Water quality offset investment in riparian restoration to reduce sewerage treatment costs - Part 1: determining the sediment loss avoided through riparian restoration.

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Key Points

- Water quality offsets create an economically efficient alternative for sewage treatment plant operators to meet licenced discharge obligations.
- Through water quality offsets an alternative funding stream for catchment restoration is made available.
- A methodology has been identified to estimate erosion avoided through river restoration.

Abstract

Sewerage Treatment Plant (STP) operators in South-east Queensland are facing increasing capital and operating costs as they strive to ensure environmental compliance regulations are met. Many of the region's receiving waters for STP discharges are already experiencing ecosystem health pressures in large part due to streambank erosion, with the result that the region faces an urgent need to invest in river restoration at a time when traditional Government funding is limited.

Innovative approaches are needed both to fund and deliver catchment restoration and to continue to supply quality STP services. Water quality offsets offer the potential to increase the efficiency of investment in both of these outcomes, by expanding the economic options available to STP operators to meet their licensed discharge obligations. Done correctly, the potential exists to increase the efficiency of social investment in both riparian restoration and STP service provision.

The key to water quality offsets is being able to measure and verify the offset. In the case of riparian restoration, it is not possible to measure sediment erosion avoided directly and, as a result, a modelling approach is required. This paper (part 1 of a three part series) assesses the potential of catchment (regional) and bank (reach) models for modelling and assessing avoided bank erosion from Reach-level river restoration, and concludes that bank models provide the needed granularity.

Keywords

Water quality offsets; Nutrient offset; River restoration; Queensland

Introduction

Sewerage treatment plant (STP) operators in South-east Queensland are facing increasing demand for new services to accommodate the region's growing population. Both new investment and ongoing maintenance investment in STP capacity are required to ensure ongoing compliance with *Environment Protection Act 1994 (Qld)* discharge licence requirements regulated by the Queensland State Government.

Not only is investment in traditional treatment plant technology expensive, but annual running and capital replacement costs of treatment plants are also high. These costs represent a serious challenge to water utilities and to the region's cost of living pressures; but are essential to protect the health of regional receiving waters and Moreton Bay.

Quite separately to the licence compliance and treatment cost challenges facing STP operators, the region's receiving waters and Moreton Bay are already under serious pressure from sediment and nutrient pollution. Important waterway values have been lost; and ongoing threats to waterway health further threaten to compromise the region's bulk water supply quality, dependent fishing and tourism industries and estuarine/marine ecosystems (Bunn *et al*., 2007).

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Numerous studies highlight stream bank erosion as the dominant source of sediment polluting Australia's river systems (e.g. Prosser *et al* (2001) and Olley *et al.,* 2013. In South-east Queensland, Government, community and business groups came together during the 1990s to better understand and manage the health of the region's waterways and Moreton Bay, culminating in the formation of the Healthy Waterways partnership in the early 2000s. The 1990s and 2000s were a period of relatively low rainfall for South-east Queensland; but nonetheless research during this period was able to identify rural diffuse sediment pollution as a major driver of the region's declining catchment health (Healthy Waterways, 2013); and, importantly, that most of the sediment reaching Moreton Bay was delivered during flood runoff events (Caitcheon *et al.,* 2001).

Working in the Logan/Albert river systems, Hancock and Caitcheon (2010) found that 50% - 75% of all sediment pollution that occurred during a 1:10 year event in 2008 resulted from stream bank erosion. Furthermore the Australian Rivers Institute following both the January 2011 and January 2013 floods concluded that stream bank erosion was the dominant sediment pollution source in South-east Queensland (Olley *et al.,* 2013).

The research clearly highlights that investment in river restoration is required throughout South-east Queensland's streams and estuaries to halt declining waterway health and to restore the economic and ecosystem values of degraded waterways. Water quality offsets provide a source of funding for this necessary investment. Working in Victoria following the January 2011 floods in that State, Alluvium (2011) demonstrated that river restoration investment which repaired riparian health was effective in avoiding ongoing bank erosion and associated sediment pollution.

