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Sediment management in the Waikato region, New Zealand

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Abstract

The Waikato region covers much of New Zealand's central North Island and has a land area of about 25,000 square km. The region encompasses about 44,000 kilometres of waterways, including three larger river catchments – the Waikato River (11,353 km^2), Waipa River (3092 km^2) and the Waihou River (1275 km^2). The soil resource is vital to the Waikato region's wellbeing, and safeguarding it requires sound knowledge of the resource and effective erosion and sediment management. The sediment regime within the Waikato region reflects both natural processes and modification of natural processes (under present climatic and landscape conditions), including changes in land use, hydro-electric power development, sand and gravel extraction and channel management works. Waikato Regional Council (formerly Environment Waikato) has several sediment management roles, including regional monitoring and research, policy development and management implementation. Information about sediment sources and sediment movement through the region, as well as ways to prioritise decision-making, are an integral part of regional sediment management. Policy development and implementation through education and rules need be evidence-based and practical. To achieve this, continued monitoring and research, including collaborations with external research providers, is critical. Examples of how sediment-related monitoring and research has assisted sediment management in the Waikato region are summarised in this paper.

Keywords

Waikato region, sediment, erosion, Waikato River, Waipa River, Waihou River, Regional Policy Statement, soil conservation, suspended sediment, bedload, land-use, intensification, streambank, sand extraction, hydro-power schemes, catchment management

Introduction

The Waikato region covers much of New Zealand's central North Island and has a land area of about 25,000 square km. Only about 1% of the region is urban. About 58% of the region is in pastoral agriculture (mainly dairy, beef and sheep farming), 18% is in plantation forestry and less than 1% is in various types of horticulture (Environment Waikato, 2010a). The region encompasses about 44,000 kilometres of waterways, including three larger river catchments; the Waikato River (11,353 km^2), Waipa River (3092 km^2) and the Waihou River (1275 km^2).

The soil resource is vital to the Waikato region's wellbeing and particularly to the primary production industry which underpins the regional economy. Soil provides services beyond supporting production; buffering water and nutrient movement, storing carbon and recycling waste. The Waikato region is dependent on sound erosion and sediment management to safeguard these life-supporting roles of the region's soil resource.

The sediment regime within the region reflects the natural processes and modification of natural processes (under present climatic and landscape conditions), including changes in land use, hydro-electric power development, sand and gravel extraction and channel management works (Hicks and Hill, 2010). Waikato Regional Council (formerly Environment Waikato) is the regional authority responsible for implementing the Resource Management Act and managing the Region's environmental issues. One of the challenges for council is to utilise the available research to make evidence-based decisions. This paper provides an overview of some of the sediment-related problems facing the region and examples of ways in which sediment research has been applied to address them.

Sediment management roles

The sediment management roles of the council can be divided into three main areas – monitoring and research, policy development, and management implementation.

Monitoring and research

Under section 35 (s35) of the Resource Management Act (RMA), the council is required to undertake State of Environment (SOE) monitoring and reporting. Generally, monitoring is carried out annually and reported at a minimum of five-yearly intervals as required under s35 of the RMA. The council has or is in the process of developing indicators to measure the state and trends relating to sediment. A description of the suite of environmental indicators is presented in Table 1.

Table 1 – Environmental indicators used by Waikato Regional Council for State of Environment monitoring for the Waikato region.

Indicator	Description	Measure
Soil stability	Soil disturbance from natural erosion and land-use activities; bare soil under land uses and land cover	Indicates potential sediment source
Riparian stock access	Stock access to waterways based on the presence or absence of fencing, vegetation and stream characteristics.	Indicates potential sediment source
Riparian vegetation	Riparian bank stability; based on the presence or absence of vegetation and vegetation size and structure	Indicates potential sediment source
Sediment	Suspended sediment yield estimates for selected catchments (23 sites)	Indicates sediment yield for selected catchments
Land use	Estimates regional land cover and land use, based on land cover database (LCDB1 and LCDB2)	Indicates potential pressures and risk that could increase sediment sources
Stock unit density	Estimates the density of stock by converting farm animals to a common stock unit and dividing by the area of land that the stock is grazing on.	Indicates potential pressures and risk that could increase sediment sources

The sediment indicator relies on monitoring of suspended sediment. Bed-load monitoring is not undertaken due to limited field resources. Regional monitoring and reporting of soil stability and riparian erosion have recently been completed. The accompanying reports (Thompson and Hicks, 2009; Storey, 2010) indicate potential sediment sources, which would include both potential bed material and suspended sediment sources.

