Continuous Simulation of Land Development Scenarios

Sediment Attributes and Urban Development

Final

Prepared for Ministry for the Environment by Morphum Environmental Ltd
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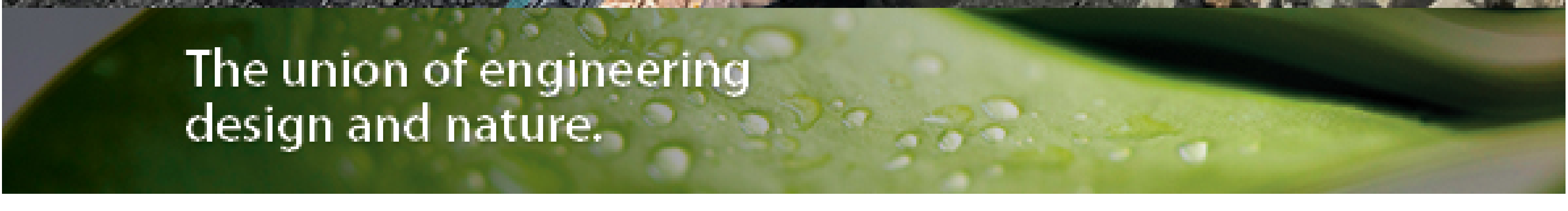

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Executive Summary

Morphum Environmental Ltd was engaged by the Ministry for the Environment to undertake a literature review on the primary sources of variability in sediment generation in an urban environment, and the impact of urban development on sediment discharges in the short and long term. The work is to form part of the Ministry for the Environment investigation on sediment attributes for consideration of inclusion with the National Policy Statement – Freshwater Management.

This report follows three previous reports:

- A literature review of the sources and variability of sediment in urban catchments, referred to as the Task 1 Report. This report discussed sediment discharges over short and long-term development scenarios, as well as the natural sources of variability for sediment discharge and variability attributed to development practice.
- The literature review was followed by a review of existing urban development plans from around New Zealand, including residential, commercial and industrial developments and New Zealand Transport Agency (NZTA) projects, referred to as the Task 2 report.
- Task 3 report investigated sediment from urban development from data available from the case study development sites as well as other potential data sources. Whilst there was some good data from development sites, this often did not include baseline or post development monitoring.

The data gaps in the Task 3 Report prompted the need for this fourth report, which looks at modelling various development scenarios.

The LSPC model was used for the continuous simulation of sediment generation for three land use types with five development area scenarios (staging), each with and without sediment control (Represented as blanket 70% reduction). A 15 year rainfall dataset (using 15 minute intervals) was applied to the earthworks scenarios. This modelling process reflects model configuration and not calibration as no observed data from disturbed earth land uses were available to support model calibration. Therefore, the results primarily provide a relative variation of sediment yield across years and earthworks practices.

The variation in year-to-year sediment yields was far greater than the variation in rainfall. The wettest year (2011, 870 mm rainfall) was not the year with highest simulated sediment yields; instead it was the year with the greatest number of days with >25 mm rainfall. The year with lowest simulated sediment yield during the construction season was 2005 which had the 11th lowest ranked annual rainfall yet the 3rd lowest number of days with >25 mm rainfall.

Staging is an important intervention to consider for erosion mitigation as a means to avoid instead of mitigating effects. The simulation outputs show that staging is potentially more effective than structural control measures. Sites without staging will also likely carry increased risk of larger sediment yields if climate conditions are unfavourable with a greater number of larger events that generate greater erosion.

The simulation shows the sensitivity of TSS concentrations to slope, as the energy to mobilize sediment is higher on the 18% slope, leading to average concentrations approximately four-fold higher when compared to 10% slope. Unlike yield, the TSS concentrations are relatively insensitive to staging, because the bare earth contribution dominates both the volume balance (relative runoff) and load balance (relative TSS concentration).

Cost analysis estimated an increase in bulk earthworks costs due to best practice erosion control through staging in the order of 45% on earthworks costs per hectare. Costs of sediment controls have the potential to add much smaller costs estimated in the order of 2-3% on earthworks cost per hectare. These cost changes are small in the greater scheme, estimated to comprise in the order of 1% of the costs of producing a section ready for sale.

Both erosion control, through staging and progressive stabilisation, and sediment controls are effective in reducing loads. However, it is noted that the benefit/cost of sediment treatment alone may be overstated by the analysis as it is based on a blanket load reduction factor, whereas sediment retention pond performance may be sensitive to rainfall event size and antecedent conditions. Furthermore, the more complex staged earthworks aligns with a low impact design approach which has the potential to realise additional benefits for the four well beings.

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1.0 Scope and Background

The Ministry for the Environment (hereafter, the Ministry) is currently considering a sediment attribute for inclusion within the National Policy Statement: Freshwater Management. As part of their process, assessment of the impacts of the proposed sediment attribute is being undertaken, particularly for urban and urban development areas.

Morphum previously completed a literature review of the sources and variability of sediment in urban catchments, referred to as the Task 1 Report. Sediment discharges over short- and long-term development scenarios, as well as the natural sources of variability for sediment discharge and variability attributed to development practice were discussed.

The literature review was followed by a review of existing urban development plans from around New Zealand, including residential, commercial and industrial developments and New Zealand Transport Agency (NZTA) projects, referred to as the Task 2 Report. From the review of existing urban development plans, Morphum, with feedback from the Ministry, selected case studies for further assessment, Task 3 Report.

Task 3 Report considered available monitoring data from the selected case studies to determine the effect of urban development on in-stream indicators. Of primary interest was suspended fine sediment, measured as turbidity (NTU/FNU) and total suspended sediment (TSS). Where available, baseline monitoring data, prior to development, was compared with monitoring that was undertaken during construction and following construction. The report discussed the lack of data available to form sound conclusions. This prompted the development of this, Task 4 Report where various urban development scenarios are modelled and costs of these are considered. This report describes a water quality modelling analysis of key variables relating to slope, staging of construction and sediment controls to provide further analysis of potential variability of sediment load from land development.

This analysis was designed to evaluate the relative effect and costs of staging land disturbance during land development construction ('earthworks') on the generation of sediment compared to structural control measures. It also evaluated annual variability in sediment generation using continuous simulation.

Annualized empirical models such as the Universal Soil Loss Equation (USLE) are common for estimating sediment yields from disturbed land, yet they do not explicitly capture the annual variability of rainfall-generated sediment. This analysis used the United States Environmental protection Agency developed Loading Simulation Program – C + (LSPC) model (Tetra Tech, 2009) to analyse the relative year-to-year variability of sediment generation for a set of land disturbance scenarios. The land disturbance scenarios elucidate a key factor for sediment generation during land development in watersheds – the proportion of developed land that is exposed as bare earth by earthworks during the construction season. The modelling outputs here are intended to highlight the relative variation of sediment yields across years and earthworks practices, as absolute values for sediment yield from a site are highly dependent on the local site conditions including rainfall time series, soil type, and slope.

The staging of construction, rapid stabilisation post works, and sediment control, including sediment treatment ponds, is common across the New Zealand construction industry. An analysis of construction costs highlights potential cost implications relating to the varying earthworks practices.

2.0 Methods

2.1 Modelling Platform

LSPC is a process-based watershed modelling system developed by U.S. Environmental Protection Agency for simulating watershed hydrology, sediment erosion and transport, and water quality processes from both upland contributing areas and receiving streams (Shen et al., 2004). A watershed model is essentially a series of algorithms for representing the interaction between precipitation and land surfaces, resulting in surface and subsurface flow that carry pollutants to streams. The model then simulates flow accumulation in stream networks and the transport of pollutants, which may be deposited or scoured from the stream bed, or may be sorbed or transformed due to various chemical and biological processes. LSPC is capable of dynamically simulating flow, sediments, nutrients, metals, dissolved oxygen, temperature, and other pollutants for pervious and impervious lands and waterbodies of varying order. The algorithms of LSPC were developed from a subset of those in the Hydrologic Simulation Program FORTRAN (HSPF) (Bicknell et al., 1996). The hydrologic portion of HSPF/LSPC is based on the Stanford Watershed Model (Crawford & Linsley, 1966), which was one of the pioneering watershed models.

The LSPC model used for this continuous simulation of sediment generation was leveraged from a regional modelling effort by the Healthy Waters Department in Auckland Council. The regional modelling tool being developed by Auckland Council is called the Freshwater Management Tool (FWMT), and LSPC serves as the "current state" model with the FWMT. The FWMT is a region-wide hydrological and contaminant load model currently under development to support planning and policy decisions associated with the National Policy Statement for Freshwater Management (NPS-FM). According to Auckland Council staff, application of a process-based model for water quality planning represents a major advance in contaminant modelling capability for Auckland Council, which previously relied upon annualized unit-area yields that varied by land cover but were not varied or disaggregated from annual data by rainfall, nor varied by wider land attributes. The process-based simulation of contaminants within the FWMT will provide the ability to analyse a variety of conditions of varying duration and intensity, from average annual load to rainfall-based or flow-based event equivalents, throughout the stream network for primary contaminants.

Stage 1 of the FWMT is currently under development through early 2020, and the models are still in draft phase. For this analysis, the existing FWMT delivered efficiencies provided an advanced starting point for continuous simulation of sediment generation, including parameterization of hydrology and sediment wash-off from pasture-like land uses and a weather time series.

