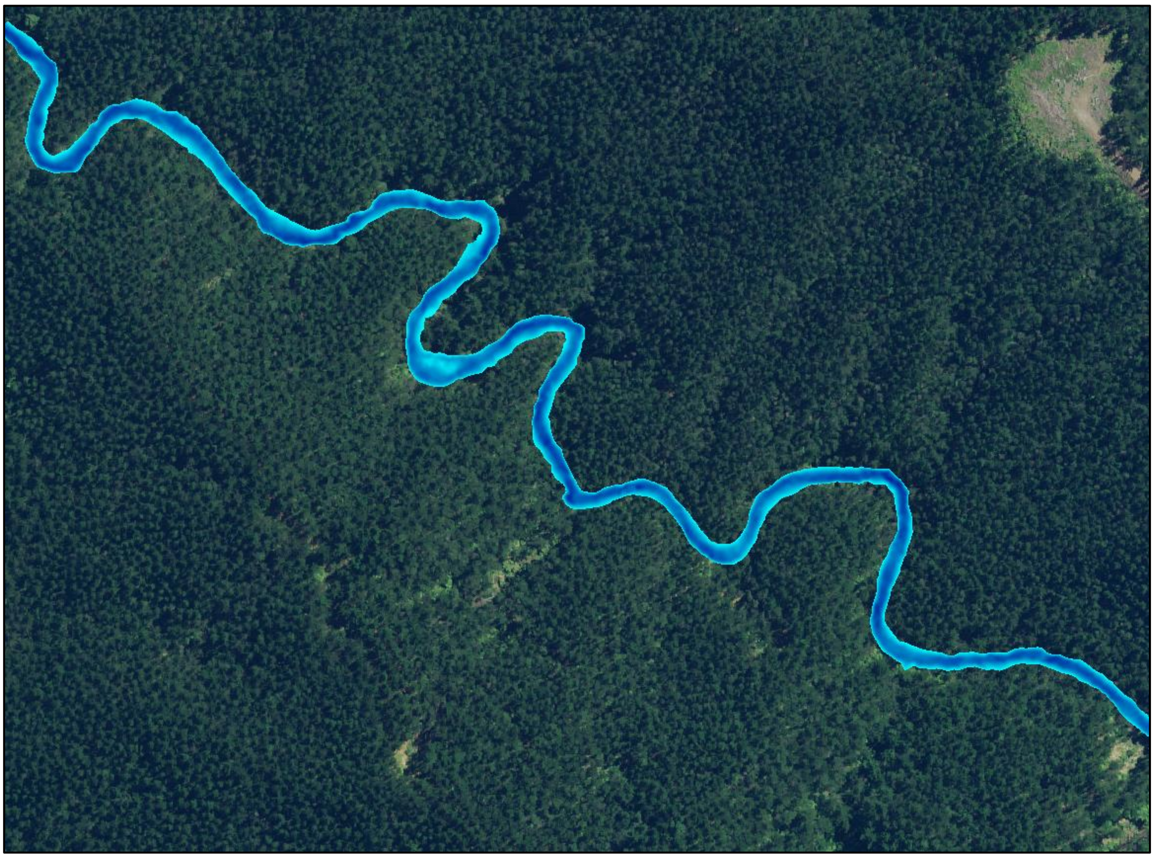
METHODOLOGY FOR ESTABLISHING STREAM SETBACKS FOR HARVEST RESIDUE REMOVAL



Arthur Elworthy

Final year honours project 2025

Forest Engineering, School of Forestry,

University of Canterbury

1. Executive Summary

Mobilised slash from floodplains is such an issue for New Zealand forestry that the Government introduced regulations under the National Environmental Standards for Commercial Forestry (NES-CF) requiring all slash to be removed from within the 5% Annual Exceedance Probability (AEP) floodplain boundary. However, no method is outlined in the NES-CF, *New Zealand Forest Road Engineering Manual*, or the *Slash Risk Management Handbook*. Therefore, this study set out to test two freely available tools for establishing the 5% AEP floodplain boundaries, firstly, using a generic pullback distance, and secondly, using floodplain modelling software (HEC-RAS) to model floodplain boundaries. HEC-RAS software is free, relatively easy to learn and use, and integrates well with existing GIS systems.

Over the course of the study, fieldwork was undertaken at 34 sites in the Opitonui River catchment (in the Coromandel Peninsula) to estimate Manning's roughness coefficient (n). Flood flows for 5% and 2% AEP events were also calculated for each site and used in HEC-RAS to model floodplain boundaries. The generic pullback distances were then compared to floodplain models and gauged flood data for validation.

The analysis found that although the average bank slope is correlated with overbank width, the relationship was not practical for determining a generic pullback distance in the field, as there was no useful correlation between flood flow and either average slope or overbank width. Alternatively, HEC-RAS using reached based estimates of roughness (n) was able to produce a 5% AEP floodplain model with a height above sea level only 0.5% different from that of a gauged 5% AEP flood event, demonstrating reasonable accuracy. However, this approach requires a considerable field effort (and cost) to generate the necessary Manning's n values. Simplifying the process by applying a conservative Manning's n value across the whole catchment increased the floodplain area by an average of 7-13%, and up to 45% in flat floodplains with a large flood flow. This shows that using a conservative n value can provide a factor of safety at a reduced modelling cost but may also lead to extra unnecessary costs from removing excessive slash. Harvest planners will need to consider the trade-off between accuracy and cost, as even though using conservative n values is a quick way to ensure compliance, it overestimates the floodplain area. Modelling waterways individually gives a better estimate of the floodplain boundary but also involves more fieldwork.

2. Table of Contents

3. Acknowledgements

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4. Introduction

Woody debris in waterways is a natural part of the ecosystem, with small amounts of stable slash providing in-stream benefits such as shelter for native fish species and reduction in water temperature (New Zealand Forest Owners Association, 2020). However, large quantities can block up or dam a waterway, leading to significant downstream effects if mobilised (Te Uru Rākau, 2024). Post Cyclone Gabrielle, the devastating impacts of mobilised slash became abundantly clear, as the sheer volume of harvest residues and other non-forestry related woody debris wreaked havoc on property and infrastructure in the Gisborne Region (Gisborne District Council, 2025).

Removing the large woody debris from a waterway's floodplain reduces the risk of mobilisation (Te Uru Rākau, 2024). The NES-CF has regulations that state all slash from harvesting must be removed from the floodplain area that a 5% AEP event would occupy ("NES-CF," 2017). Compliance with this regulation requires defining those floodplain boundaries. However, while the NES-CF, the *New Zealand Forest Road Engineering Manual* and the *Slash Risk Management Handbook*, specify methods to determine the flood flows from a catchment, no methodology is recommended to determine the floodplain area from the event flood flows.

Within this project, there is a focus on Manning's n value, which is a roughness or friction coefficient that the channel bed or floodplain applies to the water flowing over it (Oregon State University, 2006). A higher n value equates to a rougher surface and therefore slower-moving water, which in turn increases flood height and overbank width.

There are many methods to determine a waterway's floodplain area, ranging from manual hand calculations using Manning's equation, to freely available floodplain mapping software, such as HEC-RAS, to subscription-based floodplain mapping software; however, there is little guidance on which is the most useful or relevant approach.

Definitions

HEC-RAS

- Hydraulic Engineering Centre River Analysis System, is flood modelling software that allows a user to determine floodplain boundaries (US Army Corps of Engineers, 2010).

AEP

- Annual exceedance probability, is the chance of a flood of a given size or larger occurring in any one year, expressed as a percentage ("NES-CF," 2017). The peak flow rates of streams are given in m^3/s unless otherwise specified.

Flood Flow

- Flow is the amount of water moving down a river at a given time and location, and is measured as the volume of water passing per unit time (County Sheriff's Office Placer, 2025).

Floodplain

- A floodplain area is defined as the area that the waterway would occupy when in flood, with a flood event being the river height after a rainfall event that is above the height at which it normally flows (Environment Canterbury, 2025).

1D, 2D and 3D Analysis

- When computer models determine flood flows, this can be done in a 1D, 2D and 3D analysis, with a 1D flow being the simplest model of flow, a uniform constant flow in the same direction in only one plane, such as in a pipe. 2D analysis incorporates flow in two directions, and 3D analysis is the closest to reality, as the flow of fluids is 3D in nature, with parameters such as velocity, pressure and roughness varying in all three directions (EduRev, 2025).

Steady Flow Analysis

- A model doing a steady flow analysis is doing the same thing as a 1D model, where it assumes that the flow is constant past that point over time (Sánchez, 2025).

Unsteady Flow Analysis

- An unsteady analysis is more like a 3D model where the flow parameters vary over time past the same point, which is more realistic (Sánchez, 2025).

Reach

- A reach is a length of stream or river between two points (Waikato Regional Council, 2019). In the context of this project, a reach of interest would mean the stretch of stream before and after the point of interest where the n value was gathered during the field work.

Stream Order

- Stream order is a system used for classifying the hierarchy of streams draining a catchment. A first-order stream has no tributaries; a second-order stream occurs after the confluence of two first-order streams. This pattern continues with increasing stream order (Land Air Water Aotearoa, 2025).

Keywords

Floodplain modelling, HEC-RAS, slash, harvest residues, floodplain estimation.