This paper is the first of a series of three that reports findings from a pilot study designed to trial the potential for investment in river/riparian restoration to enhance receiving water quality and offset investment in STP upgrades. It deals with the estimation of sediment pollution avoided through river restoration, while Part (2) focusses on the estimation of nutrient pollution avoided through river restoration and Part (3) captures the learnings used to inform development of the State's voluntary water quality offset policy.

The importance of the work reported in this series of papers is that it brings together the region's need for increased investment in both STP services and in river restoration, within a framework that offers the potential to improve investment efficiency in both. The Queensland Government has released its draft '30-year water strategy' (DEWS, 2013), which seeks to "*deliver integrated catchment-based recreation, water supply, <u>sanitation</u>, irrigation and <u>environmental services</u> at lowest cost*" *(our emphases)*. Within this context, this series of papers details the potential for the State's voluntary water quality offset framework (DEHP, 2013) to offset increased STP nutrient discharges with river restoration.

The study was undertaken by Queensland Urban Utilities (the Proponent), the Department of Environment and Heritage Protection (the Regulator and owner of the voluntary water quality offset framework), the region's natural resource management body, SEQ Catchments through its project manager company, SEQC Services, and Alluvium Consulting.

The offset decision support framework

The river restoration offset decision support framework is shown schematically in Figure 1. Line 1 depicts the approach to determining sediment pollution avoided through river restoration, while Line 2 depicts the approach used to convert estimated sediment erosion avoided by river restoration into an estimate of nutrient pollution avoided, the parameter that will offset elevated STP nutrient discharges in a voluntary water quality offset. This paper deals with Line 1, the estimation of sediment erosion avoided through river restoration and the second paper in this series deals with Line 2.

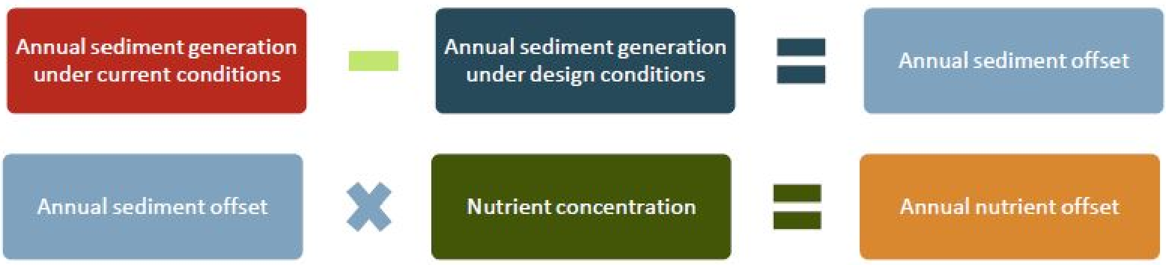

Figure 1: Stream bank erosion nutrient offsets decision support framework

The pilot study focussed on the Beaudesert STP in south-east Queensland, where investment in new treatment capacity was required to ensure ongoing compliance with the plant's *Environment Protection Act* licence Total Nitrogen (TN) discharge requirements.

An early challenge was to identify a suitable site for delivering the water quality offset. The objective was to ensure that the Beaudesert STP *Environmental Protection Act* objectives for protecting receiving water quality for TN were achieved through offset catchment investments. As bank erosion is the dominant source of sediment pollution in the Logan River (Olley *et al*., 2012), highly degraded banks 2.5km upstream of the STP were targeted for river restoration investment. Preliminary interrogation of historical aerial photographs and survey records were used to identify two severely degraded and actively eroding Reaches of the Logan River (Figure 2). Landowners at the sites selected attested that the selected reaches were experiencing ongoing serious bank erosion during every major flood flow. Moreover, the Healthy Waterways' Ecosystem Monitoring Programme gave the Logan River the lowest possible 'F' health assessment for four years leading up to the commencement of the pilot study (Healthy Waterways, 2013).

