Earth Sciences New Zealand

Pūhoi to Warkworth (P2W) roading project - Assessment of GLEAMS model sediment yield predictions

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Prepared by:
Andrew Hughes

For any information regarding this report please contact:

Andrew Hughes
Land-Water Scientist
Catchment Processes
+64 7 856 1794
andrew.hughes@earthsciences.nz

New Zealand Institute for Earth Science Limited
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

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J.P. Moores	Reviewed by:	Jonathan Moores
JDowney	Formatting checked by:	Jo Downey
M. P. [illegible]	Approved for release by:	Michael Bruce

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Executive summary

Stage 3 of the Pūhoi to Warkworth (P2W) sediment assessment programme evaluates the performance of the GLEAMS erosion model used prior to the commencement of works. The work builds on the Stage 1 and Stage 2 analyses of measured sediment losses and sediment retention pond (SRP) performance. The objectives were to compare GLEAMS-predicted hillslope sediment yields with measured sediment loads, investigate reasons for any discrepancies, assess the suitability of GLEAMS for earthworks applications, and place the findings within the context of other New Zealand studies.

GLEAMS and USLE predictions were sourced from the original Assessment of Environmental Effects (AEE) and Construction Water Assessment (CWA) reports. Both models produced very similar specific sediment yield (SSY) estimates for Hill and Flat terrain types, despite relying on different rainfall erosivity inputs. Measured sediment loads were available for two SRP inlet sites. One site (SRP57350) produced SSYs comparable to the modelled values, while the other (SRP53000) produced substantially lower SSYs due to lower measured suspended sediment concentrations. All measured loads are likely to be underestimates because event peaks were not consistently sampled, meaning the monitoring dataset is not sufficiently robust to validate or invalidate the GLEAMS predictions.

The evaluation of GLEAMS highlights that it is an empirical, USLE-based erosion model developed for agricultural land and not designed to represent rilling, gullying, or concentrated flow processes typical of earthworks. Although the model has been applied in several New Zealand earthworks assessments, it was never intended to provide absolute sediment load predictions, and no calibration to earthworks-specific erosion data has been undertaken. However, a review of other New Zealand studies shows that the GLEAMS-derived hillslope erosion sediment yields for P2W fall within the broad range reported for disturbed land.

Overall, the apparent agreement between modelled and measured sediment yields at one site should not be interpreted as evidence of model accuracy, given the substantial uncertainty in the monitoring data and the structural limitations of GLEAMS. The model can provide indicative estimates of hillslope erosion but should not be relied upon for precise quantitative predictions without calibration and a clearer understanding of site-specific erosion processes. Further refinement of GLEAMS inputs are unlikely to meaningfully reduce model–measurement discrepancies, and any future modelling would require improved field data for model calibration and consideration of alternative, process-based approaches.

1 Introduction

The Ara Tūhono – Pūhoi to Warkworth roading project (P2W) included predictive modelling of sediment loss as part of the assessment of environmental effects for resource consenting, and intensive monitoring of actual sediment loss as part of the consent conditions.

Auckland Council (AC), along with New Zealand Transport Agency Waka Kotahi (NZTA), wish to draw out key findings from the monitoring and to review modelling approaches in the light of the monitoring results. Key questions are:

- What were the sediment losses (before and after sediment controls)?
- How well did the flocculated sediment retention ponds (SRP) and decanting earth bunds (DEB) perform? How did this compare with expected performance, and were there any key observations about the performance of the devices that could inform improved designs or assessment of sediment risks?
- Did the predicted losses from GLEAMS modelling differ from the expected losses. If so, why (e.g., model assumptions not accurate, weather conditions over the monitoring period, or an underlying problem with the model)?
- What are the implications for improving assessment of sediment loss risk in future projects?

To answer these questions ESNZ was engaged to collate and analyse the measured field data collected from a number of flow/suspended sediment monitoring sites. The findings of this analysis were then to be compared to the predictions produced by the GLEAMS model prior to the commencement of the work.