5. Literature Review

Slash in a Waterway's Floodplain

There are several ways slash can enter waterways, some of which occur during harvesting when slash rolls or slides down the hillside into the creek or via landslides and slope failures (Te Uru Rākau, 2024). Slash in or near waterways is a major contributor, as "slash outside the waterway but within a floodplain is at risk of mobilisation" (Te Uru Rākau, 2024). Due to this, slash must be removed from a waterway's floodplain. However, a method to determine this floodplain area is not given in any guides, handbooks or resources for harvest planners to use. What is provided in the guidelines are methods to determine flood flows for a catchment. These can then be used in computer hydrology models to determine a floodplain, or by hand calculating channel cross sections using Manning's equation, which is time-consuming and at risk of inaccuracy when extrapolated over a large area.

How Slash Gets Mobilised in a Waterway

Slash gets mobilised in a waterway when the force of the flow is enough to push it over any resistance the bed materials offer, or when the depth of the water is such that the log floats (Braudrick & Grant, 2000). Once these large woody debris (LWD) are swept away into the waterway, they provide a greater force to dislodge other LWD further down the catchment (Visser & Harvey, 2020). However, predicting this flow rate or the depth at which a log moves is difficult, as there are many factors that impact LWD mobilisation. These factors can include log size, whether its roots are still attached, angle of log to flow direction, location in waterway relative to the greatest force of flow, as well as stream bed characteristics such as bed material (Braudrick & Grant, 2000). It was found that in smaller channels with larger logs and high roughness that a greater flow is required to move the piece over protruding bed particles (Braudrick & Grant, 2000). As it is a complicated process to determine the flow velocity and depth at which one size of log is mobilised, it would seem a waste of time to try to determine it for lots of variable pieces. Calculating the floodplain area and removing all harvest residues from this is a much more efficient use of time and energy.

The NES-CF

Flood flow estimates are required by two NES-CF regulations to ensure that rivers are not blocked, riverbanks are not eroded, and that there are no adverse effects on aquatic life and that downstream infrastructure is protected. Of the eight broad activities covered in the NES-CF, the two key activities that require a 5% AEP flood event to be calculated are River Crossings (Regulation 45) and Harvesting (Regulation 69). Regulation 69 Subclause (3) states that "Slash from harvesting must not enter into a body of water or onto the land that would be covered by water during a 5% AEP event" ("NES-CF," 2017). Slash is defined as any tree waste left behind after commercial forestry activities ("NES-CF," 2017). This implies that a floodplain area needs to be determined for the stream or river for a 5% AEP event, and that no slash shall remain in this area. Subclause (4) states that "If Subclause (3) is not complied with, slash from harvesting must be removed from a water body or the land that would be covered by water during a 5% AEP event, unless unsafe to do so, to avoid:

(a) Blocking or damming of a water body:
(b) Eroding of riverbanks:
(c) Significant adverse effects on aquatic life:
(d) Damaging downstream infrastructure, property, or receiving environments, including the coastal environment." ("NES-CF," 2017)

Global Strategies to Determine Stream Setbacks

There appear to be two strategies used for determining riparian zone boundaries that are subject to regulated management restrictions: set back distances and floodplain modelling.

Although there is no stream setback specifically defined for determining floodplain boundaries, there are arbitrary setbacks used for similar purposes, such as determining streamside activity setback zones. Within Washington State Legislation Table 1 is provided, which determines the distance back from a waterway that forest harvest operations are allowed to be carried out in (Washington State Legislature, 2001). With generic setbacks changing depending on the species being harvested and what zone operations are occurring (Washington State Legislature, 2001).

Table 1: Forest Activity Setback Zones (Washington State Legislature, 2001).

Site Class	RMZ width	Core zone width (measured from outer edge of bankfull width or outer edge of CMZ of water)	Inner zone width (measured from outer edge of core zone)		Outer zone width (measured from outer edge of inner zone)	
			stream width ≤10'	stream width >10'	stream width ≤10'	stream width >10'
I	200'	50'	83'	100'	67'	50'
II	170'	50'	63'	78'	57'	42'
III	140'	50'	43'	55'	47'	35'
IV	110'	50'	23'	33'	37'	27'
V	90'	50'	10'	18'	30'	22'

The North Carolina Forest Service use a similar methodology, applying generic setbacks based on the AEP of the event and activity location in relation to the waterway. For example, within the Goose Creek watershed, if an activity is within a 100-year floodplain, then a 200-foot-wide buffer should be applied (North Carolina Forest Service, 2020).

The US Environmental Protection Agency says that the width of a streamside management area (SMA) should be determined in one of two ways: a fixed minimum width or a variable width based on site conditions such as slope (US Environmental Protection Agency, 2005). With an overall minimum width of 35–50 ft (10.7–15.2 m) for the SMA to be effective (US Environmental Protection Agency, 2005). The width of a variable SMA depends on the type of stream or water body the activities are occurring next to. Table 2 shows the SMA widths recommended based on stream type and percent slope of adjacent land (US Environmental Protection Agency, 2005).

Table 2: Recommended Minimum SMA Widths (US Environmental Protection Agency, 2005).

Type of Stream or Water Body	Percent Slope of Adjacent Lands				
	0–5	6–10	11–20	21–45	46+
	SMZ Width Each Side (feet)				
Intermittent	50	50	50	50	50
Perennial	50	50	50	50	50
Perennial trout waters	50	66	75	100	125
Public water supplies (Streams and reservoirs)	50	100	150	150	200

Floodplain Modelling Software

A commonly used computer model for determining a waterway's flood plain is the Hydrological Engineering Centre River Analysis System (HEC-RAS). It was developed by the US Army Corps of Engineers to allow a user to perform 1D steady flow and 1D and 2D unsteady flow calculations (US Army Corps of Engineers, 2010). The HEC-RAS User's Manual defines model accuracy as "the degree of closeness of the numerical solution to the true solution" (US Army Corps of Engineers, 2010). The accuracy of the model depends on the following:

1. Assumptions and limitations of the model.
2. Accuracy of geometric data.
3. Accuracy of flow data and boundary conditions.
4. Numerical accuracy of the solution scheme (US Army Corps of Engineers, 2010).

The freely available HEC-RAS model was found to determine a water level of comparable accuracy to other, more complex models without the need for time consuming channel surveys.

Using this method, therefore, can save the flood forecaster time and money(Hicks & Peacock, 2005).

HEC-RAS outperforms other available models due to its compatibility with varying resolutions of digital elevation models (DEMs) (Moghim et al., 2023). The performance of HEC-RAS flood depth simulation is precise when compared with actual measured flood depths (Moghim et al., 2023). HEC-RAS is a favourable model option due to its preprocessing and post-processing capability (Shrestha et al., 2020). According to Hosseinipour et al. at the World Environmental and Water Resources Congress (2012), three main factors determine the accuracy of a 2D hydrodynamic floodplain model, these are:

(a) Hydrology-related factors that determine the flow, i.e. rational vs the regional method.
(b) Accurate representation of site conditions, i.e. surface topography.
(c) Waterway boundary conditions.

These factors are similar to those that determine accuracy as set out in the HEC-RAS user's manual, which highlights the importance of ensuring that, when using the model, the data input is as accurate as possible.

A study was conducted in 2023 to compare the performance of two flood models (HEC-RAS and LISFLOOD-FP) in two different terrain scenarios, one with flatter topography and the other with more mountainous topography (Moghim et al., 2023). It found that the HEC-RAS model output satisfactory results using only a few inputs, which is valuable due to limited data availability in many regions (Moghim et al., 2023). It also found that the accuracy of the HEC-RAS model output reached 80% in a 2D model when compared with a maximum recorded depth at a hydrometric station (Moghim et al., 2023).

The slope of the waterway's banks also has an impact on the accuracy of the predicted floodplain model, with floodplains that are characterised by large flat areas generating ambiguous floodplain models (Brandt & Lim, 2012). The accuracy of the model is also highly dependent on the DEM's resolution, with a positive correlation between higher resolution DEM and better accuracy of the floodplain model (Brandt & Lim, 2012). The research concluded that the factors that had the largest impact on floodplain model accuracy using HEC-RAS were DEM resolution and bank slope, with DEM quality impacting flooding extent and slope affecting the ambiguities of the floodplain boundaries produced (Brandt & Lim, 2012).

ArcGIS Pro is a commonly used GIS mapping software within the forestry industry which has a tool that allows a user to create a floodplain for a given waterway and rainfall event. This can be done by inputting rainfall rate, cell analysis size, ground infiltration rates, water source points, water flow barriers and channels and the starting water level (ESRI, 2024b). However, the accuracy of the results produced by the model will vary, as "scenarios that the mathematical model is not well suited for will result in less accurate results" (ESRI, 2024a). ESRI conducted a comparison between floodplain results generated in ArcGIS Pro with results from HEC-RAS and found generally similar results on flatter topography; however, with steeper slopes, the results varied significantly (ESRI, 2024a). The ArcGIS Pro model also does not take into account Manning's roughness coefficient n (ESRI, 2024a).

Variables Needed for Floodplain Estimation

To estimate the area that a waterway occupies under flood flow conditions, several variables are needed (US Army Corps of Engineers, 2010). A flood flow for the AEP of interest can be calculated using a number of different methods that depend on the size of the catchment and catchment characteristics. A roughness coefficient or Manning's n value, and the energy slope of the waterway are needed for both manual calculations and modelling software. Under uniform or steady flow conditions, this slope can be taken as the channel slope (Christchurch City Council, 2003). A surveyed profile of the stream and floodplain is required for manual calculations, or a digital elevation model (DEM) if using a floodplain modelling software.