An assessment of bank erosion prediction models

Water quality offsets require a quantifiable and verifiable estimate of the offset. In the case of river restoration, direct measurement of sediment erosion avoided is problematic. Conceptually, the measurement of sediment fluxes into waterways is complex, requiring expensive event-based monitoring across flood-flow hydrographs (Cheviron et al., 2014). Even with event-based monitoring, it is very difficult to detect the effect of restoration of relatively short lengths of degraded waterway as measurement error is likely to be greater than the treatment effect (Cheviron et al., 2014). Therefore the assessment of sediment erosion avoided from river restoration under a range of flow conditions requires modelling.

A desktop assessment of readily available erosion prediction models and their utility for assessing sediment erosion avoided in river restoration was undertaken. As the catchment models available were considered to lack the sensitivity needed to assess the effects of individual reach condition and restoration on sediment pollution potential, bank erosion prediction models were targeted.

The two dominant bank erosion forces observed in South-east Queensland are fluvial scour, where stream-flow shear forces exceed bank shear resistance, and gravitational mass failure, where bank mass exceeds bank shear resistance and the bank slumps (see for example Grove *et al*., 2013). The longer of the two reaches selected for the pilot study experienced fluvial scour (Figure 3a), while the smaller downstream reach experienced gravitational mass failure associated with a high-flow drainage line (Figure 4a).

The desktop assessment of bank erosion prediction models focused on those models that enable different river bank conditions and restoration treatments to be simulated; that were readily available; that were able to be applied with reasonably-obtained survey and direct measurement inputs; and that were considered to be credible by industry and academia.

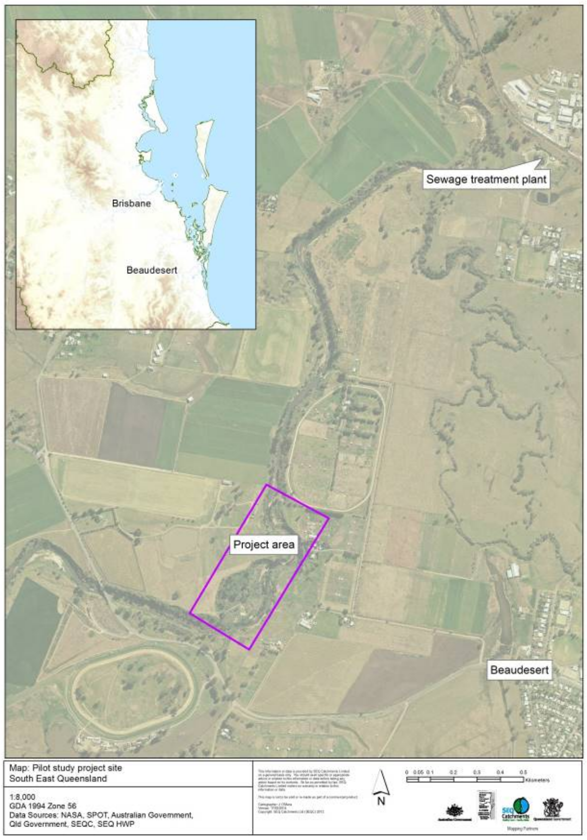

Figure 2: Location of the two target Reaches, site one to the south of the project area and site two at the north of the highlighted project area. Inset – location of Beaudesert in proximity to Brisbane.

Figure 3: The larger Reach affected by fluvial scour – (a) prior to restoration; and (b) immediately post restoration earthworks

Figure 4: The larger Reach affected by fluvial scour – (a) prior to restoration; and (b) nearing completion of restoration earthworks

Models considered included BANCS (Rosgen 2009), BSTEM (Simon *et al.,* 2010), BSTEM Dynamic (Brooks *et al.,* 2013), BSTEM coupled with geotechnical stability models (Fox *et al.,* 2007; Chu-Agor *et al.,* 2008), the Stream-power method (Alluvium 2011), CAESAR (see http://www.coulthard.org.uk/) and RVR Meander (See http://www.rvrmeander.org/). In addition to assessing the potential of various bank erosion models, the potential to interrogate historical imagery for the Logan River to assess the rate of bank morphological change associated with various flood flow events was also tested.

