Preliminary estimation of catchment capacity to develop debris flows/debris floods and indicative estimation of risks
Envirolink 2118-MLDC158

Mark Bloomberg, Te Kura Ngahere|NZ School of Forestry
Dave Palmer, Scion
Chrissy Bright, Landpro

Proposal

- Complete “hillslope to seabed” approach to operational-level landslide hazard identification and risk management.
- Can be applied by regulatory authorities, and by all forest owners from small woodlot owners upwards.
- Provide a common understanding of the risks from erosion, landslides and downslope sedimentation

Research method

- Using high-resolution DEM, it is possible to use GIS analysis to identify catchments susceptible to landslides, debris flows and floods, and to estimate the likely hazard zones ("footprints") for these.
- This allows a GIS-based exposure analysis where we spatially match hazard footprints and assets at risk.

Deliverables :

- Report describing application of “Operational-level landslide hazard identification and risk management to better manage the risk of erosion from harvested plantations on slopes”
  - Two case studies, one in Marlborough District, and one in Tasman District.
- GIS models and methodology that allow identification of:
  - Catchments susceptible to debris flows and floods, and their hazard footprints
  - Assets (built or natural environment) located within the hazard footprint.
- Training of Council staff
  - Council resource consent staff will have a tool for objectively evaluating risk of adverse effects from forestry and logging proposals.
  - Council scientists will have a tool that allows focussing of research resources
  - Council GIS staff will learn new skills in geospatial identification of landslide hazards, and evaluation of risks to built and natural environments.

Today’s agenda

Schedule for Envirolink Presentations-Marlborough (17/3/21)				
			Time	
Topic		Presenter	Start	Finish
Introduction		Mark	1000	1015
Rationale and Theory		Mark	1015	1040
Geospatial analysis and outputs		Dave Palmer	1045	1110
Effects on freshwater and marine environments		Chrissy or Mark	1115	1140
The case study areas: presentation of results, and discussion	**Marlborough**	Dave and Mark	1145	1230
	Havelock*			
	Port Underwood			
	Whatamango Bay			
	*=Field Trip Venue			

Today’s agenda

Schedule for Envirolink Presentations- Tasman (18/3/21)				
			Time	
Topic		**Presenter**	**Start**	**Finish**
Introduction		Mark	900	915
Rationale and Theory		Mark	915	940
Geospatial analysis and outputs		Dave Palmer	945	1010
Effects on freshwater and marine environments		Chrissy or Mark	1015	1040
The case study areas: presentation of results, and discussion	**Tasman**	Dave and Mark	1045	1130
	Marahau			
	Ligar Bay			
	The Shaggery*			
	*=Field Trip Venue			

Predicting hazard from debris flows and debris floods in NZ plantation forests

UNIVERSITY OF CANTERBURY
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CHRISTCHURCH NEW ZEALAND

Mark Bloomberg, Te Kura Ngahere|NZ School of Forestry
Dave Palmer, Scion
Chrissy Bright, Landpro

Background

Figure 4.1: Failure in Whataroa Bay (February 2018).

- Landslides as a source of sediment
- Very efficient at transporting sediment and slash to waterways
- Consequence of clearfelling (although earthworks failures also a factor)
- Therefore difficult to mitigate with best practice

Landslides as a source of sediment

Process	Sediment generating site	Area connected to stream (ha)	Sediment generated & delivered (t)	% of total
Slope wash	Shallow dist.	n/a	n/a	n/a
	Deep dist.	0.18	2.9	2
Soil scraping	Scalped (40 mm)	0.18	60	26
Landsliding	Landslide source area	0.07 (n=9)	165	72
Totals	All sources	0.25	227.9	100

Marden, M.; Rowan, D. & Phillips, C.J. (2006)

Debris flows and Debris floods

- Loose soil, rock, organic matter and water, mobilised and transported as a rapidly-moving slurry
- Differ from normal flood
  - V. high suspended fine sediment (30% by wt)
  - Only debris flows carry large boulders
  - But debris floods can carry slash, logs

- https://www.youtube.com/watch?v=YZTZ4VTXKIE
- https://www.youtube.com/watch?v=n1cCs-S5EKc
- https://www.youtube.com/watch?v=mHJmfySkgMw

Debris flows and Debris floods versus other "mass movement" erosion

- Most mass movements have a limited "runout"
  - Solid state, high frictional resistance
- Debris flows and debris floods behave more like liquids
  - Long runouts even on low slope angles

Direct impact of landslip

Source:TDC

Impact of debris flow and debris flood 100's of metres downstream

Debris flows as a hazard- to property, but also human health and wellbeing and the natural environment

- Note: can occur under any type of land cover including intact forest
- On forestry clearfell sites, also mobilise slash
- ‘Run out’ for long distances onto lowland environments, i.e. river flood plains and the coast


Source:TDC


Source:Steve Urlich

Sediment transport by debris flows and debris floods

- Far in excess of conventional floods
- Peak flow rates of debris flows up to 50 x flood flows
  - because travel in surges
- Debris floods don’t surge
  - but peak flows 2 x greater than floods under equivalent conditions.

Source:TDC

Research aim

- GIS models and methodology that allow identification of:
  - Catchments susceptible to landslides, debris flows and debris floods, and their hazard footprints, defined as the likely extent of runout of these flows.
  - Assets (whether in the built or natural environment) that are located within the hazard footprint, and also estimates of their vulnerability to landslides, debris flows and floods.

Melton ratio = Relative Relief Ratio

Melton ratio (R) = $H_b A_b^{-0.5}$

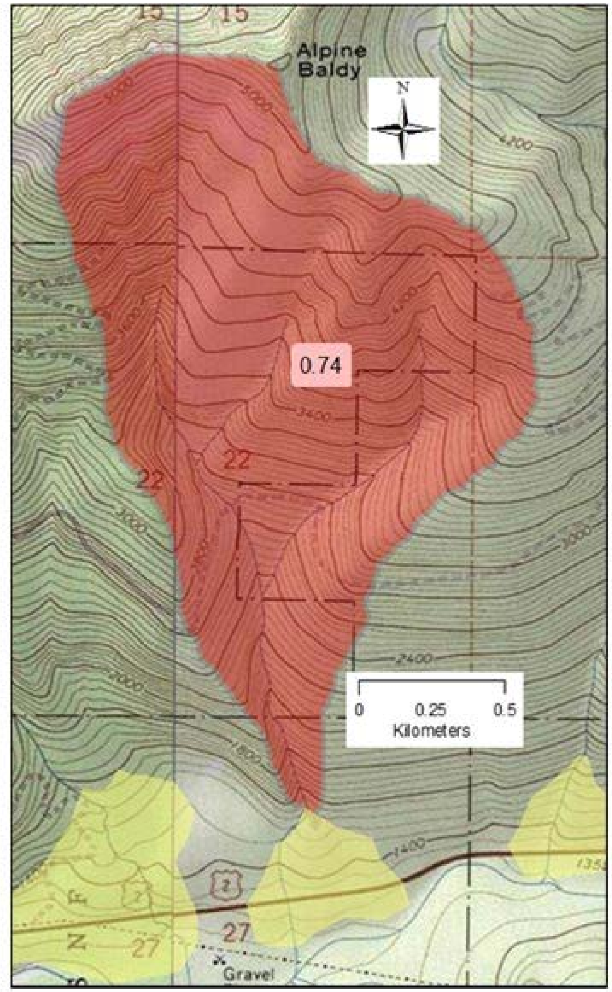
H_b: basin relief (difference between maximum and minimum elevations in the basin)

A_b: total area of the basin

Example: Alpine Baldy,
South Fork Skykomish

Top Elev.:	1,584 m
Bottom Elev.:	464 m
Area:	2,351,050 m^2
R	$= (1584 - 464) * (2,351,050)^{-0.5}$
	= 0.73

Source: Melton, M. A. (1965). The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona. The Journal of Geology, 1-38.



https://www.kingcounty.gov/services/environment/water-and-land/flooding/maps/river-landslide-hazards/mapping-methodologies.aspx

Influence of catchment definition

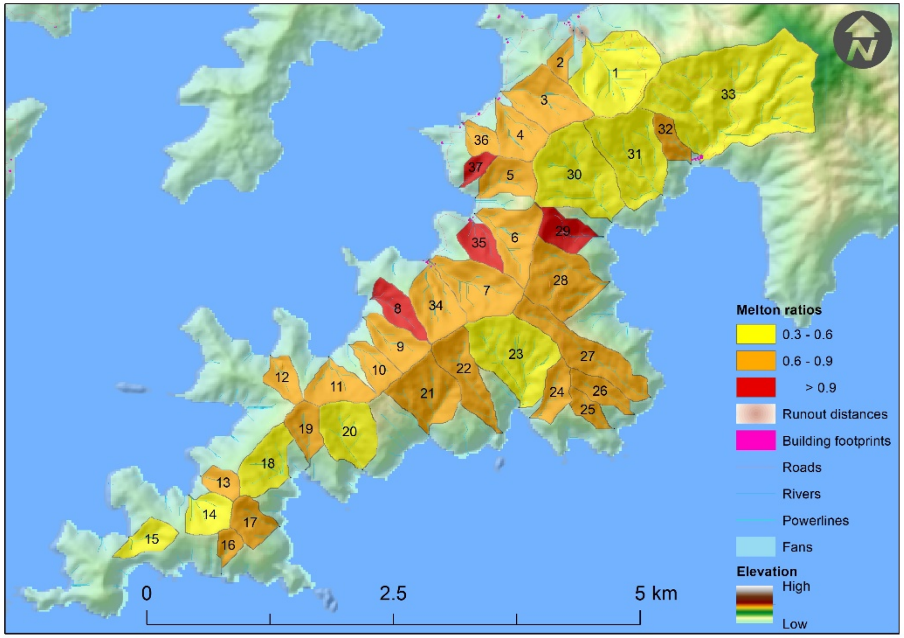
- Larger catchments
  - Melton R <0.3
  - Flood
- Medium catchments
  - Debris floods
  - Melton R 0.3-0.6
- Smallest catchments
  - Debris flows
  - Melton R>0.6

Figure 6. Statistically predicted debris flow (brown), debris flood (green) and flood (blue) stream process types near Kananaskis Village.

Holm et al. 2018

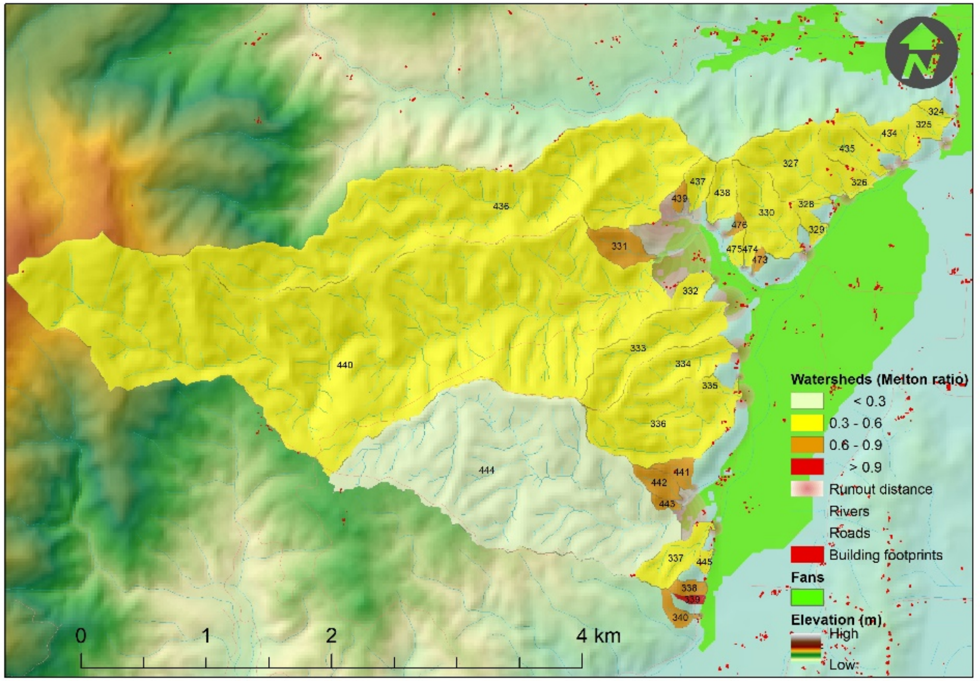
Generating maps of debris flow and debris flood hazard

