Aberdeen Western Peripheral Route

A39.2 – Fluvial Geomorphology

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1 Introduction

1.1 General Background

1.1.1 This report is a technical appendix of the Chapter 39 (Water Environment) of the Environmental Impact Assessment for the Fastlink section of the proposed Aberdeen Western Peripheral Route (AWPR).

1.1.2 This report focuses specifically on the fluvial geomorphological impacts of the proposed scheme on watercourses crossed by the road. These watercourses range in size, from small ephemeral field drains to large streams (refer to photographs in Appendix A39.4: Annex 24). The assessment examines impacts that may result during the construction and operation of the proposed scheme.

1.1.3 The main driving force behind the inclusion of geomorphological assessments in Environmental Impact Assessments such as this is the EU Water Framework Directive (WFD). The WFD, which is transposed into Scottish Law by the Water Environment and Water Services Bill, aims to classify rivers according to their ecological and chemical status and sets targets for improvements. Ecological status is split into three elements, namely ecological, hydromorphological and supporting physiochemical factors. For high status waterbodies, the WFD requires that there is no more than very minor human alteration to the hydromorphology elements. This includes a consideration of the:

- extent to which flow, sediment regime and the migration of biota are constrained;
- extent to which the morphology of the river channel has been modified; and
- degree to which natural fluvial processes are compromised, i.e. the channel's ability to adjust to changes in the flow and sediment regime is reduced.

1.1.4 Fluvial geomorphology is the study of the landforms associated with river channels and the sediment transport processes that form them. The principal focus of fluvial geomorphology is the relationship between sediment regime (erosion, transport and deposition) and channel and floodplain morphology (Appendix A39.4 Annex 22). Fluvial processes create a wide range of morphological forms that provide a variety of habitats within and around river channels. As a result, geomorphology is integral to river management.

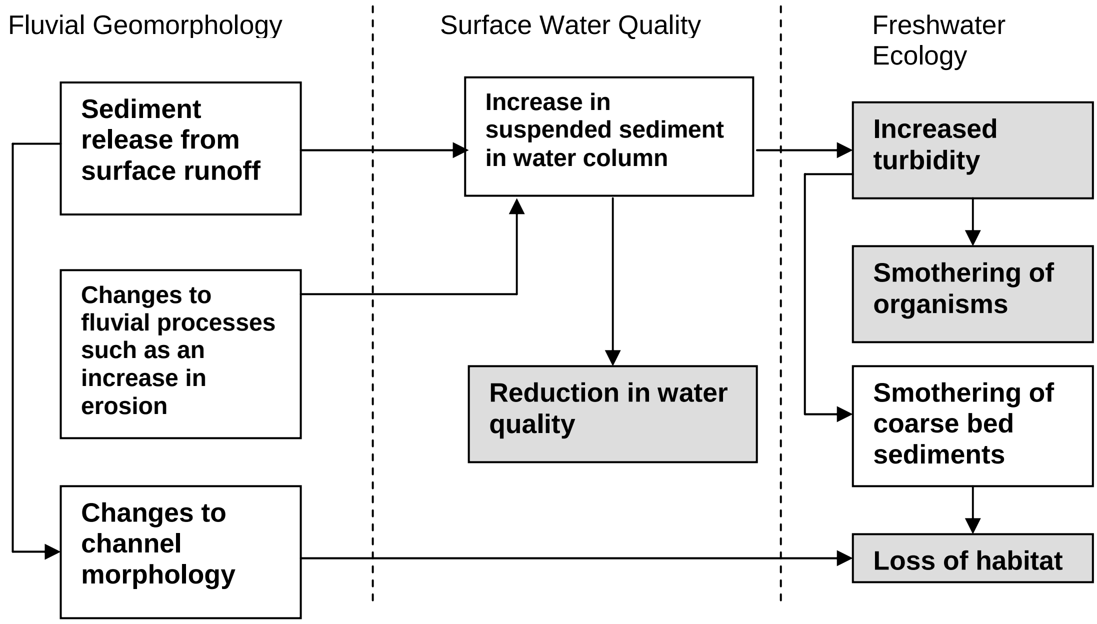

Figure 1 – Conceptual diagram illustrating the relationships between impacts on fluvial geomorphology, water quality and ecology (grey denotes an impact on receptor)

