Engineers & Consultants

Analysis of Water Quality Effects

Sediment Attributes and Urban Development

Final

Prepared for Ministry for the Environment by Morphum Environmental Ltd
September 2019

The union of engineering
design and nature.

09 377 9779 | info@morphum.com | www.morphum.com

MORPHUM ENVIRONMENTAL LTD

Engineers & Consultants

Document Control

Client Name: Ministry for the Environment

Project Name: Sediment attributes and urban development

Project Number: P02173

Document: Analysis of Water Quality Effects

Revision History

Status	Date Issued (dd/mm/yyyy)	Author	Reviewed By	Released By
Final Draft	04/06/2019	Jacqui McCord Jason Smith	Andrew Rossaak	Caleb Clarke
Final	16/09/2019	Jacqui McCord Jason Smith	Andrew Rossaak	Caleb Clarke

Reviewed by:

Reviewer: Andrew Rossaak **Signature:**

Released by:

Reviewer: Caleb Clarke **Signature:**

Level 1, 86 Symonds Street, Grafton, Auckland 1010
09 377 9779 | info@morphum.com | www.morphum.com

Executive Summary

Morphum Environmental Ltd was engaged by the Ministry for the Environment to assess the impacts of the proposed inclusion of the sediment attribute into the National Policy Statement: Freshwater Management, particularly for urban and urban development areas. The Task 1, literature review report identified sources of sediment in an urban environment and the Task 2 report identified current urban development sites and NZTA transport development sites that could be used for case studies for looking at sediment discharges and in stream sediment effects from development.

Three case studies were identified that were able to provide monitoring data from development. All other case studies were either not required to collect data, or the data was not available or in a useable format. Of the data that was collected, only turbidity measurements were provided as site monitoring of deposited fine sediment was not undertaken.

The attribute state of streams is based on a median value and focusses on the long-term trend. The data from development sites is event based and turbidity was usually assessed after a trigger value was exceeded. This approach only looks at short-term, peak turbidity events and does not monitor the turbidity during normal flow conditions. It was therefore not possible to determine the long-term trends from the development or compare these with the proposed attribute states median levels to determine if there is likely to be a change in the attribute state due to development.

Data from State of the Environment monitoring sites and NIWA's Urban Runoff Quality Information System were also assessed to look at turbidity trends comparing rural and urban catchments, however data was not available to compare changes in a single catchment before and after development. The Urban Runoff Quality Information System showed that urban catchments had higher turbidity values than rural areas. The State of the Environment (SOE) monitoring sites did not show any considerable variation between rural and urban areas. This identified a limitation of the data as the discrete, monthly sampling of SOE sites does not pick up the short-term changes that can occur.

While the data provided was not conclusive in determining if development will have a long term effect on attribute state of streams, the data did highlight other effects of development. The peak turbidity levels recorded during storm events are very high, and well above turbidity levels in normal flow conditions. While these short-term peak events may not affect the median value, they still have an adverse effect on the ecological heath of the stream. Sediment control devices are an effective way of reducing sediment yield into streams, but they are only designed to a certain sized rainfall event and require ongoing maintenance to ensure they are working effectively. In addition, the sediment control devices have reduced effectiveness when rainfall events occur in quick succession, and thus rain event frequency is important in sediment control device performance.

Recommendations as to where further information is required for better assessment of the long-term effects of urbanisation on sediment attributes in an urban watercourses is provided, as well as suggestions on improved monitoring.

Contents

Figures

Tables

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.

This report looks at 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 assessment looked to determine if development may lead to changes in the median attribute state in both the short-term (during construction), and the long-term (following the completion of earthworks). There is no defined time frame for long term effects as these may occur for months or years following urbanisation as the catchment reaches a new equilibrium.

2.0 Literature Review

2.1 Overview

Sediment generation is a natural process that occurs in the landscape with the rate of sediment generation being a function of natural landscape characteristics. Changes to land use and urbanisation within a catchment can significantly increase sediment generation. The development stage, when land is stripped bare and bulk earthworks occur, is the most significant contributor to sediment generation in an urban environment and if erosion and sediment controls are not in place, can result in a significant influx of sediment to streams.

The use of best practice erosion and sediment controls during development can reduce sediment generation. The incorporation of water sensitive design practices can also improve long term sediment generation in a mature urban catchment by reducing impervious area and improving stormwater management by retaining and detaining stormwater and reducing the rate of inflow to streams. The increase in sediment from development as well as the increased inflow from impervious areas can alter the flow regime, resulting in stream bank erosion.

The potential sediment yield of a catchment as land use changes is discussed in the Task 1 Report and shown in Figure 1. This shows the potential sediment yield with and without the incorporation of best practice sediment and erosion controls and water sensitive design.

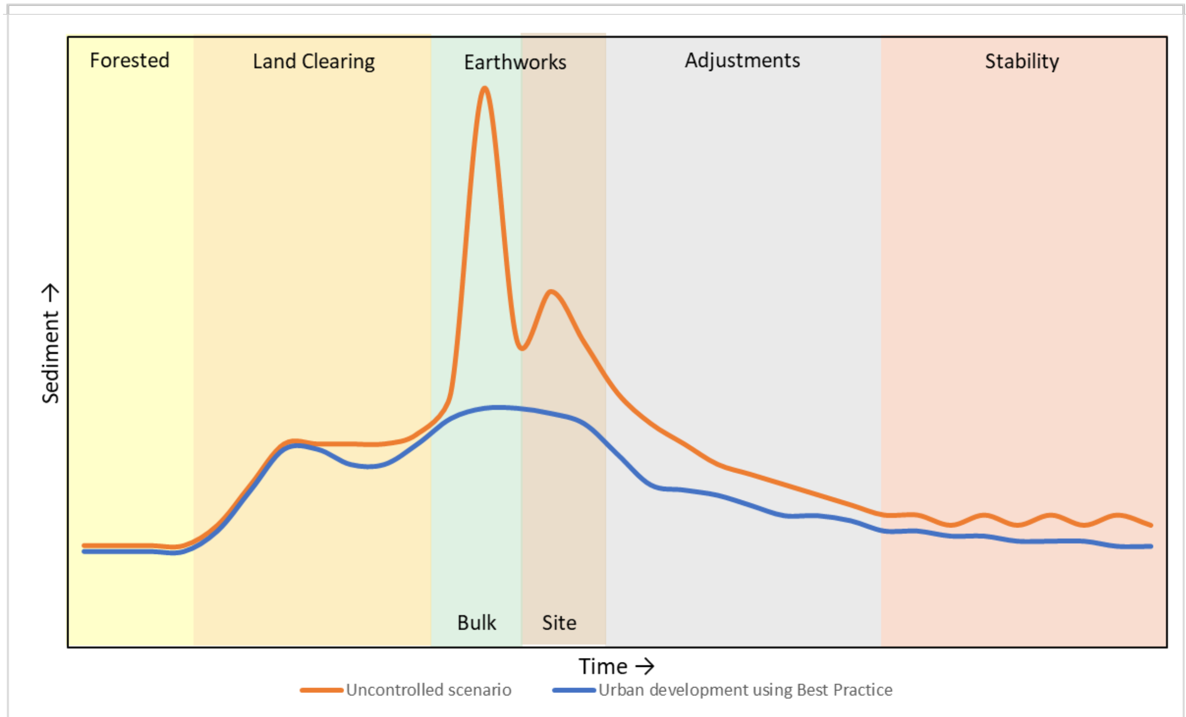


Figure 1: Conceptual Pattern for Sediment Yield with Varying Land Use

2.2 Sources of Sediment Generation

Sources of sediment generation in the urban landscape can be generally grouped into natural sources, development sources and mature urban catchment sources. The potential sources and the variability within each category are discussed below and also summarised in Appendix 1. The Task 2 report evaluates each case in reference to these categories.

2.2.1 Natural Sources

Natural sources will affect the sediment generation in an area regardless of the stage of catchment development. The influencing factors include:

- **Topography:** The potential sediment yield increases with steeper gradients and longer slope lengths due to a potential increase in velocity of overland sheet flow.
- **Geology:** The underlying geology affects the erosion rate of materials and the type of sediment to be supplied to a stream. It also affects rainfall infiltration and runoff due to the presence or absence of rock fractures and compaction of sediment.
- **Soil type:** The erodibility of a soil is a function of its grain size and cohesiveness.
- **Rainfall:** Sediment loadings increase during rainfall due to the increase in runoff, rain drop impact dislodging particles and the higher flow and velocity of water travelling through water courses. The higher the intensity of rainfall, the higher potential for sediment generation.
- **Vegetation/ground cover:** Vegetation provides a physical barrier to raindrop erosion and increases surface roughness which can retard flow across a surface and reduce runoff velocities. Vegetation contributes organic material including leaves and woody debris that are natural contributions to habitat and small quantities of turbidity. Sediment generation from bare earth is significantly greater than for forested land.

2.2.2 Development Sources

The development stage of a catchment has the potential to significantly increase sediment generation. There are two phases to the stage, the first being bulk earthworks over larger areas, and the second being site specific development.

- **Area exposed:** Increases the amount of bare earth which can be subjected to erosion from rainfall.
- **Sediment control measures:** the incorporation of sediment controls reduce the amount of sediment which leaves a site.
- **Erosion control measures:** the incorporation of erosion control measures aim to reduce the potential for rain events to cause erosion by reducing runoff velocities.
- **Storm event design sizing:** The effectiveness of sediment and erosion controls reduce as storm intensity increases.
- **Sediment control following development completion:** There is a period of time following completion of bulk earthworks where erosion and sediment controls are removed, and the land is still relatively bare when erosion can occur.
- **Maintenance and compliance of erosion and sediment controls:** erosion and sediment controls will only be effective if maintained.
- **Water sensitive urban design practice:** the incorporation of these practices reduce impervious area and better manage stormwater runoff, reducing changes to a streams flow regime.

2.2.3 Mature Urban Catchment Sources

There are numerous sources of sediment in urban catchments, but they are difficult to quantify. Infill development and maintenance are continuous within mature urban catchments and often have limited to no sediment controls in place. On-going maintenance and replenishment of facilities, such as gravel in parking areas and road side berms, can also provide continuous sources of sediment. Sources of sediment in a mature urban catchment include:

- Consented building works
- Road deposited debris
- Non-consented and non-compliance woks
- Minor earthworks
- Gravel (parking areas, road side berms, pathways)
- Garden soil
- Vegetation including leaf fall
- Grass verge parking
- Landslides
- Bankside erosion

3.0 Plan Compilation and Review

3.1 Overview

The Ministry for the Environment is currently considering a sediment attribute for inclusion within the National Policy Statement: Freshwater Management. As identified in Section 2.0 above, there are three categories of sources for sediment generation in the urban landscape, these being natural sources, development sources and mature urban catchment sources. Within each category of sediment generation in the landscape, there are potential sources of further variability that will influence sediment discharges to the receiving environment.

To examine the potential sources of sediment discharge variability further, Morphum has undertaken a review of existing urban development plans from around New Zealand. Urban development plans assessed included those for large residential, commercial and industrial developments and New Zealand Transport Agency (NZTA) projects.