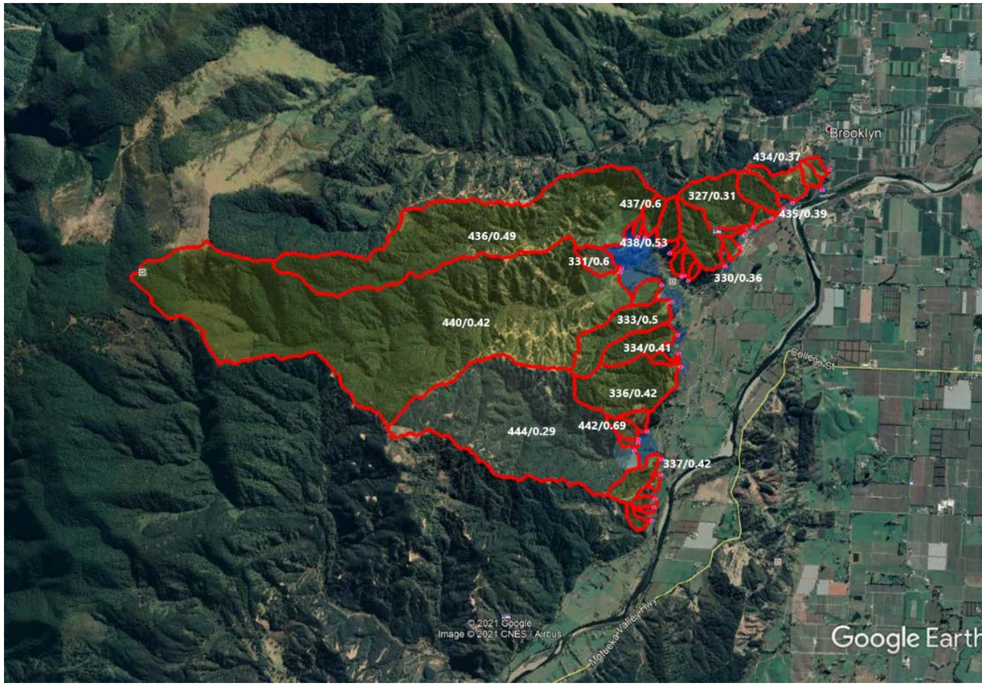
- Melton ratio and estimated runout
- Use DEMs to
  - Create catchments
  - Identify beginning of fan or depositional area
  - Measure and calculate Melton ratio and debris flow runout.



One caveat

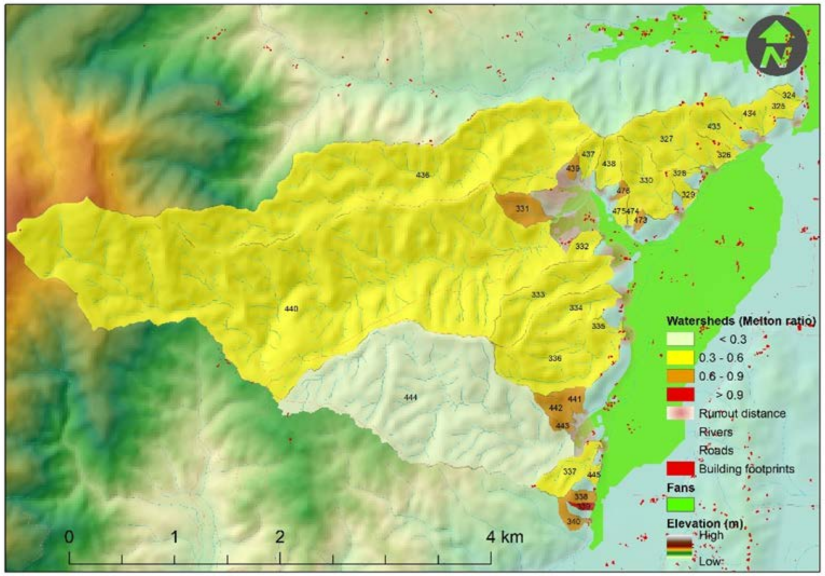
- Melton and runout are calculated for a catchment defined by fan apex
- Only consider debris flows, debris floods <u>below</u> fan apex
- Large catchment with low Melton ratio
  - Tributary catchments may generate debris flows
  - e.g. Shaggery Catchment





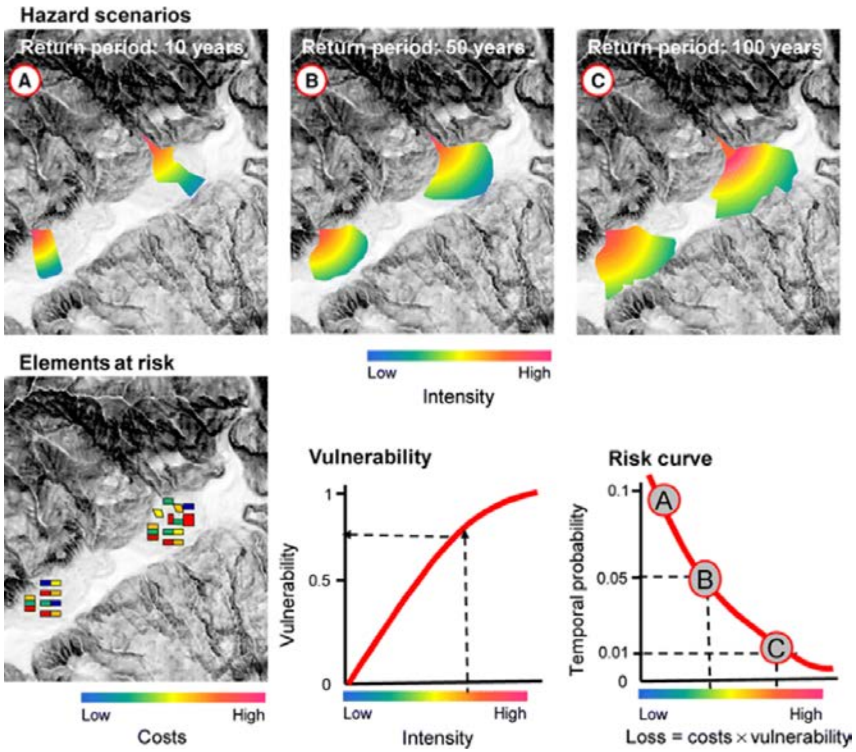
Add a layer of vulnerable assets

- "Built" environment
  - Dwellings, other buildings
  - Roads
  - Infrastructure
- The "Natural" environment
  - Freshwater and marine
  - Wetlands
- Associated human presence, activities, dependencies, values



Melton ratio and estimated debris flow runout are not the whole story

- Runout distances for debris floods?
- Return period x severity?
  - Interaction with 6-year "window of vulnerability" after forest harvesting
  - At least 50/50 chance of a landslide-triggering storm in a 6-year period for most of the study areas



(Corominas et al. 2014)

Having said that….

- Melton R and estimated debris flow runout are “red flags”
  - Take them seriously
  - Identify built and natural environments within the hazard footprint!
  - Encourage foresters and other landowners to plan accordingly.

Source:Campbell Harvey

- Many thanks for your attention
- Questions, discussion

Looking upstream at runout limit of debris flows

Source:Sally Moore

Spatial modelling of debris flow and runout distances

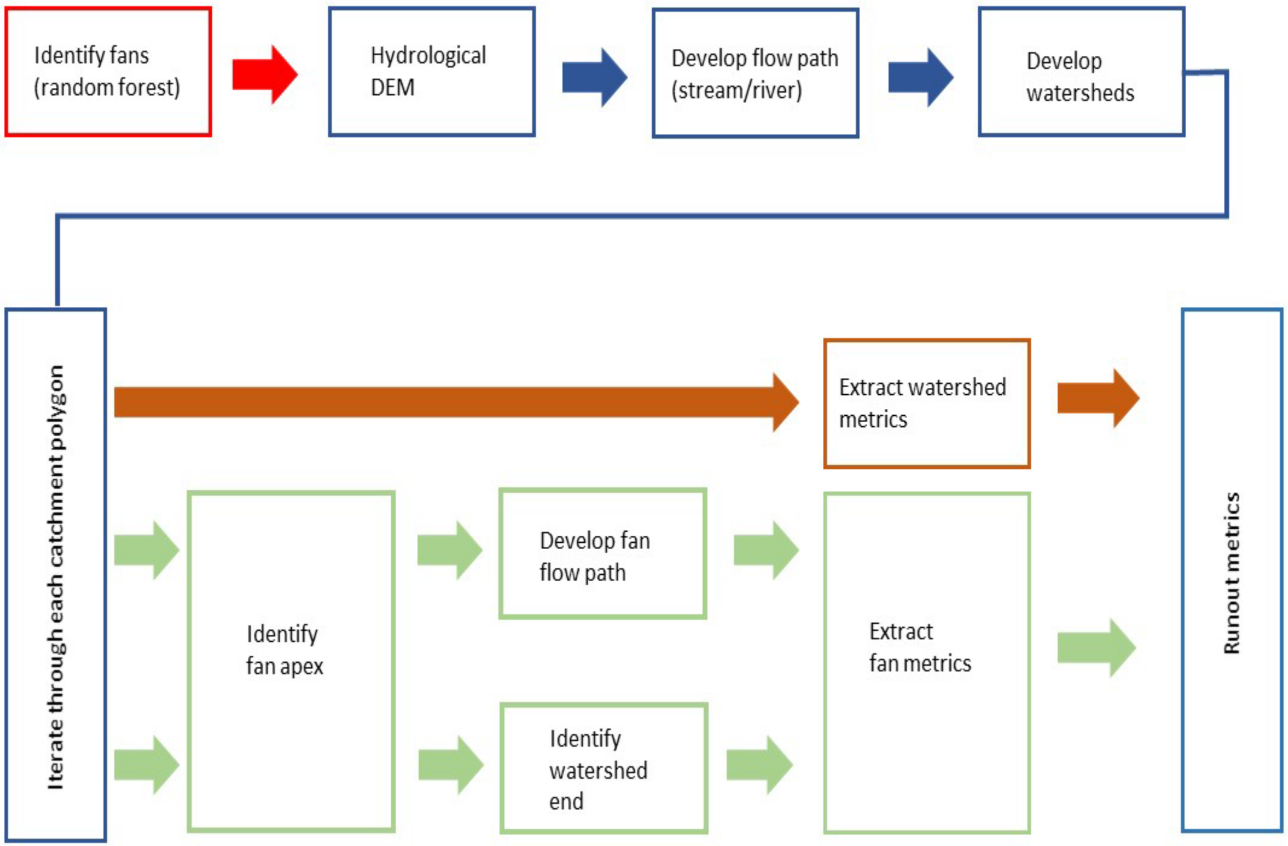
Mark Bloomberg and David Palmer (Photo Nyhane Drive, Ligar Bay)

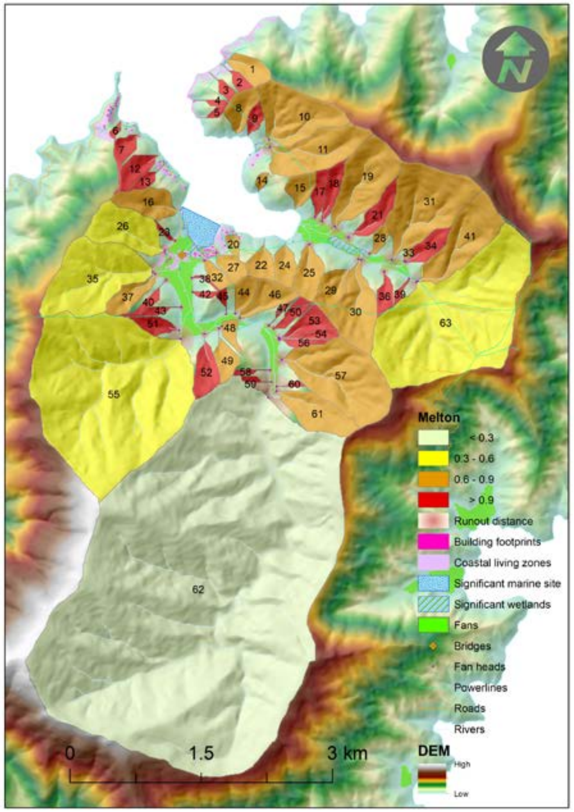
Debris flows

Definition: A type of landslide that includes a combination of loose soil, rock, organic matter, air, and water, all of which are mobilized and transported as a slurry.

