Cyclone Gabrielle

Post Event Woody Debris Assessment – Hawke's Bay

Prepared for **Hawke's Bay Forestry Group**

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1 Executive Summary

Cyclone Gabrielle impacted Hawke's Bay from 13 – 14 February 2023. It was one of the most intense storms to impact New Zealand in recorded history. During the most intense 12-hour period of Cyclone Gabrielle, 400 mm of rain fell with a peak intensity of 56 mm per hour at the Glengarry Hawke's Bay Regional Council site. The highest measured 24-hour rainfall period during Cyclone Bola was 419 mm at Te Puia Springs. This indicates that Cyclone Gabrielle was a much more intense storm than Cyclone Bola during their respective peaks, as it affected parts of Hawke's Bay. Prior to this event was a sustained, record-breaking, wet 6-month period for Hawke's Bay from July 2022 to January 2023. The impact of heavy rainfall during Cyclone Gabrielle was in addition to already saturated soils.

As a result of this extreme weather event, large masses of woody debris have been deposited across Hawke's Bay. Commentators from the media and the public have referred to this material as 'slash'. Slash is defined as woody material left as waste after harvest of plantation forest. The implication of this categorisation by the media, and resulting public impressions, is that the majority of woody debris suggested as the cause of damage to infrastructure came from waste left behind after the harvesting of the plantation forest estate. Hawke's Bay Forestry Group (HBFG) commissioned this report to independently quantify large woody debris (LWD) content along the coastal, and inland catchment areas, characterising it by species, likely source, volume per hectare, and total volume accumulated.

The methodology used in this report was an adapted Line Intersect Sampling (LIS) method. This method is well-established as a means of calculating volume of woody debris. It has been used since 1964 by the forestry industry for residual woody debris volume assessments after clear fell harvest. The adaptation of this method is to account for the non-random orientation of the LWD due to the flow of water or action of waves in determining the final resting orientation of the pieces. This was done by employing an equilateral triangle plot with randomised plot locations and randomised starting bearing of the first side of the triangle.

Results from the surveys indicate that the proportion of LWD with evidence of harvest residue origin is at 4%. The proportion of pine with root ball attached is 13% that has originated from mid-slope failure and/or streambank erosion, and 31% is pine with no root ball or harvest evidence. This latter category of material cannot be ruled out as harvest waste, but due to the significant areas of mid-rotation pine forest lost from the plantation estate to water and its tendency toward smaller diameter (than harvest material), it is likely to have originated largely from younger, standing wood sources. The total pine proportion is 48% of the LWD across Hawke's Bay. It was also found that 38% of the LWD was identified as willow or poplar. The likely origin of this material is flood-protection willow and poplar plantings along the streambanks planted to preserve the streambank from erosion during flooding. Given that willow and poplar are considered effective for this purpose, this highlights the intensity of the event and the fragility of the Hawke's Bay floodplains.

Further analysis into the area of lost standing woody vegetation of any type should be conducted to give certainty to the likely origin of the woody species in LWD and further help inform correct land use decisions.

2 INTRODUCTION

2.1 BACKGROUND

Hawke's Bay Forestry Group (HBFG) represents the principal forest owning companies in Hawke's Bay. Due to the impacts of Cyclone Gabrielle through Hawke's Bay, it was apparent that large woody debris (LWD) was implied in damage to infrastructure and was deposited on floodplains and beaches. HBFG recognises the impact of LWD on infrastructure, community, and society and seeks to gain a full understanding of the risks to the forestry estate and community during extreme weather events.

Media and public commentators often use 'slash' as a generic, or catchall term for this debris. Slash is more correctly defined as the woody residue left behind after harvest of plantation forest. HBFG members saw the need for an independent assessment of woody debris to understand the components and proportions of the LWD mix within the Hawke's Bay region post-event.

Cyclone Gabrielle impacted Hawke's Bay from 13 – 14 February 2023. Published rainfall data from Hawke's Bay Regional Council (HBRC) puts the highest confirmed measurement to date at 546 mm during the event. During the most intense period, 400 mm of rain fell within 12 hours at a peak rate of 56 mm/hour at Glengarry. The highest recorded rainfall intensity during Cyclone Bola was measured at 419 mm in 24 hours (NIWA, 2018), indicating that nearly as much rain fell during the most intense 12-hour period of Cyclone Gabrielle as did in the most intense 24-hour period of Cyclone Bola.

The event followed a record 6-month rainfall total for Hawke's Bay region with Cyclone Hale impacting prior, in mid-January (HBRC, 2023). This led to loss of standing trees within the plantation forest estate, riparian plantings, and indigenous forest alike.

Plantation forestry is a significant contributor to the Hawke's Bay economy and community. The largest forestry business in the region (Pan Pac Forest Products Ltd) is responsible for providing 6% of the total GDP for Hawke's Bay, with 3,000 jobs either directly, indirectly, or induced.

Forestry provides numerous benefits to the environment and is an essential part of the erosion control toolkit in Hawke's Bay. In the most eroding areas, closed-canopy tall woody vegetation has been shown to reduce land sliding after large storms by as much as 90% (Basher & Dymond, 2013).

Plantation forestry provides this benefit for 21 out of every 28 years with the remainder referred to as the 'window of vulnerability' (Phillips et al., 2012). Plantation forestry has also been shown to reduce stormflow peak flood levels by up to 50% due to canopy interception slowing runoff and increasing evaporation (Davie & Fahey, 2005; Fahey & Jackson, 1997; Hughes et al., 2020). This effect is reduced when soil moisture levels are similarly high across land uses, such as in winter (Davie & Fahey, 2005). Analysis of soil moisture levels during the event, if data is available, will be helpful for assessing these benefits during Cyclone Gabrielle.

2.2 OBJECTIVE

This study was commissioned to establish a robust data set for accurately categorising LWD volume and proportion by species, in areas where it has had community impact; such as beaches, infrastructure, streambanks, and properties across the Hawke's Bay region.

3 METHODOLOGY

3.1 MAPPING WOODY DEBRIS POST EVENT

Using post event aerial and satellite imagery along the length of the coastline and river catchments, areas of likely wood debris accumulation were mapped in ArcGIS. Sampling locations for plots were then applied across the mapped area as described in section 3.3.7 Initial priority was given to the coastline areas, then subsequent river catchments areas from the river mouth inland based on the mapping criteria outlined in Table 1. Areas were stratified by river mouths (within approx. 1km of the mouth of river) which were to be the focus for the study, then inland, followed by beaches. Areas were split and aggregated by the main river confluence of influence, referred to as locality.

Plot locations were then provided in GPX, Shapefile, and PDF Map formats for field survey.

Table 1 - Mapping criteria used in woody debris sampling strata.

Mapped Strata	Mapping Criteria	Coverage
Coastal River Mouth	Concentrated wood debris accumulation areas > 0.1ha, eg. 50*20m. May have sporadic gaps between debris up to 10m to map accumulated aggregate areas of impact.	Full coastline of Hawke's Bay and within +/-1km of major river mouths.
Coastal Beach		Full coastline of Hawke's Bay outside of +/-1km of major river mouths.
Inland Rivers		Mapped from river mouth by stream. Aropaoanui – 5km Esk – 8km Tutaekuri – 20km Ngaruroro – 8km Tukituki – 14km

3.1.1 Satellite or Aerial Photography Sources

Various qualities of imagery sources became available post the storm event. Initially use of Planet Labs Monitoring 3-4m resolution near daily satellite imagery was used due to timely access on the first fine day after an event. For Cyclone Gabrielle this provided imagery from 18 February onwards. Most of the coastline imagery was mapped using this imagery from the 20 February 2023. While the imagery provided a medium-resolution image, this enabled a quick assessment of the entire coastline and catchment areas assessed for accumulated woody debris.

Examples can be seen in Figure 1 and Figure 2, where woody debris is showing up clearly in imagery.

Figure 1 - Coastline assessed with an image from the 20 February showing the woody debris appearing in the 3-4m imagery at Aropaoanui Beach. Image Source: Planet Labs LLC

When additional aerial photography or higher resolution satellite imagery became available throughout the project, it was used to validate the previous mapping extents as being sufficient for establishing the sampling frame for the wood debris survey (example Figure 3) and providing a consistent approach across the region.

Figure 2 - Example of extracted coastline from imagery gathered on20 February, with enlarged view of the Mohaka River mouth, and example of mapping the woody debris area (yellow polygons) impacted on the beach. Randomised sample locations are also shown (yellow circles).

Figure 3 – Validation of woody debris mapping using varying resolutions of imagery, 3-4m GSD Planet, 0.5m (LINZ 2023A) provided satellite imagery, and 0.1m aerial imagery (LINZ 2023B) of the coastline of Aropaoanui Beach showing woody debris accumulation (yellow), and sample plots (yellow points).

3.2 Drone Aerial Photo Mapping

When areas were not likely to have other imagery sources or the debris was quickly changing (i.e., being chipped, removed from site or continuing to wash away), drone imagery was captured where time allowed during the project; Figure 4,Figure 5. This allows for additional imagery analysis and documentation of areas in the future analysis.

Drone Flight Specifications: mapping grid flight for creation of an ortho-mosaic, with a 70% overlapping swath. Typically, above ground level flight height targeted a ground sampling distance of 1-3cm/pixel with flight heights from 40-120m above ground, depending on the drone camera specifications.

