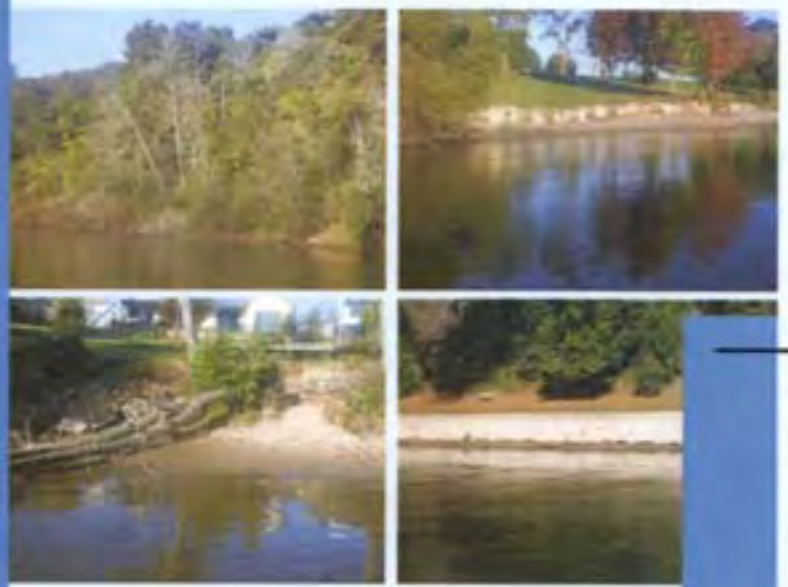
Middle Waikato Bed Degradation Investigation Stages III & IV.

Contract number: AM2004/5-30



Proposed Middle Waikato River Bed Degradation Management Strategy - Appendices

May 2006

Environment Waikato
REGIONAL COUNCIL

Beca

Appendices

▪ Appendix A

Photos


km 95.5L


km 95.7a


km 95.7b


km 96.1R


km 97.3R


km 100.6L


km 101.0L


km 102.5


km 102.5aL


km 102.5bR


km 102.5cR


km 103.05L


km 104.6L


km 104.8L


km 105.0L


km 106.3L


km 106.3aL


km 106.3bL


km 106.8L


km 107.25L


km 107.5aL


km 107.5bL


km 107.9 - 108.0L


km 108.1L


km 108.2L


km 108.5L


km 108.7a


km 108.7bL


km 108.7cL


km 108.7L


km 108.8aL


km 108.8bL


km 108.9R


km 109.1L


km 109.1aL


km 109.1bR

km 109.1cR

km 109.1dR

km 109.2aL

km 109.2bL

km 109.2cL

km 109.2dL

km 109.6a

km 109.6bL

109.6cL

km 110.2L

km 110.2aR

km 110.2bR

km 110.3R

km 110.4R

km 110.4aR

km 110.4bR

km 110.5aR

km 110.5bR


km 110.8R


km 110.8aR


km 110.0L


km 111.1R


km 111.1aL


km 111.1bR


km 111.1cR


km 111.2R


km 111.2aR


km 111.3R


km 111.3aR


km 112.05bL


km 111.9L


km 111.9aL


km 112.05aL


km 112.05cL


km 112.1L


km 112.3aL


km 112.3bL


km 112.5L


km 112.7aR


km 112.7bR


km 112.7cR


km 112.8aL


km 112.8bL


km 112.8cL


km 112.8aR


km 112.8bR


km 112.9aL


km 112.9bL


km 112.9cL


km 112.9dL


km 112.9eL


km 112.9fL


km 112.9gL


km 113.2R


km 113.3R


113.4aR


113.4bR


km 113.4cR


km 113.4dL


km 113.5a


km 113.5bL


km 113.5cR


km 113.6L


km 113.6R


km 113.7R


km 113.9aR


km 113.9bL


km 113.9cL


km 113.9dR


km 114.0L


km 114.4R


km 114.5R


km 114.5aR


km 114.5bR


km 114.85L


km 115.4a


km 115.4aR


km 115.4bL


km 115.9L


km 115.9aL


km 116.2L


km 116.3a


km 116.3bL


km 116.6R


km 116.7L


km 116.8L


km 116.9R


km 117.3aR


km 117.3bR


km 117.4L


km 117.4aL


km 117.7L


km 117.9L


km 118.5L


km 118.8R


km 119.3L


km 119.35aL


km 119.35bR


km 119.4L


km 119.4aL


km 119.4R


km 119.5L


km 119.5R


km 121.3R


km 122.75R


km 126.0L


km 126.2R


km 126.4

km 126.4aL

km 126.4bR

km 126.4cR

km 126.7L

km 126.8L

km 126.9L

km 127.1L

km 129.2L

km 132.5L

km 133.6L

km 134.05L

km 135.65R

km 137.0L

km 139.9L

km 140.2L


km 140.5a


km 140.5bL


km 142.0

km 142.0L



km 142.25aL


km 142.25bL


km 142.8a


km 142.8b


km 142.8aR


km 142.8bL


km 143.25L

km 143.7R



km 144.75L


km 145.0aL


km 145.0bL


km 145.65L


km 146.1aL


km 146.1bL


km 146.4R


km 146.6R


km 146.8aR


km 146.8bL


km 147.0aR


km 147.0bR


km 147.0cR


km 147.4aL


km 147.4bR


km 147.6R


km 148.8cR


km 148.8dR

Appendix B

Infrastructure (by River distance)

Distance from river mouth, km	Projected 100-years bed degradation, m	Beca waypoint/ cross-section No.	Photos	Bank	Feature	Land/ Property/ Infrastructure	Subjective risk assessment	Comments and Options to address bed degradation
95.3	*3.7*		No		Waipa confluence			
95.5	*3.7*	WP302	Yes	L	50-m length of riprap revetment	Property	Slight	
95.7	*3.7*		Yes		NIMT Railway Bridge 267 and SH1 Road Bridge, Ngaruawahia	Infrastructure	Severe	Two piers in river, two piers close to top of bank. Review record drawings for impact of any bed degradation.
96.1	*3.6*	WP308	J-17	R	200 dia outfall with rubble protection	Infrastructure	Slight	
96.5	*3.6*	WP309	No	L	Slips down steep bank; rock protection at base	Property		
101.0	*3.4*	CS81	Yes	L	Meatworks water intake	Infrastructure	Moderate	Review record drawings for impact of lower bed and water levels
102.5	*3.4*	CS82	Yes		Horotiu Road Bridge	Infrastructure	Slight	Arch springs from foundations set back from river edge
104.6	*3.3*	WP369	Yes	L	Overflow from dairy factory?	Infrastructure	Slight	Structure is set back from river. Riprap at river bank may need to be extended.
104.8	*3.3*	WP370	Yes	L	Overflow from dairy factory tanks?	Infrastructure	Moderate	Improved scour protection may be required
105.0	*3.3*	WP371	Yes	L	Dairy factory water intake	Infrastructure	Slight	Review record drawings for impact of lower bed and water levels
106.3	**3.23**	CS50	Yes	L	Pukete Boat Ramp	Infrastructure	Moderate	Water depth already too shallow at landing. Ramp will need extending or lowering.
106.3	3.2	CS50	Yes	L	300 dia stormwater outlet	Infrastructure	Moderate	Outlet is well above water level, and erosion protection is being undermined.
106.8	3.2	WP127	Yes	L	Waste Water Outlet	Infrastructure	Moderate	Hidden within willows, possibly piled. Review record drawings
107.9-108.0	3.2	WP134	Yes	L	Timber retaining wall for walkway	Infrastructure	Slight	
108.2	3.2	WP137	Yes	L	750 dia outfall	Infrastructure	Moderate	Gabions may need extending
108.7	3.1	CS54	Yes		Pukete Sewer Bridge	Infrastructure	Severe	Piers in river. Review record drawings for impact of lower bed and water levels
108.7	3.1	CS54	Yes	L	25-m long gabion revetment and timber steps	Infrastructure	Moderate	Gabions (which appear to be to protect walkway, rather than to protect bridge pier) may need extending. Timber steps will need extending.
108.8	3.1	WP143	Yes	L	15-m long gabion revetment below walkway	Infrastructure	Moderate	Toe of gabions is protected by rubble. Will need extended toe protection.
108.9	3.1	WP144	Yes	R	450 dia outlet structure	Infrastructure	Moderate	Gabion mattress scour protection needs extending.
109.1	3.1	WP145	Yes	L	600 dia outlet structure	Infrastructure	Slight	Rubble provides adequate scour protection
109.2	3.1	CS55	Yes	L	Ad-hoc 25-m long retaining structure, with localised gabions at toe.	Property	Moderate	Gabions already failing due to shallow foundation depth. Uneconomic to provide engineered solution.
109.6	3.1	CS56	Yes		Pukete Traffic Bridge (Wairere Drive)	Infrastructure	Severe	One pier in river, one at water's edge; piles exposed 0.4m below pile cap. Review record drawings for impact of lower bed and water levels
109.6	3.1	CS56	Yes	L	1 m dia outlet structure	Infrastructure	Slight	Outlet is largely submerged, so unlikely to be affected by bed degradation in the medium term.
110.2	3.1	WP160	Yes	L	1 m dia outlet structure	Infrastructure	Slight	Outlet is has sheet-piled toe protection.
110.3	3.1	WP161	Yes	R	40-m long timber retaining wall	Property	Moderate	Recently installed wall in good condition. Lower wall may be needed as bed degrades.
110.4	3.1	WP162	Yes	R	Timber retaining wall and landing	Property	Moderate	Landing has failed. Timber retaining wall scheduled to be replaced by sheet pile wall in near future.
110.8	3.0	WP169	Yes	R	Private landing	Property	Moderate	Steps failing, would need extending.
111.0	3.0	WP170	Yes	L	50-m long gabion wall below covered walkway at golf course	Property	Moderate	Gabion mattress toe protection will need extending.
111.1	3.0	WP171	Yes	L	10-m long gabion wall below walkway	Property	Slight	May need gabion mattress toe protection
111.1	3.0	WP171	Yes	R	30-m long riprap revetment, with concrete steps to above water level	Property	Moderate	Riprap will need top-up, and steps extending as river degrades.
111.2	3.0	WP172	Yes	R	1.5 m dia outfall with timber-piled headwall	Infrastructure	Moderate	Rock toe protection needs upgrading
111.3	3.0	WP173	Yes	R	Swarbricks Landing	Property	Moderate	Timber steps will need extending
111.9	3.0	WP174	Yes	L	Footbridge across tributary stream	Infrastructure	Slight	No issues
112.1	3.0	CS59	Yes	L	Vardon Road stormwater outlet	Infrastructure	Slight	Outlet below water level at piled structure. Review record drawings, but probably no action required.
112.5	3.0	CS60	Yes	L	Wastewater pump station and 300 dia outfall (Ann St)	Infrastructure	Slight	Located on inside of bend
112.7	3.0	WP184	Yes	R	50-m length timber retaining walls, including boat ramp	Property	Slight	Probably no action required
112.8	3.0	WP185	Yes	L	150-m long revetment below walkway, using rock and rubble	Property	Moderate	Riprap will need top-up
112.9	3.0	WP186	Yes	L	75-m long timber retaining wall and walkway	Property	Slight	Probably no action required
113.2	2.9	WP187	Yes	R	Failed timber jetty	Property	Moderate	Needs reconstruction

