Hawkes Bay Regional Council

WAIROA LAND CATEGORISATION

FLOOD MITIGATION THROUGH AFFORESTION

7 MAY 2024

FOR INTERNAL USE

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EXECUTIVE SUMMARY

To understand the potential impact of afforestation on the 1% AEP flood event in Wairoa several lines of evidence were explored. This included literature review, discussion with HBRCs Science Team, looking at rainfall run-off models, looking at river flow gauges and the practical application of large scale afforestation.

Review of the literature indicates that the benefit of afforestation on large scale flood events (in the order of 1% AEP) are poorly understood and have high uncertainty. Review of two rainfall-runoff models that account for tree cover indicate that a 10-16% reduction in flood flows might be achievable with a 100% change in land cover, but this is entirely theoretical.

46% of the Wairoa catchment is already forested, and of the remainder, only a small portion is not productive farmland. Hence for any notable benefit, large scale retirement of productive land would be required. This would be extremely disruptive for the region, hugely expensive and would take a significant amount of time for establishment to occur and benefit to be realised.

Further to this, it would likely only have a minor benefit in the order of 5-8% (best case) whilst a minimum 15% reduction is required to prevent North Clyde from flooding.

Given there are lower cost engineered schemes that can more significantly reduce flooding, can be more quickly implemented, provide more certain outcomes and would disrupt less landowners, afforestation is not considered a viable flood mitigation option on its own for this catchment.

Afforestation should however be encouraged as an organic process to compliment any engineered flood defence scheme, and it may have many other wider environmental, social, cultural and economic benefits for the catchment and community.

1 SCOPE OF ASSESSMENT

The Wairoa community have expressed the view that tree planting (afforestation) in the Wairoa River catchment could be a viable option to mitigate future flood events to protect the township.

This report has been prepared to assess if afforestation is indeed feasible to reduce flood flows to a sufficient level that it could mitigate flooding of North Clyde during a 1% AEP flood event.

Several lines of evidence have been identified to explore the feasibility of this approach to flood risk management. These are:

- Review and summarise the literature relating to this subject
- Looking for a correlation between catchment tree cover and flood flows in gauged New Zealand Rivers
- Looking at theoretical methods of flood flow estimation that account for tree cover, and the level of benefit they predict
- Looking at the practical application and limitations of this approach across the Wairoa River catchment
- Discussion with the Hawkes Bay Regional Councils Science Team on any local research works they have undertaken in this area.

The methodology for each of the items above and the findings are outlined in the following report sections.

2 LITERATURE REVIEW

Within the field of flood risk management there is a common acceptance that afforestation has benefits to a catchments flow regime, but that it is generally ineffective during major floods. This is based on well understood concepts of rainfall-run-off and published literature.

It is well understood that trees can increase catchment losses (rain that does not contribute to flood flows). This occurs via several processes including:

- Inception and capture of rainfall in the tree canopy (drips of water caught on leaves)
- Increased evapotranspiration
- Increased soil permeability (more rain soaks into the ground in forested areas) and soil absorption
- Increased amounts of water trapped on the ground surface or impeded by leaf litter and woody debris
- Increased flood plain roughness can attenuate flood peaks (by increasing upstream flooding)
- Retention and stabilisation of permeable soils that retain water as opposed to soil erosion.

However, there are scale limitations to these benefits. For example, the additional surface storage a canopy provides is small and is quickly exceeded during significant and prolonged rainfall events. Increased soil permeability can reduce surface run-off in upland areas, but in larger catchments this will have limited benefit, as much of the rainfall entering the soil can eventually enter the main river system through other processes e.g. groundwater displacement.

Studies do suggest that afforestation can decrease peak flood discharge, but tends to be for smaller, less extreme, rainfall events. Increased forest cover promotes water interception by leaves and infiltration into the soil, leading to less surface runoff. Theoretical research by Johnen et al.[1] for example found a 9-13% reduction in peak flow with increased tree cover (15-60%), but noted limited benefit during a large 1% AEP (Annual Exceedance Probability) flood event. They also noted that increased flood plain roughness was more effective than wholesale afforestation, this is likely due to due increased flooding through the catchments flood plains attenuating the flood hydrograph and modifying the catchments critical duration (the time it takes for the flood event to peak)

[1] Johnen, G., Sapač, K., Rusjan, S., Zupanc, V., Vidmar, A., Bezak, N. (2020). Modelling and Evaluation of the Effect of Afforestation on the Runoff Generation Within the Glinščica River Catchment (Central Slovenia). Nature-Based Solutions for Flood Mitigation. The Handbook of Environmental Chemistry, vol 107. Springer, Cham. https://doi.org/10.1007/698_2020_649