2.2 Model Configuration

The LSPC model configuration for land segments is represented through Hydrologic Response Units (HRUs), which are building blocks of land use, soil type, and slope of landscape. For each pervious HRU category, sediment from the land originates from two generalised sources/processes (shown in Figure 1):

1. Detachment/wash-off, or
2. Scour of the soil matrix

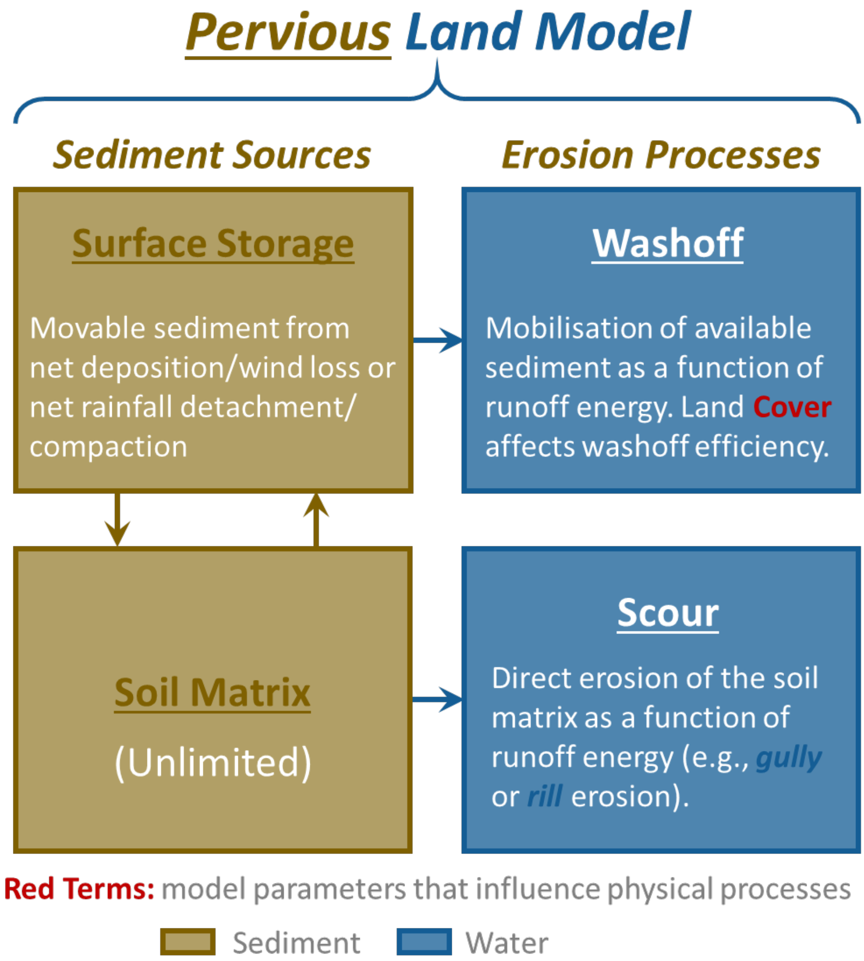


Figure 1: Pervious Land Simulation Processes in LSPC Model

The detachment algorithms use three parameters similar to the USLE parameters:

- The supporting management practice factor analogous to the "P" factor in the USLE;
- A coefficient in the soil detachment equation related to the erodibility or detachability of the specific soil type and surface conditions can be directly related to the K factor in the USLE; and
- A fraction of land surface which is shielded from rainfall can be estimated as one minus the C factor in the USLE.

Washed-off sediment from land is partitioned into sand, silt and clay fractions (by HRU) at the edge-of-stream, prior to routing. Each size class is also modelled in parallel with other size classes — sand always is conserved as sand, silt is conserved as silt, and clay is conserved as clay.

For this analysis, the LSPC model within the FWMT was adapted and configured to evaluate the response of three (3) land use types to rainfall:

1. Stable pasture land, which was used as building block because pasture is a typical land use prior to greenfield urban development.
2. Bare disturbed earth with 10% slope.
3. Bare disturbed earth with 18% slope.

The 10 and 18% slope bands were selected as a representation of typical development land slopes. They are also the slope thresholds for determination of increasing sediment treatment pond size. In the older Auckland Council TP90 document, developments with slope greater than 10% needed to use treatment ponds sized for 3% of the catchment area. The updated and current Auckland Council GD05 for land disturbing activity guidelines uses the 18% slope thresholds for determining pond size requirement changing from 2% to 3% of the catchment.

For all three land use types, the applied hydrologic soil group was Type C, which is the most common soil type in the Auckland area. The weather time series boundary condition was extracted from a rainfall gauge near Orewa (approximately 37 km north of central Auckland), including a 15-minute rainfall time series between 1 Jan 2002 and 31 Dec 2017.

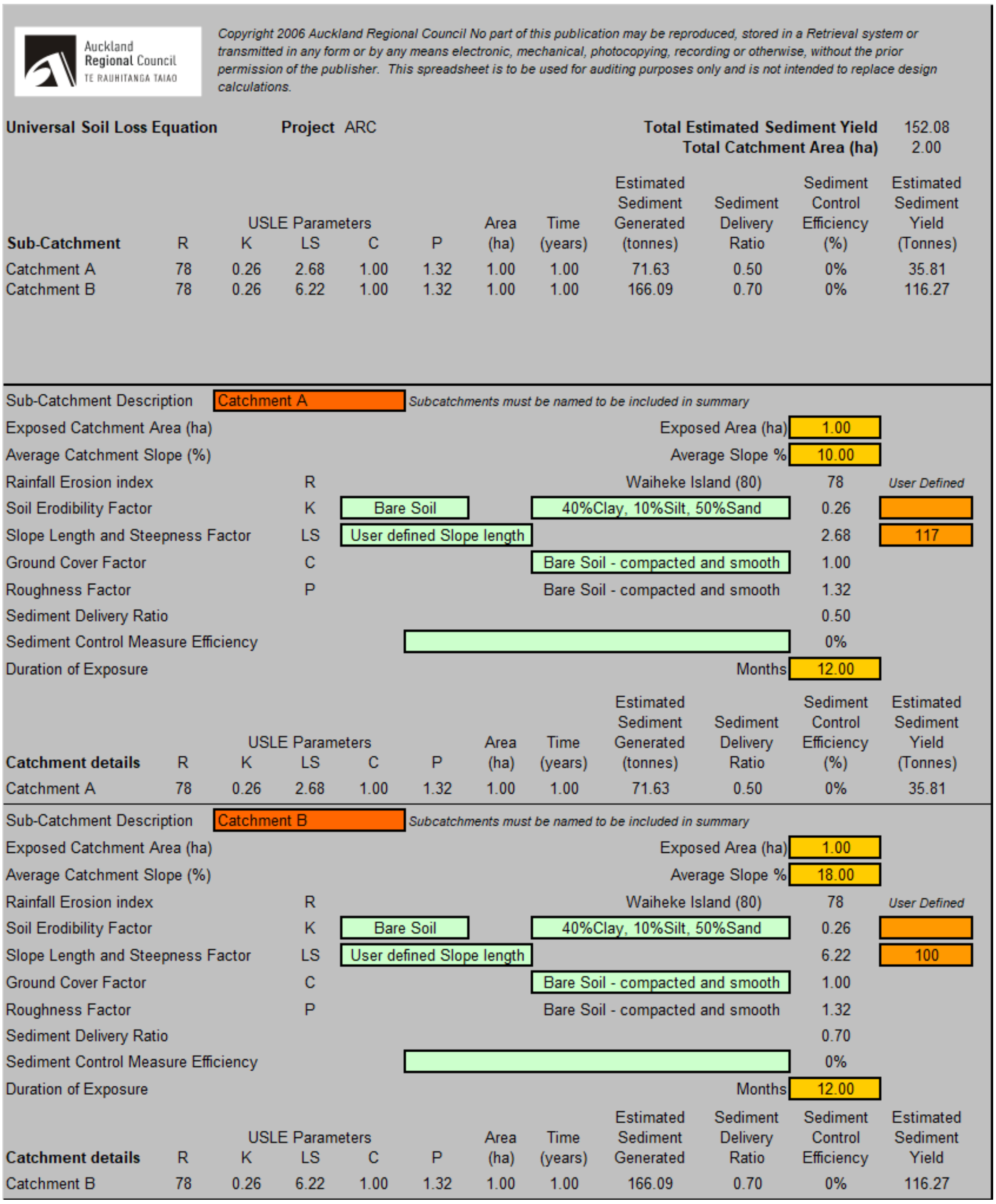
The bare, disturbed earth land uses were not an element of the existing FWMT. They were parameterized for this analysis. To parameterize the sediment generation of bare earth land use, LSPC detachment and wash-off parameters including gully/rill erosion were adjusted so the annualized sediment yields were similar to yields predicted by the USLE. It is important to note that process reflects model configuration and *not* calibration; no observed data from disturbed earth land uses were available to support model calibration. As such, as stated above, it is important to remember the application of LSPC in this case was to support understanding of *relative* variation of sediment yield across years and earthworks practices. The configured annualized yield from the disturbed bare earth land uses compared to the USLE are shown in Table 1. Shown in Figure 2 is a screenshot of a USLE tool provided by Auckland Council, to show the details of the assumptions for the USLE estimates.

Table 1: Comparison of LSPC- and USLE- Estimated Annual Average Sediment Yields (tonnes/ha/yr)

Land Type	LSPC Estimate[1]	USLE Estimate[2]
Bare disturbed earth with 10% slope	31.5	35.8
Bare disturbed earth with 18% slope	102.2	116.3

1 – Based on average annual sediment load per acre during the 2002 to 2017 simulation period using 15-minute rainfall from a gage in Orewa, NZ

2 – See Figure 1 for details of inputs


Auckland Regional Council TE RAUHITANGA TAIAO

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Universal Soil Loss Equation **Project** ARC

Total Estimated Sediment Yield 152.08
Total Catchment Area (ha) 2.00

Sub-Catchment	R	USLE Parameters K	LS	C	P	Area (ha)	Time (years)	Estimated Sediment Generated (tonnes)	Sediment Delivery Ratio	Sediment Control Efficiency (%)	Estimated Sediment Yield (Tonnes)
Catchment A	78	0.26	2.68	1.00	1.32	1.00	1.00	71.63	0.50	0%	35.81
Catchment B	78	0.26	6.22	1.00	1.32	1.00	1.00	166.09	0.70	0%	116.27

Sub-Catchment Description		Catchment A	*Subcatchments must be named to be included in summary*		
Exposed Catchment Area (ha)			Exposed Area (ha)	1.00	
Average Catchment Slope (%)			Average Slope %	10.00	
Rainfall Erosion index	R		Waiheke Island (80)	78	*User Defined*
Soil Erodibility Factor	K	Bare Soil	40%Clay, 10%Silt, 50%Sand	0.26	
Slope Length and Steepness Factor	LS	User defined Slope length		2.68	117
Ground Cover Factor	C		Bare Soil - compacted and smooth	1.00	
Roughness Factor	P		Bare Soil - compacted and smooth	1.32	
Sediment Delivery Ratio				0.50	
Sediment Control Measure Efficiency				0%	
Duration of Exposure			Months	12.00	