Morphum, with feedback from the Ministry, have selected case studies for further review. Urban development plans are reviewed in regard to their content relating to the natural, development and mature urban reasons for sediment discharge variability. Where water quality data is available that relates to in-stream sediment, such as Total Suspended Sediment (TSS) and Turbidity measurements (NTU or FNU), the data has been included and assessed.

3.2 Case Studies

A brief introduction and rationale for the selected case studies that have been assessed can be found below. Case studies were selected to provide information from a variety of urban development plans, and to represent as broad a geographic range across New Zealand as possible, with different proposed sediment attribute classes.

The case studies discussed below represent those where monitoring data could be provided. In many instances, the selected case studies were not pursued further due to a lack of relevant data sets. This was either due to the information not being available, the data being stored or collected in an inaccessible format, or it not being provided upon request.

Earthworks site 1

The first Earthworks site was selected for further study here given the large area and volume of earthworks proposed. The consented works include approximately 2.9 million m^3 of earthworks over approximately 291 ha. The area had been subject to previous master planning exercises that resulted in precinct-specific provisions being operative as well as the region wide provisions of the Auckland Unitary Plan (Operative in Part) (AUP:OP). In 2019, a subsequent consent authorised smaller scale earthworks necessary to install civil infrastructure within the DSRP.

The original application material included an AEE that was supported by a series of plans and reports from specialist technical experts including an Erosion and Sediment Control Plan, Ecological Assessment and Environmental Management and Monitoring Plan.

The application material contained no reference to any measured in-stream sediment indicators.

Transmission Gully

Transmission Gully is a 27 km long NZTA roading project from MacKays Crossing (Kapiti Coast) to Lindon (Wellington City), which is currently under construction and scheduled to be open in 2020. The purpose is to provide another route between Wellington and the lower and central North Island. The project includes 6.3 million m^3 of excavation and 5.8 million m^3 of fill over an area of approximately 200 ha.

The Transmission Gully project was selected for further study as it involves earthworks within nine catchments, most of which drain to the Pauatahanui Inlet and Onepoto Arm which discharge into the Porirua Harbour. Sediment yield calculations on the catchment and anticipated changes due to the project were undertaken as part of the consenting process. Site Specific Environmental Management Plans (SSEMPs) were required to address erosion and sediment control.

The conditions of consent require monitoring of sediment indicators in the receiving environment and we have been provided with data of the monitoring undertaken to date.

Earthworks Site 2

The second earthworks site is a residential subdivision adjacent to a stream and coastal environment. The proposal includes earthworks over approximately 14 ha which corresponds to approximately 14% of the sub-catchment. The proposal includes 293,400 m^3 of excavation and 287,500 m^3 of fill. Sediment controls were proposed for during and after earthworks construction. The sediment ponds, reticulation system and diversion channels were designed for a 20 year ARI event and chemical treatment was proposed to optimise sediment removal. The proposed sediment pond treatment area is larger than the minimum requirements as the development will use the pond as a lake for future wildlife refuge and amenity.

The Resource Consent required continuous discharge flow monitoring on the outflows from the pond and automatic sediment sampling to measure the suspended solid concentration through storm events. The Resource consent also required additional manual monitoring to determine suspended solid concentrations during major storm events. We have been provided with continuous turbidity monitoring for this site.

4.0 Methodology and Results

4.1 Overview

The focus of this report is analysis of the available material for the selected case studies on how anticipated sediment discharges over the short and long-term will affect sediment attribute achievement. We are grateful for the data provided by the various councils and developers as this has been important in understanding the sediment generation during urbanisation. It is important to point out that this data has been analysed with the view of understanding sediment in urban development and these analyses do not relate or infer compliance or performance of sites to consent conditions.

This analysis consists of the following steps:

1. Estimate of change in suspended sediment load from the development over short- and long-term timeframes.
2. Estimate of in-stream sediment indicator changes resulting from suspended sediment load changes.
3. Evaluation of in-stream indicators compared to proposed sediment attribute thresholds.

The methodologies used in each step are presented below.

The previous studies for sediment attribute determination (Hicks et al., 2016) have used statistical regression techniques to relate observed in-stream sediment parameters (Visual Clarity (VC) and Euphotic Depth (ED)) to Suspended Sediment Concentration (SSC), and then related SSC to sediment load. This approach uses coarse observation to describe a complex system including natural variability in terms of:

- Rainfall
- Infiltration/ evapotranspiration/ runoff
- Storage and time lag
- Instream scour
- Particle size
- Deposition and remobilisation

This approach would likewise ignore complex processes of human induced variability leading to short and long-term changes in the above natural processes of hydrology and erosion, as well as specific discharges of sediment from land disturbing activities. This includes:

- Earthworks Processes
- Erosion Control Methods
- Sediment Removal Methods
- Stream stabilisation
- Riparian vegetation

A key effect includes the impact of hydrological change due to impervious surface, reduced infiltration and increased peak flow concentration following rain events leading to in stream scour.

The data request overall required significant time from council staff and in some cases the information sought was not available. As a result, the results are based on the best evidence available, which is not a wide information base, but that which could be collated in the time and resource constraints of this project.

4.2 Estimate the change in suspended sediment load from the development over the short and long-term timeframes.

The results of the Task 2 Report highlight that the case study information obtained is data deficient. The case studies do not contain the necessary information to show changes in suspended sediment loads or concentrations over time.

To estimate the change in suspended sediment load from the development over the short and long-term timeframes, a content analysis of the case study material was undertaken. All of the case study material was reviewed for content that specifically considered in-stream sediment attributes changes over short (during construction and earthworks) and long term (post-construction) timeframes.

To determine the short-term changes in suspended sediment loads, the available water quality reports from the case studies were reviewed for in-stream sediment indicator monitoring results during the construction phase. Data was found to be available from Earthworks site 1 and Transmission Gully.

For Earthworks Site 1, Total Suspended Sediment (TSS) and turbidity (NTU) measurements were required to be taken at locations upstream and downstream of construction sites in response to certain rainfall triggers.

For Transmission Gully, continuous turbidity (NTU) and flow measurements were recorded upstream and downstream of construction in six catchments. Baseline monitoring was undertaken before construction commenced, which established trigger levels for turbidity. Turbidity was also measured at the inlet and outlet of sediment retention ponds to monitor device efficiency.

For Earthworks Site 2, continuous turbidity (FNU) was undertaken on the adjacent stream, upstream of the development, at an outfall structure from the development and at a wetland discharge site. There is no downstream monitoring site as the environment becomes coastal. We have been provided with all turbidity readings during the 2018/2019 earthworks season as well as some information during the winter months of June and July 2018.

To determine the long-term changes in suspended sediment loads, the available water quality reports from the case studies were initially reviewed for in-stream sediment indicator monitoring results from pre-development through to post-construction. None of the case studies had water quality information spanning from pre-development through to post-construction.

As an alternative, in-stream sediment indicators (TSS and NTU) measures have been taken from NIWA Urban Runoff Quality Information System (URQIS). The advantages of using the URQIS data set is the large number of sample points that are available across the country that can be grouped based on land-use.

Within URQIS, catchment land use of Open Space and Rural have been taken to represent a rural, pre-development stage post construction. All other catchment land use types have been taken to represent a development.

Where construction water quality data is available from the selected case studies, this information is also presented and analysed.

There are limitations to the methodology adopted to analyse changes in suspended sediment load over both the short and long-term timeframes. These limitations are discussed further below.

4.3 Estimate of in-stream sediment indicator changes resulting from suspended sediment load changes

A content analysis of the case study material was undertaken to estimate the in-stream sediment indicator changes resulting from suspended sediment load changes.

All the case study material was reviewed for content that specifically considered suspended sediment load changes from pre-development, across construction through to mature urban catchment. No case study material considered suspended sediment load changes from pre-development, across construction through to mature urban catchment. The URQIS dataset was again used to inform suspended sediment load changes, supplemented with case study data where this was available.

Case study material was reviewed for content that considered changes of in-stream sediment indicators in response to suspended sediment load changes. No case study material considered or estimated the in-stream sediment indicator changes resulting from suspended sediment load changes.

To estimate the in-stream sediment indicator changes resulting from suspended sediment load changes, we used established nationwide relationships from Dymond *et al.* (2017) and Hicks *et al.* (2016) to calculate changes in turbidity and visual clarity.

The results of the in-stream sediment indicator changes have been evaluated against the proposed sediment attribute thresholds for the relevant stream classifications.

The receiving environment was identified and the relevant sediment attribute class selected as obtained from the Ministry. Water quality data from the construction sites was used to infer if there would be changes to the sediment attribute state as a result of urbanisation.

The results of the findings are presented below under the three steps taken to analyse if anticipated sediment discharges over the short and long-term will affect sediment attribute state.

4.3.1 Short-term Effects

Earthworks site 1.

Conditions of consent require the consent holder to undertake monitoring of in-stream sediment indicators upstream and downstream of development, and at sediment control outlet discharges in response to specified levels of rainfall. The specified rainfall events are greater than 25 mm of rainfall over any 24-hour period and greater than 15 mm of rainfall within an hour period. 25 mm over a 24-hour period is less than a 1 year ARI rain event, and was justified in the ESCP as it would allow for approximately ten sampling events per year, which would give confidence in identification of water quality trends due to the number of sampling events.

Sediment indicators that are required to be monitored include Total Suspended Sediment (TSS) and Turbidity (NTU).

Data from five monitoring events were provided by Auckland Council from the 2018/2019 Earthworks season. The results are shown in Figure 2 below and summarised in Table 1.

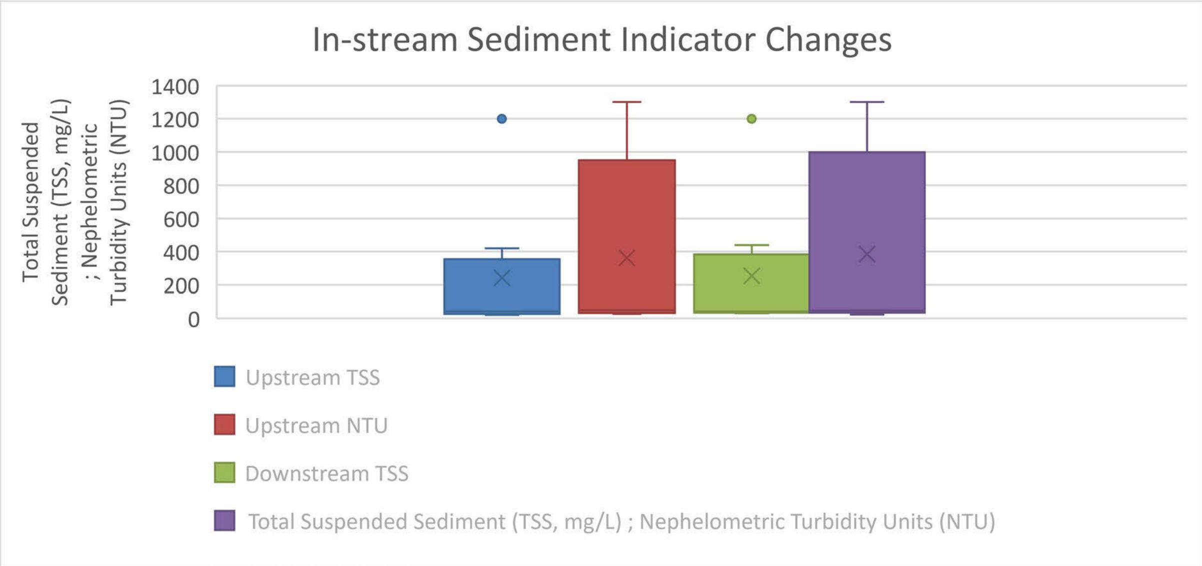


Figure 2: Changes to In-Stream Sediment Indicators Upstream and Downstream of Earthworks Site 1 Areas from Rainfall Triggered Sampling (N= 8).

