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Mahurangi Land-Use Scenario Modelling

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Reviewed by:	Approved for ARC Publication by:
	
Name: Amy Taylor	Name: Grant Barnes
Position: Project Leader Land	Position: Group Manager Monitoring & Research
Organisation: ARC	Organisation: ARC
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Oldman, J. W.
Stroud, M. J.
Cummings, V. J.
Cooper, A. B.

Prepared for
Auckland Regional Council

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Contents

1 Executive Summary

ARC Environment have recognised the Mahurangi Catchment as an important resource. To manage this resource in a sustainable manner will require careful consideration of the needs of the environment and the social and economic needs of those people with an interest in it.

To this end, ARC commissioned NIWA to develop catchment and estuary models which can be used as predictive tools to determine the fate of catchment-derived sediments within the estuary. Together with an ongoing ecological monitoring programme this enables the effects of proposed land-use changes on the Mahurangi to be determined.

Proposed land-use changes examined include an increase in the area of urbanisation, harvesting of existing Redwood forest and conversion to production forest.

This report describes the use of the BNZ catchment model to predict sediment erosion rates within the catchment and sediment delivery rates to the estuary for each of these land-use scenarios. Sedimentation rates within the estuary are then predicted using the estuary model.

Production forestry gives the lowest sediment loading under a mature forest but there is a risk that relatively high sediment loads will be delivered to the estuary during harvesting.

The level of site disturbance during development plays a vital role in determining the amount of sediment actually delivered to the estuary. Developing of relatively small blocks for urbanisation produces similar sedimentation within the estuary as harvesting of the Redwood forest.

The effect on the ecology of Mahurangi Estuary will depend on a number of factors (e.g. depth, type, area and rate of sediment deposition). These factors, and potential effects of different land-use scenarios on the estuarine ecology, are discussed.

2 Introduction

NIWA was commissioned by the ARC to develop numerical models of the Mahurangi catchment and estuary to enable the ARC to manage the Mahurangi and its environs in a sustainable manner. Earlier reports (Stroud and Cooper, 1997; Oldman and Black, 1997) give details of the development of both catchment and estuary models. These models can now be used as management tools to predict the effects of possible changes in catchment land-use on the Mahurangi Estuary. For this report the models are used to predict the level of sediment erosion within the Mahurangi Catchment and the fate of this sediment within the Mahurangi Estuary for various land-use scenarios. Combined with the ongoing ecological monitoring (Cummings et al., 1994, 1995, 1997) this enables us to predict the effects of possible land-use changes on the ecology of the estuary.

This report gives details of the effects of different land-use scenarios on the Mahurangi Estuary. These scenarios are:

- existing land-use,
- increased urbanisation,
- harvesting of existing Redwood Forest,
- having the entire Mahurangi catchment in production forest.

3 Methods

To predict the sediment load delivered to the estuary for each of the land-use scenarios, the catchment model Basin New Zealand (BNZ) was used (Stroud and Cooper, 1997). To enable the fate of the sediment within the estuary to be predicted the combined hydrodynamic and transport/dispersion models 3DD (Black, 1995) and POL3DD (Black, 1996) were used.

From the combined use of these models and our existing knowledge of the ecology of the estuary (Cummings et al., 1994, 1995, 1997), we made predictions of how different land-use scenarios may impact on the estuarine biology.

4 Catchment Modelling

For a given land-use scenario how much sediment is predicted to enter the estuary via the Mahurangi River?

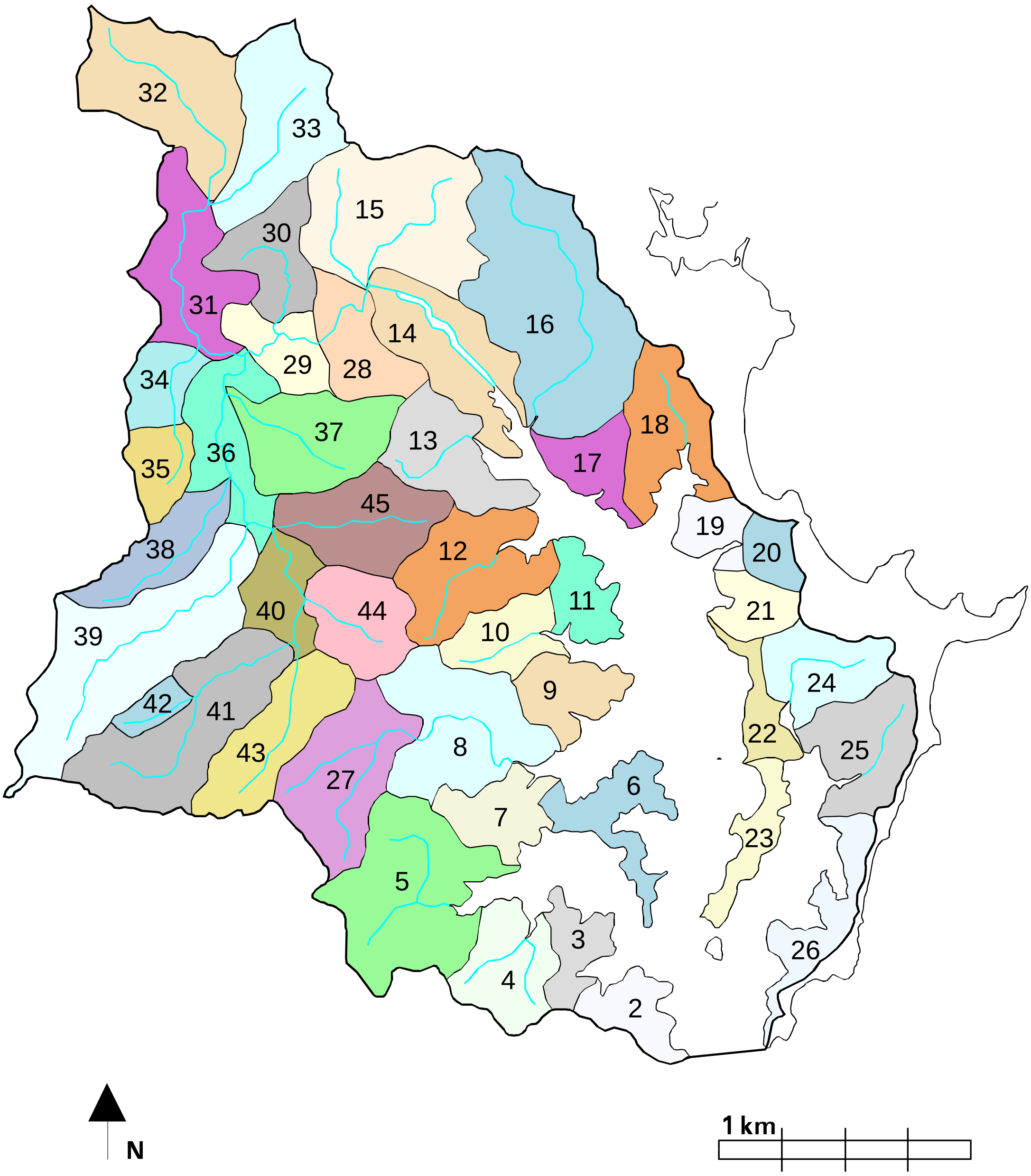
For each land-use scenario the BNZ model was run for 20 years of climate record (1976 to 1995). For each model cell a sediment erosion rate was predicted which can then be used to define a sub-catchment (Figure 1) sediment load. Allowing for sediment attenuation (i.e. trapping of sediment within catchment and stream channel deposition) an estimate of the sediment delivered to the estuary can be made. For each model run the median, 5^{th} and 95^{th} percentile sediment delivery rates (i.e. tonnes per annum) were obtained; i.e. the median rate has a 50% risk of being exceeded, the 5^{th} percentile a 95% risk of being exceeded and the 95^{th} a 5% risk of being exceeded in any given year. The model therefore provides prediction of the likelihood or risk of a particular sediment load occurring.

The actual sediment load that results from a particular land-use change will depend on:

- the weather over the time of land-use change (and in particular the amount of rainfall and its timing in relation to land disturbance),
- the management practices (e.g. sediment ponds, buffer zones) employed during the land-use change.

Figure 1

Mahurangi Estuary catchment and sub-catchments



5 Estuary Modelling

Having obtained the quantity of sediment delivered to the estuary via the Mahurangi River, where does it get deposited within the estuary?

By using the actual flows, tides and winds that occur during a storm event the combined hydrodynamic and transport/dispersion models can predict the sedimentation patterns for any storm event. Oldman and Black (1997) showed that grain size distribution, tides, freshwater inflows and winds all alter the sedimentation patterns within the estuary. For example, Figure 2 shows the predicted distribution of sediment down Mahurangi Estuary for 3 storm events of different intensities (Table 1). These predictions assumed a suspended sediment grain size of 25 µm, no winds and a mean tidal range.

Figure 2.

Predicted average inter-tidal sedimentation rates (mm per storm) for a) a 5 cumec storm event which delivers to the estuary 25% of the median annual sediment load b) a 35 cumec storm event which delivers to the estuary 100% of the median annual sediment load c) a 140 cumec storm event which delivers to the estuary 150% of the median annual sediment load.

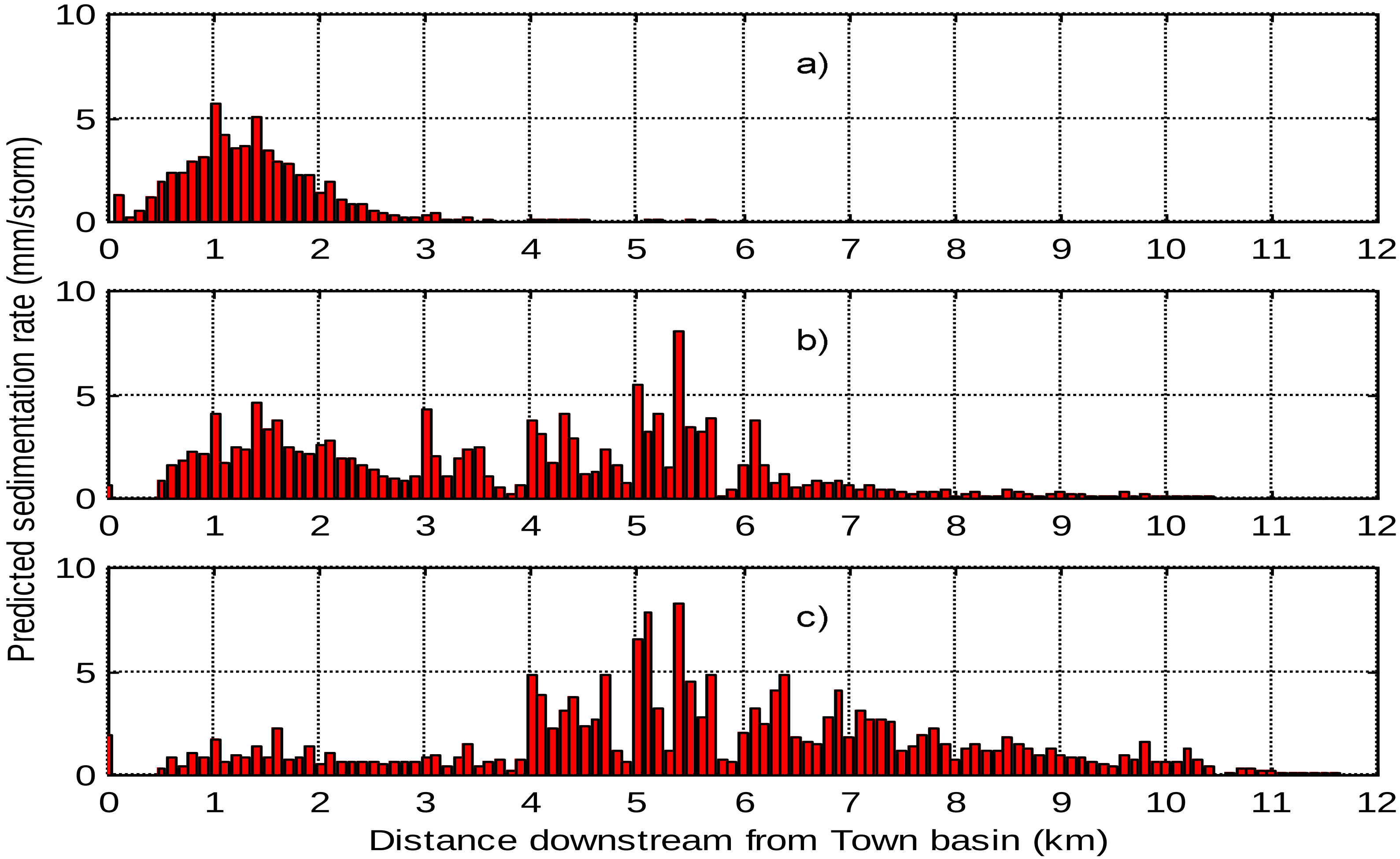


Table 1.

Storm events modelled to show the change in sediment distribution due to different Mahurangi River flows and sediment loads

	Mean daily flow at College Site (Mahurangi River) (cumecs)	Sediment delivered from Mahurangi River (% of median annual load)	Return Period (years)
1)	5	25	2.2
2)	35	100	9
3)	140	150	50+

Larger storm events (e.g. storm '3' above) occur less frequently but have higher sediment loads than smaller storm events (e.g. storm '1' above). Due to the higher vertical and horizontal mixing which occurs during large storms, sediments will be more evenly distributed throughout the estuary. Deposition rates in the lower and middle estuary will be higher, and those in the upper estuary will be lower, than in small storm events.

Wind conditions during a storm dictate not only where sediment will initially settle but also influence resuspension, further complicating the pattern of sedimentation. For example, if a strong westerly wind occurred during a storm event, sedimentation on the eastern side of the estuary would be low compared to that on the western side of the estuary. If winds continue from the west following the storm resuspension is likely to push even more sediment onto the eastern shores of the estuary. On the other hand if a period of calm wind conditions were to follow, resuspension would be negligible.