The project is divided into three stages:

1. Sediment loss measurement review.
2. Device (sediment retention pond) performance.
3. Assessment of GLEAMS modelling.

This report covers Stage 3, the scope of which is outlined below (the italicised text has been taken from the project contract):

Stage 3. Assessment of GLEAMS modelling

This will involve the following components:

1. *Compare the original GLEAMS model prediction of mean annual sediment yield to the measured mean annual sediment yield. Consider how measurement uncertainty may affect this comparison.*

2. *Examine how the measured rainfall during the monitoring period (from the on-site rainfall recorders) compared with the rainfall record used for the GLEAMS model. This will be in terms of histograms of number of events per year in rain depth bins (e.g., 50 mm to 100 mm) and number exceeding nominated depths (e.g., number exceeding 50 mm), both for daily rain and storm event rain), with emphasis on large storms that typically produce most sediment. This analysis will indicate whether the monitored period was particularly stormy or not-stormy compared with the modelled conditions, with implications for sediment loads. The rain for the monitored period will not be long enough for formal probability distribution comparison.*

3. *Comment on the implications of the rainfall distribution for model-measurement disparities.*

4. *Compare the histogram of measured event sediment yield to the histogram of modelled event load (on a daily and storm basis). This will give insight into whether the discrepancies are driven by specific event size.*

5. *Compare modelled/assumed slope distribution to the slope for the actual device catchment (noting that actual slopes were not measured and would have to be estimated by those familiar with the sites). Consider the implications for disparities between measured and modelled sediment. Note that the actual slopes may be uncertain.*

6. *If the data supports it, establish relationships between storm rainfall and sediment loss (e.g., smoothed spline curves) and examine these relationships differ between the model and the measurements. This would indicate, for example, whether a storm of a particular size produces more sediment in the model as compared with measured.*

7. *Compare assumed sediment pond performance with measured values, and the implications for disparities in exported load.*

8. *Examine other model inputs assumptions such as slope length and shape and erosion processes modelled, and the implications of these for sediment load.*

9. *Comment on the estimated GLEAMS yields from this study in comparison with estimates from other modelling studies in Auckland (a check that the predictions from the Puhoi to Warkworth study are not unusually high).*

10. *Comment on how the measured sediment yield compares with measurements from other earthworks sites (e.g., older measurements from uncontrolled earthworks in the Alexandra basin).*

11. *Synthesise the above information into an overall commentary on discrepancies and suitability of the GLEAMS model.*

12. *Comment on whether additional GLEAMS modelling using actual catchment and rain conditions as GLEAMS input would be practicable and useful and, if so, provide recommendations on the scope and design of a further piece of work.*

13. *Present interim and final results at project meetings, and document the analysis and commentary in a brief report.*

After the completion of the Stage 1 and 2 report it became apparent that some of the points above appeared to be based on a pre-determined outcome. That is, that loads determined from the field-based data would be demonstrably accurate and the disparity between the measured field data and the GLEAMS model results could be meaningfully explained by investigating the input parameters into the GLEAMS model. The uncertainty associated with measured results is such that using them as a basis for proving the GLEAMs model inaccuracy is not a sound approach. It was therefore agreed that the points (2, 3, 4, 5, 6, 7 and 8) that relate to the input parameters used in the GLEAMS model (which would, in effect, be fine tuning) would not be required to be consider here.

2 Comparison of GLEAMS sediment yield predictions with measured results

The original GLEAMS model predicted sediment load results for the Puhoi to Warkworth (P2W) motorway earthworks were presented in a NIWA report (Harper et al. 2013). This report included the total sediment load (SL) predictions (reported in t/y) for the 'Hill' and 'Flat' earthworks zones for a number of years. No specific sediment yields (SSY; reported in t/ha/y) are presented in Harper et al. (2013). The sediment load predictions from the GLEAMS model were used later in an Assessment of Environmental Effect (AEE) report (FNA 2013b) and a Construction Water Assessment (CWA) Report (FNA 2013a). Sediment load predictions from the Universal Soil Loss Equation (USLE) were also presented in these reports.

The predicted loads from both GLEAMS and USLE for each year of earthworks for 5 year and 10 year scenarios are presented in multiple tables (tables 26, 29 and 30) of the CWA report (FNA 2013a). Specific sediment yields (SSY) are presented for the USLE data. Predicted SSYs for the GLEAMS model were also determined from the information in these tables. All these predictions are summarised in Table A-1, Table A-2, Table A-3, and Table A-4.

The CWA report (FNA 2013a) used the average of the 5 year of the 10 year scenario USLE predictions to determine what it described as "representative yields". These SSYs, together with GLEAMS derived SSYs (determined using the same averaging approach) are presented in Table 2-1. The predicted SSYs for the GLEAMS (Hill = 49.0 t/ha/y; Flat = 24.5 t/ha/y) for and USLE (Hill = 41.7 t/ha/y; Flat = 26.1 t/ha/y) approaches are very similar. Certainly, in terms of model outputs, the estimates can be considered basically the same.