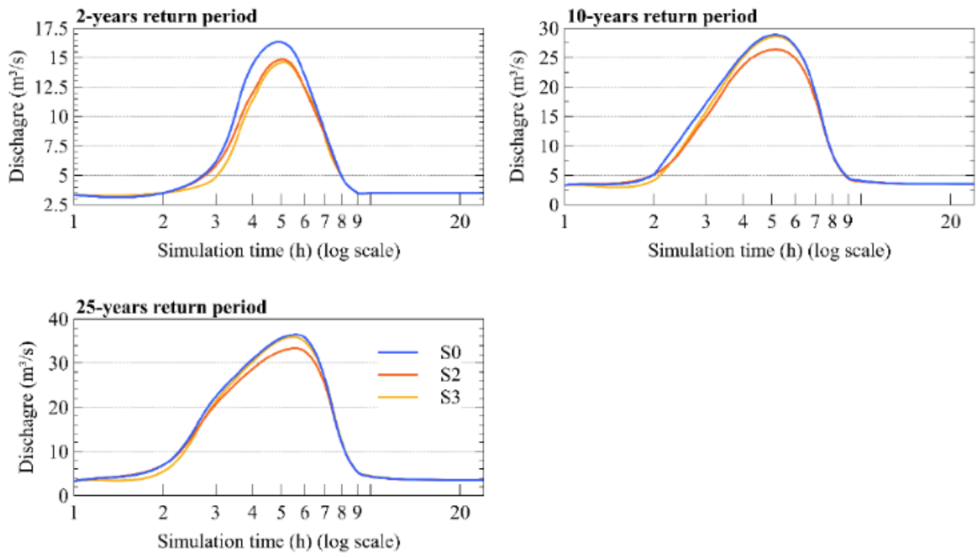

Figure 3: Comparison of the outflow hydrographs of the hydraulic model for different return periods considering the different scenarios S0 ("Current land use"), S3 ("Afforestation everywhere"), and S2 ("Afforestation downstream").

Figure 1 – Figure 3 reproduced from Johnen et al.[2] showing the predicted changes to flood flow for 50%, 10% and 4% AEP events for the Glinščica River Catchment (Central Slovenia)

The effectiveness of afforestation on mitigating large flows, like the 1% AEP flood still remains an area of ongoing debate and research. While it might reduce smaller floods, the impact on very large events might be minimal. Factors like initial soil moisture content can influence the scale of the effect[3]. Studies also suggest that benefits are more pronounced in smaller catchments with permeable soils, and thus conversely, less pronounced on large catchments.

The Chartered Institution of Water and Environmental Management (CIWEM) undertook a systematic review and meta-analysis of afforestation as a means of managing flood risk following the December 2015 floods in the United Kingdom[4]. The results highlighted a deficiency in direct evidence. From seven eligible studies of 156 papers reviewed, the results showed that increasing tree cover has a small statistically significant effect on reducing channel discharge. Meta-analysis revealed that tree cover reduces channel discharge, but the effect was variable and the potential for confounding was high, and publication bias was strongly suspected. Due to the lack of direct evidence, CIWEM concluded that the overall strength of evidence was low, indicating high uncertainty.

Buechel et al.[5] looked at a plausible afforestation scenario for the United Kingdom using a high-resolution land surface model (JULES) to quantify possible hydrological changes. They found that

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[2] Johnen, G., Sapač, K., Rusjan, S., Zupanc, V., Vidmar, A., Bezak, N. (2020). Modelling and Evaluation of the Effect of Afforestation on the Runoff Generation Within the Glinščica River Catchment (Central Slovenia). Nature-Based Solutions for Flood Mitigation. The Handbook of Environmental Chemistry, vol 107. Springer, Cham. https://doi.org/10.1007/698_2020_649

[3] Blöschl, G., Gaál, L., Hall, J., Kiss, A., Komma, J., Nester, T., Parajka, J., Perdigão, R. A., Plavcová, L., Rogger, M., Salinas, J. L., & Viglione, A. (2015). Increasing river floods: Fiction or Reality? *WIREs Water*, *2*(4), 329–344. https://doi.org/10.1002/wat2.1079

[4] Carrick, J., Abdul Rahim, M. S., Adjei, C., Ashraa Kalee, H. H., Banks, S. J., Bolam, F. C., Campos Luna, I. M., Clark, B., Cowton, J., Domingos, I. F., Golicha, D. D., Gupta, G., Grainger, M., Hasanaliyeva, G., Hodgson, D. J., Lopez-Capel, E., Magistrali, A. J., Merrell, I. G., Oikeh, I., ... Stewart, G. (2018). Is planting trees the solution to reducing flood risks? Journal of Flood Risk Management, 12(S2). https://doi.org/10.1111/jfr3.12484

[5] Buechel, M., Slater, L. & Dadson, S. (2022). Hydrological impact of widespread afforestation in Great Britain using a large ensemble of modelled scenarios. *Commun Earth Environ* 3, 6. https://doi.org/10.1038/s43247-021-00334-0

the proposed scale of afforestation was unlikely to significantly alter regional hydrology, however it could noticeably decrease low flows whilst not reducing high (flood) flows. They also found that afforestation levels minimally impacted hydrological processes compared to climatological variation (temperature, rainfall, and antecedent soil moisture).