A regional network of suspended sediment monitoring sites allows for the estimation of suspended sediment yields of selected waterways in the Waikato region. The network includes 23 sites, consisting of 15 manually gauged sites and eight sites where automatic samplers are installed (Kotze *et al.*, 2008). Suspended sediment concentration data is used to estimate sediment yields, including specific sediment yields for the catchments (Fig. 1).

The results are used to assess catchment-scale changes in sediment regime in relation to catchment activities, such as soil conservation and river management works.

Monitoring land-use change helps identify where land-use pressures may lead to greater risk of erosion and increased sediment loads to streams, especially where land management practices are not adequate or land use does not match the capability of the land. From spatial analyses of regional datasets for land cover and stock unit density, land-use intensification pressures have been identified in a number of zones of the Waikato region. As well as undertaking SOE monitoring, Waikato Regional Council regularly uses or contributes to externally-funded applied research, including the development and application of regional and national sediment-related models such as the Catchment Land Use Environmental Scenarios (CLUES) model (Semadeni-Davies

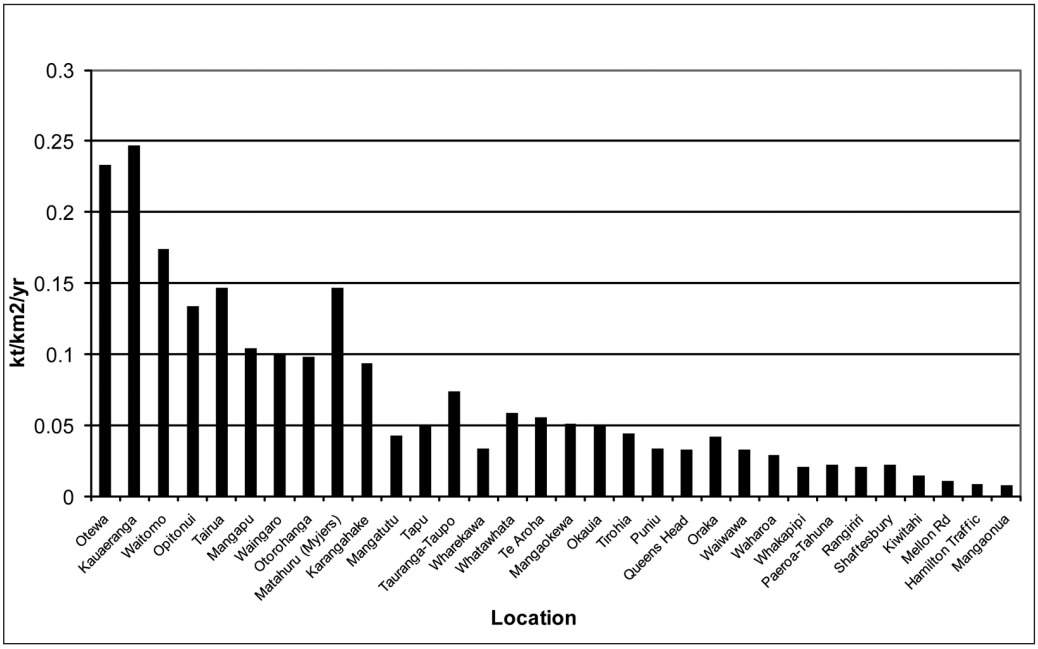

Figure 1 – Estimated average annual specific suspended sediment yield for selected waterways in the Waikato region monitored by Waikato Regional Council, in order of decreasing annual suspended sediment yield (after Kotze et al., 2008).

et al., 2009). Such research and models are invaluable for assessing and prioritising issues at a regional and catchment scale and to assist in policy development. One challenge council technical staff grapple with is the use of multiple models. The application of sediment models requires a good understanding of the model's limitations within the region of use, and care is needed when interpreting and using model outputs. For example, yield estimates using two models; the New Zealand Empirical Erosion Model (NZEEM) (Dymond *et al.*, 2010) and the Suspended-Sediment Yield Estimator (NIWA, 2011) as well as measured data at three sites along the Waikato River all show different values (Fig. 2).

The variability partly reflects the limitations of the models, but also the reality of measurement and modeling as well; regional data are essential for calibration. Factors such as antecedent flow history contribute to the variability in the yield prediction. In combination, the estimates do provide an indication of the sediment yield and, at a sub-regional catchment scale, the relative catchment yields indicate the catchments likely to be contributing the most sediment to the system. It is important that these concepts are recognized and conveyed to decision makers to ensure decisions are based on sensible interpretation of model outputs.