GLEAMS and USLE are related models and, as indicated in (FNA 2013a), some parameters were identical for both model runs. Although the rainfall component (R factor) of these two models was very different. The GLEAMS model calculated daily sediment loads (summed to produce annual loads) using 50-year historical daily rainfall from climate stations within the Mahurangi Harbour catchment and nearby. In contrast, the USLE approach used a specific event size (2 year return period, 6 hour duration storm) based off national-scale modelled data (High Intensity Rainfall Design System (HIRDS)) to determine the rainfall erosivity factor (FNA 2013a). Hence, the fact that both models produced very similar results is remarkable. This suggests that the rainfall erosivity factor used in the USLE model almost perfectly represents the average rainfall conditions for the 50-year record used, or the approaches are not particularly sensitive to the rainfall data used.

Table 2-1: Average predicted GLEAMS and USLE specific sediment yields (SSY) for the Hill and Flat zones.

Model/Terrain type	Average SSY (t/ha/y)
USLE (Hill)	49.0
GLEAMS (Hill)	41.7
USLE (Flat)	26.1
GLEAMS (Flat)	24.5

The results derived from the measured flow and sediment monitoring are presented in Stage1 and 2 report of this project (Hughes and Moghaddam (2026)). Hillslope derived sediment loads from land undergoing earthworks were measured as they entered sediment retention ponds (SRPs). Only two sites (SRP53000 and SRP57350) had adequate data to determine loads (Table B-1). Both of these sites were located within the 'Hill' terrain type. SRP53000 was located in the Mahurangi catchment, while SRP57350 was located in the Puhoi catchment. Although, these SRPs are in different catchments, they are neighbouring and therefore the broad characteristics of the two catchments (e.g., rainfall, geology type, soil type and land use) are unlikely to be significantly different. Certainly, the AEE and CWA reports (FNA 2013b; FNA 2013a) do not highlight any fundamental physiographic differences between the catchments.

The different SSYs for from the GLEAMS and USLE modelling and the measured data are summarised in Table 2-2. The measured SSY from the SRP57350 site (51.2 t/ha/y) is very similar to the modelled SSYs (49.0 and 41.7 t/ha/y). The SSY determined from the SRP53000 site (3.8 t/ha/y) is one order of magnitude less than the GLEAMS, USLE and SRP57350 estimates.

Table 2-2: Average specific sediment yields (SSY) for the 'Hill' terrain type, derived from modelling (USLE and GLEAMS) and measured data.

Source	Average SSY (t/ha/y)
USLE (Hill) - modelled	49.0
GLEAMS (Hill) -modelled	41.7
SRP57350 (Hill) - measured	51.2
SRP53000 (Hill) - measured	3.8

As stated in the Stage 1 and 2 report, data used to calculate the loads for the SRP53000 site appeared to be more reliable than that for the SRP57350 site. This is based on the fact that there was a strong relationship between event peak size and event load for all the measured events, and the fact that flow measurements appeared to be more reliable. Importantly though, the Stage 1 and 2 report also highlighted that because of limited TSS sampling of event peaks, all measured loads are highly likely to be underestimates.

The fact that the predicted average SSY at SRP53000 was markedly lower than that of SRP57350 was mentioned in the Stage 1 and 2 report (Hughes & Moghaddam 2026). It was also noted that the average TSS concentration measured at the inlet to the SRP53000 was markedly lower than that measured at all the other four SRP/DEB inlet sites (739 mg/l vs between 1269 and 3045 mg/l). The lower average TSS concentration measured at SRP53000 largely explains the lower SSY estimates at this site. The reason(s) for the lower measured TSS concentrations at SRP53000 are unknown.