1.1.5 The main potential impacts on the fluvial geomorphology of watercourses (Figure 1) are:

- increases in fine sediment delivery to watercourses with potentially detrimental impacts on sensitive species. This may occur both during construction and operation of the road scheme;
- reductions in the morphological diversity of river channels, for example due to culverting, bank and bed protection and realignment;
- alteration to the natural functioning of the river channel (natural fluvial processes), for example, prevention of channel migration due to bank protection, bridge pier installation or culverting. If this interrupts natural fluvial processes it may have consequences for both for WFD targets and have detrimental effects on habitat diversity; and
- accelerated fluvial activity such as an increase in the rate of bank erosion in response to channel engineering, such as unsympathetic channel realignment. Accelerated bank erosion leads to an increase in sediment delivery, which can have a significant impact where sites of importance for freshwater ecology are located downstream.

1.1.6 This report is one of a number of technical reports used to inform the Water Quality and Freshwater Ecology appendices (A39.3 and A40.9, respectively). Appendix 39.1 (Surface Water Hydrology) and Chapter 38 (Geology, Soils, Contaminated Land and Groundwater) have provided information for this assessment, which then input to the Water Environment Chapter. The relationship between this assessment and the other related components of the EIA is summarised in Figure 2.

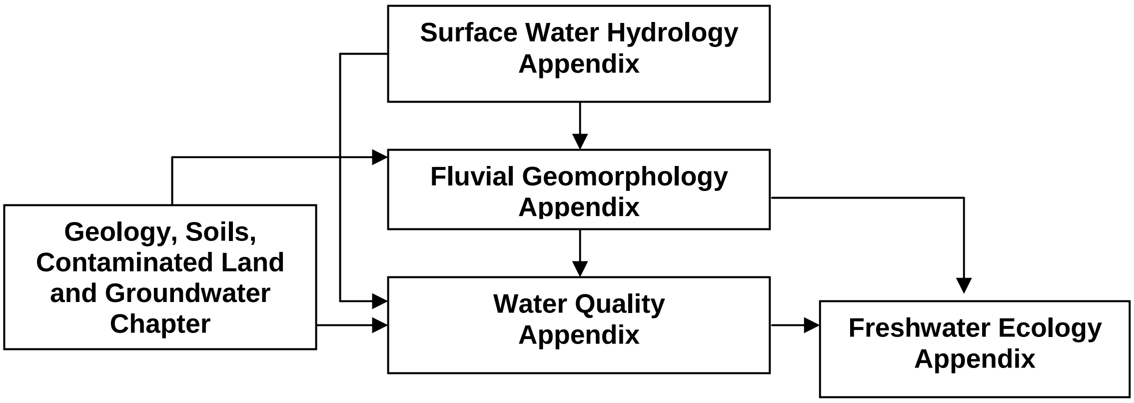

Figure 2 – Flow chart illustrating the relationships between the technical appendices and chapters

1.2 Assessment Aims

1.2.1 The overall aim of this report is to inform the water quality and ecological assessments of potential geomorphological impacts, which may affect the receptors considered in these reports.

1.2.2 Specifically, this technical appendix aims to assess the potential impacts of the road scheme during both the operation and construction phases and to outline possible mitigation measures that would reduce the impact of the road on the fluvial geomorphology of watercourses. Having outlined the mitigation measures, the report then considers the impacts of the road scheme with mitigation measures in place (residual impacts). The impact of changes in fluvial geomorphology, as a result of the proposed scheme, on specific receptors is considered in the water quality and freshwater ecology appendices (A39.3 and A40.9, respectively).

1.2.3 The specific objectives of this assessment reflect the WFD water quality and hydromorphological targets, and are to:

- assess the baseline characteristics of each watercourse;
- assess potential impacts on each watercourse affected, against the baseline, on the:
  i. sediment regime
  ii. channel morphology
  iii. natural fluvial processes
- suggest mitigation measures for the potential impacts; and
- assess the residual impacts as a result of the suggested mitigation measures.

1.2.4 In addition to identifying potential impacts on watercourses that would be affected by the proposed scheme, impacts are also evaluated in terms of whether they are direct or indirect effects. The duration of impact is also considered, as is the likelihood of cumulative impacts occurring.

