAs provide an efficient method of assessing in-stream geomorphic conditions, enabling the rapid characterisation of the stability of long reaches of channel systems. By observing erosion, deposition and the condition of riparian vegetation, RGAs can provide indications of relative channel stability.

Four steps of the RGA procedure are:

- Determine the extent of the reach (the length of channel covering 6-20 channel widths, which is scale dependent and should cover at least two pool-riffle sequences);
- Take photographs looking upstream, downstream and across the reach for quality assurance and quality control purposes;
- Make observations of channel conditions and diagnostic criteria listed on the channel stability ranking scheme; and
- Sample bed material for later characterisation of particle size distribution.

Hydrology and Hydraulics

Various software packages are available for hydrologic calculations. Flows must be calculated corresponding to a range of specified rainfall events to enable a thorough geomorphic assessment.

Hydraulic software is also available from many sources, however, the HEC-RAS package is advantageous, because it has a module for assessing bank stability. HEC-RAS is a one-dimensional numerical model that can simulate hydraulic forces in a stream channel. The hydraulic forces (shear stress) of the flow vary along a reach because of the differences in channel shape, slope and roughness.

Creek Bed and Bank Stability

Creek bed and bank stability are assessed separately, as the processes relating to stability and impacts that would result if instability was identified are different for each. Creek beds can incise once the boundary shear stress exceeds the critical shear stress of the bed material. The critical shear stress of the bed material is defined by the particle size in mobile bed creeks. Therefore, the boundary shear stress of the hydraulic model can be directly compared to the critical shear stress of these bed materials to predict the impact on bed stability.

Bank stability can be assessed using BSTEM, a fully mechanistic, spreadsheet model that incorporates all of the physical processes that control bank erosion and failure, namely undercutting by hydraulic forces and collapse of the upper part of the bank by gravity. The toe-erosion sub-model predicts the amount of particle-by-particle erosion caused by the flow, by utilising hydraulic data input from HEC-RAS or other sources and data on the resistance of the bank-surface materials. The resulting geometry is then exported into the bank-stability sub-model to test for stability of the bank mass. The bank-stability sub-model incorporates numerous features associated with bank- or slope-stability analyses including layering, the effects of soil moisture and pore-water pressure, riparian vegetation effects, and the confining force that tends to support the bank during periods of high water.

Hydraulic outputs from the HEC-RAS model can be used as inputs to BSTEM for assessment of bank stability, providing a direct process-based link between the two models. BSTEM can evaluate the potential for bank erosion using geotechnical data collected in the field or default parameters. BSTEM can be used for existing conditions and design conditions, including flow changes and erosion-control strategies.

Interpretation

The model data for existing conditions (geometry and flow) is then interpreted by comparing the hydraulic and bank-stability model results with field observations. The shear stresses predicted by the model can then be compared with the critical shear stress or resistance of the surface sediments to erosion. It is then possible to assess the potential for erosion under the prescribed flow conditions. The resistance, or critical shear stress, of the surface can be determined by analysing the particle-size of samples of the boundary materials. To test the erodibility of cohesive materials, a submerged jet-test device can also be used for greater accuracy.

Case Study – Winmalee, Blue Mountains

Introduction

A geomorphic assessment was undertaken for a stream at Winmalee, in the Blue Mountains. The stream receives flows from the Winmalee Waste Water Treatment Plant, operated by Sydney Water. The assessment techniques are presented, including in-situ soil testing, hydrologic calculations, HEC-RAS and BSTEM analysis.

Site and Project Details

The Blue Mountains are located west of Sydney and Winmalee is located in the lower mountains, near the Hawkesbury-Nepean River. The treatment plant is operated by Sydney Water Corporation and is the main treatment plant for the Blue Mountains. The location of the plant is shown in Figure 1.

Figure 1. Location of Treatment Plant

The study was undertaken in connection with the Winmalee Wastewater System Improvement Project. The project investigated options for improvements relating to the treatment plant and the network delivering to the plant, including a large sewer tunnel.

The Blue Mountains Sewer Tunnel is an important part of the wastewater network in the Blue Mountains. It is 39 km long, and transports wastewater from North Katoomba and other towns in the Blue Mountains to the treatment plant. During heavy rain, stormwater enters the wastewater system, increasing the flows in the system by up to 20 times. Parts of the system were undersized and at risk of failing in wet weather at the time of the study.