3 The use of GLEAMS for predicting yields from land undergoing earthworks

GLEAMS was developed by researchers at the USDA Agricultural Research Service (Knisel & Douglas-Mankin 2012). The USDA website[1] includes the following brief description of the model:

> *"Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) is a continuous simulation, field scale model, which was developed as an extension of the Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) model. GLEAMS assumes that a field has homogeneous land use, soils, and precipitation. It consists of four major components: hydrology , erosion/sediment yield, pesticide transport, and nutrients. GLEAMS was developed to evaluate the impact of management practices on potential pesticide and nutrient leaching within, through, and below the root zone. It also estimates surface runoff and sediment losses from the field. GLEAMS was not developed as an absolute predictor of pollutant loading. It is a tool for comparative analysis of complex pesticide chemistry, soil properties, and climate. GLEAMS can be used to assess the effect of farm level management decisions on water quality."*

Because of its ability to represent daily rainfall/runoff, GLEAMS has been described as a "process-based model". Although it would be better described as an empirical erosion model with a process-based daily rainfall (hydrology) component[2]. This is because the erosion component of GLEAMS is driven by the empirical Universal Soil Loss Equation (USLE). The USLE was developed in the USA during the mid-20th century to estimate long-term average annual soil loss from rainfall-driven sheet and inter-rill erosion on agricultural land (Alewell et al. 2019). Its development drew on decades of plot-scale experiments at a time when soil erosion was increasingly recognised as a major land use issue. USLE expresses erosion as the combined effect of rainfall erosivity, soil erodibility, slope length and steepness, land cover, and management practices. Its simplicity, flexibility, and modest data requirements led to extensive global uptake for farm planning, conservation policy, and erosion-risk screening (Alewell et al. 2019).

The conditions that occur on land undergoing earthworks are very different from agricultural land. Earthworks sites expose sub-surface soils, slopes are subject to ongoing modification, and heavy machinery compacts the surface. Furthermore, rilling, gullying and the concentration of flow (which are not represented in GLEAMS (or USLE) are common at earthworks sites. This means that GLEAMS is pushed outside of the conditions it was designed for when applied to earthworks sites.

GLEAMS has been used to predict earthworks related sediment loads and SSYs for a number of previous projects in New Zealand. These include the catchment-scale Central Waitemata Harbour Contaminant Study (Parshotam & Wadhwa 2008) and a study of the Okura Estuary (Yalden & Moores 2014).

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[1] www.ars.usda.gov/plains-area/temple-tx/grassland-soil-and-water-research-laboratory/docs/gleams

[2] Empirical models rely on statistical relationships derived from past measurements, describing patterns without representing the true processes that generate them. In contrast, process-based models use explicit physical laws and mechanistic equations to represent how a system actually behaves.

No cases were found of GLEAMS being used to determine the impact of earthworks on sediment yields outside of New Zealand. However, there are many examples from both New Zealand and overseas where USLE-based models have been used to assess the impact of earthworks on sediment yields (e.g., Balousek et al. 2000; EML 2002; Yoon et al. 2009; FNA 2013a).

Clearly it is possible to apply GLEAMS (and USLE) to earthworks conditions, and indeed, the results provide useful information around the magnitude of the sediment yield from land undergoing earthworks. However, the results should not be considered as precise estimates of hillslope erosion. Calibration of the model outputs (which has not been done to date) to erosion rates measured from land undergoing earthworks would help provide greater confidence in modelled outputs. This has been done in other some studies (e.g., Pudasaini et al. 2004). Although obtaining data for any calibration would be difficult, due to the global lack of reported hillslope erosion rates from land undergoing earthworks.

4 Sediment yields from land undergoing earthworks

4.1 Difference between hillslope scale and catchment scale

It is important to note the GLEAMS model (and USLE) was designed to be applied at the "hillslope" or "field" scale. Hence the GLEAMS-derived results are indicative of hillslope erosion (also known as sheetwash erosion) rates. There are very few studies that report hillslope erosion rates from New Zealand catchments. Sediment yields determined at the catchment scale (either by modelling or measurements) are more common. There is, however, a fundamental difference between sediment yields determined at the hillslope scale (i.e., small scale with no permanent channel) and those determined at the catchment scale (i.e., larger scale and water flows in a stream channel). This difference is related to the fact that only a small proportion of the sediment eroded from a hillslope will makes its way to the catchment outlet. This phenomenon has been explained and addressed by previous researchers and has been called "the sediment delivery problem" (e.g., Walling 1983; de Vente et al. 2007). In brief, high erosion rates on hillslopes do not always equate with high sediment delivery rates to the river network. Although a hillslope may be undergoing locally high rates of erosion, deposition and storage (temporary or permanent) may occur on the hillslope, particularly when gradients reduce further downslope, at the toe of hillslopes, in swales, on floodplains or within the river channel itself (Walling 1983). The impact of this is that *hillslope erosion sediment yields* will typically exceed *catchment sediment yields*.

A selection of studies that report sediment yields (both hillslope-derived and catchment-derived) from some Auckland and Waikato locations are presented in Table 4-1.