To model every combination of winds, tides, freshwater flows during and after a storm event and the complete distribution of sediment grain sizes would not be practicable. Throughout this report we have concentrated on the median annual sediment load predicted by the BNZ model. To link this to the estuary model an indication of the general sedimentation patterns within the estuary following a storm event is required. To do this we have presented the predicted sedimentation rates for a "typical" storm event which delivers the predicted median annual sediment load to the estuary. Data is presented which gives an indication of the initial deposition rates following such a storm event. We have not looked at resuspension and subsequent settling as again the sequence of winds, tides and flows will dictate where sediment will settle after the storm event.

Swales et. al (1997) analysed data from three different storm events. A March 1995 flood was found to have a mean daily inflow of 35 cumecs and an estimated return period of nine years. Swales et. al (1997) showed that the majority of the suspended sediment was delivered to the estuary within the first nine hours of this storm and concluded that 90% of catchment sediment load delivered to the estuary can be attributed to floods. Therefore our typical storm event assumes:

- a daily mean freshwater inflow of 35 cumecs,
- a delivery to the estuary of the median annual sediment within 12 hours,
- mean tidal conditions (range 0.5-2.5 metres),

- No winds (i.e. no wind driven resuspension of sediment following the storm),
- a grain size of 25 µm,
- sediment enters the estuary only via the Mahurangi River (i.e. is derived from the Mahurangi River Catchment).

Data from this storm event are presented for the whole estuary and are presented in terms of annual sedimentation rates (assuming this storm is the only significant event during the year). There is a risk that sedimentation loads will be higher (i.e. during large infrequent storm events) resulting in higher sedimentation rates in the lower and middle estuary, and also a risk that rates will be higher in the upper estuary (due to more frequent smaller storm events).

Earlier modelling work (Stroud and Cooper, 1997) showed that the Mahurangi River Catchment delivers 29% of the total sediment delivered to the estuary. The remaining 71% is delivered to the estuary via Te Kapa and Pukapuka Inlets and along the shores of the middle and lower estuary. This sediment load is distributed over a much larger area than the Mahurangi River Catchment sediment load and has therefore produced much lower sedimentation rates. Swales et al. (1997) showed that the largest mean sedimentation rates occurred in the Upper Estuary (of the order of 15-20 mm/annum) with rates of the order of 2-5 mm/annum elsewhere. Therefore, it is the sediment derived from the Mahurangi River Catchment that results in the highest sedimentation rates within the estuary. That is not to say that the lower sedimentation rates outside the Upper Estuary are less important in terms of the ecology of the estuary. Where we believe that a given scenario would give rise to significant sedimentation rates due to sediment loads from outside the Mahurangi River Catchment we have made predictions of the likely sedimentation rates and areas affected.

6 Ecology

What are the impacts on the estuarine biology of a given land-use scenario?

Using the combined Catchment and Estuary models general sedimentation rates that will occur within the estuary for a given land-use scenario have been presented. The potential impact of these sedimentation rates on the estuarine biology is discussed for each land-use scenario. At present the Mahurangi Estuary contains a diverse range of habitat types and, consequently, a large number of different infaunal species. A survey conducted in 1993 visited a range of intertidal and subtidal sites in the estuary, and identified eight different community types (Cummings et al., 1994). For the purposes of this report, only the intertidal sites will be considered. Generally, the intertidal sites in the upper estuary are fringed with mangroves, the substrate consists of deep sulphurous mud, and the infaunal communities are made up of relatively few, opportunistic species. The intertidal areas of the middle estuary range from polychaete dominated muddy sediments on the north and western shores to muddy sand sediments with consistent bivalve populations on the south eastern shore. The lower estuary contains sandy bivalve dominated intertidal sediments. Closer to the estuary mouth the sediments become coarse/pebbly, and the number of infaunal species decreases. Te Kapa Inlet ranges from sandy, bivalve dominated sediments near the main estuary channel, to muddier sediments further up the inlet.

7 Results

7.1 Scenario 0: Existing Land-Use

The BNZ model predicted that under existing land-use practices the median sediment load delivered to the estuary from the Mahurangi River Catchment is 10,700 tonnes per annum (Stroud and Cooper, 1997). Using the method outlined above the predicted sedimentation pattern due to this sediment load from the Mahurangi River catchment is shown in Figure 3. Table 2 gives the predicted maximum, median and mean sedimentation rates for the areas defined in Figure 4 (i.e. upper, middle and lower estuary) and Te Kapa and Pukapuka Inlets.

Figure 3.

Predicted sedimentation rates (mm/annum) for existing land-use.

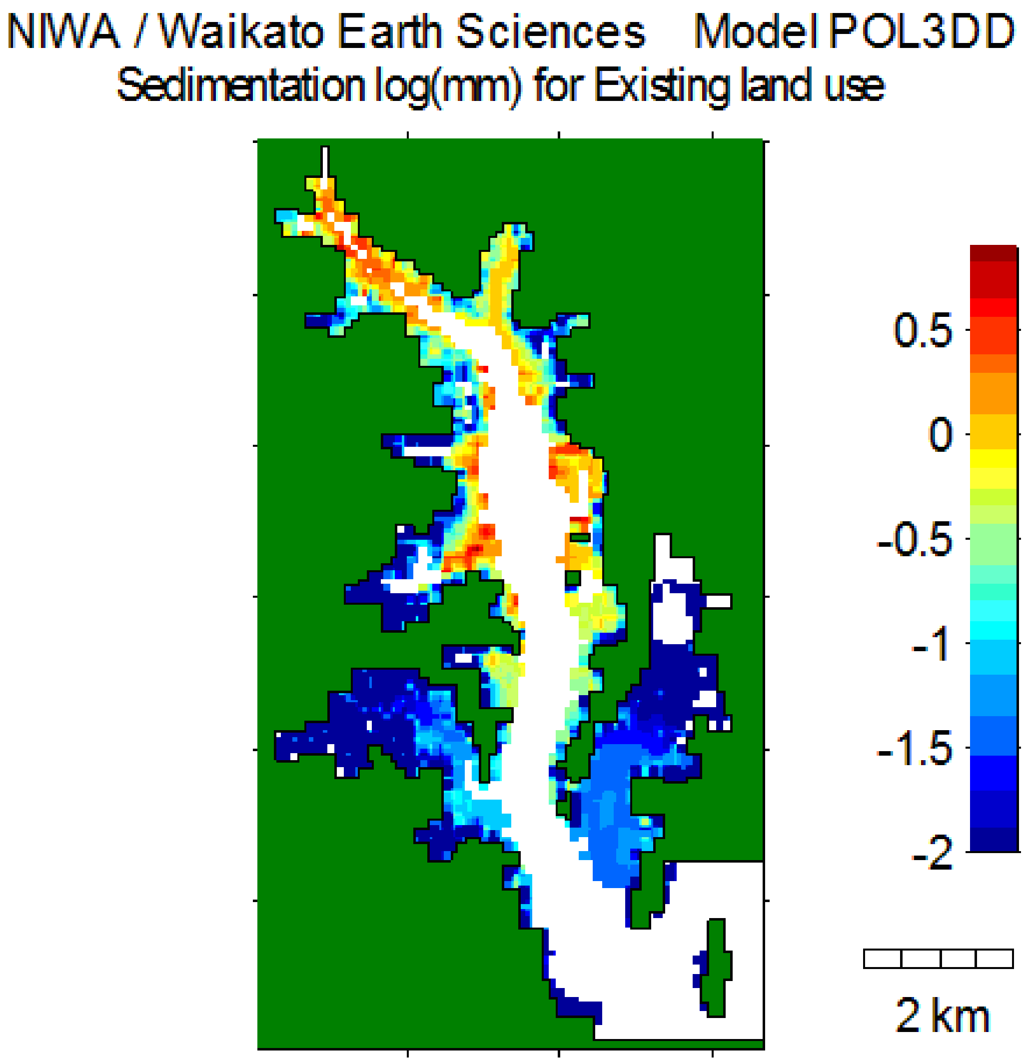


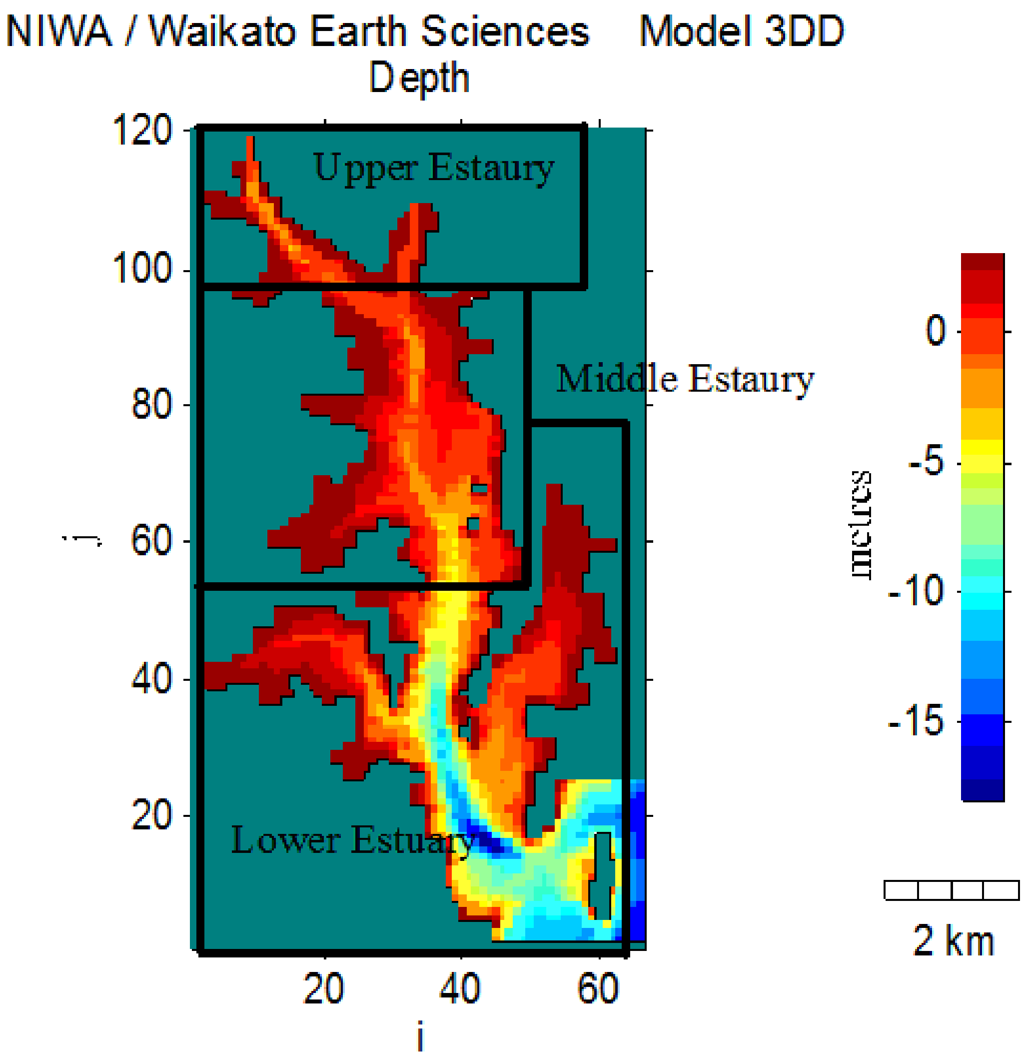
Table 2.

Sedimentation rates for existing land-use

Estuary sub-area	Maximum sedimentation (mm/annum)	Median sedimentation (mm/annum)	Mean sedimentation (mm/annum)
Upper estuary	4.587	0.750	0.453
Middle estuary	8.025	0.586	0.192
Lower estuary	0.900	0.059	0.028
Pukapuka Inlet	0.543	0.032	0.007
Te Kapa Inlet	0.433	0.027	0.021

Figure 4.

Areas defined within the estuary for the sedimentation rates from the estuary model.