Distance from river mouth, km	Projected 100-years bed degradation, m	Beca waypoint/ cross-section No.	Photos	Bank	Feature	Land/ Property/ Infrastructure	Subjective risk assessment	Comments and Options to address bed degradation
113.3	2.9	WP188	Yes	R	75-m long timber retaining wall, set back from water's edge	Property	Slight	Probably no action required
113.5	2.9	CS61	Yes		Fairfield Bridge	Infrastructure	Severe	Two piers in river. Review record drawings for impact of bed degradation
113.6	2.9	WP195	Yes	L	Waitawhiriwhiri Stream outfall under Victoria Street	Infrastructure	Moderate	Review record drawings for impact of bed degradation. Will need more riprap for scour protection.
113.7	2.9	WP196	Yes	L	1200 dia outlet structure	Infrastructure	Slight	Possible need for scour protection in future
113.9	2.9	CS62	Yes	R	20-m long revetment using old tyres	Property	Slight	
113.9	2.9	CS62	Yes	L	ad-hoc rubble protection below walkway	Property	Moderate	
114.0	2.9	WP203	Yes	L	Rubble revetment and timber landing	Property	Moderate	Revetment will need top-up. Timber steps will need extending.
114.3	2.9	WP204	No	R	Timber steps	Property	Slight	Will need extending
114.4	2.9	CS63	No		Whitiora Bridge (Boundary Road)	Infrastructure	Severe	Two piers in river, with pile caps just above water level. Review record drawings for impact of bed degradation. Slope protection will be required to protect right bank pier on terrace.
114.5	2.9	WP209	Yes	R	Timber landing	Property	Moderate	In dilapidated state
114.7	2.9	WP210	No	L	Timber steps	Property	Slight	Will need extending
115.4	2.9	CS64	Yes		ECMT Railway Bridge 6 and Claudelands Bridge	Infrastructure	Severe	Left bank slip immediately downstream of rail bridge has been retained; bridge abutment assumed to be safe on bored piles. Two piers in river, rail bridge pile caps about 0.5 m above water level. Review record drawings for impact of bed degradation
115.55	2.9	WP219	No	R	20-m long timber wall below private garden	Property	Slight	
115.65	2.8	WP220	No	R	20-m long rock revetment below private garden	Property	Slight	
115.90	2.8	WP222	Yes	L	450 dia outfall through sprayed concrete revetment	Infrastructure	Moderate	Toe of revetment is already being undermined. Alternative detail required (flexible, or with deeper cutoff).
115.90	2.8	WP222	No	R	200-m long concrete block revetment	Property	Slight	
116.20	2.8	WP224	Yes	L	Square outlet through sprayed concrete revetment	Infrastructure	Moderate	Additional rock protection will be required.
116.3	**2.82**	CS65	Yes		Victoria Bridge (Bridge Street)	Infrastructure	Moderate	Arch bridge. Left abutment is protected by a concrete block wall which is likely to need new toe protection. Right abutment looks OK at present. Review record drawings for impact of bed degradation
116.6 - 117.0	2.8	WP229 - WP234	Yes	R	400-m long rubble and riprap revetment (below walkway at New Memorial Park).	Property	Moderate	On outside of bend; additional rock protection will be required.
116.7	2.8	WP230	Yes	L	Boat ramp with masonry walls	Property	Moderate	Boat ramp is already too shallow: will need lowering and/or extension.
116.8	2.8	WP232	Yes	L	300 dia outlet above water level, scouring	Infrastructure	Moderate	Erosion protection required.
116.9	2.8	WP233	Yes	R	900 dia outlet	Infrastructure	Slight	Possible need for scour protection in future
117.2	2.7	WP236	No	R	Timber steps	Property	Slight	Will need extending
117.4	2.7	WP239 CS66	Yes	L	50-m length of riprap revetment at Old Pumping Station	Property	Slight	Possible need for additional riprap in future
117.7	2.7	CS67	Yes	L	Hospital Drain outfall	Infrastructure	Moderate	Outfall structure is "hanging" with sheet pile downstream protection. Review record drawings for impact of bed degradation
118.5	2.6	CS68	Yes		Cobham Bridge	Infrastructure	Severe	Two piers in river, with pile caps just above water level. Review record drawings for impact of bed degradation
118.7	2.6	WP258	No	R	300 dia outfall	Infrastructure	Slight	No issues evident
118.8	2.5	WP259	Yes	R	750 dia outfall with gabions	Infrastructure	Moderate	Gabions will need extending
119.0	2.5	WP260	No	L	Mangakotukutuku Stream confluence, crossed by twin 450 dia water mains on pipe bridge	Infrastructure	Moderate	Monitor pipe bridge piers for effects of downcutting
119.3	2.5	WP263	Yes	L	Water Treatment Plant intake	Infrastructure	Slight	Review record drawings for impact of lower bed and water levels
119.4	2.5	WP264	Yes		20-m lengths of riprap on LB and sheet piling on RB at a buried water pipe crossing	Infrastructure	Severe	Review record drawings for impact of lower bed level
119.5	2.5	WP265	Yes	R	50-m long gabion wall and timber landing	Property	Moderate	Timber steps will need extending. Gabions are set back from river edge, so unlikely to be affected by bed degradation
121.3	2.3	WP272	Yes	R	900 dia outfall through gabion headwall	Infrastructure	Moderate	Outfall is only 3-4 years old, but gabions are already being undercut. Gabion mattress toe protection is an option.
126.0	**1.73**	CS73						
126.4	*1.7*	CS74	Yes		Narrows Bridge	Infrastructure	Moderate to high	Arch bridge springs from vertical weak rock faces. Slopes fronting abutments on both banks will require protection.
126.7	*1.7*	CS75	Yes	L	20-m long timber wall and landing below private garden	Property	Slight	Steps will need to be extended

Distance from river mouth, km	Projected 100-years bed degradation, m	Beca waypoint/ cross-section No.	Photos	Bank	Feature	Land/ Property/ Infrastructure	Subjective risk assessment	Comments and Options to address bed degradation
126.8	*1.7*		Yes	L	Floating pontoon with access walkway	Property	Slight	Pontoon cannot go lower without excavating bed near bank.
129.2	*1.5*	CS39	Yes	L	Water intake	Infrastructure	Slight	Intake on floating pontoon
137.0	*0.9*	WP88	No	L	Water intake	Infrastructure		
138.1	*0.8*		No	L	Water intake	Infrastructure		
140.5	*0.7*	WP67	Yes	(L)	Pipe bridge	Infrastructure	Slight	Supports clear of river, but left bank pipe parallel to top of slope
142.0	*0.6*	CS18	Yes		Victoria Bridge, Cambridge	Infrastructure	Slight	Arch bridge, abutments clear of river
142.8	*0.5*	CS16	Yes		Fergusson Bridge, Cambridge	Infrastructure	Moderate	Piers founded in river banks of alluvial sandy Hinewera Formation. Rock fall in zone fronting piles triggered by deepening of bed may expose piles and require remediation
149.6	***0.00***		No		Karapiro Dam			

NOTES

1. Projected bed degradation figures between Narrows and Pukete boat ramp are interpolated from figures in Smart, August 2003. Projections beyond this reach are less reliable, and shown in italics.
   The projected bed degradation is at a steady rate (I.e. projected bed degradation after 50 years is half that projected for 100 years).

2. Water levels are projected to decrease at a reducing rate.
   Projected water level lowering at Victoria Bridge Hamilton during low flows (110 m^3/s) is 0.7 m after 50 years, and 1.1 m after 100 years.
   There are no projections for elsewhere in the reach.