Table 4-1: Sediment yield data reported in a selection of relevant New Zealand studies. The studies in bold indicate earthworks/disturbed land sediment yields.

Catchment	Area	Location	Data source	Land cover	Hillslope erosion sediment yield (t/ha/y)	Catchment sediment yield (t/ha/y)	Reference
Measured data							
Bombay Hill	**40.5 m^2 (plots)**	**Auckland**	**Plot scale measurements**	**Bare cropping land**	**56.8**	**-**	**Basher et al. (1997)**
Whangapouri	1.8 km^2	Auckland	Catchment monitoring	Rolling cropping	-	0.49	Basher et al. (1997)
Alexandra Basin	**2.2 km^2**	**Auckland**	**Catchment monitoring**	**Urbanising (28% earthworks)**	**-**	**9.6 - 23.7**	**Hicks (1990); Hicks (1994)**
Alexandra Basin	**<2.2 km^2**	**Auckland**	**Catchment monitoring**	**Earthworks**	**-**	**66**	**Hicks (1994)**
Manukau	0.3 km^2	Auckland	Catchment monitoring	Rolling pasture	-	0.5	Hicks (1994)
Mangaotama	2.7 km^2	Waikato	Catchment monitoring	Steep hill-country pasture	-	6	Hughes and Dang (2026)
Whakakai	3.1 km^2	Waikato	Catchment monitoring	Steep hill-country native forest	-	2.3	Hughes and Dang (2026)
Modelled data							
North Island hill-country 'typology'	N/A	Northland-Waikato-BOP	NZEEM model	Pasture - dry stock grazing	-	10	Monaghan et al. (2021)
Waitemata Harbour catchment	Not stated	Auckland	GLEAMS model	Mixed (non-urban only)	0.5 - 1	-	Parshotam and Wadhwa (2008)
Waitemata Harbour catchment	Not stated	**Auckland**	**GLEAMS model**	**Earthworks**	**12 - 64**	**-**	**Parshotam and Wadhwa (2008)**
New Zealand	**N/A**	**National**	**RUSLE**	**Winter forage crops**	**11**	**-**	**(Donovan 2022)**

4.2 Previous measured sediment yields

The only study from the Auckland region that reports actual *hillslope erosion sediment yields* is Basher et al. (1997). This study used data from monitoring 40 m^2 (13.1 m long, 3.1m wide) plots of bare soil, within the cropped Whangapouri catchment near Pukekohe and determined average sediment yields of 56.8 t/ha/y. This study is the only known New Zealand study to have measured erosion rates from bare soil. Although the bare soil conditions of the Basher et al. (1997) study are similar to sites undergoing earthworks, there are two key differences. Firstly, Basher et al. (1997) measured erosion from the upper soil layers, while earthworks sites expose sub-surface layers and are worked over by heavy machinery. Secondly, the plots used by Basher et al. (1997) had very short hillslope lengths (13.1 m long plots). The hillslope lengths on earthworks sites will typically be much longer. Hillslope length is an important driver of hillslope erosion rates and is specifically accounted for in USLE-based approaches.

Hicks (1990) measured *catchment sediment yields* of between 9.6 and 23.7 t/ha/y within the actively urbanising (28% bare earth) Alexandra basin (North Shore of Auckland). Based on these measurements, Hicks (1994) *estimated* that the sediment yield from the sub-catchments of the urbanising Alexandra basin undergoing earthworks would be approximately 66 t/ha/y.

To provide some context for "disturbed land" sediment yields above, the *catchment sediment yields* expected from a grazed steep hill-country pasture catchment are at least an order of magnitude lower. Hughes and Dang (2026) reporting from the Whatawhata Research Station estimated average (for an 8-year period) *catchment sediment yields* of 6.0 t/ha/y and 2.3 t/ha/y, from a steep pasture catchment and a steep native forest catchment, respectively. Hicks (1994) measured a *catchment sediment yield* of 0.5 t/ha/y from the rolling pasture catchment in the southern Auckland Region.

Finding reliable reported measured rates from international studies is challenging as there are almost no reports of yields from land undergoing earthworks in the published international literature. *Hillslope erosion sediment yields* appear to have been reported mainly in the grey literature, however, confirming these yields is difficult due to the unavailability of these reports to interrogate. Two Australian studies report rates similar to those from New Zealand. Loch (2000) reported *hillslope erosion sediment yields* of 30-35 t/ha/y from bare soil plots (18m^2 plots using rainfall simulator) at a rehabilitated mine site in Queensland. Pudasaini et al. (2004) used plot scale data to calibrate the RUSLE model from site in New South Wales and suggested that that *hillslope erosion sediment yields* from construction sites are in the range of 45-450 t/ha/year.