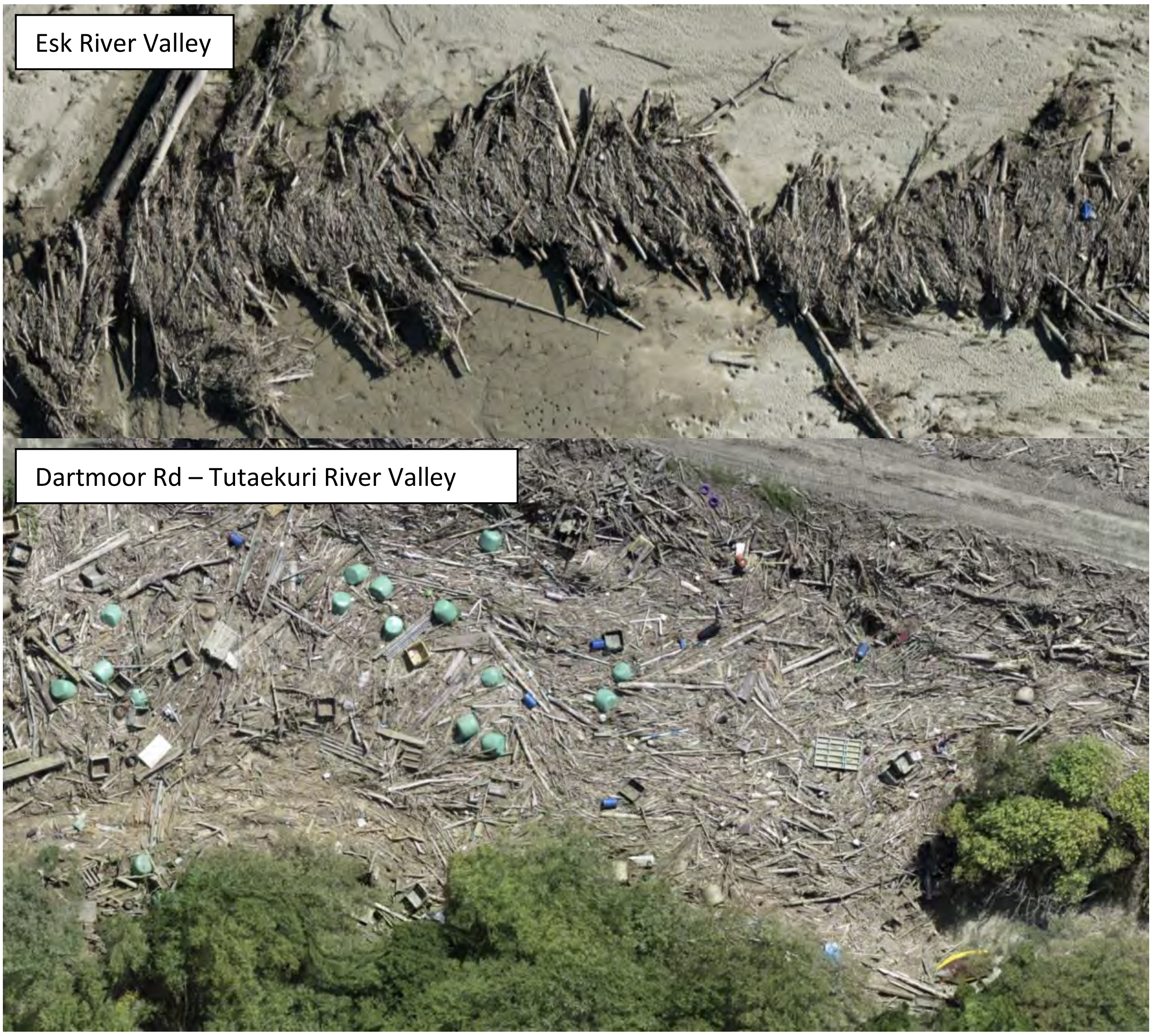


Figure 4 – Examples of drone imagery used to document discreet woody debris piles in various locations in river catchments around Hawke's Bay.

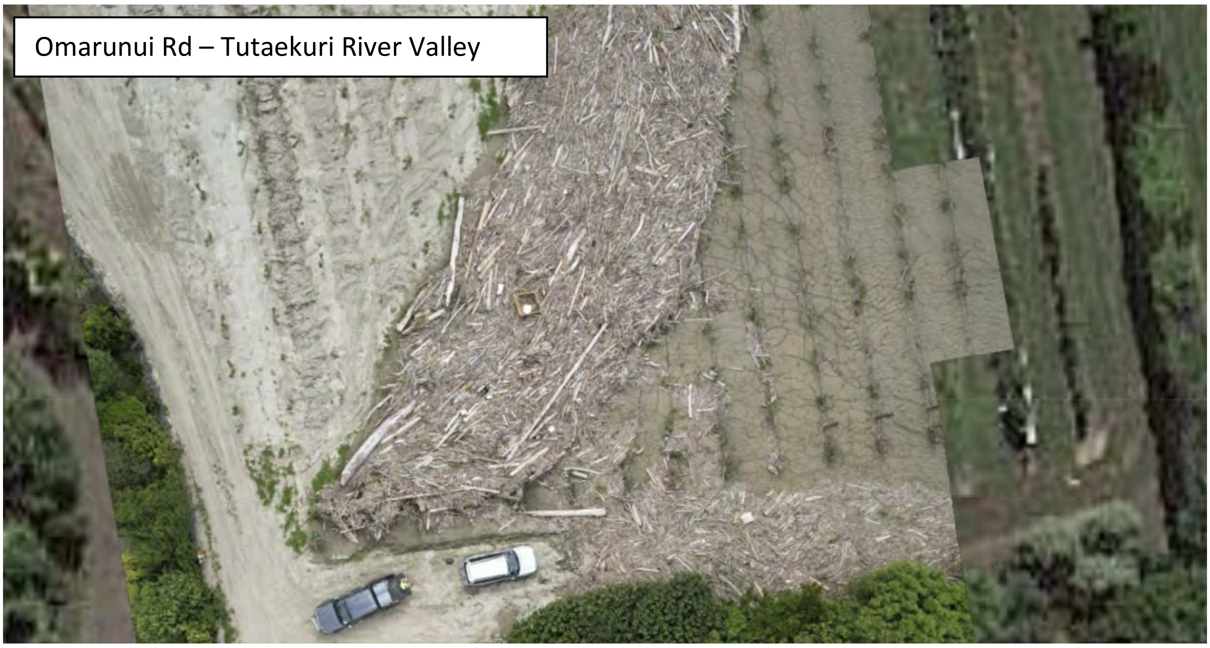


Figure 5 - Examples drone imagery used to document discreet woody debris piles in various locations in river catchments around Hawkes Bay.

3.3 Sampling Methodology Review

3.3.1 Line Intercept Sampling Method History

Due to nature of the LWD, the Line Intercept Sampling (LIS) technique was adapted from that used for cutover waste assessment as per training guidance in "NZQA Unit Standard 6956 – Carry Out Waste Assessment in Cutover Forest".

Since its original description for merchantable cutover residue assessment (Warren and Olsen, 1964), LIS is used to quantify wood lying on or near the ground. LIS continued to develop, as a simple and practical method (Bailey, 1970; Wagner & Wilson, 1976; Hall, 1986; Bell et al., 1996).

Proof of its mathematical basis (De Vries, 1973) and practical aspects of LIS to overcome bias and improve precision (Wagner, 1982; Pickford & Hazard, 1978; Bell et al., 1996) have seen it adapted worldwide for woody debris in forestry settings. Therfore, LIS is a peer reviewed and well-established method for measuring the volume of woody debris effectively.

3.3.2 Line Intercept Sampling Process

To remove the bias of piece orientation, an equilateral triangle sample plot was used. Each side of the triangle is 10m, with each plot being a total length of 30m (horizontal length), as per Figure 6. Where slope of the transect is greater than 5 degrees, a slope adjusted distance is applied to each side of the triangle.

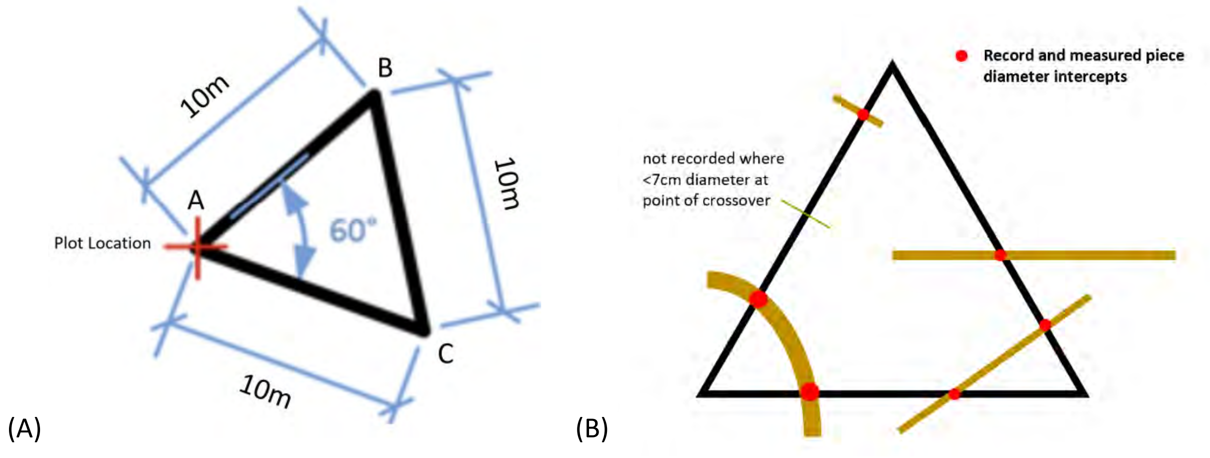


Figure 6 - (A) Line Intercept Sampling Equilateral Triangle (B) Measure and Record Piece Diameters at Crossover

The diameter of each LWD piece intersected by a line was measured at the point wherever it intercepts the line. A lower limit diameter of 70 mm is used; all material greater than or equal to 70 mm was recorded and measured. Comments were made alongside photos collected of each of the three lines per plot. There was no minimum length restriction, as the statistical likelihood of the line intersecting the piece accounts for length without arbitrary bias towards longer pieces. This also ensure inclusion of harvest slovens, and log bucking waste.