To summarise the literature, afforestation can influence catchment hydrology, particularly dry weather flows and smaller more frequent rainfall events, but it does not appear to have a significant effect on significant flood events in the order of 1% AEP (the target level of protection for North Clyde). This is due to the scale of such events which overwhelm the additional losses, saturate the catchments soils, and significantly elevate the surface water table.

It is also worth noting that afforestation can have other less obvious benefits in terms of flood management. This includes:

- Reduced soil erosion.
- Reduced stream bank erosion (a source of Large Woody Debris) during more frequent flood events.
- Reduced aggradation of riverbeds and flood plains due to reduced deposition of sediment, which in the Wairoa region is considered beneficial due to increased sediment transport following European settlement.
- Reduced flow viscosity (how 'thick' the water is) due to lower levels of entrained sediment which can have a small benefit in terms of flood elevation.

There are also other benefits to afforestation such as amenity, ecology, cultural, economic and carbon sequestration, but these are outside the scope of this assessment.

Conversely, increased afforestation may also increase the amount of Large Woody Debris from deadfall, wind fall and land erosion which can damage important infrastructure such as bridges. If it were commercial forestry, it would also limit the overall benefit, with an on-going cycle of harvesting and regrowth reducing the overall effectiveness of the forest canopy and creating periods of risk when forest cover is cleared.

3 OBSERVATIONAL TRENDS IN NEW ZEALAND

If there is a strong effect of afforestation on flood flows, it is posited that it would be discernible from observed flow data across catchments of varying levels of tree cover.
To identify if there is a strong correlation between flood flows and forest cover, a desktop review of 115 gauged river catchments in New Zealand's North Island was undertaken.

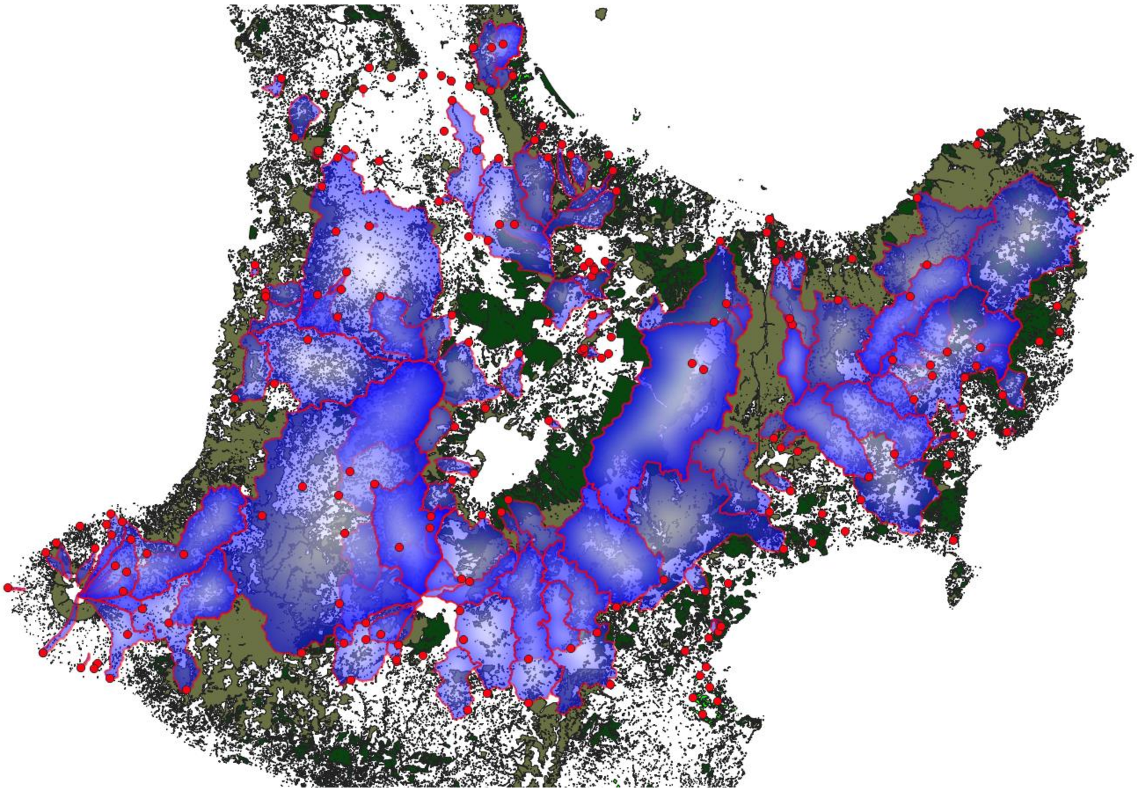

Figure 2 – selected catchment areas in blue (note some overlap due to multiple gauges within the catchment) and selected flow gauges (red dots)