Determining an Appropriate n-value

The *Roughness Characteristics of New Zealand Rivers* by D. M. Hicks & P. D. Mason (1991) (RCNZR) provides a reference dataset for visually estimating roughness coefficients that represent New Zealand conditions (Hicks & Mason, 1991). The roughness coefficient values of n were calculated by rearranging the Manning Equation as seen in Equation 1.

$$Q = \frac{A \cdot R^{\frac{2}{3}} \cdot S_f^{\frac{1}{2}}}{n} \quad [1]$$

Where Q is the waterway discharge in m^3/s, A is the wetted channel cross-sectional area in m^2, R is the hydraulic radius in m, and S_f is the friction slope of the waterway (Hicks & Mason, 1991).

A study conducted on the impacts of the n value on flood modelling errors found that a waterway's Manning's n value changes depending on the flow rate it is experiencing, so using the wrong n coefficient creates a large error in the resulting floodplain model (Al Mehedi et al., 2024). This change in n value occurs when the flow in a stream increases, the resistance parameter n decreases, as the effective relative roughness decreases and then increases again once the water reaches the floodplain (Hicks & Peacock, 2005). This is because floodplain roughness is normally higher than channel roughness (Hicks & Peacock, 2005).

There are several methods for determining a natural watercourses Manning's n value, from the use of tables such as Tables 3, 4 and 5, to conducting a full field survey with the stream profile and stream flow, then using Manning's Equation (1), back calculating what the Manning's n value was. There is also a method where full field surveys of each reach of interest are not necessary, and it explains that the n value can be estimated by comparing photos taken in the field to photos of reaches with verified n values (Arcement Jr & Schneider, 1989; Hicks & Mason, 1991). The book *Roughness Characteristics of New Zealand Rivers* (1991) has photos of many reaches, each with different bed and bank characteristics, which can be used in conjunction with photos of the stream of interest to determine an n value (Hicks & Mason, 1991).

Table 3: Manning's n values from the Hydrological and Hydraulic Guidelines (Environmental Hazards Group, 2012).

Natural stream channels				
A	Streams			
	1	Fairly regular section		
		(a)	Some grass and weeds, little or no brush	0.030-0.035
		(b)	Dense growth of weeds, depth of flow greater that weed height	0.035-0.05
		(c)	Some weeds, light brush on banks	0.035-0.06
		(d)	Some weeds, heavy brush on banks	0.05-0.07
		(e)	Some weeds, dense willows on banks	0.06-0.08
		(f)	For frees within channel, with branches submerged at high stage increase all above values by	0.01-0.02
B	Flood plains, adjacent to natural streams			
	1	Pasture, no brush		
		(a)	Short grass	0.030-0.035
		(b)	High grass	0.035-0.05
	2	Cultivated areas:		
		(a)	No crop	0.03-0.04
		(b)	Mature row crops	0.035-0.045
	3	Heavy weeds, scattered brush		0.05-0.07
	4	Light brush and trees:		
		(a)	Winter	0.05-0.06
		(b)	Summer	0.06-0.08
	5	Medium to dense brush		
		(a)	Winter	0.07-0.11
		(b)	Summer	0.10-0.16
	6	Dense willows		0.15-0.20

Table 4: Manning's n values for natural stream channels (Corrugated Steel Pipe Institute, 2007).

1. Fairly regular section:
   a. Some grass and weeds, little or no brush 0.030–0.035
   b. Dense growth of weeds, depth of flow materially greater than weed height. 0.035–0.05
   c. Some weeds, light brush on banks 0.035–0.05
   d. Some weeds, heavy brush on banks 0.05–0.07
   e. Some weeds, dense willows on banks 0.06–0.08
   f. For trees within channel, with branches submerged at high stage, increase all above values by 0.01–0.02

2. Irregular sections, with pools, slight channel meander; increase values given above about 0.01–0.02

3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:
   a. Bottom of gravel, cobbles, and few boulders 0.04–0.05
   b. Bottom of cobbles, with large boulders 0.05–0.07

Table 5: Manning's n values from Oregon State University (Oregon State University, 2006).

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. bottom: cobbles with large boulders	0.040	0.050	0.070
3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.030	0.035
2. high grass	0.030	0.035	0.050
b. Cultivated areas			
1. no crop	0.020	0.030	0.040
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.030	0.040	0.050
c. Brush			
1. scattered brush, heavy weeds	0.035	0.050	0.070
2. light brush and trees, in winter	0.035	0.050	0.060
3. light brush and trees, in summer	0.040	0.060	0.080
4. medium to dense brush, in winter	0.045	0.070	0.110
5. medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. dense willows, summer, straight	0.110	0.150	0.200
2. cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. same as 4. with flood stage reaching branches	0.100	0.120	0.160

Summary

Slash or large woody debris in a waterway's floodplain poses a significant risk to downstream infrastructure, neighbours and environments (Te Uru Rākau, 2024). Regulation 69 in the NES-CF says slash from harvesting must not enter a body of water or onto the land that would be covered by water during a 5% AEP event; however, it provides no guidance as to how this floodplain area should be determined ("NES-CF," 2017). There is also no method provided in the *New Zealand Forest Road Engineering Manual* or the *Slash Risk Management Handbook*. Although countries like the United States, use generic setback distances that are prescribed in tables based on slope and stream type, there is currently no standardised method for the forestry industry in New Zealand. HEC-RAS could be the tool that links the regulation to operational implementation. To use HEC-RAS to estimate floodplain boundaries, Manning's n values are required, which can be acquired through fieldwork (Arcement Jr & Schneider, 1989).

6. Objectives

There were two main objectives for this study. The first was to try to determine whether a generic pullback distance could be applied using bank slope and flood flow. The second was to test the potential of HEC-RAS as a tool for deriving 5% AEP boundaries by harvest managers to establish stream setbacks for harvest residue removal to comply with Regulation 69 of the NES-CF.

7. Methodology

Site Description

The study has been conducted in Whangapoua Forest on the Coromandel Peninsula, owned by Summit Forests. The forest consists of roughly 8,000 ha of plantation forestry, with most head basins being covered in native bush and lower areas of the hills consisting of pine forestry. In Whangapoua Forest, there is one gauged river, which is operated by the Waikato Regional Council, located on the Opitonui River, downstream of the Awaroa Stream confluence. See Figure 1 for the relative location.

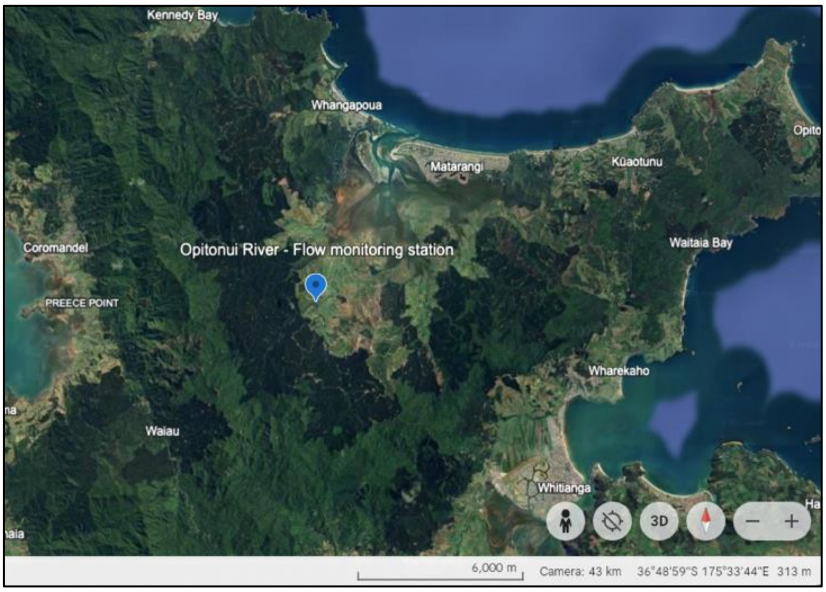

Figure 1: Location of Opitonui River Flow Monitoring Station (source Google Earth).

This gauged river was used as verification for the HEC-RAS models. The gauging station measures river flow in m^3/s and river height in m; the data was acquired with hourly height and flow readings over the operating period of the station from 1991 to the present.

Data Collection

Manning’s roughness coefficient n was determined through fieldwork for the gauged catchment in Whangapoua Forest. This gauging station sits just downstream of two large catchments, the Opitonui River catchment (~ 1,700 ha) and the Awaroa Stream catchment (~ 1,200 ha), with a total contributing area of ~ 2,900 ha. These are shown in Figure 2.