To further address the bias in debris accumulation orientation, each equilateral triangle sample has a random orientation based on a random bearing between 0 and 90 (Figure 7).

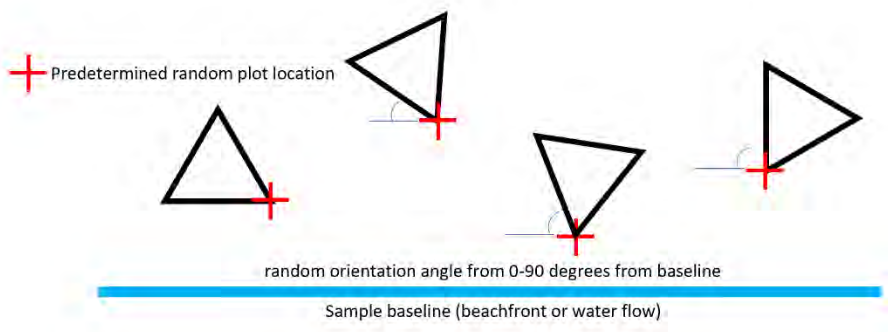


Figure 7 - Sample orientation to a baseline to ensure sample remains unbiased to direction of accumulation of woody debris.

3.3.3 Measurement of Pieces

Diameter is to be measured to the nearest cm in line with the woody debris orientation as shown in Figure 8.

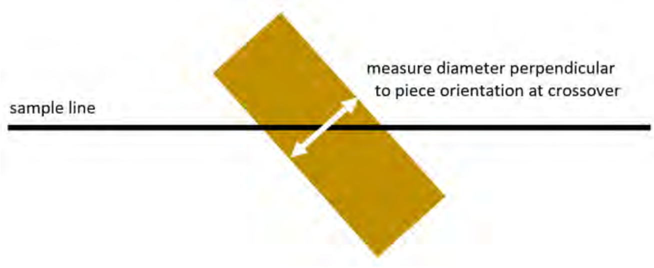


Figure 8 - Measurement of diameter of each intersecting pieces

3.3.4 Classification of Debris

Each intercept diameter measured will be classified into the following (See Table 2).

Table 2 - Classification of Debris

CODE	CLASS
N	Native Species
CH	Conifer (eg. Pine/Douglas) Plantation Harvest Residue *evidence of flush cuts / slovens / processor damage / branches cut off / cut stumps*
CT	Conifer (e.g Pine/Douglas) Plantation Full Tree Residue *evidence of full tree slippage of preharvest standing trees / full tree lengths / root plates visible / branches attached.*
CN	Conifer (e.g Pine/Douglas) Non-Plantation *old man's pine, streambank large old open grown pine.*
CO	Conifer (e.g Pine/Douglas) Other *no evidence of harvest residue (CH) or full tree lengths (CT)*
PT	Posts / Timber / Bins
PW	Poplar or Willow
E	Eucalyptus
O	Other *other orchards species (apple, avocado, citrus etc), cut firewood, and where possible make comment species / type comment.*

3.3.5 Species Identification

To ensure expert and objective species identification were made of the LWD, an independent, expert farm forester and ex-Hawke's Bay regional councillor (Alec Olsen), and a technical forest contractor (Ian Robertson) were employed to conduct plotting and characterisation of the LWD.

3.3.6 Calculating Woody Debris Volume and Summary

Volumes were calculated using the following LIS formula (Wagner, 1968).

Volume of debris: $Volume\ m^3/ha = (\pi^2/8*L)*sum(d^2)$

Where:

V= volume per unit area (m3/ha)
d= piece diameter at intersection (cm)
L= length of the sample line (m)

The resulting dataset yields volume per hectare by woody debris type. This yield of woody debris was applied to the mapped area of woody debris.

3.3.7 Randomised LIS Sampling Plot Locations and Intensity

Satellite imagery was used to pre-identify areas of woody debris depositions. Due to the nature of the material in isolated piles or long narrow beach accumulation, the plot placement was adapted from one of two approaches.

A. Predefined Plot Locations

The preferred method, in which random plots using geo-spatial plot sample tools (e.g., GeoMaster Assessment Planner) identifies plots which were navigated to using a GPS. Plots were placed using a random sampling approach (best suited for narrow width of the sample areas and yet to be determined time and resources). These plots are defined in mapped debris areas as described in 3.1.

B. Onsite Random Systematic Grid Plot Locations

A systematic interval between plots (e.g., every 25m or 50m) along the baseline (beachfront or river flow). This included taking photos using a mobile device, and/or drone imagery, video or mapped orthophoto to aid in later mapping of area in hectares of woody debris.

3.3.8 Field Plot Sampling Methodology Workflow in Practice

1. Determine the baseline (beach orientation, river flow direction)
2. Locate predefined plot locations using a GPS as outlined in 3.3.7 above, mark with stick paint mark – POINT A.
3. Record the GPS Location of the plot.
4. Determine plot orientation from base line with a random number between 0 and 90 (select from Appendix A).
5. Using a 30m tape or measured survey rope, hold the tape/rope at 0m and 30m at Point A. Lay out the first transect of 10m from the start point to POINT B. Then complete the triangle by pulling the remaining tape out to 20m POINT C.
6. Record wood debris diameters where piece at intercept is =>7cm and classify each piece by type.
7. At each corner, check slope of transect and where greater than 5 degrees add an additional length to transect as per Table 2, recording any additional wood debris.
8. Record as depth of the pile per transect 10m length which was not able to be assessed (if you measured all the pieces then depth will be 0m). Record to nearest 0.5m
9. Continue to measure wood debris each side of the triangle.
10. Take photos along each side of the transect, and any other items of interest for future reference.

Figure 9 - Example of LIS plots laid out and photos taken of each side of the transects being surveyed. Source: H. Scown

4 Results

4.1 Wood Debris Mapping and Sample Plot Allocation

Mapping approximately 280 km of coastline from Cape Kidnappers to Mahia Peninsula resulted in a total of 241 ha of woody debris piles on coastal beaches and river mouths. An additional 14 ha of inland woody debris were mapped in key catchment rivers impacted by the event, with a total of 255 ha of mapped debris piles across the region for the study.

Figure 10 – Woody debris detected in post event satellite imagery to set sampling frame for survey.

From the mapped area, 328 random plots were allocated for potential survey and stratified as shown in Figure 11, with a sample intensity of 0.8ha per plot.

Table 3 and Table 4 shows the area of accumulated mapped debris area by strata, locality, including the sampling intensity of the ground survey plots per hectare.

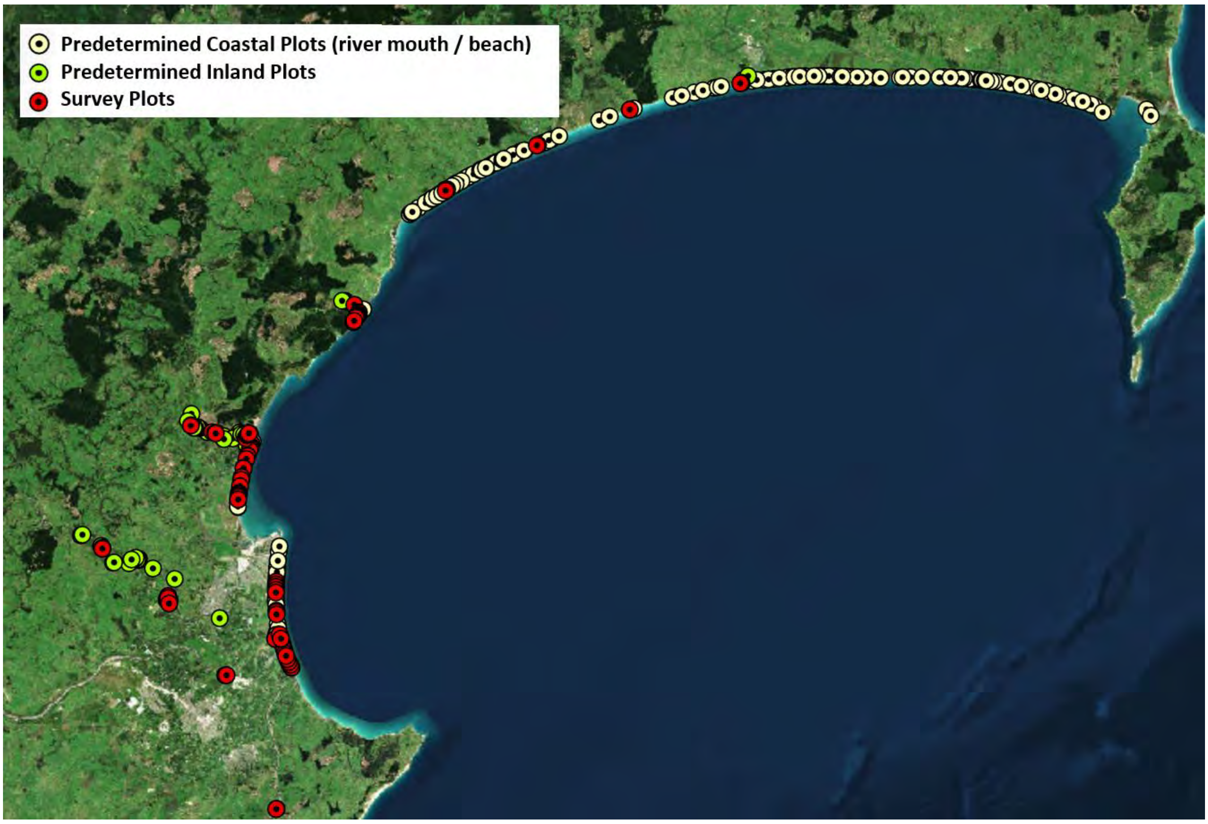


Figure 11 - Predetermined random sample locations, with actual surveyed sites shown.