The methodology employed was as follows:

- Gauge locations were obtained from NIWA (New Zealand River Flood Statistics[6]) for 115 catchments.
- NIWA's estimated 1% AEP flow was obtained for each gauge location. These were then normalised to $m^3/s/km^2$ in line with the Regional Flood Frequency Method (RFFM) to allow comparison of flows from different scale catchments.
- The level of tree cover for each gauged catchment area was calculated using GIS software and the New Zealand Land Cover Database (LCDB)[7] for land cover.

[6] New Zealand River Flood Statistics. National Institute of Water and Atmospheric Research. (n.d.). https://data-niwa.opendata.arcgis.com/app/new-zealand-river-flood-statistics-app

[7] LCDB v5.0 - Land Cover Database version 5.0, Mainland, New Zealand. Landcare Research (2018). LRIS portal. https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/

- The % tree cover for each catchment was then calculated so that flood flow could be plotted against catchment tree cover.

The levels of tree cover varied from 1% to 100% and had uniform distribution providing representative values for a wide range of tree cover.

When the results were compared, it was found that there was no statistically significant trend indicating that if there is any relationship it is likely small relative to other parameters such as flood flow estimation uncertainty, climate and soil type.

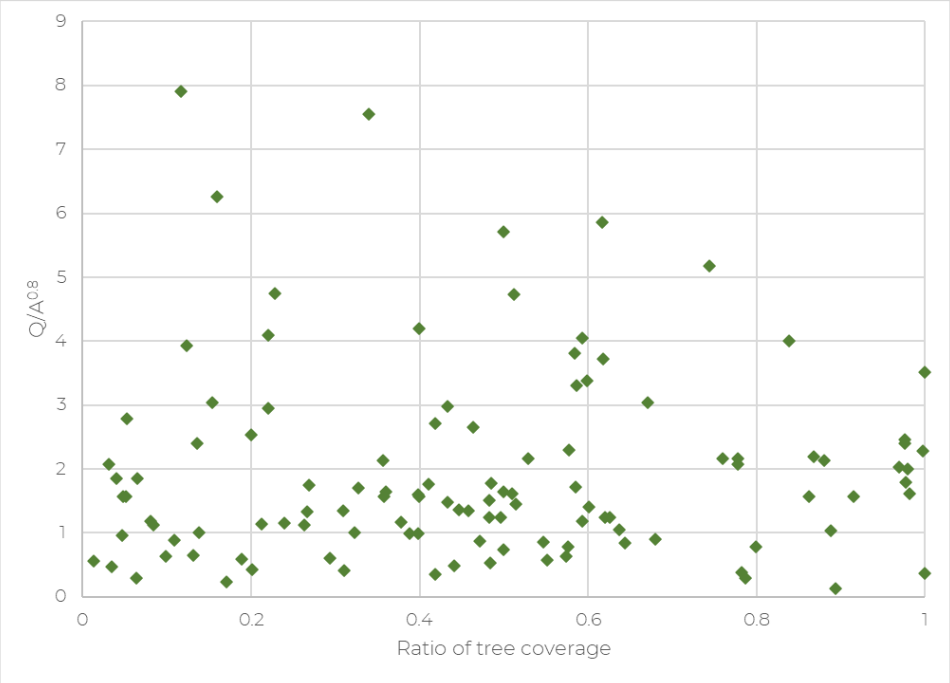

Figure 3 – Correlation of flow and catchment tree coverage.

4 THEORETICAL METHODS

Two empirical rainfall run-off models commonly used in New Zealand are TR-55 and Griffith & McKerchar 2012 (G&M). Both use empirical values estimated from observed data to approximate flood flows. TR-55 uses different 'CN curve' numbers to account for land use type, including tree cover. G&M uses a number of categories to estimate a run-off coefficient and includes a parameter to account for canopy interception. G&Ms methodology was calibrated against a selection of gauged New Zealand river catchments.

For TR-55 a CN curve number based on Figure 4 for pasture / grassland and Type B soil in good condition (61) can for example be substituted for 'Woods' with the same condition and soil type (55) to assess the change in peak flood flow.