- Appendix C

Bank Condition (by River distance)

Mid-Waikato Bed Degradation Investigation
Bank Condition

Distance from river mouth, km	Beca waypoint/ cross-section No.	Photo Filename	Bank	Feature	Bank Condition Comments
95.50	WP302	km 95.5L.jpg	L	Carpark and clubrooms	Riprap, grassed
95.50	WP302		R		Riprap protection extends about 1 m up from base of slope. Trees and scrub for about 100 m, then grassed.
95.70	CS77		L	Ngaruawahia rail and road bridges	Steep to sub-vertical bank, actively eroding; trees falling into river. Process likely to be ongoing but not direct result of bed degradation.
95.70	CS77	km 95.7b.jpg	R	Ngaruawahia rail and road bridges	Hummocky planted terrace approximately at river level, may require protection as bed degrades. Bank near vertical in places; indications of past slope movement.
95.95	WP307		L	Marae	Trees curved indicating soil creep; falling into river. Drainage outfalls causing significant erosion of beach. Eroded face will require protection with bed degradation.
95.95	WP307		R		Couple of metres high, small beach (sandy).
96.10	WP308		L	Outlet	~1 - 1.5 m high, grassed bank, increasing to ~3m high. Fronted by willow trees which are holding sediment and so protecting slope in behind. Some near vertical banks, vegetation slipping. Irregular concrete slab protection to stormwater discharge.
96.10	WP308	km 96.1R.jpg	R	Outlet	Becoming steep, about 4m high. Densely vegetated. Discharge through riprap.
96.50	WP309		L		Arcuate feature in bank.
96.80	CS78		L		Bank ~2 - 3 m high, fronted by willows. River level terrace. Local loss of grass cover, exacerbated by stock tracks to river.
96.80	CS78		R		~4 - 5 m high sub-vertical bank fronted by ~2 m wide flattish terrace. Generally trees hold soil around roots, locally tree and soil fall has occurred.
96.80	CS78		R		Loss of grass cover.
97.30	WP314		L		Shallow erosion/ creep in soil.
97.30	WP314	km 97.3R.jpg	R		
97.55	WP315		L		Sandy beach developed, grades to mud downstream.
97.75	WP316		L		Slope rises, tree form suggestive of creep.
97.75	WP316		R		Creep/ slide movement in grassed area; extends downstream. Frontal terrace increasing in width to 10m + (?) with 1 - 2 m wide short slope and flat ground behind.
98.00			L/R		Low slopes with trees bending toward river; small sandy beaches.
98.70	WP317		R	Private property	Beach with willow trees; sediment caught in roots is retained. Where trees absent, beach eroded. Creeping slope above with large home beyond.
98.90	CS79		L		Bank split by intermediate bench. Erosion occurring around trees (roots holding soil), likely to be exacerbated by bed degradation.
98.90	CS79		R		Exposed grassed bank.
99.15	WP325		L	Private property	Slope movement and gully erosion. Slopes fronting home subject to ongoing movement.
99.15	WP325		R		Root 'stacks' remain elevated while surrounding ground lowered by erosion. Active creep/slide/erosion occurring in grassed slope behind. South of here slope retaining works present, creep occurring below.
100.35	WP326		L		Active slope movement: fallen trees, soil creep/ fall.
100.35	WP326		R		Loss of vegetation exposes silty sediment at top of short bank.
100.40	CS80		L		Small scarps and vegetation loss.
100.60	WP331	km 100.6L.jpg	L	Property fences, at bank crest. Homes behind.	Slipping and slumping, trees moving, scarps behind.
100.80	WP332		R	Homes very close to crest.	
101.00	CS81	km101.0L.jpg	L	Horotiu meatworks intake.	Minor rock riprap protection - will require reconstruction.
101.60	WP335		L		Very hummocky, marginal slope. Loss of vegetation to expose sub-vertical soil faces in tall slopes. Minor creep in upper slope.
102.50	CS82	km 102.5aL.jpg	L	Horotiu Road Bridge	Geotextile used to protect present slope; must be maintained to avoid increasing problems as bed degrades. Very little space available for further retreat without significant consequences.
102.50	CS82	km102.5bR.jpg	R	Horotiu Road Bridge	Minor slabbing and formation of platform in riverbed. Sandy beach developed on silt downstream.
102.50	WP348	km 102.5cR.jpg	R		Significant retreat between willow trees (roots retaining soil).
102.55			L		Bank becoming higher, with some curved trees indicating soil creep.
102.55			R		Tree roots, but no soil, 'blanket of grass' remains with soil washed out from underneath.
103.50	WP349	km 103.05L.jpg	L		Rock undermined. Past silt beach level is being undercut.
103.65	WP357		R		Large homes on the terraces above slope ~20 - 30 degrees. Beach fronting the slope provides protection against the effects of bed degradation.
103.70	CS83		L/R		Partially undercut banks.
104.15	CS85		L		Slope actively creeping; soil lost from beneath tree roots.
104.15	CS85		R		Steep marginal bank.
104.55	WP368		L	Dairy factory overflow (?)	Rock riprap and geofabric protection; will require extension/ redesign with bed degradation.
104.55	WP368		R		Creep mid-slope.
104.65	WP369		R		Cliff: scarp at top of slope; trees with curved form at base.
104.80	WP370		L	Dairy factory tanks on terrace, overflow (?) below tanks.	Concrete slabs and minor riprap protection.
105.00	WP371		L	Dairy factory intake, chamber in riverbed (sheetpiled).	Water discharge adjacent to downstream side of bank. Erosion will be significantly exacerbated by bed degradation. Depth of sheetpiles not known.
105.30	WP372		L	Houses close to top of bank.	Bank actively failing.
105.50	CS86		L	Golf course.	Steep marginal banks with actively eroding toe platform.
105.50	CS86		R	Buildings close to edge of bank.	Steep, vegetated. Large trees cut down but stumps remain. Fallen trees small.

Mid-Waikato Bed Degradation Investigation
Bank Condition

Distance from river mouth, km	Beca waypoint/ cross-section No.	Photo Filename	Bank	Feature	Bank Condition Comments
106.30	CS50	km 106.3L.jpg	L	Pukete boat ramp.	Vegetation retaining short banks (up to 4m high), some trees bent to horizontal. Wooden retaining wall at boatramp. Rocks and material entrained from beneath planks, cement already exposed ~0.5 m above beach level. Erosion beyond jetty, some willow protection at toe, very hummocky slope above. Slumping timber and tyre wall just downstream. Bank will be undermined with degradation. Small beach a short distance further south; trees bent over at bank edge.
106.30	CS50		R		Cut platforms and reasonably flat-lying area, unlikely to be significantly affected by bed degradation. Moderately steep terraced slope behind, trees holding it; no major instability observed.
106.60	WP126		L		Hummocky, vegetated, moderately steep slope.
106.60	WP126		R		Shallow fall/ slabbing failures (1-3m high cut).
106.80	WP127	km106.8L.jpg	L	Spillway from WWTP.	Protected by willow trees.
106.80	WP127		R	Houses.	Riprap bank protection. Evidence of ongoing active erosion. Houses set back from river.
107.25	WP128	km 107.25L.jpg	L	Wide road reserve.	Soil failure; shallow beach with high terrace behind. Benched slope.
107.25	WP128		R	Houses close to river.	Active erosion; tree roots exposed in river. Fenceline midway up cliff. Small beach developed at base of bank.
107.50	CS51	km 107.5bL.jpg, km 107.5aL.jpg	L		Slightly further south the shallow beach platform is lost, slope steepens, becomes sub-vertical (~5 m high), bush clad. Further south, few trees bent over; much regeneration of vegetation; pumiceous white soil in bank. Slightly further south again, active slope movement, trees bent over.
107.50	CS51		R		Gentle to moderately sloping beach with willows fronting 2 - 3 m slope. Upstream into curve of river, dead trees and fallen material, followed by recently slabbed faces with low scrub.
107.90	WP134		L		Timber pole retaining wall, beach developed in front, houses in behind on terrace. Wall undermined in several places.
107.90	WP134	km 107.9-108.0L.jpg	R		Slope steepens; creep. Beach fronting terraces.
108.10	CS53	km 108.1L.jpg	L		Timber retaining wall, steep grassed slopes fronting large homes. Hummocky to flat bench ~1.5 - 3 m wide. Willows. Slope cleared and grassed in front of houses, active creep.
108.10	CS53		R		Very hummocky slope.
108.20	WP137	km 108.2L.jpg	L	Piped outfall, private properties.	Degradation likely to activate failures further upslope. Private properties close to top of bank. Bench will be too narrow to maintain stability if river degrades. Short steep slope in front of reserve.
108.20	WP137		R		Unstable; degradation likely to trigger deeper-seated instability.
108.45			L		Retaining wall curves, beach in front, trees bent to horizontal.
108.45			R		Moderately steep actively moving slope; large scale movement expected with degradation.
108.50	WP138	km 108.5L.jpg	L		Shallow soil failure; small gravely beach.
108.50	WP138		R	Private property	Houses at top of steep arcuate scarp. Slope tree covered; trees will need to be maintained to maintain stability.
108.70	CS54	km 108.7L.jpg	L	Pukete Sewer Bridge	Pumiceous silt/ sand bluff. Gabions fronting abutment appear already above surface of beach. Gabion baskets also around pier of bridge. Jetty access, abutment and in-river piers will be vulnerable as a result of bed degradation.
108.70	CS54		R	Pukete Sewer Bridge	Housing close to edge of bank. Gentle slope with small bench for walking track. Shallow soil flow/creep occurring. Bank protection needed. Irregular timber retaining wall and blocks distributed to protect right bridge abutment; appears sufficient land to limit effects of bed degradation. Designed retaining structure recommended.
108.80	WP143	km 108.8aL.jpg km108.8bL.jpg	L		Rock riprap protection continues south, then more gabion baskets with concrete riprap in front. Willows becoming dry. Protection likely to be undermined if trees lost.
108.90	WP144		L	Private property	Terraced (shallow), few bent trees and minor soil erosion. Beach in front. Actively eroding riverbank, especially where trees lost. Wide berm (~4m) in front of properties, but rapidly diminishes.
108.90	WP144	km 108.9R.jpg	R	Stormwater drain	Drain discharging onto mattress and rock, scoured and undermined by 0.2 - 0.3 m.
109.10	WP145	km 109.1aL.jpg	L	Outfall, boardwalk	Concrete block protection for outfall. Trees lost, and sandy bank exposed. Already 'high and dry'.
109.10	WP145	km 109.1bR.jpg, km 109.1cR.jpg, km 109.1dR.jpg	R		Fallen trees. Recent cut prepared for walkway; bench too narrow to maintain stability if lower slope lengthened due to degradation.
109.20	CS55	km 109.2dL.jpg	L		Broken retaining wall with gabion baskets, bent trees, active movement. To South, short bank gently sloping with terrace behind; soil creep in terrace slope.
109.20	CS55	km 109.2cR.jpg	R	Walkway, private properties.	Steep, bush covered. Walkway bench being cut resulting in loss of bush. Platform (~4m wide) developed beyond toe of slope providing protection to bank and homes. Small timber retaining structure below private property, insufficient in the event of degradation, but house itself is retained.
109.60	CS56		L	Pukete Traffic Bridge	Bridge piles exposed below pile cap, 7 visible. Will require support. Piled outfall (sheetpiles) upstream. Bare soil on terrace - creep? Slope cleared of vegetation for view?
109.60	CS56	km 109.6bL.jpg	R	Pukete Traffic Bridge	Bridge piles exposed (2), encased by pile cap. Sandy bank about 50 degrees down to beach. Bush should be maintained for future protection. Slope south of bridge at shallower angle; houses close to edge of actively moving bank. Large flat area adjacent to river associated with stream.
109.75	WP159		L	Private property	Flat/ gentle sloping platform below slope and houses.
109.75	WP159		R	Private property	Homes very close to top of bank. Slope will need to be maintained (by planting?). Wide road reserve upstream.
110.20	WP160	km 110.2aR.jpg, km 110.2bR.jpg	R	Private property, jetty.	Retaining wall may be undermined by bed degradation.
110.30	WP161	km 110.3R.jpg	R		Timber retaining wall, 2 tiers - lower tier likely to be undermined as a result of bed degradation.

