NZ TRANSPORT AGENCY
WAKA KOTAHI

Roads of national significance

Ara Tūhono – Pūhoi to Wellsford

This document records technical and factual information used to support the NZTA's Assessment of Environmental Effects for the Pūhoi to Warkworth Project. It has been supplied to the Environmental Protection Authority by the NZTA in response to a section 149(2) Resource Management Act 1991 request. This document did not form part of the NZTA's application for the Project, which was lodged on 30 August 2013.

FURTHER NORTH

Pūhoi to Warkworth

Water Assessment Factual Report 8
Cross Drainage and Stream Diversion Design

August 2013

FURTHER NORTH

Pūhoi to Warkworth

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Glossary of abbreviations

Abbreviation	Definition
ARC	Auckland Regional Council (legacy Council of the Auckland Council)
ARI	Average Recurrence Interval
BPO	Best Practicable Option
CMA	Coastal Marine Area
CN	Soil Conservation Service Curve Number
ha	Hectares
HEC-14	Federal Highway Administration Hydraulic Engineering Circular No. 14 Hydraulic Design of Energy Dissipaters for Culverts and Channels
HIRDS	High Intensity Rainfall Design System
HY-8	Federal Highway Administration Culvert Design Software, USA
LiDAR	Light Detection and Ranging
m	Metres
NGTR	Northern Gateway Toll Road
NZSOLD	New Zealand Society on Large Dams
NZTA	NZ Transport Agency
OWAR	Operational Water Assessment Report
PWA	Public Works Act 1981
RDC	Rodney District Council (legacy Council of Auckland Council)
RMA	Resource Management Act 1991
RoNS	Roads of National Significance
SHx	State Highway (number)
TP10	ARC Technical Publication Number 10: Stormwater Management Devices Design Guideline Manual
TP90	ARC Technical Publication Number 90: Erosion and Sediment Control Guidelines for Land Disturbing Activities
TP108	ARC Technical Publication 108: Guidelines for Stormwater Runoff Modelling in the Auckland Region

Glossary of defined terms

Term	Definition
Alignment	The route or position of a proposed motorway or state highway.
Average Recurrence Interval	The average time period between rainfall or flow events which equal or exceed a given magnitude. Similar to return period.
Culvert	A pipe with an inlet from a watercourse and outlet to a watercourse, designed to convey water under a specific structure (such as a road).
Diversion of stormwater	The turning aside of stormwater from its natural course of flow; causing it to flow by a different route.
Earthworks	The disturbance of land surfaces by blading, contouring, ripping, moving, removing, placing or replacing soil or earth, or by excavation, or by cutting or filling operations.
Erosion Control	Methods to prevent or minimise the erosion of soil, in order to minimise the adverse effects that land disturbing activities may have on a receiving environment.
Fish Passage	The movement of fish between the sea and any river, including up-stream or downstream in that river.
Heading up	Heading up is the term used to denote the condition when the water surface immediately upstream of the culvert rises to an elevation greater than the soffit of the culvert inlet.
Headwater	The water depth from the culvert invert at the inlet, to the water surface of the pool that forms as a result of heading up, is called the headwater.
Indicative Alignment	A route and designation footprint selected after short-list and long-list development to enable consultation with the community. This development involved specialist work assessing environmental, social and engineering inputs.
Intermittent Stream	Any stream or part of a stream that is not a Permanent stream.
Motorway	Motorway means a motorway declared as such by the Governor-General in Council under section 138 of the PWA or under section 71 of the Government Roading Powers Act 1989.
Overland Flow Path	The flow path of stormwater over the ground.
Permanent Stream	Downstream of the uppermost reach of a river or stream which meets either of the following criteria: (a) has continual flow; or (b) has natural pools having a depth at their deepest point of not less than 150mm and a total pool surface area that is $10m^2$ or more per 100m of river or stream bed length. The boundary between Permanent and Intermittent river or stream reaches is the uppermost qualifying pool in the uppermost qualifying reach.
Pier	Vertical support structure for a bridge.

Term	Definition
The Project	The Ara Tūhono Pūhoi to Wellsford Road of National Significance Project: Pūhoi to Warkworth section.
Project Area	From Johnstone's Hill portals in south to Kaipara Flats Road in the north.
Secondary flow path	The flow path of stormwater or floodwater that activates from larger storm events.
Sediment Control	Capturing sediment that has been eroded and entrained in overland flow before it enters the receiving environment.
Wetland	Vegetated stormwater treatment device designed to remove a range of contaminants.

Contents

1. Introduction

This report provides a factual basis for the Operational Water Assessment Report (OWAR) prepared for the New Zealand Transport Agency (NZTA). The OWAR provides an assessment of the environmental effects associated with water, arising from the operational aspects of the Pūhoi to Warkworth section (the Project) of the Pūhoi to Wellsford Road of National Significance (RoNS) Project. The OWAR supports the Assessment of Environmental Effects resource consent applications and Notices of Requirement for the Project.

This report records the methodology and process we used to carry out the following activities:

- Design of culverts including hydrology, hydraulics, energy dissipation, fish passage and assessment of effects;
- Analysis of hydraulic requirements for bridges and viaducts;
- Development of a debris management framework to assess the risk of debris flow and to determine mitigation measures to reduce the risk of culvert blockage;
- Design of stream diversions to recreate streams and habitats to replicate the natural state of the streams that exist prior to the Project; and
- Design of sediment traps at the base of rock cut faces to act as pre-treatment by capturing sediment generated from rock cuts.

2. Culvert design

2.1 Introduction

Where the Project crosses existing streams (permanent and intermittent) we propose bridges and culverts to provide conveyance of normal flows and flood waters from one side of the motorway to the other, whilst minimising the effect on the existing flow and ecological condition of the waterways. Another option is to divert the stream to another cross drainage location.

The Project alignment has numerous stream crossings. Bridges impose the least environmental impact, but are more costly. Culverts have more environment impacts however are more cost effective. Furthermore, the fill associated with culverts is often required to balance the volumes of earthworks required for cuts through ridges that are necessary to achieve an appropriate vertical alignment for the motorway.

Considerations for the choice of a bridge or culvert include:

- Vertical geometry of the road;
- Height and length of the crossing;
- Magnitude of the stream flows and width of the floodplain;
- Constructability of bridge or culvert;
- Other requirements for a bridge such as secondary roads or stock access; and
- Environmental considerations such as effects on aquatic and riparian ecology.

In general the culverts we propose for the Project will be concrete pipes. This is the most cost effective type of cross drainage because concrete pipes are economical to produce and satisfy long-term strength and durability requirements. The exception is where flows are large and concrete arch culverts are required for flow capacity.

Culverts are labelled "Culvert ######" in the assessment reports and the Project drawing set, with the numbers representing the culvert location in reference to the motorway chainage (rounded to the nearest 100m).

The cross drainage proposed for the Project is summarised in Table 1. This Factual Report describes the design considerations and methodology for the culverts.

Table 1: Summary of Culverts*1 and Bridges*2

Catchment	Culverts	Sector	Catchment Land Use	Ecological Reference	Culvert Size (mm)	Culvert Length*3 (m)	Grade (%)	Minimum Cover (m)	Catchment Size (ha)	CN [Composite]	Tc (min)	Peak Flow [100Y] (m^3/s)	Peak Flow [10Y] (m^3/s)	Peak Flow [2Y] (m^3/s)	Designed Fish Passage	Debris Management	Energy Dissipating Structure
Pūhoi	**ON PROPOSED MOTORWAY ALIGNMENT**																
	BRIDGE - OKAHU VIADUCT	Pūhoi	BRIDGE - OKAHU VIADUCT														
	Culvert 63800	Pūhoi	Farmland	P2	1600	165	2%	16.7	13.8	74	13	6.55	3.87	1.80	None	Relief Inlet	SAF Stilling Basin
	Culvert 63500	Pūhoi	Farmland	P3	1800	262	4%	7.2	16.7	79	10	8.83	5.36	2.63	None	Relief Inlet	SAF Stilling Basin
	Culvert 63000	Pūhoi	Farmland	P3a	1350	92	5%	2.5	8.0	74	10	4.02	2.37	1.11	None	None	SAF Stilling Basin
	BRIDGE - PŪHOI VIADUCT	Pūhoi	BRIDGE - PŪHOI VIADUCT														
	Culvert 61900	Hungry Creek	Forestry	P5	1600	99	1%	1.9	12.4	73	12	5.89	3.46	1.59	None	None	Riprap Basin
	Culvert 61600	Hungry Creek	Forestry	P6	1800	62	2%	1.8	19.8	77	15	9.25	5.53	2.63	None	None	SAF Stilling Basin
	Culvert 61300	Hungry Creek	Bush	P6a	1200	75	9%	2.3	2.5	70	10	1.20	0.69	0.31	None	None	SAF Stilling Basin
	Culvert 61100	Hungry Creek	Bush	P7	1350	81	10%	9.1	10.1	70	10	4.90	2.83	1.27	None	Relief Inlet	SAF Stilling Basin
	Culvert 60800	Hungry Creek	Forestry	P8	2550	127	4%	9.9	26.9	70	18	11.13	6.41	2.85	None	Debris Rack and culvert sized to pass 100Y ARI	SAF Stilling Basin
	Culvert 60200 ARCH	Hungry Creek	Forestry	P9	Arch (7315 Span, 3658 Height)	104	4%	12.4	93.9	71	39	28.07	16.00	7.19	Natural Bed	Debris Rack and culvert sized to pass 100Y ARI	Riprap Basin
	Culvert 59900	Hungry Creek	Forestry	P9b	1200	65	8%	2.3	0.8	70	10	0.39	0.23	0.10	None	None	SAF Stilling Basin
	Culvert 59800	Hungry Creek	Forestry	P9a	1600	121	6%	8.4	9.3	70	12	4.35	2.52	1.12	None	Relief Inlet	SAF Stilling Basin
	BRIDGE - HIKAUAE VIADUCT	Hungry Creek	BRIDGE - HIKAUAE VIADUCT														
	Culvert 59400	Hungry Creek	Farmland	P10a	1200	55	5%	2.3	0.6	74	10	0.32	0.19	0.09	None	None	SAF Stilling Basin
	BRIDGE - SCHEDEWYS VIADUCT	Hungry Creek	BRIDGE - SCHEDEWYS VIADUCT														
	Culvert 58700	Schedewys Hill	Forestry	P11a	1600	116	23%	1.9	2.5	71	10	1.23	0.72	0.33	None	None	SAF Stilling Basin
	Culvert 58400	Schedewys Hill	Forestry	P11b/c	1600	146	25%	4.4	4.9	72	10	2.41	1.40	0.64	None	Relief Inlet	SAF Stilling Basin
	Culvert 57600	Schedewys Hill	Forestry	P11f	1600	137	12%	12.9	10.8	70	10	5.24	3.03	1.36	None	Relief Inlet	SAF Stilling Basin