Cover description		Curve numbers for hydrologic soil group			
Cover type	**Hydrologic condition**	**A**	**B**	**C**	**D**
Pasture, grassland, or range—continuous forage for grazing.[A]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	[illegible]	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	[illegible]
Brush—brush-weed-grass mixture with brush the major element.[B]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[C]	48	65	73
Woods—grass combination (orchard or tree farm).[D]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[E]	Poor	45	66	77	83
	Fair	36	60	72	[illegible]
	Good	30	55		77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

Figure 4 – CN curve numbers for different land uses (source Wikipedia)[8]

[8] Runoff curve number. Wikipedia. (2024). https://en.wikipedia.org/wiki/Runoff_curve_number

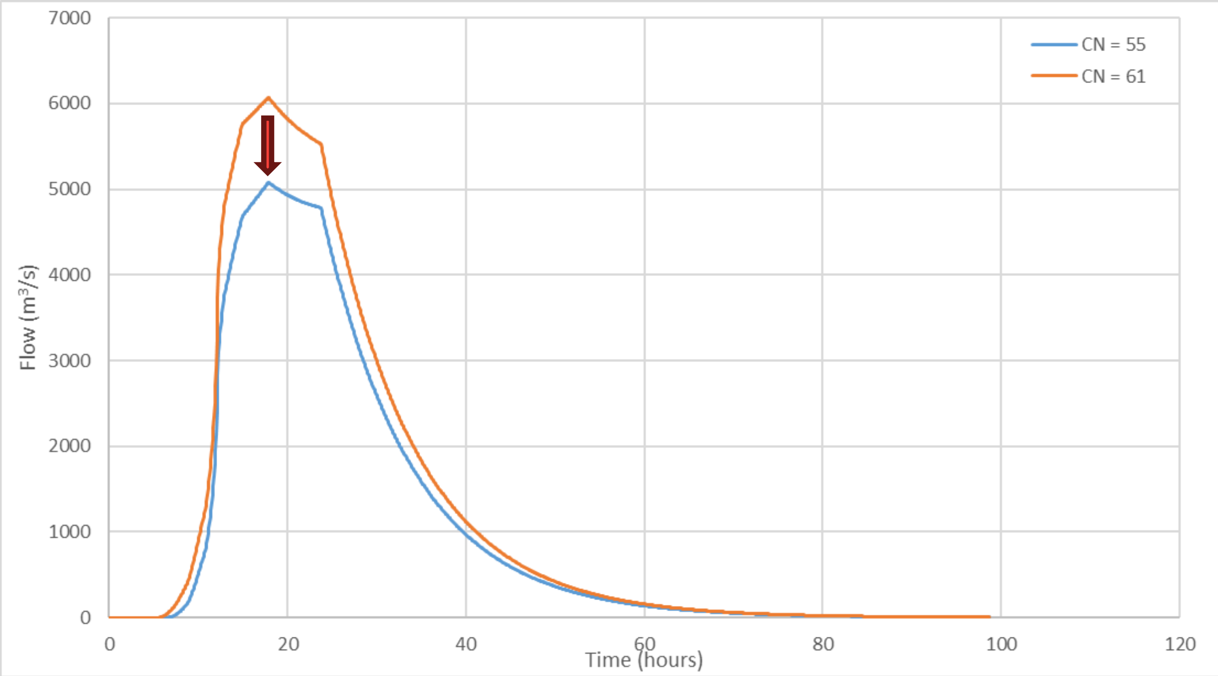

Figure 5 – Predicted flow hydrograph within CN 55 and CN 61 overlaid.

For the Wairoa catchment, looking at it simplistically, a 100% change in land use from pasture to forest cover results in a predicted 16% reduction in peak flood flow using TR-55.

Note that for areas with lower soil permeability the benefit predicted reduces using TR-55. The Wairoa catchment is classified as having 'moderate' permeability with soil drainage that is primarily 'well drained' to 'moderately well drained' by Landcare Research (S-MAPS)[9].

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9 Soil Drainage. S-Maps Online. (n.d.). https://smap.landcareresearch.co.nz/maps-and-tools/app/

Figure 6 – Map of soil drainage for the region.

Griffith & McKerchar (2012)[10] provide a range of 0 to 10% for the effect of vegetation (no effective cover to significant canopy cover) in their table of runoff producing characteristics. This table is based largely on the earlier work of Turner (1960) which noted that the run-off coefficient should be reduced by 10% where there is rainfall interception by thick forest cover.