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Distance from river mouth, km	Beca waypoint/ cross-section No.	Photo Filename	Bank	Feature	Bank Condition Comments
110.40	WP162	km 110.4aR.jpg, km 110.4bR.jpg	R	Retaining wall and jetty.	Adhoc retaining structures undermined by about 0.5 m at present. To be sheetpiled? Soils appear fairly competent in bank toe. Gabions in lower slope. Just upstream banks steep, vegetated, fallen rocks at toe.
110.50	CS57		L	St Andrews Golf Course	Hummocky; pine trees; bank ~4m high. Soil exposed in banks. Willows provide protection.
110.50	CS57	km 110.5aR.jpg	R		
110.50	CS57	km 110.5bR.jpg	R-L		Steep slope, active movement, trees falling downslope, houses immediately behind trees. Fallen rock blocks at toe. To south, retaining wall at top of slope with houses behind.
110.80	WP169	km 110.8R.jpg	R		Steep slopes with active movement, trees bent. Adhoc bank protection.
111.00	WP170		L		Retaining wall in front of golf course. Rock riprap and gabions.
111.00	WP170		R		Steep slope, houses at top, grading into gentler slopes.
111.10	WP171		L		Riprap toe of slope; active movement.
111.10	WP171	km 111.1R.jpg	R	Outflow	Small rock riprap and some bouldery riprap toward toe. Material/fabric exposed below trees where rock cover lost.
111.20	WP172		L		(Natural) rock platform. Beach formed in gentle eroding slopes.
111.20	WP172	km 111.2aR.jpg	R	Outflow	Riprap; steps extend down to 1-2 m above river level.
111.30	WP173		L	Jetty	Low gently sloping banks.
111.30	WP173	km 111.3aR.jpg	R	Walkway	Local riprap and concrete block protection of lower slope.
111.90	WP174		L	Outfall with piled walkway about 0.8 m up cliff.	Steep high banks. Tree form indicates creep; spalling and slabbing failures.
111.90	WP174	km 111.9aL.jpg	R-L		
112.05	CS59	km 112.05aL.jpg, km 112.05bL.jpg	L		Hummocky slope failing next to sheet-piled outfall (3 sheetpiles at 2 m spacing and timber). Loss of material below; walkway above; houses beyond. Bare of vegetation.
112.05	CS59	km 112.05cL.jpg	L	Stormwater outfall.	Steep slopes. Active slumping. Trees curved; vegetation obscures slope.
112.05	CS59		R		Bushclad; rockfall in places. Low slope overall, gentle parkland in behind.
112.30	WP181	km 112.3aL.jpg, km 112.3bL.jpg	L		Soils pumiceous, current bedded. Trees falling down gentle slopes.
112.30	WP181		R		Vertical cliff with arcuate scarps.
112.50	CS60	km 112.5L.jpg	L		Flat terraced reserve with active eroding face.
112.50	CS60		R	Private property	Debris at toe; steep subvertical slopes, curved tree form.
112.70	WP184-185		L		Riprap retaining wall; much rock lost. Supplemented with concrete paving slabs, sandbags, concrete blocks and timber.
112.70	WP184-185		R		Timber retaining structures.
112.80	WP185	km 112.8aR.jpg, km 112.8bR.jpg	R		Retaining structures.
112.90	WP186	km 112.9cL.jpg - km 112.9gL.jpg	L	Private property	Substantial timber retaining wall (depth of piles unknown, degradation may affect it). Much loose rubble debris at bank face, houses behind. Becomes willow protected.
112.90	WP186		R		Presently protected by willow trees.
113.20	WP187	km 113.2R.jpg	R		Adhoc attempts to maintain bank; loss of jetty.
113.30	WP188	km 113.3R.jpg	R		Low timber retaining wall, fronted by beach.
113.40	WP189	km 113.4dL.jpg	L	Bridge abutment and pier.	
113.40	WP189	km 113.4aR.jpg - km 113.4dR.jpg	R		Paved slope face?
113.50	CS61	km 113.5bL.jpg	L	Fairfield Bridge.	Adhoc protection downstream of abutment. Needs attention to maintain.
113.50	CS61	km 113.5cR.jpg	R	Fairfield Bridge, private properties.	Shallow beach fronting abutment. Upstream of bridge, slope becomes hummocky and houses close to top of slope.
113.60	WP195	km 113.6L.jpg	L	Outfall and walkway bridge.	Flattish terrace behind bank; failure of front of bank. Riprap protection; bush lost and cut away.
113.60	WP195	km 113.6R.jpg	R	Jetty	Significant 5 tiered timber retaining wall. May become undermined with bed degradation. Active movement/ slide/ flow/ creep upstream.
113.70	WP196	km 113.7R.jpg	R		Concentrated outfall - beach is paved with fine riprap and scattered boulders.
113.90	CS62	km 113.9cL.jpg	L		Erratic use of riprap on bank; slope movement evident; curved trees; debris. Slope benched for walking track. Tree roots exposed. Likely to fail in response to bed degradation.
113.90	CS62	km 113.9dR.jpg	R	Private property	Tyre wall; riprap; concrete slabs (home owner efforts to preserve property).
114.00	WP203		R		Scrub; tree roots exposed; active erosion. Needs maintenance.
114.30			L		Steep.
114.30			R		Moderate slope; small bench for path.
114.40	CS63		L	Boundary Road Bridge	Piles and pier okay. Bed degradation may expose piles. Moderately steep bank, soil failure at toe.
114.40	CS63	km 114.4R.jpg	R	Boundary Road Bridge	Adhoc protection of pier - will require support. Moderately steep with frontal bench and soil movement at toe.
114.50	WP209	km 114.5aR.jpg, km 114.5bR.jpg	R	Private properties.	Retained private properties at top of slope. Steep slope; arcuate feature; slipping trees; loss of material off bank. Need to maintain vegetation.
114.70	WP210		L	Jetty and outfalls.	Moderate slopes with gentle frontal slope. Riprap protection. Cliff set back from terrace.
114.85	WP211	km 114.85L.jpg	L	Urban	Steep unretained bank with road close to cliff. Concrete slab riprap where reserve meets river. Bank height increases from 4 to 10 m.
114.85	WP211		R		New concrete wall constructed at top of subvertical slope about 5 m high. Banks increase to about 10 m high.
115.25	WP212				Fallen trees, erosion.
115.40	CS64	km 115.4bL.jpg km 115.4aL.jpg	L	Claudelands Bridge	Moderate to subvertical slopes obscured by vegetation; small beach in front. Remedial works in place for slip on northern side of bridge. Main pile at abutment close to slope face, but probably not exacerbated by bed degradation. Vegetated slopes, but actively eroding. Water discharges from mid-slope just downstream of instability.
115.40	CS64	km 115.4aR.jpg	R	Claudelands Bridge	Slope in front of abutment pile has been subject to rockfall and loss of vegetation. Unlikely to be worsened by bed degradation. Slip with debris mostly washed away just north of bridge.
115.55	WP219		L	Buildings	Weak rock; fallen trees and active slope movement; many buildings above. Timber retaining wall tipping; riprap placed to reduce loss of material from beneath wall in two places.