Catchment details	R	USLE Parameters K	LS	C	P	Area (ha)	Time (years)	Estimated Sediment Generated (tonnes)	Sediment Delivery Ratio	Sediment Control Efficiency (%)	Estimated Sediment Yield (Tonnes)
Catchment A	78	0.26	2.68	1.00	1.32	1.00	1.00	71.63	0.50	0%	35.81

Sub-Catchment Description		Catchment B	*Subcatchments must be named to be included in summary*		
Exposed Catchment Area (ha)			Exposed Area (ha)	1.00	
Average Catchment Slope (%)			Average Slope %	18.00	
Rainfall Erosion index	R		Waiheke Island (80)	78	*User Defined*
Soil Erodibility Factor	K	Bare Soil	40%Clay, 10%Silt, 50%Sand	0.26	
Slope Length and Steepness Factor	LS	User defined Slope length		6.22	100
Ground Cover Factor	C		Bare Soil - compacted and smooth	1.00	
Roughness Factor	P		Bare Soil - compacted and smooth	1.32	
Sediment Delivery Ratio				0.70	
Sediment Control Measure Efficiency				0%	
Duration of Exposure			Months	12.00	

Catchment details	R	USLE Parameters K	LS	C	P	Area (ha)	Time (years)	Estimated Sediment Generated	Sediment Delivery Ratio	Sediment Control Efficiency	Estimated Sediment Yield
Catchment B	78	0.26	6.22	1.00	1.32	1.00	1.00	166.09	0.70	0%	116.27

Figure 2: USLE Assumptions for Bare Earth with 10% and 18% Slope
(10% is labelled 'Catchment A', and 18% is labelled 'Catchment B'; Screenshot courtesy of Auckland Council USLE Tool)

2.3 Sediment Treatment Assumptions

Sediment management during the construction phase such as urban development and road construction projects is implemented through either erosion or sediment control practices.

Erosion control practices are aimed at preventing or reducing the potential for erosion to occur. There are three broad categories of erosion control:

- **Non-structural approaches:** Key principles and concepts to limit the potential for erosion to occur: minimise disturbance, stage construction, protect slopes, protect watercourses, stabilised exposed areas rapidly and consider the timing of works.

- **Water management controls:** To manage water onsite and below site with the overall aim of minimising sediment generation.
- **Soil and surface stabilisation practices:** Measures to protect exposed soil and prevent erosion by forming a physical barrier between the exposed surface and the agent of erosion.

Sediment controls, or sediment retention devices, focus on measures to trap any sediment before it moves offsite and into waterways. A wide variety of sediment controls exist including: silt fences, super silt fences, Decanting Earth Bunds (DEBS) and Sediment Retention Ponds (SRP). Recent innovation has introduced the concept of chemical treatment to aid coagulation and flocculation of sediments entrained in DEBs and SRPs.

The efficiency of each of these methods differs as does the scale of effectiveness and the cost of implementation. These factors generally influence the chosen methods to reach the required performance standards for the construction site.

2.3.1 Erosion control practices

These generally consist of various mulch, vegetation and other coverings of various thicknesses. International experience indicates high variability in success, depending on the application and combination of applications, ranging from 22% to 99% control.

In the New Zealand study (ARC, 2000 cited by Basher et al., 2016), bare subsoil plots had the highest load generation, double that of topsoil plots. In comparison, grassed plots generated 87% less than bare topsoil plots, with mulched topsoil plots achieving up to 94% less than bare topsoil plots.

The model representation of stabilisation practices was to consider both the pre-development and stabilised earthworks as represented by the stable pasture land type in the conceptual analysis of non-disturbed portion of the catchment.

A common erosion control practice is the observation of a construction season whereby earthworks are limited to the months of October to April, with sites stabilised for the period May-September inclusive. This project modelled sediment yields only for the earthworks season.

2.3.2 Sediment control practices

Performance of silt fences has been found to be more a function of the settling of sediments in ponded water upstream of a fence rather than through the filtering by the fence fabric. Never the less, the fences are reported to achieve varying degrees of sediment load reduction, depending on load composition. Removal of between 21 and 91% are indicated. In Auckland, with a relatively high percentage of fine clay soils, the accepted sediment removal of silt fences is typically 50%.

New Zealand studies of Decanting Earth Bund efficiency provided ranges from 23 to 79%, with the floating decant type performing best

International literature on sediment pond performance is reported (Basher et al.,2016) to vary widely, with reported sediment removal efficiencies ranging from virtually zero to 99%. This wide range reflects not only variations in site conditions, pond sizing and design but also the fact that many of these studies involved assessing various experimental modifications aimed at improving performance.

New Zealand studies reported by Basher et al. (2016) are of a SRP, designed to the TP90 2% design criteria on a site in Albany. Over the 11 storm events monitored, sediment removal efficiency was calculated at 90%. 376 tonnes of sediment were measured at the inflow and 39 tonnes at the outflow. Auckland models using USLE generally assign an 80% reduction to standard sediment ponds.

The sediment removal efficiency of DEBS and SRPs can be improved through chemical treatment. Chemical treatment is a broad term used to refer to the addition of chemicals (usually PAC) to promote flocculation and coagulation within the sediment control device to promote sediment deposition within the device. New Zealand trials on Sediment Retention Ponds provided in most cases efficiencies of between 94 and 98%. These are generally considered to achieve 95% in Sediment Retention Ponds in Auckland models.

Both the intensity and antecedent conditions of rainfall events have a critical impact on the performance of sediment management devices and strategies. In many cases, if devices are designed for five-year return events, they are logically more often at capacity than those designed with a higher event return period.

Whilst sediment devices can achieve up to 95% reduction in sediment, there is often wash off sediment laden water from development sites that is not able to be manged or does not flow through a treatment device. In addition, sites including management devices have been known to have periodic releases of sediment that due to events exceeding the device capacity or back to back events with the second washing through before the device has had time to decant. Many of the studies and monitoring has been undertaken at sites that are implementing best practice and above sediment control, often due to the particular site location or other factors. This is likely to lead to considerably better outcomes than the average standard across all urban development sites.

Based on this, and the variety of options and performance expectations, it was determined that a control level modelled at 70% would a reasonable representation of common urban development sites sediment management using available guidelines for the Auckland Region for comparison of treated versus non-treated yields.

3.0 Results

The configured LSPC model was used to estimate sediment yield for treated and untreated sites (assuming 70% treatment efficacy) at an hourly time step over the 15-minute simulation period for 10% and 18% slopes, for multiple scenarios of land development:

- 0% disturbed bare earth on the developed site (100% pasture)
- 25% disturbed bare earth on the developed site (75% pasture)
- 50% disturbed bare earth on the developed site (50% pasture)
- 75% disturbed bare earth on the developed site (25% pasture)
- 100% disturbed bare earth on the developed site

In addition, these same scenarios were generated with treatment, assuming in a 70% reduction in TSS concentration prior to discharge from the site. Yields shown below are derived from the concentration multiplied by the water volume. The time series were post-processed to analyse the sediment loading from the site during the 'construction season' within each year, from 1 October to 30 April. It is important to note the units for sediment yield in this section are by 'season', or 8-month periods within each year.

3.1 Annual Variation in Sediment Yields

A key advantage of process-based, continuous simulation modelling is the ability to characterize hydrology and contaminant transport across short-term (e.g., individual storm events) and long-term (e.g., years or decades) periods. Annualized empirical models do not explicitly capture year-to-year variability, which limits their ability to inform decisions around critical conditions that might drive sediment loading such as high-precipitation seasons.

As shown in Table 2, the rainfall across the construction season time period varied from 340 mm to 869 mm. From a sediment generation standpoint, however, the more important rainfall variation was likely the number of high-rainfall days, as shown in the right-hand columns of Table 1 using thresholds >10 mm daily rainfall and >25 mm daily rainfall. The number of days with>10 mm rainfall during the period ranged from 10 to 29, and the number of days with >25 mm rainfall during the period ranged from 1 to 10. The conceptual model for sediment generation implies that rainfall energy is a key driver of sediment loading, and thus wetter years dominated by light rainfall days would exhibit lower sediment yields than drier years dominated by heavy rainfall days.

Shown in Table 3 through Table 6 are the LSPC-simulated sediment yields for each construction season between 2003 and 2017. The variation in year-to-year sediment yields was far greater than the variation in rainfall. The coefficient of variation in rainfall was 0.27, while the coefficient of variation in sediment loading from 10% bare earth was 1.05 (nearly 4 times higher). Further, the wettest year (2011, 870 mm rainfall) was not the year with highest simulated sediment yields; instead it was 2017, the year with the greatest number of days with >25 mm rainfall. The year with lowest simulated sediment yield during the construction season was 2005 which had the 11th lowest ranked annual rainfall yet the 3rd lowest number of days with >25 mm rainfall. A detailed factor analysis on the simulated sediment yields with more rainfall bins might highlight the rainfall variables that are most strongly correlated to sediment yield, but such an analysis was not in the scope of this memo.

Table 2: Summary of Rainfall Statistics for Orewa, NZ (Construction Season, 2003-2017)

Year	Construction Season Rainfall (mm)	Number of Rain Days during Construction Season (October – April)			
		>= 1 mm	>= 5 mm	>= 10 mm	>= 25 mm
2003	756.1	70	43	29	5
2004	658.4	67	35	21	4
2005	476.2	59	31	14	3
2006	748.5	66	31	16	9
2007	612.2	62	32	14	4
2008	617.2	65	26	18	6
2009	512.3	69	24	10	5
2010	340.2	41	15	10	3
2011	869.9	72	42	27	8
2012	516.4	62	26	15	4
2013	362.2	48	19	10	3
2014	433.7	70	27	11	1
2015	402.7	57	30	13	2
2016	646.1	63	30	17	9
2017	816.9	62	33	22	10

Table 3: Seasonal Sediment Yield by Scenario for 10% Bare Earth Slope, No Treatment. The four highest total rainfall years are shown in red, illustrating the effect of rain intensity compared to annual rain.