4.3 Previous modelled sediment yields

Monaghan et al. (2021) using data derived from the NZEEM model (described by Dymond et al. (2010)) determined that an indicative *catchment sediment yield* for hill country within the northern part of the North Island would be ~10 t/ha/y. This is similar to the hill-country *catchment sediment yield* calculated by Hughes and Dang (2026).

Parshotam and Wadhwa (2008) modelled existing land use and earthworks-derived *hillslope erosion sediment yields* using GLEAMS within Waitemata Harbour catchment.

They estimated *hillslope erosion sediment yields* of between 0.5 and 1 t/ha/y for existing non-urban land uses (e.g., forest, scrub, pasture) and between 12 and 64 t/ha/y for the same land assuming 100% earthworks. They stated that the main controlling factors on range of yields for these earthworks predictions were soil type and hillslope angle.

National-scale modelling using the Revised Universal Soil Loss Equation (RUSLE) by (Donovan 2022) predicted *hillslope erosion sediment yields* of 11 t/ha/y from winter forage crops. This is in contrast to the 0.83 t/ha/y predicted for pastoral grassland. Winter forage crops are often grazed to pugged bare soil in wet winter conditions, so provide some further context of erosion rates from disturbed terrain with no vegetative cover.

4.4 Comparison of measured results with previous measured and modelled sediment yields

The Basher et al. (1997) study is the only known study that has reported measured *hillslope erosion sediment yields* from New Zealand. Basher et al. (1997) reported rate of 56.8 t/ha/y suggest that the GLEAMS (and USLE) predictions for the P2W motorway earthworks may be within the correct order of magnitude. The previous GLEAMS based predictions of *hillslope erosion sediment yield* (12-64 t/ha/y from Parshotam and Wadhwa (2008) from the Waitemata Harbour catchment are also of a similar scale, which provides some confidence that the P2W motorway GLEAMS predictions are not outside of what the model has predicted on comparable terrain in the past. The national-scale RUSLE modelling by Donovan (2022) predicted *hillslope erosion sediment yields* of 11/t/ha/y from very disturbed agricultural land.

The two studies from the Alexandra Basin (Hicks 1990; Hicks 1994) are of particular relevance as they report high *catchment sediment yields* from an Auckland catchment undergoing earthworks. However, because these two studies report *catchment sediment yields,* they are not directly comparable to the GLEAMS *hillslope erosion sediment yields*. As mentioned earlier, *hillslope erosion sediment yields* are usually higher than *catchment sediment yields*, hence the actual *hillslope erosion sediment yields* at this site will be higher than the yields presented in these publications.

As previously noted, *hillslope erosion sediment yields* from the two SRP sites are different by one order of magnitude (i.e., ~10-fold difference; SRP57350 average yield of 51.2 t/ha/y; SRP53000 average yield of 3.8 t/ha/y). Therefore, the SRP57350 site has a *hillslope erosion sediment yield* similar to the GLEAMS and USLE results, but the SRP53000 site's results are one order of magnitude lower. The measured *hillslope erosion sediment yield* for the SRP53000 site is, in fact, similar to the *catchment sediment yield* could be expected from a steep pasture catchment (compare to yields in Table 4-1).

This presents a conundrum, as the Stage 1 and 2 report concluded that the data used to calculate the *hillslope erosion sediment yields* at SRP53000 was superior to that of SRP57350, but comparison with previous measurements suggest that the estimates are too low. However, it was also noted in the Stage 1and 2 report that the average TSS concentrations recorded at the inlet to the SRP53000 site were markedly lower than the other four measured sites (and the reason for this was unknown). The fact that the average yield determined for SRP53000 is similar to the *catchment sediment yield* for pasture catchments strongly suggests that *hillslope erosion sediment yield* (determined in the Stage 1 and 2 report) is underestimated at this site.

This, together with the fact that the average inlet TSS concentrations were markedly lower at the SRP53000 than the other measured sites, suggests that the SRP53000 yield estimates are spurious. The reasons for this are unknown, however, there may have been some systematic issue with the way TSS samples were collected from SRP53000, or unreported fundamental physiographic difference at this site.