Policy development

The two main policy documents in the Waikato region that guide and determine policy (what policy instruments are used to address issues) are the Waikato Regional Policy Statement and the Waikato Regional

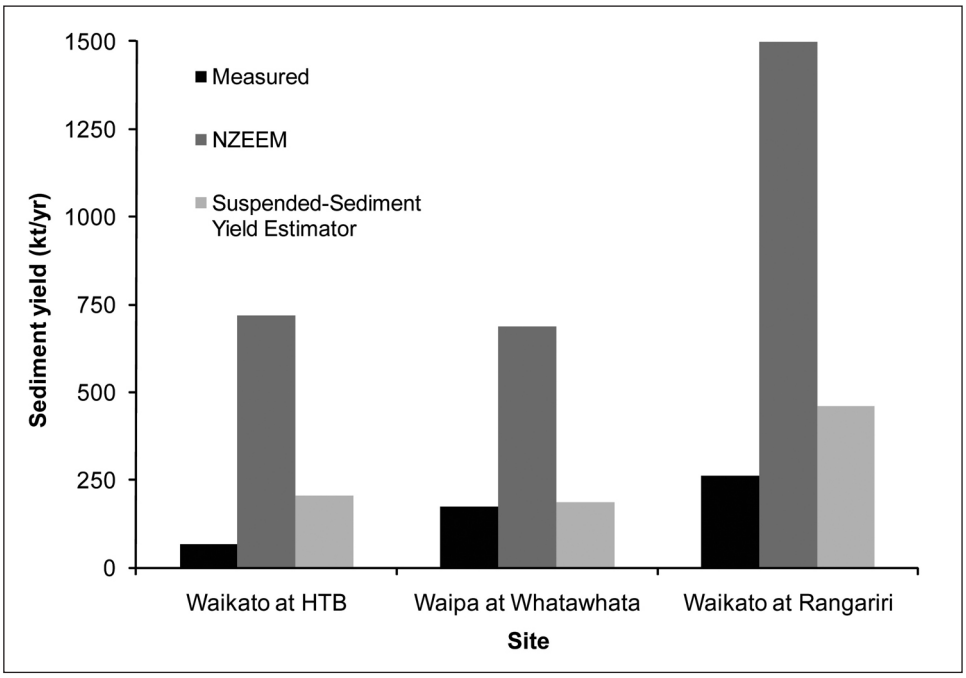

Figure 2 – Comparison of estimates of suspended sediment yield for the Waikato River at the Hamilton Traffic Bridge (HTB), Waipa River at Whatawhata,and the Waikato River at Rangiriri, using measured data and model outputs using the NZEEM model and NIWA's Suspended-Sediment Yield Estimator.

Plan. Generally, a mix of rules and education is used, with the level of intervention determined by the level of risk of not acting on the given issue. The Regional Policy Statement identifies the significant resource management issues of the region and sets out the objectives, policies and methods to address the issues (Environment Waikato, 2010a). The Policy Statement is currently under review (the proposed Regional Policy Statement, 2010). Policy related to sediment management is being updated and the Vision and Strategy/Te Ture Whaimana, the key document setting directions for the protection of the Waikato River, established as part of the Treaty of Waitangi settlements (Environment Waikato, 2010a) is being incorporated. The Vision's focus is on restoring and protecting the health and wellbeing of the river. The application of the vision includes the river, as well as the catchment activities affecting the river. Management of sediment is also a focus in the proposed freshwater bodies and soil policy areas. *Freshwater bodies* policy includes managing activities to maintain or enhance the values of water bodies, such as reducing sediment, bank instability and accelerated sedimentation of estuaries as well as specific catchment intervention policy (Environment Waikato, 2010b). *Soils* policy focuses on managing land-use activities to retain soil on site and in situ to reduce erosion risk, as well as using methods such as soil conservation programmes and pest management to maintain protective vegetation cover. In general, ongoing research and monitoring are essential to identify emerging issues and trends, to develop and implement education methods to inform land owners of good environmental practice, and to construct evidence-based policy, including practicable rules that ensure the sustainable use of resources.