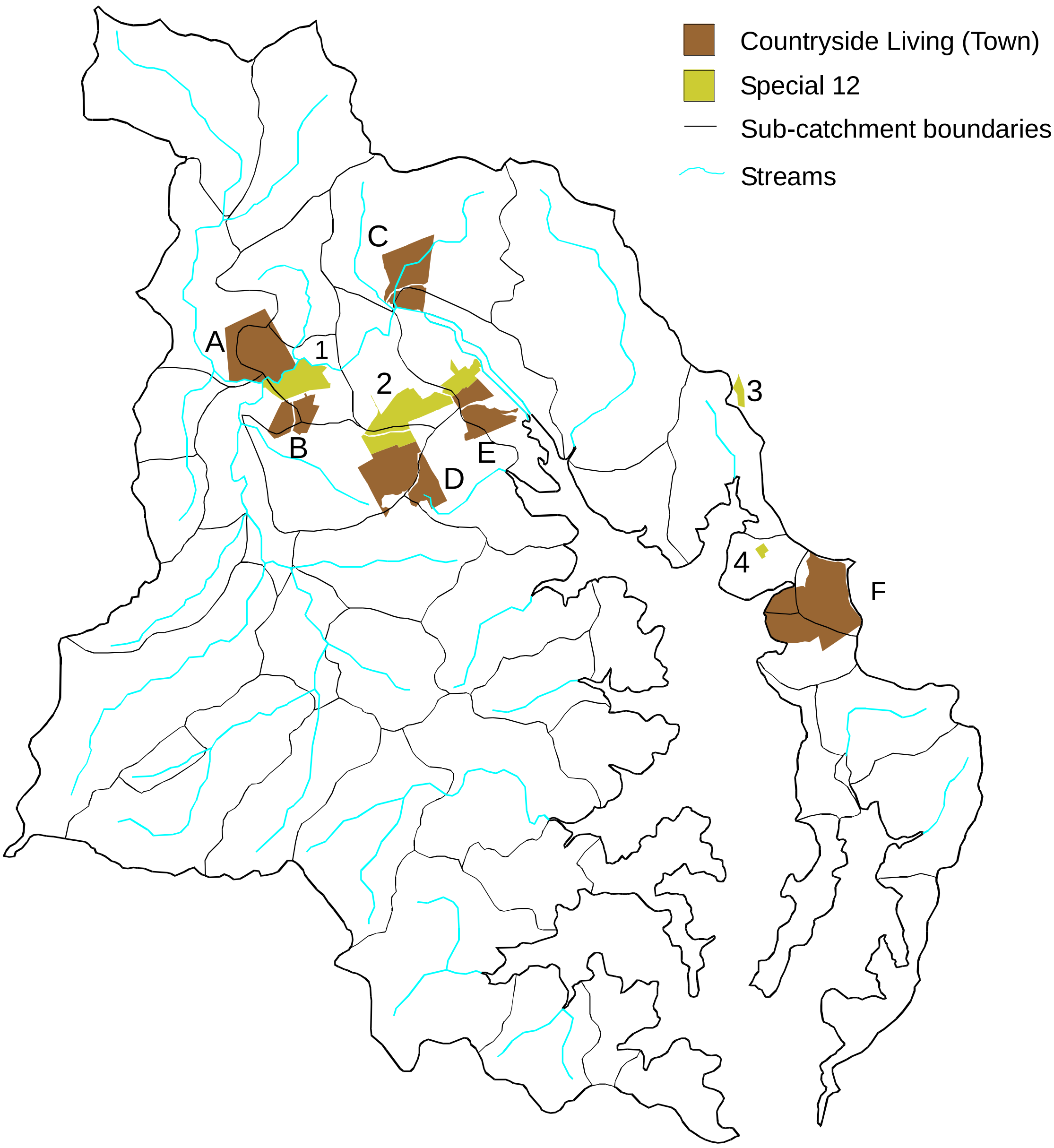
Maximum sedimentation occurs on the intertidal banks north of Hamilton Landing. Between Hamilton Landing and Grants Island rates decrease but maximums still occur on the fringes of the intertidal banks. Relatively low sedimentation rates occur over most of Te Kapa and Pukapuka Inlets.

7.2 Scenario 1: Increased Urbanisation

For these scenarios a proposed increase in land being developed for urbanisation was modelled. The areas were defined on cadastral maps provided by ARC staff, and represent those areas proposed for urbanisation by Rodney District Council. The effects of developing blocks of land for Special 12[1] and Country Living (Town)[2] (refer to Table 3 and Figure 5) were examined.

Figure 5.

Areas of proposed urban development.



[1] Special 12 = lot sizes of 300 m^2 to 8,000 m^2

[2] Country Living (Town) = a minimum lot size of 1 ha and an average lot size of 1.5 ha

Table 3.

The areas of land under proposed development for urbanisation

Zoning	Block	Area (ha)
Special 12	1	33.6
	2	74.9
	3	5.2
	4	2.6
	Total	**116.3**
Country Living (Town)	A	77.5
	B	29.3
	C	57.7
	D	75.9
	E	39.9
	F	124.5
	Total	**404.8**

The BNZ model was used to predict hillside erosion rates for each unique combination of soil type and slope within the areas of proposed urbanisation, for both the existing land-use and for land-use parameters reflecting urbanisation earthworks and development. A field trip was made to the proposed urbanisation areas to ground truth the slope data obtained from New Zealand Land Resource Inventory maps before it was used in the modelling.

The hillside erosion rates together with an estimate of the extent of earthworks expected on the proposed urbanisation blocks were used to calculate predicted sediment loads from each block. ARC staff advised that the extent of earthworks thought possible on Country Living (Town) regions ranged from as high as 100% to as low as 10% on gently rolling to flat land and 4% on rolling to steep land. Therefore, both extremes were modelled. Special 12 areas were expected to have 90 to 100% earthworks: our modelling assumed 100%.

The model predicted sediment loads from each of the proposed urban blocks assumes no sediment trapping control measures and no natural redeposition of sediment on land or in streams. It could be thought of as a prediction of gross erosion. It also assumes complete and not partial development of each block.

7.2.1 Scenario 1A: Increased areas of special 12

Table 4 gives the predicted 5th, median and 95th percentiles of sediment loss for the blocks designated Special 12. The model predicts there is a significant risk that Special 12 urbanisation will lead to a large increase in sediment loss from the proposed area.

Table 4.

Rates of sediment erosion as predicted by the BNZ model for the blocks of land designated for Special 12 development, under their existing land-use and during development.

Block	Area (ha)	Existing land-use sediment load median (t /annum)	Special 12 sediment load median (5-95%ile) (t /annum)	Increase in sediment load median (5-95%ile)
1	33.6	9	1,240 (590-3,120)	140 (66-350)
2	74.9	430	25,900 (11,600-61,000)	60 (27-140)
3	5.2	63	2,910 (1,550-5,030)	46 (25-79)
4	2.6	4	420 (220-980)	105 (55-245)

Assuming all the sediment generated on the hillslope reaches a waterway (i.e., no sediment retention by engineering structures), the model predicts Special 12 urbanisation of Blocks 1, 2 and 4 will make a significant additional contribution to the sediment loading to the Mahurangi River. From our field observations we consider that Block 3 will not drain to the Mahurangi Estuary but to the coast in the vicinity of Snells Beach.

Assuming all proposed Special 12 urbanisation blocks are developed simultaneously, the model predicted that the median annual sediment load from the Mahurangi River increases from 10,700 to 37,800 tonnes /annum, with most of the increase being associated with Block 2 (see Figure 6). This would lead to the following sedimentation rates within the estuary.

Figure 6.

Predicted sediment load to the estuary due to urbanisation of Block 2.

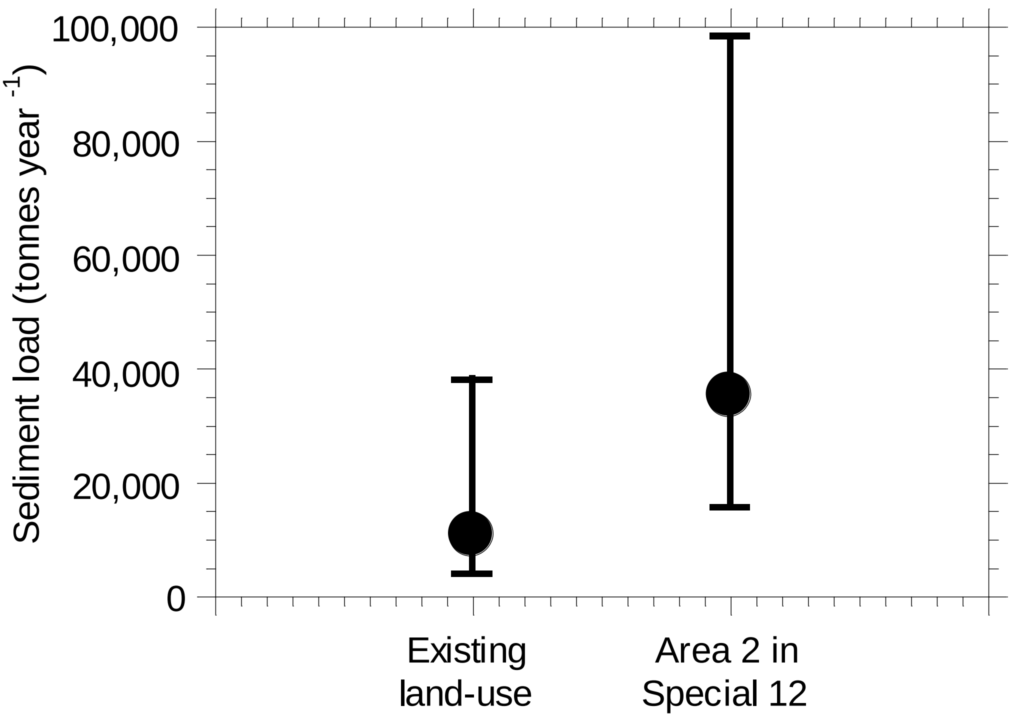


Table 5.

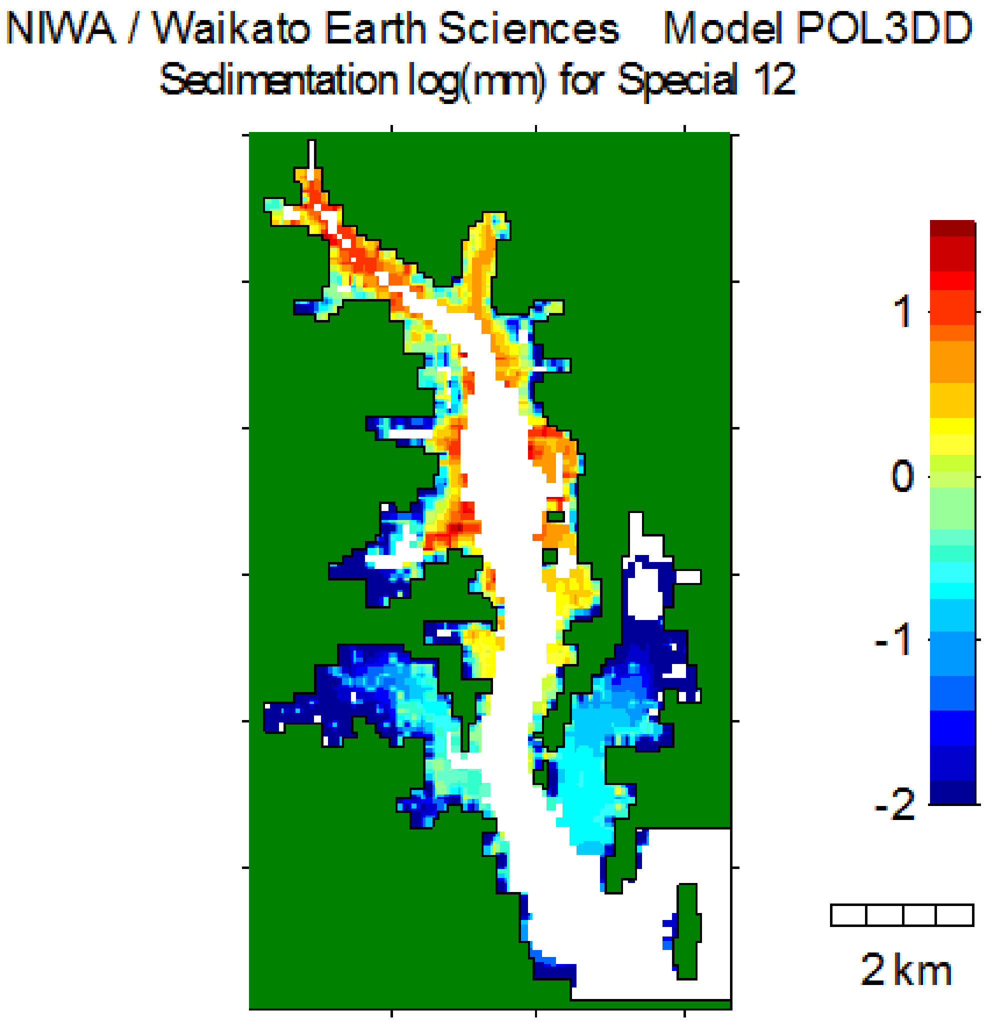
Sedimentation rates for Special 12 urbanisation land-use.

Estuary sub-area	Maximum sedimentation (mm/annum)	Median sedimentation (mm/annum)	Mean sedimentation (mm/annum)
Upper estuary	16.211	2.649	1.601
Middle estuary	28.363	2.072	0.677
Lower estuary	3.181	0.208	0.100
Pukapuka Inlet	1.920	0.112	0.026
Te Kapa Inlet	1.530	0.096	0.072

Figure 7 shows the plot of the sedimentation data for the whole estuary. Data is presented as $\log_{10}$ plots of mm of sediment build-up following the modelled storm.

Figure 7.

Predicted sedimentation rates (mm/annum) for Special 12 urbanisation.



7.2.2 Scenario 1B: Increase in Area of Country Living (Town)

Figure 5 shows those areas within the catchment that are proposed for development to Country Living (Town). The importance of this urbanisation to sediment load is not only dependent upon soil type, slope and area but also on the way in which it is developed, i.e., the extent of site disturbance. Table 6 shows that at low levels of site disturbance, (i.e. 4-10%), median sediment loads are predicted to increase by about 4 fold over existing land-use loads. However, for maximum disturbance by earthworks (i.e. 100%) the predicted increases in median loads range from about 40 to over 80 fold. Figure 8 shows the predicted sediment erosion rates (tonnes per annum) for the 6 blocks under both the 4-10% and 100% disturbances.

Figure 8.

Predicted sediment erosion rates for Country Living (Town).

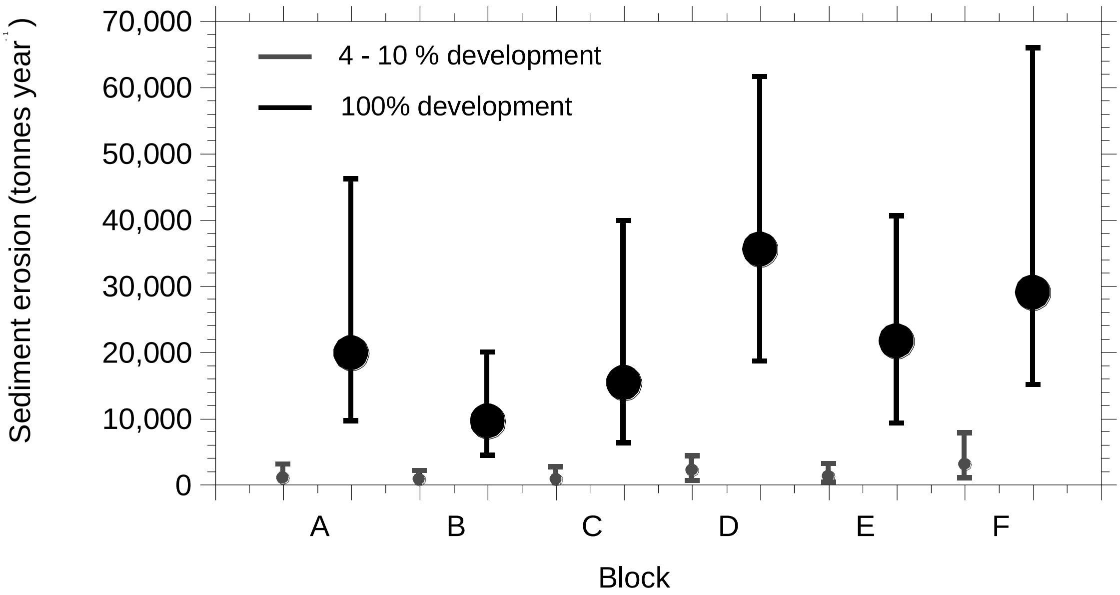


Table 6.