The impact of this is that we have a low of confidence in the measured *hillslope erosion sediment yields*. This means that it is not possible to use the measured data to make a definitive statement about the accuracy of the GLEAMS (and USLE) predictions. However, the GLEAMS predictions are not inconsistent with some other relevant measured and modelled *hillslope erosion sediment yields*. While there may limitations with the data obtained from these other studies, they do provided confidence that GLEAMS has not over-predicted the *hillslope erosion sediment yields* from land undergoing earthworks.

5 Assessment of suitability of the GLEAMS model

Despite the limitations of GLEAMS (outlined in Section 3), the modelled predictions for the P2W motorway project are reasonable when compared to other reported measured and modelled yields. Certainly, GLEAMS does not appear to be overpredicting *hillslope erosion sediment yields*. It is not possible to make a definitively statement about whether it underpredicts yields. It is worth noting though that hillslope lengths experienced at earthworks sites will be typically much longer that those from plot scale studies such as Basher et al. (1997) (which predicted a similar yield to GLEAMS). Longer hillslope lengths result in higher erosion rates as they allow runoff to accumulate, gain energy, and transport more sediment downslope. Furthermore, it could be argued that land that has been reshaped and had sub-surface layers exposed by heavy machinery would be more suspectable to erosion than bare cropping land in the Basher et al. (1997) study. The high *catchment sediment yields* presented by (Hicks 1994) and (Hicks 1990) also suggest that *hillslope erosion sediment yields* may be higher than the 66 t/ha/y predicted *catchment sediment yield*.

As is the case with all modelling, more accurate predictions from GLEAMS could be achieved if the modelled outputs were calibrated to good quality measured data. This has not been done in the past, because there are no reliable measurements of *hillslope erosion sediment yields* from land undergoing earthwork from New Zealand. Unfortunately, the data presented in the Stage 1 and 2 report do not appear to be reliable enough to be considered as a basis for future GLEAMS model calibration. There may, however, be some benefit from re-examining measured data from specific events where the sampling was considered reasonable and re-running GLEAMS (using the measured rainfall) on those specific days. There may also be other sources of useful data (including compliance monitoring from other sites) that may be worth investigating.

Furthermore, other suitable models exist that may be better suited for predicting erosion from land undergoing earthworks. One possible such model is the process-based Water Erosion Prediction Project (WEPP) (Renschler & Harbor 2002). There may be some benefit of carrying out a review of the currently available models to assess whether they would be more suited to predicting sediment yields from future earthwork projects. Even if another model was demonstrated to be more suitable, the current issue of the lack of reliable measured data for model calibration remains.

6 Summary

This Stage 3 assessment compared GLEAMS-predicted sediment yields for the Pūhoi to Warkworth (P2W) project with sediment loads estimated from flow and concentration measurements at sediment retention pond (SRP) inlets during construction. Modelled specific sediment yields (SSY) from GLEAMS and USLE were very similar for both Hill and Flat terrain types, despite the two models using different rainfall erosivity inputs. For Hill terrain, GLEAMS predicted 41.7 t/ha/y and USLE predicted 49.0 t/ha/y.

Measured SSYs were available for only two SRP sites. One site (SRP57350) produced a measured SSY (51.2 t/ha/y) that closely matched the modelled values. The other site (SRP53000) produced a much lower SSY (3.8 t/ha/y), largely due to substantially lower measured TSS concentrations. However, all measured loads are likely underestimates because of limited sampling of event peaks during the data collection phase.

GLEAMS was developed for agricultural land and uses an empirical USLE-based erosion component. It does not represent rilling, gullying, or concentrated flow processes typical of earthworks, and it was not designed to provide absolute sediment load predictions. While GLEAMS has been used in several New Zealand earthworks assessments, its outputs should be interpreted as indicative rather than precise estimates of hillslope erosion. Calibration to earthworks-specific erosion data has not been undertaken and would be difficult due to the scarcity of measured hillslope erosion rates from land undergoing earthworks.

Comparison with other New Zealand studies shows that hillslope erosion rates from disturbed land can be high, but catchment-scale sediment yields are typically much lower due to deposition and storage along flow paths. The GLEAMS-derived SSYs for P2W fall within the broad range of values reported for disturbed land in the region.