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Distance from river mouth, km	Beca waypoint/ cross-section No.	Photo Filename	Bank	Feature	Bank Condition Comments
115.55	WP219		R		Shallow slope; active soil failure. Wooden retaining wall would be undermined by bed degradation.
115.65	WP220		R		Riprap and boulder protection; unlikely to be affected by bed degradation.
115.90	WP222	km 115.9aL.jpg	L		Concrete retaining wall already undermined. Slopes flattish to moderate behind.
115.90	WP222		R	Waipa Delta Jetty	Concrete, hexagonal style 2-layer retaining wall and jetty. Undermining possible.
116.30	CS65	km 116.3bL.jpg	L	Bridge Street Bridge, outflow, rowing club.	Outflow tunnel with rock riprap in water. Fine gravel beach fronts rowing club. Concrete slab wall upslope, needs repair.
116.30	CS65		R	Bridge Street Bridge	Slopes ~5 m, vegetated but actively eroding and regular attempts at protection by riprap. Retaining wall where bridge struts enter bank. Willow and small gravel protection below. Need to support soils in front of bridge abutment.
116.60	WP229		L		Riprap, mesh and fabric. Actively eroding.
116.70	WP230	km 116.7L.jpg	L		Cemented rock wall retaining carpark. Will be redundant with bed degradation.
116.70	WP230		R		Riprap.
116.80	WP232	km 116.8L.jpg	L		Outfall onto flat sandy to gravelly beach; significant scour; will be high and dry with bed degradation. Slopes in behind are showing signs of movement.
116.80	WP232		R		Rip rap, concrete and boulders - erratic bank protection.
116.90	WP233	km 116.9R.jpg	R	Outfall	Riprap protection of 1.5 - 2 m slope below walkway.
117.00	WP234		R		Cessation of riprap protection.
117.10	WP235		R	Outfall	Concrete cone protects outfall.
117.20	WP236		L		Rock riprap protecting slabbing cliff.
117.20	WP236		R	Jetty	
117.20			R	Wellington Street Beach	Low to moderate slope; sandy beach.
117.30	WP237	km 117.3aR.jpg, km 117.3bR.jpg	R		Silt exposed below past beach, about 0.3 m erosion. Trees moving down bank.
117.40	WP239	km 117.4aL.jpg	L	Skills Centre	Riprap protection; slope 4 - 5m.
117.40	CS66	km 117.4L.jpg	L		Riprap protection; disused outflow. Slopes below road bush and willow protected, but some loss of trees to river.
117.40	CS66		R		Slope debris at toe; active loss of vegetation to the river. Willows provide protection to slope toe upstream.
117.55	WP245		L		Tree form indicative of creep; bedded soils/weak rock outcropping at water edge; ongoing loss of large trees at top of slope anticipated with bed degradation.
117.70	CS67		L	Outfall	Fallen trees at base of slope; dense scrubby vegetation.
117.70	CS67		R		Low terrace, moderately steep; if willows lost, bank will fail. Bank becomes vertical and prone to slabbing toward Cobham Bridge.
117.90	WP250	km 117.9L.jpg	L		Slope movement: sliding of weathered soils and vegetation. Arcuate headscarps extend along bank. Upper soils saturated and slide on underlying low permeability weak rock; rock fails by spalling and slabbing. Slope becomes subvertical cliff with gorse; active slabbing.
117.90	WP250		R		Low lying terrace with established willows; unlikely to be affected by bed degradation.
118.00	WP251		L		Movement of porous soils on low permeability layer below; slabbing of weak rock.
118.00	WP251		R		Shallow beach; slope behind moderate.
118.50	CS68	km 118.5L.jpg	L	Cobham Bridge	Beach elevated. Protection may be required downstream of pile slab if bed degradation occurs.
118.50	CS68		R	Cobham Bridge	Open fractures allow water to percolate into slope behind face causing slabbing of bank; continues upstream. Loss of vegetation below walkway above stormwater outfall. Pile will be vulnerable if bed degradation occurs. Active bank erosion.
118.70	WP258		L	Stormwater outfall	Beach of sand. Becoming flat terrace.
118.70	WP258		R		Cliff with trees. Debris and vegetation at toe.
118.80	WP259	km 118.8R.jpg	R	Stormwater outfall, Hamilton Gardens.	Erosion behind gabions.
119.00	WP260		L	Water supply pipe	Water supply pipe on concrete piles in bank; may be compromised by degradation. Runs parallel to river along top of bank for a distance; may necessitate bank protection. Rock exposure in middle of river.
119.00	WP260		R		Adhoc protection - dense scrub, but actively eroding.
119.15	WP261		L		Saturated zone discharging above low permeability sub-horizontal bedded weak rock.
119.30	WP262		R	Hamilton Gardens - building	Small beach with shallow eroding bank behind (creeping).
119.35	WP263	km 119.35aL.jpg	L	Water treatment plant flow gate structure	Gate structure will be elevated if bed degradation occurs. 50 m upstream; riprap protection.
119.35	WP263	km 119.35bR.jpg	R		
119.40	WP264	km 119.4aL.jpg	L		Riprap on slopes about 3 m high. Weak 'rock' platform formed in lower slope. Water discharging over bank.
119.40	WP264	km 119.4R.jpg	R	Hamilton Gardens	Sheetpile wall. Rockfall along discontinuities.
119.50	WP265	km 119.5L.jpg	L		Spalling and slabbing of subvertical cliff.
119.50	WP265	km 119.5R.jpg	R	Cemetery	Gabion protection below road. Beach developed. Slope steepens and lengthens; well vegetated but susceptible to spalling/ slabbing/ oversteepening. Terraced next to cemetery/ walking track.
120.20	CS70		L		Terrace about 1m high, 3 - 4 m across bank about 4 - 5 m. Fronting beach, partly gravel covered.
120.20	CS70		R		Headscarps; regrowth on lost face.
120.80	WP271		L		Steep slope with debris at toe; pumiceous soil with weathered crust. Trees moving downslope. Spalling and slabbing.
120.80	WP271		R		Bank becoming less steep.
121.00		km 121.3R.jpg	R		Moderate slope eroding above vertical bank susceptible to slabbing.

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Distance from river mouth, km	Beca waypoint/ cross-section No.	Photo Filename	Bank	Feature	Bank Condition Comments
121.30	WP272		R	Outfall and walkway bridge.	Outfall with gabion protected walkway; timber bridge above cut in cliff. Slabbing of slope fronting piles; may require mitigation in future.
121.60	WP273		L	Riverglade Drive area.	Short vertical faces, actively eroding. Gully/stream tributary.
121.60	WP273		R	Riverglade Drive area.	Slope movement may be initiated by bed degradation. Bank gains willow protection and becomes flattish beach/ terrace.
122.75	CS71		L		4 - 5 m high, willow fronted; active slumping.
122.75	CS71	km 122.75R.jpg	R		Slabbing; tree roots overhang; tree fall into river.
122.85	WP276				Old slip.
123.40	WP277		L		Gentle slopes with creep in behind.
123.40	WP277		R		Moderate slope. Tree form suggests creep.
123.80	WP278		R		Debris at toe forming beach at inside bend; creep of slope occurring behind.
124.10	WP279		L		Low terrace with moderate slope behind; vegetation moving downslope. Erosion of soil into river.
124.10	WP279		R		Moderate slope; small slips.
124.55	WP280		L		Slope flattens.
124.65	WP281		L	Private property	Home made timber retaining wall. Slopes susceptible to shallow sliding.
124.65	WP281		R	Boat ramp	Retaining structure undermined.
125.10	WP282		L		Vegetation moving down moderate slope, with small beach in front. Susceptible to slumping.
125.10	WP282		R		Fallen trees.
125.30	WP283		L		Loss of trees has resulted in active soil erosion and spalling/ slabbing of bank. Arcuate scarps. Dense vegetation.
126.00	CS73	km 126.0L.jpg	L		Cleared bank: toe maintained by root systems; bank incised 2m+ where trees absent.
126.20	WP286	km 126.2R.jpg	R		Actively eroding subvertical slope below houses, ~ 5m high.
126.40	CS74	km 126.4aL.jpg	L	Narrows Bridge	Abutment extends to edge of slope; may require attention.
126.40	CS74	km 126.4bR.jpg, km 126.4cR.jpg	R	Narrows Bridge	Abutment piles extend to edge of top of slope; may require mitigation irrespective of bed degradation. Erosion upstream may lead to loss of bank.
126.70	WP291	km 126.7L.jpg	L		Active sliding/ creep on old landslide surface.
126.70	CS75		L		Timber retaining wall facing with riprap in behind; private effort, no value on bed degradation.
126.70	CS75		R		Lower terrace 2 - 3 m wide and slope increasing.
126.90	WP295	km 126.9L.jpg	L		Shallow slide movements extend several 10's of metres along bank.
127.10	CS76	km 127.1L.jpg	L		Loss of all trees over sections of bank of about 10 m length each. Evidence of slabbing/ rockfall. Water ~8.5 m deep.
127.10	CS76		R		Recent loss of trees; subvertical bank; fractures open.
127.10	WP296	km 127.1L.jpg	L		Slabbing. ~13 m water depth (gorge).
129.20	CS39	km 129.2L.jpg	L	Private water intake	
129.20	CS39		R	Private property	Creeping slope.
129.40	CS38		L		Creeping slope, unlikely to be exacerbated by bed degradation.
129.40	CS38		R		
129.85	WP116		L		Bank ~3 m high. Pines planted together with Willows, obscure slope profile.
131.00	CS36		L	Mystery Creek	Water discharges from bank above low permeability materials about 2/3 way down the slope. Limited private slope protection attempts. Beyond Mystery Creek, Willow margin developed.
131.00	CS36		R		Bank strongly vegetated; willows at margin. Saturated short steep slopes; rock and vegetation fall.
132.50	WP107	km 132.5L.jpg	L		Active tree fall from top of subvertical "sandstone" bank. Bank fails by slabbing through the rockmass. Low slopes at edge both sides.
132.50	WP107		R		Landslide zone.
133.50	WP102		R		Large scallop/amphitheatre above river; evidence of tree fall downslope.
133.60	CS31	km 133.6L.jpg	L	Pipe discharge (?)	Waterfall in bank (discharging from pipe?) in natural gully in rock; rockfall.
133.60	CS31		R		More gentle slopes (~40 degrees). Willows at water's edge on low shallow toe platform.
134.05	CS30	km 134.05L.jpg	L		Shorter hummocky slope. Large scallop just above slope.
134.05	CS30		R		Longer hummocky creeping slope.
135.65	CS28		L		Large residence above overhanging bank. Slope marginal. Vegetation regenerating; may assist in maintaining margin of stability.
135.65	CS28	km 135.65R.jpg	R		Bank just beyond pine plantation has scalloped form sloping down toward the beach. Frontal low shelf offers protection.
136.80	CS26		L		Low strength sandy soils exposed in bank.
136.80	CS26		R		Bush-clad tall slopes with evidence of historic movement. Trees curving toward river indicating some movement.
137.00	WP88	km 137.0L.jpg	L	Heritage Farm water intake	Water supply intake already subject to loss of material.
137.90	CS24		L	Private property	Tall slopes actively eroding, slightly over-steepened. Bench forms in places. Just past here is a large replanted zone - old landslide? Bench adjacent to river protects upslope property. However, tree fall continues to impact bank stability.
137.90	CS24		R		Bank more gentle and irregular.
138.55	WP79		L/R		Gorge'; erosion occurring by spalling and slabbing. Estimated 3 -4m high banks.
138.70	WP78		L		Abundant tree movement on bank.
138.70	WP78		R		Opens out to more gentle slopes; evidence of slope movement in farmland.
138.90	WP77		L-R		Entering broad 'gorge' with subvertical (more resistant) beds forming lower part of bank 0.5 to 1.0 m above water level; instability above these beds.
139.30	CS21		L-R		Slopes reducing in height. Abundant tree, soil and rock block fall. Large shallow bowls formed on both banks.
139.90	CS20	km 139.9L.jpg	L		Instability on both sides of river. Strong laminations in geology picked out by water/ weathering. Blocky failures in lower slope with more gentle instability above.
140.20	WP68	km 140.2L.jpg	L		Sandy soils over lower permeability weak rock; bank fails at interface both sides of river.
140.50	WP67	km 140.5a.jpg km 140.5bL.jpg	L-R	Pipe bridge	Pipe extends close to top of L bank crest. Log protection. Check - may get quite close to incised gully.
141.20	WP66		L		Slide and flow movement.