Management implementation

In addition to the Waikato regional policy documents, the Soil Conservation and Rivers Control Act 1941 provides Waikato Regional Council with the ability to implement soil conservation, river management and flood control activities and focus on preventing erosion and sedimentation of waterways. Historically, Waikato Regional Council and its predecessors implemented soil conservation programmes (schemes) with the support of Government grants. However, since about 1999, these activities have been funded predominantly through target rates implemented via eight catchment-based zones. The programmes include wide-ranging catchment control schemes and more than 500 separate property plans. Land Improvement Agreements, between landowners and Waikato Regional Council, set out the future maintenance and management needs for most of the soil conservation work. Soil conservation programmes include tree planting on hills and streambanks, retiring land, and fencing gully areas and waterways to prevent stock access. A summary of Waikato Regional Council's soil conservation progress and investment is shown in Table 2.

Sediment problems

Sediment production, transfer and deposition have historically been controlled by the geology of the region, with human activities on the land and in the waterways increasingly modifying the sediment regime. The rivers and catchments of the Waikato region are now largely considered highly modified systems. The human activities that have variously affected the supply, transfer and storage of sediment in the Waikato include forest clearance and other land-use conversion, hydro-electric power development, sand and gravel extraction, and channel management works.

Land use

Land use strongly influences sediment production in the Waikato region. The effects of land use on sediment production

Table 2 – A summary of Waikato Regional Council's soil conservation on-ground progress and investment (after Environment Waikato, 2010c).

Scheme	Land retired (ha)	Fencing (km)	Planting (ha)	Structures	Water supply systems	Replacement value ($ million)
Taupo	5,145	1,125	4,252	86	41	15.20
Waihou Valley	2,600	410	780	150	–	4.72
Paeroa Range	1,181	564	1,267	54	65	7.70
Reporoa	1,015	269	958	38	8	3.10
Waitomo	883	50	369	4	3	0.58
Karapiro and Arapuni	600	37	126	37	150	0.55
Separate Plans	–	–	–	–	–	3.33
Total	11,424	2,455	7,752	331	259	35.18

and transport relate to groundcover, and to bare soil exposure resulting from land-use activities such as cultivation and tracks (Hicks and Hill, 2010). State of Environment monitoring of soil disturbance and bare soil for the Waikato region in 2002 and 2007 indicated that soil disturbance increased from 10% to 30% of sites (Hicks, 2004; Thompson and Hicks, 2009). The increase was largely caused by significant increases in land-use-related soil disturbance (an increase from 6.7% to 23.0% of the regional sample) compared with natural disturbance (an increase from 3.3% to 7.5% of the regional sample). Three-quarters of the recorded disturbance related to land-use activities and the remaining quarter to natural erosion. Of the areas affected by land use, most bare soil relates to tracks, and cultivation, with bare soil greatest on pastoral land. The monitoring was not designed to find evidence that increasing bare soil on areas affected by a given land use resulted in a proportional increase in sediment source areas. However, the area of bare soil on areas affected by a land use are potential sediment sources if not correctly managed. For example, poorly-designed and poorly-maintained tracks and raceways can collect and channel sediment-loaded farm runoff into nearby waterways. Of the natural processes, bare soil is associated mostly with sheetwash, landslides and rockfalls. Bare soil related to land-use disturbance is about 4 times greater than that caused by natural processes and collectively regional bare soil totals about 2.85% of the region by area or about 71,000 hectares.

Along with hillslope mass movement (e.g., landslides, slips and gullying), streambank erosion is perceived to be a significant sediment source in areas of pastoral land-use, particularly along unfenced banks accessible to stock (Hicks and Hill, 2010). State of Environment monitoring of riparian characteristics (including streambank disturbance) for the Waikato region in 2002 and 2007 (Storey, 2010) indicates about 4% of the streambank length in pasture areas in the Waikato is actively eroding and that about 25% of bank length is subjected to pugging by stock or shows signs of recent erosion (Storey, 2010). A strong correlation between fencing of both banks and reduced streambank disturbance demonstrates that fencing is an effective management practice for reducing potential sediment in waterways.

Similar findings at a catchment scale (the Waitomo Stream catchment) confirm that for flows and runoff events of a given size, suspended sediment concentrations and loads have been reduced downstream of reaches that have been fenced-off from stock and replanted (McKerchar and Hicks, 2003; Hill and Quinn, 2010).

Historically, land-use conversion to pasture, involving forest and scrub removal, created large increases in sediment loads, particularly in the basins in the upper Waikato and upper Waipa, which drain Taupo Pumice terrain. Thus, current trends for widespread conversion of exotic forest blocks to dairying carry a threat of a potential repeat phase of high sediment production (Hicks and Hill, 2010).