Table 1: Summary Results In-Stream Sediment Indicators Collected at Earthworks Site 1

Results	Upstream TSS (Mg/L)	Downstream TSS (Mg/L)	Upstream NTU	Downstream NTU
Minimum	7	3	8	1
Median	32	37	27	37
Mean	149	147	216	221
Maximum	1200	1200	1300	1300

Results have been rounded to the nearest whole number.

The results show that there is an increased average and median value in both TSS and NTU at Earthworks Site 1 downstream monitoring locations.

There is no down-stream river or coastal water quality data for this site and there is no continuous monitoring in-place on-site. A condition of consent requires sampling of one SRP via an automatic, rainfall activated system; however, this was still under construction at the time of writing.

Transmission Gully

Sediment data from Transmission Gully includes preconstruction baseline information which was measured for one year prior to development commencing and turbidity data records from trigger events. The baseline monitoring established the turbidity trigger level for dry and rainfall conditions which was based on the 95th percentile of the turbidity measure in baseline data and adjusted accordingly for daily maximum turbidity under non-trigger event rain conditions.

Figure 3 shows the turbidity recorded in seven catchments affected by the development of Transmission Gully. The records are only for downstream turbidity readings that exceeded the trigger levels set out in the Sediment and Erosion Control Management Plans. These were as follows:

- During rainfall exceeding 4 mm per hour or 20 mm per 24 hours, trigger thresholds were between 200 and 300 NTU
- For dry conditions and where rainfall is less than 4 mm per hour or less than 20 mm per 24 hours, trigger thresholds were between 80 and 200 NTU.

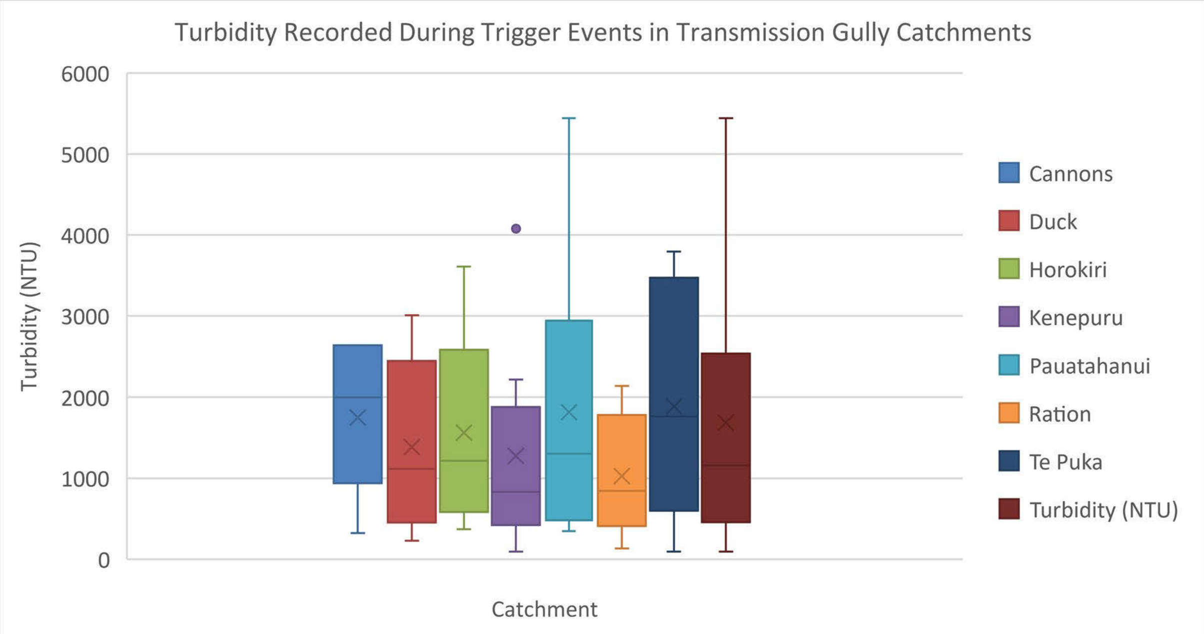


Figure 3: Maximum Turbidity Levels Recorded During Trigger Events in Transmission Gully Catchments and Average of All Streams

A summary of results from the baseline monitoring undertaken prior to development is shown in Table 2. This shows that turbidity was generally low, with average turbidity below 9 NTU. The maximum turbidity in all but one catchment was in excess of 1500 NTU, indicating that in natural conditions, the sediment yield is very high. In the case of Horokiri, the high maximum value was attributed to forest harvest in the catchment during the monitoring period. Median values were not provided.

Table 2: Baseline Monitoring Results in Transmission Gully Catchments

	Catchment					
Turbidity (NTU)	Cannons	Duck	Horokiri	Pauatahanui	Ration	Te Puka
Minimum	0	0	0	0	1	0
Maximum	492	1895	2888	1613	1519	1638
Mean	3.8	7.8	7.4	8.8	7.8	8.8

The baseline maximum turbidity values were compared to the mean and maximum turbidity values recorded during trigger events in different catchments during construction. This is shown graphically in Figure 4. The development maximum turbidity in all catchments is significantly higher than the baseline maximum reading, even in Horokiri catchment where the baseline turbidity maximum was affected by forest clearing.

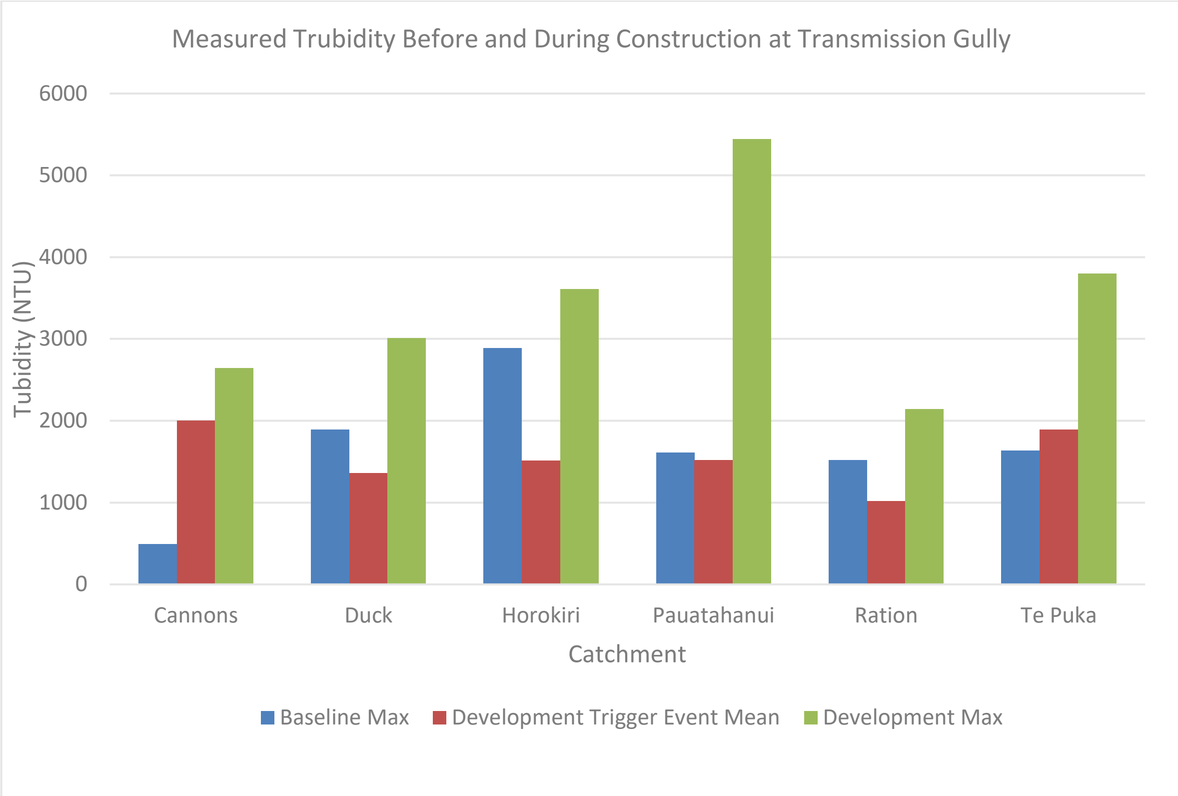


Figure 4: Comparison of Baseline Turbidity Measurements in Transmission Gully Catchments with Event Trigger Turbidity Measurements During Construction. Only the Max Is Shown for Baseline Data as The Baseline Mean for All Catchments Is Less Than 9 NTU.

The Transmission Gully Annual Monitoring Report (CPB HEB Joint Venture, 2018) includes a summary of the water turbidity for the biannual monitoring in the Horokiri Catchment, undertaken during September 2017 to February 2018. There were 188 readings over 300 NTU (event trigger level), which equates to 0.04% of the all the readings during the monitoring period. Comparison with the baseline monitoring data showed that large events which result in turbidity above baseline levels are not considerably different in frequency before or after construction.

The report goes on to compare turbidity values below the trigger level of 300 NTU. It was found that during construction, the waterways are more frequently raised to between 20 and 70 NTU. The baseline data is generally less than 10 NTU. The spike in high readings for the 2014 baseline monitoring is contributed to forest clearing upslope of the monitoring site. The turbidity readings are shown in Figure 5.

It was concluded that it is not the large and infrequent rain events with large turbidity events that cause lasting benthic faunal stress and change, but the more constant lower level raised NTU periods.

We were not provided with the raw data of all turbidity readings and the annual report does not provide any statistical data such as the median turbidity recorded. It is therefore difficult to assess if the median turbidity has changed from pre-development to during development.