Griffith & McKerchar (2012) indicates that a heavily forested catchment can result in a 10% reduction in run-off compared to a catchment with no effective vegetation cover. Note that this applies to estimation of the Mean Annual Flood (MAF) and might be further reduced in practice during a 1% AEP flood event based on the literature. However, this is beyond the scope of Griffith & McKerchar (2012) which focussed primarily on estimation of the MAF which is then scaled for larger flood events.

[10] Griffiths, Gareth & Mckerchar, Alistair. (2012). Estimation of mean annual flood in New Zealand. Journal of Hydrology New Zealand. 51. 111-120.

Catchment characteristics	Runoff producing characteristics			
Rainfall intensity	(30) >30 mm/hr	(20) 21-30 mm/hr	(10) 11-20 mm/hr	(5) ≤ 10 mm/hr
Relief	(20) Very steep rugged country Channel slope >0.05	(5) Rugged hilly country Channel slope 0.01 – 0.05	(0) Rolling country Channel slope 0.004 – 0.009	(0) Relatively flat land Channel slope <0.004
Surface and subsurface storage	(25) Negligible depression/ detention/ subsurface storage	(15) Low depression/ detention/ subsurface storage. Well defined stream network	(5) Moderate depression/ detention/ subsurface storage	(0) Significant depression/ detention/ subsurface storage
Infiltration	(15) Negligible infiltration capacity. No effective vegetation cover. Rapid overland and subsurface flow	(10) Low rate of infiltration and high rate of overland and subsurface flow	(5) Moderate rate of infiltration and of overland and subsurface flow	(0) High rate of infiltration. Low rate of overland and subsurface flow
Vegetation	(10) No effective vegetation cover	(5) Low canopy/ interception/ litter storage	(5) Moderate canopy/ interception/litter storage	(0) Significant canopy/ interception/litter storage

Figure 7 – Run-off producing characteristics from Griffith and McKerchar (2012)

5 FEEDBACK FROM HAWKES BAY REGIONAL COUNCIL

WSP contacted the HBRC Science team to see if there was any local research on afforestation. Unfortunately, much of the HBRCs prior research has been more focussed on reducing sediment yields into rivers rather than flood reduction. However, HBRC did share a draft literature review produced by NIWA[11] on Nature Based Solutions (NBS), which does include afforestation as part of land management practices. Nature Based Solutions is a holistic term that refers to a number of techniques that utilise natural processes to better management flood risk, such as providing rivers with space to move, restoring wetland habitat within flood plains and improving landcover and soil management. The key finding of the report is that there is limited empirical evidence on the short and long term effectiveness of NBS and that more research is needed to enable wider update and implementation.

For landcover and soil management, the report concluded that:

- There is limited evidence about the impacts of woodland creation at the small to medium catchment scale on flood flows.
- Improvements needed in the way that hydrology and hydraulic models represent relevant processes (evaporation, soil infiltration, surface roughness and ideally sediment interactions) and the selection of appropriate parameter values.
- Technological developments needed in sensor design to improve estimation of flood flows during extreme events and woodland impact on flood generation and conveyance.
- Limited direct study of relative influence that soil and land management measure can have on flood risk relative to their area and location in the catchment.

Their draft summary aligns with our own conclusions, in that the benefit of large-scale afforestation is likely to be relatively small in terms of extreme flood events and is highly uncertain.

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[11] Nature-based solutions for flood management – Literature Review, NIWA, April 2024

6 PRACTICAL APPLICATION

Review of multiple lines of evidence indicates that effect for afforestation on significant flood events is poorly understood but is likely small in effect relative to other factors, with the upper bound benefit likely being in the order of a 10-16% reduction for a 100% change in land use, though this is entirely theoretical.

Under our current climatic regime, a reduction in flood flow of approximately 15% (1000 m^3/s) is required to stop flooding of North Clyde during a 1% AEP event. Hence the required reduction would only be feasible if the existing catchment is currently entirely unforested.

Also, the scale of such an undertaking must not be under-estimated. The Wairoa catchment has a significant area of 3664 km^2, equivalent to 424,000 rugby pitches, 6 cities the size of Auckland or 1.4% of New Zealand's total land area for context. Afforestation on such a scale would be challenging to implement without massive investment and large-scale disruption. Afforestation would not be limited to stream margins and steep gullies but would need to be applied almost all unforested land.