Table 3 - Accumulated Strata of Mapped Woody Debris and Plots Sampled

Wood Debris Strata	Locality	Area (ha)	%	Plots	ha/plot
Coastal River Mouth +/- 1km of River Mouth	Aropaoanui River	7.1	9%	7	1.0
	Esk River	5.5	7%	4	1.4
	Mohaka River	9.0	12%	2	4.5
	Ngaruroro / Tutaekuri River	12.9	17%	9	1.4
	Nuhaka River	4.0	5%	0	na
	Ridgemount River	0.4	1%	0	na
	Tukituki River	2.5	3%	3	0.8
	Waihua River	1.1	1%	1	1.1
	Waikari River	16.7	21%	3	5.6
	Wairoa River	10.1	13%	2	5.1
	Waitaha River	8.7	11%	0	na
	TOTAL RIVER MOUTH	**78.0**	**31%**	**31**	**2.5**
Coastal Beach	Esk South	16.5	10%	14	1.2
	Mohaka North	3.1	2%	0	na
	Mohaka South	22.4	14%	0	na
	Te Awa / Awatoto	21.8	13%	8	2.7
	Opoutama	5.9	4%	0	na
	Nuhaka North	10.3	6%	0	na
	Nuhaka South	28.5	18%	0	na
	Waihua South	1.4	1%	0	na
	Waikari South	11.0	7%	0	na
	Wairoa South	7.6	5%	0	na
	Whakaki	34.2	21%	0	na
	TOTAL BEACH	**162.7**	**64%**	**22**	**7.4**
Inland Rivers	Aropaoanui River	0.2	1%	1	0.2
	Esk River	4.9	35%	12	0.4
	Ngaruroro River	0.4	3%	2	0.2
	Tukituki River	0.1	1%	1	0.1
	Tutaekuri River	8.6	61%	12	0.7
	TOTAL INLAND	**14.2**	**6%**	**28**	**0.5**
TOTAL		**254.9**	ha	**81**	**3.1**

Table 4 - Accumulated Locality of Mapped Woody Debris and Plots Sampled

Wood Debris Region	Locality	Area (ha)	%	Plots	ha/plot
Aropaoanui River	Aropaoanui River Mouth	7.1		7	
	Aropaoanui River Inland	0.2		1	
		7.3	3%	**8**	**0.9**
Esk River	Esk River Mouth	5.5		4	
	Esk South Beach	16.5		14	
	Esk River Inland	4.9		12	
		26.9	**11%**	**30**	**0.9**
Mohaka River	Mohaka River Mouth	9		2	
	Mohaka North Beach	3.1		0	
	Mohaka South Beach	22.4		0	
		34.5	**14%**	**2**	**17.3**
Ngaruroro / Tutaekuri River	Ngaruroro / Tutaekuri River Mouth	12.9		9	
	Te Awa / Awatoto Beach	21.8		8	
	Ngaruroro River Inland	0.4		2	
	Tutaekuri River Inland	8.6		12	
		43.7	**17%**	**31**	**1.4**
Nuhaka River	Nuhaka River Mouth	4		0	
	Nuhaka North Beach	10.3		0	
	Nuhaka South Beach	28.5		0	
		42.8	**17%**	**0**	**na**
Mahia	Opoutama Beach	**5.9**	**2%**	**0**	**na**
Ridgemount River	Ridgemount River	**0.4**	**0%**	**0**	**na**
Tukituki River	Tukituki River Mouth	2.5		3	
	Tukituki River Inland	0.1		1	
		2.6	**1%**	**4**	**0.7**
Waihua River	Waihua River Mouth	1.1		1	
	Waihua South Beach	1.4		0	
		2.5	**1%**	**1**	**2.5**
Waikari River	Waikari River Mouth	16.7		3	
	Waikari South Beach	11		0	
		27.7	**11%**	**3**	**9.2**
Wairoa River	Wairoa River Mouth	10.1		2	
	Wairoa South Beach	7.6		0	
	Whakaki Beach	34.2		0	
		51.9	**20%**	**2**	**26.0**
Waitaha River	Waitaha River Mouth	**8.7**	**3%**	**0**	**na**
	TOTAL	**254.9**		**81**	**3.1**

4.2 Line Intersect Sampling of Wood Debris

4.2.1 Hawke's Bay

A total of 81 plots were installed from the 3 to 24 March 2023. Sampling effort focused on the river mouths and inland rivers. Plots were selected from the random pre-planned plot network, starting closest to the river mouth and working outward. The number of plots collected at each catchment had elements of time and access constraints with some sites visited by helicopter. Plots were abandoned where hazardous or disturbed by clean-up activity.

These represent a plotting intensity of 3.1 ha per plot of mapped woody debris across Hawke's Bay. Sampling intensity varied due to plot access, with plots north of Aropaoanui only accessible by helicopter during the time of survey.

Plots show an average of 445 m3/ha in the woody debris piles mapped across the region with a probable limit of error (PLE) of 17.3% (95% confidence interval of the mean expressed over the mean).

Plantation pine/conifer accounted for 48% of the total survey volume per hectare (214 m3/ha) with the next highest classification being poplar/willow at 38% (170 m3/ha)

Pine/conifer harvest slash accounted for 4% of the total survey volume per hectare (19 m3/ha)

Table 5 - Average Volume Per Hectare by Wood Debris Strata, Locality and Classification

	Plantation Pine/Conifer									
Average m3/ha	Pine/Conifer OTHER	Pine/Conifer FULL TREE	Pine/Conifer HARVEST SLASH	Pine/Conifer OLD PINE	POPLAR WILLOW	NATIVE	EUCALYPT	POST/TIMBER	OTHER	TOTAL m3/ha
Coastal River Mouth	**132**	**53**	**23**	**15**	**177**	**31**	**1**	**5**	**21**	**458**
Aropaoanui River	123	21	22	4	215	20	0	1	18	425
Esk River	194	201	46	107	225	8	6	7	18	812
Mohaka River	210	102	33	0	26	87	0	4	9	470
Ngaruroro / Tutaekuri River	33	0	22	0	118	5	0	4	37	218
Waihua River	233	23	20	0	268	81	0	36	0	661
Wairoa River	96	107	16	0	271	218	0	4	50	762
Tukituki River	0	0	5	0	353	2	0	0	0	359
Waikari River	443	79	13	0	38	17	0	12	0	601
Coastal Beach	**128**	**18**	**18**	**8**	**113**	**33**	**1**	**7**	**22**	**346**
Esk River	145	17	19	12	99	33	2	1	19	346
Ngaruroro / Tutaekuri River	97	19	17	0	136	32	1	17	27	345
Inland	**155**	**91**	**16**	**14**	**207**	**5**	**0**	**10**	**10**	**509**
Aropaoanui River	48	270	0	0	140	0	0	0	0	457
Esk River	174	144	2	10	61	11	0	4	21	428
Ngaruroro / Tutaekuri River	157	39	31	20	343	0	0	17	3	609
Tukituki River	0	0	0	0	127	0	0	0	0	127
TOTAL m3/ha	**139**	**56**	**19**	**13**	**170**	**22**	**1**	**7**	**17**	**445**
% of TOTAL m3/ha	31%	13%	4%	3%	38%	5%	0%	2%	4%	
	48% Combined Plantation Pine/Conifer				**52%** Other					

Table 6 - Average Volume Per Hectare as % Total Wood Debris by Strata and Classification

	Plantation Pine/Conifer									
Average m3/ha as %	Pine/Conifer OTHER	Pine/Conifer FULL TREE	Pine/Conifer HARVEST SLASH	Pine/Conifer OLD PINE	POPLAR WILLOW	NATIVE	EUCALYPT	POST/TIMBER	OTHER	TOTAL m3/ha
Coastal River Mouth	29%	11%	5%	3%	39%	7%	0%	1%	5%	**458**
	45%			**55%**						
Coastal Beach	37%	5%	5%	2%	33%	9%	0%	2%	6%	**346**
	47%			**53%**						
Inland	30%	18%	3%	3%	41%	1%	0%	1%	2%	**509**
	51%			**48%**						

Table 7 - Average Volume Per Hectare by Wood Debris Locality and Classification

Average m3/ha	Pine/Conifer OTHER (Plantation Pine/Conifer)	Pine/Conifer FULL TREE (Plantation Pine/Conifer)	Pine/Conifer HARVEST SLASH (Plantation Pine/Conifer)	Pine/Conifer OLD PINE	POPLAR WILLOW	NATIVE	EUCALYPT	POST/TIMBER	OTHER	TOTAL m3/ha
Aropaoanui River	114	53	20	3	205	18	0	1	16	429
Esk River	163	92	16	24	101	21	2	3	19	441
Mohaka River	210	102	33	0	26	87	0	4	9	470
Ngaruroro / Tutaekuri River	105	22	25	9	224	10	0	13	19	428
Tukituki River	0	0	3	0	296	1	0	0	0	301
Waihua River	233	23	20	0	268	81	0	36	0	661
Waikari River	443	79	13	0	38	17	0	12	0	601
Wairoa River	96	107	16	0	271	218	0	4	50	762
TOTAL m3/ha	**139**	**56**	**19**	**13**	**170**	**22**	**1**	**7**	**17**	**445**
% of TOTAL m3/ha	31%	13%	4%	3%	38%	5%	0%	2%	4%	
	48% Combined Plantation Pine/Conifer			**52%** Other						