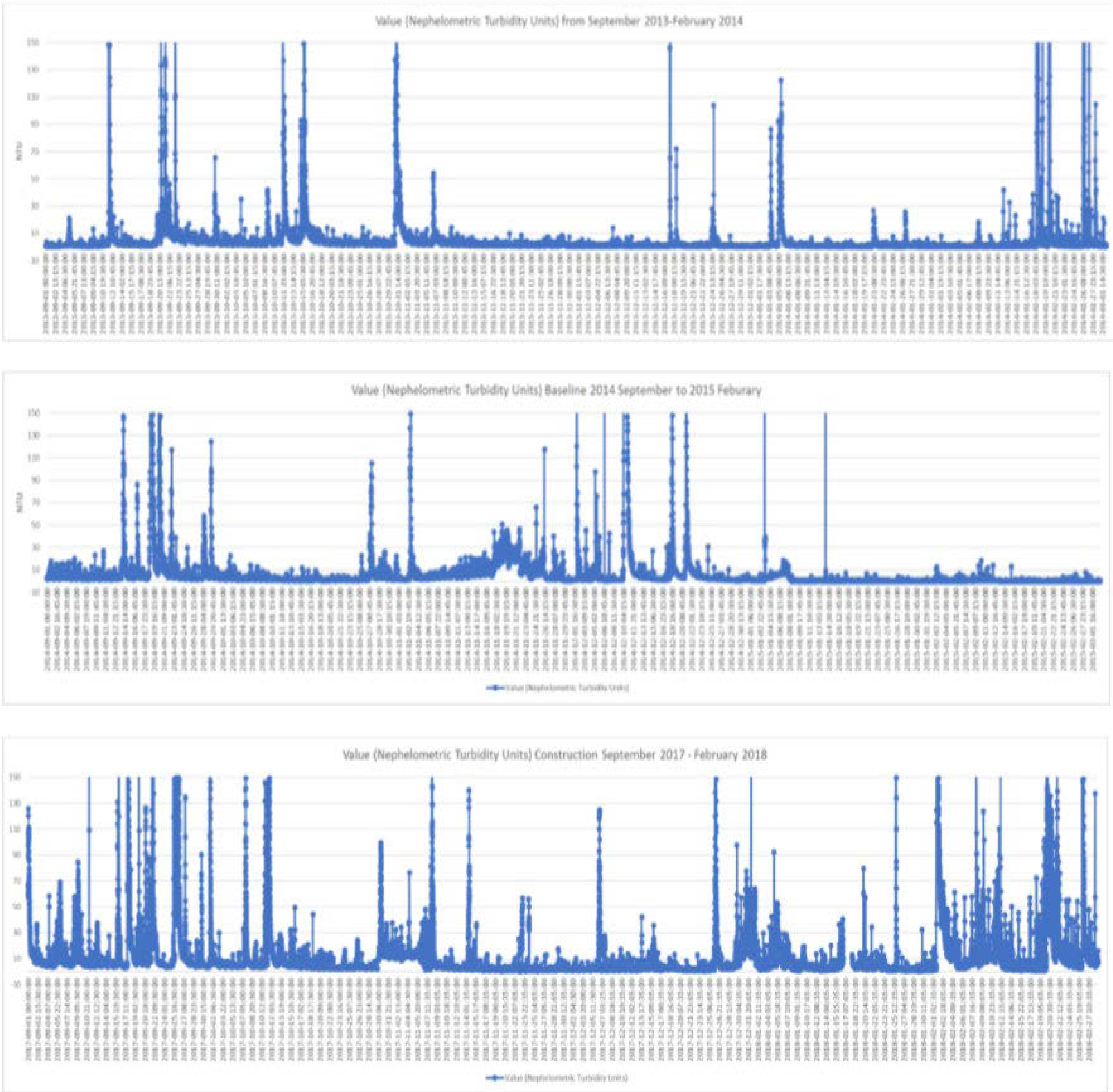


Figure 5: Turbidity Readings in Horokiri Catchment. Top: September 2013 – February 2014 (Baseline), Middle: Top: September 2014 – February 2015 (Baseline), Bottom: September 2017 – February 2018 (Construction). Source Transmission Gully Annual Monitoring Report.

The Annual Monitoring Report discusses follow up monitoring of incidents that occurred during the 2017/2018 season and the 2016/2017 season. An incident was defined by the Resource Consent and involved release of sediment to the water course due to any of the following.

- Discharge from non-stabilised areas that are not treated by erosion and sediment control measures
- Failure of any erosion and sediment control measures
- Any other incident which either directly or indirectly, or is likely to cause, adverse ecological effects in any watercourse that is not authorised by the Resource Consent.

Each incident was investigated for deposited sediment, and if the effects were found to be more than minor, additional monitoring took place. This involved comparing sediment depth between the affected site and a control site as well as looking at aquatic fauna and epifauna differences between the affected and control sites. In all cases, there was no clear or meaningful difference identified between the affected and control sites to suggest there were short or long term effects and monitoring was ceased.

Earthworks Site 2.

Continuous turbidity readings for three sites at Earthworks Site 2 have been obtained. The full data set was analysed to provided turbidity statistics, comparing the turbidity in the stream, measured upstream of the development and turbidity at development outfalls. The median and mean recorded turbidity is shown in Table 3 and is shown graphically on Figure 6.

The information shows that the median turbidity in the stream is higher than at the outfalls, however the spread of turbidity values is much greater at the outfalls with very high peak turbidity values. We point out that the outfalls represent sediment concentration in the outflow water only, and without flows, no-load estimates are possible. We are led to understand that the site outfalls had low flows and thus, may not lead to noticeable changes to the stream turbidity.

Table 3: Summary of Turbidity Data Recorded at Earthworks Site 2

	Turbidity (FNU)				
	Median	**Mean**	**Standard Deviation**	**Max Value**	**Number of Values**
Stream	9.2	11.92	20.44	1257.38	44626
Site Outfalls	5.61	19.43	173.64	23226.28	89629

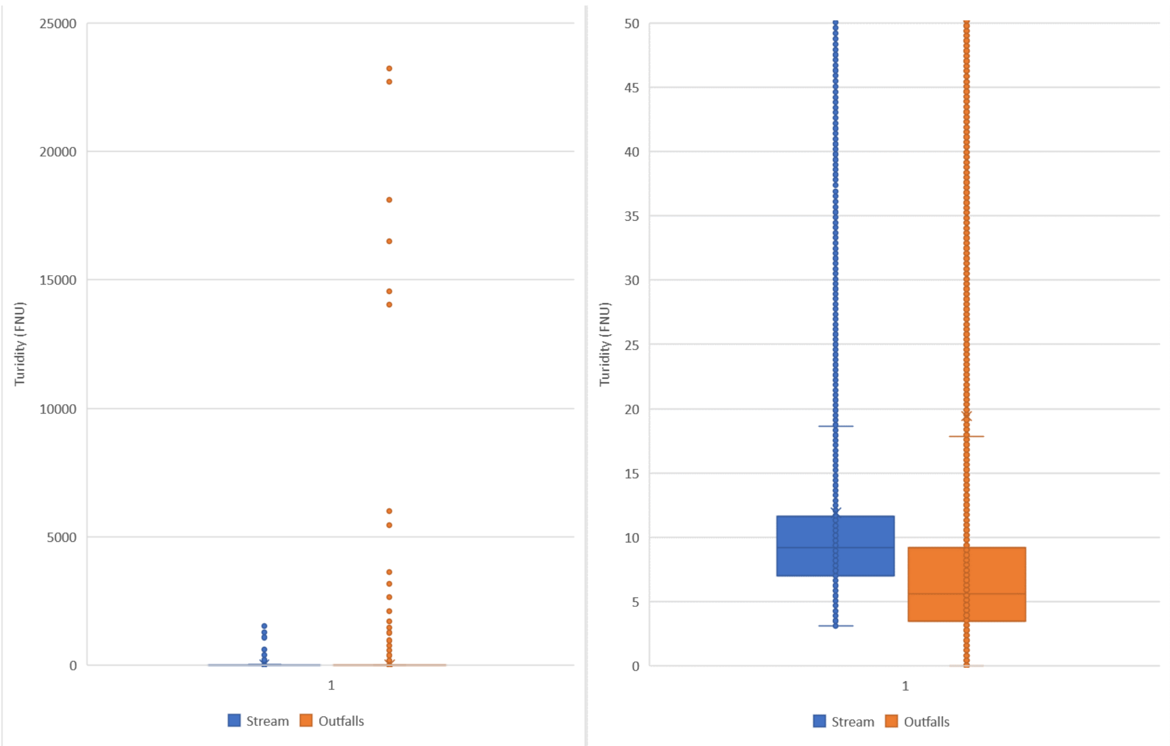


Figure 6: Turbidity Recorded at Stream and Development Outfalls at Earthworks Site 2. Left: All Data, Right: All Data With Scale Capped At 50 FNU.

We have also compared the turbidity recorded during the earthworks season (November to April 2018) and winter months (June and July 2018). This is shown in Figure 7.

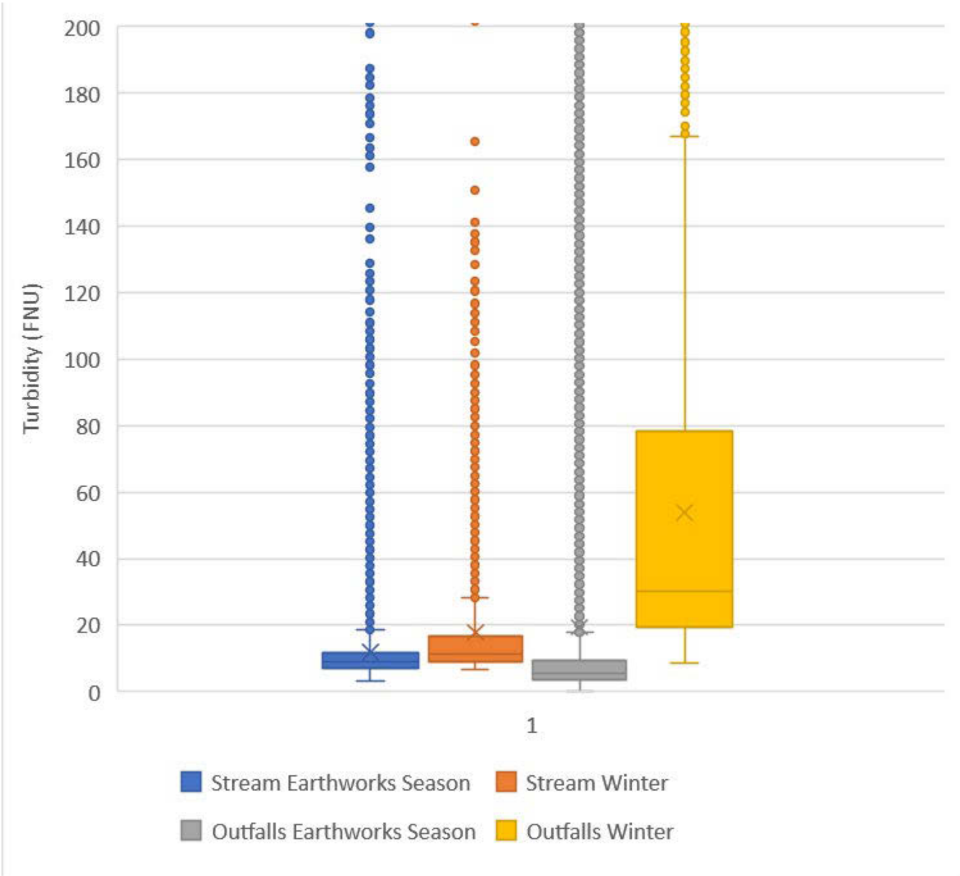


Figure 7: Comparison of Turbidity Between the Earthworks Season and Winter at Earthworks Site 2. Scale Has Been Capped At 200 FNU.