Overall, the comparison between modelled and measured sediment yields is constrained by substantial uncertainty in the monitoring dataset and by the structural limitations of GLEAMS. The available evidence does not indicate that GLEAMS systematically over- or under-predicts hillslope sediment yields, but the model should not be relied upon for precise quantitative estimates without calibration and a clearer understanding of site-specific erosion processes.

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Appendix A revious USLE and GLEAMS modelling results

Table A-1: USLE and GLEAMS predicted sediment loads and specific sediment yields (SSY) for the 'Hill' zone (5 year scenario). Data derived from FNA (2013a). Numbers in bold are the average predicted SSYs from USLE and GLEAMS.

Year	Contributing exposed earthworks area (ha)	USLE load (t)	GLEAMS load (t)	USLE SSY (t/ha/y)	GLEAMS SSY (t/ha/y)
2016	16.8	670	563	39.8	33.4
2017	26.0	1171	853	45.0	32.8
2018	44.5	1494	1413	33.5	31.7
2019	44.2	1931	1953	43.7	44.2
2020	22.6	2067	1598	91.5	70.7
Total	154.2	7333	6380		
Average	30.8	1467	1276	**47.6**	**41.4**

Table A-2: USLE and GLEAMS predicted sediment loads and specific sediment yields (SSY) for the 'Flat' zone (5 year scenario). Data derived from FNA (2013a). Numbers in bold are the average predicted SSYs from USLE and GLEAMS.

Year	Contributing exposed earthworks area (ha)	USLE load (t)	GLEAMS load (t)	USLE SSY (t/ha/y)	GLEAMS SSY (t/ha/y)
2016	23.0	380	472	16.6	20.6
2017	31.8	483	532	15.2	16.7
2018	22.2	558	533	25.1	24.0
2019	16.1	586	560	36.5	34.8
2020	n/a	n/a	n/a	n/a	
Total	93.1	2007	2097		
Average	23.3	502	524	**23.3**	**24.0**

Table A-3: USLE and GLEAMS predicted sediment loads and specific sediment yields (SSY) for the 'Hill' zone (10 year scenario). Data derived from FNA (2013a). Numbers in bold are the average predicted SSYs from USLE and GLEAMS.

Year	Contributing exposed earthworks area (ha)	USLE load (t)	GLEAMS load (t)	USLE SSY (t/ha/y)	GLEAMS SSY (t/ha/y)
2016	16.8	648	535	38.5	31.8
2017	16.8	980	642	58.2	38.1
2018	26.0	997	720	38.3	27.6
2019	31.8	979	773	30.8	24.3
2020	31.8	1139	1320	35.8	41.5
2021	44.2	1330	1329	30.1	30.1
2022	12.8	1950	1384	152.9	108.5
2023	12.8	1730	1412	135.7	110.7
Total	193.0	9753	8115	-	-
Average	24.1	1219	1014	**50.5**	**42.1**

Table A-4: USLE and GLEAMS predicted sediment loads and specific sediment yields (SSY) for the 'Flat' zone (10 year scenario). Data derived from FNA (2013a). Numbers in bold are the average predicted SSYs from USLE and GLEAMS.

Year	Contributing exposed earthworks area (ha)	USLE load (t)	GLEAMS load (t)	USLE SSY (t/ha/y)	GLEAMS SSY (t/ha/y)
2016	23.0	348	442	15.2	19.3
2017	23.0	470	431	20.5	18.8
2018	31.8	399	431	12.5	13.5
2019	13.1	630	450	48.2	34.4
2020	22.2	482	456	21.7	20.5
2021	16.1	677	479	42.1	29.8
2022	16.1	512	456	31.9	28.4
2023	n/a	662	483	-	-
Total	145.2	4180	3628	-	-
Average	20.7	523	454	**28.8**	**25.0**

Appendix B Sediment yields determined from measured data

Table B-1: Sediment yields determined from measured data at the inlet measurement sites for the SRP53000 and SRP57350. Both sites are from the "Hill' terrain type. SRP53000 was located in the Mahurangi catchment. SRP57350 was located in the Puhoi catchment. Note: Both t/ha and t/km^2 are indicated.

	SRP53000 (Mahurangi Hill)		SRP57350 (Puhoi Hill)	
Year	**TSS yield (t/ha)**	**TSS yield (t/km^2)**	**TSS yield (t/ha)**	**TSS yield (t/km^2)**
2018	4.7	468	59.3	5933
2019	1.7	171	54.5	5445
2020	5.1	510	39.7	3971
Average	3.8	383	51.2	5116