Catchment	Culverts	Sector	Catchment Land Use	Ecological Reference	Culvert Size (mm)	Culvert Length[*3] (m)	Grade (%)	Minimum Cover (m)	Catchment Size (ha)	CN [Composite]	Tc (min)	Peak Flow [100Y] (m^3/s)	Peak Flow [10Y] (m^3/s)	Peak Flow [2Y] (m^3/s)	Designed Fish Passage	Debris Management	Energy Dissipating Structure
	Culvert 57400	Schedewys Hill	Forestry	P11g	1350	96	24%	2.6	10.3	82	12	5.25	3.22	1.62	None	None	SAF Stilling Basin
	Culvert 57200	Schedewys Hill	Forestry	P12	1600	235	10%	8.9	2.4	72	10	1.18	0.69	0.32	None	Relief Inlet	SAF Stilling Basin
Mahurangi	Culvert 56700	Moirs Hill Rd	Forestry	M13	1600	123	14%	2.4	4.0	72	10	2.22	1.30	0.63	None	None	SAF Stilling Basin
Mahurangi	Culvert 56400	Moirs Hill Rd	Forestry	M13a	1200	97	10%	4.3	3.7	70	10	2.02	1.18	0.56	None	Relief Inlet	SAF Stilling Basin
Mahurangi	Culvert 56100	Moirs Hill Rd	Forestry	M13b	1200	84	13%	2.3	1.6	70	10	0.87	0.50	0.24	None	None	SAF Stilling Basin
Mahurangi	Culvert 55300	Moirs Hill Rd	Forestry	M13d	2550	81	6%	1.5	33.8	77	24	15.42	9.20	4.59	Baffle	Relief Inlet	Modified SAF Stilling Basin
Mahurangi	Culvert 54700 ARCH	Moirs Hill Rd	Forestry	M15	Arch (8534 Span, 4267 Height)	258	1%	43.7	345.8	71	71	87.04	50.19	23.96	Natural Bed	Debris Rack and culvert sized to pass 100Y ARI	Riprap Basin
Mahurangi	Culvert 53800	Moirs Hill Rd	Forestry	M15a	1600	70	1%	2.4	11.4	73	11	6.34	3.75	1.83	None	None	Riprap Basin
Mahurangi	BRIDGE - PERRY ROAD VIADUCT	Perry Rd	BRIDGE - PERRY ROAD VIADUCT														
Mahurangi	Culvert 53000	Perry Rd	Bush	M16a	1600	175	8%	12.9	4.3	71	10	2.36	1.38	0.66	None	Relief Inlet	SAF Stilling Basin
Mahurangi	BRIDGE - KAURI ECO VIADUCT	Perry Rd	BRIDGE - KAURI ECO VIADUCT														
Mahurangi	Culvert 51900	Perry Rd	Bush	M19a	1200	77	8%	2.8	1.1	70	10	0.63	0.37	0.17	None	None	SAF Stilling Basin
Mahurangi	Culvert 51600	Perry Rd	Bush	M19b	1200	84	5%	5.8	6.6	70	10	3.64	2.12	1.01	None	Relief Inlet	SAF Stilling Basin
Mahurangi	Culvert 51300	Perry Rd	Farmland	M19c	1800	172	4%	10.2	13.6	80	10	8.07	4.93	2.56	None	Relief Inlet	SAF Stilling Basin
Mahurangi	Culvert 51000	Perry Rd	Farmland	M21a	1600	124	4%	8.4	6.2	74	10	3.51	2.08	1.02	Baffle	Relief Inlet	Modified SAF Stilling Basin
Mahurangi	Culvert 50800	Perry Rd	Farmland	M21b	1200	94	7%	4.3	2.2	74	10	1.27	0.75	0.37	None	Relief Inlet	SAF Stilling Basin
Mahurangi	Culvert 50500	Perry Rd	Farmland	M21c	1200	92	4%	2.3	3.7	74	10	2.13	1.26	0.62	Baffle	None	Modified SAF Stilling Basin
Mahurangi	Culvert 50200	Perry Rd	Farmland	M21d	1600	109	2%	4.4	7.6	75	12	4.18	2.49	1.23	Baffle	Relief Inlet	Riprap Basin
Mahurangi	BRIDGE - WYLLIE ROAD OVERPASS	Perry Rd	BRIDGE - WYLLIE ROAD OVERPASS														
Mahurangi	Culvert 49500 ARCH	Perry Rd	Forestry	M22	Arch (7315 Span, 3658 Height)	104	1%	4.3	195.2	70	76	47.32	27.18	12.93	Natural Bed	Debris Rack and culvert sized to pass 100Y ARI	Riprap Basin
Mahurangi	BRIDGE - WOODCOCKS ROAD VIADUCT	Carran Rd	BRIDGE - WOODCOCKS ROAD VIADUCT														

Catchment	Culverts	Sector	Catchment Land Use	Ecological Reference	Culvert Size (mm)	Culvert Length*3 (m)	Grade (%)	Minimum Cover (m)	Catchment Size (ha)	CN [Composite]	Tc (min)	Peak Flow [100Y] (m³/s)	Peak Flow [10Y] (m³/s)	Peak Flow [2Y] (m³/s)	Designed Fish Passage	Debris Management	Energy Dissipating Structure
	BRIDGE - CARRAN ROAD FLOOD RELIEF BRIDGE	Carran Rd	BRIDGE - CARRAN ROAD FLOOD RELIEF BRIDGE														
	Culvert 48000	Carran Rd	Farmland	M23a	1350	45	1%	1.2	8.2	74	13	4.41	2.62	1.28	None	None	Riprap Basin
	Culvert 47700	Carran Rd	Farmland	M23b	1350	71	0%	1.0	6.5	74	11	3.59	2.13	1.05	None	None	Riprap Basin
	Culvert 47400	Carran Rd	Farmland	M23c	1600	60	4%	1.0	11.4	74	10	6.50	3.85	1.89	Baffle	None	Riprap Basin
	Culvert 47200	Carran Rd	Farmland	M23d	1200	61	6%	2.5	2.3	74	14	1.21	0.72	0.35	Baffle	None	Modified SAF Stilling Basin
	ON PROPOSED EASTERN LINK TO WARKWORTH																
	Culvert 700SH1S	Carran Rd	Farmland	SH1-700	1600	69	7%	2.4	8.8	77	10	5.13	3.10	1.57	None	None	SAF Stilling Basin
	ON PROPERTY ACCESS ROAD (WYLLIE ROAD)																
	Culvert 100A	Perry Rd	Farmland	PA100A	1050	22	2%	1.0	5.0	76	13	2.74	1.64	0.82	Baffle	None	Riprap Basin
	Culvert 200A	Perry Rd	Farmland	PA200A	900	21	1%	0.6	8.6	75	17	4.35	2.58	1.28	Baffle	None	Riprap Basin
	Culvert 500A	Perry Rd	Farmland	PA500A	900	33	5%	3.1	5.5	75	10	3.17	1.89	0.94	Baffle	Relief Inlet	Riprap Basin
	MINOR BRIDGE - PROPERTY ACCESS ROAD	Perry Rd	MINOR BRIDGE - PROPERTY ACCESS ROAD														

*1 Excludes ancillary roads other than Access Road off Wyllie Road as these have not been designed at this stage. Modifications to SH1 culverts are summarised in Table 6.

*2 Only bridges associated with streams are included.

*3 Lengths (m) are measured in plan (horizontally). Actual lengths may differ and are longer due to the slopes.

2.2 Culvert design criteria

Culvert design criteria are detailed in Water Assessment Factual Report 6: Stormwater Design Philosophy Report. The key criteria for sizing the culverts are as follows:

Table 2: Culvert design criteria for the motorway.

Design Criteria	Parameters	Source
Hydraulic capacity	• Pass a 10 year ARI storm event without heading up; • Minimum freeboard of 500mm during 100 year ARI 500mm from edge of carriageway; and • Accommodate 100 year ARI with Headwater Depth ÷ Culvert Diameter < 2.	NZTA RoNS Standard, Rodney District Council (RDC) Standard for Engineering Design (2009), Water Assessment Factual Report 6: Stormwater Design Philosophy Report (2013)
Debris blockage	• In high risk catchments; increase the culvert size to accommodate a 100 year ARI without heading up; and • In moderate risk catchments; provide a relief inlet (Drawing SW-306).	Refer to Section 4 of this report.
Safety and maintenance	• Culvert < 30m length = Culvert to be 600mm minimum diameter; • Culvert 30 – 100m length = Culvert to be 1200mm minimum diameter; and • Culvert > 100m length = Culvert to be 1600mm minimum diameter.	Water Assessment Factual Report 6: Stormwater Design Philosophy Report (2013)
Minimum cover	• Culverts shall be provided with not less than 600mm of cover.	NZTA RoNS Standard, Austroads Guide to Road Design part 5 Drainage Design

For culverts proposed for ancillary public roads (SH1, Moirs Hill Rd and roads associated with underpasses) the hydraulic criteria in Table 2 will apply.

For culverts located in new private roads, we propose less onerous design criteria because of the high level of performance necessary for a motorway is not warranted for a low usage and low speed private road. The culvert sizing criteria for new private roads (such as the property access road off Wyllie Road) are listed below:

- Culvert to pass 10 year ARI flows with heading up of less than 1000mm;
- Culvert to have a minimum depth of cover 600mm below road surface level; and
- Overland flow paths are to accommodate flows exceeding the 10 year ARI.

2.3 Catchment analysis

We determined the need for and the location of culverts based on catchment analysis. We identified existing sub-catchments and land-uses within the Pūhoi and Mahurangi catchments using a combination of land-use maps, aerial imagery and 2m contours derived from LiDAR. By considering the geometric design and nominated spoil disposal sites within the Project designation, we identified post-development catchments and land-uses. The delineation of each catchment and land-use is supported by observations we made on a number of site visits to the indicative Project alignment.

Sub-catchments associated with the bridges and culverts for the Project are shown in Figure 1. The Pūhoi and Mahurangi catchment extents are also shown.

Figure 1: Culvert and Bridge Sub-Catchments.

2.4 Hydrology

The hydrology is based on the TP108 method which uses a US Department of Agriculture, Soil Conservation Service (SCS, 1986) guidelines approach. The TP108 method is considered appropriate and industry practice for the Auckland Region.

The SCS method uses a curve number (CN) to describe the runoff characteristics of the land with a higher CN resulting in greater runoff. The SCS guidelines suggest that the major factors determining the curve number are the hydrological soil group, surface cover type, soil treatment, hydrological condition, and antecedent ground condition (i.e. the soil moisture content prior to a rainfall event). We assessed that the Project area consisted of group C soils (mudstone/sandstone), which is consistent with the geology of the catchments (refer Section 4.2 of the OWAR). The curve numbers adopted for the land-uses in the Project catchments are shown below in Table 3. Project areas modified by earthworks such as fill embankments, cut slopes and spoil sites are likely to generate higher runoff and to reflect this higher runoff anticipated we assigned higher CN numbers to these areas.

Table 3: Curve numbers adopted for the Project.

Land	CN
Forestry Area	70
Native Bush	70
Farmland/Pasture	74
Project fill embankments, vegetated cut slopes and spoil locations (>1.2:1 Slope)	79
Project motorway surface and rock cuts	98

2.5 Rainfall and runoff

Full details about the rainfall data and climate change allowance can be read in Water Assessment Factual Report 7: Hydrological Data.

Rainfall data used to calculate the catchment runoff was derived from TP108 based on the maximum predicted 24 hour rainfall depths for each catchment. We compared the 24 hr rainfall depths to the summary statistics for the Auckland Council Warkworth, Mahurangi and Orewa rain gauges, and the High Intensity Rainfall Design System (HIRDS) databases. We used the TP108 based rainfall depths for our assessment as they were higher than rainfall depths obtained from the rain gauge summary statistics and HIRDS databases.

Our hydrological assessment included an increase in rainfall intensity to allow for predicted climate change effects. Increased rainfall intensity is an important consideration because these changes are predicted to occur over the life of the Project's water infrastructure. Climate change variations to rainfall were estimated for 2120, which corresponds to 100 years after the Project completion.

We multiplied the TP108 rainfall data by the factor recommended in the Climate Change Effects and Impacts Assessment (Ministry for the Environment, 2008). Extreme rainfall events relative to 1990 were increased based on a mean predicted temperature rise for the Auckland region of 2.1°C to 2090. We then applied linear extrapolation of the 2040 and 2090 values in order to estimate the projected 2120 rainfall data.

The projected increase in maximum 24 hour rainfall depth for the 100 year ARI event in 2120 compared to TP108 values was 22.6%. The projected 2120 rainfall data for the Pūhoi and Mahurangi catchments that were used to estimate design flows and for the hydrological assessments are provided in Table 4.

We used peak runoff flow for a 2 year, 10 year and 100 year ARI in our hydraulic design calculations and hydrological assessments.

Table 4: Design 24 hour rainfall depths for 2120.