Distance from river mouth, km	Beca waypoint/ cross-section No.	Photo Filename	Bank	Feature	Bank Condition Comments
141.20	WP66		R	Private property	Significant arcuate scarps; slides undermine slopes.
141.30	CS19		L		Bank well vegetated with minor ongoing movement; scalloped morphology downstream toward the corner.
141.30	CS19		R		Bank bush-clad. Bench in bank (sharp) ~3 m above waterline.
141.70	WP61		L		Clearing trees at top of bank, leading to failures downslope.
142.00	CS18	km 142.0L.jpg	L	Victoria Bridge (Cambridge)	Appears clear of river.
142.25	CS17	km 142.25bL.jpg, km 142.25aL.jpg	L		Next 100 m trees falling into river. Path and fence lost into river.
142.25	CS17		R		Willows adjacent to river, low slope.
142.80	CS16	km 142.8bL.jpg km 142.8a.jpg	L	Fergusson Bridge	Front rock bulge may be vulnerable to loss exposing buttress piles on bed degradation. Crib wall and riprap protection at present. Resistant lower section of slope. If this continues at depth degradation may not have significant effect.
142.80	CS16	km 142.8aR.jpg	R	Fergusson Bridge	
143.10	WP51		L-R		Subvertical bedding entering "gorge".
143.25	WP50	km 143.25L.jpg	L	Private properties.	Slopes cleared of vegetation below Cambridge houses.
143.70	WP45	km 143.7R.jpg	R		Slope bare of vegetation; moderate to steep slopes ~45 deg.
143.80	CS14-15		R		Much rock and vegetation fall by slabbing.
144.10	CS13		L-R		Widened river. Slopes ~5 -8 m tall. Evidence of significant rockfall, tree fall and revegetation. 10 m further downstream, rock outcrops in riverbed with fallen boulders on top.
144.30	WP40		L-R		River widens from about 50 m upstream of here.
144.75	CS12	km 144.75L.jpg	L		Tall steep slope back beyond gorge. 17 - 18 m water depth shallows to 12 m.
144.75	CS12		R		Joint controlled 'ignimbrite' with open fractures. Some weak sandy lenses within.
145.00		km 145.0bL.jpg, km 145.0aL.jpg	L		Just past intersection with river branch, 13 m depth to riverbed; 'ignimbrite gorge', then sediment banks once more.
145.50	CS9		L		Upper 1.5 m of bank failing above a more resistant gravely river deposit.
145.50	CS9		R		Dense vegetation; scalloped bank inferred to occur behind.
145.65	WP32	km 145.65L.jpg	L		Very low banks, 2.5 - 3.0 m.
145.65	WP32		R		Slope movement on cleared face of about 45 deg.
146.10	CS8	km 146.1bL.jpg, km 146.1aL.jpg	L		Sandy gravel beach developed;plants regenerating. Amphitheatre nearby planted in pines. Water held up on a low permeability zone causing sediments above to fail.
146.10	CS8		R		Erosion occurring in behind a frontal block of the bank; block will eventually be lost.
146.40	CS7-8	km 146.4R.jpg	R		
146.60	CS7		L		Subvertical bank, gorse covered; coarse sub-horizontal sandstone beds. Slabbing and loss of trees and rock downstream.
146.60	CS7	km 146.6R.jpg	R		Loss of vegetation and rock blocks with debris accumulating at toe. Some large arcuate scarps. Slopes decreasing in height.
146.80	WP23	km 146.8bL.jpg	L		
146.80	WP23	km 146.8aR.jpg	R		Active slabbing of bank.
146.90	CS6		L		Rockfall fan fronts slopes, providing protection.
146.90	CS6		R		Rock falls straight into river.
147.00	WP18	km 147.0cR.jpg, km 147.0bR.jpg, km 147.0aR.jpg	R		Low point in riverbank; sub vertical trees actively falling in the river. Waterfall incised in rock. Between this and next site, banks becoming better vegetated and appear relatively stable.
147.40	CS5	km 147.4aL.jpg	L		Steep beach developed. Rockfall. Boulders to coarse gravel.
147.40	CS5	km 147.4bR.jpg	R		Clean face, with current bedded sandy-gravely deposits. Slope height is reduced. Next 50 m has many trees falling downslope.
147.60	CS4-5	km 147.6R.jpg	R		
148.20	WP13		R		Rockfall accumulating at slope base via spalling and slabbing. Steep beach at toe of bank formed from river sediments trapped between fallen rock blocks. Undercutting in places.
148.30	CS3		L		Tall slopes with small beach developed (~40 degrees bank in behind).
148.80	CS2		L		Water discharging down bank.
148.80	CS2	km 148.8dR.jpg, km 148.8cR.jpg	R		Falling trees facilitating building up of toe zone.
148.90	WP4		R		Pumiceous near top; sandy gravel toward base. Slabbing. Active erosion of bank with roots crawling downslope.
149.00	WP3		L		
149.10	WP2		R		
149.50			R		Greywacke exposed in bank; pines falling into river. Rock blocks and debris at base of slope.

▪ Appendix D

Geotechnical Assessments

1 Introduction

The middle reaches of the Waikato River (between the Karapiro Dam and the Waipa confluence at Ngaruawahia) are undergoing bed degradation. Over the next 100 years bed degradation is predicted to reach around 3 m at Hamilton, (Smart, 2003). It is expected that bed degradation will impact on the stability of the existing, marginally stable, riverbanks (the causes of this degradation are not considered in this study).

The affected stretch of the Waikato River passes through the urban areas of Cambridge, Hamilton and part of Ngaruawahia, and is crossed by more than ten bridges (including traffic and services). Instability triggered by bed degradation has the potential to adversely affect land and infrastructure, such as bridge abutments and piers, private properties, and utilities/services, in or in proximity to the river.

This appendix summarises the risk to bank stability and the resultant bank stability hazard, as a result of the projected bed degradation. The principal conditions controlling bank stability are considered (soil/rock type, slope height and angle, vegetation cover, river morphology and past instability), with each attribute being weighted and summed to identify the relative risk. The projected bed degradation profiles for 100 and 50 years (Smart, 2003) have been factored and multiplied by the bed degradation induced slope instability weightings to provide a slope instability hazard classification resented in the bank slope hazard map in this appendix.

2 Conditions that Affect Bank Stability

The underlying causes of slope instability are fairly well known from case studies of specific failures. The causes can often be directly related to the rock and soil composition, which are relatively constant, or may be transient (e.g. seismic vibration or storm events) or imposed by new events (e.g. construction activities and bed degradation).

In a given area the more constant factors can be recognised and their effects rated. Some can be mapped and correlated with each other and with past slope movements. An understanding of the mechanisms of slope failure and why failures occur when and where they do, allows prediction of susceptibility by extending local information to larger areas.