1.2.5 Under the Water Framework Directive, the Controlled Activities (Scotland) Regulations 2005 (CAR) state that it is an offence to discharge to all wetlands, surface waters and groundwaters without CAR authorisation (SEPA, 2007). There are three different types of authorisation under CAR: General Binding Rules (GBR), Registration and License (both simple and complex). The level of regulation increases as the activity poses a progressively deleterious impact on the water environment. The level of authorisation required for the AWPR is dependent on the activity proposed, but is likely to range from GBR, covering some construction activities and outfalls, to licences required for outfalls (draining over 1km of road in length), culverting and watercourse realignment.

2 Approach and Methods

2.1 General Approach

2.1.1 This report concentrates on outlining the potential effects of the road scheme on the fluvial geomorphology of watercourses that would be crossed by the proposed scheme. The approach adopted in this appendix differs from that followed in the other appendices, as fluvial geomorphology does not have any direct receptors (entities such as organisms or ecosystems) that are susceptible to the adverse effects of impacts. Change to the geomorphology is the mechanism (pathway) by which receptors such as water quality and freshwater ecology are affected by the scheme (A39.3 and A40.9, respectively).

2.1.2 Unlike the other assessments in this ES, impacts have not been considered in terms of sensitivity or significance to lead to an assessment of residual impact. However, the geomorphological processes and forms associated with each watercourse are vulnerable to change as a result of external influences such as the road construction. The 'vulnerability' of the watercourse to undergo change has been evaluated for each watercourse.

2.1.3 The criteria used to assess the vulnerability of watercourses to undergo change as a result of disturbance are outlined in Table 1.

Table 1 – Criteria to Assess the Vulnerability of Watercourses

Vulnerability	Criteria
High	**Sediment Regime** A watercourse supporting a range of species and habitats sensitive to a change in suspended sediment concentrations and turbidity, such as migratory salmon or freshwater pearl mussels. This includes sites with International and European nature conservation designations due to water dependent ecosystems e.g. a Special Protection Area, Special Area of Conservation, Ramsar Site, EU designated freshwater fisheries. This also includes all nature conservation sites of national importance designated by statute, including Sites of Special Scientific Interest and National Nature Reserves. **Channel Morphology** Watercourses exhibiting a range of morphological features such as pools and riffles, active gravel bars and varied river bank types. Such morphological variability is a primary determinant of ecological diversity. **Natural Fluvial Processes** Dynamic rivers, those that show evidence of channel migration and other morphological changes such as bar evolution. These processes ensure high ecological diversity, but are vulnerable to interventions such as bank protection, culverting, realignment and construction on the surrounding floodplain. In addition, laterally stable rivers can be vulnerable to change as a result of realignment, particularly where this alters gradient, which may lead to increased erosion and deposition within the channel. Boundary conditions such as the presence of bedrock are a key control on the likelihood of such a response. Such a change in river behaviour may be very significant where an ecologically sensitive site is located downstream.
Medium	**Sediment Regime** A watercourse supporting limited species sensitive to a change in suspended sediment concentrations or turbidity. This includes non-statutory sites of regional or local importance designated for water dependent ecosystems. **Channel Morphology** Watercourses exhibiting limited morphological features such as pools and riffles, few active gravel bars and relatively uniform bank types. **Natural Fluvial Processes** Rivers that may be vulnerable to changes in fluvial processes that are likely to have a limited impact on habitat quality. This also includes watercourses which may be vulnerable to localised change in rates of adjustment but which are not located upstream of important ecological sites.
Low	**Sediment Regime** A watercourse that does not support any significant species sensitive to changes to suspended solids concentration or turbidity. **Channel Morphology** Watercourses exhibiting no morphological diversity; flow is uniform, gravel bars absent and bank types uniform and stable. Such watercourses may have been subject to past modification such as bank protection and culverting. **Natural Fluvial Processes** Watercourse that shows no evidence of active fluvial processes and which is not likely to be affected by modification to boundary conditions.

2.1.4 The assessment of potential impacts is based on evaluating the potential change in baseline conditions (sediment regime, channel morphology and natural fluvial processes) caused by the road.