ARI	Pūhoi (mm/24hr)	Mahurangi (mm/24hr)
2 year	129	146
10 year	224	247
100 year	343	380

2.6 LiDAR survey check

We carried out field survey work to establish the profile of a selection of existing streams where we are proposing culverts. The survey work provided us with data to determine whether the LiDAR derived contours were sufficiently accurate to use for our consent design. We surveyed the streams where culverts 58400, 57600 and 54700 are proposed. When compared to the survey data, the LIDAR derived contours were found to be similar. This comparison provided us with confidence in the design we have carried out elsewhere on the Project based on the LiDAR survey information.

2.7 Hydraulic design

We determined the sizing of each culvert using HY-8 (Federal Highway Administration, U.S.A.) culvert design software. Inputs into HY-8 include:

- Design flows for each catchment (2 year, 10 year, 100 year ARI flows). We calculated these design flows using the TP108 graphical method;
- Existing stream characteristics invert levels, side-slopes, stream gradient and Manning's friction coefficient;
- Estimates for tailwater levels calculated using Manning's equation based on existing stream characteristics;
- Motorway/road elevation and width (geometric design); and

- Culvert shape, material, Manning's friction coefficient, diameter, length, inlet type, invert levels.

The culvert sizes we propose are in accordance with the design criteria listed in Table 2. Once the culvert size was determined, we used HY-8 to calculate the following outputs:

- Headwater depths at upstream end of culverts;
- Culvert outlet velocities; and
- Energy of flow at culvert outlet (Froude number).

These outputs have then been used in our assessment of headwater flooding, and design and assessment of energy dissipation structures. The outputs also support our assessment of effects of the Project on bed scour, bank erosion and flooding. These assessments are in Section 7 of the OWAR.

2.8 Culvert types

In total, we propose 40 culverts for the Project discussed in detail in Section 3.2 of the OWAR. The culvert types and number of each we propose are:

- 37 concrete pipe culverts (1.2m to 3.06m diameter); and
- Three concrete arch culverts (7.3m to 8.5m span).

The main design features of our proposed concrete pipe culverts include:

- Erosion protection at inlet;
- Wingwalls with handrails at inlet and outlet;
- Debris management if required (e.g. debris rack or relief inlet);
- Baffle type fish passage (if fish passage is required); and
- Energy dissipation structure for erosion protection at outlet.

The main design features of our proposed concrete arch culverts include:

- Upstream debris rack (relief inlet not applicable for large concrete arch culverts);
- Erosion protection at inlet;
- Handrails above inlet and outlet;
- Sufficient cross-section areas to meet the flow capacity, debris mitigation and access requirements;
- Raised platform on one side for safer maintenance environment;
- Natural bed for fish passage (if fish passage is required); and
- Energy dissipation structure for erosion protection at outlet.

The large concrete arch culverts are proposed for culverts 49500, 54700 and 60200. These three crossings of main tributaries to the Mahurangi River and Hikauae Creek are specified as arch culverts because the design flows calculated for their respective catchments are too large for conventional concrete pipe culverts.

Ancillary roads that require new culverts or extensions to existing culverts include:

- SH1, requiring upgrades to three culverts (refer Table 1);
- Moirs Hill Road realignment, requiring extensions to existing culverts (not detailed in consent design);
- Access road off Wyllie Road, requiring new culverts and a minor bridge (refer Table 1);
- Access road to Perry Road Viaduct, requiring culvert upgrades (not detailed in consent design); and
- Roads associated with underpasses (not detailed in consent design).

Refer to drawing SW-201 for typical concrete pipe and concrete arch culvert details. Table 1 provides a comprehensive culvert data table.

2.9 Fish Passage

The Project's freshwater ecologists identified the permanent and intermittent streams, as documented in the Freshwater Ecology Assessment Report. With the exception of only two streams in the northern valley area of the indicative alignment, fish passage in culverts has been provided for all permanent streams with upstream habitats, and for intermittent streams where there is potential for fish habitat upstream.

As part of our best practicable option (BPO) design approach, we have considered the type of fish passage (if required) at each culvert based on the characteristic of the site and the type of fish passage required. The flow chart for determining the fish passage requirement is shown in Figure 2.

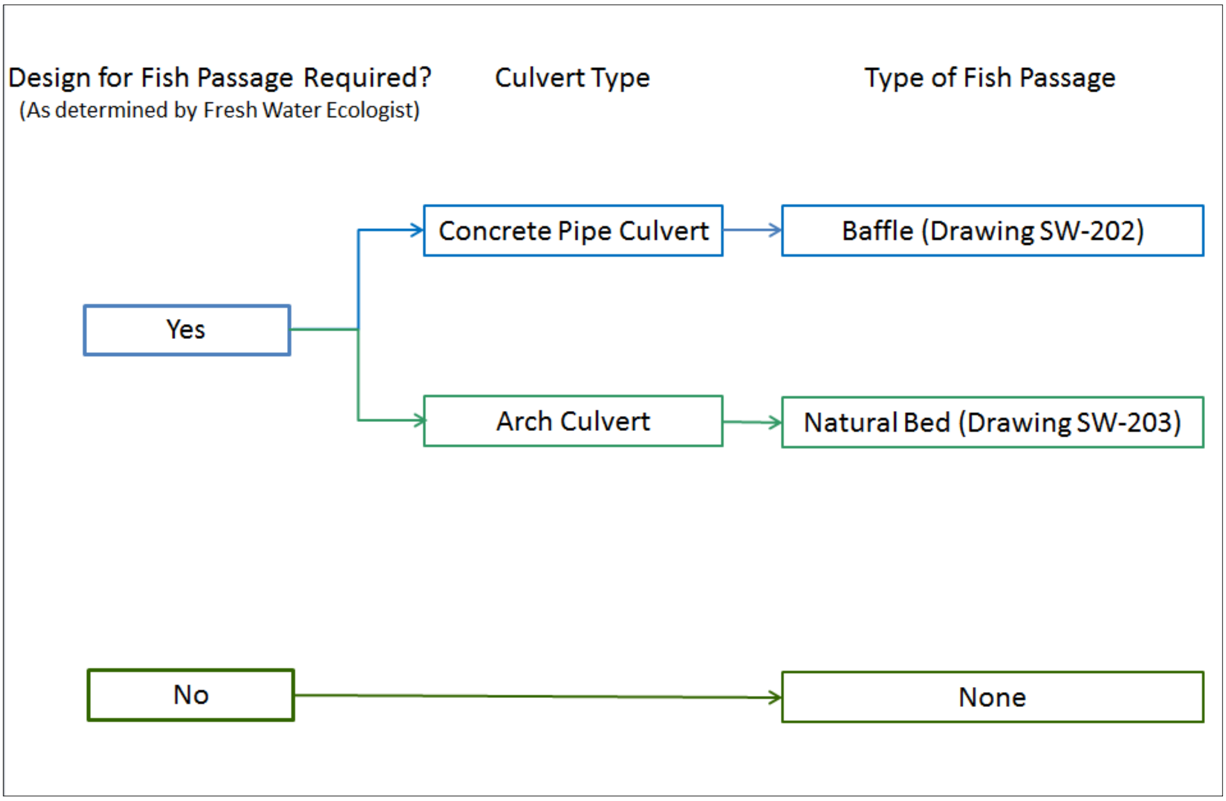

Figure 2: Flow Chart for Fish Passage.

The types of fish passage we propose are described below. Table 1 identifies the culverts where we are providing fish passage, and the type of fish passage we propose.

Baffle Type Fish Passage

The baffle design is based on Auckland Regional Council Technical Report Number 84, June 2009 (Fish Passage in the Auckland Region – a synthesis of current research). Plastic rectangular baffles create low velocity zones allowing fish to rest as they move through the culvert. These baffles are successfully used for fish passage in concrete pipe culverts for the adjacent Northern Gateway Toll Road (NGTR) section of SH1, refer Photo 1.

We propose a baffle type fish passage for concrete pipe culverts where both swimming and climbing fish species are expected. Refer to drawing SW-202 for typical details.

Fish passage baffles can introduce additional turbulence and obstruction to flow within a culvert. The baffles also increase the effective roughness of the culvert barrel, in some cases to the detriment of a culvert's hydraulic efficiency and flow capacity.

Research carried out by Leong et al (2007) on selected NGTR culverts show that in some cases the roughness of the culvert wall with fish passage baffles in comparison to a plain concrete pipe barrel can double. This research is referenced in an American Society of Civil Engineers (ASCE) paper which investigates the influence of fish passage baffles on flow within culverts (Feurich et al, 2007). The findings from both papers conclude that although the installation of baffles does improve fish passage, it can increase water depth and decrease velocity of flow. As a consequence the flow capacity of the culverts can decrease, especially if the hydraulics are outlet controlled.

In practice, for the NGTR and similarly for the Project culverts we propose, culvert flow capacity is generally governed by inlet control conditions and rarely by the capacity of the culvert. Thus the effect of fish baffles on the effective culvert flow capacity may be limited. Inlet control of a culvert is when a culvert barrel is capable of conveying more flow than the inlet will accept. Hydraulic characteristics downstream of the inlet control section do not affect the culvert capacity. Also the minimum size of many Project culverts is governed by access arrangements (refer Table 2) and they are often larger than required for hydraulic capacity.

There may be instances in the Project where detailed design establishes that a culvert is outlet controlled and baffles are required for fish passage. Outlet control of flow occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. This outlet control component in a culvert is either located at the culvert outlet or is further downstream and may be in the form of an obstruction in the downstream channel or hydraulic resistance of the stream channel. Further investigation and analysis during the detailed design phase of the Project will confirm the fish passage requirements and culvert sizes.

Photo 1: Baffle type fish passage installed at NGTR culvert

Natural Bed Type Fish Passage

The natural bed type of fish passage replicates a natural stream bed by using raised baffles at intervals to hold sediment within the bed of the culvert. The alternating baffle openings and sediment basins create a low flow channel with low velocity zones to encourage fish passage through the culvert.

We propose a natural bed type of fish passage in arch culverts where both swimming and climbing fish species are expected (Culverts 49500, 54700 and 60200). Refer to drawing SW-203 for typical details.

The drop structure required at the upstream end of culverts 47700 and 48000 (ecological ref. M23a and M23b respectively) will create a barrier to swimming fish passage. These drop structures are required because the motorway is in cut or close to the level of the existing ground, which requires a drop at the inlet to the culvert for the culvert to be located at sufficient depth under the road surface. The effect of the barrier to fish passage in these two locations is discussed further in the Freshwater Ecology Assessment Report.

2.10 Erosion control / energy dissipation

Energy dissipation structures are used to reduce high velocity and energy at the outlet of culverts prior to discharge back into the natural stream. Energy dissipation structures include stilling basins, impact basins and a range of other US Army Corps of Engineers (USACE) and Federal Highway Administration Hydraulic Engineering Circular No. 14 Hydraulic Design of Energy Dissipaters for Culverts and Channels (HEC-14) structures to suit different applications.

We assessed all culvert flows and velocities and assigned energy dissipation structures to ensure that potential downstream erosion is minimised.

The energy dissipation structures we identify as the BPO solutions for the Project are described in the sub-sections below the selection flow chart in Figure 3.