Rates of sediment erosion as predicted by the BNZ model for the regions of proposed Country Living (Town) under their existing land-use and during development.

Block	Area	Existing land-use sediment load median (t /annum)	Disturbance by earthworks: Country Living (Town) sediment load median (5-95%tile)(t /annum)		Increase over existing land-use loads	
	(ha)		4-10%	100%	4-10%	100%
A	77.5	294	1,070	19,800	3.6	67
			(520-2,600)	(10,000-45,900)	(1.8-8.8)	(34-160)
B	29.3	128	600	9,240	4.7	72
			(290-1,400)	(4,900-19,500)	(2.3-11)	(38-150)
C	57.7	176	780	15,200	4.4	86
			(340-2,000)	(6,800-39,300)	(1.9-11)	(39-220)
D	75.9	702	2,220	35,600	3.2	51
			(1,100-3,560)	(18,990-61,100)	(1.6-5.1)	(27-87)
E	39.9	495	1340	21,700	2.7	44
			(610-2,770)	(9,900-39,900)	(1.2-5.6)	(20-81)
F	124.5	272	3,160	29,100	12	110
			(1,650-7,220)	(15,500-65,300)	(6.1-27)	(57-240)

All the blocks except F, which drains to two small inlets on the Eastern Shore of the Mahurangi Estuary, drain to the Mahurangi River (see Figure 5). Assuming, as for the Special 12 scenario, that all proposed urbanisation blocks A to E are developed simultaneously and there are no control measures or in-stream attenuation, the predicted median annual sediment load to the Mahurangi Catchment via the Mahurangi River for the 4-10% disturbance increases from 10,700 tonnes per annum to 14,915 tonnes per annum. The following sedimentation rates are predicted for the estuary.

Table 7.

Predicted sedimentation rates within the estuary for Country Living (Town) (4-10% land disturbance).

Estuary sub-area	Maximum sedimentation (mm/annum)	Median sedimentation (mm/annum)	Mean sedimentation (mm/annum)
Upper estuary	6.394	1.045	0.031
Middle estuary	11.186	0.817	0.267
Lower estuary	1.255	0.082	0.039
Pukapuka Inlet	0.757	0.044	0.010
Te Kapa Inlet	0.603	0.038	0.029

Figure 9 shows the plot of the sedimentation data for the whole estuary.

For the 100% disturbance the predicted median annual sediment load to the Mahurangi Catchment increases from 10,700 tonnes per annum to 110,445 tonnes per annum. The following sedimentation rates are predicted for the estuary.

Figure 9.

Predicted sedimentation rates (mm/annum) for Country Living (Town) urbanisation with land disturbance at 4-10%.

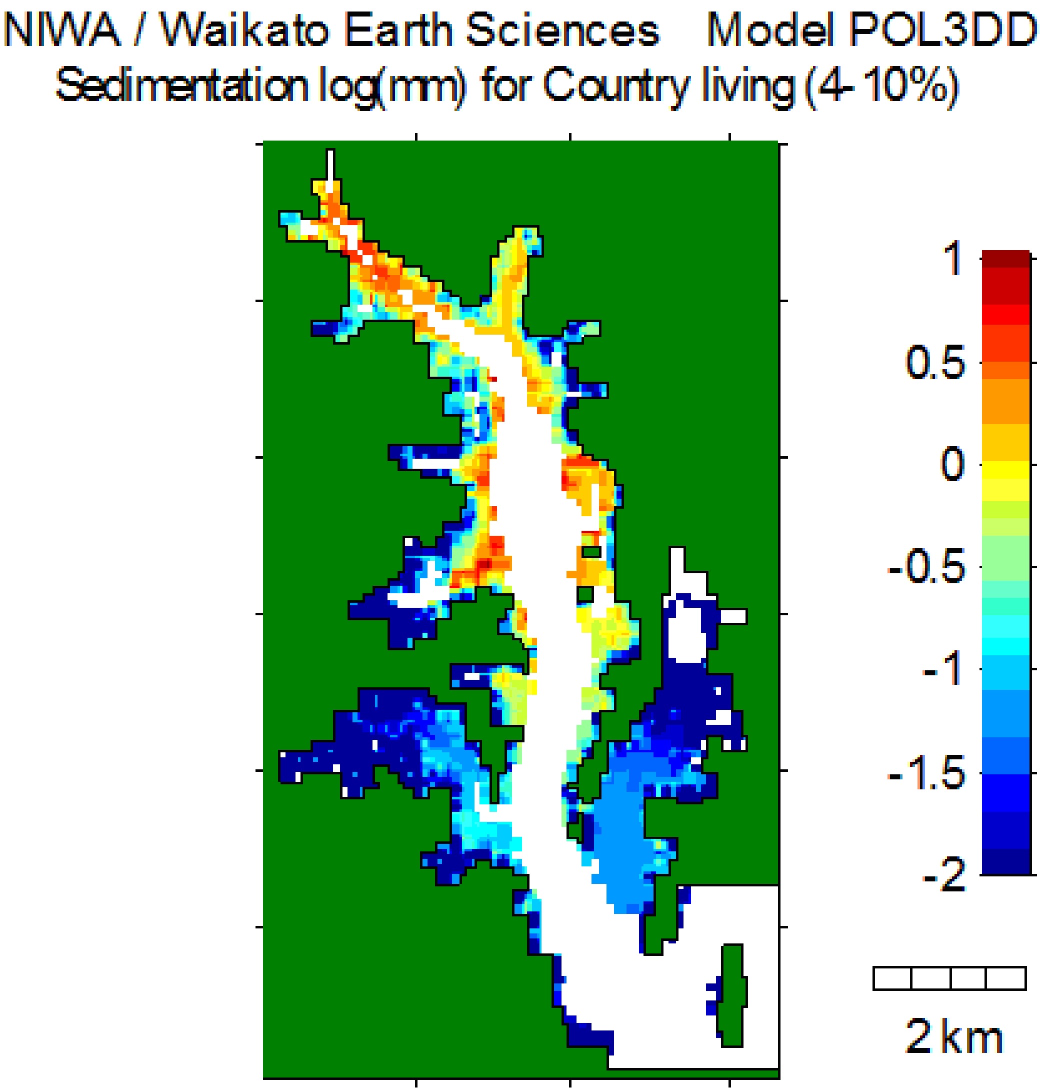


Table 8.

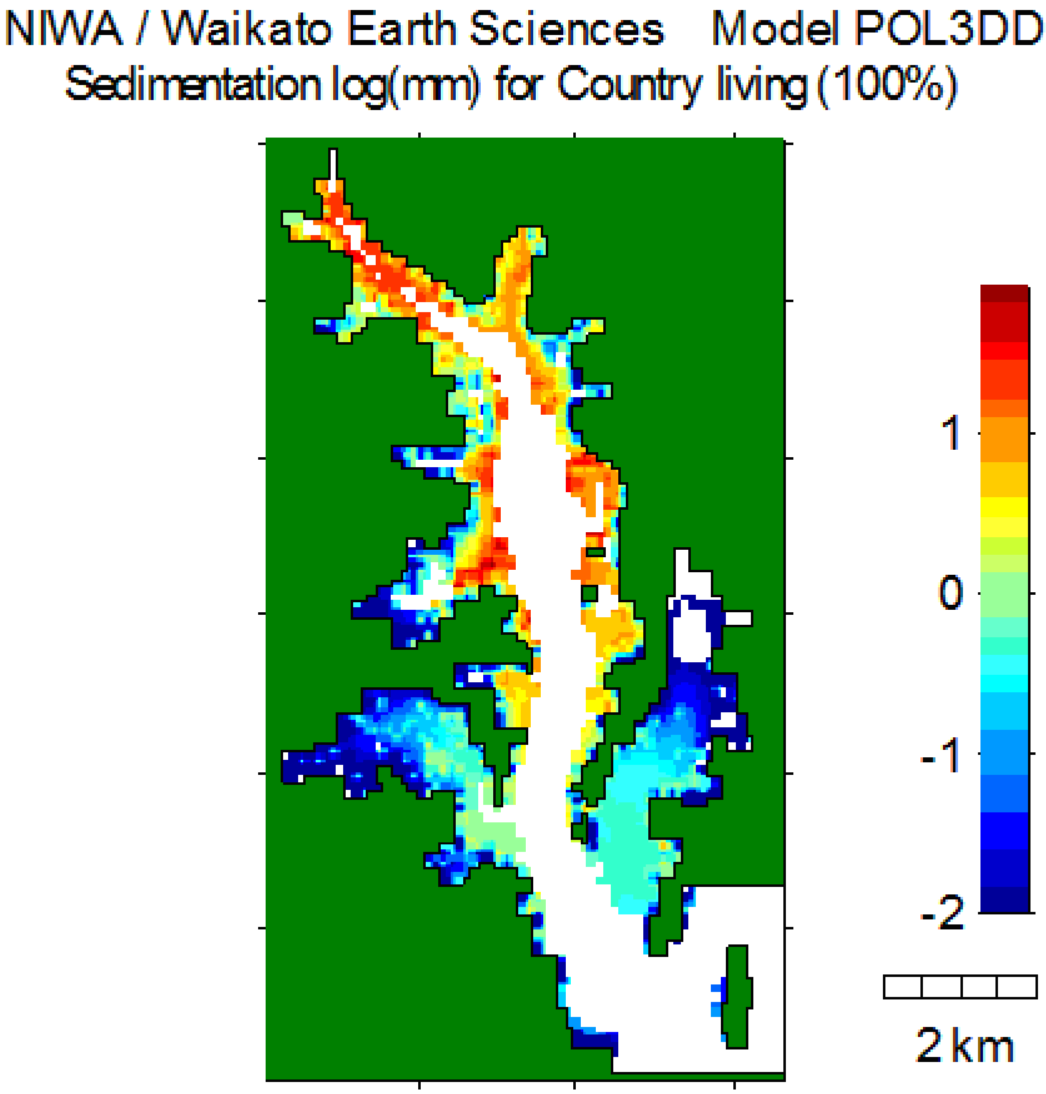
Predicted sedimentation rates within the estuary for Country Living (Town) (100% land disturbance).

Estuary sub-area	Maximum sedimentation (mm/annum)	Median sedimentation (mm/annum)	Mean sedimentation (mm/annum)
Upper estuary	47.344	7,737	4.675
Middle estuary	82.834	6.052	1.977
Lower estuary	9.291	0.607	0.292
Pukapuka Inlet	5.609	0.326	0.075
Te Kapa Inlet	4.468	0.279	0.212

Figure 10 shows the plot of the sedimentation data for the whole estuary.

Figure 10.

Predicted sedimentation rates (mm/annum) for Country Living (Town) urbanisation with land disturbance at 100%.



7.2.3 Block F

Block F is the largest block proposed for Country Living (Town) urbanisation and is predicted to have the greatest increase in sediment erosion rates (see Table 6). This, together with its close proximity to the Mahurangi Estuary, suggests that on development of the area there is a potential for large amounts of sediment to be delivered to the estuary. As the hydrodynamic and transport dispersion model is not calibrated for sources other than the Mahurangi River, the contribution of Block F sediment to estuary sedimentation cannot be modelled. However, if we assume that the sediment load from Block F is deposited evenly on the eastern intertidal flats from Grants Island to Hamilton Landing we can calculate the mean sedimentation rate due to Block F. Under existing land-use we estimate that Block F would produce sedimentation at a rate of 0.084 mm/annum. For the 4-10% disturbance scenario this increases to a rate of 0.975 mm/annum, while for the 100% disturbance scenario a rate of 8.981 mm/annum is predicted.

7.3 Scenario 2: Harvesting of the Redwood Forest

For this scenario, the area of the Redwood Forest that drains to the Mahurangi Estuary (via the Mahurangi River) was harvested.

The BNZ model was run for the Mahurangi Estuary catchment with Redwood Forest grid cell parameters set for a harvested condition, and assuming no sediment control measures (e.g., no riparian setbacks, no ponds). The model predicted median, 5^{th} and 95^{th} percentiles sediment loads given in Table 9 are for the outlet of the catchment which contains the Redwood Forest (see Figure 11). The table compares the predicted sediment load leaving the catchment when the trees are standing to the predicted load leaving the catchment when the trees are harvested.

Figure 11.

Area of Mahurangi Catchment in Redwood Forest.