Photos, Bay of Plenty 2011

Geospatial modelling process





Prediction of fan locations

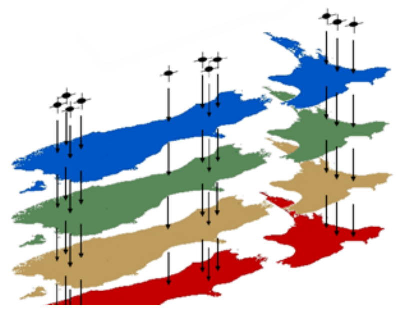
Process:

(1) Generally, identify fan and non-fan locations

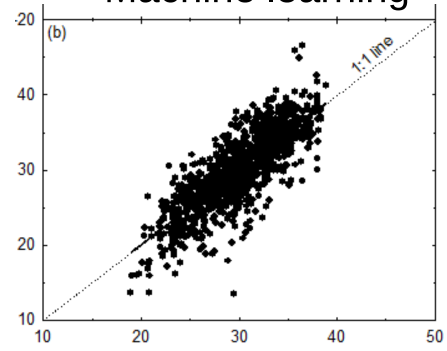
(2) Randomly extract terrain data within each polygon

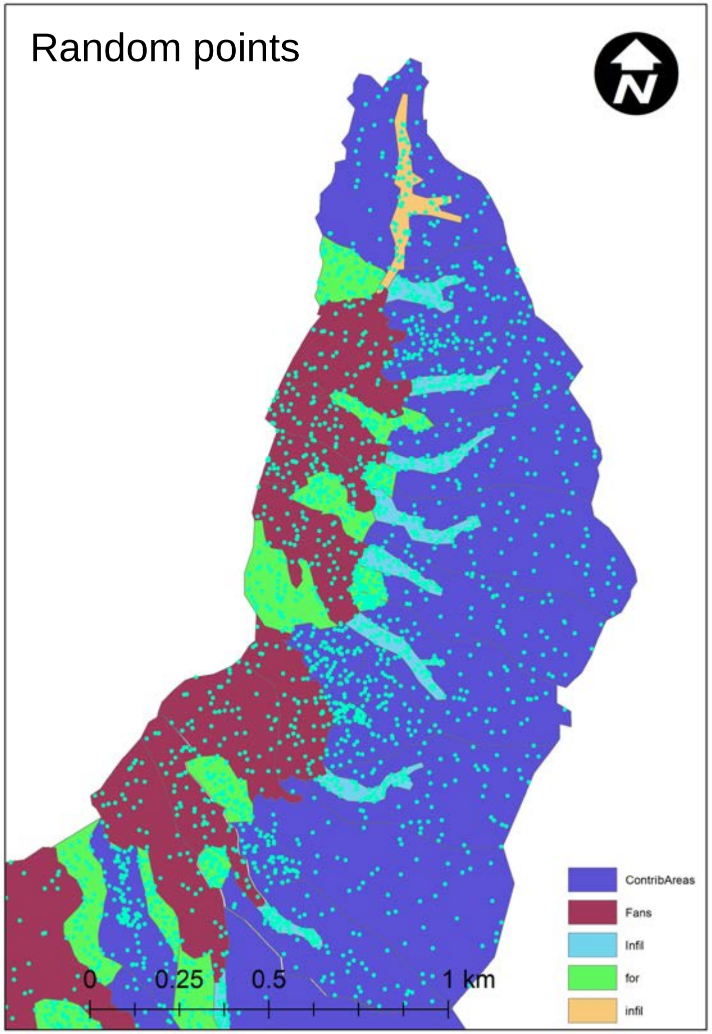
(3) Use the Random Forest model to predict presence (brown)/absence (blue) of fans

Point data extraction



Machine learning





Watershed and fan metrics calculations

Develop watersheds

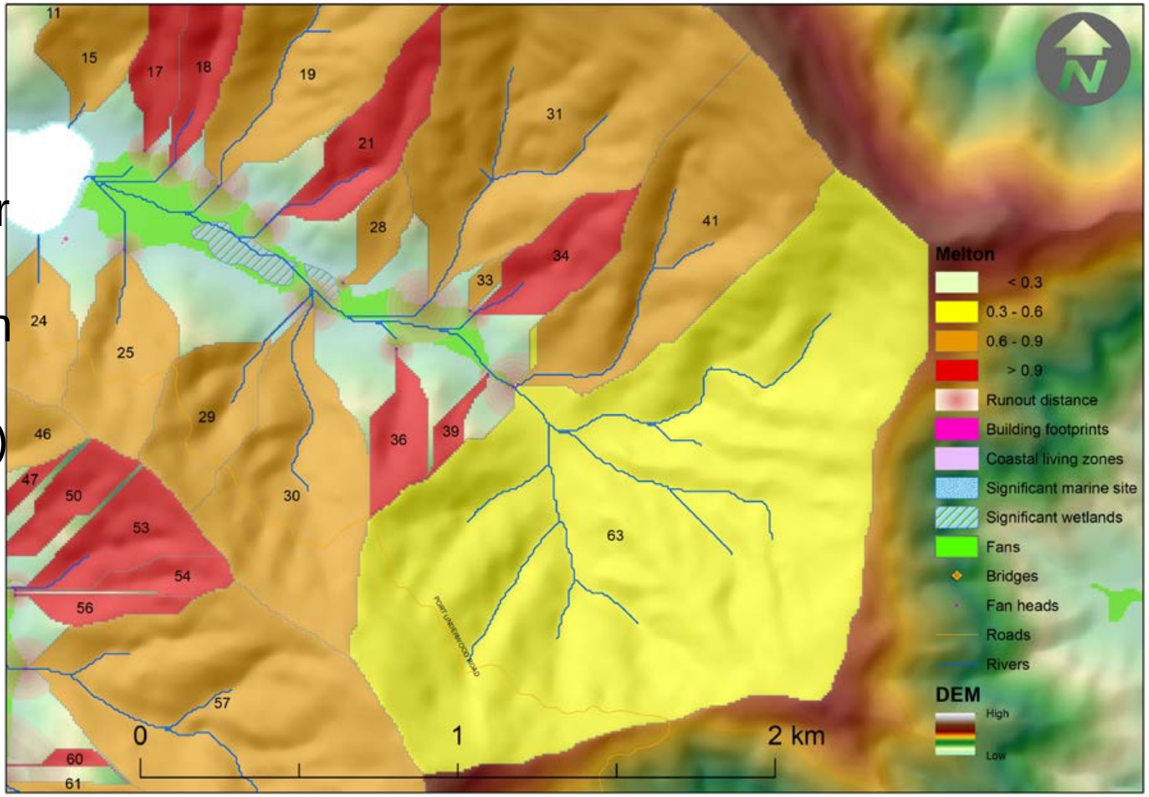
- Develop a hydrologically sound Digital Elevation Model (DEM)
- Use flow direction and accumulation to develop river paths
- Identify fan apex (intersection between fan and river path)

Watershed metrics (Melton ratio)

- From each fan apex develop watershed
  - Watershed length
  - Watershed height

Runout distance

Distance from the fan apex across the fan



A good one from BC—how to get logs into a waterway! Notice that the flow comes in waves, apparently this is pretty standard.
https://www.youtube.com/watch?v=n1cCs-S5EKc

This US example seems to have debris flood characteristics, but has originated in a timber catchment so slash-transportation is to the fore. Key point-debris flows have much higher transporting power than ordinary flood waters.
https://www.youtube.com/watch?v=ORJtxkuD62E

Finally, the famous Illgraben—looks like a debris flow out front, with a debris flood in behind?
https://www.youtube.com/watch?v=2Rfuoylv34k

A risk management framework for landslides in NZ plantation forests

Mark Bloomberg, NZ School of Forestry
Dave Palmer, Scion
Chrissy Bright, Landpro

Definitions of "Erosion" and "Landslide" (Mass Movement)

- **Erosion**: Localised removal of rock or soil
  - Water
    - gully erosion, rill, streambank
  - Surface
    - Wind, sheet wash
  - **Mass movement (landslide)**
    - Soil slip
    - Debris flows
- Transport, deposition

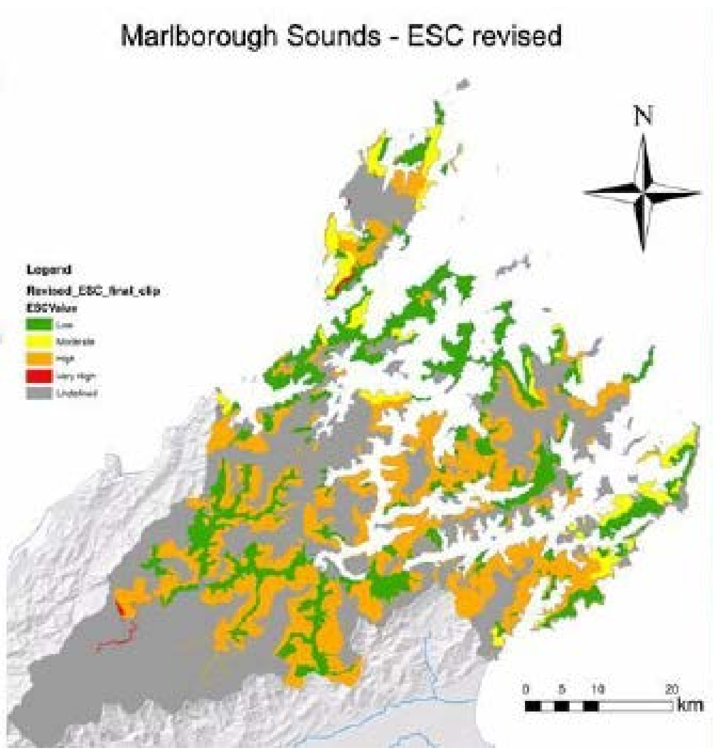
Tunnel gully erosion, Marlborough

Soil slip (landslide) erosion, Tasman

NZ National Environmental Standard for Plantation Forests

- Need to evaluate and manage risk of erosion from forestry activities
  - NES-PF lacks a comprehensive erosion risk management framework
  - Erosion Susceptibility Classification (ESC)

Erosion Susceptibility Classification (ESC)



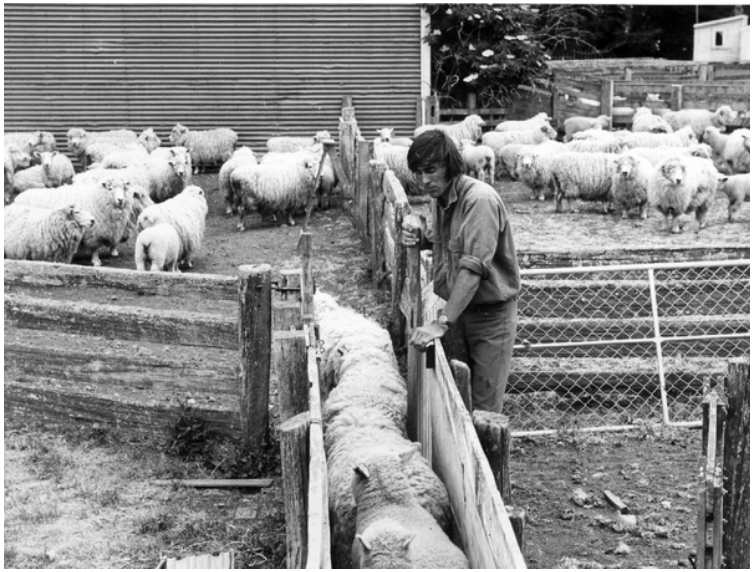
- 1/50,000 scale
  - SI uses old NZLRI mapping (1970s) of potential erosion
    - Except Southern Marlborough!
- Problems
  - Outdated, insufficient detail,
    “Summary notes from meeting and field trip on land resource data and forestry issues in the Marlborough Sounds:Envirolink Advice Grant: 1704-MLDC118”
  - ESC is only part of risk assessment process