A recommended expert system for selecting an appropriate approach to modelling bank erosion was developed (Figure 5). BSTEM was considered to be best suited to modelling degraded banks subject to scour erosion, as was the case for the larger Reach in the pilot study. No model was considered to be well suited to the smaller Reach in the Pilot study, which is dominated by characteristically large bowl-shaped, high-flow, wet-flow slumping. However, as the historical records for this site were considered to be adequate, review of historical information was considered sufficient for use in estimating unremediated sediment erosion risk.

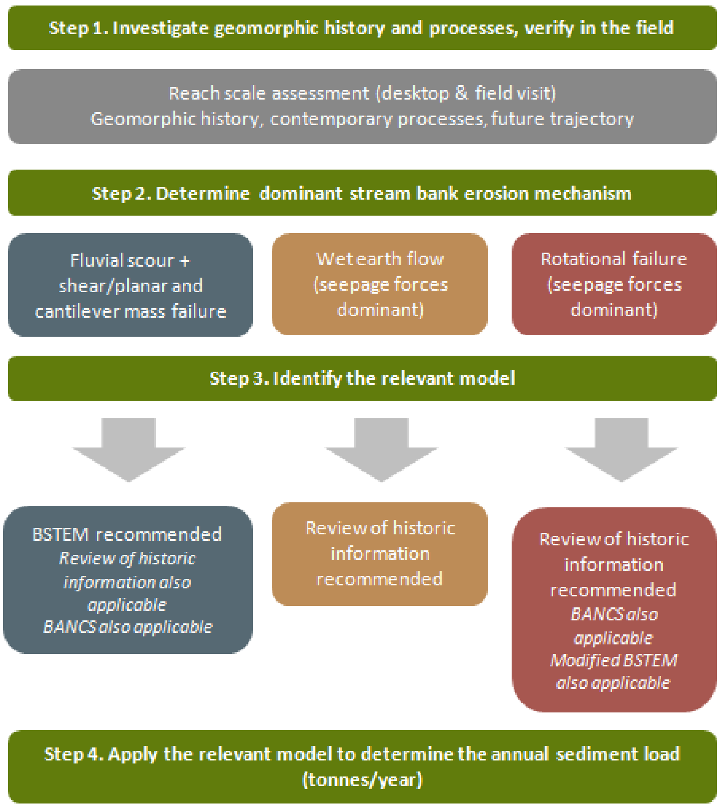

Figure 5: Expert model proposed to model bank erosion

Application of the BSTEM model to assess sediment erosion at the major target reach

In the work reported here, BSTEM was used interactively to simulate bank stability and toe erosion over the duration of flood hydrographs. The components and inputs of BSTEM, together with notes relating to the inputs are shown schematically in Figure 6.

Once developed, the model was calibrated for known historical erosion losses during 2010-2013, a period for which LiDAR and topographic assessment of bank change was possible. An assumption was made that the sediment erosion was associated with the January 2013 flood event. There were two smaller floods during that period with a 4 year Average Recurrence Interval (ARI). The historical data did not allow for an assessment of the contribution of these floods.

The major target reach was then sub-divided into sub-reaches requiring different restoration treatments. As each of these involved different types of works to the toe and bank, BSTEM was calibrated for each and used to model a range of flood events using 50 years of gauged historical flood flow data to develop relationships between flood peak flow rates and total sediment erosion expected for the unremediated bank.