Table 8 - Average Volume Per Hectare as % Total Wood Debris Region and Classification

Average m3/ha as %	Pine/Conifer OTHER (Plantation Pine/Conifer)	Pine/Conifer FULL TREE (Plantation Pine/Conifer)	Pine/Conifer HARVEST SLASH (Plantation Pine/Conifer)	Pine/Conifer OLD PINE	POPLAR WILLOW	NATIVE	EUCALYPT	POST/TIMBER	OTHER	TOTAL m3/ha
Aropaoanui River	26%	12%	5%	1%	48%	4%	0%	0%	4%	**429**
	43%			**57%**						
Esk River	37%	21%	4%	5%	23%	5%	0%	1%	4%	**441**
	61%			**38%**						
Mohaka River	45%	22%	7%	0%	6%	18%	0%	1%	2%	**470**
	73%			**27%**						
Ngaruroro / Tutaekuri River	25%	5%	6%	2%	52%	2%	0%	3%	4%	**428**
	36%			**64%**						
Tukituki River	0%	0%	1%	0%	98%	0%	0%	0%	0%	**301**
	1%			**99%**						
Waihua River	35%	3%	3%	0%	41%	12%	0%	5%	0%	**661**
	42%			**58%**						
Waikari River	74%	13%	2%	0%	6%	3%	0%	2%	0%	**601**
	89%			**11%**						
Wairoa River	13%	14%	2%	0%	36%	29%	0%	1%	7%	**762**
	29%			**71%**						

The average size of pieces measured was 168mm, with a std deviation of 115 (Table 9, Figure 12, Figure 13).

Table 9 – Woody Debris Size Distribution by Locality and Classification

Avg Diam (mm)	Pine/Conifer OTHER (Plantation Pine/Conifer)	Pine/Conifer FULL TREE (Plantation Pine/Conifer)	Pine/Conifer HARVEST SLASH (Plantation Pine/Conifer)	Pine/Conifer OLD PINE	POPLAR/WILLOW	NATIVE	EUCALYPT	POST/TIMBER	OTHER	Total
Aropaoanui River	200	368	430	260	167	107		135	560	**180**
Esk River	181	316	343	543	158	140	158	103	224	**186**
Mohaka River	161	222	400		105	225		132	144	**170**
Ngaruroro / Tutaekuri River	186	389	322	830	140	128	90	115	190	**153**
Tukituki River			130		143	120				**143**
Waihua River	156	236	220		197	223		158		**178**
Waikari River	162	246	150		131	135		130		**161**
Wairoa River	141	305	275		164	211		104	304	**178**
Total	**177**	**311**	**296**	**543**	**148**	**144**	**135**	**115**	**216**	**168**
	198 (Plantation Pine/Conifer)									

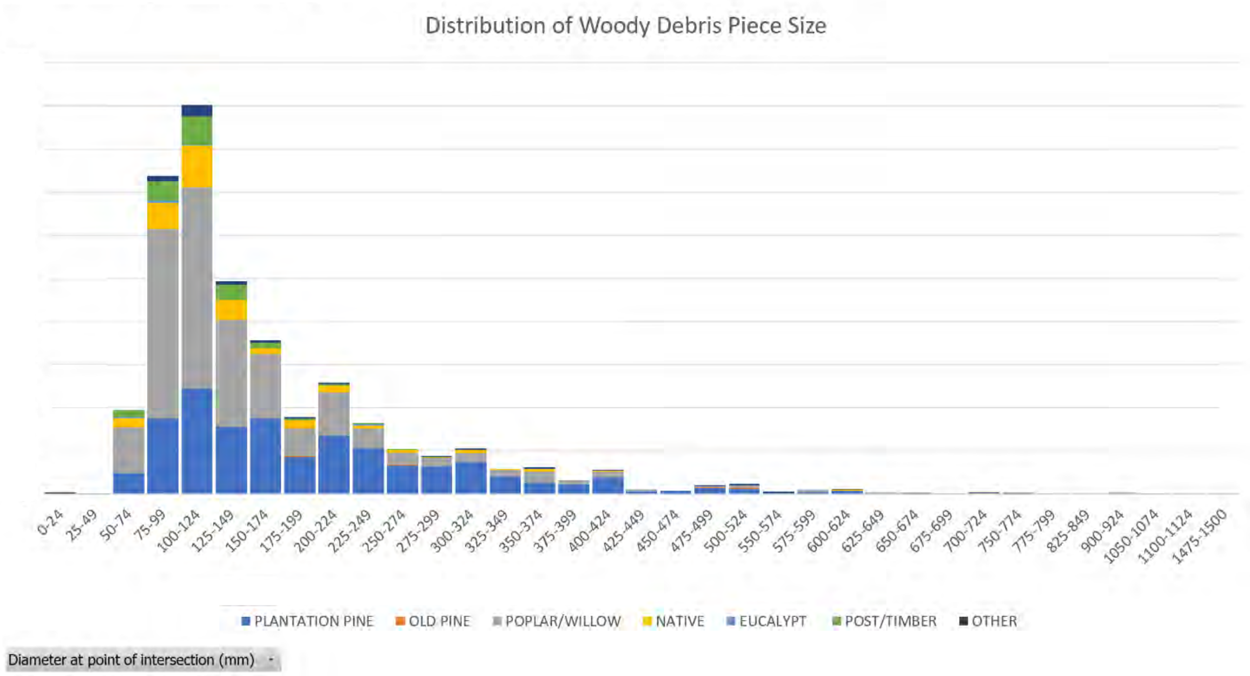


Figure 12 - Distribution of woody debris by diameter

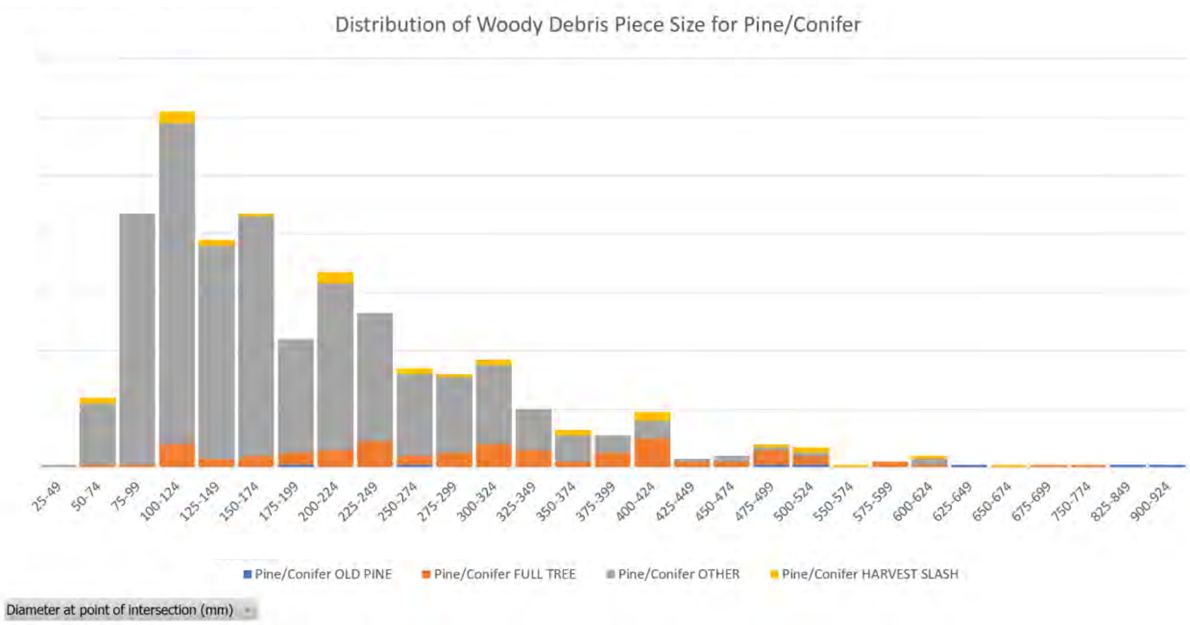


Figure 13 - Distribution of woody debris by diameter for pine/conifer

4.2.2 Aropaoanui

The Aropaoanui catchment woody debris deposition was measured to be 7.3 ha. Eight plots were measured, representing a plotting intensity of 0.9 ha per plot of mapped woody debris.

Plots show an average of 429 m3/ha in the woody debris piles mapped across the Aropaoanui catchment with a PLE of 59.3%.

Plantation pine/conifer accounted for 43% of the total Aropaoanui survey volume per hectare (186 m3/ha), with the highest classification being poplar/willow at 48% (205 m3/ha).

Pine/conifer harvest slash accounted for 5% of the total Aropaoanui survey volume per hectare (20 m3/ha).

4.2.3 Esk

The Esk catchment woody debris deposition was measured to be 26.9 ha. Thirty plots were measured, representing a plotting intensity of 0.9 ha per plot of mapped woody debris.

Plots show an average of 441 m3/ha in the woody debris piles mapped across the Esk catchment with a PLE of 28.9%.

Plantation pine/conifer accounted for 61% of the total Esk survey volume per hectare (271 m3/ha), with the next highest classification being poplar/willow at 23% (101 m3/ha).

Pine/conifer harvest slash accounted for 4% of the total Esk survey volume per hectare (16 m3/ha)

Pine/ conifer with root ball attached (full-tree) accounted for 21% of the total Esk survey volume (92 m3/ha).

4.2.4 Mohaka

The Mohaka catchment woody debris deposition was measured to be 34.5 ha. Two plots were measured, representing a plotting intensity of 17.3 ha per plot of mapped woody debris.