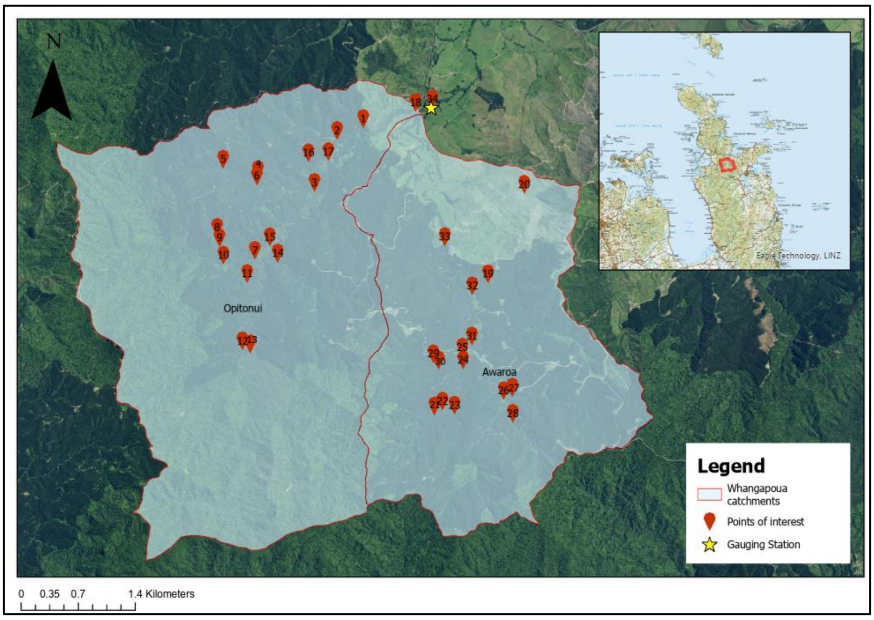

Figure 2: Map showing Whangapoua catchments and points of interest visited in fieldwork.

The n value was determined by visiting 34 sites within the Opitonui and Awaroa catchment area, the sites were chosen based on their stream order, with at least 10 sites of each first, second and third order streams. This was done to ensure there was a range of data for a mix of peak flood flows and different channel topographies. Some sites were chosen to be on the same stream so they would have similar flows but different terrain, again ensuring a range of data was gathered. Once at each site, photos were taken both upstream and downstream, as well as of both the left and right overbank floodplain area, as done by Arcement Jr & Schneider (1989). This is an established method of determining an n value, comparing photos of the stream of interest to photos of streams with verified n values (Arcement Jr & Schneider, 1989). The photos of streams with corresponding n values came from the RCNZR (Hicks & Mason, 1991).

Another fieldwork component that was completed but is not strictly necessary was surveying stream profiles at the river gauging station. This was done using a clinometer, measuring tape and a second person. With one person standing on the riverbank and the other standing at different points across the streambed, namely the stream edges, just below the stream bank and then at points where the riverbed changes. At each point, the person on the bank used the clinometer to determine the slope and the tape to determine the distance apart. This was done twice to create two stream profiles, then using the flow data from the gauging station for that time, it allowed the n-value for that reach to be calculated by rearranging Manning's Equation as seen in Equation 1. The calculations can be seen in Appendix B.

Data Processing

For each site, a Manning's n value was determined using the reference guides in RCNZR (Hicks & Mason, 1991), as well as n value tables found in the BOP Hydrological and Hydraulic Guidelines, as shown in Table 3 and the n values and descriptions shown in Tables 4 and 5. The RCNZR was used by selecting a reach that is similar to the one of interest and matching the characteristics as well as possible, including channel size and shape, bed material, slope and bank vegetation (Hicks & Mason, 1991). This was done using the photos collected in the field, and finding similar reaches based on channel characteristics. Once an appropriate reference reach was chosen, the value of n could be assigned to the channel bed and the overbank floodplain area.

Using any of the flood flow calculations requires a rainfall depth for the area of interest. This was acquired from the NIWA High Intensity Rainfall Design System V4, by selecting a rainfall gauging station closest to the area of interest and then exporting the table of rainfall depths. For the flood flow calculations, the rainfall depths used were under the RCP 2.6 scenario for a period between 2031 and 2050, which forecasts the predicted future rainfall depths due to climate change (Ministry for the Environment, 2024; NIWA, 2017).

Estimating a flood flow for each of these points was done using at least two methods for each reach of interest (New Zealand Forest Owners Association, 1999). The methods applied to each reach was determined by catchment area to the point of interest. For catchments less than 120 ha, the Rational and Modified Rational methods were used, and the flow rate was taken as the average between these two values (Kellagher, 1981; New Zealand Forest Owners Association, 1999). For catchments between 120 ha and 700 ha, the TM61 and Regional methods were used (Costley, 2018; New Zealand Forest Owners Association, 1999). For catchments greater than 700 ha, the Area Scaling and Regional methods were used (New Zealand Forest Owners Association, 1999).

Running the HEC-RAS model required an accurate Digital Elevation Model (DEM) of the whole catchment, a projection file, the flow rate and the n value. The DEM model was sourced from LINZ Data Service, which has a 1 x 1 m resolution and was compiled in 2025. The projection file that ensures the HEC-RAS floodplain model output is in the correct projection was sourced from epsg.io (NZGD2000 Zone 6 EPSG2135).

Once the 5% and 2% AEP flood flow for each point of interest was determined, a 1D steady flow model was created in HEC-RAS for the gauging station. The floodplains for all points of interest and the gauging station were all made under 1D steady flow models, as the steady flow system was designed for application in floodplain management and mapping (US Army Corps of Engineers, 2010). Once the steady flow model had been created for the reach where the gauging station lies, the height above sea level that the model estimated was compared with the height above sea level that the gauging station read for the same flow. This was done to see how different the floodplain model was from an actual event; this was repeated for the flow on the day the fieldwork survey was completed, and the respective heights above sea level were compared. Once it was determined that the HEC-RAS model could output floodplains with similar heights to actual events, 1D steady flow floodplains were run for the rest of the 34 points of interest with both the 5% and 2% AEP flows.

The estimated floodplains were then exported into ArcGIS Pro. Comparisons of the Stream/River Centrelines downloaded from LINZ with actual stream paths showed that they were not accurate enough to estimate overbank width. To remedy this, the process was as follows:

1. Create a new stream centreline using the Derive Stream As Line tool in ArcGIS Pro.
2. Model floodplain cross sections every 10 m along new stream centrelines using the Create Cross Sections tool.
3. To assign terrain data to the cross sections, the Interpolate Shape tool was used.
4. Once cross sections had been made, a 100 m section of the floodplain model close to the point of interest was chosen. Then every 10 m within this section, the left and right floodplain width was determined using the measure tool.
5. This process was repeated for both the 5% and 2% AEP floodplains for each of the 34 points of interest within the catchment.

The left overbank width is defined as the width from the centreline of the left-hand side looking downstream, and the right overbank width is defined as the width from the centreline of the right-hand side looking downstream.

At the same time as each of the overbank widths were measured, an average floodplain slope was also measured using the profile view of each cross-section in ArcGIS Pro. As there is no direct measure tool within the profile view within ArcGIS Pro, the slope was measured as rise/run, then converted to degrees. The rise was taken as the maximum height above sea level of the floodplain minus the height above sea level of the base of the riverbank. The run was determined as the horizontal distance between the floodplain edge point and the base of the riverbank. This produced an average slope across the floodplain. However, due to the topography of the area, the slope could change dramatically over the floodplain, often having steep riverbanks and then flat floodplains.

The downside of taking the average slope is that to determine it, the floodplain boundary needs to be known, which is not a reflection of how it would be in the field. Often, the larger streams and rivers had steep banks, which would have been simple to determine a slope; however, in a flood flow, these are often overtopped, and the flow at which they are overtopped is not known. See Appendices C – F for examples of how a floodplain cross-section changes over the length of the reach. With the average bank slope within the floodplain known, and the overbank width for that flow and slope, a correlation was able to be drawn between overbank width and slope.

8. Results

It was found that the model created for the gauging station reach was able to predict the flood flow height of the 5% AEP flood flow to within 0.5%, as it modelled a height above sea level (ASL) at the gauging station of 8.57 m, where for the same flow, the historic data recorded a flow height of 8.525 m, only 4.5 cm lower (Table 6). The HEC-RAS model also created floodplain models that were between 0.5% and 2.1% different to actual events (Table 6), with higher modelled flows creating more accurate floodplain heights. This is because at lower flows the DEM quality impacts the accuracy. As the DEM is created from LiDAR which cannot penetrate the water's surface, there is some error as the bathymetry below the water's surface is not included in the DEM model. This source of error has more of an effect at lower flows because at lower flows the depth of the water is lower, so the relative size of the missing bathometry is larger, creating a larger error. This shows that the model created for the gauging reach and Manning's n values determined through fieldwork were reasonable estimates of real values. Because of this, it would not be unreasonable to assume that for the rest of the points of interest, there would be a similar level of error between the 5% AEP floodplain model created in HEC-RAS and an actual 5% AEP event floodplain.

Table 6: Difference in Floodplain Height ASL (m) Between HEC-RAS and Actual.

	Model ASL (m)	Actual ASL (m)	Difference (m)	% Change
5% AEP	8.57	8.525	0.045	0.5%
10% AEP	8.46	8.39	0.07	0.8%
20% AEP	8.35	8.257	0.093	1.1%
50% AEP	8.19	8.038	0.152	1.9%
MAF	7.91	7.751	0.159	2.1%

A stream's channel and floodplain shape, bed material and flood flow all have an impact on how much area a certain flow will take up when the river is in flood (Hosseinipour et al., 2012). It was found that the average bank slope and overbank width were correlated. Evidence of this can be seen in Figure 3, where the average bank slope in degrees has been plotted against overbank width. Channel and floodplain shape is linked to overbank width through the slope of the banks, see Figure 3, with banks and floodplains that have a lower slope having a larger overbank width and banks with a higher slope having a smaller overbank width.