Year	Construction Season Sediment Yield, October – April (tonnes/hectare)				
	100% Pasture 0% Bare Earth	75% Pasture 25% Bare Earth	50% Pasture 50% Bare Earth	25% Pasture 75% Bare Earth	0% Pasture 100% Bare Earth
2003	0.15	2.63	5.12	7.60	10.09
2004	0.82	8.54	16.25	23.97	31.69
2005	<0.01	0.56	1.11	1.66	2.22
2006	2.33	15.71	29.09	42.48	55.86
2007	0.34	6.58	12.82	19.06	25.30
2008	0.01	2.71	5.41	8.12	10.82
2009	0.22	5.55	10.88	16.22	21.55
2010	<0.01	0.75	1.49	2.24	2.98
2011	0.83	9.01	17.19	25.37	33.55
2012	0.03	1.87	3.72	5.57	7.42
2013	<0.01	0.44	0.89	1.33	1.78
2014	0.01	1.05	2.10	3.14	4.19
2015	<0.01	0.04	0.07	0.11	0.15
2016	0.25	4.34	8.42	12.51	16.59
2017	2.78	18.96	35.14	51.32	67.50

Table 4: Seasonal Sediment Yield by Scenario for 10% Bare Earth Slope, With 70% Pond Treatment. The four highest total rainfall years are shown in red, illustrating the effect of rain intensity compared to annual rain.

Year	Construction Season Sediment Yield, October – April (tonnes/hectare)				
	100% Pasture 0% Bare Earth	75% Pasture 25% Bare Earth	50% Pasture 50% Bare Earth	25% Pasture 75% Bare Earth	0% Pasture 100% Bare Earth
2003	0.15	0.87	1.59	2.31	3.03
2004	0.82	2.99	5.16	7.33	9.51
2005	<0.01	0.17	0.33	0.50	0.67
2006	2.33	5.94	9.54	13.15	16.76
2007	0.34	2.15	3.96	5.78	7.59
2008	0.01	0.82	1.63	2.44	3.25
2009	0.22	1.78	3.34	4.90	6.46
2010	<0.01	0.22	0.45	0.67	0.89
2011	0.83	3.14	5.45	7.76	10.06
2012	0.03	0.58	1.13	1.68	2.23
2013	<0.01	0.13	0.27	0.40	0.53
2014	0.01	0.32	0.63	0.94	1.26
2015	<0.01	0.01	0.02	0.03	0.04
2016	0.25	1.43	2.61	3.80	4.98
2017	2.78	7.15	11.52	15.88	20.25

Table 5: Seasonal Sediment Yield by Scenario For 18% Bare Earth Slope, No Treatment. The four highest total rainfall years are shown in red, illustrating the effect of rain intensity compared to annual rain.

Year	Construction Season Sediment Yield, October – April (tonnes/hectare)				
	100% Pasture 0% Bare Earth	75% Pasture 25% Bare Earth	50% Pasture 50% Bare Earth	25% Pasture 75% Bare Earth	0% Pasture 100% Bare Earth
2003	0.15	11.22	22.29	33.36	44.43
2004	0.82	20.91	41.01	61.10	81.20
2005	<0.01	2.36	4.72	7.08	9.44
2006	2.33	40.81	79.29	117.77	156.24
2007	0.34	17.80	35.26	52.72	70.18
2008	0.01	9.82	19.63	29.44	39.25
2009	0.22	17.72	35.23	52.74	70.24
2010	<0.01	6.01	12.03	18.04	24.05
2011	0.83	25.51	50.19	74.87	99.55
2012	0.03	6.53	13.04	19.55	26.06
2013	<0.01	4.22	8.44	12.66	16.88
2014	0.01	4.46	8.91	13.36	17.82
2015	<0.01	0.60	1.19	1.79	2.38
2016	0.25	15.65	31.04	46.44	61.83
2017	2.78	47.61	92.44	137.28	182.11

Table 6: Seasonal Sediment Yield by Scenario for 18% Bare Earth Slope, with 70% Pond Treatment. The four highest total rainfall years are shown in red, illustrating the effect of rain intensity compared to annual rain.

Year	Construction Season Sediment Yield, October – April (tonnes/hectare)				
	100% Pasture 0% Bare Earth	75% Pasture 25% Bare Earth	50% Pasture 50% Bare Earth	25% Pasture 75% Bare Earth	0% Pasture 100% Bare Earth
2003	0.15	3.44	6.74	10.03	13.33
2004	0.82	6.70	12.59	18.47	24.36
2005	<0.01	0.71	1.42	2.13	2.83
2006	2.33	13.46	24.60	35.74	46.87
2007	0.34	5.52	10.70	15.88	21.05
2008	0.01	2.95	5.89	8.83	11.77
2009	0.22	5.43	10.65	15.86	21.07
2010	<0.01	1.80	3.61	5.41	7.22
2011	0.83	8.09	15.35	22.61	29.86
2012	0.03	1.97	3.92	5.87	7.82
2013	<0.01	1.27	2.53	3.80	5.06
2014	0.01	1.34	2.68	4.01	5.34
2015	<0.01	0.18	0.36	0.54	0.72
2016	0.25	4.83	9.40	13.97	18.55
2017	2.78	15.74	28.71	41.67	54.63

3.2 Effect of Staging on Sediment Yields

The scenarios regarding the mix of pasture with disturbed bare earth can be related to 'staging' practices during land development, meaning the development site has earthworks undertaken in smaller units over time with progressive revegetation. By exposing only those areas that are needed for active earthworking at any one time, the duration of exposure and risk of erosion/sediment discharge could potentially be reduced. Staging is an important intervention to consider for erosion mitigation, as staging is non-structural and therefore potentially cost-effective when compared to structural interventions.

The results of the staging scenarios are presented in Figure 3 (10% slope) and Figure 4 (18% slope), which show the yields for individual seasons as well as the average and 5th, 25th, 75th, and 95th percentile values between 2002 and 2017. The outputs show that staging is potentially more effective than structural control measures. For example, the simulated average sediment yield when 25% of the site is exposed earth during the construction season was 5.25 tonnes per hectare on 10% slope, compared to 5.83 tonnes per hectare for 100% exposed earth that is treated to a 70% concentration reduction performance standard. Similarly, for the 18% slope scenario, the simulated average sediment yield when 25% of the site is exposed earth during the construction season was 15.42 tonnes per hectare, compared to 18.03 tonnes per hectare for 100% exposed earth that is treated to a 70% concentration reduction performance standard.

The variability in sediment load is largely due to the differences in precipitation events. Staging earthworks affects this risk profile by reducing the extent of the earthworks exposed to erosive events. However, it is not a guaranteed relationship due to the variability in the frequency and spread of erosive events. If a single stage is adopted, and the earthworks operation occurs during a season with increased number of larger rainfall events, then the sediment yield can be very high as shown by the 95th percentile single stage figures. However, if it occurs in a year with less erosive events yield can be quite low as shown by the single stage 5th percentile figures.

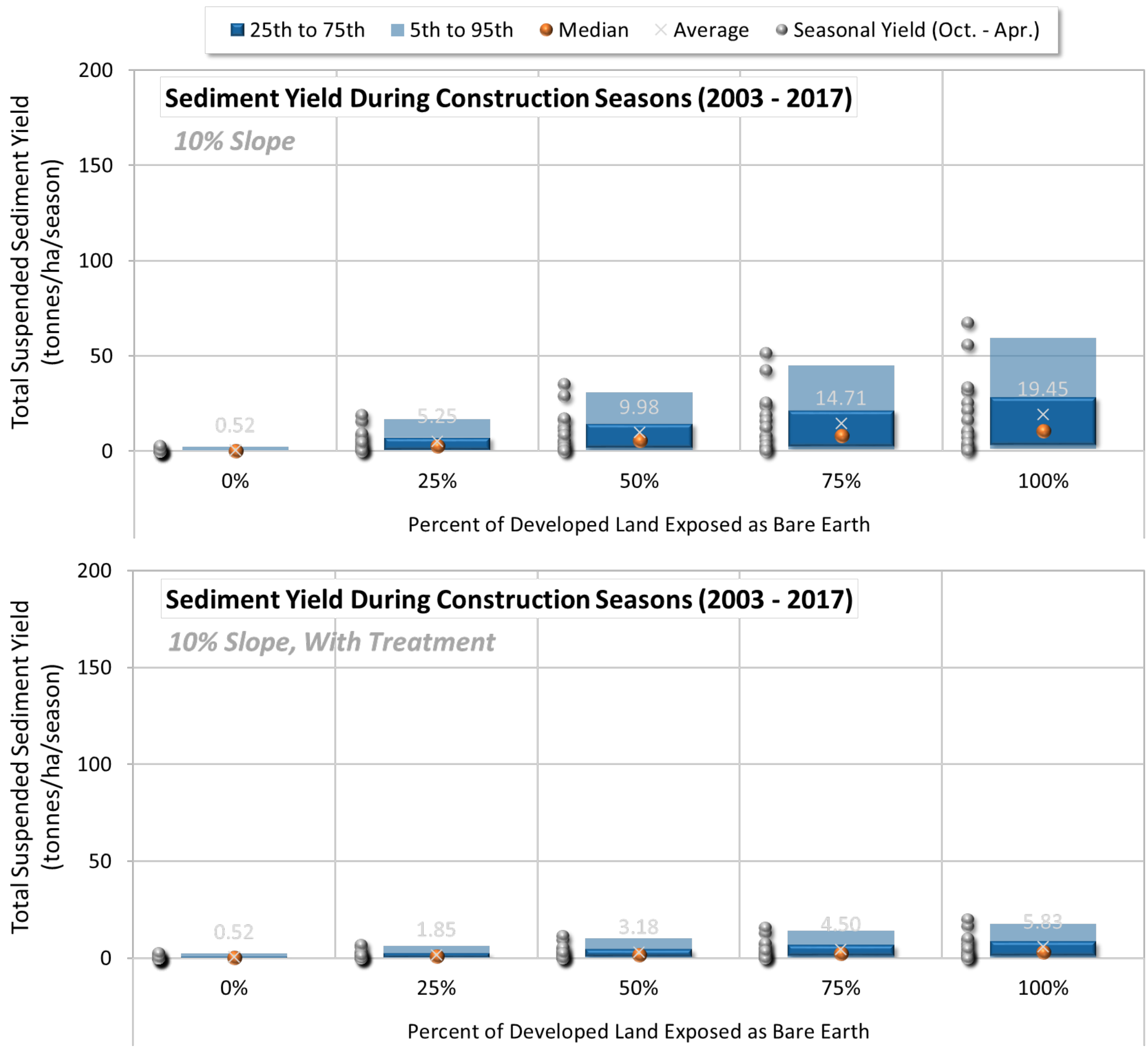

Figure 3: Simulated Effect of Staging on Sediment Yields for 10% Slope, with and without treatment.