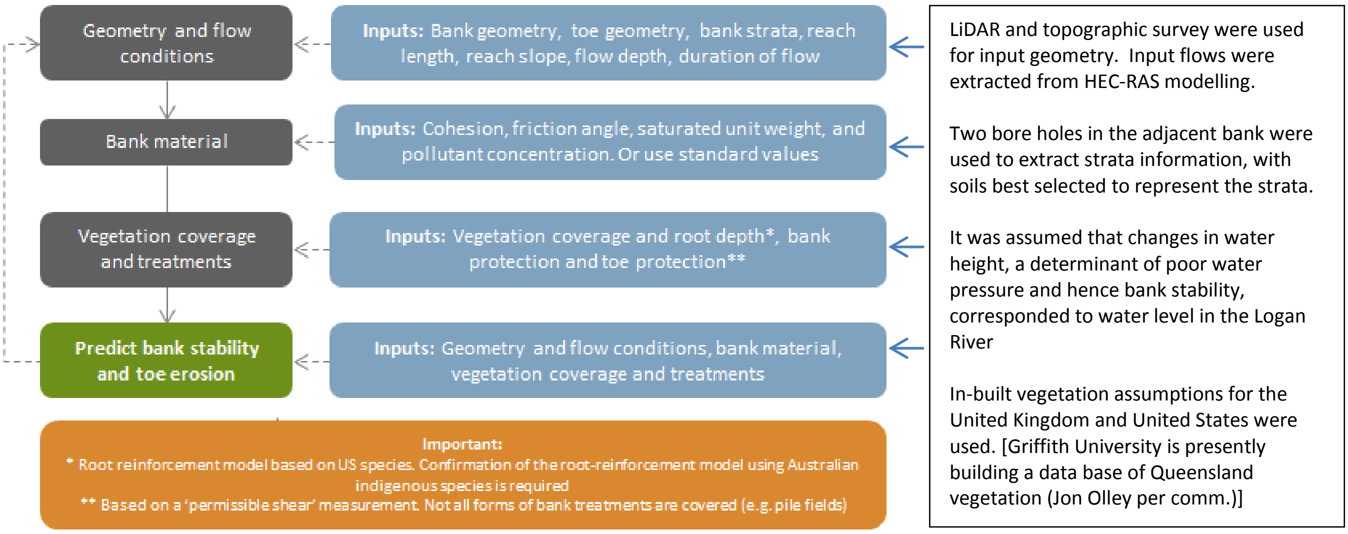

Figure 6: Components of BSTEM showing inputs

Bio-engineering river restoration plans were produced consistent with best practice bio-engineering river restoration design practices (Dept. Sustainability and Environment, 2007) and BSTEM was again used to model erosion generation of the restored Reache 1, 2, 5 and 10 years following works. The restoration works and assumptions made relevant to BSTEM modelling are as follows:

- Earthworks (Figure 3b) -
    - Rock revetment, rock beaching and pile fields – BSTEM has default values that were used unless experience and/or literature findings suggested an enhancement,
    - Bank battering – Actual changes to bank and toe geometry were input into BSTEM;
- Revegetation comprising sowing of cover grass and establishment of trees and shrubs – Default United Kingdom and United States data were used to represent the additional cohesion provided by developing roots in the revegetated banks. The resistance to bank erosion provided by vegetation increases as the vegetation matures and both the above ground and root biomass of the replanted riparian vegetation extends and increases. While the input earthworks' parameters were assumed not to change over time, changes were made to represent a lower shear resistance of younger vegetation. For year 1, a resistance equivalent to mature grass was assumed.

Modelled total erosion losses for design flood events at the major target site are shown in Figure 7 for the pre-remediation condition, 1 and 10 year post-remediation condition. Noting the scale on the Ordinate, the curves highlight the increasing contribution made by maturing riparian vegetation to bank stability over time. They also highlight the relatively greater contribution of high flood-flow events to bank erosion loss. However, it should be noted in this context that while not as significant in quantum, the effects of low flow toe erosion on the un-remediated site are important contributors to high flow instability.