The high-level turbidity readings were also analysed to compare variations between the upstream turbidity and the development site. For the purpose of analysis, all values below 100 FNU were excluded. The median FNU was higher at the upstream site, however, the range of values recorded at the outfalls is more variable and the peak values are also much higher than upstream. This is shown on Figure 8.

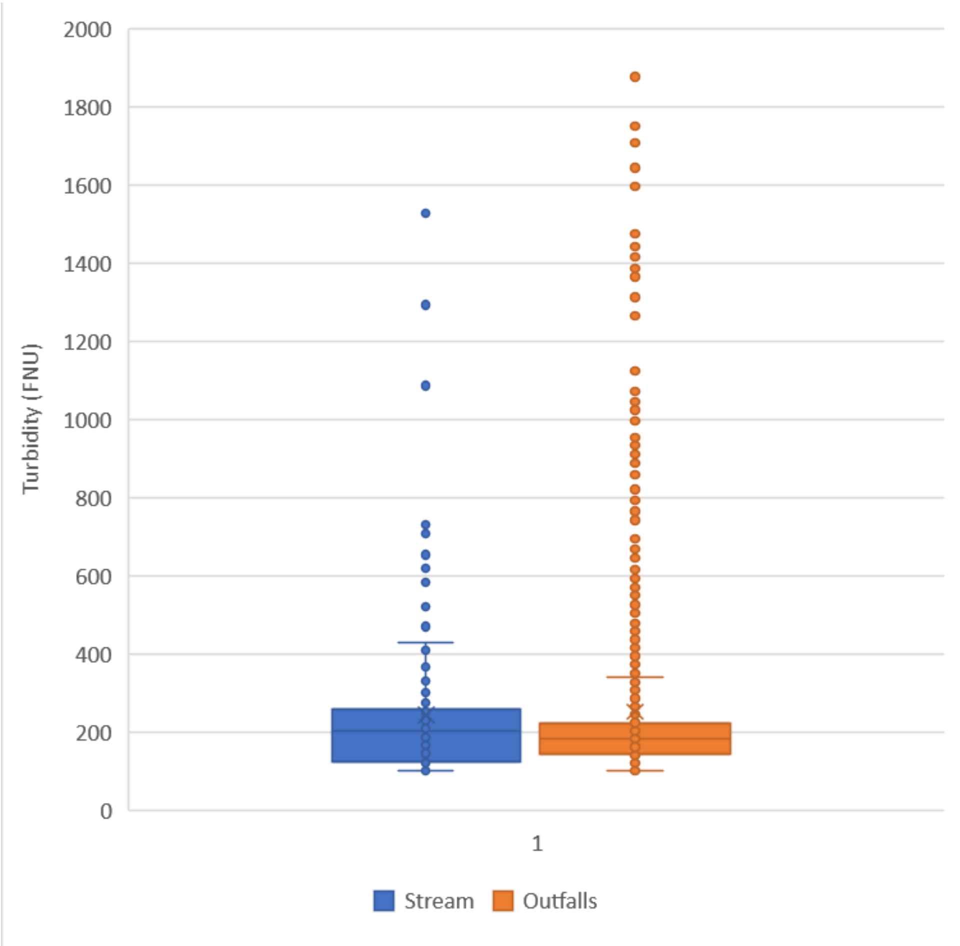


Figure 8: Comparison of Turbidity at Earthworks Site 2 For Peak Event Flows When Turbidity is in Excess Of 100 FNU. Scale Is Capped At 2000 FNU. Refer To Table 3 For Maximum Values.

To assess the effects of rainfall on turbidity rainfall data from the nearest Council Rainfall Station was obtained. The most significant rain event occurred during 20 to 25 December 2018 where approximately 182 mm of rain fell in two peak events, the first on the 20th December and the second on the 24th December. The rainfall information from 19 to 26 December was compared with the turbidity records from the stream and outfalls. The results are shown in Figure 9**.**

The peak stream turbidity and peak site outfall turbidity are offset from each other with the stream turbidity reaching its peak prior to the outfalls. The peak stream turbidity generally coincided with the peak rain event indicating little detention in the catchment. The turbidity levels increased sharply and then slowly decreased downwards baseline levels.

The peak site outfalls turbidity readings that occurred after rain events were delayed, indicating some retention time, but too little in these events to adequately reduce sediment. The subsequent small rain events also caused high peak turbidity readings, indicating that frequency is an important factor as the sediment controls were likely at capacity following the previous rainfall.

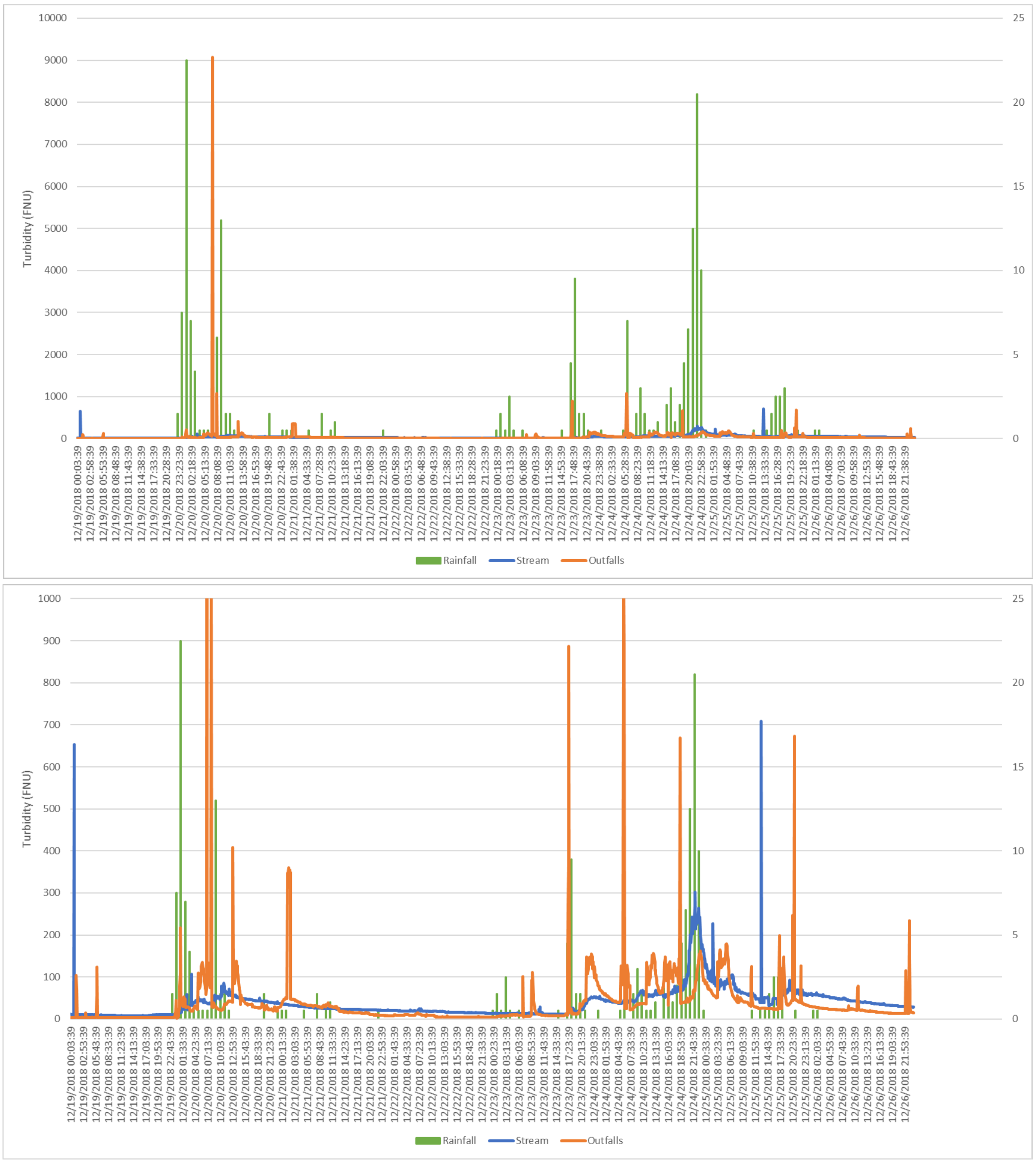


Figure 9: Comparison of Turbidity Recorded at The Stream and Outfalls During a Rain Event. Top Graph: All Data Shown. Lower Graph: Turbidity Scale Capped At 1000 FNU.

4.3.2 Long-term Effects

Urban Runoff Quality Information System Data

The Urban Runoff Quality Information System (URQIS) is a resource developed in 2012 that provides stormwater and urban stream quality data to the public by accessing a database of urban runoff quality data collected from all over New Zealand and compiled by NIWA. The database includes data supplied by Councils, Transport Agencies, Research Institutes and Universities across New Zealand. The data set includes data collected from a range of flow conditions and collected using a range of sample methodologies (for example: grab samples, multiple samples throughout a storm event, multiple samples combined before analysis, mean concentrations and continuous data).

Data available from URQIS has been assessed and the results of the sediment indicator results available from the URQIS data set are summarised in Table 4 below. The results presented in Table 4 show that developed catchments have higher median values for selected in-stream sediment indicators compared to rural catchments.

Table 4: Summary Results In-Stream Sediment Indicators Taken From URQIS:

Results	TSS (Mg/L) Rural Catchments	TSS (Mg/L) Developed Catchments	NTU Rural Catchments	NTU Develop Catchments
N =	81	218	796	2912
Minimum	0.1	0.04	0.4	0.15
Median	4	27	5.6	20
Mean	18	85	14	54
Maximum	470	11000	450	6000

State of Environment Sites

State of the Environment (SoE) monitoring sites located close to the case study sites were identified and the turbidity values (NTU) extracted. These were characterised into the phases forest through to urban, as illustrated in Figure 10.

The forested phase used an SoE site from the Waitakere Ranges, a mature forested area near Auckland (light blue).

The land clearing used a site on the Mahurangi River near Warkworth (grey) which has an extensive agricultural catchment and also one on the lower Kaituna River near Tauranga (yellow).

The stream adjustment phase used monitoring sites on the Vaughan Stream (green), Lucas Creek (dark blue) and Omaru (brown), all based in urban and urbanising areas of Auckland.

The results show that the medium, turbidity ranges from approximately 2 to 9 NTU, with the mean ranging from approximately 3 to 14 NTU.

SoE sites near development were also investigated for the development period, however are not presented here as these followed similar patterns as those presented above.