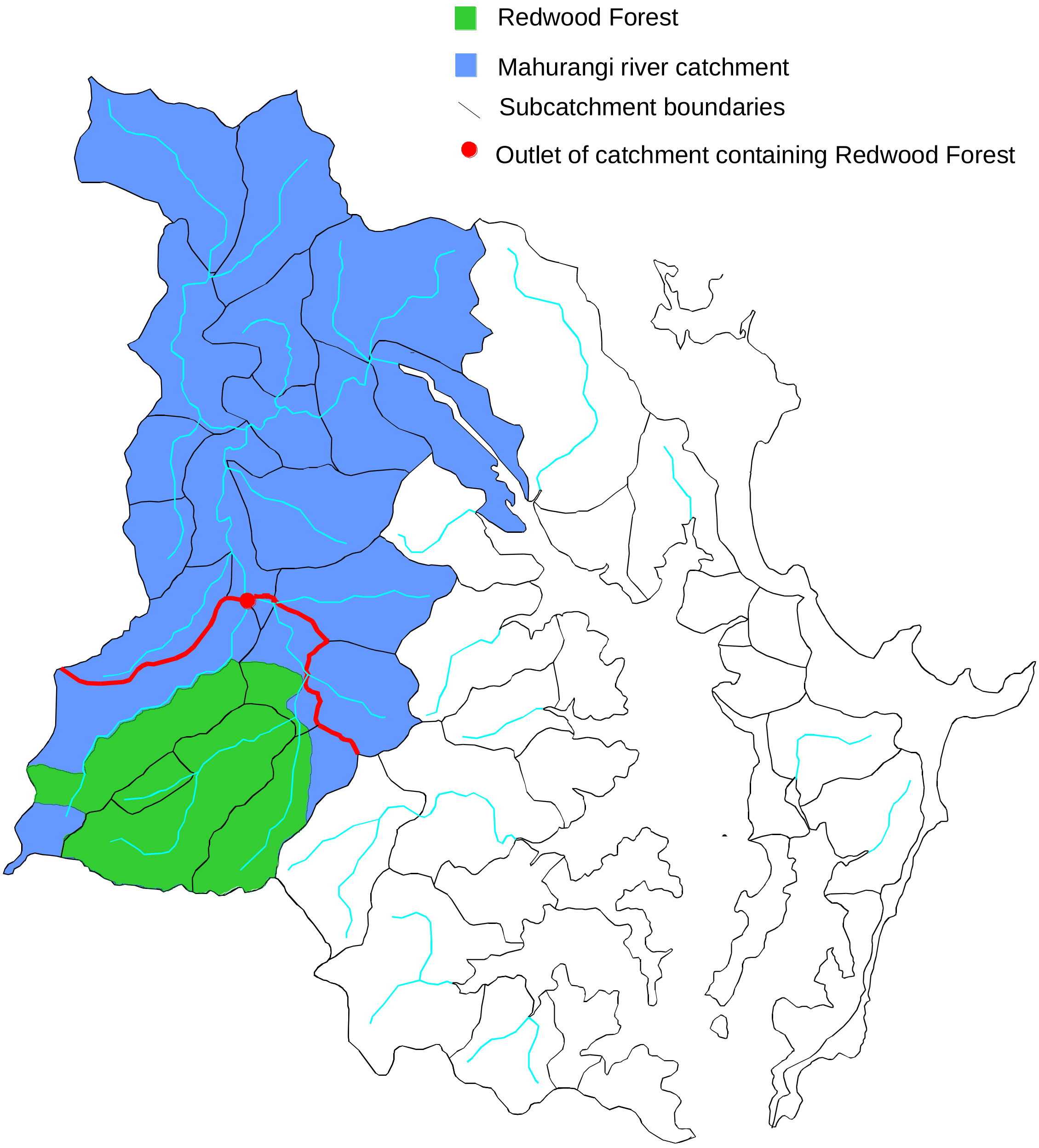


Table 9.

Predicted sediment loads from the catchment containing the Redwood Forest, with the forest as standing pines and when recently harvested.

Area (km^2)	Standing Forest sediment load median (5-95%ile) (t /annum)	Harvested Forest sediment load median (5-95%ile) (t /annum)	Increase median (5-95%ile)
16.25	2,780 (1,060 - 12,100)	22,900 (9,900 - 69,900)	8.2 (3.6 - 25)

After taking into account in-stream retention, the model predicts that with the Redwood Forest under a harvested condition the sediment load delivered to the estuary by the Mahurangi River has a 50% risk of increasing from 10,700 tonnes per year to 24,400 tonnes per year, a 95% risk of increasing to 10,200 tonnes/annum and a 5% risk of increasing to 82,700 tonnes/annum. For the 50% value of 24,400 the following sedimentation rates are predicted for the estuary.

Table 10.

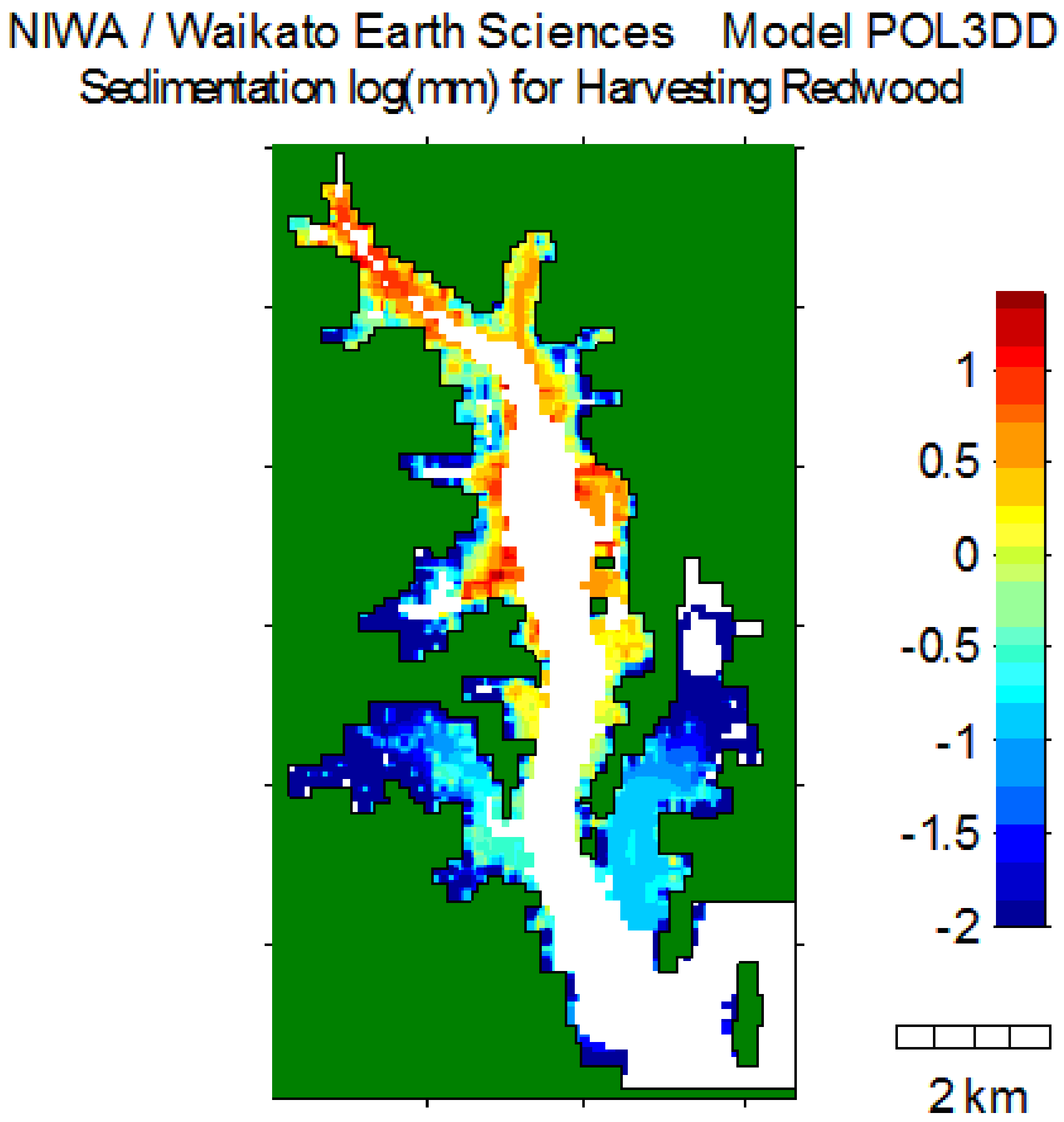
Predicted sedimentation rates within the Estuary for harvested Redwood Forest.

Estuary sub-area	Maximum sedimentation (mm/annum)	Median sedimentation (mm/annum)	Mean sedimentation (mm/annum)
Upper estuary	10.459	1.709	1.033
Middle estuary	18.300	1.337	0.437
Lower estuary	2.053	0.134	0.065
Pukapuka Inlet	1.239	0.072	0.017
Te Kapa Inlet	0.987	0.062	0.047

Figure 12 shows the plot of the sedimentation data for the whole estuary.

Figure 12.

Predicted sedimentation rates (mm/annum) for Harvested Redwood.



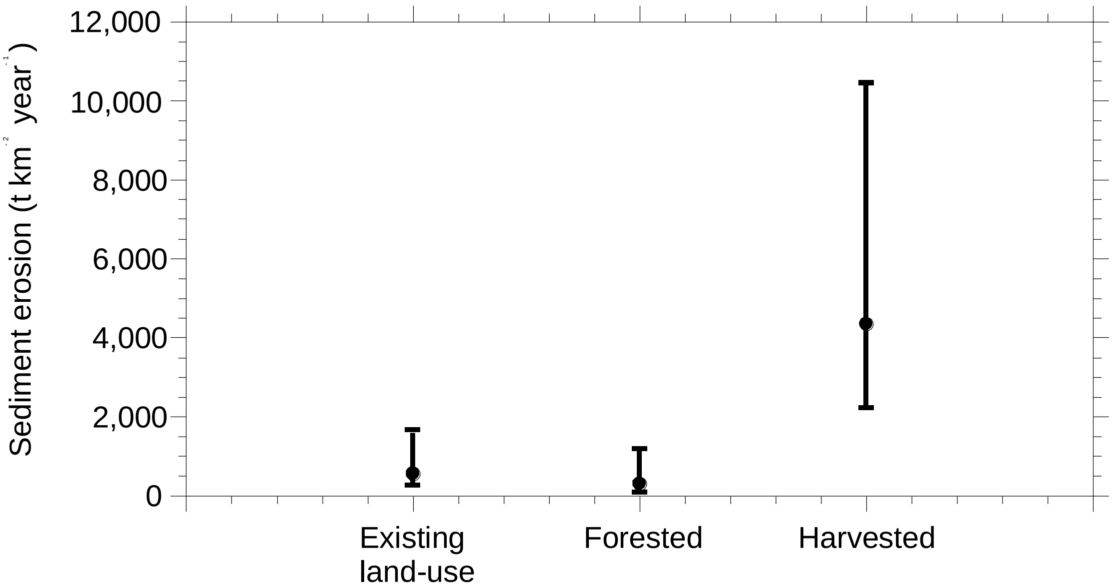
7.4 Scenario 3: Conversion to production Forest

For this scenario it is assumed that the whole of the Mahurangi estuary catchment was planted in exotic forest. Although this is clearly an unrealistic scenario, such modelling allows prediction of those areas of the catchment most suited/unsuited to production forestry land-use from a sediment erosion viewpoint.

7.4.1 Predicted Erosion Rates

The BNZ model was run with the Mahurangi estuary catchment in a land-use of 1) mature standing pine forest and 2) recently harvested forest. This was done in order to predict sediment generation rates for each sub-catchment for both land-uses (Figure 13). This data gives an indication of the relative impact that a change in land-use within sub-catchments will have on sediment erosion rates.

Figure 13.
Model predicted sub-catchment sediment generation rates for existing land-use, established forest and harvested forest.



The predicted rate of sediment generation per sub-catchment for forested, harvested and existing land-uses are included in Appendix 1. The predicted median sediment generated per sub-catchment ranged from 50 to 690 t km^{-2} /annum for established forest and from 700 to 10,600 t km^{-2} /annum for recently harvested forest. Figure 14a shows the predicted erosion rates for each sub-catchment under harvested conditions. Although the predicted rates are much lower for the sub-catchments in mature forest (Figure 14b), their relative spatial distribution is very similar.

Figure 14a.

Sub-catchment predicted median sediment generation map during harvesting of production forest.