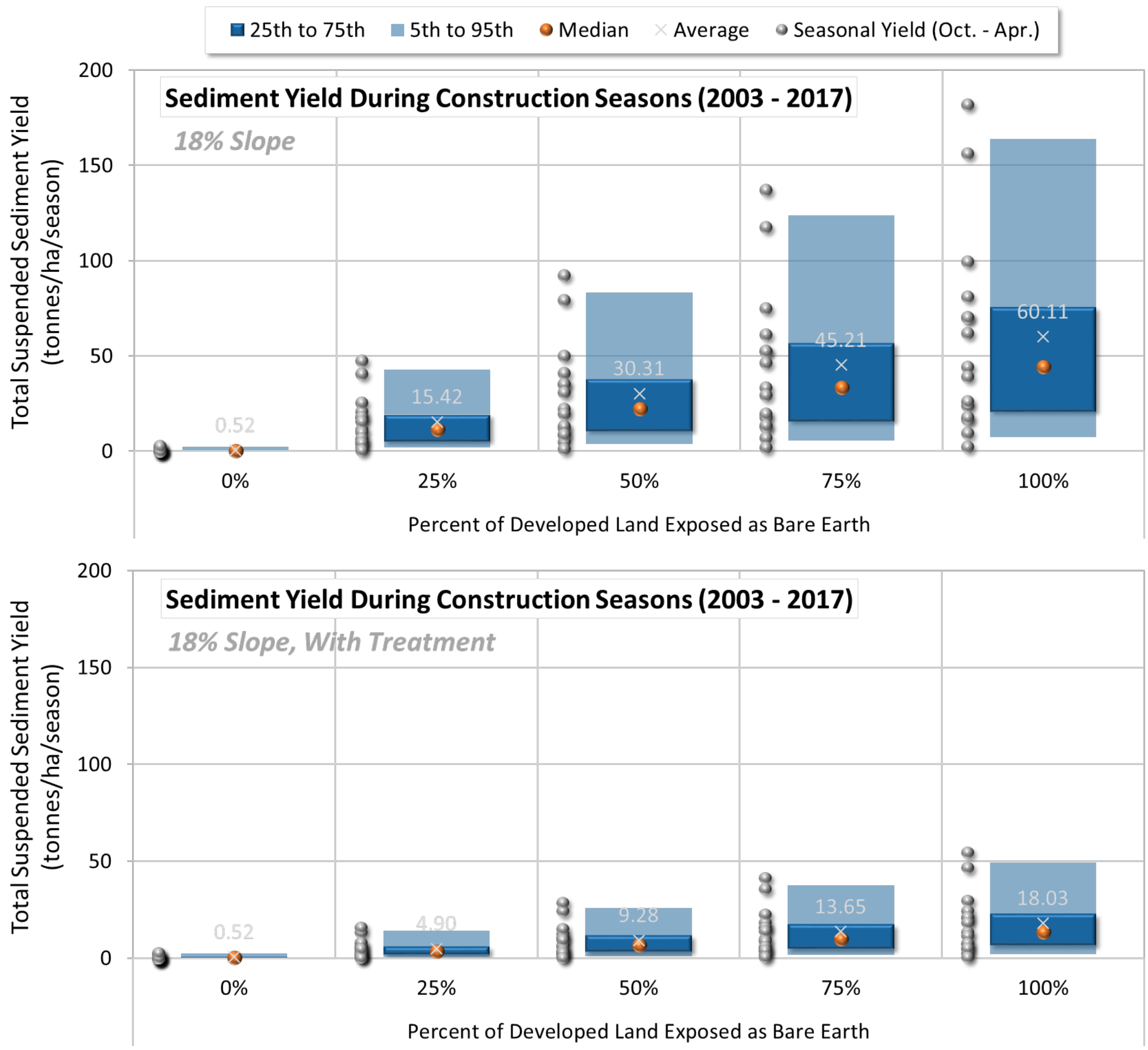

Figure 4: Simulated Effect of Staging on Sediment Yields for 18% Slope, with and without treatment.

The effect of staging on medians is summarised in Figure 5 where the linear relationship between percent earth exposure and median sediment yield is apparent. This is due to the hypothetical area modelled being uniform in shape and the change in runoff is not a factor. This also demonstrates the significant role slope plays and indicates that even with good sediment controls, the higher slope yield is greater than the lower slope.

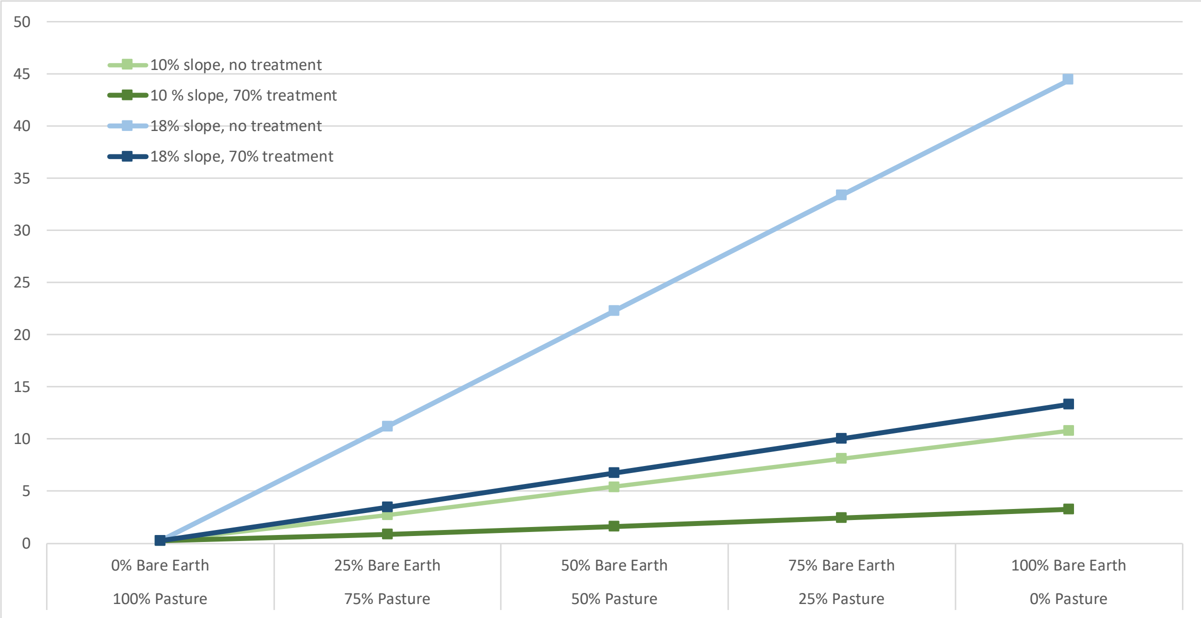

Figure 5: Median TSS Yield Values (Tonnes/ha/season) for All Scenarios

3.3 Effect of Staging and Slope on Sediment Concentrations

Shown in Figure 6 and Figure 7 are the corresponding scenario outputs for TSS concentration, respectively, for 10% and 18% slope. The daily TSS concentrations vary over 3 orders of magnitude during the simulation period, depending on the storm intensity and antecedent conditions. The outputs show the sensitivity of TSS concentrations to slope, as the energy to mobilize sediment is higher on the 18% slope, leading to average concentrations approximately four-fold higher when compared to 10% slope. Unlike yield, the TSS concentrations are relatively insensitive to staging, because the bare earth contribution dominates both the volume balance (relative runoff) and load balance (relative TSS concentration). For example, on average for the 10% slope scenario with 50% bare earth, the runoff volume contributed by bare earth is 81% of the total volume, while the average TSS concentration from bare earth is approximately 25 times higher (4128 mg/L for bare earth compared to 168 mg/L for pasture). These outputs illustrate the importance of structural/treatment sediment controls regardless of the staging approach used. Staging of earthworks has a major impact on sediment yields but less of an impact on flow-weighted sediment concentrations from the site.