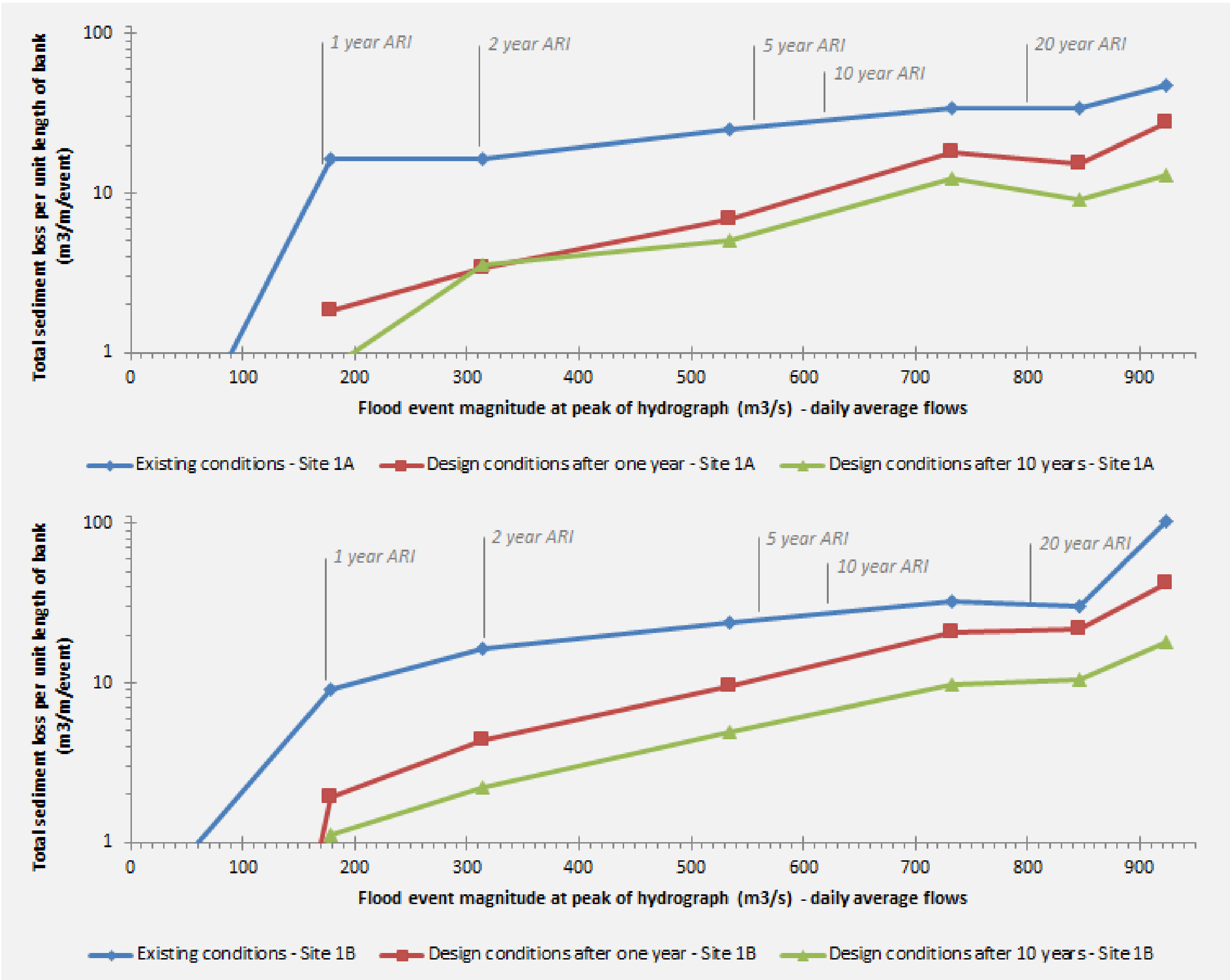

Figure 7: Modelled BSTEM estimates of sediment erosion under non restored (blue) and post bank restoration (red= year 1 and green = year 10) at both sites of the major target Reach.

Assessment of average annual sediment erosion avoided through river restoration in the pilot study

The relationship shown in Figure 7 between flood event magnitude and total event sediment load was applied to the complete flow record for the target Reach in an un-remediated condition and remediated condition. A total of 160 flood events were recorded over the 50 year record. An average annual sediment loss for the major target Reach in both the un-remediated and remediated condition was determined by summing the sediment loads for all 160 events and dividing by the 50 years of records. The average annual sediment offset, or average annual sediment avoided by river restoration was calculated as the difference between the average annual sediment loads for the un-remediated and remediated conditions.