Erosion susceptibility, Erosion Hazard, Risk

1. Landslide Inventory Where, which and when landslides occurred before?	Patchy coverage, although progress towards a national landslide database
2. Landslide susceptibility Where is it more likely that landslides may occur in future?	1/50,000 scale too coarse • means specific landslide features cannot be easily identified Mapping is old, needs updating
3. Landslide Hazard How often and how severe landslide may occur in future?	Need to calculate Footprint-initiation, pathway, deposition Frequency (annual probability, return interval) Severity-volume, velocity
4. Landslide Risk What is the chance of losses due to landslides?	Losses (Consequences)=impact of hazard on assets “Assets” • built & natural environment, other property • human health, welfare

Problem-insufficient information to accurately assess risk

- Accuracy of resource maps
- Uncertainty about
  - Probability of triggering event
  - Behaviour of landslides
- Information about assets?
- Solution-use existing information as a “drafting gate”
  - Where risk <u>may</u> be high, require further investigation
- ***So what information do we have?***



http://wairarapapast.blogspot.com/2011/08/lambs-at-kahumingi-station-1970s.html

Frequency of Landslide-triggering Events

- Random, infrequent
- ARI= Average Return Interval (yrs)
- AEP= Annual Exceedance Probability
  - 1/ARI (approximately)
- Hicks (1995)
  - AEP of **landslide events** α mean annual rainfall
  - Catchment-scale

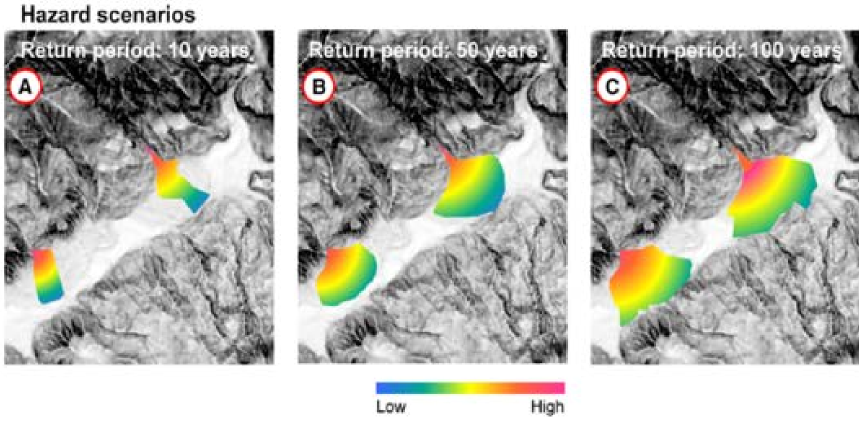
Likelihood of Landslide Triggering Rainfall Event during "window of vulnerability"

		6-year* probability		
MAR (mm)	AEP	No event	≥1 event	Likelihood (Saunders and Glassey)
<400	0.06	>0.67	<0.33	Unlikely
400	0.06	0.67	0.33	Possible (50/50)
999	0.16	0.34	0.66	
1000	0.16	0.33	0.67	Likely
2175	0.32	0.10	0.90	
>2175	>0.32	<0.10	>0.90	Almost certain

*=window of vulnerability after clearfelling

Hazard-Likelihood, spatial occurrence and severity

- Footprint
  - initiation, pathway, deposition
- Frequency
  - annual probability
- Severity-volume, velocity
- ***Needs site-specific studies at fine resolution***



Consequences

- Can occur at human scales
- Depend on what is impacted
  - ***Vulnerability, value***
- Footprint, severity varies within short distances
  - ***Can we identify at 1/5-10,000 scale?***
- Temporal probability
  - ***Use intensity?***

Source: GNS

Consequences
(Saunders and Glassey)

Measures of Consequences to Property

Level	Descriptor	Description
1	CATASTROPHIC	Structure destroyed or large scale damage requiring major engineering works for stabilisation.
2	MAJOR	Extensive damage to most of structure, or extending beyond site boundaries requiring significant stabilisation works.
3	MEDIUM	Moderate damage to some of structure, or significant part of site requiring large stabilisation works.
4	MINOR	Limited damage to part of structure, or part of site requiring some reinstatement / stabilisation works.
5	INSIGNIFICANT	Little damage.
Note: "The Description" may be edited to suit a particular case.		

Consequences

Measures of Consequences to Safety and Human Health and Wellbeing

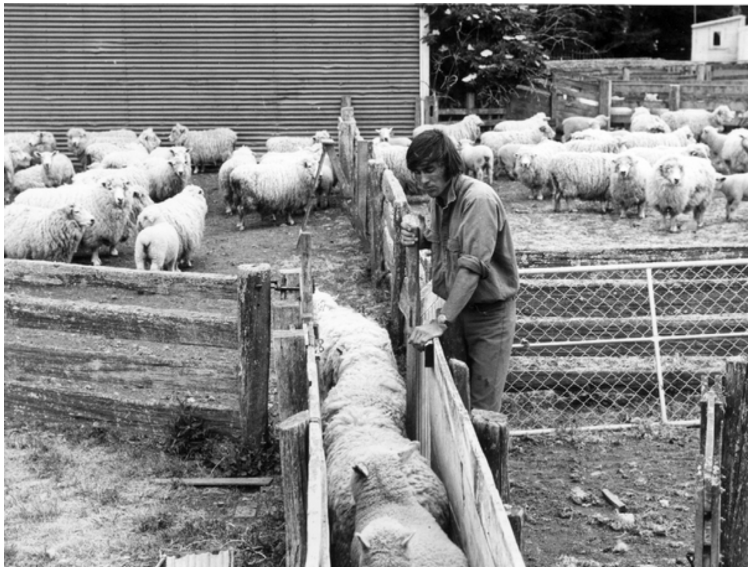
Level	Descriptor	Description
1	CATASTROPHIC	Death and/or widespread major injuries. Trauma widespread in the community.
2	MAJOR	Major injuries to a few people. Localised trauma where people are severely impacted.
3	MEDIUM	Widespread minor injuries. Some individuals traumatized.
4	MINOR	Few minor injuries, no trauma.
5	INSIGNIFICANT	No injuries, no trauma.
Note: “The Description” may be edited to suit a particular case.		

Measures of Consequences to the Environment

Level	Descriptor	Description
1	CATASTROPHIC	Permanent and extensive adverse effects Effects cannot be avoided, remedied or mitigated Of concern at a community, regional and national level.
2	MAJOR	An extensive or local adverse effect that is noticeable Will have a serious and possibly permanent adverse effect on the environment but could potentially be mitigated or remedied. Of concern at a community, regional and possibly national level
3	MEDIUM	Local adverse effects that are noticeable May cause an adverse effect but could be potentially mitigated or remedied. May be of concern at the community or regional level.
4	MINOR	Local adverse effects that are discernible but temporary and too small to be of concern at an individual community or regional level.
5	INSIGNIFICANT	Adverse effects are absent or temporary, may not be discernible.

The drafting gate!

- Risk=hazard x consequences
  - Hazard has a “footprint” and a likelihood
- Qualitative assessment
  - Risk assessment matrix
  - Assign likelihood and consequences to categories
- Investigation, planning effort determined from preliminary risk assessment



http://wairarapapast.blogspot.com/2011/08/lambs-at-kahumingi-station-1970s.html

Risk=Likelihood x Consequences

Risk Analysis Matrix — Level of Risk

LIKELIHOOD	CONSEQUENCES TO PROPERTY OR HUMANS				
	1: CATASTROPHIC	2: MAJOR	3: MEDIUM	4: MINOR	5: INSIGNIFICANT
A – ALMOST CERTAIN	VH	VH	H	M	L
B – LIKELY	VH	H	H	M	L
C – POSSIBLE	H	H	M	L–M	VL–L
D – UNLIKELY	M–H	M	L–M	VL–L	VL
E – RARE	M–L	L–M	VL–L	VL	VL
F – TOO RARE TO BE CONSIDERED	VL	VL	VL	VL	VL

VH=very high, H=high, M=medium, L=low, VL= very low

Risk management depends on level of risk

Risk Level Implications

Risk Level		Example Implications
VH	VERY HIGH RISK	Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to acceptable levels; may be too expensive and not practical.
H	HIGH RISK	Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels.
M	MODERATE RISK	Tolerable provided treatment plan is implemented to maintain or reduce risks. May be accepted. May require investigation and planning of treatment options.
L	LOW RISK	Usually accepted. Treatment requirements and responsibility to be defined to maintain or reduce risk.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.
Note: "The Description" may be edited to suit a particular case.		

Risk management system for plantation forestry: advantages

- Makes the components of risk explicit, shows how these interact to create risk
- Facilitates communication with planners, consent authorities and stakeholders about landslide risk
- Sensitivity of landslide risk assessments to their different components can be evaluated
  - **Research or resource assessments prioritised in terms of their contribution to reducing uncertainty about risk**

Conclusions

1. NES-PF is incomplete risk management tool
2. Conceptual model of risks from landslides
    1. Hazard x Consequences=Risk
3. Managing Risk
    1. "Drafting gate" assessment of landslide risks
    2. When risk may be high, gaps in information and methods need to be filled
    3. Communication—what is the risk level, do we have agreement?

Envirolink Project

- “Operational-level landslide hazard identification and risk management to better manage the risk of erosion from harvested plantations on slopes”
- Risk assessment for ~6 case study areas
  - Marlborough Sounds, North Marlborough, Separation Point Granites
    - Anywhere else?

Envirolink Project-People

- Mark Bloomberg (UC)
  - Project design
  - Risk analysis and reporting
  - Development, presentation of training material
- Dave Palmer (Scion)
  - Geospatial analysis
  - Development, presentation of training material
- Chrissy Bright (Landpro)
  - Assessment of effects on marine and freshwater environments

Questions for discussion

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- Can erosion risk management format be incorporated into the RM planning process?
- Can erosion risk management format be incorporated into the RM consent process?
- Delays, cost? Who pays—the forester!
  - Geotech survey and engineering plan $500-1000/ha?
  - Sure, but compare with other costs
    - Harvesting and transport cost $25,000/ha
    - Harvest management $2500/ha
    - Fines in court up to $600,000 ($200k the going rate!)