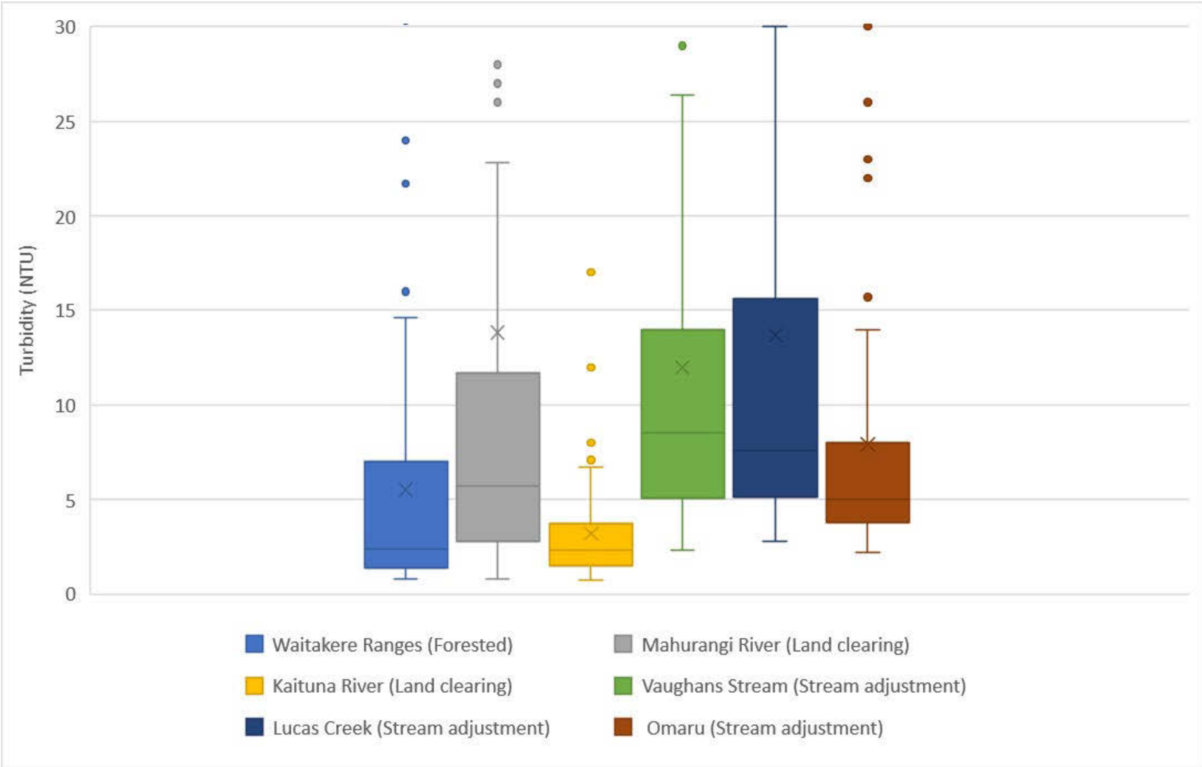


Figure 10: Turbidity Recorded at SoE Sites for Forested Catchments, Land Clearing (Agricultural) Catchments and The Stream Adjustment Phase in Urban Catchments. (Scale Capped At 30 NTU)

5.0 Discussion

5.1 Changes in suspended sediment load from the development over short and long-term timeframes

5.1.1 Short-term

Earthworks Site 1

The results from Earthworks Site 1 in-stream sediment attributes show a decrease in water quality downstream of the earthworks area during rainfall events. On average, the turbidity (as measured as TSS) increased and visual clarity (NTU) of the water decreased in samples collected from below the earthworks area and this change was more pronounced downstream of the earthworks than from upstream monitoring sites.

However, it is not known how this effects the turbidity during the antecedent dry period nor the presence of Fine Deposited Sediment (FDS) within run environments in receiving streams.

Transmission Gully

Data of turbidity levels provided to us for Transmission Gully is for trigger events when turbidity exceeds the design trigger levels, specified in the Erosion and Sediment Control Plans. Data was provided for the period September 2016 to April 2019 and includes 321 instances of turbidity exceeding the trigger levels. This indicates that while there are instances where high turbidity was recorded, in general, sediment levels are below the trigger levels, and approximately 90% of trigger level events occurred during or following rainfall.

The 2018 annual report indicates that the low level turbidity readings, below the trigger level, in the Horokiri Catchment have increased from the baseline monitoring period. We do not have the raw data to be able to analysis the information further, nor have we been provided with information on other catchments.

The Erosion and Sediment Control Plans specified trigger levels for two aspects:

- Effectiveness of erosion and sediment control devices based on Suspended Solid Concentration (SSC) readings taken at the inlet and outlet of the device. This is triggered when efficiency reduced below 80%. This is based on recording turbidity at the inflow and outfall of sediment retention ponds.
- In-stream sediment indicators, including continuous turbidity monitoring. There are two trigger levels, one based on rainfall events and the second based on dry weather conditions. There is also a long-term trigger if observed sediment load is noted to be greater than the AEE rating curve.

An events register has been kept, which details trigger level exceedances, their causes and the actions taken. The data is monitored continuously. Therefore, when triggers are exceeded, they could be assessed quickly and mitigated.

In regards to sediment and erosion controls, the main causes of trigger exceeded were:

- Catchment larger than the design capacity of the treatment device
- Intense or long duration rainfall events which exceed the device design guidelines
- Breakages, such as hole in floc outlet pipe
- Maintenance issues such as, pumping in of dirty water, sediment accumulation within devices, spoil piled near sediment devices.

- Scouring from high velocities at inlets/inflows.

Trigger events for stream turbidity generally occurred during rainfall events. Within 12 hours of a trigger, the activities and sediment controls in the catchment were assessed. The possible causes of high turbidity are below:

- Heavy rainfall events
  - Increased sediment due to natural erosion upstream of works
  - Increased sediment due to treatment devices being over capacity
- Natural occurrences such as slips in streams
- Access track slips
- Maintenance issues of erosion and sediment controls resulting in sediment discharge
- Resuspension of sediment in streams
- Activities upstream of development site, such as forest clearing or bank erosion.

Where events were deemed to have an ecological effect, further monitoring was undertaken. For the 2017 to 2018 period, two events required additional monitoring and for the 2016 to 2017 period, six events required additional monitoring. Sediment depth and cover were compared to a reference site in all instances, and no evidence of short or long-term effects were found.

Earthworks Site 2

The continuous turbidity data from Earthworks Site 2 show that the median turbidity is slightly higher for the stream than at the development outfall points. There was no monitoring undertaken downstream of the development site due to it becoming an estuarine environment. The data also indicates that the range of turbidity values for the outfalls is greater than for the stream with very high peak values recorded.

The comparison of rainfall and turbidity recorded at the different sites showed that in the stream, turbidity increased after a rainfall event and then returned to lower levels. For the outfalls, the turbidity generally also increased after rainfall, but was found to have much higher peak turbidity levels and more frequent sudden increases in turbidity that didn’t directly correspond with rainfall immediately preceding the spike.

5.1.2 Long-term Results

Case Study Sites

Earthworks Sites 1 and 2, and Transmission Gully are still undergoing construction and the long-term effects of construction cannot yet be ascertained.

State of Environment Sites

State of the Environment turbidity results were similar regardless of the upstream catchment land use. The results indicate that despite the catchment land use, flow conditions outside of storm events usually have low suspended sediment loads.

Data at SoE sites is sampled monthly, and does not represent a reasonable view of turbidity from urban sources. This is due to the timing of the sampling favouring ‘normal’ conditions and therefore sampling is usually not undertaken during or soon after periodic storm events. High sediment concentrations in rivers are often short lived and follow storm events, however under some conditions the sediment may be re-suspended following smaller hydrographic changes.

In all SoE sites presented, the high points (outlier data points) may be seen as indicative of the sediment from the catchment land use and development, however there is uncertainty in duration and intensity of these sediment events as the sampling is not continuous.

Generally, SoE site turbidity values representing the different phases of catchment development as well as SoE sites representing different periods of development did not provide useful indicators of the pulse nature of rainfall event sediment. The SoE turbidity monitoring has limited value in monitoring event driven sediment loads.

SoE sites were not used further in the determination of turbidity to catchment state due to the above identified issues in sensitivity to the pulsed nature of rainfall event generated sediment loading.

Urban Runoff Quality Information System Data

No case study considered suspended sediment load changes from pre-development, across construction through to mature urban catchment. URQIS was used to infer pre- and post-development catchment changes through using the catchment land-use layer to sort the dataset.

In-stream sediment indicators (TSS and NTU) were then used to infer sediment indicator changes associated with land use and land use change. Note, that we advise against attributing the higher in-stream sediment indicator values to different catchment land use alone. There is potentially a range of sampling, methodological and geographical differences in where, how and under what environmental conditions the data was collected, processed and analysed that have not been controlled for. However, with the large number of data points, and a lack of alternatives, a number of inferences can be made regarding the higher median values in post-development catchments.

As represented in the schema derived from the Task 1 Report, the higher median values could relate to higher sediment inputs than pre-development catchments. This could be a result of the catchment responding to the development stage, when land is stripped bare and bulk earthworks occur, or a physical, geomorphic response as streams adjust to increased impervious surfaces associated with developed, urban catchments.

5.2 Evaluation of in-stream indicators compared to proposed sediment attribute states.

Franklin *et al.* (2019) divided streams throughout New Zealand into 12 Sediment State Classification (SCC) classes based on their River Environment Classification (REC). The classification approach takes into account climate, topography and geology characteristics to reflect natural variation in riverine sediment.

Franklin *et al.* (2019) analysed biotic responses to in-stream sediment indicators; turbidity, visual clarity and deposited fine sediment as determined by areal coverage. The analysis was used to develop attribute states for deposited fine sediment and suspendered fine sediment for the 12 SCC classes. The attribute states ranged from A, minimal likelihood of instream biota being impaired, or ecologically communities being disturbed; to D, being a high likelihood of instream biota being impaired due to deposited sediment or turbidity, for the probable loss of sensitive macroinvertebrate and fish species and a change in community composition. Attribute Site D was considered as the National Bottom Line.

For each case study, the deposited and suspended sediment SCC class and the suspended fine sediment attribute state, measured as turbidity, were identified for the rivers that could be affected by development. For Transmission Gully, the works are located in six catchments, with some containing multiple rivers. The sediment attribute classes from the proposed sediment attribute framework (as per the draft guidelines provided to us) for each case study is shown in Table 5 below.

Table 5: Case Studies River Classification (Franklin *et al.*, 2019).

Case Study	River Environment Classification (REC)	Deposited Sediment Class	Suspended Sediment Class	Suspended Fine Sediment Attribute State
Earthworks Site 1	WW/L/HS	6	6	C
Transmission Gully				
• Te Puka	CW/L/HS	10	11	C
• Horokiri	CW/L/HS	10	11	C
• Ration	WW/L/HS	7	5	A
	WW/L/HS	10	11	D
• Pauatahanui	WW/L/SS	7	5	A
	CW/L/HS	10	11	D
• Duck	CW/L/HS	10	11	D
• Kenepuru	CW/L/HS	10	11	D
Earthworks Site 2	WW/L/SS	7	5	A

The attribute states shown in Table 5 are determined on median values and represent the long-term state of the stream. The data collected from the development sites show the short-term effects of the stream, with very high turbidity values measured following storm events.

Most of the data received from the development sites did not measure turbidity continuously or only provided the peak turbidity levels. Continuous turbidity monitoring was only available from Earthworks Site 2 which enabled a medium value to be calculated. However, monitoring at development sites is often only required at sediment retention pond outfalls or the immediate receiving environment and do not provide information on the overall changes to the stream. The data was not able to be used to determine the long-term impact on the stream and if the impact of the development could lead to a change to the current attribute state.

The infrequent measurements taken to determine the attribute state do not pick up the short-term variations in stream sediment. The data received from the development sites indicate that these peaks can be very high over short duration which may be significant enough in concentration or duration to have an ecological effect.