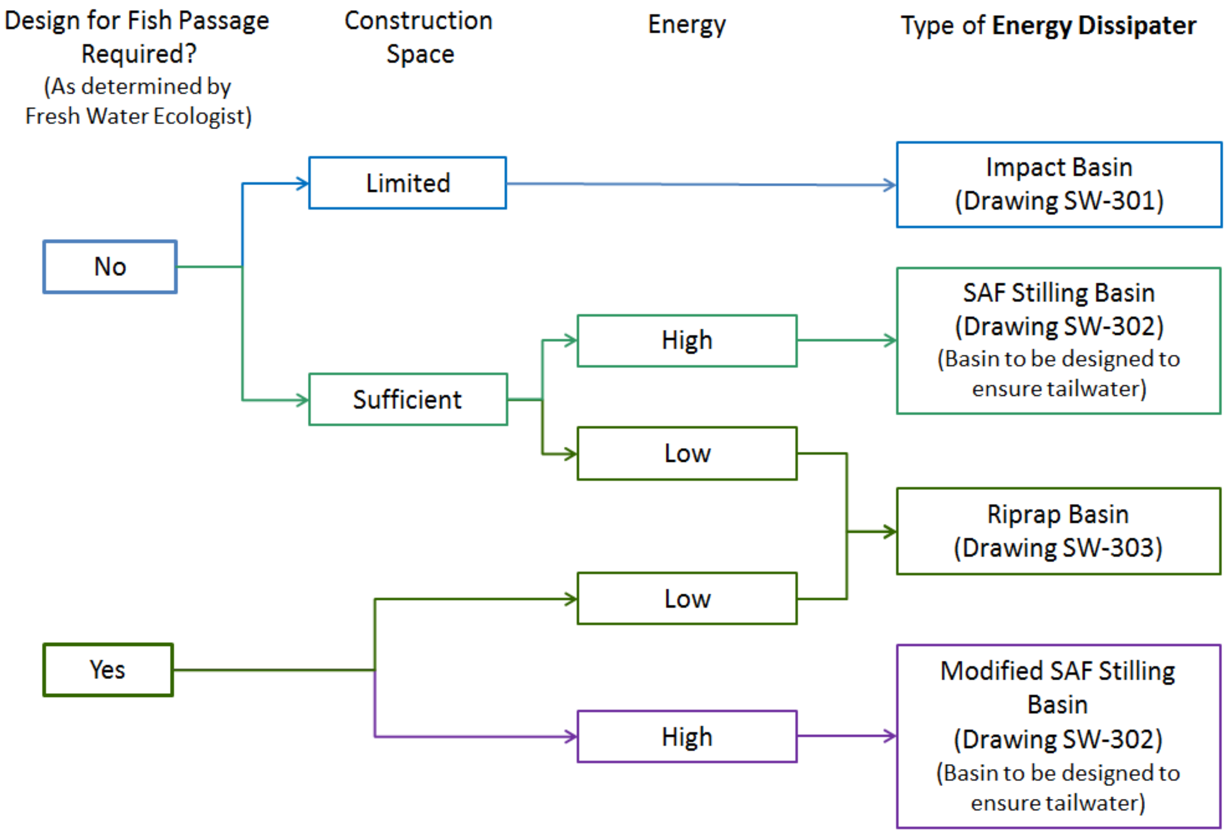

Figure 3: Flow chart for energy dissipation.

The options we considered for energy dissipation and erosion control for culvert outlets are outlined below. Options were shortlisted from 21 options in the Federal Highways Administration (2006) HEC-14, based on site and hydraulic conditions and the application of similar devices on the NGTR. A brief discussion of the merits of each method is provided to highlight which solutions we consider the BPO for the Project.

Impact Basin

An impact basin is a box structure at the culvert outlet that dissipates energy by directing the flow onto a vertical baffle. It has the advantages of only requiring a small area for construction, it can be precast off site, and the structure is applicable to a range of flows. A typical detail for an impact basin is shown on drawing SW-301. An example of an impact basin is shown in Photo 2 for the Otanerua wetland outfall on NGTR.

An impact basin is not suitable for fish passage.

Impact basins are also not suitable where there is potential for debris load, as they are susceptible to blockage and it is difficult to remove any blocked material. Impact basins are not proposed for any culverts, but may be used for stormwater outfalls.

Photo 2: Impact basin on NGTR Otanerua Wetland outfall. Note inlet pipe is located behind concrete baffle

SAF Stilling Basin

A St Anthony Falls (SAF) stilling basin is a concrete structure that receives discharges from a culvert into a basin via a baffled chute with blocks on the invert. The basin also has baffle blocks and a sill at the downstream end. The sill, in conjunction with a tailwater condition, produces a hydraulic jump. These three elements combined dissipate energy and return water downstream in a movement similar to the existing flow regime. The SAF Stilling Basin is most appropriate for culvert outfalls with high energy flows.

The standard SAF stilling basin is not suitable for fish passage and requires a large area. A typical detail for a SAF stilling basin is shown on drawing SW-302. SAF stilling basins are proposed for many of the culverts where our freshwater ecologist has determined there is no need for fish passage (Table 2). There is one instance where we propose a modified SAF stilling basin that is engineered for fish passage (Culvert 51000). This modification for fish passage is shown indicatively on the drawing.

Riprap Basin

A riprap basin is a rock lined basin containing a water pool at the culvert outlet to dissipate energy from the discharged flow. The basin includes a rock sill to form the pool and a rock apron downstream of the pool. The rock apron spreads the flow to further reduce the velocity and help to transition flow to the natural waterway downstream.

Riprap basins are suitable for fish passage provided they have appropriate details (e.g. fish passage into culvert outlet). Riprap basins require a large area. A typical detail for a riprap basin is shown on drawing SW-303. Riprap basins are proposed for many of the culvert outlets for the Project.

An example of a riprap basin is shown in Photo 3 for the Nukumea culverts on NGTR. At this location concrete baffles are also used on the wingwall apron. The rock that forms the riprap basin is obscured by vegetation that has established around the pool. The presence of the vegetation confirms the effectiveness of the riprap pool for energy dissipation prior to discharge to the downstream environment. The pool also assists with fish passage into the culverts.

Photo 3: Riprap basin for NGTR Nukumea culverts

Table 5 identifies the energy dissipation structure we propose for each culvert.

2.11 Effectiveness of proposed energy dissipation structures

Effectiveness of the energy dissipation structures has been modelled using HY-8's inbuilt energy dissipater module. HY-8 calculates culvert exit velocity and energy, sizes of the energy dissipation structures, and provides post-energy dissipation flow velocities for analysis.

We have assessed the change in flow velocity at culvert outfalls based on the 2 year ARI flows as these storm events are important with regard to potential erosion of a stream bed. These velocities are also provided in Table 5. We have compared peak flow velocities for a 2 year ARI event at proposed culvert outlets with energy dissipation, to pre-development conditions. This comparison forms the basis for our assessment of the effects for each outfall on its respective receiving environment, described in Section 8 of the OWAR.

Table 5: Energy dissipation structures and performance in a 2 year ARI storm event.

Culvert ID	Stream	Culvert Diameter (mm)	Energy Dissipation Structure	2 Year ARI Existing Stream Velocity Pre–Development*1 (m/s)	2 Year ARI Stream Velocity Pre-Energy Dissipation (m/s)	2 Year ARI Stream Velocity Post–Energy Dissipation (m/s)	% Velocity Increase (+) / Decrease (-) due to Project
ON PROPOSED MOTORWAY ALIGNMENT							
Culvert 63800	P2	1600	SAF Stilling Basin	1.29	4.84	1.29	0%
Culvert 63500	P3	1800	SAF Stilling Basin	1.67	6.16	1.67	0%
Culvert 63000	P3a	1350	SAF Stilling Basin	1.41	5.49	1.41	0%
Culvert 61900	P5	1600	Riprap Basin	0.72	2.68	0.47	-35%
Culvert 61600	P6	1800	SAF Stilling Basin	1.45	4.97	1.45	0%
Culvert 61300	P6a	1200	SAF Stilling Basin	1.11	5.50	1.11	0%
Culvert 61100	P7	1350	SAF Stilling Basin	1.87	7.41	1.87	0%
Culvert 60800	P8	2550	SAF Stilling Basin	1.82	6.29	1.82	0%
Culvert 60200 ARCH	P9	Arch (7315 Span, 3658 Height)	Riprap Basin	2.28	2.74	0.40	-82%
Culvert 59900	P9b	1200	SAF Stilling Basin	0.72	2.65	0.72	0%
Culvert 59800	P9a	1600	SAF Stilling Basin	1.49	5.58	1.49	0%
Culvert 59400	P10a	1200	SAF Stilling Basin	0.60	2.18	0.60	0%
Culvert 58700	P11a	1600	SAF Stilling Basin	1.53	5.27	1.53	0%
Culvert 58400	P11b/c	1600	SAF Stilling Basin	1.99	6.88	1.99	0%
Culvert 57600	P11f	1600	SAF Stilling Basin	2.04	8.24	2.04	0%

Culvert ID	Stream	Culvert Diameter (mm)	Energy Dissipation Structure	2 Year ARI Existing Stream Velocity Pre–Development*1 (m/s)	2 Year ARI Stream Velocity Pre-Energy Dissipation (m/s)	2 Year ARI Stream Velocity Post–Energy Dissipation (m/s)	% Velocity Increase (+) / Decrease (-) due to Project
Culvert 57400	P11g	1350	SAF Stilling Basin	2.74	10.94	2.74	0%
Culvert 57200	P12	1600	SAF Stilling Basin	1.17	3.95	1.17	0%
Culvert 56700	M13	1600	SAF Stilling Basin	1.64	6.09	1.64	0%
Culvert 56400	M13a	1200	SAF Stilling Basin	1.40	5.89	1.40	0%
Culvert 56100	M13b	1200	SAF Stilling Basin	1.12	4.31	1.12	0%
Culvert 55300	M13d	2550	Modified SAF Stilling Basin	1.40	8.06	1.40	0%
Culvert 54700 ARCH	M15	Arch (8534 Span, 4267 Height)	Riprap Basin	1.92	1.33	0.30	-84%
Culvert 53800	M15a	1600	Riprap Basin	0.85	3.16	0.55	-35%
Culvert 53000	M16a	1600	SAF Stilling Basin	1.41	5.17	1.41	0%
Culvert 51900	M19a	1200	SAF Stilling Basin	0.87	3.26	0.87	0%
Culvert 51600	M19b	1200	SAF Stilling Basin	1.36	5.35	1.36	0%
Culvert 51300	M19c	1800	SAF Stilling Basin	1.73	6.38	1.73	0%
Culvert 51000	M21a	1600	Modified SAF Stilling Basin	1.32	4.86	1.32	0%
Culvert 50800	M21b	1200	SAF Stilling Basin	1.12	4.80	1.12	0%
Culvert 50500	M21c	1200	Modified SAF Stilling Basin	1.07	4.26	1.07	0%
Culvert 50200	M21d	1600	Riprap Basin	1.13	4.25	0.68	-40%

Culvert ID	Stream	Culvert Diameter (mm)	Energy Dissipation Structure	2 Year ARI Existing Stream Velocity Pre–Development*1 (m/s)	2 Year ARI Stream Velocity Pre-Energy Dissipation (m/s)	2 Year ARI Stream Velocity Post–Energy Dissipation (m/s)	% Velocity Increase (+) / Decrease (-) due to Project
Culvert 49500 ARCH	M22	Arch (7315 Span, 3658 Height)	Riprap Basin	1.84	1.11	0.26	-86%
Culvert 48000	M23a	1350	Riprap Basin	0.89	3.38	0.64	-28%
Culvert 47700	M23b	1350	Riprap Basin	0.59	2.25	0.43	-27%
Culvert 47400	M23c	1600	Riprap Basin	1.57	5.56	0.93	-41%
Culvert 47200	M23d	1200	Modified SAF Stilling Basin	1.03	4.39	1.03	0%
ON PROPOSED EASTERN LINK TO WARKWORTH							
Culvert 700SH1S	SH1-700	1600	SAF Stilling Basin	1.80	6.91	1.80	0%
ON PROPERTY ACCESS ROAD (Wyllie Rd)							
Culvert 100A	PA100A	1050	Riprap Basin	1.43	3.49	1.20	-16%
Culvert 200A	PA200A	900	Riprap Basin	1.22	3.15	1.19	-3%
Culvert 500A	PA500A	900	Riprap Basin	1.30	4.89	1.21	-7%

*1 Pre-development existing stream velocities based on assumed trapezoidal channel cross section of 3m bottom width and 3:1 (H:V) side slopes.

2.12 Headwater extents

The water depth at the inlet of culverts from the water surface of the pool that forms as a result of heading up is called the headwater. Headwater flood levels upstream of culverts for a 100 year ARI storm event have been determined using HY-8 culvert design software. The extent of the headwater flooding has been plotted on the Project drawings using LiDAR contours.