Predicting hazard from debris flows and debris floods in NZ plantation forests

Marlborough District Case Studies

Mark Bloomberg, Te Kura Ngahere|NZ School of Forestry
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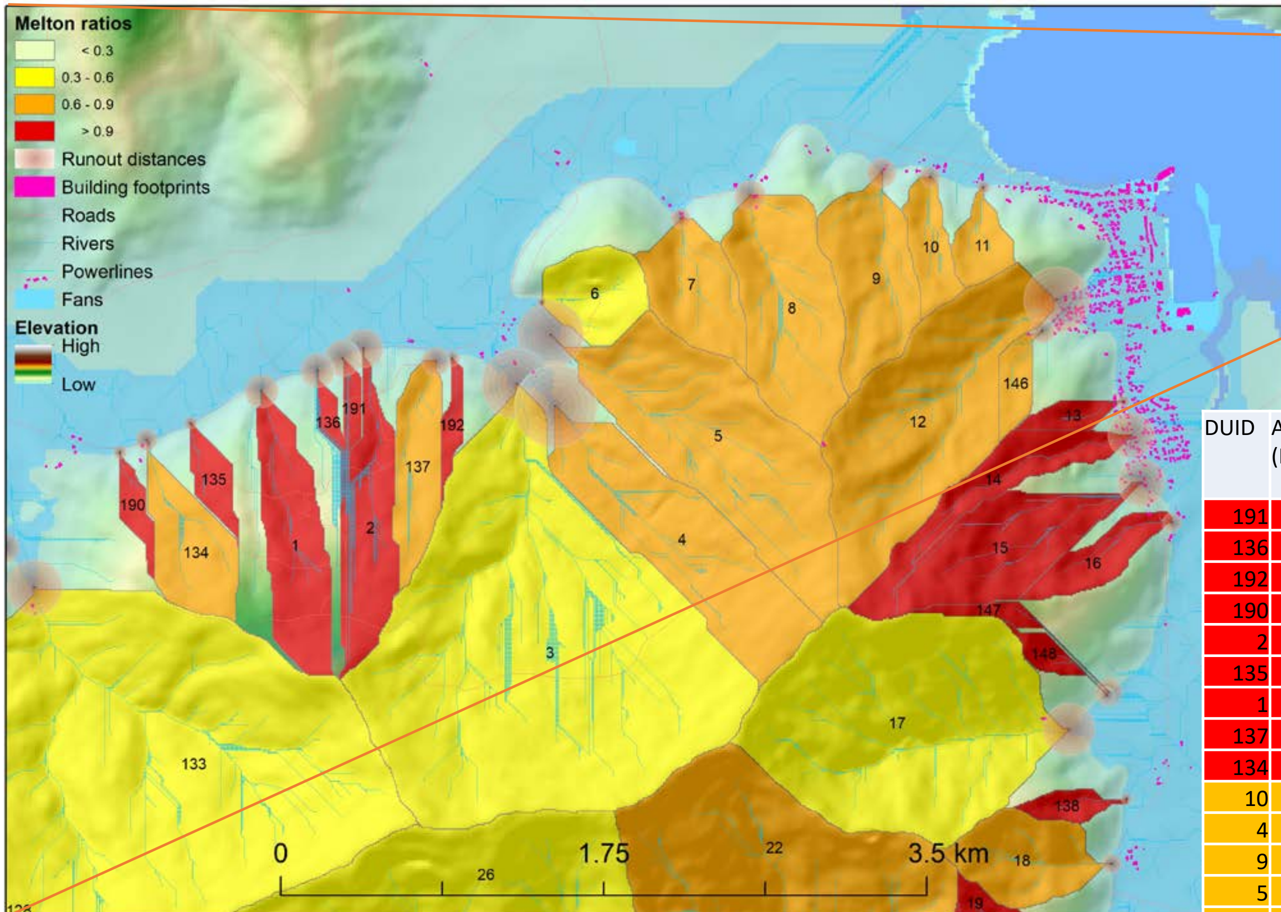
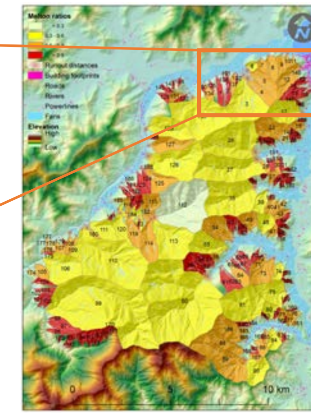
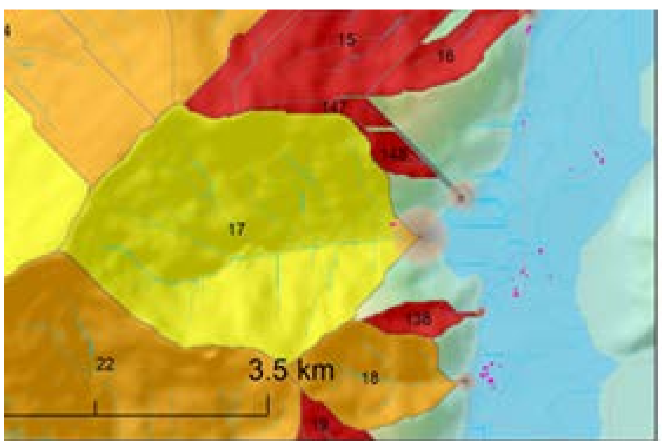




DUID	Area (Ha)	Elev max (m)	Elev min (m)	Distance max (m)	Melton ratio	Runout distance (m)	Focus areas
191	5.8	635.4	20.6	1637.1	2.54	102.0	Area 2
136	7.0	640.7	20.4	1588.0	2.34	94.1	Area 2
192	5.4	327.8	20.6	806.7	1.33	44.3	Area 2
190	6.2	349.6	20.6	708.5	1.32	36.3	Area 2
2	32.1	661.7	20.5	1793.3	1.13	108.0	Area 2
135	8.7	352.0	20.3	707.8	1.13	36.0	Area 2
1	41.1	660.5	20.8	1581.6	1.00	92.1	Area 2
137	24.7	466.8	20.6	1287.9	0.90	76.9	Area 2
134	28.3	489.6	20.7	1090.8	0.88	60.0	Area 2
10	14.3	303.5	19.4	774.3	0.75	56.1	Area 1
4	76.9	713.1	68.5	1887.4	0.74	226.3	Area 1
9	41.0	463.5	19.4	1225.1	0.69	81.3	Area 1
5	103.4	719.5	35.2	2146.4	0.67	182.2	Area 1
11	11.1	241.2	17.5	548.8	0.67	36.0	Area 1
12	104.9	719.7	39.5	2028.3	0.66	182.0	Area 1
8	61.4	536.1	20.6	1401.8	0.66	84.9	Area 1
7	29.8	377.0	20.5	906.8	0.65	53.4	Area 1
3	299.9	863.0	34.9	2450.2	0.48	194.4	Area 1

Havelock areas 1 and 2

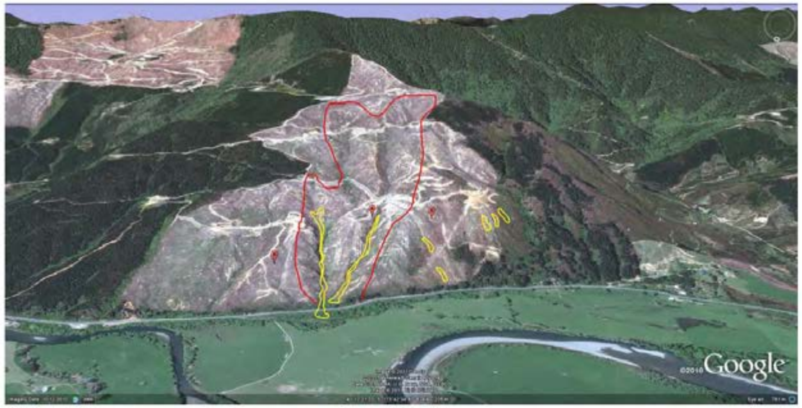
Catchment 18, Havelock 2010



Site	Site 17 a, b
GPS	1663722 5426745
Land cover - a	Recently harvested
Land cover - b	Recently harvested
Type of erosion - a	2Ss 3Da 4Df
Type of erosion - b	2Ss 1Da
LUC Class - a	8e2
LUC Class - b	Upper part of slope 7e9 and 6e11 for lower part
Infrastructure damage	Public road closure; property damage

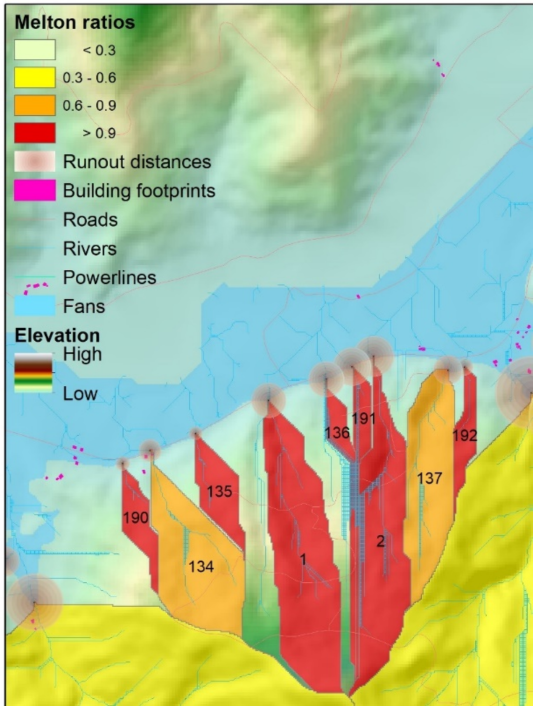
Source: Gray and Spencer 2011

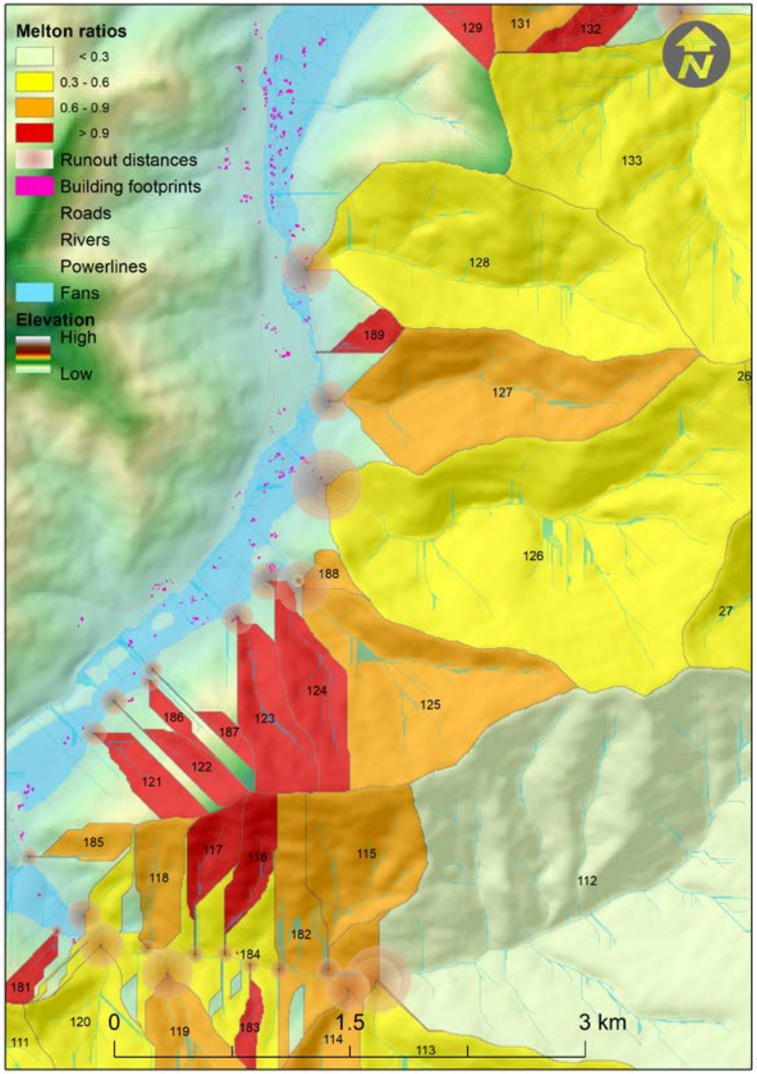
Catchments 1, 2 and 134, 135, 190, Havelock

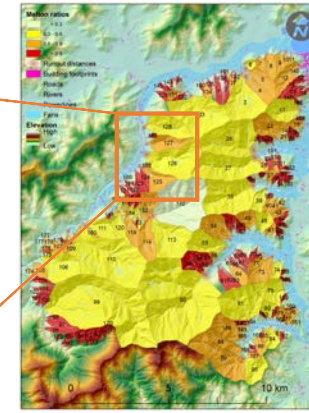


Site	Site 20 a, b
GPS	1659535 5429238
Land cover - a	Recently harvested
Land cover - b	Recently harvested
Type of erosion - a	3Ss 2Da 2Df
Type of erosion - b	2Ss 3Da
LUC Class - a	7e9
LUC Class - b	7e9
Infrastructure damage	Public road closure