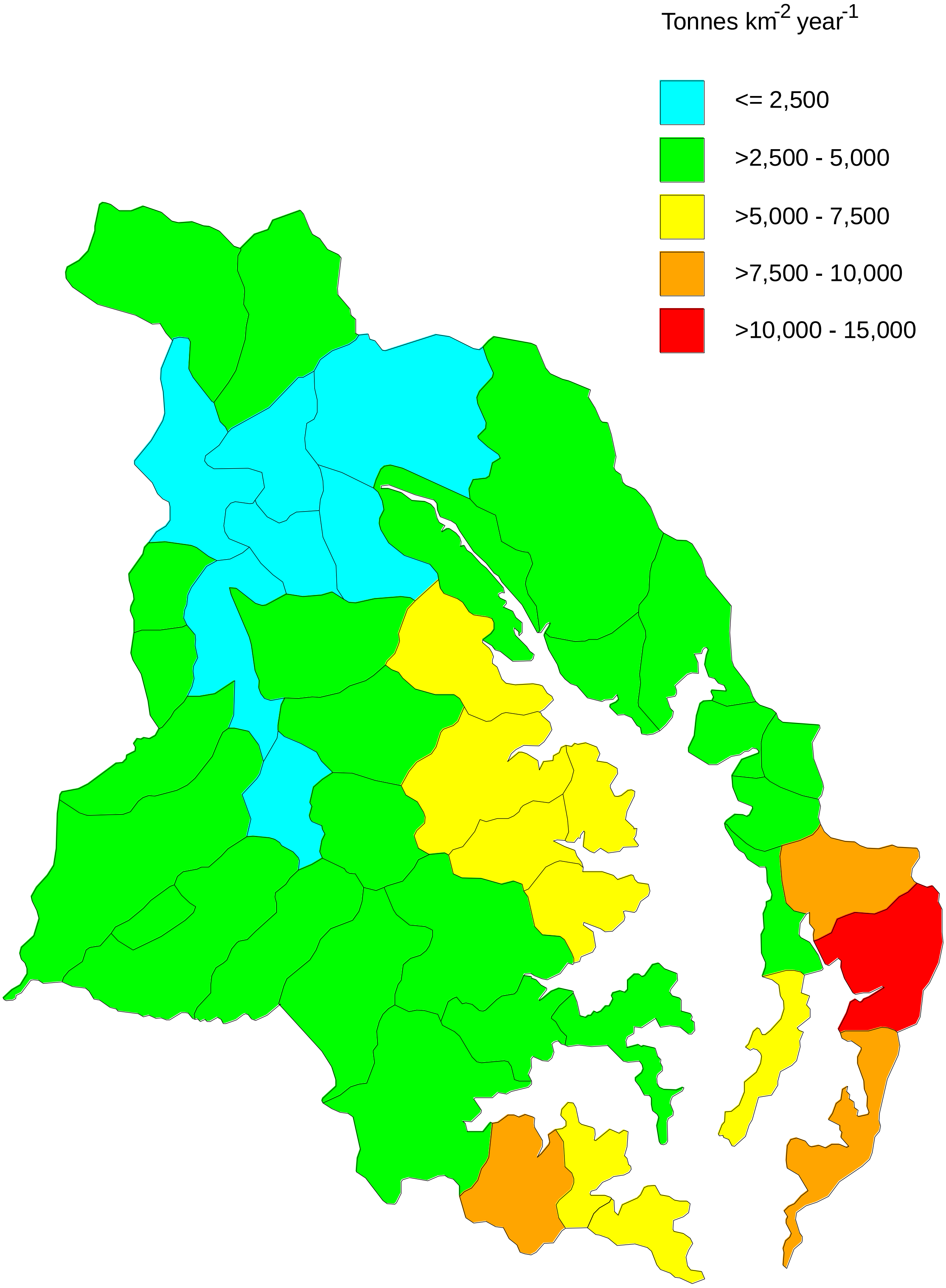
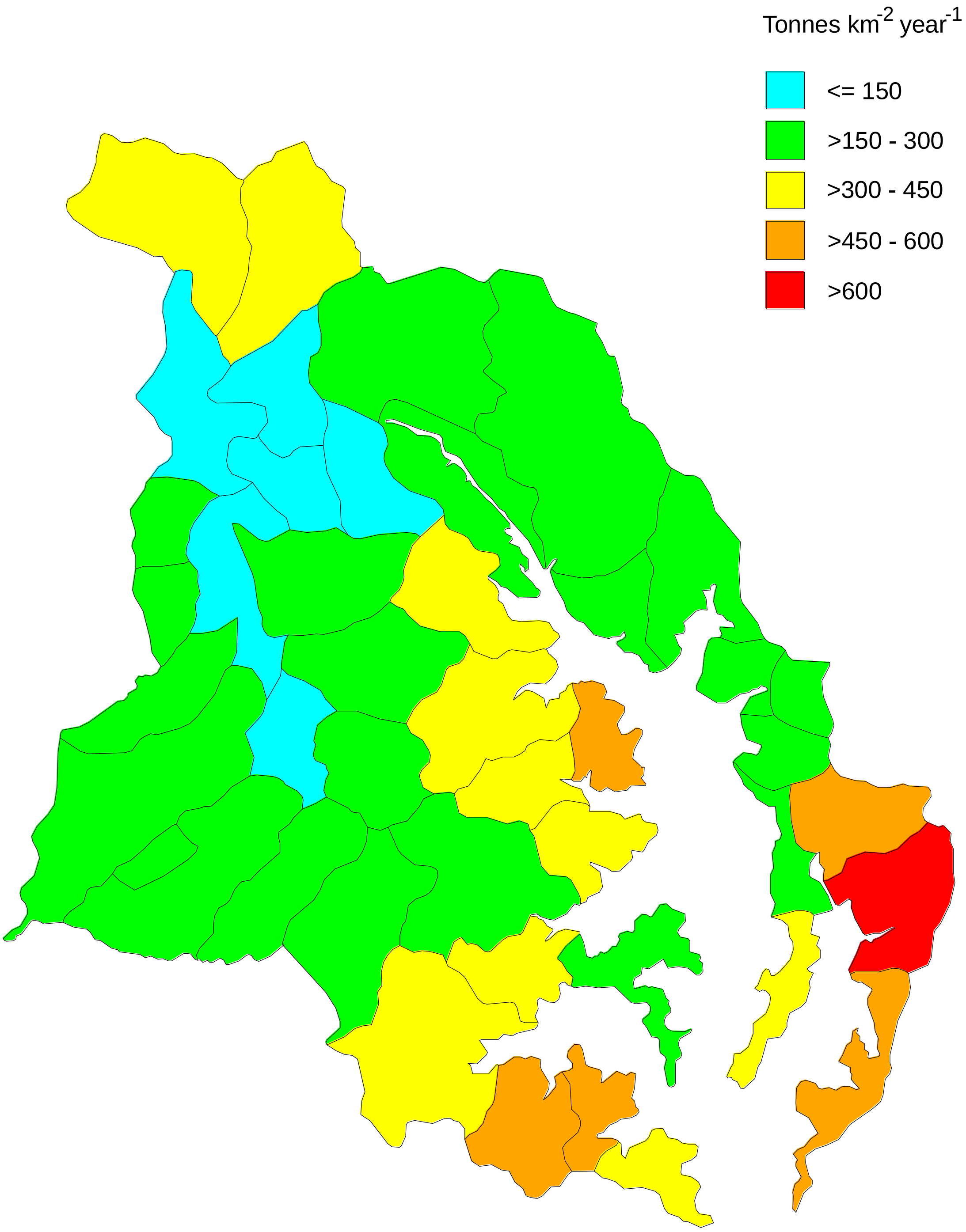


Figure 14b.

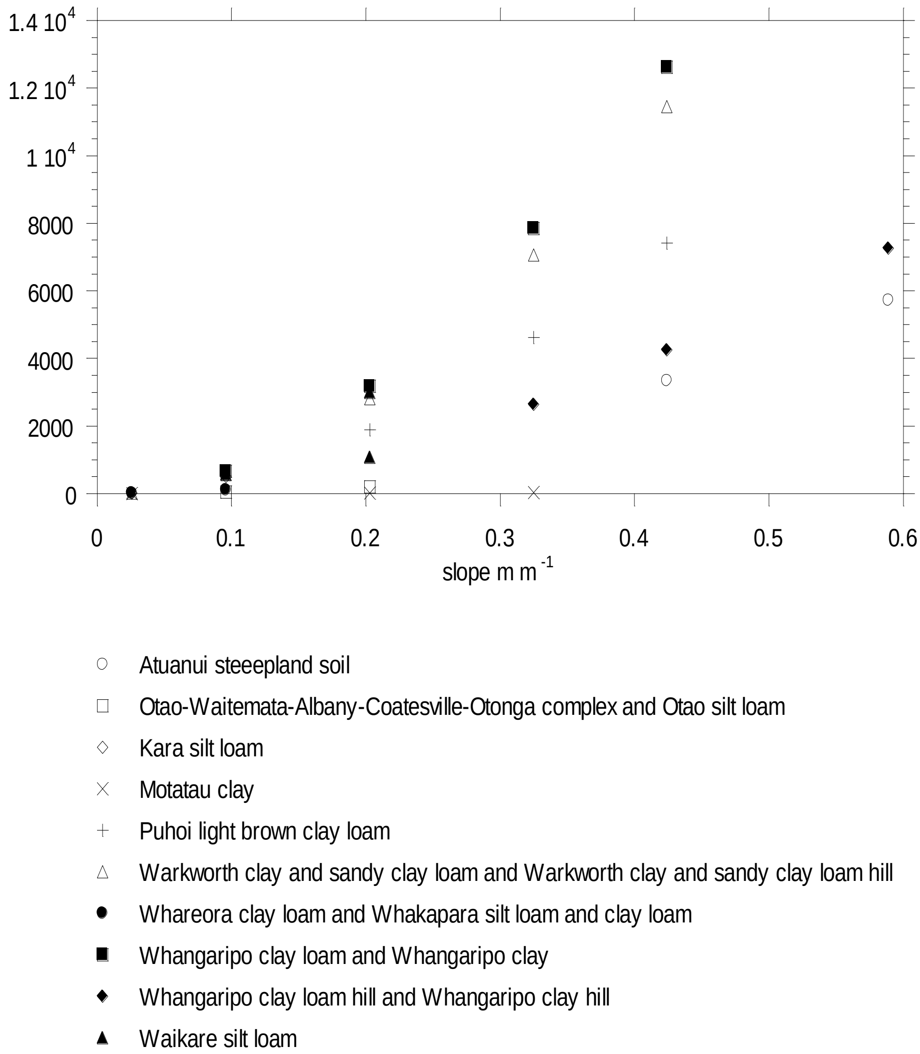
Sub-catchment predicted median sediment generation map for mature production forest.



In an attempt to understand the factors behind the differences in sediment generation rates predicted throughout the catchment, 30 unique combinations of soil type and slope occurring within the catchment were identified and their predicted median rates of sediment erosion for a harvested land cover were compared. Figure 15 shows there is a weak relationship between sediment generation rate and slope. However the scatter in the plot indicates that factors other than slope are important i.e., soil properties. For example, within the model soils with a high saturated hydraulic conductivity on steep slopes produce lower rates of sediment production than soils with a low saturated hydraulic conductivity on less steep slopes. Other soil properties also influence sediment generation, e.g., two soils have the same saturated hydraulic conductivity, but the soil on the steeper slope produces less sediment than that on the gentler slope. Obviously there are many factors and mechanisms that interact in the process of sediment generation. The model is used to bring all these together in order to predict a final sediment generation potential.

Figure 15.

Sediment erosion rates as a function of soil slope and soil type.

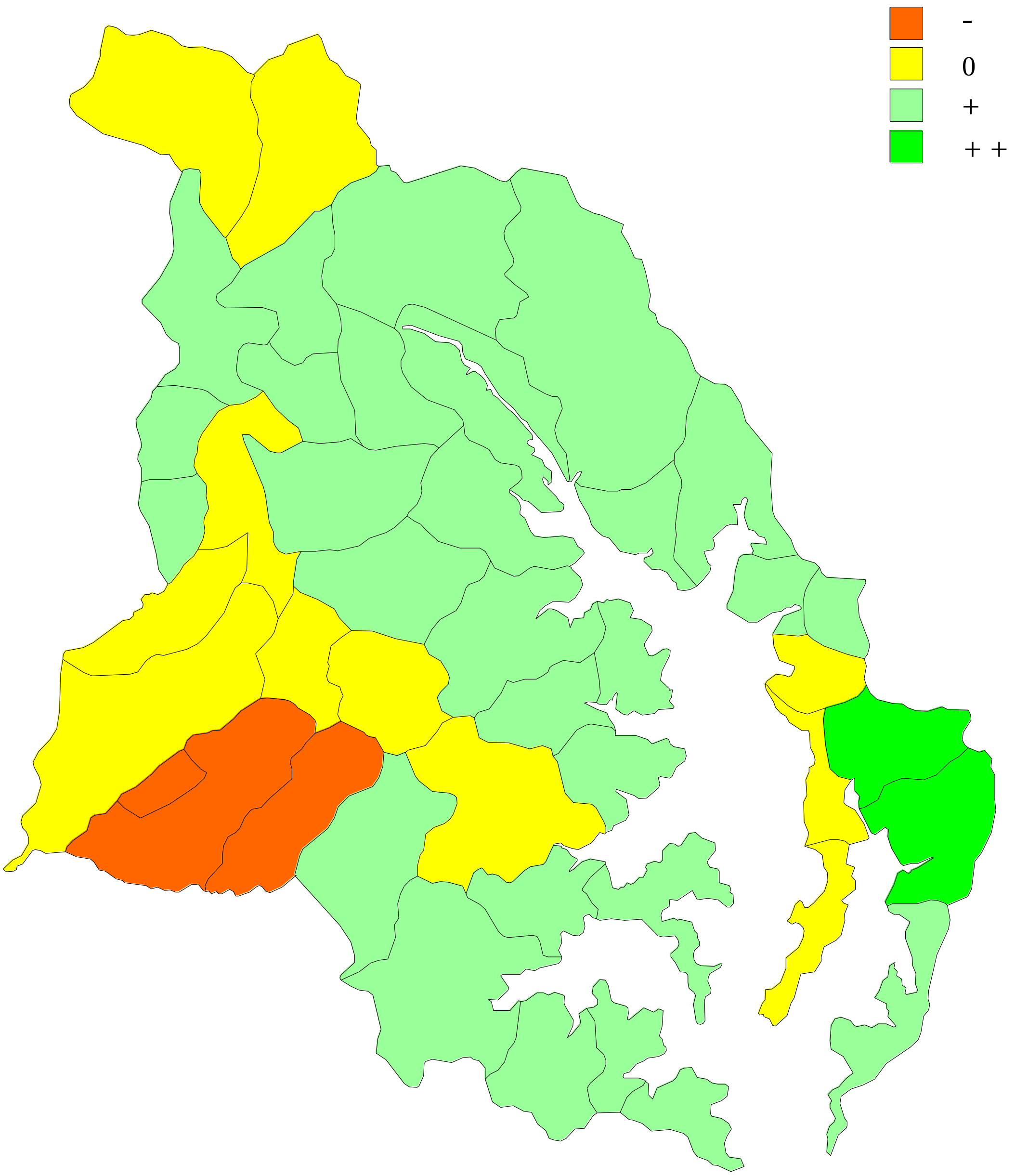


Taking a long term approach to compare production forestry and pastoral farming land-uses, model predicted sediment erosion over a 30 year forestry cycle, with harvesting assumed to occur in one year, was compared to sediment erosion predicted for 30 years for the current land-use. No allowance was made in the modelling for the establishment of the pine trees i.e., it was assumed the pines were a mature crop for 29 years.

The difference between the predicted 30 year sediment loss for the existing land-use and the above forestry rotation scenario was calculated for each sub-catchment and is shown in Figure 16. A positive difference represents a benefit due to forestry i.e., a predicted reduction in long term sediment loss compared to existing land-use. A negative difference represents a predicted increase in long term sediment loss with forestry. The latter only occurs on sub-catchments with existing production and/or native forest. This is because the 30 year sediment loss calculation for the full production forestry rotation includes a year of harvesting whereas the 30 year sediment loss for existing land-use scenarios doesn't.