We designed the culverts to head up in accordance with the design sizing criteria in Section 2.2. This design approach is standard practice to efficiently convey flow through a culvert.

The headwater extents are generally local and/or within the floodplain of the streams. The only location where 100 year ARI flood headwater extents are predicted to extend beyond the designation is at Culvert 49500. The headwater floods a major branch of the Mahurangi River for approximately 500m of stream length beyond the Project designation (measured inclusive of stream meander). There are no dwellings affected. The predicted headwater extent is contained within the floodplain of the rapid flood hazard assessment for the area outside the designation, indicating that flooding here is not made worse by the Project.

Culvert headwater extents have not been assessed in fill areas (spoil disposal and landscape fill sites) as the fill extents and profiles are subject to detail design.

2.13 Upgrades of existing SH1 culverts

The performance of existing SH1 culverts through the Pūhoi and Hungry Creek Sectors was assessed in the hydrological assessment described in Section 6.2 of the OWAR. The location of the existing SH1 culverts referred to above are shown in Figure 4: Existing State Highway 1 culverts.

We identified that three culverts require upgrading because additional flow will be discharged to those streams by the Project. The performance criterion for these culverts is conveyance of the 100 year ARI flood with minimum 500mm freeboard. Post-development, the three culverts listed in Table 6 were not achieving this criterion. To mitigate this and achieve the performance criteria, we propose upgrading these three culverts by providing an additional concrete pipe. The existing pipe will remain. The twin barrel will then convey post-development flow to the same outlet location as the existing SH1 culvert. Pre and post-development scenarios for the three existing SH1 culverts are shown in Table 6.

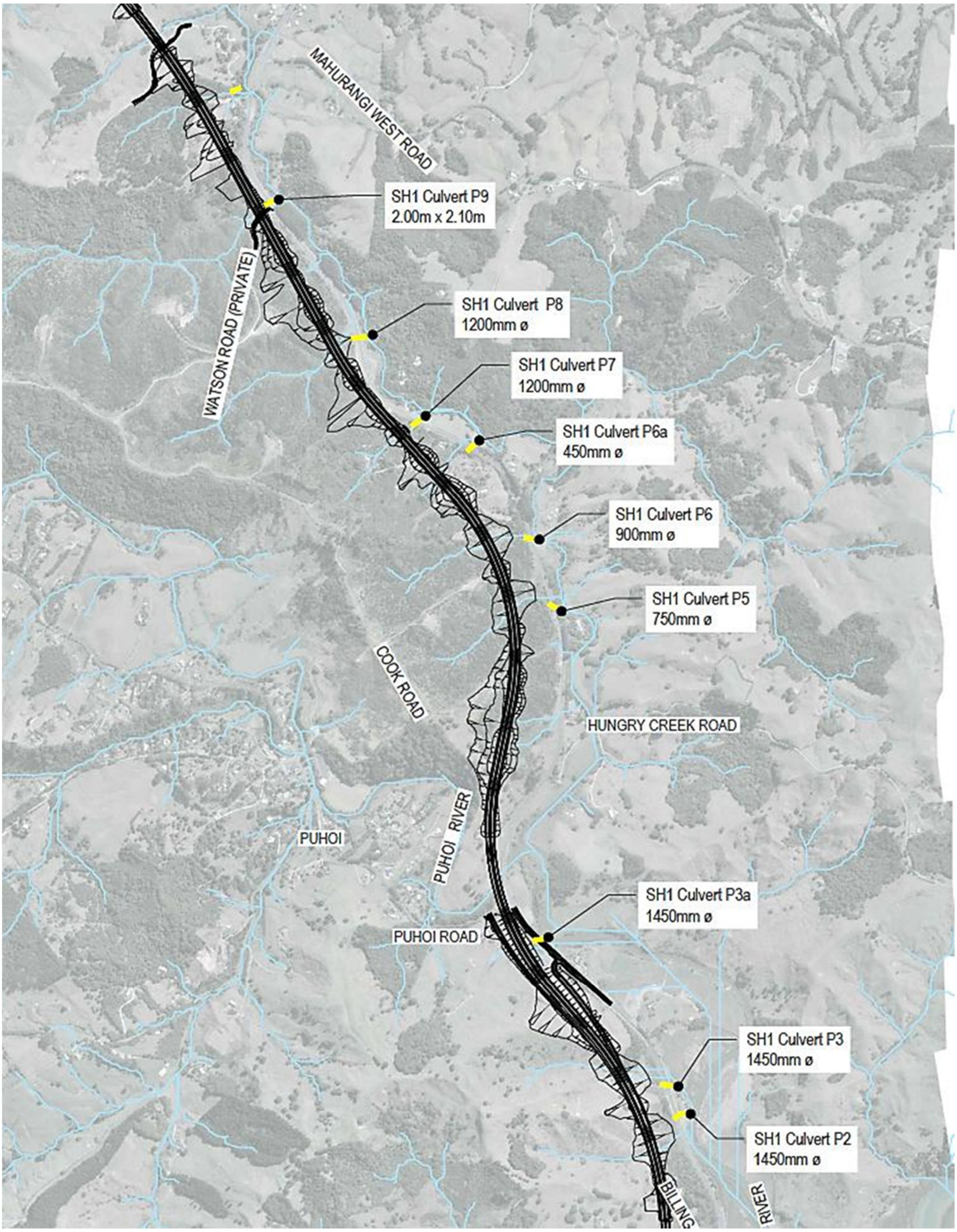

Figure 4: Existing State Highway 1 culverts.

Table 6: Proposed upgrades to existing SH1 culverts.

Culvert	Ecological Reference	Culvert Type	Diameter or Size	Sufficient Capacity Pre-development?	Flow Increase Post-development?	Sufficient Capacity Post-development with no Mitigation?	Mitigation Proposed	Sufficient Capacity Post-development with Mitigation?
SH1 Culvert P6	P6	Concrete pipe	900mm diameter	N	Y	N	Existing culvert to remain. Construct new 1.2m diameter concrete pipe culvert next to existing.	Y
SH1 Culvert P8	P8	Concrete pipe	1200mm diameter	Y	Y	N	Existing culvert to remain. Construct new 0.9m diameter concrete pipe culvert next to existing.	Y
SH1 Culvert P9	P9	Concrete box culvert	2m x 2.1m box culvert	N	Y	N	Existing culvert to remain. Construct new 1.6m diameter concrete pipe culvert next to existing.	Y

3. Bridge design (hydraulic criteria only)

3.1 Introduction

Considerations for the choice of a bridge or culvert are presented in Section 2.1. A bridge structure offers a range of advantages over a culvert. These advantages include:

- Physical works required within a watercourse/stream are minimised. Bridge piers can be spaced to suit site constraints etc;
- Fish passage through an existing stream channel can remain unchanged from the pre-development condition;
- Higher capacity for flow conveyance then a culvert; and
- Risk of blockage from debris flow significantly reduced or eliminated.

Where possible, bridge piers are positioned outside of watercourses to:

- Reduce impacts of working within a water course during construction;
- Reduce potential scour of the riverbed; and
- Minimise the need for structures (abutments and piers) being located within the coastal marine area (CMA).

3.2 Catchment analysis and hydrology

We adopted the same methodology for identifying bridge sub-catchments and assessing the catchment hydrology as the methodology described in Section 2 for culverts.

Sub-catchments associated with the bridges for the Project are shown in Figure 1.

3.3 Bridge design criteria

The design requirements for bridges are detailed in Table 7.

Table 7: Bridge sizing criterion (hydraulic considerations only).

Criteria	Source
Accommodate a 100 year ARI with a minimum freeboard to the edge of the motorway of 600mm in non-forested areas and 1200mm in forested areas.	NZTA RoNS Design Standards & Guidance Document (2009) NZTA Bridge Manual Section 2.3.4 Hydraulics)

The conveyance and minimum freeboard requirements are met for all bridges without difficulty as the motorway surface and soffit levels are significantly above flood levels to meet requirements of the road vertical geometry.

3.4 Bridge locations

The Project proposes seven large viaducts and five bridges, of which nine are required for stream/river crossings. These locations and the key considerations associated are listed in Table 8, and described in full in Section 7.6 of the OWAR.

Table 8: BPO assessment for bridges for stream/river crossings.

Bridge name	Consideration
Okahu Viaduct	• Estuary crossing • Moderate sized catchment (331ha) • Desire to avoid reclamations (in the CMA) and effects on estuary • Combined crossing of Billing Road Driveway • Height and length of crossing required (vertical grade from Johnstone's Hill tunnels) • Prestressed concrete box girder has 75m spans which reduce the piers and construction activity in water • Reduced impact on Te Pā o Te Hemara Tauhia at the southern abutment
Pūhoi Viaduct	• Significant river crossing with large 3,312ha catchment, so design flow too high for culvert • Height and length of crossing required
Hikauae Viaduct	• Minor creek crossing (22ha)
Schedewys Viaduct	• Major river crossing (527ha) • Height and length of crossing required
Perry Road Viaduct	• Major river crossing (548ha) • Height and length of crossing required
Kauri Eco Viaduct	• Major river crossing (190ha) • Height and length of crossing • Kauri natural forest in area
Woodcocks Road Viaduct	• Major river (399ha) and floodplain crossing - Mahurangi River Left Branch
Carran Road Flood Relief Bridge	• Major secondary flow path • Passing over local road
Minor Bridge – Property Access Road	• Stream crossing • Natural bush area conserved by minor bridge structure

3.5 Carran Road Flood Relief Bridge

Flooding in the Carran Road Sector is a major consideration for the indicative Project alignment. The main issues are the floodplain of the Mahurangi River Left Branch, and the major secondary flow path that spills from the Mahurangi River Left Branch and flows north before returning via the Hudson Road area to the Mahurangi River downstream of Falls Road (refer Factual Report 10: Flood Assessment and Section 4.3 of the OWAR).

The Carran Road Flood Relief Bridge is the only bridge where waterway capacity requirements are the primary constraint and we therefore undertook preliminary hydraulic design in this area. We developed a concept design using HY-8 (Federal Highway Administration, U.S.A.) culvert design software, and carried out further assessment using the rapid flood hazard model (refer Section 6.3 of the OWAR). The effect of the Woodcocks Road Viaduct on flooding was also assessed in the same flood hazard model. Flood conveyance and the afflux (rise in water level on the upstream side of the bridge) are key to our design and assessment therefore are also considered.

We initially proposed a 28m span for the Carran Road Flood Relief Bridge however the afflux (rise in water level on the upstream side of the bridge) was greater than we consider acceptable. A 60m span Carran Road Flood Relief Bridge is the BPO that provides an afflux we consider acceptable. Details of the modelling are included in the Factual Report 10: Flood Assessment.

Section 8.6 of the OWAR provides our assessment of the effect of the Project on flooding. The effects of predicted afflux and changes in peak flow are also assessed in that report.

4. Debris hazard

4.1 Introduction

We used a risk framework to assess the risk from debris to culvert blockage and determine mitigation measures for inclusion in the Project. Debris are carried by flood flows and by less frequent and more hazardous debris flows. A summary of our risk framework follows.

Debris flows are a fast flowing mixture of water with a medium or high proportion of solids, which moves down watercourses. Debris flows are triggered by heavy rainfall and can often occur in conjunction with landslides within the catchment. Debris flows are potentially destructive and can encompass a wide range of objects, such as fallen trees, stumps, boulders, gravels and soils, plus water.

Debris can accumulate at a culvert inlet or become lodged in the inlet or barrel. When this debris accumulation happens, the culvert will fail to perform as designed. Upstream flooding may occur and there may be a risk of roadway overtopping. This overtopping may put the motorway embankments at risk and their subsequent failure puts downstream environments, infrastructure and people at risk.