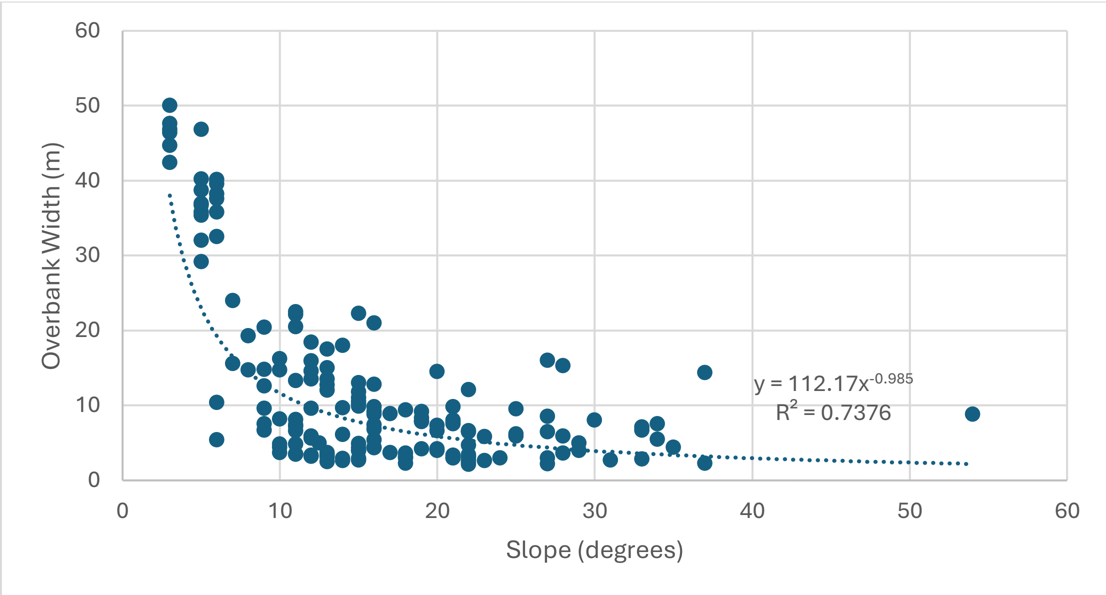

Figure 3: Average Bank Slope Plotted Against Overbank Width.

There is a good correlation between these two factors, as expected, as it makes sense for the flood to expand further over areas with flatter floodplains and not increase that much in height. Whereas in a steep-sided channel, the water level must rise more than a flatter floodplain to spread laterally. This relationship can be seen in Figure 3. The steeper-sided banks have a smaller overbank width than banks with a shallow gradient, which have a higher overbank width. However, what is not considered within the relationship between bank angle and overbank width is the effect that the flood flow has on overbank width. This is likely what causes some of the variation within the data, as a stream with a lower bank slope but also a lower flood flow will have a lower overbank width. However, as can be seen in Figure 4, there is little relationship between flood flow and overbank width. This lack of correlation is likely due to the variance of floodplain topography and bank slope (see Appendices C-F). This is shown in Figure 4, where floodplains were created at two points of interest along the same stream, the first point had a flatter floodplain, and the second point had steeper banks and floodplain. The 5% AEP flood flow over the upper section of the stream was 45.3 m^3/s, whereas 300 m downstream, after the confluence of a first-order stream, the flow was 48.0 m^3/s. The point of interest with the flatter floodplain and lower flow had a higher overbank width. Whereas just further downstream, where the flow was only 3.3 m^3/s larger the overbank width is significantly smaller, having a maximum overbank width of 14.8 m compared to the lower flow with a maximum overbank width of 46.8 m. This shows that there is little correlation between flood flow and overbank width, where a waterway's floodplain topography is variable.

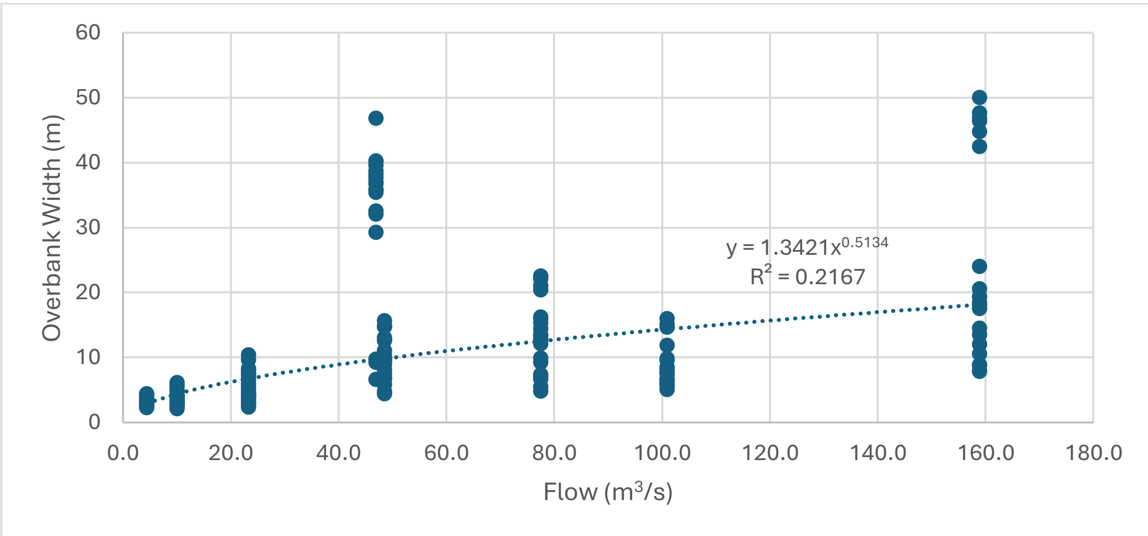

Figure 4: 5% AEP flood flow plotted against overbank width.

The lack of correlation between flood flow and overbank width can be seen in Figure 5, with the very low R^2 value highlighting the distinct lack of correlation between data points.

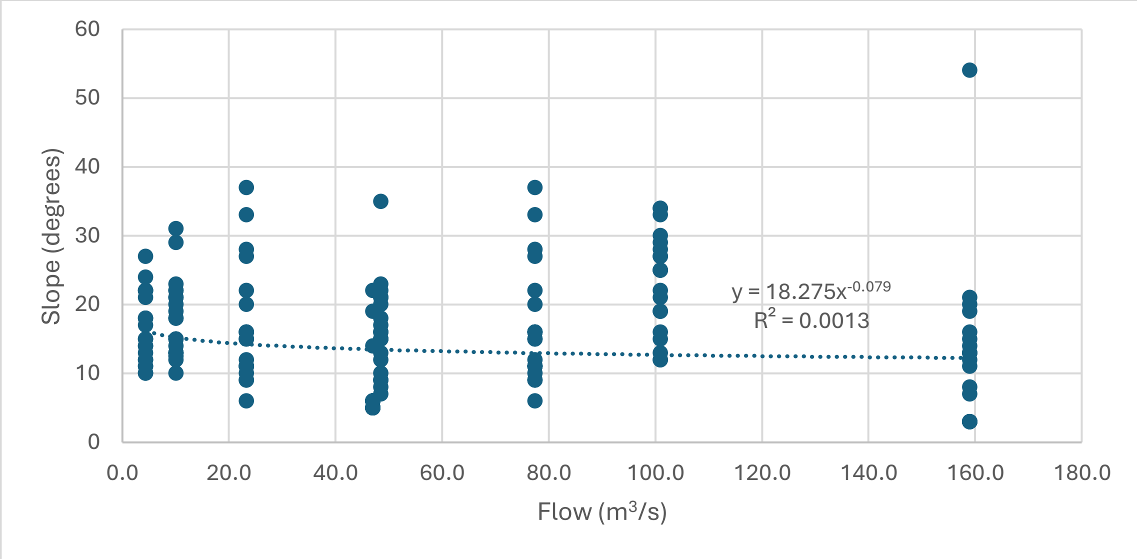

Figure 5: 5% AEP flood flow plotted against average bank slope.

Although Figure 3 shows a good correlation between bank slope and overbank width, the estimated bank slope did not accurately reflect a bank slope that could be easily determined in the field. This is because of the way the bank slope varies across a floodplain. It was also found that there is little to no correlation between flood flow and overbank width with floodplains of varying topography, and almost no correlation between flood flow and bank slope, which was to be expected. This means it would not be recommended to use a generic pullback distance based on bank slope and flood flow, or Equation 2 from Figure 3. As can be seen in Figure 3 the equation is derived from the relationship between overbank width and average bank slope in degrees.

$$Overbank\ Width = 112.17 \cdot (slope)^{-0.985} \qquad [2]$$

When Equation 2 was used to determine overbank widths, it was found that overbank width is underestimated on steeper banks and overestimated on flatter banks. A comparison with the floodplain profile created in HEC-RAS can be seen in Figure 6. Where LH AVG and RH AVG represent the pullback distance for the average bank slope for the left and right bank respectively. RH 1 is the pullback distance that would be used if the steep first section of the right bank was used in the average bank slope to overbank width relationship. RH 2 is the pullback distance that would be used if the flatter second section of the right bank was used in the average bank slope to overbank width relationship. These show how the pullback width would vary if slopes were determined infield and then used in the average bank slope to overbank width relationship from Equation 2. The two pullback distances based on average bank slope are both less than the floodplain boundaries as found by HEC-RAS and equate to different elevations above sea level (ASL), which would not reflect a real floodplain boundary. RH 1 reflects an infield slope measurement that could be taken and used, however, as the floodplain slope is variable it does not reflect a usable slope but is likely what would be recorded in the field for this cross section.