From preliminary analyses of land-use change in the Waikato region, pine-to-pasture conversion from 2002 to 2008 is estimated at about 39,000 ha, of which about 31,000 ha is in the upper Waikato River catchment (Environment Waikato, unpublished information). Regionally, a major proportion (46%) of the land converted to pastoral land-use has occurred on Land Use Capability (LUC) class 6 land (Fig. 3).

Good environmental practices, including managing land use in a manner appropriate for the LUC class, is required to minimise the risk of increased sediment production.

Modelling the impacts of land-use change on the flood hydrology in the upper Waikato River catchment (Environment Waikato, 2009) showed that a significant increased peak flows resulting from land-use change were likely to cause localised erosion and potentially result in increased sediment production from streambanks. Additionally, a study by Taylor *et al.* (2009) suggests that, for soils in the upper Waikato catchment, infiltration under pasture is around an order of magnitude lower than under plantation forestry. Potentially, the resultant increased runoff is expected to increase peak flows and susceptibility to erosion.

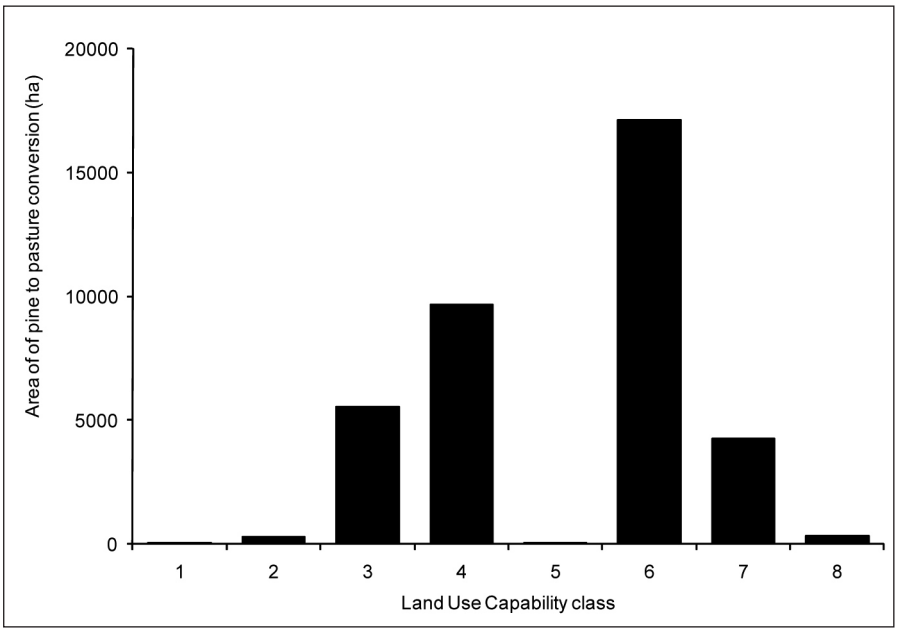

Figure 3 – Estimated area of land converted from plantation forest to pastoral land for Land Use Capability (LUC) classes in the Waikato region between 2002 and 2008.

From preliminary analyses of regional pastoral intensification (measured by a change in farm type as the result changes in stock unit density) for the Waikato region, it is estimated that a net regional intensification of pastoral land-use of about 9% occurred from 2002 to 2008 (Environment Waikato, unpublished information). However, the intensification has been focused in several parts of the region – Waipa, upper Waikato (driven by pine-to-pasture conversion), and the Waihou-Piako, with the greater proportion on LUC Class 6 land (Fig. 4).

tributaries, as well as part of the suspended load. The rate at which each reservoir traps sediment depends on the rate of sediment supply from local tributaries, the rate of delivery out of reservoirs upstream, and the reservoir's sediment trapping efficiency, which depends on its volume, geometry and water discharge (Hicks and Hill, 2010).