A general description of soil and rock masses outcropping in the vicinity of the Waikato River between Ngaruawahia and Karapiro is given in Section 2.1. A simple classification of the types of slope movement observed is given in Section 2.2 and the main conditions that promote instability are identified in Section 3. Their relative contribution is estimated in Section 4 and the relative effects of the amount of bed degradation predicted are incorporated in Section 5. In this way a summary of the potential hazard has been built up which depends on the number of failure inducing factors present, their severity and their interaction.

2.1 Soil and Rock Types

2.1.1 Geological Setting

The Waikato River runs through the Hamilton Basin, a depression formed by faulting and uplift of the surrounding ranges in Pliocene times. The soil and rock types in the Mid-Waikato (between Lake Karapiro and Ngaruawahia) are largely the result of sedimentary filling of this Basin in the Quaternary (though volcanism has also played a part).

The geology (as mapped) in the vicinity of the river is described below in Table D1 (in top-down stratigraphic order):

Table D1: Surface Geology of the Mid-Waikato

Unit Name	Description*	Age (years BP)
Alluvium	Alluvial sand, silt and gravel	0 to 10,000
Peat	Peat and peaty silt	
Taupo Pumice Alluvium	Alluvial pumice with charcoal, c.130 AD	
Hinuera Formation	Mainly rhyolitic, current-bedded sand and gravel, interbedded with peat and pumiceous silt and sand	10,000 to 1.6 million
Walton Subgroup, Karapiro Formation	Fluviatile/ lacustrine sand and gravel with silt interbeds (less pumiceous than Puketoka Fmn and more weathered than Hinuera Fmn)	
Walton Subgroup, Puketoka Formation	Very stiff to hard (weakly cemented) sensitive silt, very weak to very soft pumiceous cemented silt/ignimbrite, well sorted light grey-white pumiceous clay, sand and breccia	
?	Siltstone, sandstone and conglomerate with interbedded airfall and redeposited pumice tuff	
?	Fluviatile silt, sand, gravel and interbedded pumiceous tuff	
Manaia Hill Group	Banded siltstone, rare sandstone and conglomerate	144 to 208 million
	Indurated sandstone and siltstone, with tuffaceous beds	208 to 245 million
*Descriptions assembled from Selby and Lowe (1992) as well as published geologic maps: Kear (1960); Healy, Schofield and Thompson (1964); and records of investigations in the area.		

The filling of the Hamilton Basin comprised two stages of alluvial fan building:

- Walton Subgroup alluvium deposited by pre-Waikato rivers and subsequently incised by river meanders to leave upstanding hills; and
- Hinuera Formation deposited by the ancestral Waikato River when it changed course from the Hauraki Plains to its present path.

The Waikato River ceased its depositional phase and took a meandering form some 15,000 years ago, and has downcut into the Hinuera Formation and Walton Subgroup by up to 70 m.

Sediment from the 130 AD Taupo Eruption was carried by the Waikato River, and filled the river channel and tributary stream gullies with Taupo Pumice Alluvium. The River has largely cut through this material, although a thickness of up to 30 m of Taupo Pumice Alluvium remains on Hinuera terraces at about 6 m above river level.

Today the river cuts through an unknown thickness of alluvium, confined by ranges of greywacke at Karapiro and Ngaruawahia. The greywacke is understood to occur in the riverbed:

- At Karapiro for a distance of a few hundred metres or so, dipping to the north; and
- Toward Ngaruawahia, possibly at much greater depth due to down-faulting.

The depth to greywacke between these points is expected to be significant, and it is considered unlikely that there is an erosion-resistant stratum to be reached in the foreseeable future to which the river may degrade and reach a stable profile.

2.1.2 Soils and Rocks in the River Bed and Banks

For the most part, the Waikato River cuts through readily erodible alluvium, with occasional pockets of slightly more resistant 'cemented' alluvium and/or ignimbrite, and possibly greywacke. The inherent variability of Mid-Waikato geology means that bed degradation is likely to occur at a variable rate, with varying effect on bank stability along the course of the River. The geological units have been grouped according to their expected geotechnical behaviour.

Direct observations during the River reconnaissance trip indicated that there are broadly two extremes in geotechnical behaviour within the alluvial deposits, as expressed through the bank geomorphology. At one extreme is a gorge-like morphology where the geology is more resistant to erosion, and is competent enough to stand almost vertically. This is inferred to be due to cementation of the alluvium and/or corresponds with ignimbrite flow deposits. These banks fail by spalling or slabbing of blocks along discontinuities. At the other extreme are loose silty to sandy banks where the materials sit in a state of limit-equilibrium (at their angle of repose). These banks are particularly susceptible to erosion where vegetation has been lost/removed. A combination of these extremes is also observed, typically with slide failure occurring in the weaker alluvial materials on a lower permeability interface with the more resistant stratum, which extends below river level.

2.2 Slope Height and Angle

The steepness and height of a bank in relation to the properties of the soil and rock slopes may be critical to bank stability. While most natural slopes are irregular, comprising sections of different steepness, average slope angles and heights have been used for this assessment. Bed degradation essentially increases slope height.

2.3 Active Movement

Evidence of past instability indicates a potential for failure of geologically similar slopes of similar slope grade in the same area, thereby providing an important guide to the likely future behaviour of slopes in the locality.

3 Hazard Contributions

3.1 Geomorphic Type (soil type + slope angle)

Because the soil/rock units exposed along the length of the Waikato River include a range of soil types of unknown distribution, the geomorphic expression of these soil and rock differences has been used instead as an input to the hazard assessment. The geomorphic type is a summation of the soil/rock properties, groundwater and slope angle. The riverbanks can be grouped into four geomorphic types as described in Table D2. The table also shows a sub-category, B1, which has been identified from aerial photographs as areas of historical deeper-seated instability.

Table D2: Geomorphic Types

Class	Description
A	Wide platforms gently sloping to river
B	Moderately steep banks (evidence of shallow slips, slumps and slides)
B1	As for B, with evidence of larger scale historical slope movements
C	Steep to very steep banks exhibiting spalling and slabbing type failures
D	Slopes comprising a lower portion as per C and an upper portion as per B, that has failed

Back-Analysis

With the exception of type B1, each bank geomorphic type was modelled using the computer program SLOPE/W to assess the effects of bed degradation on bank stability. Typical cross-sections were identified from a combination of bed cross-section data and range-finder profiles created during river reconnaissance trips as part of this investigation.

Soil properties were broadly grouped as alluvium and "cemented" alluvium, and parameters applied derived from available geotechnical data and back-analysis of existing slopes (assuming existing slopes have a factor of safety of around 1.0 to 1.1). The properties modelled are given in Table D3.

Table D3: Geotechnical Properties

Material	Unit Weight γ(kN/m^3)	Cohesion c' (kPa)	Friction angle ϕ' (°)
Alluvium	17	3	28
Cemented alluvium	19	20/50/100	34

Class A

Failure by sliding or creep on a moderately shallow circular failure surface.

Class B

Failure by sliding along a circular failure surface and passing through the toe of the slope. Of the four geomorphic types modelled, Class B is most at risk from bed degradation.

Class C

Failure by individual rock falls spalling or slabbing vertically. Where these extend to depth, the failure surface may change to a curved profile extending to the slope toe.

Bed degradation has only a small influence on the margin of stability, provided similarly cemented materials exist to depth. Should weaker soils become exposed on bed degradation, then the influence will be significant and slope movement is likely to extend back into the riverbank. The likely distance back from the bank crest affected is expected to be equivalent to the height of the slope at the friction angle of the weaker soils.

Class C is considered to have a low risk of bed degradation induced failure, provided the same cemented materials extend to depth. This will need to be confirmed by site specific subsurface investigation in critical areas.

Class D

Failure by sliding along a circular failure surface on the water-lubricated interface with the underlying cemented alluvium.

As for type C, the effect of degradation is small, as the geotechnical properties of the lower cemented alluvium layer control stability. However, should these materials be of limited vertical extent and weaker materials become exposed by bed degradation, the effect on bank stability will be significant.

Typical Profiles

Once the profiles and parameters were established, the effect of bed degradation (i.e. lengthening of the slopes) by 1.5 m and 3.0 m was modelled. The results of these analyses are shown in Table D4.

Table D4: Effect of Bed Degradation on Existing Slope Stability

Class	Materials	Slope Height (m)	Slope Angle (°)	2005 FoS	FoS 2055	FoS 2105
A	Alluvium	4	7°	1.5	1.2	1.1
B	Alluvium	12	30°	1.0	0.9	0.8
C	Cemented Alluvium	50	70°	1.1	0.9	0.8
D	Alluvium/Cemented alluvium	20	30° on 85°	1.1	1.05	0.8

3.2 Slope Height

Slopes are generally higher at the Karapiro end of the Waikato River section studied (average height of 35 m) and lower at the Ngaruawahia end of the river (average height of 4 m). The heights of banks have been grouped as shown in Table D5. The mapped height groupings have been developed from on-river range-finder measurements, correlated with DTM heights.

Table D5: Slope Height Classes

Class	Description	Bank Height Range (m)
A	Low	0 – 5
B	Low to Moderate	5 – 15
C	Moderate to High	15 – 30
D	High	30 +

3.3 Active Slope Movement

Inferred areas of past instability extending back from the immediate area of the riverbank have been identified from examination of stereopairs of aerial photographs. These areas have been allocated Class B1 within the geomorphic type series (see Table D2).

3.4 Vegetation

The presence of willows was observed to have a noticeable influence on the position of the toe of the riverbank and the maintenance or loss of a "beach" fronting the riverbank. Maintenance of a beach or terrace in front of the bank significantly reduces the risk of bank movement in response to bed degradation. Native and other species provide more limited protection to banks. Classes have been assigned according to the presence and type of vegetation as described in Table D6.