Plots show an average of 470 m3/ha in the woody debris piles mapped across the region with a PLE of 13.2%.

Plantation pine/conifer accounted for 73% of the total Mohaka survey volume per hectare (345 m3/ha), with the next highest classification being native at 18% (87 m3/ha).

Pine/conifer harvest slash accounted for 7% of the total Mohaka survey volume per hectare (33 m3/ha).

Pine/ conifer with root ball attached (full-tree) accounted for 22% of the total Mohaka survey volume (102 m3/ha).

4.2.5 Ngaruroro/Tutaekuri

The Ngaruroro/Tutaekuri catchment woody debris deposition was measured to be 43.7 ha. Thirty-one plots were measured, representing a plotting intensity of 1.4 ha per plot of mapped woody debris.

Plots show an average of 428 m3/ha in the woody debris piles mapped across the region with a PLE of 41.2%.

Plantation pine/conifer accounted for 36% of the total Ngaruroro/Tutaekuri survey volume per hectare (152 m3/ha), with the highest classification being poplar/willow at 52% (224 m3/ha).

Pine/conifer harvest slash accounted for 6% of the total Ngaruroro/Tutaekuri survey volume per hectare (25 m3/ha).

4.2.6 Tukituki

The Tukituki catchment woody debris deposition was measured to be 2.6 ha. 4 plots were measured, representing a plotting intensity of 0.7 ha per plot of mapped woody debris.

Plots show an average of 301 m3/ha in the woody debris piles mapped across the region with a PLE of 169.3%.

Plantation pine/conifer accounted for 1% of the total Tukituki survey volume per hectare (3 m3/ha), with the highest classification being poplar/willow at 98% (296 m3/ha).

Pine/conifer harvest slash accounted for 1% of the total Tukituki survey volume per hectare (3 m3/ha).

4.2.7 Waihua

The Waihua catchment woody debris deposition was measured to be 2.5 ha. One plot was measured, representing a plotting intensity of 2.5 ha per plot of mapped woody debris.

The plot showed an average of 661 m3/ha in the woody debris piles mapped across the region. With only a single plot installed no PLE is calculated.

Plantation pine/conifer accounted for 42% of the total Waihua survey volume per hectare (276m3/ha), with the next highest classification being poplar/willow at 41% (268 m3/ha).

Pine/conifer harvest slash accounted for 3% of the total Waihua survey volume per hectare (20 m3/ha).

4.2.8 Wairoa

The Wairoa catchment woody debris deposition was measured to be 51.9 ha. Two plots were measured, representing a plotting intensity of 26 ha per plot of mapped woody debris.

Plots show an average of 762 m3/ha in the woody debris piles mapped across the region with a PLE of 776.7%.

Plantation pine/conifer accounted for 29% of the total Wairoa survey volume per hectare (219 m3/ha), with the highest classification being poplar/willow at 36% (271 m3/ha), and native with 29% (218 m3/ha).

Pine/conifer harvest slash accounted for 2% of the total Wairoa survey volume per hectare (16 m3/ha)

4.2.9 Waikare

The Waikare catchment woody debris deposition was measured to be 27.7 ha. Three plots were measured, representing a plotting intensity of 9.2 ha per plot of mapped woody debris.

Plots show an average of 601 m3/ha in the woody debris piles mapped across the region with a PLE of 133.3.

Plantation pine/conifer accounted for 89% of the total Waikare survey volume per hectare (535 m3/ha), with the next highest classification being poplar/willow at 6% (38 m3/ha).

Pine/conifer harvest slash accounted for 2% of the total Waikare survey volume per hectare (13 m3/ha)

5 DISCUSSION AND RECOMMENDATIONS

5.1 FINDINGS AND DISCUSSION

The results of this study show that very little material has evidence of being harvest slash (4%) across Hawke's Bay showing evidence of harvest activity, i.e., flush cuts / slovens / processor damage / branches cut off / cut stumps. The LWD also has a significant proportion (13%) of pine with root ball attachment.

Conifer without harvest evidence or root ball attachment cannot be attributed to mid slope failure or streambank failure with certainty. However, the implication of finding a higher proportion of pine material with root ball attachment (13%) versus pine material with evidence of harvest (4%) indicates that it is mathematically much more likely that pine material of unknown origin was in standing tree form immediately prior to the cyclone. Evidence of harvest is easily recognisable even on aged material from an earlier event.

Given that the root ball and subsequent stem material attached is the widest, most structurally stable part of a tree, tops and large branches likely broke away from the stem in its journey downstream. Therefore, it is likely that much of the pine of unknown-origin was brought down in floodwaters after mid-slope failure or streambank erosion caused by mechanical failure of waterlogged soil and prolonged intense rainfall.

Where there are significant areas of indigenous forest, or flood-protection willow/poplar plantings on erodible sites within the catchment, significant volumes of indigenous or willow/poplar woody debris have been measured in the LWD.

It has been shown that sediment loads after rain events are reduced when pastoral land is converted to close-canopy tall woody vegetation (Basher & Dymond, 2013; Fahey & Marden, 2000; Fransen & Brownlie, 1996; Page et al., 1999; Phillips et al., 2012). To this end, pine forest plantings were incentivised on the most erodible sites in Hawke's Bay Catchment Board and NZ Forest Service extension projects and following Cyclone Bola through the Erosion Control Funding Programme (ECFP) on the East Coast.

These plantings were enacted to mitigate sedimentation impacts primarily attributable to pastoral landscapes in the erosion-prone country and were largely successful. Therefore, in a significant storm event, the most impacted sites, outside of pastoral land uses, will be overly represented by vegetation cover consisting of exotic plantation forests.

By increasing the level of tall, closed-canopy woody vegetation, the overall risk of sedimentation decreases by a factor of 3 to 4 (Fahey & Marden, 2000). The Pakuratahi land-use study (Eyles & Fahey, 2006) states, "Over the 12-year period of record, the total suspended yield from the pasture catchment was over one-and-a-half times that for the catchment going through the forest rotation". Further analysis into the aspect, slope, and vegetation cover, type and so forth of areas that have eroded into the waterway after this event will help guide future land use decisions, and a topic for future work.

Almost half, or 48%, of the LWD volume measured originated from pine plantation forests, and 38% of the volume was from flood-protection willow/poplars. In total, at least 86% of the LWD volume measured originates from unstable, erosion-prone landscapes that vegetation was planted to protect. Most of the time, outside of significant events, this is achieved successfully by these plantings. Therefore, the risk of woody debris from forested catchments is inherent in the risk of significant weather events impacting these fragile landscapes. Solutions to mitigate these risks to the receiving environment should be well thought out and allow for the sustainable use of land in an environmental, economic, and social sense in perpetuity.

Much of the area defined as 'coastal beach' area in Hawke's Bay is underrepresented in the data collection. This was due to the data stratification that separated 'coastal beach' from 'river mouth' (defined as beach within 1 km of the river mouth). It was perceived that priority should be given to plots closer to the river mouths to add certainty to the make-up of material brought down in each catchment to aid in further analysis. Additionally, river mouths and coastal beach north of Aropaoanui are underrepresented due to logistical constraints from lack of access by land from Napier during the time of the study which is reflected in the high PLE statistics. Future work should develop more efficient use of drones for collection of imagery in lieu of inaccessible plots.

A helicopter was used to allow the collection of data from the Waikare mouth, Waihua mouth, Mohaka mouth, and Wairoa mouth (Figure 14) due to the absence of road access following the cyclone. Results for these catchments do not have the same level of certainty as other catchments. Wairoa River mouth was found to have the highest proportion of indigenous woody debris out of any catchments measured. Another notable observation regarding the Wairoa mouth was the prevalence of material that appeared to be aged (Figure 15). This may have been debris brought down that was lodged in the upper catchment from a previous event(s). In the future, weathered wood should be noted as a separate category.

Figure 14 - Helicopter (Hawke's Bay Helicopters - BK117) parked on Wairoa River mouth for plotting. Photo source: H. Scown

Figure 15 – Left: Example of woody debris scattered on Wairoa River mouth. Note the weathered appearance of much of the wood indicating it may be aged. Right: Looking down from helicopter at Wairoa River mouth. Photos source: H. Scown

The volume of pine LWD with root ball attached measured at Mohaka and Esk was 22% and 21%, respectively. These are the highest recorded catchments of pine with root ball attachment, and this appears to correlate strongly with rainfall data released by HRC, NIWA for these catchments (See Appendix D). The LWD measured for Tutaekuri/Ngaruroro catchments were majority willow/poplar (52%), followed by plantation pine (37%). Rainfall data appears to show this catchment received significant rainfall; with floodwaters overtopping the stopbanks in many places. Flood-protection willows and poplars planted along the riverbank, especially around Dartmoor/Puketapu area, have been inundated by water and dislodged from the riverbanks (Figure 17).

Aropaoanui catchment was found to have a higher proportion of willow/poplar (48%) followed by plantation conifer/ pine (43%). This is consistent with the relocation of the river just inland from the river mouth, where large areas of willows have been removed (Figure 16).

Figure 16 – Aropaoanui: showing loss of significant areas of willows alongside the original river course.

Figure 17 - Tutaekuri River at Hakowhai access entrance, Dartmoor Road. Note the willows on far-right with tight spacing next to interspersed willows, and finally a row of missing and flattened willows can be seen across the river from mid to left. Photo source: H.Scown

Tukituki catchment was notable in that 98% willow/poplar, a low overall volume per hectare (301 m3/ha), and a low mapped area (2.6ha) being measured. This is likely due to a combination of lower storm intensity (rainfall) in the catchment (See Appendix D) and low levels of pine plantation within the catchment. This catchment is a good example of where further analysis into the distribution of land uses, storm intensity, and LWD measured in each catchment will help inform better future land use decisions.