Hicks *et al.* (2001) used data on tributary sediment loads to estimate the supply of suspended load into the Waikato main stem and used reservoir sediment trap-efficiency calculations to estimate the downstream-

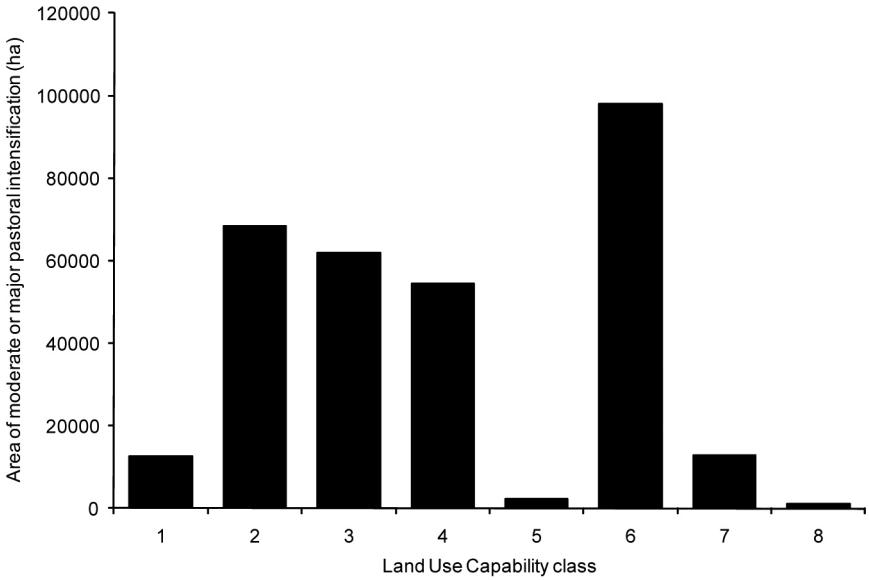

Figure 4 – Estimated area of pastoral land use intensification for Land Use Capability (LUC) classes in the Waikato region between 2002 and 2008.

Hydro-power schemes

The introduction of hydro-power schemes along the Waikato River has been the other human activity to have a major impact on the sediment regime in the Waikato region. There are eight hydro-dams and reservoirs on the Waikato main stem. These reservoirs trap the entire bed-material load supplied by their

cumulative average annual suspended load. Figure 5 shows that if the hydro-lakes were not present, the suspended load delivered to the coast would be around 526,000 t/yr, with 37% derived from the Waipa River and 37% derived from upstream of Karapiro (Hicks *et al.*, 2001).

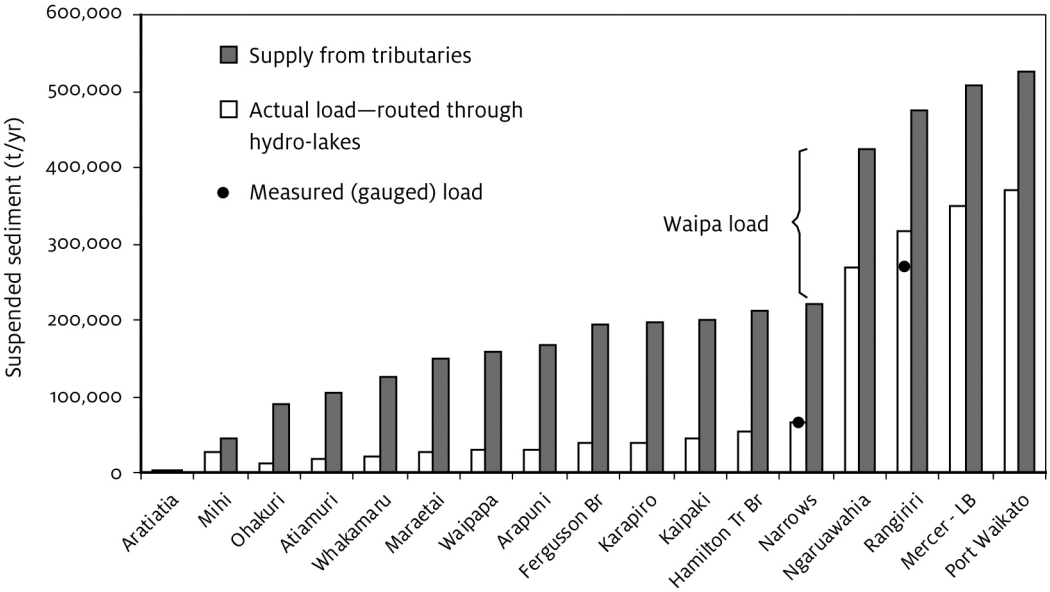

Figure 5 – Downstream cumulative average annual supplies of suspended sediment and estimated load for the Waikato River mainstem. Measured loads at Hamilton Traffic Bridge and Rangiriri are also included. All data collected since 1991. Source: Environment Waikato; NIWA (after Hicks and Hill, 2010).