Figure 16.

Sub-catchment erosion rates based on a 30 year rotation. Existing land-use versus production forestry with 29 years in established forest and one year harvesting.



Under the assumptions made, the modelling is therefore predicting that conversion of any areas in pastoral farming to production forestry will most likely result in a net decrease in the long-term sediment inputs to the estuary. However, these inputs would be dominated by the high episodic inputs associated with harvesting. The relative environmental effects of pastoral farming versus production forestry therefore becomes an issue of the relative effect on the estuarine ecology of episodic versus chronic sediment loadings (see Ecological Consequences section for a discussion of this). The model runs were conducted without sediment control measures during harvesting, suggesting that the long-term benefits of production forestry could be further enhanced and the risk of episodic sediment loads reduced with such measures in place. Likewise, the model was run for current pastoral farming practices and the use of sediment control measures (e.g. riparian strips, conservation plantings) also have the potential to reduce sediment loadings to the estuary from this land-use.

7.4.2 Estuary Sedimentation Rates

To determine the effect of production forest land-use on sedimentation rates within the estuary the output from the BNZ with in-stream attenuation accounted for are considered. Table 11 shows that the median annual sediment load delivered to the estuary for established production forest would be reduced to below the existing land-use load. During harvesting there is a risk that high amounts of sediment will be generated.

Table 11.

Model predicted median loads of sediment delivery to the Mahurangi Estuary via the Mahurangi River and the entire catchment, when the whole catchment is in standing forest and harvested forest.

Region of sediment load delivery	Area (km^2)	Standing Forest median load (t /annum)	Harvested Forest median load (t /annum)
Mahurangi River catchment	58.25	6,000	85,000
Mahurangi Estuary catchment	116.75	21,000	300,000

For this scenario, median annual sediment load to the Mahurangi River Catchment decreases from 10,700 tonnes per annum to 6,000 tonnes per annum. The following sedimentation rates are predicted for the estuary.

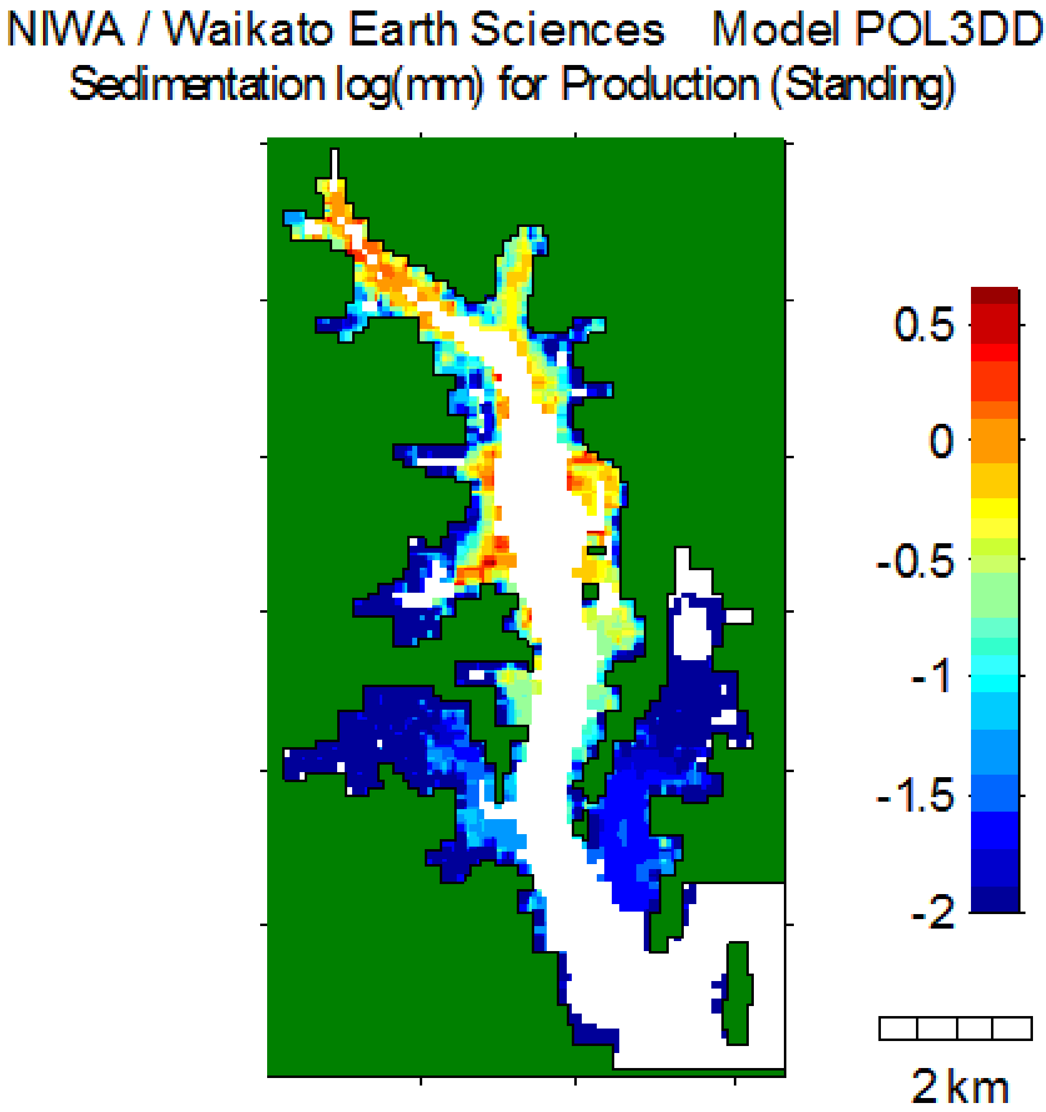
Table 12.

Sedimentation rates within the Estuary for Mahurangi River Catchment under established production forest.

Estuary sub-area	Maximum sedimentation (mm/annum)	Median sedimentation (mm/annum)	Mean sedimentation (mm/annum)
Upper estuary	2.572	0.420	0.254
Middle estuary	4.500	0.329	0.107
Lower estuary	0.505	0.033	0.016
Pukapuka Inlet	0.305	0.018	0.004
Te Kapa Inlet	0.243	0.015	0.012

Figure 17 shows the plot of the sedimentation data for the whole estuary.

Figure 17.
Predicted sedimentation rates (mm/annum) for established Production Forest.



Harvesting the Mahurangi River Catchment would increase the average annual sedimentation load to the estuary from 10,700 tonnes per annum to 85,000 tonnes per annum. The following sedimentation rates within the estuary are predicted.

Table 13.

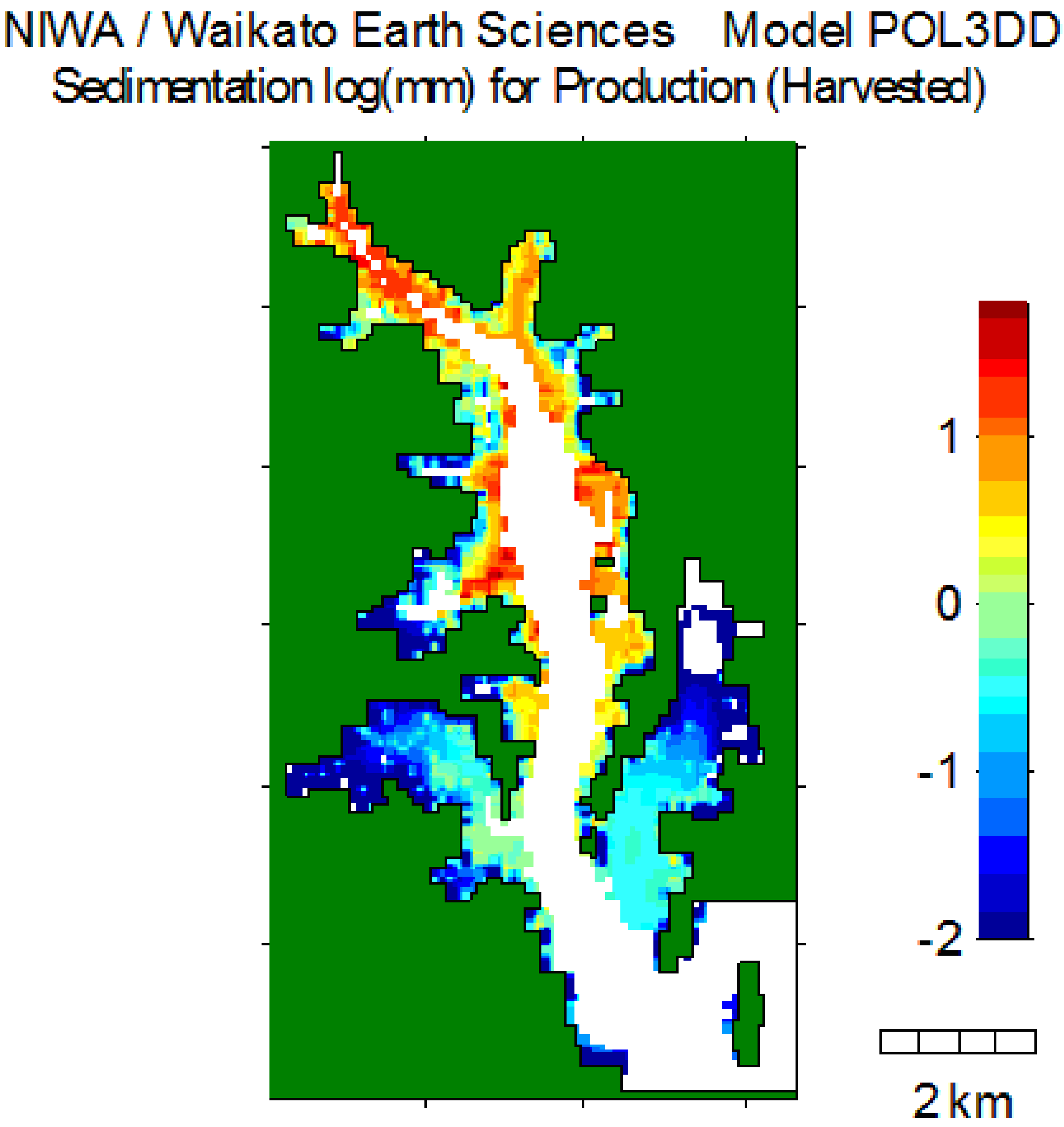
Sedimentation rates within the Estuary during harvesting of Mahurangi River Catchment under production forest.

Estuary sub-area	Maximum sedimentation (mm/annum)	Median sedimentation (mm/annum)	Mean sedimentation (mm/annum)
Upper estuary	36.437	5.954	3.598
Middle estuary	63.750	4.658	1.521
Lower estuary	7.151	0.467	0.225
Pukapuka Inlet	4.317	0.251	0.058
Te Kapa Inlet	3.439	0.215	0.163

Figure 18 shows the plot of the sedimentation data for the whole estuary.

Figure 18.

Predicted sedimentation rates (mm/annum) for Harvested Production Forest.



7.4.3 Sedimentation within Te Kapa and Pukapuka inlets

Under production forestry large quantities of sediment are predicted to be generated within the Te Kapa and Pukapuka Inlet catchments (Figure 1). As the hydrodynamic and transport dispersion model isn't calibrated for sources other than the Mahurangi River, the contribution of these catchments to estuary sedimentation cannot be modelled. However, if we assume that the sediment load from these catchments is deposited evenly within the intertidal areas of these inlets we can calculate the mean sedimentation rate.

For Te Kapa Inlet under existing land-use this method gives a mean sedimentation rate of 1.515 mm/annum. For Pukapuka Inlet a rate of 1.664 mm/annum is predicted. These figures are in broad agreement with the rates given by Swales et al. (1997) and reaffirms the discussion above about the relative effects of the Mahurangi River Catchment in terms of sedimentation rates within the estuary.

For Te Kapa Inlet under standing production forest a predicted mean sedimentation rate of 0.673 mm/annum is predicted while during the harvest phase rates increase to 10.522 mm/annum. For Pukapuka Inlet under standing production forest a predicted mean sedimentation rate of 0.773 mm/annum is predicted while during the harvest phase rates increase to 11.789 mm/annum.

8 Discussion

As discussed in Section 4 the conditions of winds, tide, and freshwater inflows during a storm event all determine the pattern of sedimentation immediately after a storm event. Additionally, the conditions of winds, tide, and freshwater inflows following initial sedimentation will effect how long sediment remains in the area, how much of it is resuspended, how long it is resuspended for, how far it will spread from the area where it is initially deposited and the depth of deposition. The effect on the infauna and indeed on the physical characteristics of the habitat is therefore highly dependent on the prevailing conditions of winds, tide, and freshwater inflows both during and after any storm events. Because of the stochastic nature of winds and rains it is difficult to determine an “average” sedimentation rate within the estuary for a given land-use scenario. However, we have presented sedimentation rates for a “typical” storm for each of land-use scenarios considered, which enables us to determine the likely ecological consequences.

8.1 Estuary Sedimentation

The BNZ modelling gives predictions of the changes to sediment delivery to the estuary under different land-use scenarios. Table 14 summarises the predicted change in median annual sediment load delivered to the estuary for the different land-use scenarios examined in this report, and these numbers give an indication of the likely increase in estuary sedimentation rates (over existing rates) for each of the scenarios.

Table 14.

Predicted median sediment load from the Mahurangi River Catchment (expressed as a ratio of predicted median sediment load under existing land-use) for different land-use scenarios. Table is ranked from lowest to highest median sediment loading.