Waikare catchment was notable in that it contained the highest proportion of pine volume within the LWD deposits. The mean diameter of the measured plantation pine/conifer pieces (other, full tree, harvest) at the Waikare River mouth was 168 mm. In contrast the overall mean pine diameter for this study was 198 mm. Only 2% volume of LWD measured at Waikare was pine with harvest evidence, of which it was solely from fresh scarf cut (felled) pine with an average diameter of 150mm. Due to the occurrence of smaller diameter scarf face felled pine, it is likely most of the pine material found at the Waikare River mouth originated from a recently waste-thinned plantation forest block(s) that entered the water either by streambank erosion or mid-slope failure. Further analysis of recent LiDAR data from the region would confirm source with high confidence.

Waihua River mouth was observed to be mostly small debris in shallow water. Only one plot could be taken and this fell on a raised area, so data cannot be said to be representative without further information. The plot had accumulated large poplar trees with root balls attached. It was noted as the helicopter left that the likely source of these poplars appeared to be a row of riverside poplars with some clearly missing upstream.

5.2 Conclusion

In conclusion, Hawke's Bay experienced its wettest 6-month period on record from July 2022 – January 2023. This left the land susceptible to damage by sustained heavy rainfall and wind events. Cyclone Gabrielle was one of the largest weather events to affect New Zealand in living memory, especially in parts of Hawke's Bay.

The severity of this set of conditions led to levels of damage to the landscape affecting all types of standing woody vegetation on the most erodible sites.

The data show that LWD deposits across Hawke's Bay do not contain high levels of harvest residue. Therefore, it is inaccurate to use the catchall term 'slash' when referring to causes of damage to infrastructure across the Hawke's Bay region.

Understanding gained from this study may be applied within wider spatial exercises to determine optimal land use decisions given the erodibility existing within parts of Hawke's Bay landscape and storm events which occur periodically.

More closed-canopy forest across the Hawke's Bay would help to prevent record flood peaks, sedimentation, and landslides in future. There may be a resulting benefit in preventing dislodgement of flood-protection willows downstream by delaying water flow in flood conditions. Therefore, overall damage to the community may be mitigated beyond immediate local protection of erodible sites.

Permanent indigenous forest cover may be a preferred local option for some, due to the range of benefits it provides. At scale, its high cost of establishment, extreme vulnerability to pests and slower growth may lead to perverse outcomes and risk in the interim until full canopy develops.

Production forestry provides some of the benefit of closed-canopy permanent forest for most of the rotation, while creating economic output that can further progress the community towards achieving a safer, more resilient landscape and provide funding for rational mixes of land use in erodible areas. Integrated approaches to land use will be necessary to provide for more resilient landscapes and communities.

5.3 RECOMMENDATIONS

5.3.1 Methodology

It is recommended that LWD categorisation be standardised in future to use best practice to ensure data validity. This will also ensure that a standardised dataset may be built if multiple entities perform relevant surveys.

The method outlined within this report, alongside a strategy to implement the collection of data as soon as practicable after an event, will allow for the collection of good data using a method that is well-established and peer-reviewed for accuracy and validity, while remaining cost-effective (Fletcher, 2023). Some minor adaptations to the method outlined are recommended as follows.

a. Weathered wood that is clearly aged beyond the event in question should be recorded separately and distinct from fresh woody debris. This will help distinguish debris from previous events. Harvest data in stands upstream of the catchment can also reconcile the likelihood that aged pine material is from harvest waste or old debris from another event. This should be a subclassification to retain the existing classes. Suggest adding a subclass with option for WX = Weathered.

b. Piece length data could be collected in future, to aid in identifying the likely origin of woody debris by reconciling forestry stand data. This can be performed with auto-detection software and drone orthophotography, or for in-field categorisation of length into bins (e.g., <1m, <3m, <6, <9m, <12m, >12m etc.) could be used to speed up field measurement of length, a precise measurement is not required in just broad classification.

c. Research into the appropriate approaches for use of depth of pile assessment, packing ratios, and or drone volumetric approaches.

d. Trial the capture and use of <0.5cm ground sampling distance drone imagery for surveying and assessing debris piles. This could provide greater coverage, reduce collection time, increase safety, provide better pile depth estimates, and ease access (such as fly across rivers, or to far side of river mouths) post an event. This would include review and guidance for classification using this type of data. This approach is now routine for many forest owners for harvest residue volume using LIS where assessment is done on the desktop[1].

e. Include a methodology for edge plots, where the transact travels outside of the mapped debris extent. This is to implement the transect mirage plotting methodology, whereby the edge of plot is folded back on itself into the sample area as shown in Figure 18.

[1] Drone based Harvesting Cutover Merchantable Volume Assessment | Interpine Innovation

Figure 18 - Edge plot mirage methodology for narrow debris piles or where transects fall into areas outside of the mapped debris extent.

5.3.2 Further Analysis Opportunities

Hawke's Bay LiDAR collected recently in 2020-21 has now been released (LINZ 2023C). This would enable individual tree segmentation (Figure 19) and assessment of the trees lost in slips with direct connection to the waterways of the rivers (Figure 20, Figure 21) in comparison to recent satellite imagery. This would also provide an indicator for tree height at time of loss (all trees including native, willow and so forth), and comparison of the piece size being seen in the woody debris present downstream in the receiving environment. Combined with knowledge of recent forest activity such as waste thinning operations, this would provide correct information on the source of the debris within each catchment.

It is recommended that catchments are buffered by 1km and mapped for vegetation loss using 0.5m resolution satellite data (LINZ 2023A). LiDAR can then be used to extract trees lost by heigh class and classification (species groups) to quantify source.

New LiDAR data can also be gathered over affected woody vegetation areas and analysed to determine the soil volume of mid-slope failure and streambank erosion origin that carried the woody debris. This will further inform correct land use decisions.

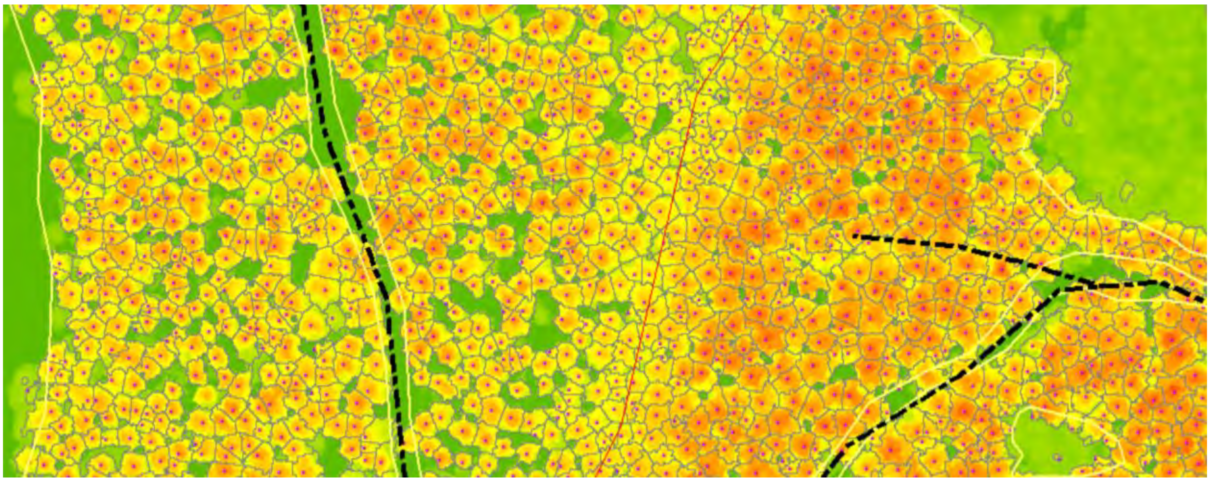


Figure 19 - Example of canopy height model (coloured by height above ground) and tree segmentation in 23yr old radiata pine plantation from LINZ LiDAR survey that could be then used to detect types and sizes of trees lost to water, using change detection from imagery.