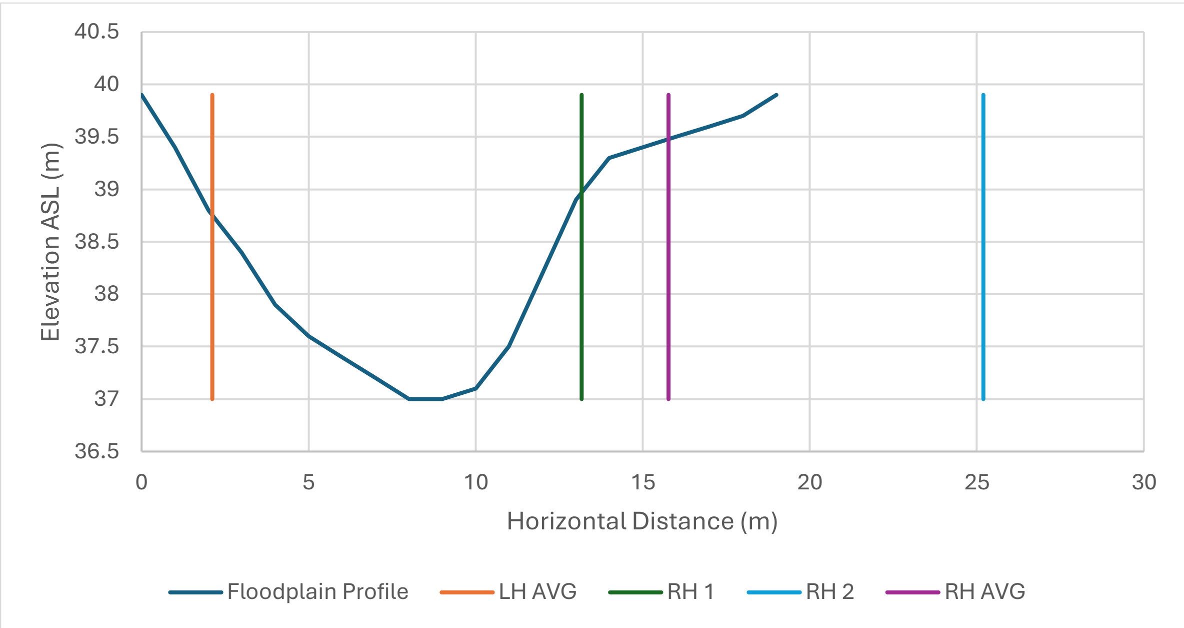

Figure 6: Comparison of HEC-RAS Floodplain Boundary and Generic Pullback Distances.

Due to the topography of a waterway's floodplain varying greatly as the stream or river flows down the catchment, this changes how far laterally the floodwaters will reach (overbank width). As this topography changes so does the bank slope which as seen in Figure 3 has a good correlation with overbank width. However, as mentioned previously, the average bank slope has been determined using a cross section; by taking the difference in height from the edge of the floodplain to the bottom of the riverbank and dividing this by the distance the change in height occurs over. The problem with this method is that although it reflects an average bank slope, it does not actually reflect a slope that someone in the field would be able to measure and get the same value, as to determine the average slope, the point where the floodplain ends needs to be known. As well as this, there is very little correlation between flood flow and bank slope and only a marginal relationship between flood flow and overbank width.

9. Discussion

There are several reasons for not using a generic pullback distance, from how it could be applied in the field, to the problems with determining a pullback width that could be used in the first place without many gross assumptions. Rivers and streams that have higher flows often have floodplains with a cross-section like that of Appendices C–F, so deciding in the field which slope to use, either the slope of the riverbank adjacent to the river or the slope of the floodplain adjacent to the riverbank, is a difficult task. Without knowledge of the exact flow a waterway breaks its banks from historical data or running flood modelling software such as HEC-RAS, it is not known at what flow rate the river breaches its banks. This would need to be known to compare with the 5% AEP flood flow, as if the flow it breaches its banks is greater than the 5% AEP flow, then the riverbank slope would be used to determine the pullback distance. Whereas if the 5% AEP flow is greater than the flow it breaches its banks, then the slope of the floodplain should be used.

Another factor not considered when determining a floodplain's width using a generic pullback distance is the roughness coefficient (Manning's n value). As floodplain size for a given flood flow changes with stream roughness, a generic pullback distance implies the use of a single n value across the whole stream. By necessity, a generic pullback distance will be defined by an n value that covers the variation in that value across the whole catchment. That will result in extending the modelled floodplain boundaries beyond what is necessary to meet the NES-CF requirement. As such, a better solution to finding the floodplain boundary of a 5% AEP flow to comply with the NES-CF would be to use HEC-RAS with an n value that reflects the changes in roughness across the catchment.

The best method to use HEC-RAS would be to visit the stream of interest in the field and, using the RCNZR or Tables 3, 4 and 5 or online resources, estimate a roughness coefficient (n value) for that reach. Then use HEC-RAS to model the floodplain for a 5% AEP flood flow for that catchment. However, if the harvest manager does not have time or is not able to visit the stream reach to estimate a roughness coefficient, then an alternative method would be to use very conservative roughness coefficients and apply these generically over the catchment.

By way of example, the floodplain boundaries modelled for this project were re-worked using HEC-RAS with conservative generic estimates of Manning's n value. Two sets of conservative n values were used, one was the maximum channel bed and floodplain n value as found from fieldwork (channel bed of 0.07 and floodplain of 0.1), and the other was upper end estimates from Tables 3, 4 and 5 (channel bed of 0.08 and floodplain of 0.15) which are guides used to help determine an n value from visual inspection of a natural stream. The maximum n values were deliberately chosen to be larger than n values likely to be seen in the Opitonui catchment. This was done to see how much extra area the floodplain would cover when a detailed survey cannot or has not been done. These n values were then applied generically to the whole catchment. The floodplains these estimates produced were compared with the 5% AEP floodplains produced with the n values from fieldwork, as well as the 2% AEP floodplains.

Using the same geometry files for each floodplain created in HEC-RAS, floodplains were also determined using different n values. This was done to determine how much further the floodplain setback would be with higher or more conservative n values. A higher n value slows the water down, effectively increasing the depth and therefore floodplain width.

The floodplain outputs from the models run with the higher n values were also exported into ArcGIS Pro as polygons (Figure 7). Since the start and end points were the exact same for the floodplain models run with the n values determined from fieldwork, any change in floodplain area due to the change in n values would be lateral due to the upstream and downstream conditions. This means that any change in flood height is linked to the change in floodplain area. Therefore, using the polygon area in m^2, in each floodplain attribute table, the floodplain area of each scenario could be compared, changing the flood flow (5% and 2% AEP events) and changing the roughness coefficient (0.07, 0.1 and 0.08, 0.15). A visual comparison of floodplains created with a 5% AEP flow and 2% AEP flow can be seen in Figure 7.

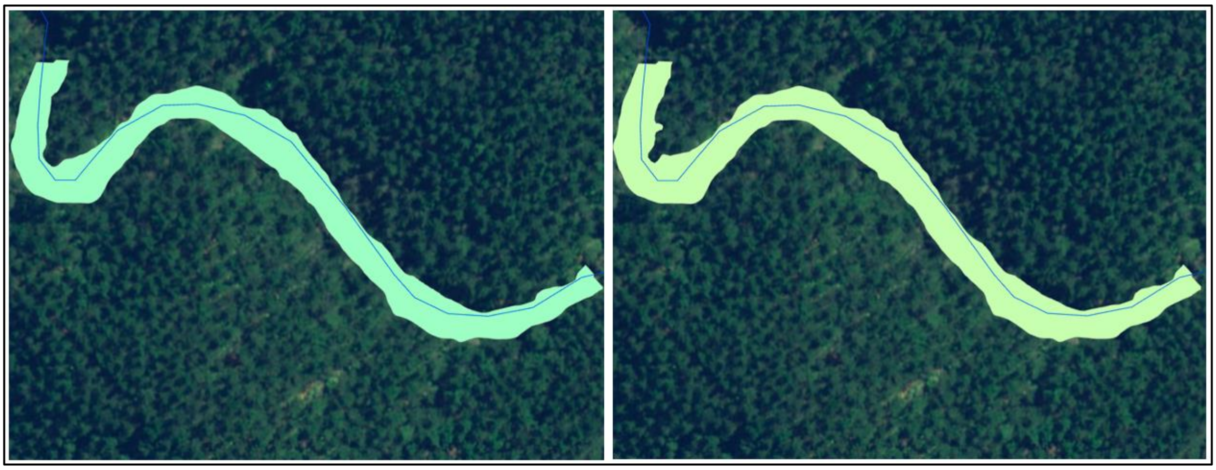

Figure 7: Comparison of 5% AEP (left) and 2% AEP (right) Floodplains.