Based on LCDB mapping of vegetation, it is estimated that:

- 46.90% of the Wairoa catchment is already forested (native and exotic / harvested forest).
- 0.14% of the Wairoa catchment consists of roads, parks, mines, landfill and urban areas
- 42.86% of the Wairoa catchment is productive farmland (pasture, orchards, vineyard)
- 2.34% of the Wairoa catchment cannot be afforested (lakes, rivers, estuary, rock, gravel, beach, freshwater or saline vegetation)
- 7.90% of the Wairoa catchment is in non-productive / non-urban land that could be afforested (flax and fern land, slips, gorse or broom, exotic shrubland, manuka or kanuka, matagouri or 'grey scrub')

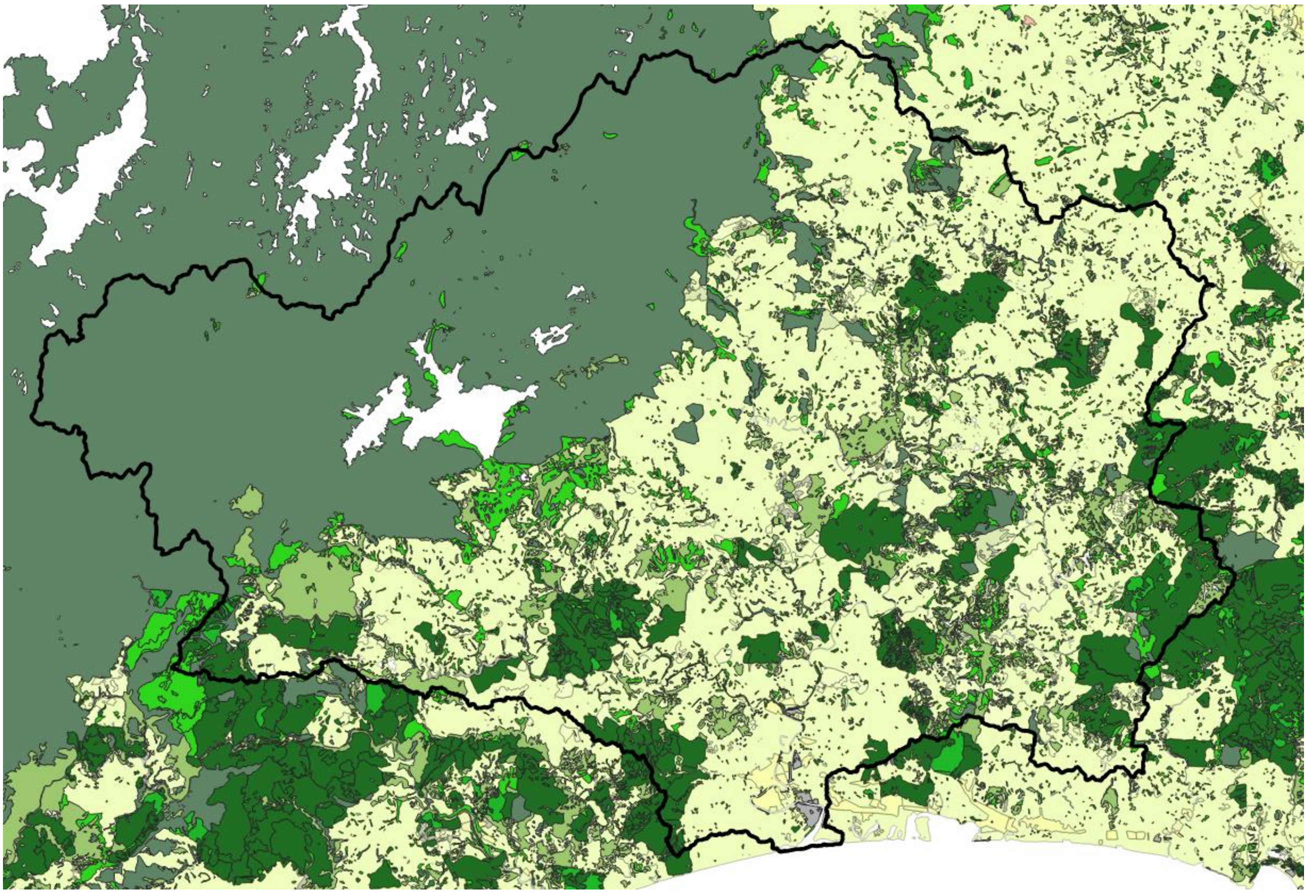

Figure 8 – Land use cover within the Wairoa River catchment (LCDB). Greens represent forested areas, grey represents urban areas and yellows represent grassland / farmland.

Some of the non-productive, non-urban land that could be afforested (7.90%) will be conservation land and likely includes regionally significant native habitat.

The maximum level of afforestation that might be achieved, retiring all productive land in the catchment is 50.76%. Hence a maximum flow reduction in the order of 5-8% might be achievable, **but this is still less than the amount required to prevent flooding of North Clyde (a required 15% reduction).**

Based on average farm sale price for the Bay of Plenty[12] (October to December 2023) the value of the productive farmland in the catchment is in the order of **$16 billion dollars**. It is assumed that to afforest this land it would need to be purchased by the crown, as landowners are unlikely to volunteer their productive land. This would require almost all rural landowners to agree to sell their land. This would be a serious impasse given the scale of afforestation that would be required. An alternative would be pay landowner's a subsidy for productive farmland converted to forest.