Source: Gray and Spencer 2011



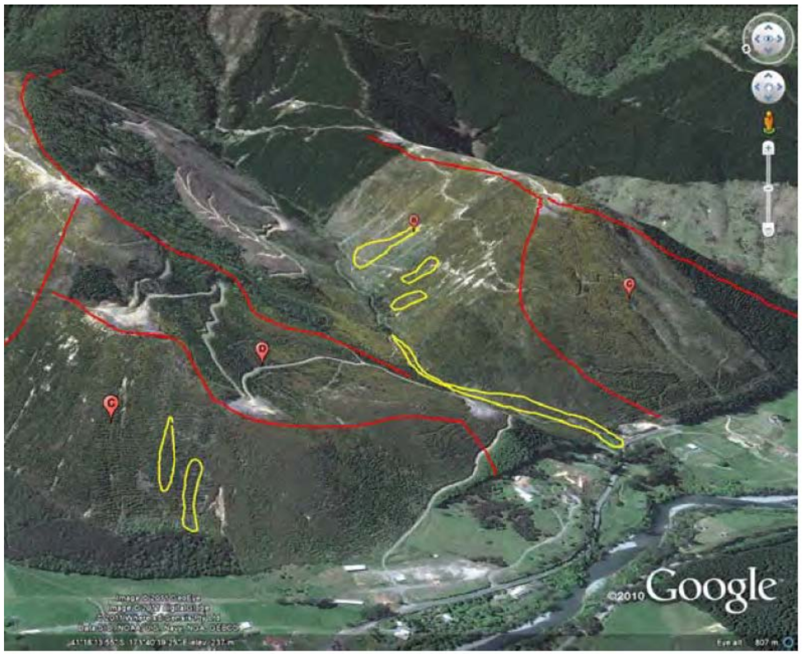




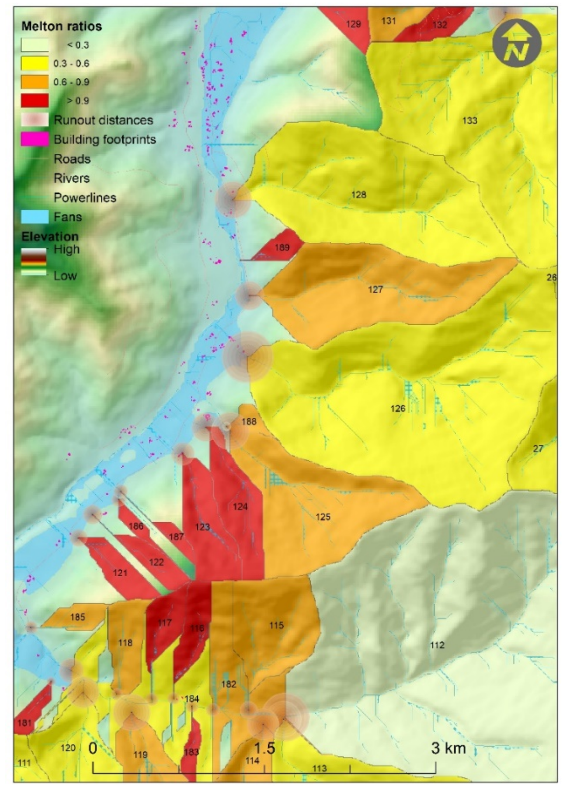
Havelock areas 3 and 4

DUID	Area (Ha)	Elev max (m)	Elev min (m)	Distance max (m)	Melton ratio	Runout distance (m)	Focus areas
122	12.5	599.6	71.6	1034.2	1.49	84.9	Area 4
189	7.6	302.6	20.6	576.3	1.02	12.0	Area 3
121	16.2	478.3	70.7	881.3	1.01	76.9	Area 4
123	35.7	604.9	60.4	1213.0	0.91	102.0	Area 4
124	35.6	596.5	56.7	1419.4	0.91	124.1	Area 4
127	124.1	788.9	20.8	2382.0	0.69	127.6	Area 3
128	192.1	793.9	21.1	2593.5	0.56	164.4	Area 3
126	358.7	844.8	40.8	2864.8	0.42	228.0	Area 3

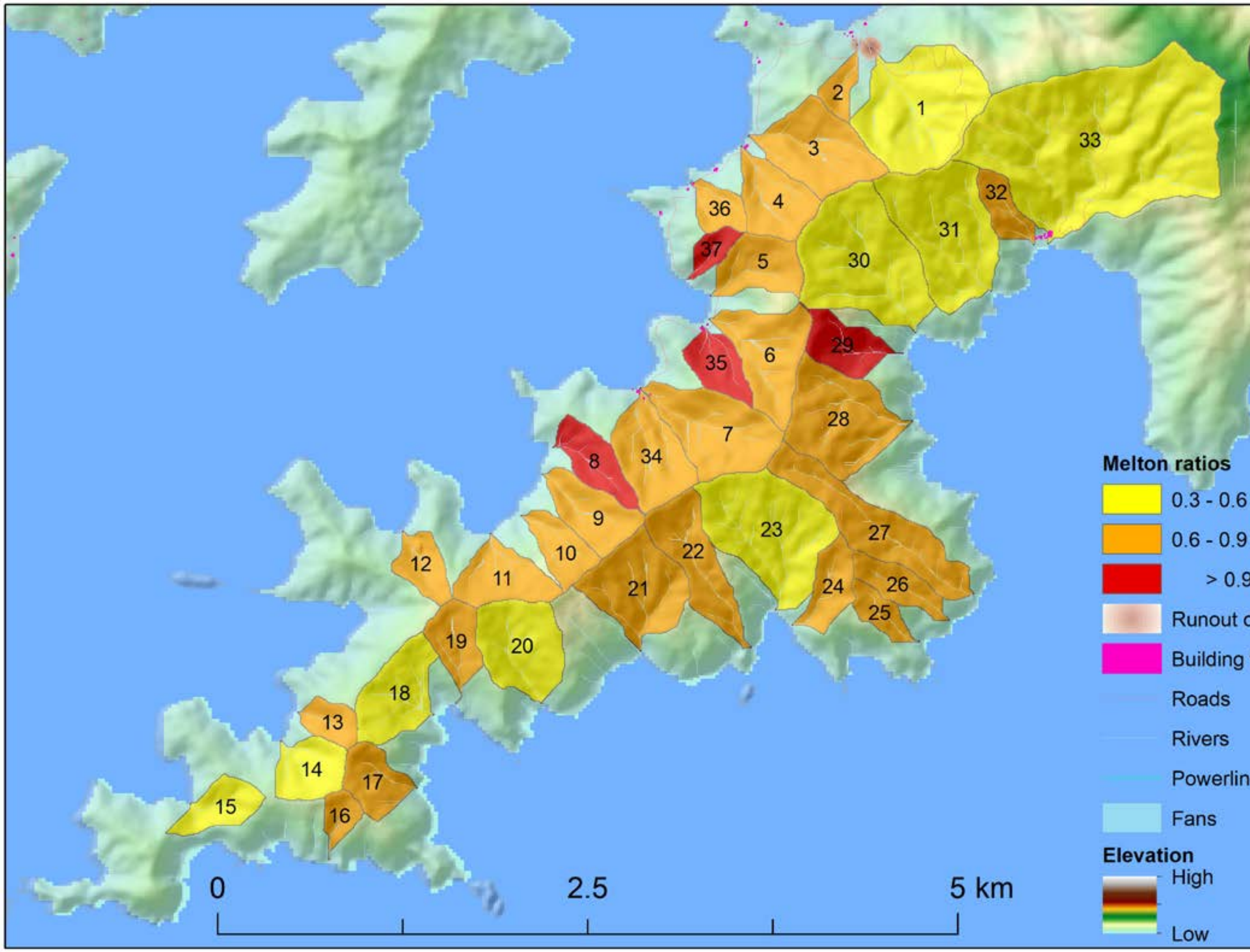
Catchment 128 Havelock
(also 123, 124, 126, 127) 2010



Site 22b. 3Ss, 3Da, 3Df. LUC Class 7e9.
Public road closure, culvert-bridge damage
Source: Gray and Spencer 2011