The floodplain areas were compared using a percentage change calculation (see Equation 3), where the 5% AEP floodplain was the base for any change.

$$Percentage\ Change = \frac{(x_2 - x_1)}{x_1} \quad [3]$$

This percentage change shows the impact on floodplain area of either increasing flow volumes (2% AEP) or increasing n (0.07, 0.1 and 0.08, 0.15). The extent to which changing a Manning's n value can have on a floodplain area can be seen in Appendix A.

To make the floodplain models within HEC-RAS, a digital elevation model or DEM was needed, as this reflected the channel and floodplain shape and in a steady flow analysis, HEC-RAS models a flood flow over this area. During the analysis, a 1x1 m DEM was used, which was free to download from LINZ. It was also trialed using a 0.1x0.1 m DEM created from LiDAR data downloaded from Open Topography; however, under the dense canopy, the 0.1x0.1 m DEM had areas with a lack of coverage, which then created lots of artefacts. The 0.1x0.1 m DEM also took up a lot of storage and could only be downloaded in small sections, which is not ideal for modelling a large catchment. The advantage of using the 1 m DEM is that it is freely available to download for everyone and takes up less storage space, so it was decided to use the 1x1 m DEM. Although this DEM also had artefacts in it that caused the model to create some strange features, however, it only seemed to happen in smaller streams with a flood flow of less than 5 m^3/s.

Table 7 shows the change in area between the 5% AEP floodplain using n values determined through fieldwork, the 2% AEP flow floodplain using the same n values, the floodplain produced using (0.07, 0.1), and the floodplain produced using (0.08, 0.15). As can be seen in Table 7, the 2% AEP floodplain was a maximum of 16% greater, it was also a minimum of 3% greater and on average, over the 34 points of interest, 7% greater in floodplain area. This is as expected, as a larger flood flow through the same stream covers a larger area, and as the water level rises, it spreads laterally. The (0.07, 0.1) floodplain was a maximum of 32% greater; however, its minimum was 0% meaning that its floodplain area occupied the same area that the floodplain did using the fieldwork n values, and on average, the (0.07, 0.1) floodplain was also 7% greater in floodplain area. The (0.08, 0.15) floodplain was a maximum of 45% at a minimum of 1% greater, and on average 13% greater in floodplain area.

Table 7: Maximum, Minimum and Average change in area.

	Area % different		
	2% AEP	0.07, 0.1	0.08, 0.15
MAX	16%	32%	45%
MIN	3%	0%	1%
AVG	7%	7%	13%

It can be seen from Table 7 that using the 2% AEP flood flow with Manning's estimates from fieldwork or a 5% AEP flow with conservative (higher) Manning's n values (0.08, 0.15) produced a floodplain that occupied more area 100% of the time. Whereas, when using the largest Manning's n values as found through the fieldwork and applying this generically across the catchment, sometimes the floodplain produced occupied the same area as the floodplains made with fieldwork Manning's n values. The percentage change in floodplain area for each of the points of interest can be seen in Appendix A.

As the catchment has a gauging station which records flow in m^3/s and height above sea level in m, the output from the HEC-RAS models was able to be compared with gauged data to get an estimate of the accuracy of the model and estimates from the fieldwork. As can be seen in Table 8, using Manning's n estimates from the fieldwork, the height of the modelled floodplain was 0.5% or 4.5 cm greater than the measured flow height for that same 5% AEP flow rate.

Table 8: Gauging Station data compared with HEC-RAS model outputs.

	Height ASL (m)	% Change
Gauging Station Data	8.525	
Calibrated model (0.05, 0.065)	8.57	0.5%
0.08, 0.15	9.12	7.0%
0.07, 0.01	8.83	3.6%

This was done by comparing the floodplain areas created using 5% and 2% AEP flows and unique Manning's n values determined from fieldwork for each of the 34 points of interest, with floodplains created using conservative n values (0.07, 0.1) and (0.08, 0.15). The outcome from this was that 100% of the time, the conservative n values of (0.08, 0.15) created a larger floodplain than the fieldwork n value floodplains and were on average 13% larger. However, the downside to using this method is that on flatter floodplains with high flows, the conservative n values create much larger floodplains, up to 45% larger, implying that 45% more area is marked for slash removal, which may not need to be removed. If the catchment of interest has a gauging station in it, then the floodplain model can be run for the reach where the gauging station is. As gauging stations collect data on the flow and water height above sea level, the model can be run using a flow that the gauging station has experienced before, so it has a height above sea level for that flow. This can be compared with the height above sea level layer in HEC-RAS to estimate how different the estimated n value floodplain is to an actual floodplain in that catchment (Table 8).

There are two ways that a factor of safety could be built into an HEC-RAS model to ensure that the floodplain model covers all the area a real 5% AEP floodplain is likely to cover. These are: increasing the flood flow volume and using highly conservative n values or doing both. It was found that increasing the flood flow from a 5% AEP event flow to a 2% AEP event flow increases the floodplain area by an average of 7%, meaning that to comply with the NES-CF further than what is required a model can be run with the 2% AEP flood flow and on average it would mean that only 7% extra area has slash being pulled away from it. Or if the other path is followed using conservative n values of (0.07, 0.1), it is also on average 7% greater in area. If the highly conservative n values are used (0.08, 0.15), then on average 13% more area is pulled back from.

MPI are currently proposing to make changes to the NES-CF, making amendments to slash management regulations 69(5-7) (Te Uru Rākau, 2025). This potential change could mean that areas that are considered at high risk of slash mobilisation, such as floodplains, require the removal of most slash from the cutover or by mitigations agreed through a resource consent (Te Uru Rākau, 2025). This would mean that outlining the 5% AEP floodplain area, as in the NES-CF, now would become an important task in identifying where the high-risk areas of slash mobilisation are.

10. Conclusion

The purpose of this study was to determine a methodology for determining a floodplain area within a commercial forestry environment utilising HEC-RAS, to comply with Regulation 69 in the NES-CF.

The key findings of the project were that the average bank slope correlates well with overbank width, but this slope does not correlate with a slope that would be measurable in the field and therefore a generic pullback distance would not be the best method to use. It was also found that there is little to no correlation between overbank width and flood flow due to topographic variability along a reach, and as expected, no correlation between bank slope and flood flow. Due to this, it was found that using a generic pullback distance based on bank slope and flow would be inaccurate, again because of the topographic variability along a stream or river and the difficulty determining a floodplain bank slope in field. For the above reasons, it was decided that a better option would be to use HEC-RAS with field estimates of n value, as this generates a model closest to an actual flood event. It was found that HEC-RAS was able to create a floodplain only 4.5 cm higher than gauged data for the same flood flow, using Manning's n values determined through fieldwork for the gauging station reach. However, if the harvest planner does not have time or is not able to visit each site, then conservative (high) n values could be used, which would add a factor of safety to the model. Using a conservative n value can save time through lack of field work; however, it does overestimate the floodplain area by up to 45% in certain circumstances.

The advantage of using HEC-RAS is that it is free, accessible to everyone, relatively simple to learn and use and integrates well with existing GIS systems and harvest planning software. However, there are some limitations associated with using HEC-RAS, with smaller streams (a flood flow less than 5 m^3/s), the model is prone to creating artefacts due to the coarse DEM. The assumptions in n value are also a limiting factor in the accuracy of the output floodplain models, as it means that any outputs will only be estimates. Using a conservative approach may also lead to the extra cost of removing slash from areas that are not actually within the 5% AEP floodplain; to avoid this, a consulting engineer could be used, but it would be up to the harvest manager to determine which level of cost is most appropriate. HEC-RAS provides a more defensible method than applying generic pullback distances, and by determining the floodplain area, it shows compliance with the NES-CF and any potential future amendments.

Future research could build on this study by carrying out a cost-benefit analysis of whether a forest manager is better off paying a consulting engineer to model a stream's floodplain more accurately or whether the manager would be better off using n values determined themselves. Through visiting the site or using conservative values, modelling it themselves and possibly paying more to remove slash from areas where it does not need to be removed.

All models are wrong in some way, and even the best estimate is still an estimate. In saying that, HEC-RAS provides a practical, adaptable and defensible tool that could be used by forest managers throughout New Zealand for floodplain mapping to meet Regulation 69 in the NES-CF.