At present, much of the potential load past Karapiro is lost to hydro-lake sedimentation. The Waipa now contributes approximately two-thirds of the suspended load that is delivered to the coast.

In a sediment mass balance for all of the hydro-lakes combined, Hicks *et al.* (2001) estimated that 280,000 t/yr of sediment is trapped on average, while some 37,000 t/yr of washload passes downstream from Karapiro Dam. Of the trapped total, 167,000 t/yr is bed-material load (sand and gravel) and 112,000 t/yr is suspended load (silt and clay), leaving a deficit of approximately 104,000 m^3/yr in the bed-material supply to the Waikato River downstream of Karapiro Dam (Hicks *et al.*, 2001). This bed-material supply deficit has been a major cause of falling riverbed levels along some sections of the lower Waikato River. Downstream from Karapiro Dam over recent decades, the bed in the Hamilton area has degraded on average (over all dates and sections) at approximately 25–30 mm yr-1 (Hicks 2002; Smart 2006; Joynes, 2008; Hicks and Hill, 2010). Hicks and Hill (2010) consider that if the lifetimes for reservoirs before being filled in with sediment are in the range of one to several thousand years, this deficit should be considered permanent, at least for the next millennium.

Examples of monitoring and research applications

Lower Waikato River sand extraction

Sand and gravel extraction from the bed of the lower Waikato began in the 1940s, largely to service the construction industry. Records available since 1953 (Fig. 6) show that the overall rate of extraction increased up until the mid 1970s, peaking in 1974.

Extraction in recent years (1996–2006) has averaged around 214,000 m^3/yr of sand. Of the total 18.2 million m^3 extracted between

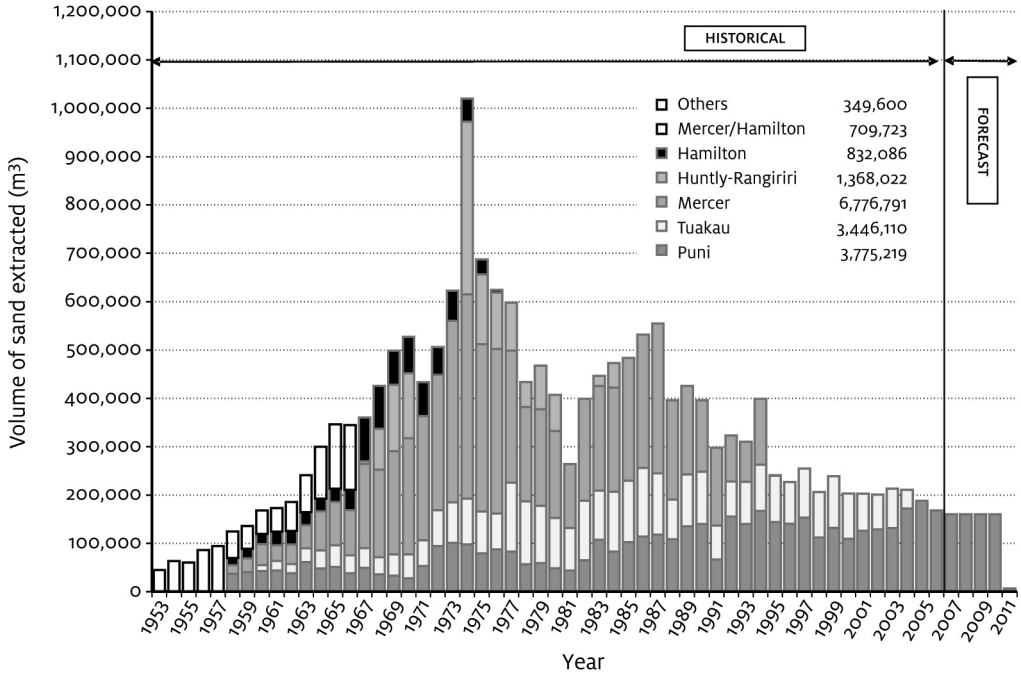

Figure 6 – Historical and forecast volumes of sand and gravel annually extracted from various reaches of the lower Waikato. Forecasts are based on existing consents. Figures in legend are totals in m^3 over the period of record. Source: Environment Waikato (after Hicks and Hill, 2010)

1953 and 2006 (averaging 350,000 m^3/yr), the greatest proportion (41%) was taken from the Mercer area, with approximately 5% being taken from the Hamilton area. Over this period, the average extraction rate was over three times the average rate of bed-material entrapment in the hydro-lakes (Hicks and Hill, 2010).