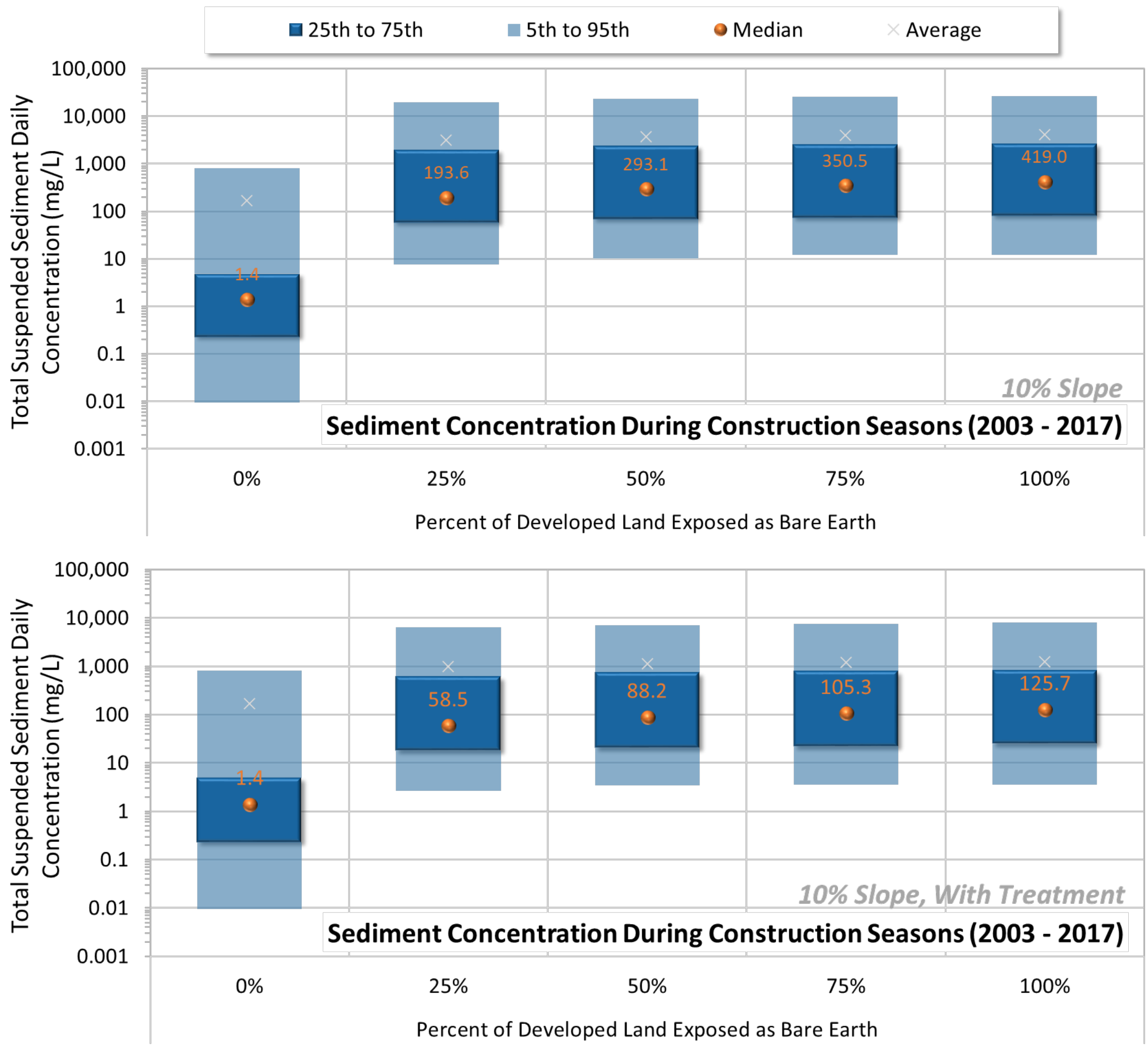

Figure 6: Simulated Effect of Staging on TSS Daily Concentrations for 10% Slope, with and without treatment.

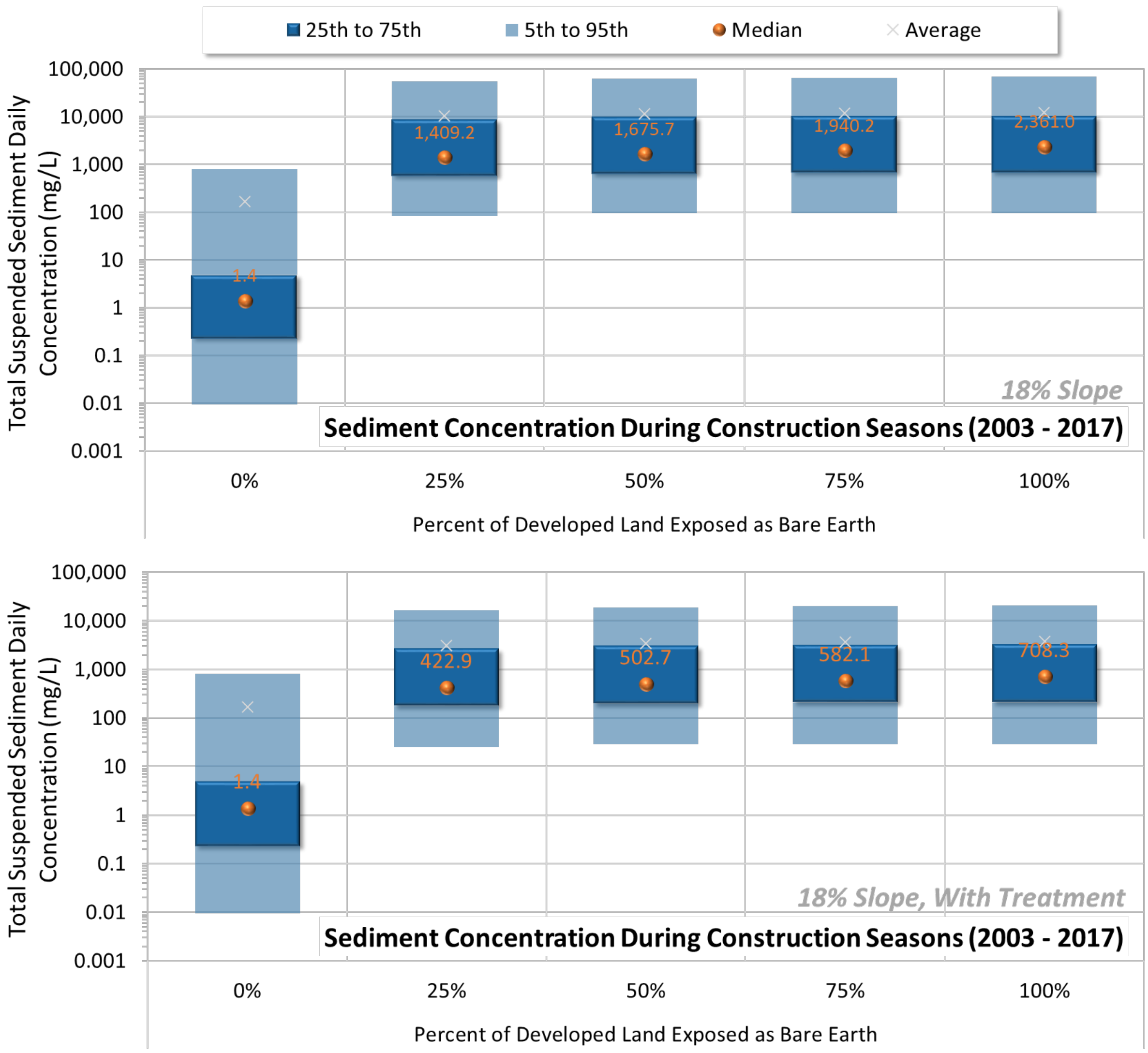

Figure 7: Simulated Effect of Staging on TSS Daily Concentrations for 18% Slope, with and without treatment.

3.4 Effect of Sediment Retention Ponds on Sediment Yield and Concentrations

As described in Section 2.3.2, The scope of the modelling included representation of sediment treatment measures equivalent to a blanket removal of 70% of suspended sediments. Therefore, the results simply represent this same performance by a direct shift in sediment concentration and yield at each timestep of the modelling.

It is important to note that actual Sediment Retention Pond (SRP) performance may be sensitive to several factors.

- Capacity - Typically these ponds are constructed based on volume and discharge relationships relative to catchment area. When a storm volume exceeds the design storm volume, and or antecedent conditions result in prior engagement of live storage, the retention time in the pond may be reduced.
- Particle Size – Sites with finer particles, having reduced settlement velocities, may remove less suspended sediment

Therefore, there is a risk that the findings relating to sediment pond effectiveness overstate the benefit of this infrastructure. Further modelling could be undertaken to model a typical SRP using process based representation to identify sensitivity of performance to capacity and particle size.

4.0 Costs and Benefits Associated with Earthworks Staging and Treatment for Development Sites.

The practices of erosion control including staging of construction and rapid stabilisation post works, and sediment control including sediment treatment ponds is common across the New Zealand construction industry. Both of these items have been shown by the modelling to have a high level of effectiveness in managing construction related sediment discharge. The Auckland Council Guidelines GD05 and its predecessor TP90 include requirements to adopt these measures on earthwork sites.

4.1 Cost Assessment.

Consideration of cost variability has been undertaken using a standard land development earthworks schedule as included in Appendix 2. The key variables that are expected to change between the varying scenarios are as follows:

1. **Per m^3 earthworks rates:** These relate to the physical costs of excavation, transport within a site including any stockpiling and fill and compaction processes. The per m^3 rate will likely increase with increased staging as the earthworks processes, staging and possible additional temporary stockpiling between stages could add complexity and reduced efficiencies. However experienced operators would be expected to adopt staging as best practice and be efficient despite this complexity. This is the largest portion of costs and therefore the most sensitive parameter. Costs used ranged from $8 for a single stage to $12 per m^3 of earthworks for 25% staging, based on Rawlinsons, recent project examples and communication with development contractors.
2. **Per m^3 topsoil stripping and reinstatement rates:** These would increase with staging similar to bulk earthworks rates. Costs used ranged from $6 for single stage to$9 per m^3 for 25% staging, for topsoil striped and re-laid, based on Rawlinsons, recent project examples and communication with development contractors.
3. **Time based overheads:** Running costs for the development including costs for management and maintenance of the site, implementation of Health and Safety, Environmental and Quality plans including testing, record keeping and maintenance of measures. These would increase when the earthworks processes take longer than would be expected with a back to back staging approach versus a simultaneous earthworks process. Earthworks durations were assumed to range from 25 weeks for a single stage to 40 weeks for 25% staging.
4. **Erosion and Sediment controls including costs per sediment retention pond and numbers of ponds:** As the maximum sediment pond catchment area is typically 5 ha, and the modelled area was 40Ha, It was assumed that the smallest contiguous earthworks area of 10 ha within the 25% scenario would have multiple ponds, and that the optimal 5 ha per pond is achievable within topographic constraints. Therefore the cost of sediment control was consistent across the staging and treatment scenarios with low slope, however these were binary between the untreated/treated scenarios.

Other variables that are not expected to be sensitive and were not priced are considered to include:

1. **The scale of earthworks:** This was included as a typical rate of 7,000 m^3/Ha (cut to fill). Varying topography, design standards, urban design approaches and soil conditions would affect earthworks volumes however these could be expected to be consistent across scenarios.
2. **Off-site disposal of earthworks:** This may or may not be required depending on earthworks cut/fill balance and are considered to be unaffected by the staging scenarios. Whist this cost may be more commonly associated with steeper sites they have not been included in the assessment.
3. **Geotechnical stabilisation measures:** Items such as counterfort drains, keyways, cut to waste of unsuitables, importing approved clean fill have not been included

4. **Civil works:** including retaining and stream works have not been included.
5. **Duration of Earthworks:** It was assumed that earthworks did not incur additional stabilisation/re-establishment costs during winter seasons as the staged constructions, with longer duration, would have more opportunity to align staging to earthworks seasons.

The costs that were estimated are included in Table 7 and Figure 8. This shows that the key increase in cost is attributable to the changes in earthworks rates due to assumed efficiency with larger sites where cut to fill operations are unimpeded by staging and allow for larger equipment to access the site. It is noted that the cost estimates for the conceptual scenarios used unit rates rather than detailed time and equipment cost analysis. It is also noted that staging earthworks is adopted by common best practice guidance such as ARC GD05 and therefore already built into the costs of land development and housing supply to some extent.