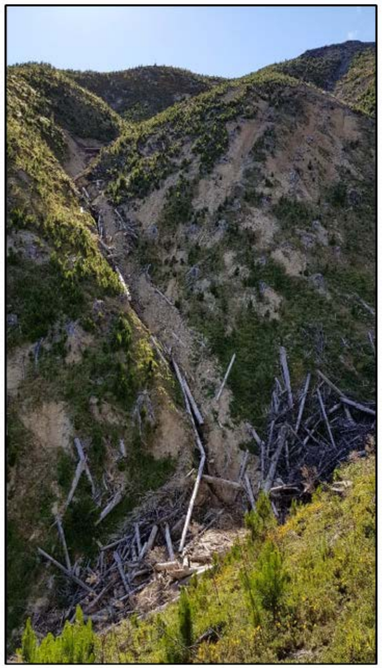


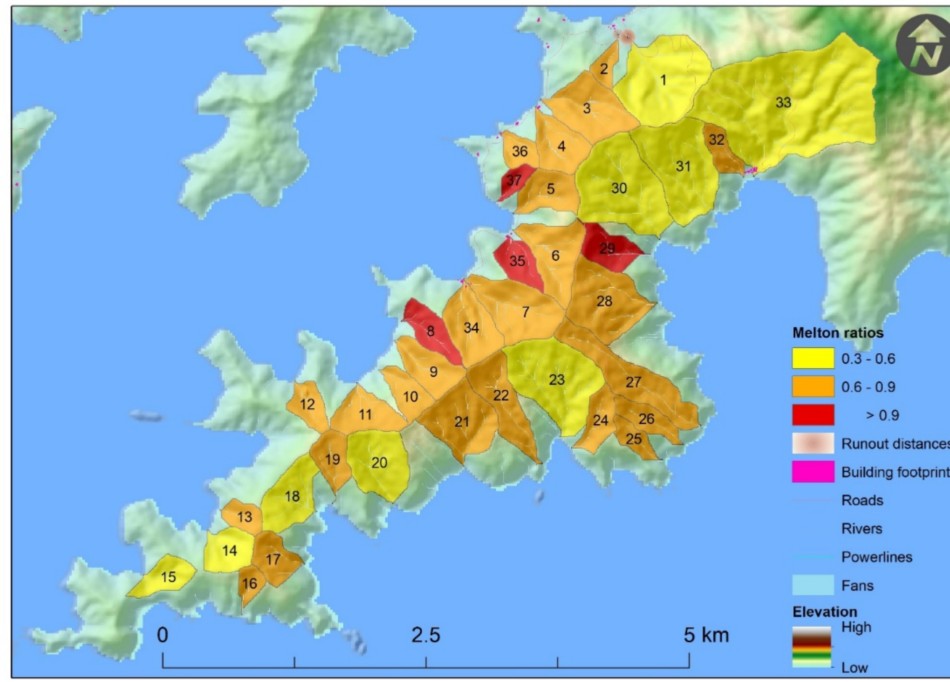
Port Underwood



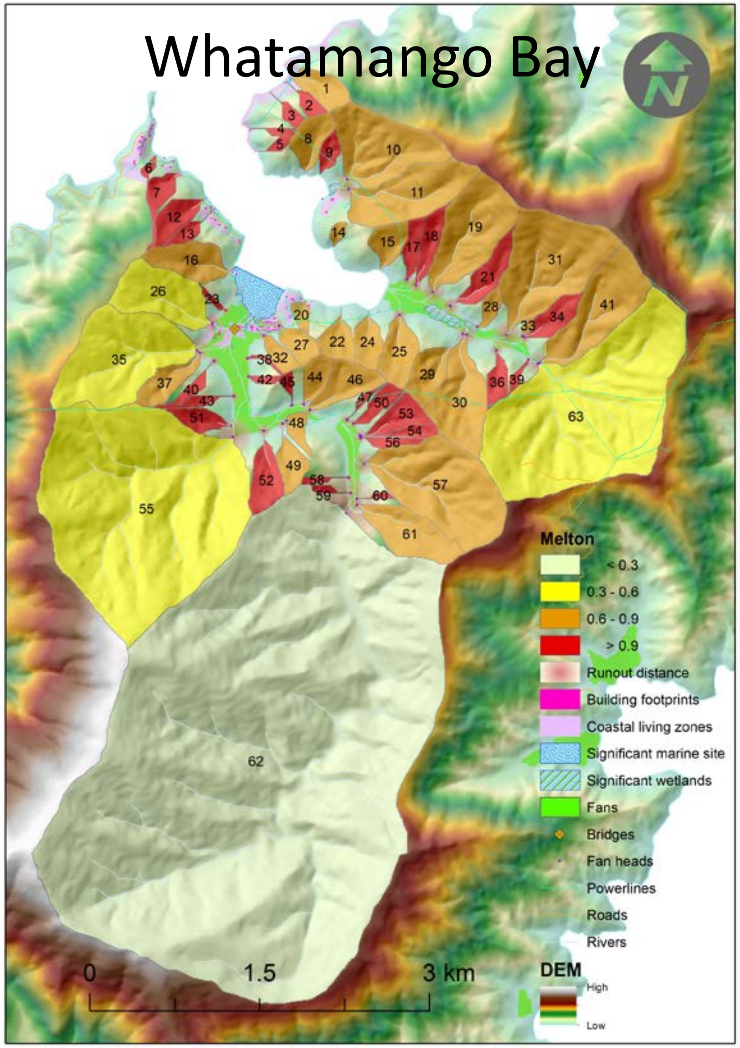
DUID	Area (Ha)	Elev max (m)	Elev min (m)	Distance max (m)	Melton	Runout distance (m)
37	6.4	258.9	8.1	490.6	0.99	0.0
8	16.2	398.9	5.8	761.6	0.98	0.0
35	13.8	356.5	5.0	641.2	0.94	0.0
29	16.7	378.3	8.1	771.5	0.90	0.0
32	10.5	294.7	5.3	625.8	0.89	0.0
16	7.0	245.2	9.6	478.1	0.89	0.0
10	14.1	334.5	9.5	614.8	0.87	0.0
9	20.7	397.0	5.3	754.4	0.86	0.0
5	19.7	379.2	5.2	679.4	0.84	0.0
2	7.0	241.3	18.1	534.5	0.84	53.0
36	9.4	262.9	5.8	494.1	0.84	0.0
4	21.5	374.6	5.4	726.4	0.80	0.0
24	14.6	316.0	12.5	693.8	0.79	0.0
25	8.7	246.2	16.9	611.7	0.78	0.0
6	30.7	426.3	4.8	904.8	0.76	0.0
34	27.7	399.7	5.0	844.8	0.75	0.0
26	13.4	282.0	10.6	785.5	0.74	0.0
22	28.8	399.7	13.4	1147.5	0.72	0.0
13	9.3	221.9	8.2	435.6	0.70	0.0
11	20.8	324.3	5.0	625.1	0.70	0.0
7	37.1	427.2	4.9	1017.9	0.69	0.0
3	34.0	406.4	4.7	972.1	0.69	0.0
12	12.2	239.5	5.0	566.2	0.67	0.0
28	41.6	426.9	15.4	875.7	0.64	0.0
27	40.8	423.4	16.7	1650.5	0.64	0.0
21	34.9	381.7	6.3	853.3	0.64	0.0
19	15.1	263.4	21.2	693.3	0.62	0.0
17	15.7	246.5	5.4	525.0	0.61	0.0
14	17.2	246.3	5.0	520.0	0.58	0.0
20	32.1	321.2	5.2	765.4	0.56	0.0
31	52.9	405.7	8.0	1087.5	0.55	0.0
23	55.4	405.5	5.9	996.1	0.54	0.0
1	56.8	403.3	18.8	930.8	0.51	75.0
30	61.1	405.6	8.4	1087.0	0.51	0.0
18	26.3	221.1	4.2	561.1	0.42	0.0
33	153.1	528.0	4.5	1620.9	0.42	0.0
15	14.3	162.1	5.7	502.4	0.41	0.0

North Whataroa Bay, Port Underwood (Catchments 8-10) 2018





Whataroa Peninsula Forestry Block Failures. Opus (2018)



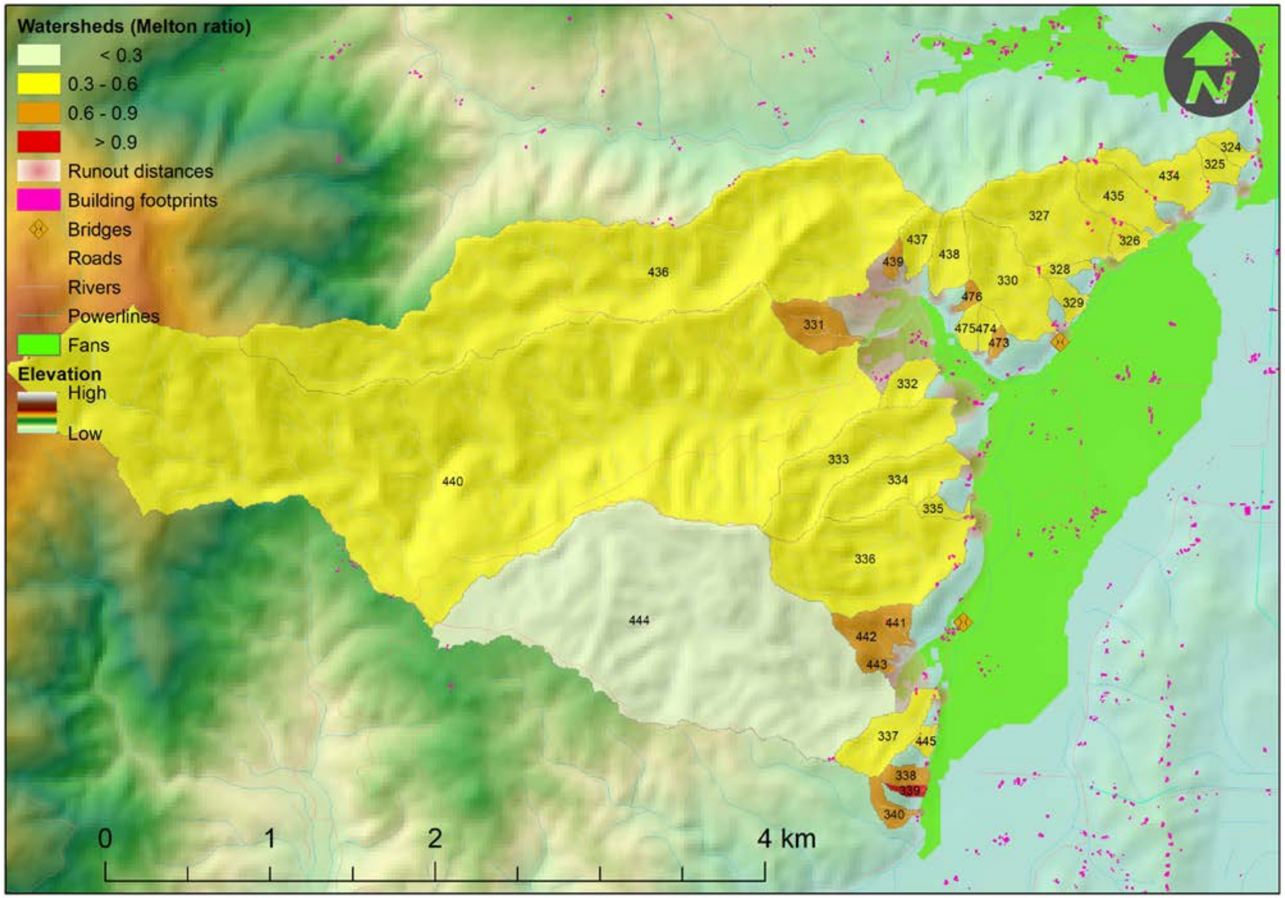
DUID	Area (Ha)	Elev max (m)	Elev min (m	Distance max (ı	Melton ratio	Runout distance (m
47	1.3	248.4	37.0	425.0	1.85	41.7
60	1.1	225.3	40.3	384.7	1.75	28.3
58	1.5	240.0	40.4	423.3	1.62	29.3
54	4.3	363.3	39.8	685.6	1.56	60.0
13	3.8	298.6	9.6	567.9	1.49	0.0
23	1.2	176.3	17.7	333.8	1.44	29.4
39	1.8	226.7	40.2	390.5	1.39	30.5
56	3.6	301.7	40.0	565.0	1.38	44.0
38	1.1	162.4	20.1	339.6	1.35	28.0
40	3.3	264.5	19.1	579.0	1.35	46.2
4	1.8	189.6	8.9	397.0	1.35	0.0
59	1.5	202.9	40.3	345.3	1.33	29.3
43	2.6	221.8	20.5	466.4	1.26	35.0
2	3.6	246.8	9.0	442.2	1.26	0.0
5	1.8	181.9	12.0	303.5	1.25	0.0
6	1.4	155.3	8.7	254.3	1.22	0.0
7	7.5	334.9	9.7	747.8	1.19	0.0
3	2.8	207.4	10.5	384.6	1.18	0.0
21	12.6	434.5	20.3	899.6	1.17	73.9
45	1.8	175.9	20.7	300.0	1.16	24.2
18	9.4	357.9	17.8	805.0	1.11	68.8
42	1.6	158.3	19.7	285.0	1.09	20.4
50	6.2	305.0	38.3	534.7	1.07	44.3
17	6.3	282.5	16.5	580.0	1.06	57.6
52	13.7	386.9	20.5	747.7	0.99	56.9
12	10.4	322.9	7.7	623.6	0.98	0.0
36	6.3	280.2	37.2	530.5	0.97	55.7
34	10.1	340.7	40.3	656.1	0.95	51.6
53	10.5	345.4	39.5	660.6	0.95	52.0
9	4.6	207.8	7.5	410.2	0.93	0.0
51	8.3	288.3	20.2	703.4	0.93	52.7
61	27.0	505.5	40.4	1041.5	0.90	78.6
37	12.1	326.2	19.9	719.8	0.88	59.9
41	44.3	624.9	41.5	1276.6	0.88	102.0
29	13.5	325.9	21.6	743.7	0.83	61.4
49	9.0	268.0	20.9	637.1	0.82	48.3
1	11.3	280.5	6.8	577.0	0.81	0.0
16	18.4	345.8	6.4	805.6	0.79	0.0
30	34.3	481.7	21.0	1132.8	0.79	88.5
28	4.3	182.2	20.7	413.7	0.78	28.4
33	1.1	120.6	40.1	230.3	0.78	13.6
11	41.3	519.1	19.4	1175.4	0.78	108.7
24	9.7	245.1	6.6	529.5	0.77	0.0
15	9.3	235.6	5.1	489.2	0.75	0.0
19	46.2	522.3	20.2	1143.5	0.74	96.9
25	15.2	302.8	18.6	654.0	0.73	60.0
31	67.1	635.5	38.1	1304.5	0.73	119.6
14	2.0	113.1	9.9	231.3	0.73	0.0
8	12.4	259.3	7.2	579.2	0.72	0.0
32	5.4	180.7	17.4	427.0	0.70	39.6
22	9.3	215.3	8.2	498.9	0.68	0.0
48	4.8	167.6	20.6	386.4	0.67	28.0
20	3.1	122.3	6.7	285.8	0.66	0.0
10	46.6	464.6	19.7	943.9	0.65	80.1
46	14.9	272.3	21.1	719.6	0.65	48.3
27	7.7	193.9	16.8	429.4	0.64	39.6
44	7.9	195.1	21.0	478.7	0.62	36.3
57	74.3	567.9	40.5	1352.2	0.61	102.0
35	73.3	502.0	19.8	1371.8	0.56	109.1
26	34.0	346.4	18.9	947.7	0.56	78.3
55	280.9	949.9	20.3	2088.5	0.55	156.5
63	197.5	580.9	40.7	1376.4	0.38	103.2
62	1075.5	967.2	40.3	4415.9	0.28	314.0