Extraction amounts are managed according to a strategy set out in the Lower Waikato and Waipa Control Scheme's Asset Management Plan (Environment Waikato, 1997) and includes maintaining a target water-level profile at a reference discharge. Commercial sand extraction or, if necessary, maintenance dredging, is directed where needed. In terms of resource sustainability, the average extraction rate since 1953 has been almost twice the rate that the river has been able to replace. A sustainable average extraction rate is set at 180,000 m^3/yr, which matches the estimated bed-material load going into the extraction reach. The current sand extraction consents expire in 2011 and the forecast extraction until then is expected to be 160,000 m^3/yr (Environment Waikato, unpublished information).

Suspended sediment sources in the upper Waipa

Following a large rainfall event in 1998, the high suspended sediment loads observed in the Waipa River at the confluence of the Waikato River triggered a programme to identify sediment sources in the Waipa River catchment. Waikato Regional Council undertook a programme of synoptic 'snapshot' sampling of suspended sediment

concentrations at stream sites around the Waipa catchment under high- and low-flow conditions (Stewart *et al.*, 2001). The results of the sampling indicated that at high flows the major suspended sediment source area is the upper Waipa River, where a maximum suspended sediment concentration of 1300 g/m^3 (Stewart *et al.*, 2001) was measured. Ongoing suspended sediment monitoring in the upper Waipa at Otewa, about 8 km south-east of Otorohanga, shows a yield of 291 t/km^2/yr (Hicks and Hill, 2010). The high yield largely reflects the geological setting, with much of the western side underlain by Tertiary marine sediments and the eastern side by ignimbrite and greywacke. However, during further field reconnaissance the main sediment source was identified as a large landslip that occurred near Tunawaea in the early 1990s. The slip took place on a steep, tephra-mantled, greywacke hillslope at the junction of two fault zones and temporarily dammed the Tunawaea Stream. The slip and associated dam breach fed a large amount of gravel into the upper Waipa River. Subsequent aggradation of the riverbed downstream has resulted in extensive lateral channel migration and streambank erosion. The bank erosion has consumed 15-m high terraces of Taupo Pumice, as well as valley-wall colluvium. Remedial works have since been implemented to divert the river away from the eroding terraces and stabilise the landslip.

Waihou River catchment scheme

The Waihou River catchment scheme was implemented to reduce the potential for flood damage, soil instability and associated sediment production. The scheme involves catchment works (e.g., retirement of steep, erosion prone land), river management (e.g., maintenance along 8980 km of streams) and flood protection on the lower plains, including 174 km of stopbanks. An estimated 150,000 tonnes of sediment from the Waihou each year still makes its way to the Firth of Thames, where it has potential to affect the coastal environment (P. Singleton, personal communication, 2010). With increasing use of the Firth for aquaculture, and the presence of the internationally recognised Ramsar site on the southern and western shores of the Firth of Thames (Brownell, 2004), the catchments of the Firth require further research attention to minimise the effects of sediment and other contaminants, such as nutrients. The pressures on the catchment are complex, sediment management being but one of many identified problems (e.g., animal pests, flooding and drainage, intensive land use and aquaculture in the Firth of Thames).

Increasingly, Waikato Regional Council is taking an integrated approach to catchment management, identifying catchment priorities and engaging multiple stakeholders, including the community, to develop a common vision, principles and strategy for catchments with schemes such as the Waihou catchment. Regionally, sediment management remains a key component of this approach.

Conclusions

The Waikato region depends on sound erosion and sediment management for the continued prosperity of the regional economy. Ongoing regional and catchment-scale monitoring of erosion and sediment and extensive and collaborative research provide a sound understanding of the region's sediment regime and its management. The application of regional and national sediment models is required to prioritise sediment-related issues and to target and implement soil conservation and sediment management. There are some limitations to the application and interpretation of current information, and continued research is required to further refine these models and overcome the existing model limitations.

Second-generation policy documents for the Waikato region, such as the Regional

Policy Statement are being developed. Changes to policies and methods within these documents, together with the recognition of the Waikato River Settlement and the inclusion of iwi co-management, will further enable council to develop and implement evidence-based and practical policy around education and regulation.

Soil conservation programmes and catchment schemes are an integral part of sediment management in the Waikato region. An integrated approach to catchment management provides a framework that allows a broader range of catchment stakeholders to develop a shared vision, share responsibilities and the work required to address catchment issues, including sediment management.

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