Table D6: Vegetation Classes

Class	Description
A	Willows
B	Other tree and bush species
C	Grass

3.5 River Morphology

The bank inside a river meander will be protected against scour and to some extent against bed degradation, whereas the bank on the outer side of a river meander will be exposed to maximum scour and bed degradation. Inside, straight, outside and sharp outside bends have therefore been identified for weighting in the hazard assessment as described in Table D7.

Table D7: River Morphology Classes

Class	Description
A	Inside meander
B	Straight river
C	Outside meander
D	Sharp outside meander

3.6 Projected Bed Degradation

The expected depth of bed degradation has been grouped as described in Table D8. Projected (100 years) bed degradation figures between Narrows and Pukete boat ramp have been interpolated from figures in Smart (2003); projections beyond this reach (north of Pukete boat ramp and south of Narrows) are less well constrained.

Table D8: Projected Bed Degradation

Class	Description	Degradation Range (m) (50 yrs)	Degradation Range (m) (100 yrs)
A	Nil – low	0 – 0.2	0 – 0.5
B	Low	0.2 – 0.5	0.5 – 1.0
C	Moderate	0.5 – 1.0	1.0 – 2.0
D	High	> 1.0	> 2.0

4 Hazard Assessment

Regional scale assessment of bank stability hazard due to bed degradation has been carried out by allocating weighted scores to each of the key attributes contributing to bank movement and presenting these on a series of maps at a scale of 1:75,000. The scores for each attribute have been summed using Geographic Information Systems technology to produce a regional bank stability hazard map.

4.1 Geomorphic Type and Past Instability

The distribution of geomorphic types (types A – D) and past instability (type B1) have class scores as summarised in Table D9.

Table D9: Geomorphic Type

Class	Score
A	2
B	4
B1	5
C	1
D	2

4.2 Bank Height

The variation of slope height (Classes A – D) class scores are summarised in Table D10.

Table D10: Bank Height

Class	Score
A	1
B	2
C	3
D	3

4.3 Vegetation

The variation of vegetation (Classes A – C) class scores are summarised in Table 11.

Table D11: Vegetation

Class	Vegetation Score
A	0
B	1
C	2

4.4 River morphology

The distribution of inner, outer and straight sections of river (Classes A – C) class scores are summarised in Table D12.

Table D12: River Morphology

Class	Description	Score
A	Inside bend	0
B	Straight	0.5
C	Outer bend	1.5
D	Sharp outer bend	2

4.5 Projected Bed Degradation

The variation in projected bed degradation (classes A – D) class scores are summarised in Table D13.

Table D13: Projected Bed Degradation

Class	Score (50yr)	Score (100 yr)
A	0.5	0.5
B	0.5	0.65
C	0.65	0.85
D	0.85	1.0

4.6 Hazard Scores

The scores from Tables D8 to D12 have been combined using GIS and presented on the attached Map "Bank Slope Hazard Map" as Hazard Assessment Scores for 50 and 100 year projected degradation. The total scores are interpreted in terms of bank stability hazard in Table D14.

Table D14: Hazard Assessment

Total Score	Class	Hazard Risk
0 – 4	A	Low bank instability hazard
>4 - 7	B	Moderate bank instability hazard: stability will be dependent on local factors such as depth of weathering and degree of saturation
>7 - 9	C	High bank instability hazard: slopes unstable; ongoing movement anticipated
>9 - 12	D	Severe bank instability hazard

5 Set-back Distances

The contributors to slope instability described in the sections above have been used in conjunction with the projected bed degradation to develop a "set-back" beyond which there is judged (from regional data) to be an unacceptably high risk that movement could occur over the period in which 1.5 m of bed degradation occurs in Hamilton City (Smart, 2003). A "set-back" is identified with the aim of assisting decision makers in planning future land use and identifying where development should not take place without specific investigation of bank slope stability and the potential for slope movement due to its present marginal state, accelerated by bed degradation. The proposed "set-back" is shown approximately on Map 2 attached. In producing Map 2, the toe of the bank has been assumed to be the interface of the river with the shore.

Because this is a regional scale study, set-backs have been assessed conservatively to provide stable bank angles of 7° (reworked weak silty materials) and 14° (sandy materials). These stable angles are derived by taking the present (marginally stable) slope angle of the existing river bank grouped broadly into these two types of materials, and allowing for the winter conditions when these banks become saturated. Then, assuming a saturated slope, a margin is added to yield the stable slope angle recommended.

For example a sandy bank could stand marginally stable at around 40° when dry, but can be expected to fail to 20° when saturated, and so for a safe location a set-back angle of 14° is assumed. Similarly, banks in a weak silt soil may be marginally stable at 20° when dry, and 10° when saturated, and so a set-back angle of 7° is assumed.

These approximate regional set-backs can be refined by specific geotechnical investigation and design. The approximate, and coarse, two categories assumed for discussing set-backs would not cover for example, some of the stronger more cemented banks. For this example, a 14° residual slope angle has been assumed because it is not known whether the more cemented materials extend to depth (i.e. significantly below the projected bed degradation depth). These set-backs could be (and should be) refined by specific geotechnical investigation and stability analyses.

Projected riverbed degradation (Smart, (2003) 50-year case) was grouped into four degradation categories (Table D15) to allow the average projected increase in bank height at any location to be identified.

Table 15: Degradation Classes

Degradation Class	Degradation Range (m)	Average Depth of Degradation (m)
D1	0 – 0.2	0.15
D2	0.2 – 0.5	0.4
D3	0.5 – 1.0	0.8
D4	> 1.0	1.5

These average degradation "heights" were added to existing bank height data along the length of the river and classified as shown in Table D16, using the "typical" height for trigonometric calculations.

Table 16: Projected Bank Heights

Bank Height Class	Bank Height Range (m)	Typical Height (m)
A	0 – 5	5
B	5 – 15	13
C	15 – 30	25
D	> 30	33

The set-back angle for outside meanders was determined by trigonometry, using the projected bank height measured from the "bottom of the bank" (bank/river interface) and the residual bank angle for the soil type exposed. For straight sections of river, bank retreat will be lesser and is graded from the minimum estimated by the above method according to height. The shortest set-back calculated by the trigonometric method is allocated to banks on inside meanders.

The resulting set-back estimates were rounded to 25 m, 50 m, 100 m, and 130 m as shown in Table D17 and on Map 2.

Table D17: Proposed Set-Back

Bank Height + Degradation	Material Type	River Morphology Class	Set-Back (m)
A	Silt	A	50
A	Silt	B	25
A	Sand	A	25
A	Sand	B	25
A	Silt or Sand	C and D	25
B	Silt	A	100
B	Silt	B	50
B	Sand	A	50
B	Sand	B	25
B	Silt or Sand	C and D	25

Bank Height + Degradation	Material Type	River Morphology Class	Set-Back (m)
C	Silt	A	Does not occur
C	Silt	B	50
C	Sand	A	100
C	Sand	B	50
C	Silt or Sand	C and D	25
D	Silt	A	Does not occur
D	Silt	B	50
D	Sand	A	130
D	Sand	B	50
D	Silt or Sand	C and D	25

The set-back identified for areas designated 'steep' (dotted on Map 2) may be reduced if site-specific investigation proves that the stronger materials exposed in the river bank at these locations extend to depth below the river bed.

6 References

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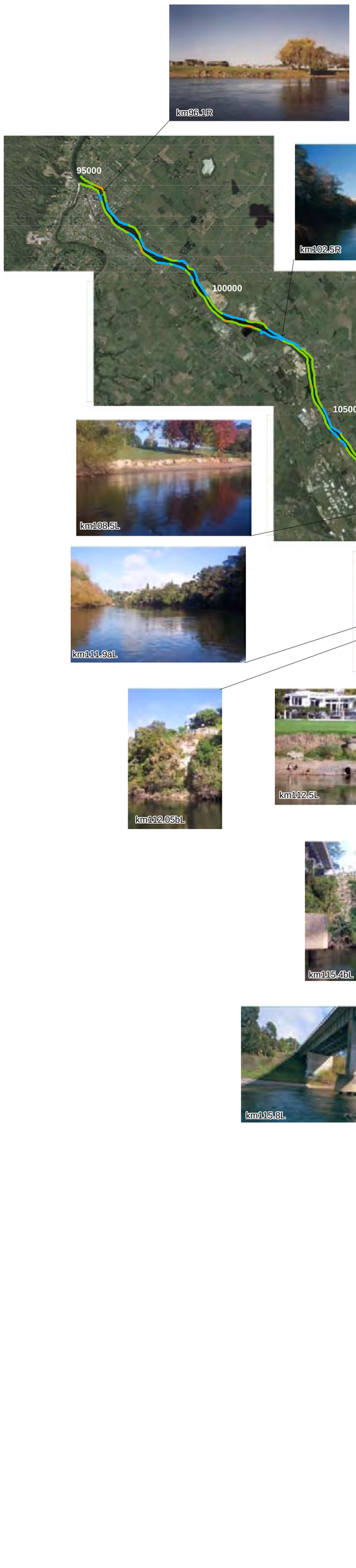

50 Year Degradation

(Linear degradation profile from 0 m at Karapiro Dam to 1.5 m below Hamilton)

Bank Slope Hazard Classification

- Severe
- High
- Medium
- Low

(Refer Table D14)

Chainage 95,000 m at Ngaruawahia to 149,600 m at Karapiro Dam

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Scale 1 : 75,000 at A1

Imagery sourced from Terralink International Limited.
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Map D1
Mid Waikato Bed Degradation
Bank Slope Hazard Classification