Cardno was commissioned to undertake a geomorphic assessment of the impact of proposed improvement works on the unnamed creek downstream of the plant. This creek already received regular treated flows from the plant and partially treated wet weather flows. With the improvements, flows increase in the unnamed creek.

The unnamed creek is 3.5 km long from the discharge point of the treatment plant to the confluence with the Nepean River. The topography of the creek in the vicinity consists of a steep (20-30%) valley slope on the left side (north) with a floodplain and gentler valley slope on the right side (south). The creek experiences a range of different reaches from a sandy channel to cascading rock riffles and even rock gorges at dramatic changes in grade. The catchments of the unnamed creek are shown in Figure 2.

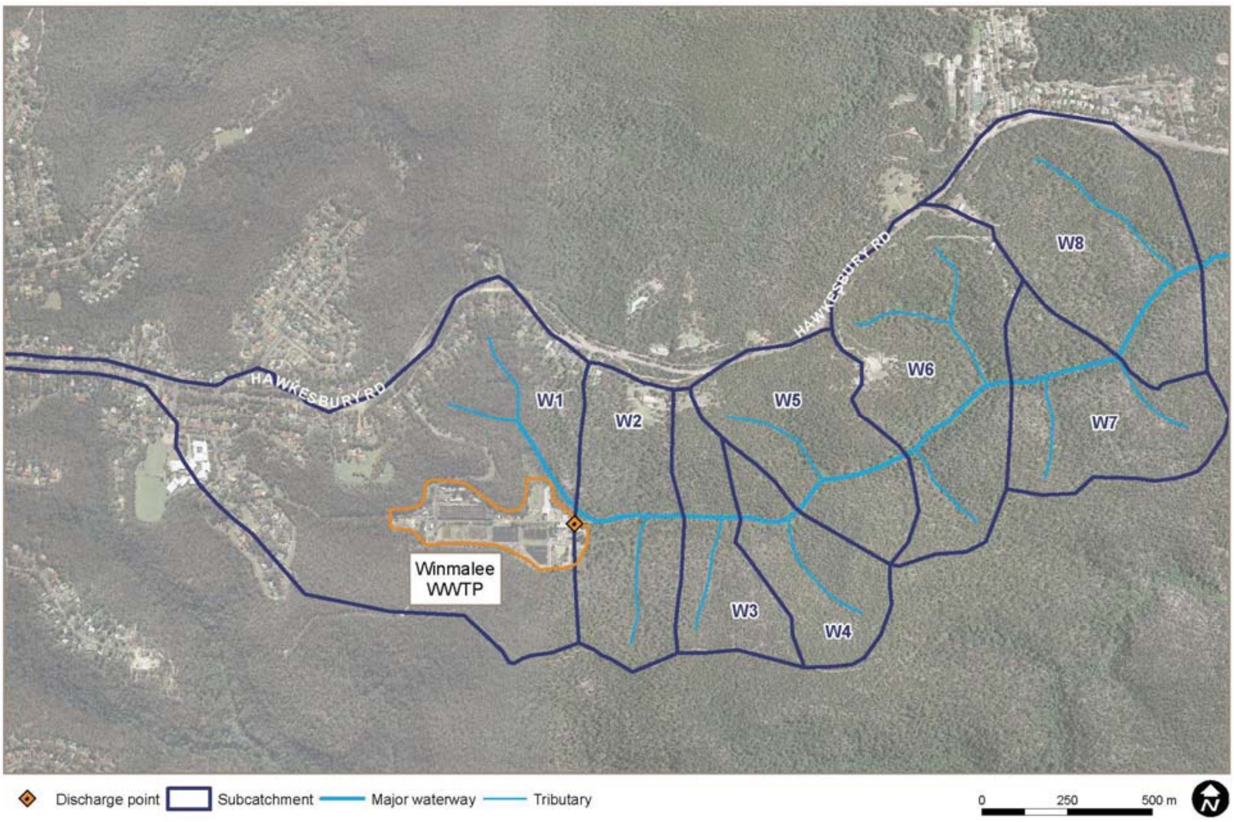

Figure 2. Catchments of the unnamed creek

The creek is mostly stable beyond 400 m downstream of the treatment plant excluding a few locations where tight meanders and/or tributaries join the main channel. However, it was evident that the creek had undergone disturbance over the total reach length to the Nepean River confluence. This disturbance was found to be by erosion of the bed and banks in the upper 1.5 km of the creek from the treatment plant and deposition of sand in the lower 2 km until the river confluence. A photo of the creek is shown in Figure 3.