The use of the median value for determining the attribute state reduces the risk that that the data is skewed by single high values that represent a short-term condition. However, a focus on median values only for a stream will not take account of the short duration, but potentially ecologically significant, high turbidity events.

Short-term, higher turbidity events were recorded at Transmission Gully, but could not always be linked to an event on site, such as the failure of sediment controls, and suggests that there are natural events that produce high turbidity spikes in streams. Without understanding the natural turbidity variations in-stream, it is difficult to determine the level to which the development is affecting the natural turbidity flux of a stream and if the short-term peaks recorded at the development sites are similar in concentration and length to natural events.

6.0 Conclusions

6.1 Implications of implementing sediment attributes

The information obtained from case studies and URQIS indicates that development affects turbidity levels in streams. It also shows that the recorded turbidity levels downstream of development sites often have a much greater range of values and higher peak values.

High turbidity levels were most commonly associated with rainfall events. High turbidity levels occur naturally in streams during rainfall events; development is shown to increase the peak turbidity levels. During rainfall, the velocity in a stream also increases, resuspending deposited sediment (both natural and from development sites) which further increases turbidity. Any natural events such as slips, or sediment laden flows from earthworks sites will lead to sudden increases in turbidity. However, rainfall events are of short duration, the stream will normally return to base flows conditions and any stormwater input from the development sites will cease. Suspended sediment in stream will either be flushed further downstream or resettle and turbidity levels will return to background levels after rain ceases.

High turbidity levels within the monitoring data assessed in this study were found to be pulsed events, and short-term; high turbidity is unlikely to impact greatly on median values. Sediment monitoring at development sites is focussed on peak events of short duration, while the attribute states are based on long term trends. Based on the case study data received, changes to the median turbidity values from before and during development could not be determined and therefore it was not possible to assess if the development was leading to a change in attribute state for the affected catchment, as shown in Table 5. The National Objective Framework monitoring and attributes are focussed on long-term changes in watercourses, however the turbidity from urban development is a short duration, high peak event that will have little effect on the median of the attributes. Long-term baseline data from large development sites, which could provide some insight, is generally not collected.

However, there was evidence from an Annual Monitoring Report for one catchment at Transmission Gully that suggests that the turbidity during normal flows was increasing during development, which could have the potential to increase turbidity and result in a change in the attribute state in the developing area.

Increasing sediment loads can lead to higher turbidity for longer periods following rainfall. Increasing sediment deposition in stream can lead to increased resuspension during rainfall events, and even during base flows depending on in stream hydraulics. This pattern of resuspension is complex and variable. However, it will likely lead to impacts on the attribute states of turbidity and fine deposited sediments in stream reaches impacted by large scale upstream development.

6.2 Availability of data

Sourcing of data to analyse proved to be a challenge and several case studies were rejected on the basis that no monitoring information existed or was available within the study timeframes. This was because it was either not required by the consenting authority or was stored in a format that required significant time to collate and re-produce in a useable format. In some cases, records are kept by the contractors and are not required to be submitted to Council.

A further aspect to note is that data on sediment (turbidity or clarity) from developing sites was typically only available from sites where sediment was an identified issue and best practice interventions were in operation. The controls are constantly monitored to meet consent conditions and issues are quickly identified and addressed so that any adverse effects are minimised. The data available is therefore by its nature, from sites that are sensitive to the risk and are generally employing best practice in sediment management and response to events. No information or data is available from sites where there was no sediment or erosion planning or control. This 'missing data' should be kept in mind when considering the results presented.

Where consents for works do not require monitoring of turbidity or outfall discharges, the reliance is on the developer to maintain best practice and ensure that the sediment and erosion controls are put in place and working effectively. It must be expected that the success of this will be heavily reliant on each developer. Where sediment and erosion control requirements are reduced, either through permitted activity status or non-compliance, there will be a cumulative effect on the environment which could result in an increase in median turbidity over time.

The requirement for continuous data monitoring is relatively recent for development sites. While data has been sourced for recent projects, no information is yet available to determine the long-term impacts of the development on turbidity and if this impacts on the attribute state.

Where data was available, it often focussed on events where turbidity levels raised above a pre-defined trigger level. It was therefore not useful in determining changes to the median turbidity levels which is indicative of the turbidity during normal flow conditions.

Not all sites provided monitoring data from upstream and downstream of the development sites to be able to determine the effect of development in both baseline conditions and during rain events.

6.3 Wider catchment

Natural variability between catchments is recognised as a source of suspended sediment variability that is described in other reports. The grain size of material entering streams and the flow velocity of stream will determine if the material remains in suspension or can resuspend and increase turbidity. During development, it is generally the finer grained material that is released to streams while the coarse grained fraction is trapped by the sediment control devices and remains on site.

Impacts on sediment attribute state will also be influenced by the size of the catchment compared to the area of the development site. An earthworks site, which was considered as a case study but was unable to be used due to lack of monitoring information, was approximately 5.5 ha, while the adjacent Clutha River is a 7th order stream that drains over 1.4 million ha catchment at the outlet of Lake Wanaka. The contribution of this earthworks site is therefore unlikely to exert much influence on the sediment attribute state of the Clutha River in this location.

Consequently, the effects of additional sediment input from development and the potential for increased turbidity in the receiving environment may have a more pronounced effect on smaller first and second order streams where the catchment area is smaller.

The Task 4 Report undertakes modelling of predicted sediment yields during construction, taking into account the variation in bare earth exposed within a catchment at any one time and the impact of slope variations.

6.4 Targets Based on Current Guidelines

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC Guidelines), , provides a default trigger value for turbidity of 4.1 NTU in upland rivers and 5.6 NTU in for lowland rivers. The default trigger values are for unmodified or slightly modified stream ecosystems and were derived based on ecosystem reference data collected from five geographical regions across New Zealand. The trigger value for turbidity is based on the 80th percentile of the assessed data. They are considered to be used in combination with professional judgement to provide an initial assessment of the state of a water body, and can be used to determine if further monitoring is required.

McDowell, Snelder, & Cox (2013), provide trigger levels based on the River Environment Classification (REC). The trigger levels range from 0.8 NTU to 6.9 NTU.

A comparison with the URQIS data, shown in Table 4, shows that the median for all data is 5.6 NTU, which corresponds to the default trigger value on ANZECC. Data from, upstream of development at Earthworks Site 2 shows the stream median turbidity to be above the trigger value.

6.5 Consent Processing

The Regional Policy Statement (RPS) must state the significant resource management issues for the region. As discussed in the guidance note on NZCPS policy 22, where excess sediment is identified as a significant issue within a region, this should be identified in the RPS. This then leads to the inclusion of appropriate objectives and policies in the RPS, Regional Plans and District Plans.

Regional Plans, including regional coastal plans, may contain policies for controlling sediment arising from land use activities that are designed to guide the implementation of objectives at the regional level to address the identified issues. Regional Plans may also contain freshwater objectives to implement the NPS-FM through quantitative or qualitative sediment attributes and/or limits, having regard to the connection between freshwater bodies and coastal waters when setting any such limits.

District Plans can also have controls on earthworks and vegetation clearance that contribute to minimising sedimentation from widespread, small-scale activities.

Methods in plans can be regulatory (rules) or non-regulatory (e.g. education, incentives, support for community initiatives). Rules can be used to address both direct and diffuse sediment impacts from land uses or activities. They may refer to management or farm plans, codes of practice and good management practices. Provisions could also be included in regional or district plans to control or manage land use activities or their effects to help reduce sediment loadings in runoff and stormwater systems. Development standards in plan rules can set minimum requirements for the management of sediment loss from development sites. Restricting the area of land within a catchment area that can be disturbed or have vegetation cleared within a given period of time may assist in reducing runoff, while controlling the amount of new urban development within a catchment can reduce the generation of stormwater and subsequent sedimentation in the coastal environment.

Most regional councils have produced guidelines for earthworks. Including: Bay of Plenty (2001; 2010), Waikato (2009), Hawkes Bay (2009), Taranaki (2006), Wellington (2006), Canterbury (2007; 2017) and Auckland (1992; 1999; 2016).

The framework of planning instruments means that sediment is managed differently across the country.

6.6 Compliance, Monitoring and Enforcement

Councils have a duty to undertake compliance, monitoring and enforcement (CME) to ensure compliance with the RMA (Ministry for the Environment, 2018). It is critical that councils perform their CME functions to promote sustainable management of the natural and physical resources in their region. Councils that perform their CME activities poorly can significantly undermine investment in good planning, policy-making, and resource consenting processes. Councils' CME activities set clear expectations for the regulated community on the need to comply and are necessary to achieve desired behaviour change.

Whilst not the subject of this report, anecdotal communications has revealed a wide variety of different CME processes being undertaken around the country. For example, within the case study material analysed for this report, there is evidence that smaller sites had no CME other than engineering plan approvals whereas there is evidence that larger roading projects were visited by a dedicated team of council officers on a regular, multiday basis. This is supported by the work of Auckland Council that identified a lack of erosion and sediment control on small sites is an on-going issue and the cumulative effect of non-compliance, including permitted activity non-compliance, adds significant loadings of sediment and other contaminants to Auckland's waterways. Auckland Council (2018) also note a reduced regulatory burden on developers as a result of the adoption of the Unitary Plan, as well as almost 20,000 small sites being developed in Auckland every year creating significant time and cost burdens on compliance teams. Auckland Council (2018) further notes that high quality, sustained, compliance inspections supported by enforcement is required to achieve on-going compliance.

Guidance from the Ministry for the Environment (2018) encourages council to undertake CME on a risk-based approach. This means that the level of CME effort expended is proportional to the risk of adverse environmental effects from the monitored activity.

Given the significance of CME for implementing the Resource Management Act (RMA) and providing for good environmental outcomes, it is critical that CME activities are adequately resourced.

6.7 Mitigation and Interventions

6.7.1 Erosion and Sediment Control

The water quality results from Earthworks Site 1 and Transmission Gully show that the earthworks during construction can increase sediment yield. The erosion and sediment controls did not capture and treat all sediment-laden flows originating on-site prior to discharge into the receiving environment.

In part, this is because they are not designed to do so. As identified in the Task 1 Report, most erosion and sediment control guidelines have adopted a design standard for controls to be able to either convey or treat the flows associated with rainfall events up to the 5% AEP rainfall event. Although not specified, it is assumed that this is the 24-hour duration 5% AEP rainfall event and as such could be overwhelmed by shorter or longer duration rainfall events of an equivalent volume, or a sustained series of frequent, but small events.

Sediment controls do not withhold all sediment laden flows. Even the most efficient sediment control, a sediment retention pond, which with chemical treatment can achieve sediment removal efficiencies greater than 90%, there will be some discharge of sediment-laden water to the receiving environment.

An assessment of the non-compliance events from the stormwater sediment retention ponds at Transmission Gully shows that approximately 45% of events were due to maintenance or design issues and approximately 20% were due to the sediment ponds being too small for the catchment that they were servicing. In approximately 30% of events, high intensity or prolonged rainfall was given as a contributing factor and was occurring at the time that maintenance issues were highlighted.