Predicting hazard from debris flows and debris floods in NZ plantation forests

Tasman District Case Studies

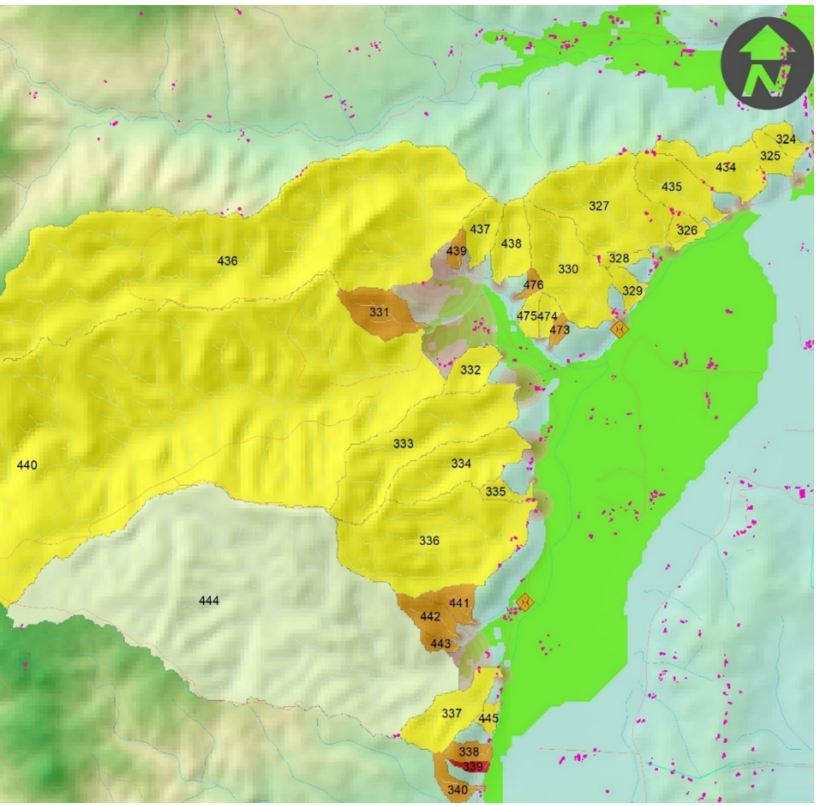
Mark Bloomberg, Te Kura Ngahere|NZ School of Forestry
Dave Palmer, Scion
Chrissy Bright, Landpro

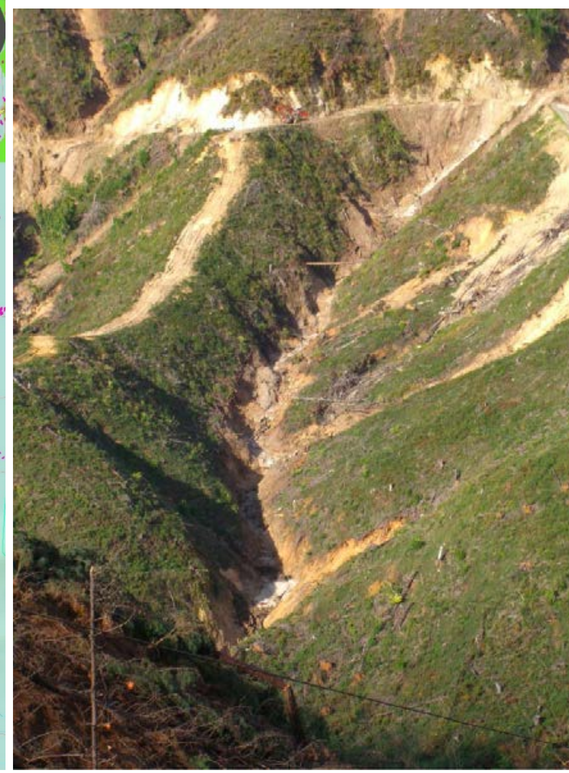
Shaggery Catchment



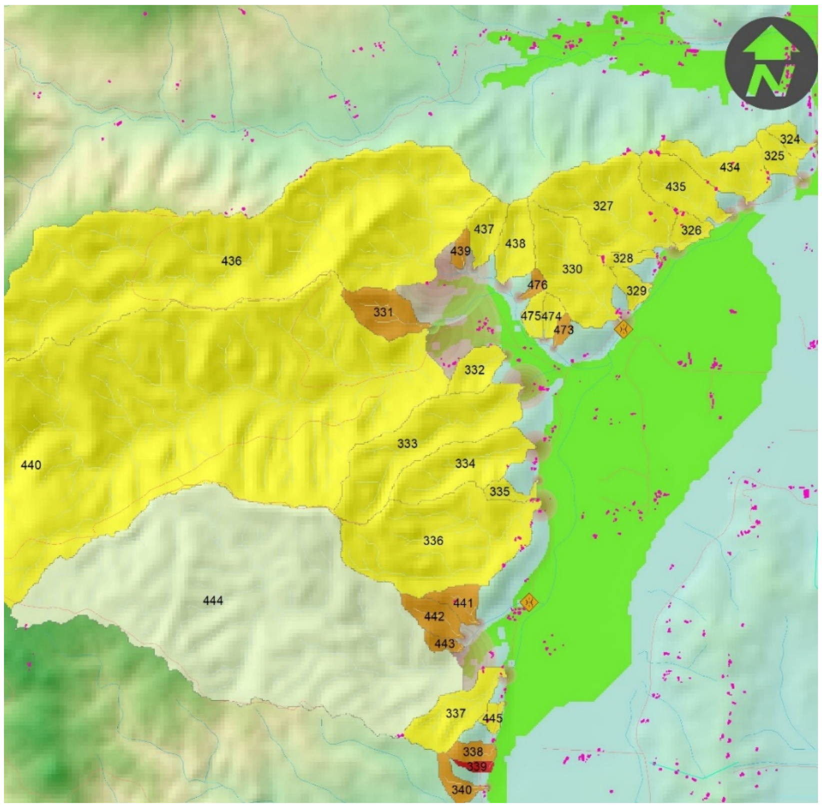
DUID	Area (Ha)	Elev max (m)	Elev min (m)	Distance max (m)	Melton ratio	Runout distance (m)
339	1.3	139.9	23.9	244.8	1.01	17.7
476	1.4	142.5	38.4	203.6	0.87	38.9
443	1.9	154.4	33.3	240.3	0.87	23.9
439	1.9	154.6	44.6	245.7	0.81	29.7
338	3.2	149.3	23.2	294.3	0.70	24.2
442	6.2	208.1	34.9	471.6	0.69	53.2
340	3.9	154.0	24.1	369.4	0.66	29.3
473	1.6	104.4	23.8	225.6	0.64	29.3
441	4.8	164.9	29.6	388.7	0.62	38.9
331	10.7	246.5	49.0	587.6	0.60	51.6
437	7.1	201.8	42.2	463.5	0.60	39.2
328	2.5	105.7	17.8	357.1	0.56	29.4
335	2.8	114.9	21.6	339.1	0.55	37.0
438	9.7	199.3	33.6	550.4	0.53	58.3
474	2.7	109.6	24.9	276.3	0.52	29.4
475	3.0	112.5	24.4	300.3	0.51	24.7
333	38.5	340.9	31.7	1429.0	0.50	144.0
436	235.9	803.3	46.4	3825.2	0.49	327.1
329	3.6	101.2	14.5	271.1	0.46	17.7
336	57.0	338.3	21.2	1276.0	0.42	103.2
337	14.4	181.9	22.6	737.3	0.42	64.1
440	536.0	1018.4	49.4	5166.4	0.42	448.2
332	7.2	147.7	36.0	441.1	0.42	45.2
334	22.0	216.4	24.5	961.7	0.41	103.2
435	14.1	161.7	13.7	671.3	0.39	53.0
324	3.3	81.6	14.7	319.2	0.37	31.8
434	14.0	152.0	13.7	658.5	0.37	60.4
325	4.5	92.2	14.8	403.1	0.36	58.3
330	24.9	193.0	15.7	938.9	0.36	70.8
445	1.9	71.1	24.7	196.3	0.33	21.0
326	4.0	77.5	13.4	231.0	0.32	13.0
327	34.9	200.0	14.8	969.0	0.31	70.0
444	236.5	474.2	34.5	2777.0	0.29	252.6

Shaggery Catchment, 2013



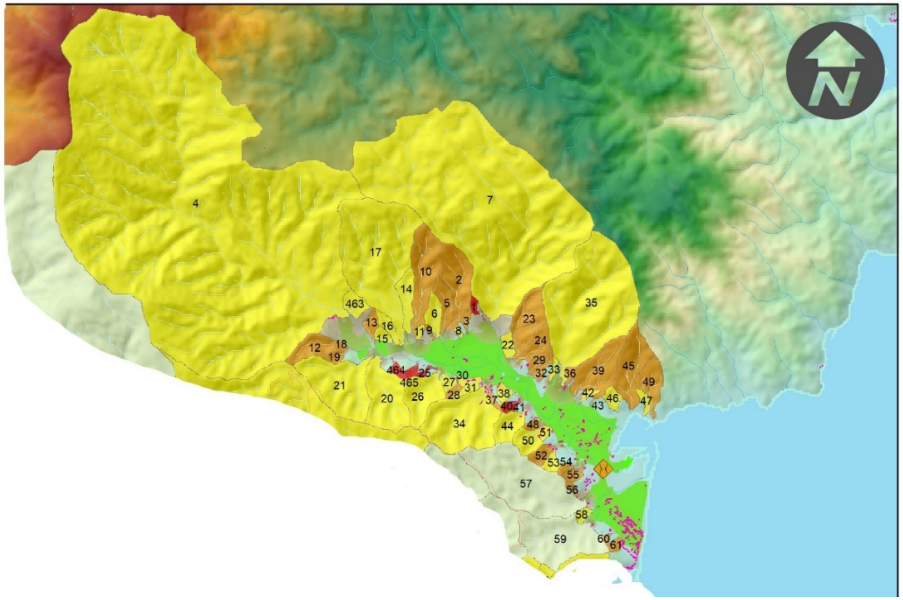


Shaggery Catchment, 2018



https://www.stuff.co.nz/nelson-mail/news/102283089/debris-from-gita-ticking-timebomb-in-rain-says-tasman-district-resident

Marahau Catchment 2018



https://www.rnz.co.nz/news/national/351299/gita-cleanup-you-don-t-wait-for-outside-help

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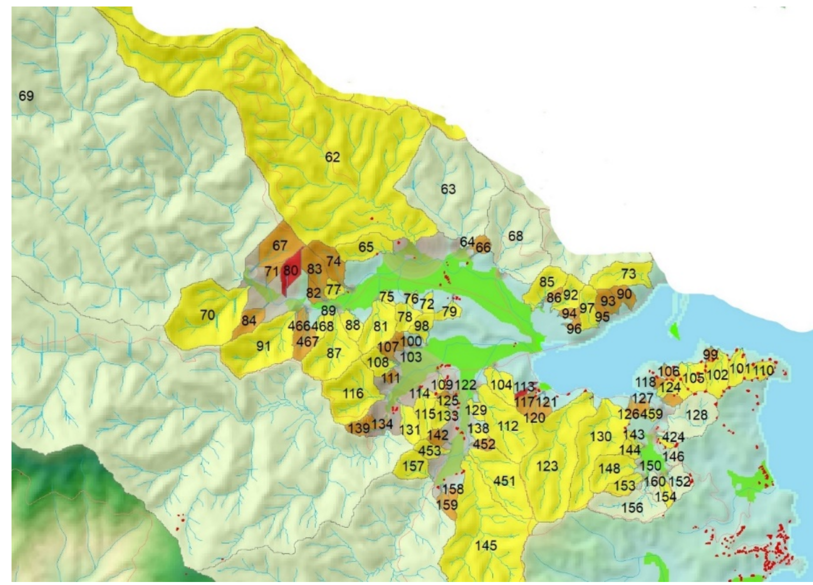
CHRISTCHURCH NEW ZEALAND

Otuwhero Catchment 2018



https://www.stuff.co.nz/business/123635319/landslide-study-offers-suggestions-for-forest-management-in-tasman