Figure 3. Looking downstream at the channel approximately 600 m downstream of the plant

Assessment

Cardno assessed dry weather and wet weather conditions. Cardno carried out the following:

- Site Investigations – field studies to record the physical properties of the creek in order to obtain the necessary inputs for the RGA. The fieldwork component included photographing and logging the geomorphic conditions of the creek, hand auguring boreholes, shear strength testing and the collection of soil samples for particle size analysis at three locations. Cardno carried out an RGA at four 'intensive sites' along the unnamed creek, using the channel-stability ranking scheme to evaluate channel-stability conditions and stage of channel evolution.

- Ground survey of cross sections from the proposed discharge point to approximately 860 m downstream at 20-50 m intervals.

- Hydrology – quantifying the volume of flow expected in the creek during a range of storm events (2 year, 10 year and 100 year Average Recurrence Interval events using numerical models (XP-RAFTS)). XP-RAFTS is a robust runoff-routing model that is used extensively in the Australia and Asia Pacific regions.

- Partially treated wet weather flows – quantifying the wastewater flow that would be discharged to the creek during storm events using numerical models.

- Hydraulic assessment – quantifying the dynamics of the flow as it is carried in the creek using a numerical model (HEC-RAS). HEC-RAS is a one-dimensional numerical model that simulates flow depth, flow velocity, shear stress and hydraulic forces in a stream channel.

- Creek bed stability – assessing the resistance of the creek base to the applied hydraulic forces using hand calculations.

- Creek bank stability – quantifying the ability of the banks of the creek to resist the applied hydraulic forces using numerical models (BSTEM). BSTEM is a fully mechanistic, spreadsheet model of bank stability that incorporates all of the physical processes that control bank erosion and failure.

- Recommendations on potential mitigation measures for the impacts identified.

Results

The hydrology assessment showed that any increase in flow volume from the treatment plant is more evident at the discharge point than further downstream. The progressive contribution of catchment runoff to total flows moving downstream results in a progressively lesser impact by the treatment plant or wet weather flows.

The geomorphic assessment concluded that impacts due to infrastructure improvements would dissipate over the first 1,500 m, with the first 400 m being subject to the most impact.

Other Applications

Cardno has conducted these kinds of studies worldwide over a diverse range of channel conditions.

Burnett River, Qld, Australia

BSTEM was used to model streambank stability, erosion rates and volumes at five sites along the Burnett River, in Queensland, Australia. This river was impacted by the large floods of 2011 and 2013 and sediment loadings are a serious concern to the Great Barrier Reef. Results showed that bank erosion was the single largest contributor to fine-grained sediment loadings, in stark contrast to results from upland modellers. At-a-site BSTEM results were used to develop cost-effective bank mitigation strategies for each of the five sites, while extrapolation of these site-specific results provided estimates of fine sediment load contributions from banks over the 300 km study reach.

Wyong River and Ourimbah Creek Streambank Rehabilitation Plans, NSW, Australia

This project included a geomorphic assessment of over 100 key locations to assess the river condition, river behaviour and vegetation condition. Rehabilitation measures were identified and prioritised for implementation. Significant outcomes of the project were to deliver an implementation program for Wyong Council to rehabilitate the creek.

Connecticut River, USA

BSTEM is being used to determine the role of dam operations on bank erosion at 25 sites along a 32 km reach of the Connecticut River. This is accomplished by comparing predicted bank erosion over a 15-year flow series using hourly flow data (with fluctuations due to dam operations) and daily data (without those fluctuations). In addition, a boat-way sub model has been developed to incorporate the effects of boat waves on bank-toe erosion and overall bank retreat.

Sacramento River, USA

BSTEM simulations along 480 km of main stem and tributary channels were conducted over 50 years using mean-daily flow data to quantify threats to levees and suspended-sediments load originating from stream bank sources. These simulations indicated where levee setbacks may be insufficient in terms of lateral bank retreat.

Conclusions

A method for conducting impact assessments of infrastructure and development on fluvial geomorphology was presented and demonstrated through a case study. The application of RGAs and BSTEM to geomorphic assessments was illustrated to be effective.

Acknowledgments

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