Land-use scenario	Area (km^2)	Ratio of sediment load to existing
Established Production Forest	58.25	0.56
Countryside living (Town) with 4-10% land disturbance	2.80	1.39
Harvesting of Redwood Forest	16.25	2.28
Special 12	1.11	3.53
Harvested Production Forest	58.25	7.94
Countryside living (Town) with 100% land disturbance	2.80	10.32

We have presented predicted sedimentation rates within various sub-areas of the estuary based on the above median sediment delivery rates. The sedimentation rates in the estuary represent an “average” case (both in terms of terms of sediment loading and prevailing conditions). The actual pattern of estuary sedimentation will be dependent upon prevailing conditions of wind, tide, rainfall and freshwater inflows during storm events and could be either higher or lower.

The important points to note are:

1. Production forestry gives the lowest sediment loading under a mature forest but there is a risk that relatively high sediment loads will be delivered to the estuary during harvesting.
2. It is clear from the Countryside living (Town) scenarios that the degree of disturbance will have an important influence on the amount of sediment actually delivered to the estuary.
3. The developing of Special 12 blocks and the harvesting of the Redwood forest represent vastly different areas of land-use but they are predicted to produce similar sedimentation within the estuary.

The predicted increases in sediment delivery to the estuary will result in higher suspended sediment concentrations in estuary waters. However, it not clear what effect this will have on clarity (Davies-Colley and Nagels, 1995). Additionally, there may be more frequent higher suspended sediment concentrations under proposed land-use developments. This is because rainfall events that would not, under existing land-use, have caused sediment runoff may do so when the land is cleared for development. With the predicted increase in sedimentation within the estuary there is likely to be an increase in localised resuspension of sediment (due to the greater source of sediment). All these phenomena along with the predicted increase in sedimentation have the potential to impact on the estuarine biology of the Mahurangi Estuary.

8.2 Ecological Consequences

Having predicted the sediment loads from the catchment and the subsequent rate and patterns of sedimentation within the estuary we now examine the effect of the deposition on the Mahurangi Estuary ecology.

The points covered in this section are based on our knowledge of the literature, our current research into the influence disturbance processes have on benthic communities, and our knowledge of the ecological communities in the Mahurangi Estuary (Figure 19; Cummings et al., 1994, 1995, 1997). We predict that the immediate or short term effect of sediment deposition on infauna will depend on the following important factors (the ordering of which is not significant):

1. The depth of the sediment deposited. The greater the depth of the sediment, the greater the effect on the infauna and the longer the duration of the impact.
2. The type of sediment deposited. Dumping terrestrial sediments onto a sand or mudflat will have a greater effect on the infauna than dumping like on like.
3. The area of sediment deposition. The greater the area the sediment is spread over, the greater the effect on the infauna. For example, if an entire bay is covered in sediment, recolonisation by adult infauna emigrating from outside the area is difficult, and recolonisation will depend on recruitment of larvae and juveniles from outside the bay. Conversely, if sediment is deposited in a small area of the bay only, there is a chance that infauna from elsewhere in the bay will move in to the disturbed area. In addition, there is more chance of the sediment deposited in a small area of the bay being 'diluted' or spread more widely over the bay via subsequent tidal currents and wind waves.

4. The water content of the deposited sediment. Low water content may make it more difficult for benthic organisms to escape.

5. The rate of sediment deposition. The longer the deposition time, the greater chance the infauna have to escape.

6. The timing of the deposition. If sediment is deposited following or during recruitment of infauna, there is likely to be mortality due to their inability to escape. This holds for larger adults as well.

7. The habitat type on which the sediment is deposited. Some habitats will be more sensitive to sediment deposition than others.

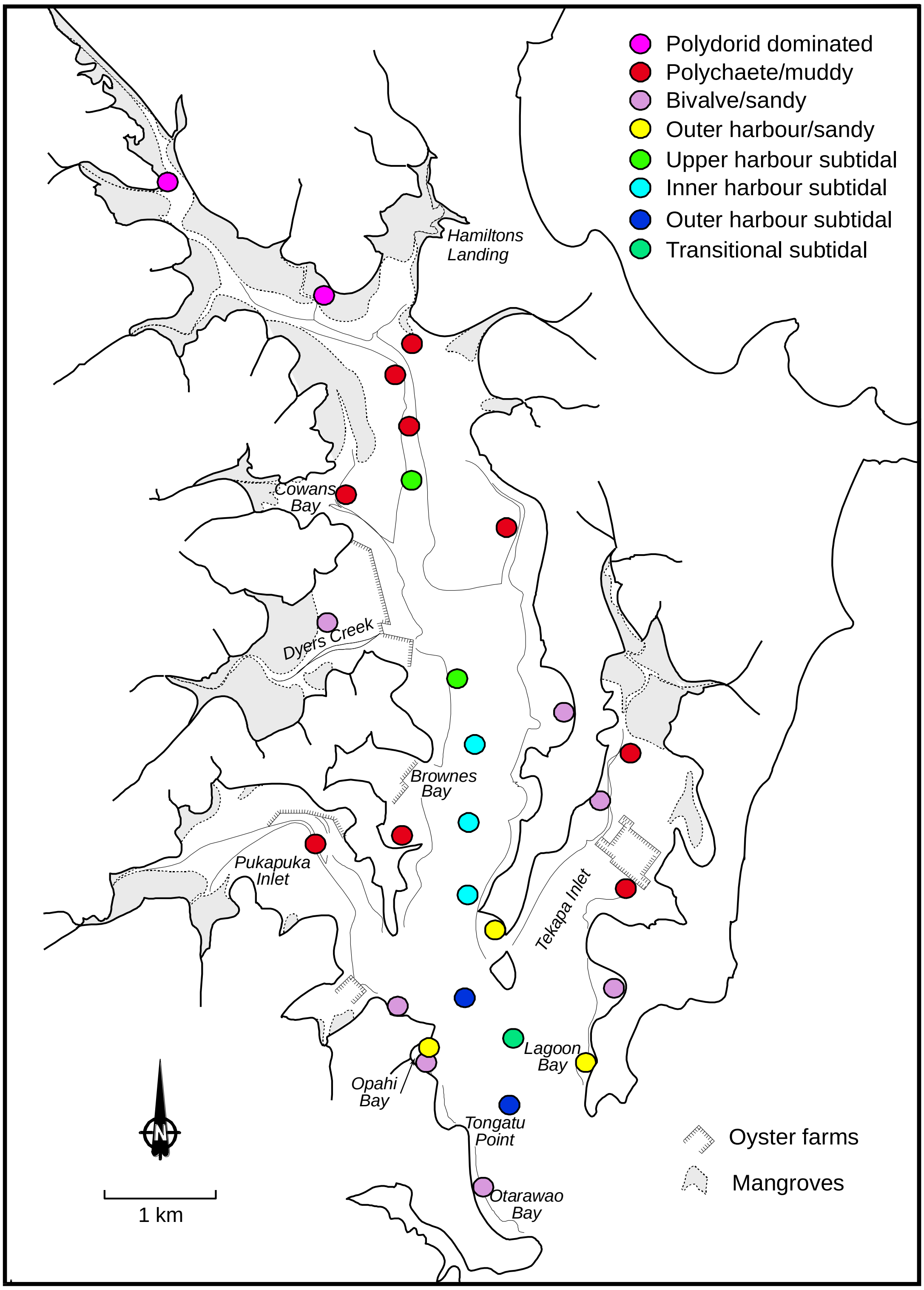
8. The type of infauna. Some types of organisms (e.g., sedentary animals, tube dwellers, deep burrowing species) are less able to move/cope with sediment deposition than others (e.g., highly mobile animals, surface dwellers).

9. Resuspension of deposited sediments. This is an important consequence of sediment deposition not considered by the modelling (note that one of the modelling assumptions was no wind immediately following the storm sediment depositions, and thus no resuspension). As well as physical processes, biological factors such as benthic diatoms and the macrofauna present will influence resuspension. Resuspension is likely to increase the area effected by the sediment deposition beyond the area of initial deposition; therefore even if the initial deposition site was in an area not considered to be sensitive, it could potentially be transported to more sensitive habitats.

10. High amounts of suspended sediment in the water column may adversely affect suspension feeders [e.g., horse mussels (*Atrina zelandica*), cockles (*Austrovenus stutchburyi*), pipis (*Paphies australis*), oysters (*Crassostrea gigas*)]. This may influence their physiological condition, and thus (for example) their reproductive success or their ability to cope with disease.

Figure 19.

Infaunal communities within the Mahurangi Estuary.



Map of Mahurangi Estuary Infaunal Communities

8.2.1 Ecological Monitoring

The infaunal communities at three sites in the upper/middle estuary areas (i.e., southern entrance to Hamilton Landing, Cowans Bay, and eastern shore just north of Grants Island) are currently monitored as part of a long term ecological monitoring programme of the estuary being conducted by NIWA for the ARC (Figure 19). One of the reasons for including these sites in the monitoring programme was their location in areas likely to be impacted by potential development. The communities at each of these sites have been described in previous reports (Cummings et al., 1995, 1997). In addition, the effect of suspended sediments on suspension feeding bivalves is currently being investigated for the ARC ('Responses of horse mussels to sediment inputs').

8.2.2 Ecological Effects of Altered Sedimentation Rates

Each of the land-use scenarios modelled results in sediment being deposited in these areas: Upper estuary, Dyers Creek, Cowans Bay, Hamilton Landing and the eastern shores of the middle estuary. The scenarios differ in the depth of the sediment deposited and the area covered by the sediment. Within the context of the Mahurangi Estuary, the 1 ha cell size used in the Estuary model is very large in terms of the size of habitats and the variation within them. For example, the intertidal area of Jamieson Bay in the lower estuary is only 1 ha in size, yet it contains several different types of habitat (Cummings et al., pers obs.). If sediment were to be deposited in this bay we would consider this a significant impact.

Of the sediment deposition figures presented in this report, those of relevance to the estuarine ecology are the maximum and median sediment depths. The Estuary Model only includes sediment loads from the Mahurangi River Catchment, but the BNZ modelling has identified other areas of the estuary where high sediment inputs occur during storm events via direct runoff from the catchment (viz., Te Kapa Inlet, Pukapuka Inlet, Dyers Creek). Thus, considerably greater amounts of sediment are likely to be deposited in Te Kapa and Pukapuka Inlets than is predicted by the estuarine modelling of the land-use scenarios. In fact, sediments at the intertidal site monitored in Te Kapa Inlet as part of the ecological monitoring programme have become considerably muddier since monitoring began in July 1994 (Cummings et al., 1997).

For Scenario 1A (Special 12 urbanisation) sediment is predicted to be deposited in the same places as for the existing land-use scenario (Figures 3 & 12), but is quite widespread within these areas (Figure 7). Predicted sedimentation rates in several adjacent 1 ha cells in these areas are high and are likely to kill juveniles.

Scenario 1B (Countryside living (town) with 4-10% land disturbance) gives the lowest increase in sedimentation rates (Table 14 & Figure 9) and will have similar effects as Special 12 in terms of ecological effects.

Scenario 1B (Countryside living (town) with 100% land disturbance) is predicted to give the highest rates of sedimentation within the estuary. High rates of sedimentation occur over the entire mid and upper estuary (Figure 10). Significant rates of sedimentation are also predicted in Te Kapa and Pukapuka Inlets, Huawai, Jamieson and Opahi Bays. Sedimentation rates are predicted to be 10 times greater than for the existing land-use. Both the depth and extent of sediment coverage in this scenario are likely to have significant effects on the estuary ecology.

Any dilution due to wind waves and tidal currents in the upper and middle estuary is likely to be limited due to the fact that deep sediment is deposited over such large areas. Almost certainly there will be mass deaths of both adult and juvenile infauna. The large area of sediment deposition will mean that recolonisation of these areas will likely depend on the supply of recruits from outside these areas (i.e., from the lower estuary or outside the estuary). This will extend the time scale of the recovery processes.

Scenario 2 (Harvesting of Redwood Forest) is predicted to produce an increase in sedimentation which will have similar ecological effects as Scenario 1A.

For Scenario 3A (Established forest) the models predict that sedimentation within the estuary will decrease in the order of two thirds (xx is this significant in terms of ecology xx).

For Scenario 3A (Harvested forest) The models predict slightly lower sedimentation rates than Countryside Living (Town) with 100% disturbance, and therefore produces similar sedimentation extent and coverage. Ecological consequences will therefore be very similar to Scenario 1B with the added complication of the influence of the 30 year forestry cycle as discussed in Section 6.4.1.

8.3 Long Term Ecological Effects

Generally, intertidal macrobenthic communities found in muddy or wave exposed very coarse sediments are less diverse than those found in sandier substrates (as illustrated by the upper vs. middle/lower Mahurangi estuary communities, Cummings et al., 1994). High sedimentation rates will cause sediments to become muddier, thus decreasing habitat diversity within the estuary (e.g., by wiping out eelgrass such as that found in Jamieson Bay) and also infaunal diversity. This may in turn affect the more transient populations such as fish and birds that use these different habitats as nursery areas and for feeding.

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Appendix 1

Table A1

The predicted rate of sediment generation per sub-catchment for forested, harvested and existing land-uses (ranked by harvested sediment rate).

Catchment Number	Existing land-use Median t/km^2/annum	Forested Median t/km^2/annum	Harvested Median t/km^2/annum
25	1680	690	10600
4	1210	560	8550
26	960	470	7850
24	1270	490	7540
3	1070	450	7200
11	1020	460	7070
12	850	410	6260
2	660	380	6140
10	900	400	6080
13	680	390	5660
9	770	370	5660
23	510	340	5580
32	450	320	4990
7	730	330	4950
33	580	370	4640
5	690	300	4580
43	400	300	4490
35	700	290	4390
6	600	290	4380
42	290	290	4260
41	290	290	4260
27	520	290	4260
8	500	290	4260
45	710	280	4240
44	450	280	4110
34	600	270	4060
39	410	270	3990
22	430	260	3980
17	540	240	3870
21	430	250	3730
14	500	250	3440
38	390	220	3260
16	510	210	3170

37	430	200	3010
19	460	190	3000
20	440	190	2920
18	400	190	2910
15	410	160	2290
30	340	140	2090
40	250	140	2080
31	390	140	2000
29	340	130	1980
28	310	130	1880
36	100	50	710