Table 7. Estimated Bulk Earthworks Cost Comparison by Modelled Scenario

Scenario	Fixed Cost	Earthworks Cost	Time Cost	E and S Cost	Total Cost	$/ha
25% Bare Earth, No Treatment	$80,000	$4,260,000	$80,000	$239,740	$4,659,740	$116,494
25% Bare Earth, With Treatment	$80,000	$4,260,000	$80,000	$325,451	$4,745,451	$118,636
50% Bare Earth, No Treatment	$80,000	$3,600,000	$70,000	$270,940	$4,020,940	$100,524
50% Bare Earth, With Treatment	$80,000	$3,600,000	$70,000	$356,651	$4,106,651	$102,666
75% Bare Earth, No Treatment	$80,000	$3,220,000	$60,000	$205,553	$3,565,553	$89,139
75% Bare Earth, With Treatment	$80,000	$3,220,000	$60,000	$291,264	$3,651,264	$91,282
100% Bare Earth, No Treatment	$80,000	$2,840,000	$50,000	$228,035	$3,198,035	$79,951
100% Bare Earth, With Treatment	$80,000	$2,840,000	$50,000	$313,746	$3,283,746	$82,094

NB – Costs limited to main earthworks costs.

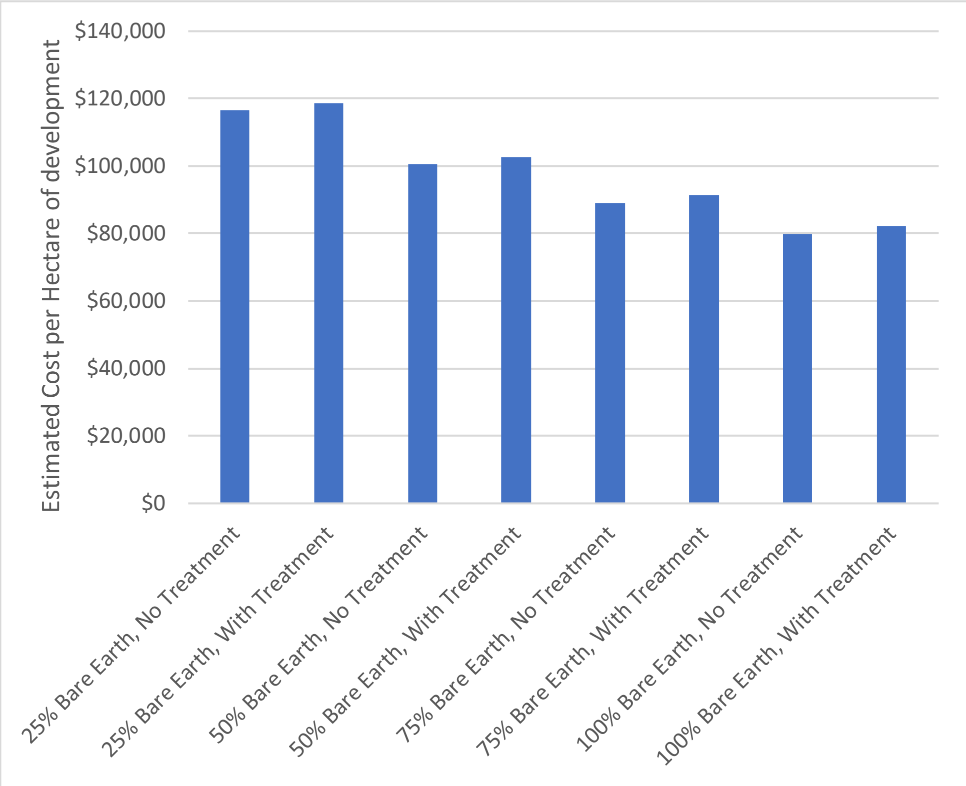

Figure 8: Estimated Cost per Hectare

Typical costs of a subdivided sections in Auckland are in the order $420,000 per section, with civil and infrastructure costs including earthworks in the order of $113,000-$126,000 per section for New Zealand cities (Deloitte Access Economics 2018). This translates to finished section costs in the order of 4 - 6 million dollars per hectare. Therefore, the estimated increase from no staging to a maximum of 25% of the site open at less than $40,000 per hectare is in the order of 1 percent of land supply costs for housing construction.

4.2 Additional Costs and Benefits

The costs and benefits of a low Impact Design or Water Sensitive Design approach are well documented (Shaver, 2009; Redmond, 2011). These approaches typically include a staged approach to earthworks as well as adopting a minimum earthworks strategy that preserves natural features such as streams, ridgelines and high value vegetation. A series of additional costs and benefits that could be considered alongside increasing staging and complexity of earthworks are listed below. However, these have not been included in the quantitative assessment.

Additional Costs

- **Time value of money including interest:** These are dependent on the ownership and financing of the land development and could vary greatly.
- **Carbon emissions costs of earthworks:** There may be lifecycle efficiencies with smaller more careful earthworks processes however conversely there may be more emissions associated with multiple handling, stockpiling and offsite disposal operations potentially associated with increased staging.
- **Offsite costs of increased sediment discharges:** These could be significant and long lasting but have not been quantified as part of this work.

Additional Benefits

- **Environmental Wellbeing:** Staged earthworks are more likely to lead to sympathetic urban and landscape design and to facilitate retention of streams and natural areas. There is also potential for reduced compaction and greater preservation of infiltration capacity leading to reduced hydrological change and off-site discharge effects.
- **Cultural Wellbeing:** Environmental benefits and reduced discharges associated with increased staging are likely to preserve tangata whenua values including the mauri of the water, its ability to provide for mahinga kai and rongoā. Also, these benefits provide for greater recreational access to waterbodies and facilitate the identification of archaeological finds.
- **Social Wellbeing:** Staged earthworks can facilitate preservation of amenity and landscape features such as streams leading to improved sense of place and mental wellbeing. Added complexity of construction potentially provides greater employment and skill building experience.
- **Economic Wellbeing:** Smaller earthworks scale associated with staging can have an increased labour component creating local benefits and utilise smaller equipment and potentially a wider range of suppliers.

Overall there are likely to be a range of benefits associated with more complex earthworks operations and staging to weigh against increased costs.

5.0 Conclusions

This analysis has provided useful insights into the importance of intra- and inter-annual variability of sediment yields, along with the potential effect of non-structural staging control measures on sediment yields. Process-based continuous simulation has provided a powerful tool for quantifying the relative magnitude of annual variability and potential benefit of staging practices compared to structural control measures alone. Annualized empirical models do not capture the range of sediment generation conditions, and the average yield estimates are not reflective of sediment yields that occur in any given year. The variation in total annual rainfall is likely not the principal factor in determining sediment yield. Instead, it is likely the number of intense rainfall events that mobilize sediment during each year is the main factor. Staging to expose up to 25% of the site during the construction season was simulated to be more effective than structural control measures that achieve 70% reduction in sediment concentration.

Sediment concentrations, while very high, varied less dramatically across the scenarios as the bare earth of construction site was shown by modelling to produce more runoff to dilute the loads.

More refined modelling of sediment treatment devices including process-based time series modelling of storage and settlement processes would potentially reveal more climate driven variability in the performance of these devices.

The outputs show the capability of continuous simulation for predicting concentrations across a range of storm types, seasons and slope. The outputs of the continuous simulation modelling may inform decisions on the types of modelling platforms to use for estimates of sediment generation, as well as informing decisions regarding appropriate guidance for non-structural approaches to erosion and sediment control via timing and staging of earthworks. It is important to recall that the modelling outputs here are intended to highlight the relative variation of sediment yields across years and earthworks practices, as absolute values for sediment yield from a site are highly dependent on the local site conditions including rainfall time series, soil type, and slope.

Cost analysis estimated an increase in bulk earthworks costs due to best practice erosion control through staging in the order of 45% on earthworks costs per hectare. Costs of sediment controls have the potential to add much smaller costs estimated in the order of 2-3% on earthworks cost per hectare. These cost changes are estimated to comprise in the order of 1% of the costs of producing a section ready for sale.

This information shows both erosion control through staging and progressive stabilisation and sediment controls are effective in reducing loads. However, it is noted that the benefit/cost of sediment treatment alone may be overstated by the analysis. More complex staged earthworks integrates well with a low impact design approach, including minimised earthworks, that has the potential to realise additional benefits for the four well beings.

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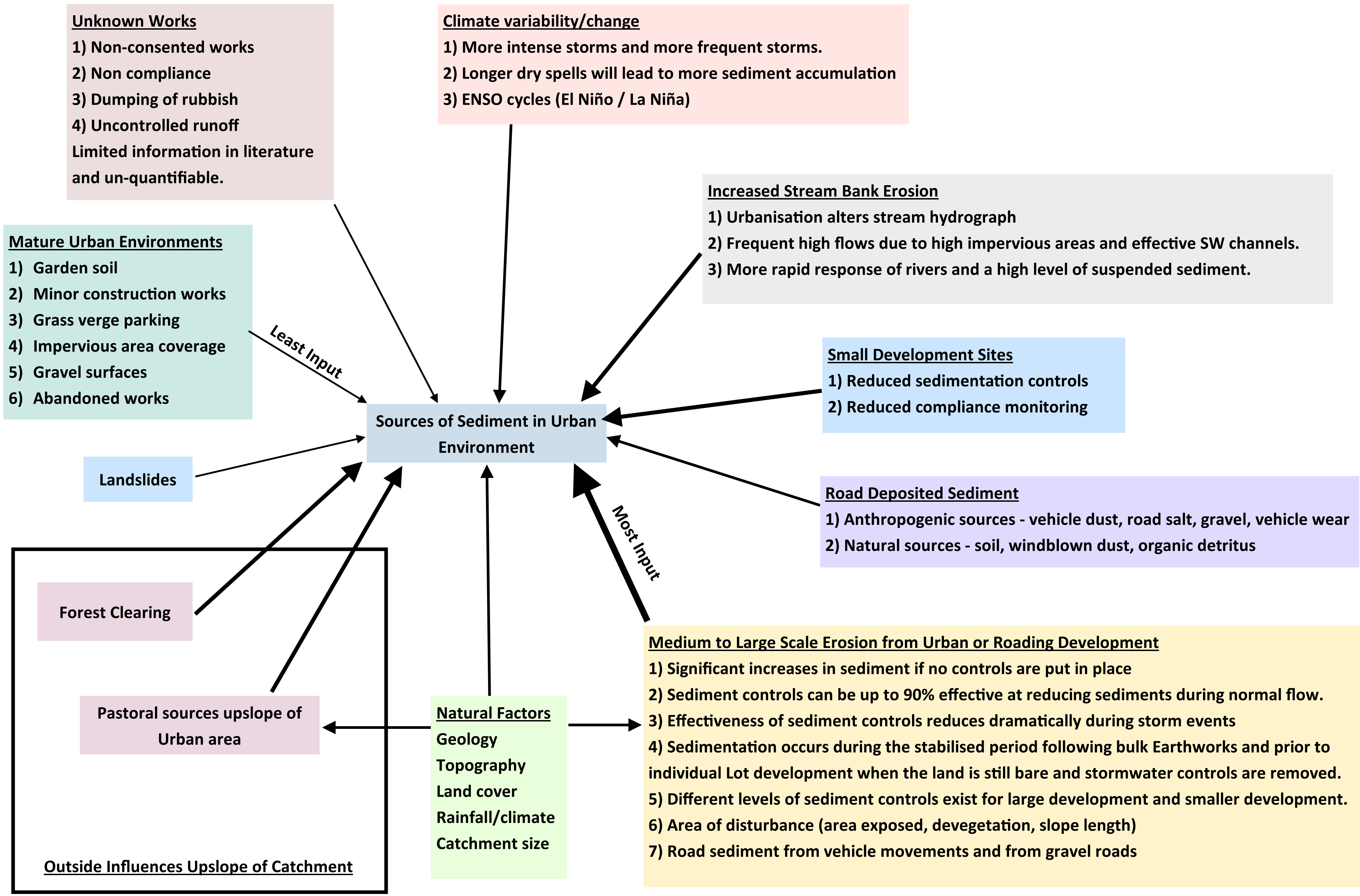
Appendix 1 Sources of Sediment in an Urban Environment