We developed a Debris Management Framework for the concept design of the Project. The Framework will be updated at the detailed design stage. At detailed design the debris flow potential in the catchments will be more closely examined considering geology and slope characteristics of catchments. It will also be necessary to consider the potential for overtopping of the motorway embankment. Where there is a high consequence of culvert blockage, the potential impact category may need to be considered in accordance with the New Zealand Society on Large Dams (NZSOLD) guidelines, which may require higher design standards to be adopted for detailed design.

4.2 Risk

The risk associated with debris flow occurrence is a product of the likelihood of debris flows and culvert blockage, and the consequence of this culvert being blocked. This relationship is described in Table 9.

Table 9: Risk matrix for debris flows.

		Likelihood of debris flows and culvert blockage		
		Low	*Moderate*	*High*
Consequence of culvert blockage	*Low*	Low	Moderate	Moderate
	High	Moderate	High	High

We categorise the likelihood of debris flow occurrence as follows in Table 10.

Table 10: Likelihood of debris flow occurrence and culvert blockage.

Likelihood	Description
Low	Culverts where there is a low likelihood of debris in the upstream catchment are generally servicing small catchment areas where land-use is predominantly farmland or pasture. Farmland and pasture are unlikely to produce significant volumes of debris with culvert blocking potential during a storm event, particularly if the catchment is small.
Moderate	Culverts where there is a moderate likelihood of debris in the upstream catchment are generally servicing moderate sized catchment areas where the land-use is predominately bush or forestry. Bushland and forestry (both planted and clear-fell state) may produce tree and foliage debris in the event of a storm, generating landslides and resulting debris flows. A moderate sized catchment may create sufficient flow to transport debris material.
High	Culverts where there is a high likelihood of debris in the upstream catchment are generally servicing large catchment areas that include extensive bush and/or forestry. Bushland and forestry (both planted and clear-fell state) are likely to produce tree and foliage debris in the event of a storm, generating landslides and resulting debris flows. A large sized catchment is most likely to create sufficient flow to transport debris material.

The consequence associated with a blocked culvert is related to the potential flooding impact on the upstream side of the motorway and the risk to downstream areas from failure of road embankments. We have used the classification of a dam in the NZSOLD guidelines to categorise the consequence as low or high as shown in Table 11.

Table 11: Consequence for debris flows.

Consequence	Description
Low	When blockage of a culvert occurs, a low consequence is either no effect or no inundation of buildings. In terms of the risk to the embankment, the volume of water stored behind the embankment is < $20{,}000m^3$ and less than 3m in depth.
High	When blockage of a culvert occurs, a high consequence is inundation of one or more buildings, flooding of the motorway, motorway embankment failure, and/or potential for loss of life. The volume of water stored behind the embankment is likely to be > $20{,}000m^3$ and more than 3m in water depth.

4.3 Debris control measures

Where the risk of blockage of a culvert by debris is moderate or high, this risk needs to be mitigated by incorporating debris control measures. Table 12 lists the mitigation measures we propose for the Project for different degrees of risk of blockage of a culvert and the consequence associated with the occurrence of debris flow.

Table 12: Debris blockage mitigation measures.

Risk	Mitigation
High	Debris rack upstream of culvert (Drawing SW-305) AND Culvert sized to pass 100 year ARI without heading up
Moderate	Relief inlet (Drawing SW-306)
Low	None

High Risk

For culverts with a high risk of debris blockage, our preferred mitigation measure is to construct a debris control structure. This structure comprises a steel rack at least 20m upstream of the culvert and is designed to trap a proportion of large debris before it reaches the culvert. A typical detail of a debris rack is shown in drawing SW-305.

The debris rack will allow flow to overtop the trapped debris to maintain conveyance of flow through to the culvert. During operation of the motorway, ongoing inspections will be required to inspect debris screens and to undertake maintenance as required.

Further mitigation is provided by sizing the culvert with additional capacity to accommodate 100 year ARI flow with the top water level not exceeding the culvert soffit level (the highest point on the inside of the culvert). The additional sizing of the culvert to accommodate the 100 year ARI flow provides a generous culvert cross-sectional area that also reduces the potential risk of blockage due to debris.

Moderate Risk

For culverts with a moderate risk of blockage due to debris accumulation, our preferred mitigation measure is to install a relief inlet, as shown in drawing SW-306. A relief riser is a secondary intake with debris screen that is mounted on a vertical manhole over the culvert. In the event of any blockage of the culvert inlet the water will rise up the embankment to the relief inlet. The relief inlet allows flow to enter the culvert by this secondary inlet, and reduces flooding depths at the culvert. The relief inlet has some resilience to blockage as rising water levels cause debris to float off the debris screen.

Low Risk

For culverts within the Project that are at low risk of blockage due to debris accumulation, we do not consider any mitigation measures are necessary.

In addition to the risk framework above, culverts over a specified length are oversized to accommodate access/maintenance requirements. Refer to Section 2.2 which summarised the culvert design criteria. This oversizing provides a generous culvert cross-sectional area that results in a generally lower risk of debris blockage for the Project.

The debris blockage mitigation measures proposed for the Project are summarised in Table 1.

5. Stream diversion requirements

5.1 Introduction

Stream diversions are required where natural streams will be affected by the construction of the motorway. The diversions either convey flow to a culvert, a bridge, or to another stream or water body. Our mitigation objective for stream diversions is to recreate streams and habitats to replicate as much as possible the natural state and habitats of the steams that existed prior to the Project.

Diversions are required:

- Where fill and spoil sites impinge on streams and/or flow channels; or
- Where proposed culverts are built off-line and require a diversion to and from the natural stream to convey the flow.

We developed stream diversion requirements to describe the outcomes for stream diversions, and these are discussed in more detail in Section 5.2. We developed three stream diversion typologies collaboratively with the Project's engineers and ecologists, with input provided from Hōkai Nuku.

A summary of the lengths of streams affected by culverts and associated stream diversions is included in Table 13. All culverts are assumed to require 10m of stream diversion upstream and downstream to tie back into the existing stream as they will normally be constructed off-line (i.e. out of the stream in the dry and protected from flooding of the stream). The construction of culverts is described in the Construction Water Assessment Report.

Table 13: Summary of stream diversions.

Stream				Cross Drainage	Stream Diversion		
Catchment	Stream	Ecological Status	Fish Type	Associated Culvert / Bridge	Type 1 (m)	Type 2 (m)	Type 3 (m)
Pūhoi	ON PROPOSED MOTORWAY ALIGNMENT						
	P1	Estuarine	"Swimming"	BRIDGE - OKAHU VIADUCT	76		
	P2	Intermittent	None	Culvert 63800			61
	P3	Intermittent	None	Culvert 63500			163
	P3a	Intermittent	None	Culvert 63000			90
	P5	Intermittent	None	Culvert 61900			660
	P6	Intermittent	None	Culvert 61600			621
	P6a	Permanent	None	Culvert 61300			28
	P7	Permanent	None	Culvert 61100			20
	P8	Intermittent	None	Culvert 60800			42
	P9	Permanent	"Climbing"	Culvert 60200 ARCH		32	
	P9b	Intermittent	None	Culvert 59900			20
	P9a	Intermittent	None	Culvert 59800			20
	P10a	Intermittent	None	Culvert 59400			20
	P11a	Intermittent	None	Culvert 58700			122
	P11b/c	Permanent	None	Culvert 58400			226
	P11f	Intermittent	None	Culvert 57600			439
	P11g	Intermittent	None	Culvert 57400			304

Stream				Cross Drainage	Stream Diversion		
Catchment	**Stream**	**Ecological Status**	**Fish Type**	**Associated Culvert / Bridge**	**Type 1 (m)**	**Type 2 (m)**	**Type 3 (m)**
	P12	Intermittent	None	Culvert 57200			447
Mahurangi	M13	Intermittent	None	Culvert 56700			20
	M13a	Intermittent	None	Culvert 56400			44
	M13b	Intermittent	None	Culvert 56100			42
	M13d	Permanent	"Climbing"	Culvert 55300		1486	
	M15			STREAM DIVERSION			605
	M15	Permanent	"Climbing"	Culvert 54700 ARCH		20	
	M15a	Intermittent	None	Culvert 53800			335
	M16a	Intermittent	None	Culvert 53000			155
	M18/19	Permanent	"Swimming"	BRIDGE - KAURI ECO VIADUCT	289		
	M19a	Intermittent	None	Culvert 51900			20
	M19b	Intermittent	None	Culvert 51600			111
	M19c	Intermittent	None	Culvert 51300			20
	M21a	Intermittent	"Climbing"	Culvert 51000		37	
	M21b	Permanent	None	Culvert 50800			20
	M21c	Intermittent	"Swimming"	Culvert 50500	20		
	M21d	Intermittent	"Swimming"	Culvert 50200	73		
	M22	Permanent	"Swimming"	Culvert 49500 ARCH	31		
	-	Permanent	"Swimming"	BRIDGE - CARRAN ROAD FLOOD RELIEF BRIDGE	344		

Stream				Cross Drainage	Stream Diversion		
Catchment	Stream	Ecological Status	Fish Type	Associated Culvert / Bridge	Type 1 (m)	Type 2 (m)	Type 3 (m)
	M23a	Permanent	"Swimming"	Culvert 48000	220		
	M23b	Permanent	"Swimming"	Culvert 47700	145		
	M23c	Permanent	"Swimming"	Culvert 47400	51		
	M23d	Intermittent	"Climbing"	Culvert 47200	191		
	ON PROPOSED EASTERN LINK TO WARKWORTH						
	SH1-700	Intermittent	None	Culvert 700SH1S			40
	ON PROPERTY ACCESS ROAD (WYLLIE ROAD)						
	PA100A	Intermittent	"Swimming"	Culvert 100A	20		
	PA200A	Intermittent	"Swimming"	Culvert 200A	20		
	PA500A	Intermittent	"Swimming"	Culvert 500A	20		

5.2 Stream diversion typologies and requirements

Our mitigation objective for stream diversions is to replicate as much as possible the natural state and habitats of the steams that existed prior to the Project.

The number of stream diversions required has been reduced in consultation with the Road Design and Geotechnical teams, and by agreeing the spoil location sites and manipulating the road alignment to avoid existing streams where possible.

A summary of the lengths of streams affected by culverts and associated stream diversions in the Pūhoi and Mahurangi catchments are included in Table 14 and Table 15 respectively.

Table 14: Streams affected in the Pūhoi Catchment.

Stream	Stream Loss (m) (Lost Habitat)	Stream Diversion Proposed (m) (New Habitat)	Net Change in Habitat (m)
Permanent Stream	1013	108	-905
Intermittent Stream	3388	0	-3388

Table 15: Streams affected in the Mahurangi Catchment.

Stream	Stream Loss (m) (Lost Habitat)	Stream Diversion Proposed (m) (New Habitat)	Net Change in Habitat (m)
Permanent Stream	3469	2586	-883
Intermittent Stream	4144	381	-3763

5.2.1 Stream diversion typologies

We have developed three stream diversion typologies to best replicate the existing environment as follows:

- Stream Diversion Type 1 – "Lowland Stream" that recreates habitats associated with a natural lowland stream.
- Stream Diversion Type 2 – "Steep Stream" that recreates habitats associated with a natural steep stream.
- Stream Diversion Type 3 – Flow Channel for flow conveyance only.

The total lengths as summarised from Table 13 are as follows.

- Stream Diversion Type 1 = 1,500m
- Stream Diversion Type 2 = 1,575m
- Stream Diversion Type 3 = 4,695m

Stream diversion types 1 and 2 are natural stream forms that replicate the stream bed morphology and the flow hydraulics of the natural stream being diverted. Type 3 (Flow channel) only provides for water conveyance.

Figure 5, Figure 6 and Figure 7 provide typical cross sections of the three types of stream diversions we propose.