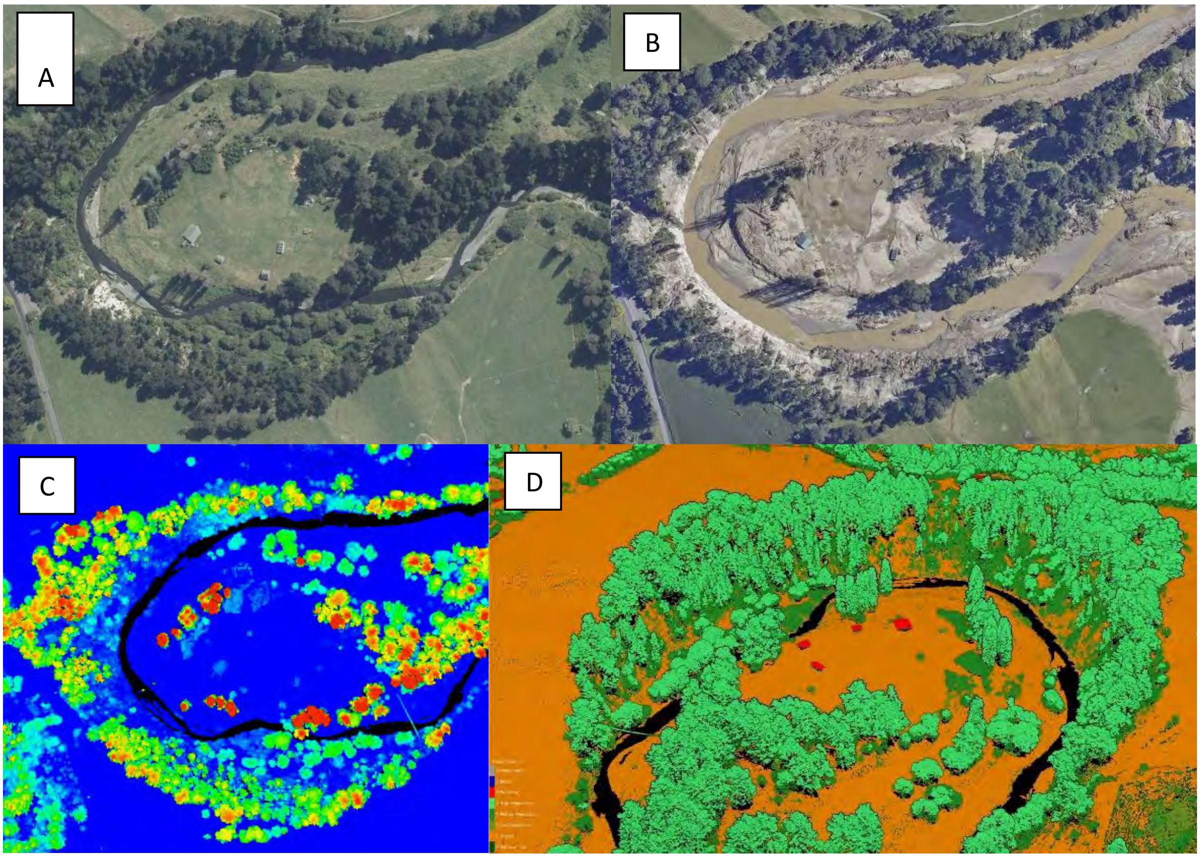
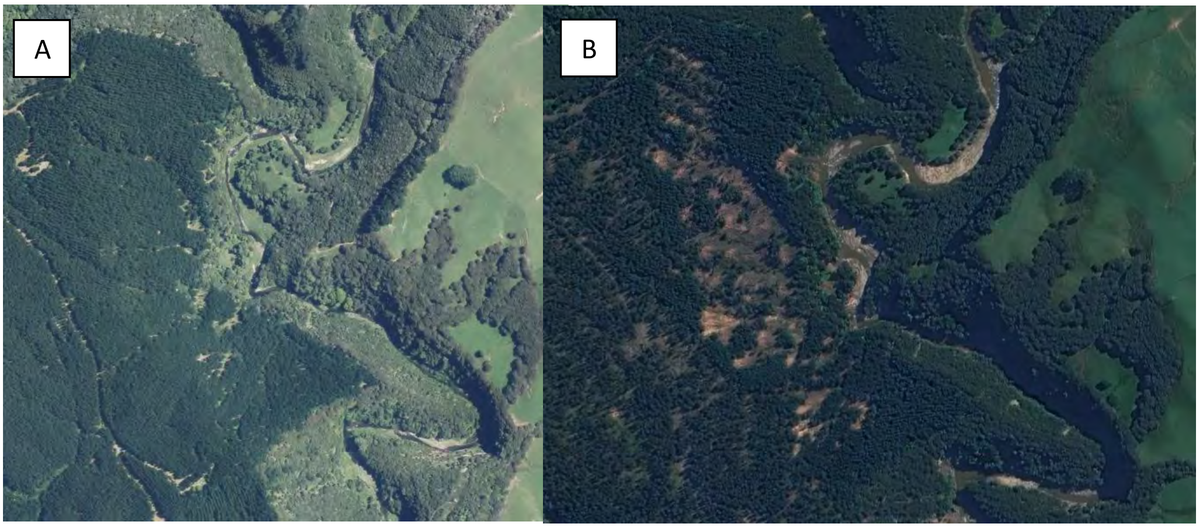


Figure 20 – Mangaone River: Example of identification of wilding pine and riverbank poplar/willow trees can be mapped and extracted from LiDAR to quantify those lost to water within catchment. A=before, B=after, C=tree height model, D=LiDAR data vegetation classification in 3D.



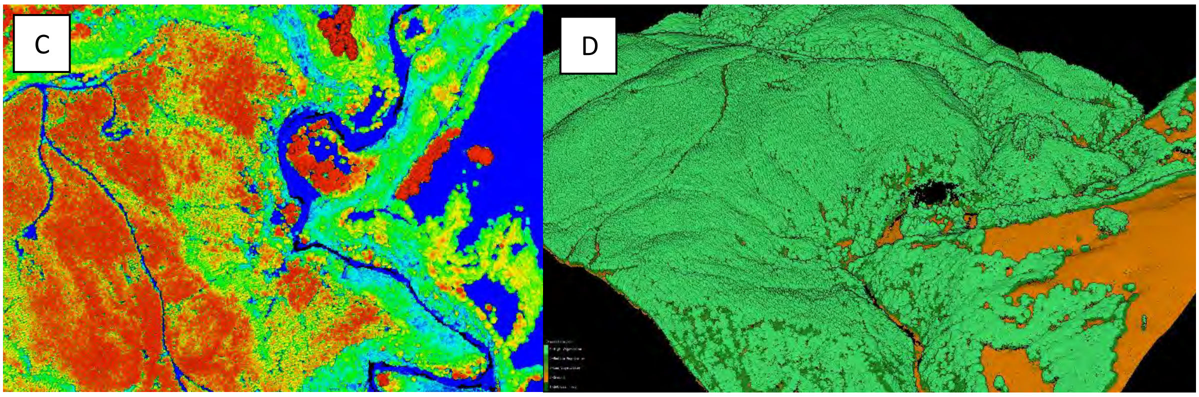


Figure 21 – Anaura Stream (Waikari River Catchment): Example of identification of plantation pine loss to water within catchment. A=before, B=after showing ground slips and tree loss, C=LiDAR tree canopy height model, D=3D view of vegetation vs ground.

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Further detail on this can be found in a review of the line intercept approach.

- Harvest Cutover Residue Assessment > History | Interpine Innovation
- Cutover Residue Assessment Using Line Intercept Sampling | Interpine Innovation
- Drone based Harvesting Cutover Merchantable Volume Assessment | Interpine Innovation

Downloads

- NZQA Competenz 6956 Unit Module Study Guide:
- EXCEL Sheet – Plot Form and Appendices
- Woody Debris Sampling Methodology (as a PDF)

8 APPENDICES

8.1 APPENDIX A – RANDOM BEARINGS 0 TO 90 AND SLOPE ADJUSTMENT TABLE FOR 10M

Random Number Table Between 0-90				
46	74	90	46	61
88	3	53	75	1
3	3	69	27	70
58	56	59	2	66
22	8	71	57	51
89	64	69	60	38
79	30	85	29	9
90	11	32	60	40
50	82	11	4	74
70	73	66	68	88
1	69	42	83	33
10	2	22	74	70
59	50	63	22	79
66	69	56	77	65
72	47	5	8	27
26	15	88	5	28
62	64	65	61	66
52	59	69	27	81
26	66	44	69	65
2	63	61	52	84
62	2	54	60	73
65	48	45	11	19
6	25	73	72	60
79	16	19	6	85
7	4	43	51	10
38	71	43	22	58
10	14	4	35	1
50	78	4	49	34

Slope	Slope Adjusted 10m Dist. (m)	Extra Length (m)
0	10.00	0.00
5	10.04	0.04
7.5	10.09	0.09
10	10.15	0.15
12.5	10.24	0.24
15	10.35	0.35
17.5	10.49	0.49
20	10.64	0.64
22.5	10.82	0.82
25	11.03	1.03
27.5	11.27	1.27
30	11.55	1.55
32.5	11.86	1.86
35	12.21	2.21
37.5	12.60	2.60
40	13.05	3.05
42.5	13.56	3.56
45	14.14	4.14
47.5	14.80	4.80
50	15.56	5.56
52.5	16.43	6.43
55	17.43	7.43
57.5	18.61	8.61
60	20.00	10.00
62.5	21.66	11.66
65	23.66	13.66
67.5	26.13	16.13
70	29.24	19.24

8.2 APPENDIX B – PLOT FORM PAPER FORMAT

WOODY DEBRIS SURVEY FORM				
Plot Ref:		Date & Time:		
Location Description:				
Org + Plot Crew:				
GPS:				
Random Orientation Bearing (0-90):				
Transect	**Slope (Deg)**	**SlopeDist (m)**	**Debris Depth (m)**	**Comment**
A (A to B)				
B (B to C)				
C (C to A)				
Transect (ABC)	Diameter (cm)	Class/Type	Comment	

Notes

8.3 APPENDIX C – FIELD PHOTOS

Photos source: H. Scown & I. Robertson

A = Plot transect line photo at Esk River mouth.
B = Close-up of woody debris at Esk River mouth. Note the willow in foreground with alternate branching. Pine in background with branch whorls next to Alec's arm.
C = Two large measured willow logs. Note the epicormic flush growth that occurred since dislodgement from streambank.
D = Wide shot of woody debris at Aropaoanui River mouth, featuring Alec.

E = Orthographic photo of Mohaka River mouth debris. Note the abundance of smaller woody debris.
F = Aerial shot looking Southwest from Waikare River mouth. 15 km long.
G = Alec digging into a willow log to ID. Note the colour and alternating branching.
H = Tutaekuri River inland. Note the large pine log in the mid-ground and branch whorling with internodes.
I = Large Pines with root balls attached, Tutaekuri riverbank at Dartmoor Road.
J = Esk River debris pile and pivot irrigator. Note the green/red flushing epicormic growth from willow logs in mix.


I


J

8.4 Appendix D – Cumulative Rainfall in Hawke's Bay and North Island