Afforestation could take a range of paths, such as:

[12] Statista Research Department. (2024). New Zealand: Median farm prices by region 2023. Statista. https://www.statista.com/statistics/1028660/new-zealand-median-farm-prices-by-region/

- Native revegetation with the associated ecological benefits (retirement into conservation land)
- Native revegetation with managed harvesting of native timber
- Commercial pine plantations with on-going harvesting
- Planting of pine and native tree species for carbon emission offsets
- Incentivised conversion of productive farmland to forestry through subsidisation

How it would be done is a matter for future deliberation, but in some scenarios could generate revenue that would somewhat offsets the establishment cost.

Assuming a planting density of 5000 stems per hectare[13] for quick canopy establishment, **0.8 billion trees** would be required. At an assumed cost of $8 per tree planted[14] the total afforestation cost could be in the order of **$23 billion dollars** with land purchase. As noted above, under some scenarios, some of this initial outlay could be recuperated from selective or larger scale logging, or through carbon trading schemes.

Also worth noting is that such a significant change could take a long time to implement with significant upfront costs, the scale of consultation required, the land purchase process, and the time associated with establishment of forest cover. For example, if it were feasible to plant 10 million trees per year (for reference the One Billion Trees scheme is planting 1 billion trees across all of New Zealand over 10 years[15]), it would take **79 years to plant the catchment**. During this process, North Clyde would remain subject to flooding, and would likely still remain subject to flooding once completed, though at a somewhat reduced level.

Afforestation on a smaller scale, e.g. only targeting non-productive land, would be ineffective due to the smaller benefit expected e.g. 7.9% of 10-16% = 0.8-1.3% flow reduction, though it could form part of a wider package of measures if say combined with an engineered flood relief scheme.

So, from a practical flood management perspective, the scale of flow reduction needed relative to the limited benefit of afforestation makes such a scheme wholly unfeasible and highly risky. **Engineered interventions by comparison provide higher certainty of outcome, have a significantly lower cost and occupy a smaller parcel of land, and provide sooner benefit with minimal to no loss of productive land.**

This does not rule out afforestation, it can be applied as a complimentary activity, or achieved to some extent through other programs (e.g. carbon sequestration, ecological enhancement, or soil conservation), but it cannot be relied on as a sole means of flood mitigation.

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[13]Bergin, D. (2012). Planting pattern and density for natives on open sites. https://www.tanestrees.org.nz/site/assets/files/1069/8_2_planting_patterns_and_density_for_natives_on_open_sites.pdf

[14] Trees that count - Tree prices. Trees That Count. (n.d.). https://treesthatcount.co.nz/businesses/price-guide, as of April 2024

[15] Ministry for Primary Industries. (2024). How we'll plant one billion trees: NZ government. Ministry for Primary Industries. https://www.mpi.govt.nz/forestry/funding-tree-planting-research/one-billion-trees-programme/about-the-one-billion-trees-programme/

7 SUMMARY OF FINDINGS

Tree planting (afforestation) is not traditionally considered a primary means of flood mitigation by flood management specialists. It is considered a complimentary technique, that in the long term might provide some additional benefit to more engineered interventions. There is sound reasoning behind this approach.

Afforestation might reduce peak flows during large flood events such as Cyclone Gabrielle, but the effect is likely to be small whilst requiring wholesale land use change of the entire catchment for any meaningful change. This would come at a significant cost and the risk of flooding would likely still exist at the end of the process due to uncertainty over the effectiveness of afforestation. It is also a solution that would take a significant period to implement.

Retiring and afforesting the unforested areas of the catchment would also have significant economic impact on the Wairoa community, removing productive farmland from use and relies on landowners being willing to sell up their land.

Other more engineered solutions by comparison provide a more immediate benefit and more certain outcomes at lower cost and can be implemented faster with less disruption to the Wairoa community.

Whilst afforestation has many benefits, such as ecology, cultural wellbeing, amenity, and carbon sequestration, it does not appear to be a feasible option in terms of reducing flooding in North Clyde during a 1% AEP flood event.

8 LIMITATIONS

This report ('**Report**') has been prepared by WSP exclusively for Hawke's Bay Regional Council ('**Client**') in relation to testing the feasibility of the flood protection options for Wairoa ('**Purpose**') and in accordance with the proposal 'Scope – Afforestation' dated 21/07/2023. The findings in this Report are based on and are subject to the assumptions specified in the Report. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

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