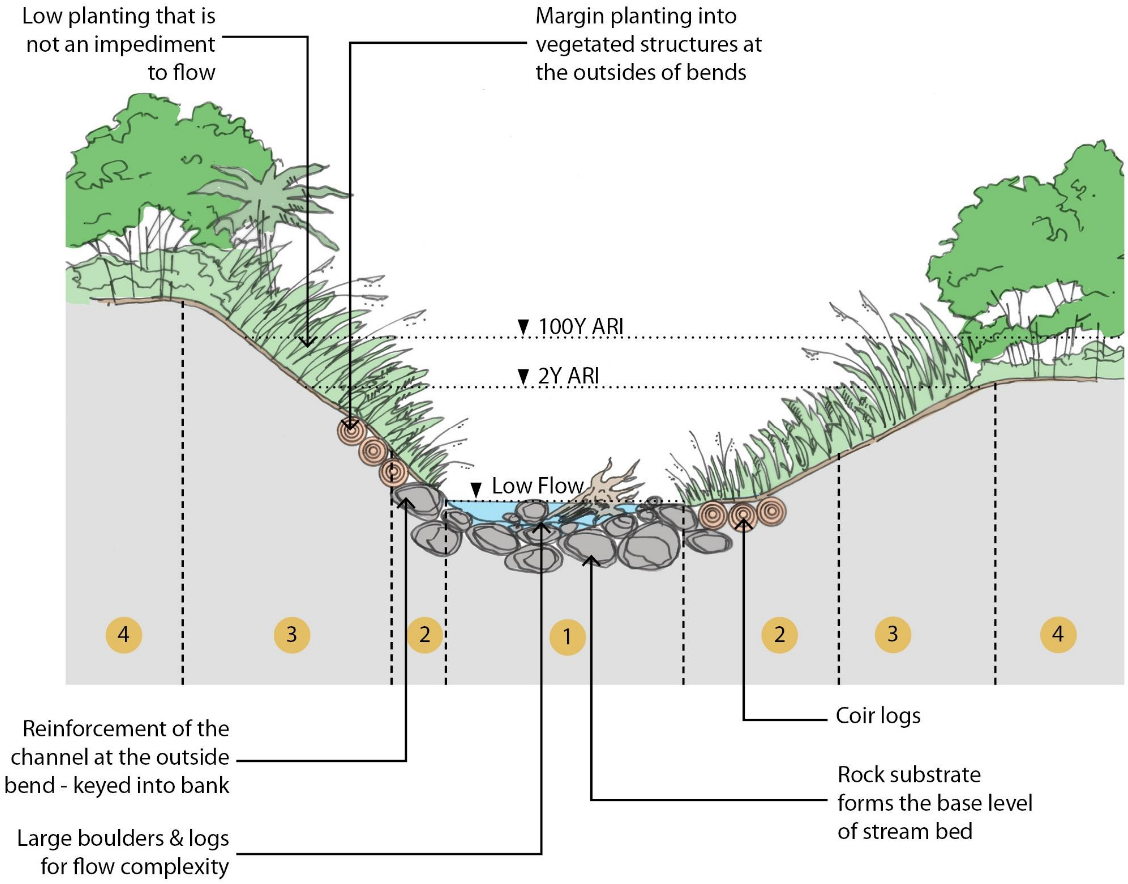

Figure 5: Stream Diversion Type 1 – Lowland Stream Cross Section (extract from Drawing SW-401).

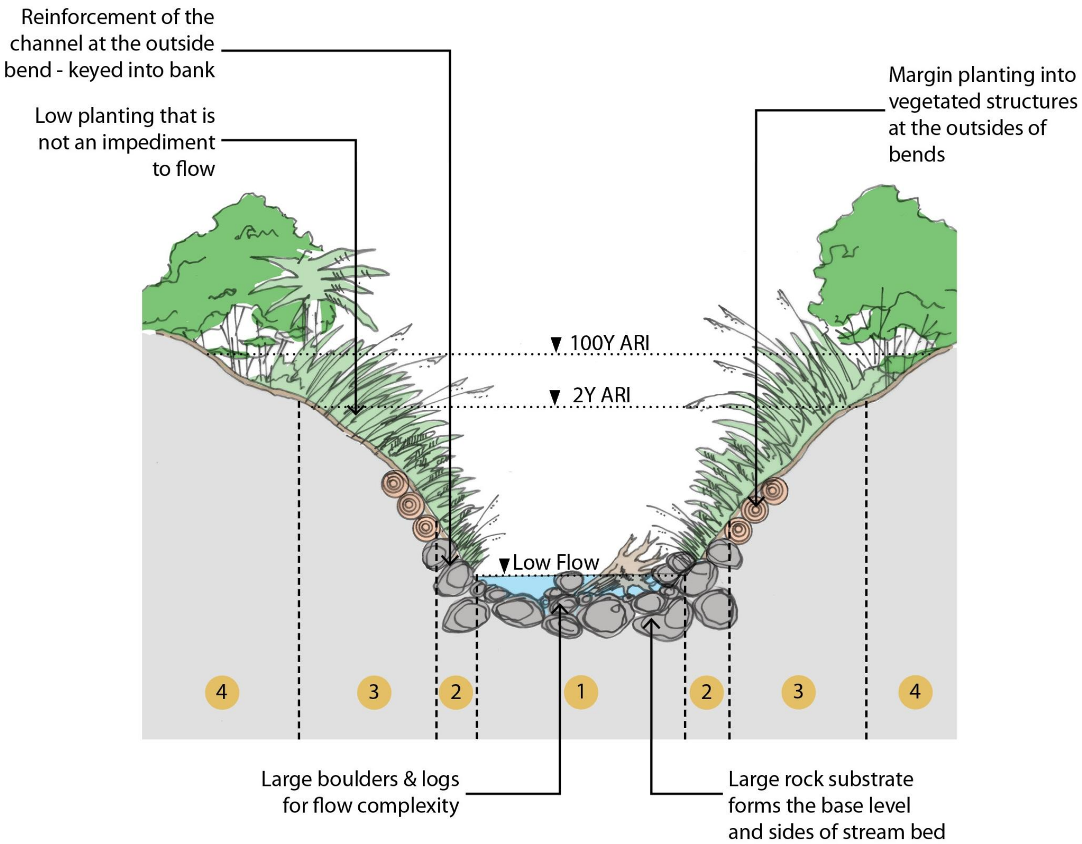

Figure 6: Stream Diversion Type 2 – Steep Stream Cross Section (extract from Drawing SW-402).

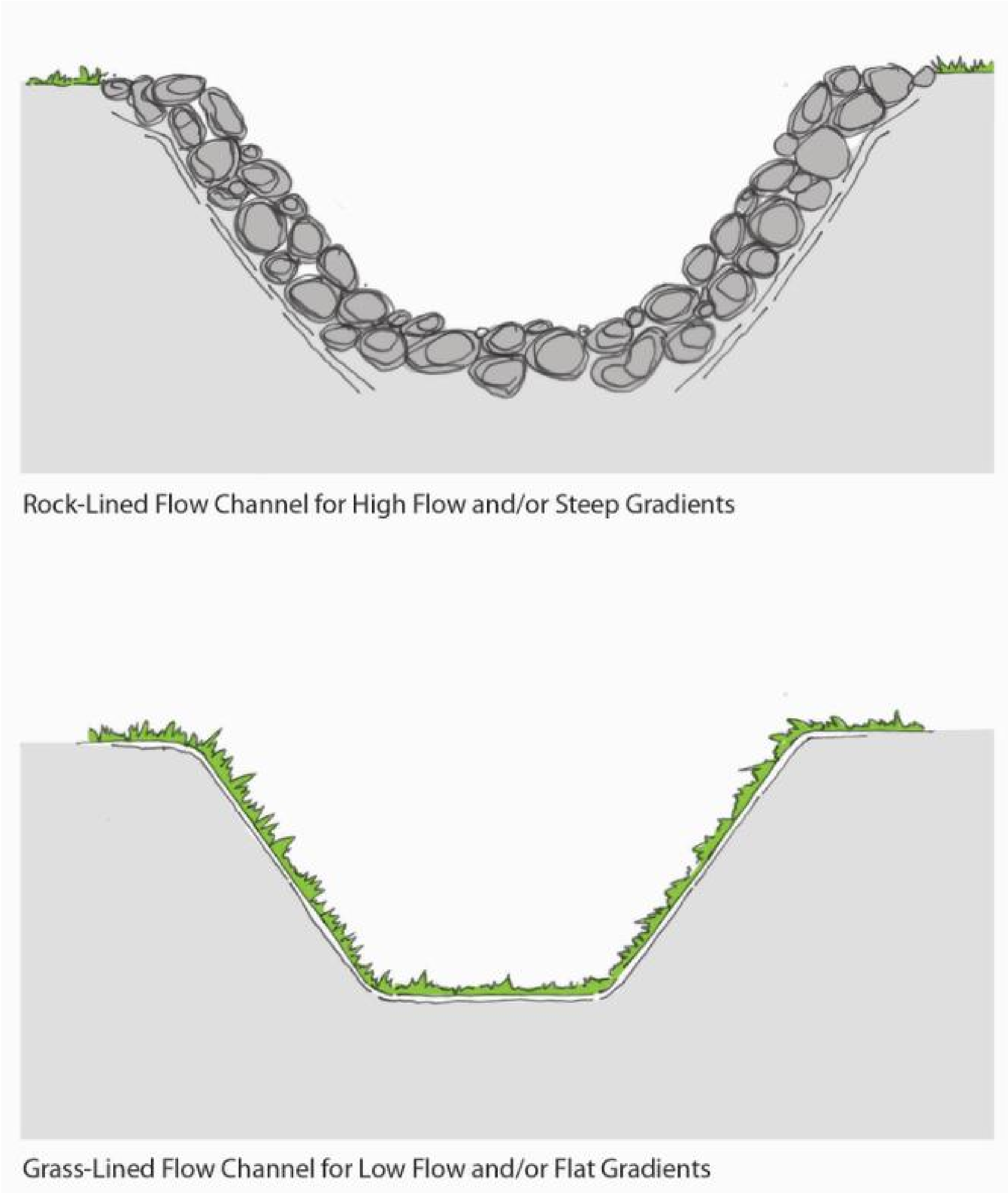

Figure 7: Stream Diversion Type 3 – Flow Channel Cross Section (extract from Drawing SW-403).

5.2.2 Stream Diversion Requirements

Table 16 describes stream diversion requirements we have created for the three stream/channel types.

Table 16: Stream Diversion Requirements.

	STREAM DIVERSION TYPE		
Requirement	**1 Lowland Stream**	**2 Steep Stream**	**3 Flow Channel**
Flow	• Flood conveyance of 100 year ARI rainfall event with stop bank if required • Low flow channel • Main channel for the 2 year ARI event • Flood berm for larger events • Maintain velocity to mitigate ponding and stagnant water	• Flood conveyance of 100 year ARI rainfall event • Low flow channel • Main channel for the 2 year ARI event • Flood berm for larger events	Flood conveyance of 100 year ARI rainfall event
Channel Stability	Stable for 2-year ARI floods	Stable for 2-year ARI floods	Stable for 100-year ARI floods, lined as appropriate to achieve stability (e.g. grass or rock lined).
In-stream Habitat	• Low continuous gradient • Meanders • Complexity (variety of logs and rocks that change flow patterns and provide resting places) • Continuous low flow channel	• Steep gradients • Pools and cascade sequences • Complexity (variety of logs and rocks that change flow patterns and provide resting places) • Continuous wetted surface for climbing species	No requirement for in-stream habitat

Riparian	• Replicate the existing environment as much as possible • Riparian zone to be 10-20m on either side of the stream edge. Riparian zone to be a heterogeneous planting regime, which reflects what is existing. Planting to be species found in the Rodney Ecological District. Planting to replicate lowland and Steep streams in accordance with Drawings SW-401, SW-402 and SW-403 respectively. • Recovery of plants and re-planting is encouraged • Provide a bat-friendly corridor by inclusion of puriri and taraire trees. • Establish a closed canopy cover early.	No requirement for riparian planting

5.3 BPO flow chart for stream diversion type selection

As part of our BPO process to select a stream diversion type for each specific site (described in Section 7.9 of the OWAR), we developed a flow chart that selected the most suitable type of stream diversion based on fish passage criteria. The flow chart is shown in Figure 8.