A common cause of sediment retention pond efficiency reducing was high velocity flows entering the ponds that stir up the sediment or result in scour (resolved with inclusion of a forebay). Other issues included breakages to the floc pipes and build-up of silt in the ponds. It was also noted that while sediment retention ponds were achieving the required efficiency, there were instances where the discharge had high turbidity levels. At other times, high readings were recorded during non-work hours, so the cause of the high turbidity readings could not be determined. If a cause could not be determined, the high turbidity readings was often attributed to resuspension of sediment in the streams, rather than from the site works.

The information recorded for each event varies and it is unclear if the non-compliance events also correspond with a 10 year ARI event (Hicks et al., 2016). It is therefore difficult to determine the effect of turbidity when rain events exceed the 10 year ARI design of the sediment ponds. Where high rainfall was a contributing factor, it was stated that there was not enough time for settling of sediment during high velocity flows. Scouring of site soils from rainfall runoff and land slips also added additional sediment to ponds during storm events.

While the data shows that the effectiveness of sediment controls varies based on a number of factors and results in high peak turbidity, it was unable to indicate if the high turbidity fluxes from failures or rainfall events beyond the sediment control design effect the long-term attribute state medians.

Not considered in this assessment but significant to erosion and subsequent generation is the earthwork methodology. Various technical reports and reviews have noted methodological controls such as: limiting the area of land disturbance, reducing the slope length of earthworks areas, timing works to avoid working in wetter, winter conditions and rapidly stabilising worked areas upon completion can have in reducing sediment yield. Such a detailed assessment is beyond the scope of this report, but the effect of some of these controls are modelled in the Task 4 Report. It is also hoped that these controls are captured by the Council Officers processing the resource consent application.

6.7.2 Water Sensitive Urban Design and Long-Term Controls

Water Sensitive Urban Design (WSUD) is shown to reduce the sediment discharges from urban land uses. The initial aim is to reduce impervious area and also reduce earthworks by maintaining the streams and working with the natural topography for the development. Stormwater is also collected and treated as much as practicable with retention and detention devices such as stormwater ponds or wetlands, and raingardens. This minimises the impact to streams as the potential for erosive flows and contaminant discharge is reduced.

The sediment and erosion control ponds that are formed as part of design can be utilised as long-term stormwater retention ponds. There can be a period following development where the sediment and erosion controls are decommissioned, but with the removal of vegetation, the land is exposed and there is the potential for increased sediment loss. By careful transition from sediment retention ponds to long-term stormwater management devices, sediment controls effectively remain in place following bulk earthworks and during individual lot development.

Stormwater retention ponds and wetlands provide long-term sediment control within an urban environment but do require on-going maintenance to remove sediment accumulation. The on lot development phase can significantly shorten the required timeframes for initial maintenance actions.

7.0 Recommendations

Urban development has the potential to significantly increase sediment yield. Erosion and sediment controls are required in many instances to minimise sediment from development sites entering the environment. The assessment of case studies of various development projects around the country highlighted the variations in monitoring requirements and therefore availability of data. There is also a lack of long-term records following the completion of developments to assess the long-term effects of development on the attribute state.

We provide the following areas where we consider further information is required for better assessment of the long term effects of urbanisation of sediment attributes in an urban environment:

- To assess if there are changes to median values over time, turbidity readings must be continuous and measured at short durations, such as 15 minute intervals. This enables a baseline median to be determined which will include, but not be skewed, by short duration, peak events. This is not the case with typical rain event triggered sampling which comprises much of the data collected from the case studies.
- Insufficient data was available to determine if attribute states within receiving waters would change due to changes in the site median value.
- Encourage councils to develop data management systems for the capture and storage of sediment monitoring data.
- Set guidelines on sediment monitoring for urban developments, such as installing upstream and downstream continuous turbidity monitoring stations.
- Earthworks controls are not 100% effective and there is still residual sediment discharge, even if device efficiency is high. A multi-targeted approach is required to address sediment during urban development to reduce sediment discharge.
- Consideration of increasing the required design performance of sediment ponds to reduce the frequency that they are overwhelmed by either frequent or large rain events.
- Consideration of limits applied to the proportions of catchments exposed or being actively earthworked at any one time development at any one time.

Beyond the specific scope of work undertaken, the report findings are relevant for broader development practice and planning in a number of ways. These include:

- Consideration could be given to testing capacity of sediment controls such as sediment retention ponds. There may be potential for the arrangement of pond volumes vs outflow rates to be further optimised so that back to back events or larger events are better captured and overall sediment yields reduced.
- If earthworks monitoring were to more regularly include continuous turbidity monitoring, upstream and downstream of worksites, this could add value to compliance monitoring and enforcement and contribute to the wider understanding of sediment effects from urban development.
- In order to monitor effects of short-term sediment discharges not captured by median results of isolated sampling, sample reach sites could be monitored for fine deposited sediment within state of the environment programs.
- Standardised capture and storage of earthworks site information such, as staging and consent monitoring information, would potentially aid understanding and management of erosion and sediment control from urbanising activities.
- Investment in targeted monitoring programs spanning the development cycle at catchment and site scale could be valuable alongside wider state of the environment monitoring to confirm effects of urban development.

References

Auckland Council. 2018. Environment and Community Meeting Minutes, Meeting held 4 December 2018, Minutes available online at: http://infocouncil.aucklandcouncil.govt.nz/Open/2018/12/ENV_20181204_AGN_6846_AT_files/ENV_20181204_AGN_6846_AT_Attachment_64074_1.PDF, accessed 21 May 2019.

Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, October 2000.

Basher, L. Moores, J. & McLean, G. 2016. *Scientific basis for erosion and sediment control practices in New Zealand,* report prepared for Tasman District Council. Landcare Research Contract Report: LC2562.

CPB HEB Joint Venture, *Transmission Gully annual Monitoring Report 2018 (G.14)*, Reference TF-CPBH-RPT-ALL-GE-9301 Rev 00.

Dymond, J. R. Davies-Colley, R. J. Hughes, A. O. & Matthaei, C. D. 2017. Predicting improved optical water quality in rivers resulting from soil conservation actions on land. *Science of the Total Environment* 603-604: 584-592 p.

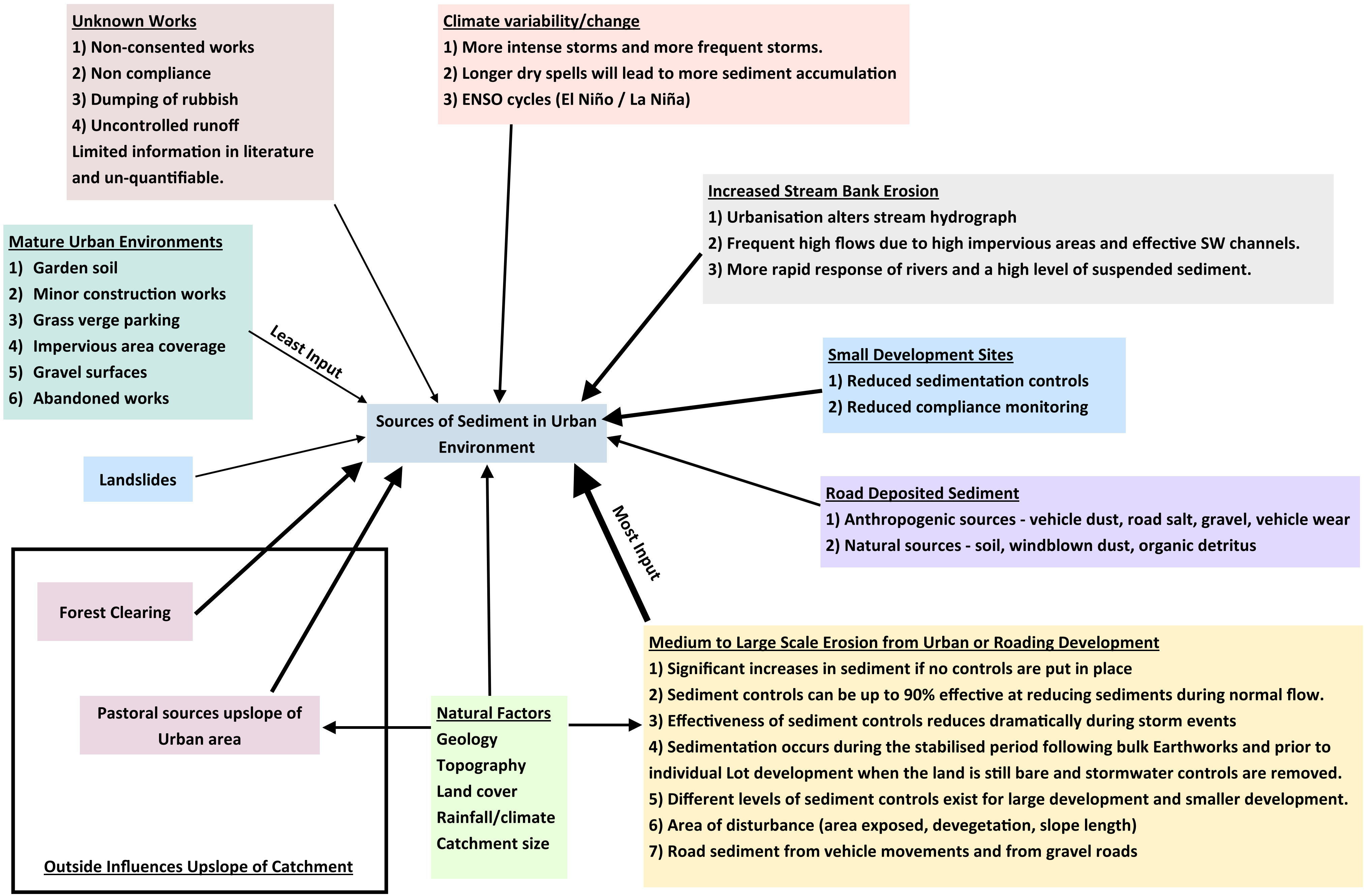
Hicks, D. Greenwood, M. Clapcott, J. Davies-Colley, R. Dymond, J. Hughes, A. Shankar, U. & Walter, K. 2016. *Sediment Attributes Stage 1* NIWA client report No: CHC2016-058 prepared for Ministry for the Environment.

McDowell, R.W., Snelder, T.H., Cox, N,. 2013. Establishment of reference conditions and trigger values for chemical, physical and micro-biological indicators in New Zealand streams and rivers. Prepared by AgResearch Ltd for the Ministry for the Environment.

NZCPS. 2010. Guidance Note Policy 22: Sedimentation. Retrieved from: https://www.doc.govt.nz/globalassets/documents/conservation/marine-and-coastal/coastal-management/guidance/policy-22.pdf

Ministry for the Environment. 1991. Resource Management Act (RMA) Section 61(1)(a). New Zealand Government, Wellington.

Appendix 1 Sources of Sediment in 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
Sources of Sediment in Urban Environment
Small Development Sites
1) Reduced sedimentation controls
2) Reduced compliance monitoring
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
Pastoral sources upslope of Urban area
Outside Influences Upslope of Catchment
Natural Factors
Geology
Topography
Land cover
Rainfall/climate
Catchment size
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