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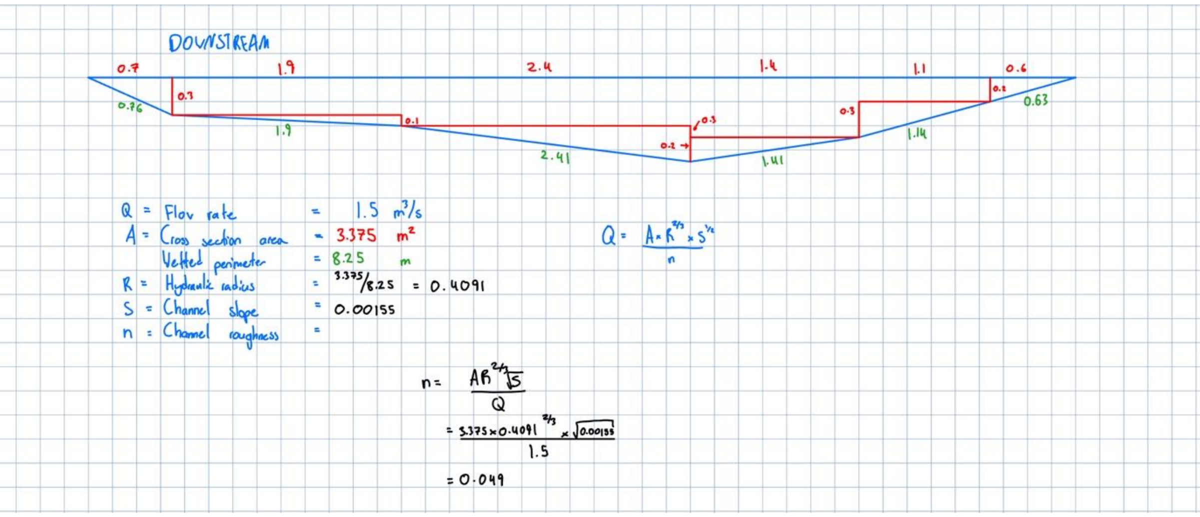
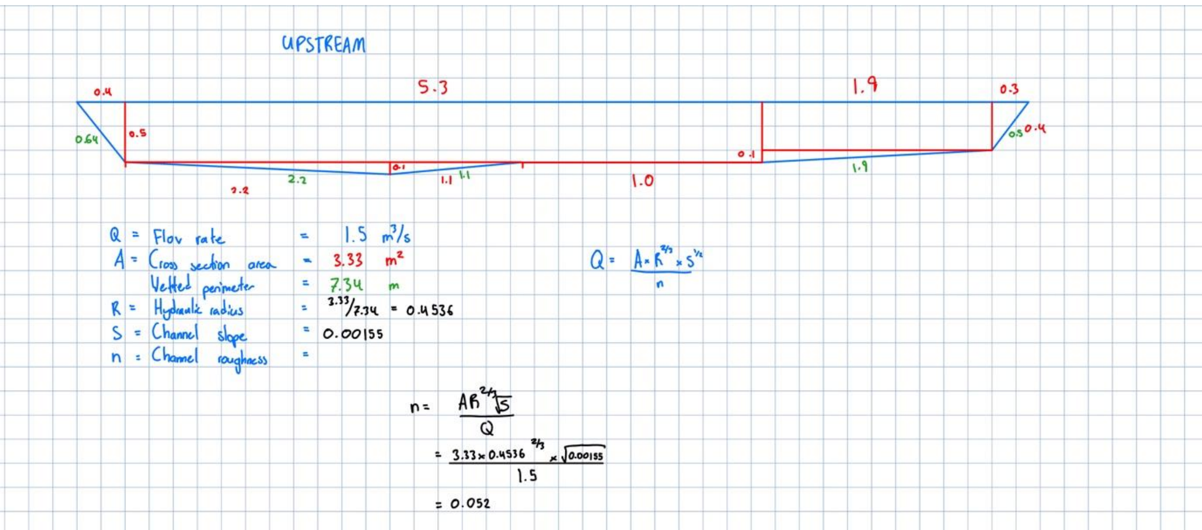
12. Appendices

Appendix A: Percentage Change in Floodplain Area.

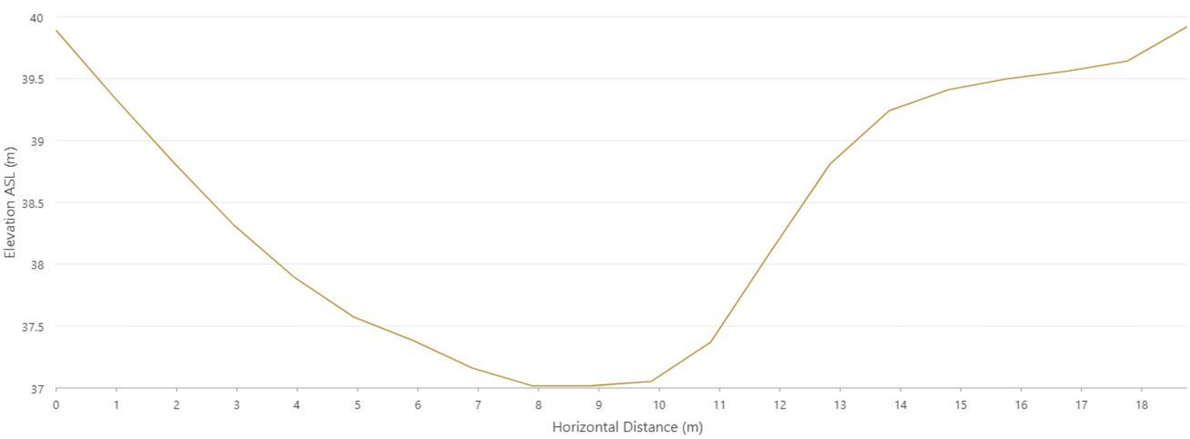
	Percentage Change in Area		
Point of interest	**2% AEP**	**0.07, 0.1**	**0.08, 0.15**
1	7%	10%	11%
2	4%	2%	9%
3	7%	4%	11%
4	6%	1%	4%
5	5%	2%	4%
6	6%	1%	2%
7	8%	7%	19%
8	7%	0%	1%
9	6%	1%	4%
10	3%	1%	3%
11	6%	7%	14%
12	4%	3%	9%
13	12%	11%	22%
14	7%	8%	13%
15	13%	12%	18%
16	5%	4%	10%
17	12%	17%	25%
18	8%	21%	37%
19	4%	2%	5%
20	7%	3%	9%
21	6%	1%	6%
22	10%	5%	14%
23	6%	0%	2%
24	16%	15%	29%
25	5%	6%	11%
26	6%	7%	15%
27	5%	0%	4%
28	5%	1%	4%
29	7%	2%	5%
30	5%	3%	7%
31	14%	11%	25%
32	14%	32%	45%
33	10%	23%	43%
Gauging Reach	3%	5%	10%

Appendix B: Calculations for Manning's n value using fieldwork survey data.

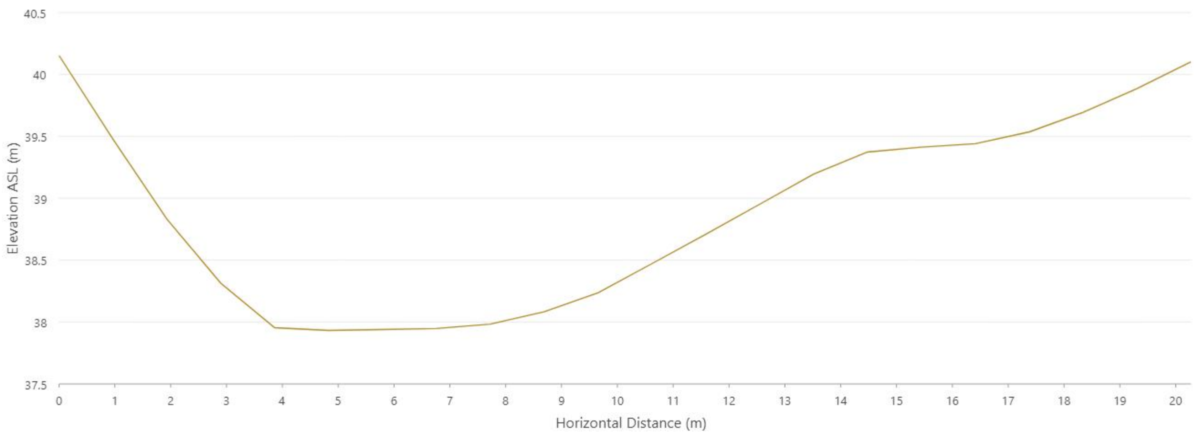




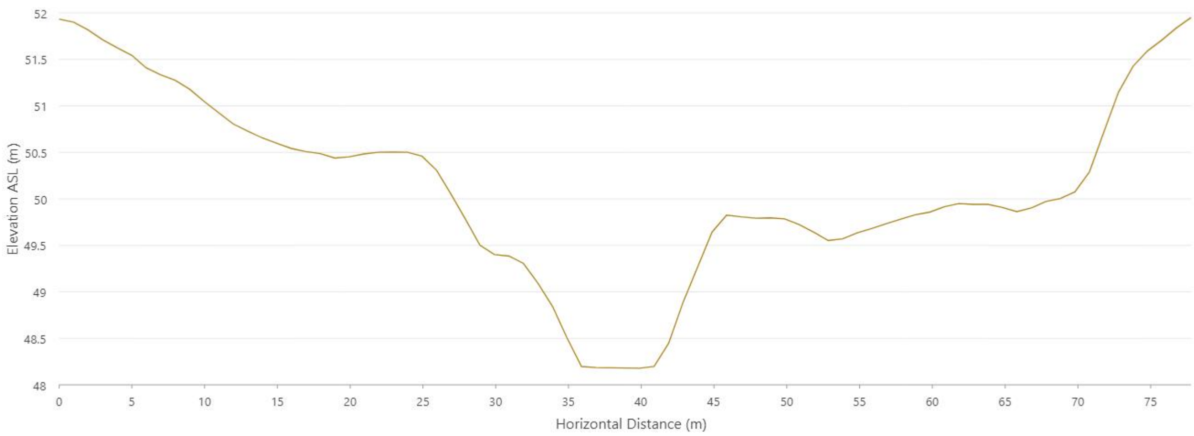
Appendix C: Cross section of point of interest 7, upstream.



Appendix D: Cross-section of point of interest 7, downstream.



Appendix E: Cross section of point of interest 10, upstream.



Appendix F: Cross section of point of interest 10, downstream