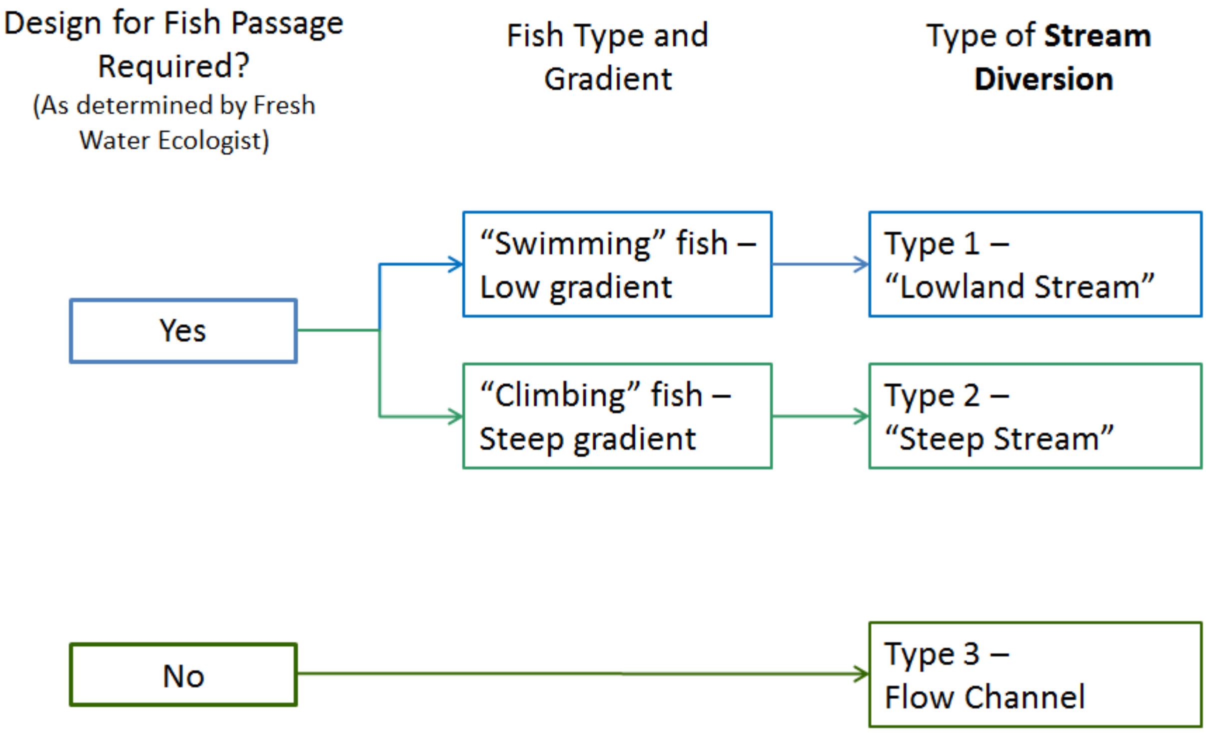

Figure 8: Flow chart for stream diversion type.

The Project's freshwater ecologists identified the streams requiring fish passage in their Freshwater Ecology Assessment Report. Fish passage is required where there is currently fish habitat in or near the streams being affected, or where there is potential for future fish habitat.

6. Sediment traps

6.1 Introduction

Sediment traps are proposed for the Project in drains at the base of rock cut faces. These sediment traps are bespoke treatment devices that will capture sediment generated from rock cuts. On the NGTR project, cut faces have yielded larger sediment loads than anticipated over the initial years since opening (2009). The sediment has built up within rock lined swales that have proved challenging to maintain i.e. the rock lined swales are not easily cleared of sediment. Sediment has also accumulated in the rock fall zones at Chin Hill, which is shown in Photo 4.

Photo 4: NGTR sediment yield at base of rock cut

The proposed sediment traps collect sediment close to the source and protect the downstream wetlands from excess sediment. Maintenance will be required, especially during the early years of operation, to remove accumulated sediment and rock fall from the sediment traps.

Sediment traps are proposed as the BPO to manage sediment generated from rock cut faces. They will be used in conjunction with the downstream wetlands for the treatment of stormwater runoff from the motorway and associated rock cuts.

The locations of the sediment traps at rock cuts are shown in the Project drawing set. A typical detail for a sediment trap is shown on drawing SW-307.

6.2 Sediment trap design

Information from Peter Mitchell of the Auckland Motorway Alliance informed us that in late 2012 the NGTR maintenance team removed 405m^3 of sediment from the drain at the base of Chin Hill which has a plan surface area of 13,300m^2. We were able to use this sediment generation information to estimate the sediment yield per year per m^2 of rock cut surface area for the NGTR. The indicative alignment for the Project is through similar geological terrain therefore our calculated sediment yield rate for the NGTR is likely to be similar for the Project. From our sediment yield calculation, we have developed a baffle spacing table that can be tailored to suit a range of rock cut heights and longitudinal swale slopes at the base of the rock cuts. The calculations considered the sediment yield, baffle storage widths and volumes, and a desired maintenance interval of 2 years. Table 17 provides the sediment trap baffle spacing we consider appropriate for the Project.

We developed our sediment trap design and associated spacing requirements in collaboration with the Project's geotechnical team who have concurrently designed concept rock traps at the base of the rock cuts, which capture falling rock to mitigate the risk of it reaching the motorway. The sediment traps do not compromise the function and performance of the rock traps.

Approximately 3,650m length of rock cut in the Project will require sediment traps installed at the spacing identified in Table 17.

Table 17: Sediment trap baffle spacing.

	Baffle Spacing (m)	Rock Cut Height (m)			
		5 to 10	10 to 20	20 to 30	30 to 40
Swale Slope	0 to 1%	100	100	100	100
	1 to 3%	100	45	25	25
	3 to 5%	60	20	15	15

Note - Refer to Appendix A for sediment trap baffle spacing calculations.

7. References

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Appendix A. Sediment Trap Calculations

Project: Puhoi to Warkworth

Calculation title: Sediment trap baffle spacing

Calulation by: S Wang | **Date: 8th July 2013**

Checked by: D Sloan | **Revision: 1**

Reference: Water Assessment Factual Report 8: Cross Drainage and Stream Diversion Design Memo, Appendix A

EXPLANATION OF METHODOLOGY IN COLOURED CELLS.

STEP 1. Estimate sediment yield rate from NGTR information / experience

NGA - Chins Hill Western Side		
Yield before maintenance (from Peter Mitchell AMA)	405	m^3
Maintenance Period (2009-2012)	4	years
Yield / year	101.25	m^3
Rock cut area in plan	13300	m^2
Sediment yield / rock cut area / year	0.007613	m^3/m^2/year

FNA - assumed sediment yield rate based on NGTR data		
Sediment yield / rock cut area / year	0.007613	m^3/m^2/year

Figure 1: Storage Length (minimum allowed Baffle spacing)

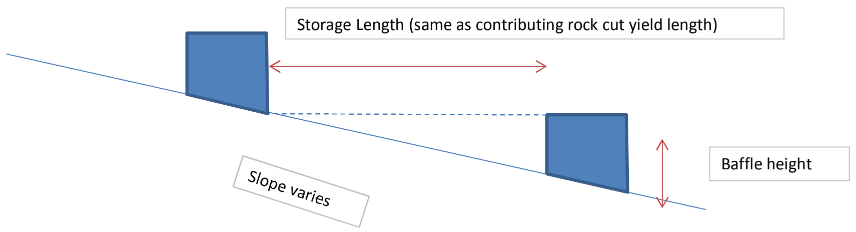
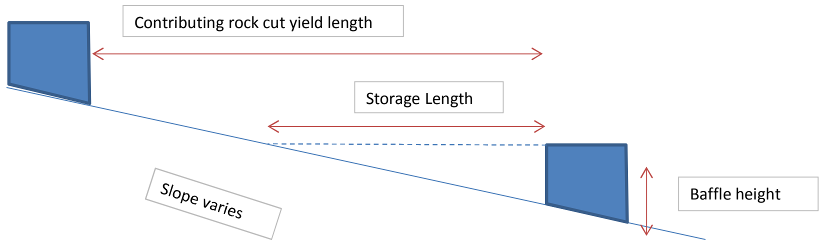


Figure 2: Baffle Spacing (maximum allowed Baffle spacing)



Baffle Width - in accordance with geotech rock trap schedule (DWG R013)

	Rock Cut Height (m)			
	5 to 10	*10 to 20*	*20 to 30*	*30 to 40*
Baffle Bot Width (m)	1.4	0.9	0.7	0.6
Baffle Top Width (m)	3	2.5	2.3	2.2
Baffle Height (m)	0.5	0.5	0.5	0.5

STEP 2. Calculate baffle dimensions based on rock trap schedule and design shown in drawing R013
Checked with geotech: Baffle height of 0.5m does not compromise integrity of rockfall function.

Storage Length - assuming sediment builds up no higher than top of baffle

	Slopes		
	0 to 1 %	*1 to 3 %*	*3 to 5 %*
Baffle Height (m)	0.5	0.5	0.5
Storage Length (m)	100	25	12.5

STEP 3. Calculate length of storage available due to slope constraints.
Assume sediment stored is no higher than top of baffle (see Figure 1).
Assume swale slope is same as road slope.

Baffle Storage Volume m3

		Rock Cut Height (m)			
	Baffle Storage Volume (m^3)	*5 to 10*	*10 to 20*	*20 to 30*	*30 to 40*
Slopes	*0 to 1 %*	55	43	38	35
	1 to 3 %	14	11	9	9
	3 to 5 %	7	5	5	4

STEP 4. Calculate baffle storage volume (height x length x mid-width).
Use storage lengths determined in step 3.

Rock Cut Produced Volume m3 per year

		Rock Cut Height (m)			
	Rock Cut Yield (m^3/year)	*5 to 10*	*10 to 20*	*20 to 30*	*30 to 40*
Slopes	*0 to 1 %*	5.7	11.4	19.0	26.6
	1 to 3 %	1.4	2.9	4.8	6.7
	3 to 5 %	0.7	1.4	2.4	3.3

STEP 5. Calculate sediment yield from rock cut per year.
Use assumed sediment yield rate determined in step 1.
Use storage lengths determined in step 3.
Assume average height in rock cut height band (e.g. 10 to 20 = 15m).

Years before maintenance required

		Rock Cut Height (m)			
	Years before storage is full	*5 to 10*	*10 to 20*	*20 to 30*	*30 to 40*
Slopes	*0 to 1 %*	9.6	3.7	2.0	1.3
	1 to 3 %	9.6	3.7	2.0	1.3
	3 to 5 %	9.6	3.7	2.0	1.3

STEP 6. Calculate years before storage is filled by rock cut.

Spacing - Assuming Desired Maintenance Period = 2 Years

		Rock Cut Height (m)			
	Maximum Baffle Spacing (m)	*5 to 10*	*10 to 20*	*20 to 30*	*30 to 40*
Slopes	*0 to 1 %*	482	186	99	66
	1 to 3 %	120	47	25	16
	3 to 5 %	60	23	12	8

STEP 7. Calculate maximum spacing allowed (increase contributing rock cut area) assuming the desired maintenance period is 2 years.
See Figure 2. Same storage volume (in step 4) is used to take larger rock cut length.

Baffle Spacing - To go on Drawing SW307

		Rock Cut Height (m)			
	Baffle Spacing (m)	***5 to 10***	***10 to 20***	***20 to 30***	***30 to 40***
Swale Slope	***0 to 1 %***	100	100	100	100
	1 to 3 %	100	45	25	25
	3 to 5 %	60	20	15	15

STEP 8. Replace highlighted (step 7) with minimum allowed baffle spacings to maintain storage volume. Limit maximum to 100m.
Round numbers to 5m.
Refer to figure 2 for rock cut height 5 to 20m scenarios