Unknown Works
1) Non-consented works
2) Non compliance
3) Dumping of rubbish
4) Uncontrolled runoff
Limited information in literature and un-quantifiable.
Climate variability/change
1) More intense storms and more frequent storms.
2) Longer dry spells will lead to more sediment accumulation
3) ENSO cycles (El Niño / La Niña)
Increased Stream Bank Erosion
1) Urbanisation alters stream hydrograph
2) Frequent high flows due to high impervious areas and effective SW channels.
3) More rapid response of rivers and a high level of suspended sediment.
Mature Urban Environments
1) Garden soil
2) Minor construction works
3) Grass verge parking
4) Impervious area coverage
5) Gravel surfaces
6) Abandoned works
Least Input
Small Development Sites
1) Reduced sedimentation controls
2) Reduced compliance monitoring
Sources of Sediment in Urban Environment
Landslides
Road Deposited Sediment
1) Anthropogenic sources - vehicle dust, road salt, gravel, vehicle wear
2) Natural sources - soil, windblown dust, organic detritus
Most Input
Forest Clearing
Medium to Large Scale Erosion from Urban or Roading Development
1) Significant increases in sediment if no controls are put in place
2) Sediment controls can be up to 90% effective at reducing sediments during normal flow.
3) Effectiveness of sediment controls reduces dramatically during storm events
4) Sedimentation occurs during the stabilised period following bulk Earthworks and prior to individual Lot development when the land is still bare and stormwater controls are removed.
5) Different levels of sediment controls exist for large development and smaller development.
6) Area of disturbance (area exposed, devegetation, slope length)
7) Road sediment from vehicle movements and from gravel roads
Pastoral sources upslope of Urban area
Natural Factors
Geology
Topography
Land cover
Rainfall/climate
Catchment size
Outside Influences Upslope of Catchment

Appendix 2 Template Earthworks Schedule.

SCHEDULE OF QUANTITIES			
Item	**Description**	**Unit**	**Cost Apportionment for Table 7**
100	**PRELIMINARIES AND GENERAL**		
101	**Site establishment**		
	Allow for the establishment on site of all facilities and equipment. Item to include for all construction signage, temporary services, offices, sheds, toilet facilities, hardstands and security required to complete the Contract.	Sum	Fixed Cost
102	**Maintenance of Site Establishment**		
	Allow for the maintenance of the site establishment facilities for the duration of the Contract.	Week	Time Cost
103	**Demobilisation of Site Establishment**		
	Allow for the dis-establishment of all site faculties at the completion of the Contract including the removal of hard standings and disconnection of	Sum	Fixed Cost
104	**Insurance**		
	Allow for paying and maintaining all insurance premiums as stipulated in the contract documents for the duration of the Contract. Plant only. Not inc Contract Works Insurance	Sum	Time Cost
105	**Traffic Management**		
	Allow to prepare and submit a Traffic Management Plan (TMP) for the approval of the Engineer and Auckland Transport for all temporary traffic control for works on public and private roads.	Sum	Fixed Cost
106	**Earthworks Management Plan**		
	Allow to prepare and submit a Earthworks Management Plan (EMP) for the approval of the Engineer and Auckland Council (NRSI).	Sum	Fixed Cost
107	**Site Management**		
	Allow for construction supervision and administration for the duration of the	Week	Time Cost
108	**Setting out of all the works**		
	Allow for setting out the Contract works, including boundary stakes, maintaining survey marks and responsibility for the same.	Sum	Fixed Cost
109	**As Builts - (provisional)**		
(a)	Allow to undertake as built surveys ,drawings preparation and provide supply of information as set out in the Contract Documents (this item includes Sediment and Erosion)	NC	Fixed Cost
110	**Location and protection of services**		
	Allow for all costs for the location of all buried services and for the protection or removal as required of the services over the extent of the construction	Sum	Fixed Cost
111	**Health and Safety**		
(a)	Allow to prepare and submit a site specific Health and Safety Plan (HSP) as required by the Contract documents and for maintaining and updating the HSP as required for the duration of Contract.	Sum	Fixed Cost
(b)	Allow to maintain health and safety controls for the duration of the Contract	Week	Time Cost
112	**Liaison With Other Parties**		
	Allow for all costs for liaison with Council, Utilities service providers, other land owners, road users, businesses, tenants and other interested parties for the duration of the works.	Sum	Fixed Cost

Item	Description	Unit	Cost Apportionment for Table 7
200	**EROSION AND SEDIMENT CONTROL, DEMOLITION, CLEARING &**		
	Refer Contract Specification for earthworks and compaction standards.		
	Allow all costs to construct and maintain throughout the Contract period (including Defects Liability Period) and remove on completion, the required erosion and silt control works, dewatering systems, spillways etc. including all necessary temporary works		
201	**Erosion and Sediment Control - GENERAL ITEMS (Provisional Sum)**		
(a)	Silt Retention Pond complete including floating arm dewatering system, overflow spillway, safety fence and removal as required. Includes all costs for flocculation of ponds as per the Flocculation Management Plan	No.	E and S Cost
(b)	Construct Earth Bund with Decant, stabilised with geotextile and 160dia non-perforated pipe through bund.	No.	E and S Cost
(c)	Construct clean water diversion drains/bunds including mulching. (Provisional	m	E and S Cost
(d)	Construct dirty water diversion drains/bunds including mulching. (Provisional	m	E and S Cost
(e)	Allow for the construction and reinstatement of contour drains at the end of each working day and when rain is imminent.	week	Time Cost
(f)	Construct silt fences complete	m	E and S Cost
(g)	Stabilised construction entrance as detailed including metalled bund. required for the duration of contract period.	No.	E and S Cost
(h)	Extra over Item 201 (i) to provide grass seed in straw mulch (Provisional Item).	m^2	E and S Cost
(i)	Extra over Item 201 (b) to form emergency spillway.	No.	E and S Cost
(j)	Allow all cost to decommissioned Silt Pond and all other sediment control devices at site. Including removal offsite of extra materials to tip (Include tip fees), decommission etc.	No.	E and S Cost
202	**As Builts**		
	Allow to undertake survey and as-building of all erosion and sediment controls once constructed to enable accurate as-built plans to be prepared	Sum	E and S Cost
203	**Cleaning of Roads**		
	Allow for the cleaning of all public and private roads as required over the duration of the Contract Works.	Sum	E and S Cost
204	**Clearing**		
(a)	Allow to strip off grass, clear all vegetation/scrub/trees/etc. over total site area, mulch vegetation and stockpile/spread mulch where directed on site, including clean-up along all adjoining boundaries/fence lines to Engineer's	Sum	Fixed Cost
205	**Removing**		Excluded
206	**Topsoil and Grassing**		
(a)	Strip 250mm of topsoil and stockpile for re-use.	m^3	Earthworks Cost
(b)	Take from stockpile, spread topsoil balance areas, to 150mm compacted depth as directed/detailed on the drawings. The balance topsoiled area of 6130m3 will be remove off site, by others.	m^3	Earthworks Cost
(c)	Prepare and sow areas topsoiled with approved grass seed mix.	m^2	Earthworks Cost

Item	Description	Unit	Cost Apportionment for Table 7
207	**Cut to Fill.**		
(a)	Excavation of material from within earthworks area and place in as fill to class "A" compaction.	m^3	Earthworks Cost
(b)	Excavation of material from within earthworks area and place in as fill to class "A" compaction. (PROPOSED)	m^3	Excluded
(c)	allow to cut unsuitable and stockpile that would be dried and re use as fill	m^3	Excluded
(d)	Building platform (laser levels) for preparation of building foundation construction. **(Provisional Item)**	No.	Excluded
(e)	Import suitable approved clean fill from offsite and place as fill to class A	m^3	Excluded
208	**Subsurface Underfill Drains - (Provisional Items)**		
(a)	Allow all cost to import drainage materials for counterfort drain TBC by	m^3	Excluded
(b)	Keyway Subsoil Drains	m	Excluded
209	**Removal Offsite (Provisional Items)**		
(a)	Allow cut to waste and remove excess **unsuitable** Include Tip Fees. Stockpile	m^3	Excluded
(b)	Allow to remove existing excess **CLAY** material from Civil Works Volume includes for Drainage, Services, Subsoil's, Watermains etc. Stockpile Measure.	m^3	Excluded
210	**Miscellaneous Items**		
(a)	Dust control. (Measure shall be actual hours of operation by water truck). (Provisional Item)	Hr	E and S Cost