For the second smaller target Reach in the pilot study, no bank erosion model was identified as being able to model the high-flow, wet-flow slumping (Figure 4). However, the historical record of topographic and LiDAR data was deemed to be sufficient to estimate annual sediment loss in the un-remediated condition. An assumption was made that failure only occurred when flood flow was high enough to engage the high-flow channel. Hydraulic modelling was used to assess the flood stage needed to engage the high-flow channel. Cross-checking this height with 50 year flood records revealed that four floods over the last 50 years engaged the high-flow channel. Historical bank morphologic change was used to assess average annual loss from the unremediated bank. As restoration works at the Reach (Figure 4b) comprised total rock lining of the bank face, the restoration works were assumed to remove the bank erosion risk. Revegetation was undertaken, but was assumed not to contribute further to bank stability.

Based on the BSTEM simulations for the longer Reach dominated by fluvial scour (Reach 1 – 300m) and historical analysis for the downstream Reach dominated by high-flow, wet-flow slumping (Reach 2 – 100m), the estimated annual sediment erosion avoided through the river restoration works in the pilot study was determined. The results are summarised in Table 1. The results reported in the Table assume *a* soil bulk density of 1600 kg/m^3. SEQC Services' experience with the sandy loam, loam and sandy clay loam soils found at both sites is for bulk densities of non-disturbed soils to increase from around 1500-1650 kg/m^3 in the surface 20cm to 1600-1750 kg/m^3 in lower horizons. Bulk densities of clay lenses in the soil profile would be expected to be lower at 1400-1500 kg/m^3.

Table 1: Annual sediment erosion avoided through river restoration works at the pilot study

	Annual offset tonnes/year		
	Reach 1	**Reach 2**	**Total for Pilot Study**
Average annual offset for Years 1-5 following restoration	10,300	900	11,200
Average annual offset for Years 6-10 following restoration	11,200	900	12,100
Average annual offset for Year 11 and beyond	11,500	900	12,400

Ultimately the accuracy of bank erosion prediction modelling will depend upon the chosen model's validity, and the assumptions made during modelling. Of the assumptions made, some will have had the effect of under-estimating sediment erosion, some will tend to over-estimate sediment erosion and others will have had little effect.

- Assumptions that would have tended to over-estimate erosion included –
  - Attributing the 2010-2013 historical bank erosion losses solely to the January 2013 flood and using this single flood to calibrate BSTEM is likely to over-predict sediment loss associated with individual flood events;
  - The assumption that all failed soil mass is removed from the toe of the bank and transported from the site after each failure event, an assumption that would tend to over-estimate sediment loss.
- Assumptions that would have tended to under-estimate erosion –
  - Using the hydrology from a gauging station some 18km upstream of the pilot study, will lead to lower flow rates being used for calibration and a likely under-estimate of erosion;
  - The use of default data for tree and shrub growth based on United Kingdom and United States data is likely to under-estimate the vigour of root and above ground vegetative development in Queensland and, therefore, understate erosion;

- The assumption that water-table heights followed flood levels would under-estimate slumping if, in fact, water-table heights lagged behind falling flood levels.

- Assumptions that were likely to have had a limited impact on the erosion estimate –
  - Soil profile and one-dimensionally modelled flow rate / flood stage assumptions are unlikely to skew erosion estimates.

The BSTEM modelling also assumed the same bank profile at the beginning of each flood event test means that subsequent modelled flood events do not 'build upon' earlier events. The effect of this assumption on prediction accuracy is likely to depend upon bank condition and the dominant erosion forces.

Quantifying sediment erosion avoided following the described methodology next feeds into the quantification of nutrient pollution avoided through riparian restoration activities, described in detail in paper 2 of this series. In applying this methodology it has been possible to provide economically efficient options for STP operators to meet their environmental licence obligations, while ensuring efficient social investment in both riparian restoration and STP service provision. In paper 2 of this series, the estimation of sediment loss avoided via river restoration activities described in this paper, is used to understand the amount of nutrients offset that directly relate to the licensing requirements of the STP.

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