2.1.5 As the Design Manual for Roads and Bridges (DMRB) (The Highways Agency et al., 1993) does not outline a specific methodology to enable the geomorphological impacts to be evaluated, the methodology adopted in this appraisal was developed using the guidelines from Research and Development Programmes of the National Rivers Authority, Environment Agency and Scottish Natural Heritage. These guidelines are outlined in the Defra/Environment Agency R&D Report FD1914 Guide Book of Fluvial Geomorphology (Sear et al., 2003).

2.1.6 In addition, the requirements of the EU Water Framework Directive were also taken into account when developing the methodology using SEPA policy guidance ‘The Future for Scotland’s Waters, Guiding Principles on the Technical Requirements of the Water Framework Directive’ (SEPA, 2002).

2.1.7 A range of standard geomorphological methodologies is available to fulfil the requirements of the variety of different river management activities which require geomorphological investigations. Typically, these studies fall into two categories, those designed to provide information at the catchment-scale, such as a Detailed Catchment Baseline Survey and Fluvial Audit, or reach specific investigations which provide a far greater level of detail such as Geomorphological Dynamics Assessment and Environmental Channel Design (see, Defra/Environment Agency R&D Report FD1914 (Sear et al., 2003) for further information). These differing methodologies reflect the trade-off between the spatial scale of an investigation and the level of detail that can be provided.

2.1.8 This study does not fit readily into this existing framework as it requires geomorphological information for a number of different watercourses, each with their own catchments. Adopting a whole-catchment approach to the analysis of each watercourse would have been prohibitively time-consuming, due to the total length of watercourse that would need to have been examined. Similarly, the logistics of undertaking detailed Geomorphological Dynamics Assessments of each watercourse would also have been prohibitively time consuming due to the volume of data collection required for this type of analysis. Due to the spatial coverage required, an approach similar in resolution to the catchment-scale fluvial audit was adopted to examine the sediment system, fluvial processes and potentially destabilising phenomenon (the proposed scheme) in the vicinity of the scheme for each watercourse. This was deemed an appropriate scale of survey for the likely impact that would be created for each crossing point.

2.2 Impact Assessment Methodology

2.2.1 Potential impacts were considered in terms of the likely degree of change to the baseline conditions for each individual watercourse as a result of the operation and construction of the road. The method used to determine the baseline conditions comprises two parts, namely a desk study and a field investigation.

2.2.2 The potential impacts of the proposed scheme on the fluvial geomorphology of watercourses are:

- increases in fine sediment delivery to watercourses with potentially detrimental impacts on sensitive species. This may occur both during construction and during the operation of the road scheme;
- reductions in the morphological diversity of river channels, for example, due to culverting, bank and bed protection and realignment; and
- change in natural fluvial processes such as a reduction in the ability of the river channel to naturally self-adjust its form. This could be caused by bank protection, bridge pier installation, or culverting. This may have detrimental effects on habitat diversity and consequences for WFD targets. Secondly, accelerated fluvial activity such as an increase in bank erosion may occur in response to engineering, for example as a result of unsympathetic channel realignment. Bank erosion, or channel incision, both can lead to an increase in sediment supply, which can have a significant impact where sites of ecological importance are located downstream.

2.2.3 The criteria used to assess the magnitude of potential impacts on watercourses are outlined in Table 2. The overall vulnerability is described by the highest risk, e.g. if a watercourse had low vulnerability in sediment regime and channel morphology but medium vulnerability in natural fluvial processes then it would be described as being of medium risk overall.

Table 2 – Criteria to Assess the Magnitude of Potential Impacts on Watercourses

Magnitude	Criteria
High	Major shift away from baseline conditions. **Sediment Regime** Major impacts to the river bed over the reach due to accelerated deposition or erosion. Major impacts to sensitive species or habitats as a result of changes to suspended sediment load or turbidity. **Channel Morphology** Major impacts on channel morphology over the reach leading to a reduction in morphological diversity with consequences for ecological quality. **Natural Fluvial Processes** Major interruption to fluvial processes such as channel planform evolution or erosion and deposition.
Medium	Moderate shift away from the baseline conditions. **Sediment Regime** Moderate impacts to the river bed and sediment patterns over the reach due to either erosion or deposition. Changes to suspended sediment load or turbidity resulting in a moderate impact on sensitive habitats or species. **Channel Morphology** Moderate impact on channel morphology. **Natural Fluvial Processes** Moderate interruption to fluvial processes such as channel planform evolution, deposition or erosion.
Low	Minimal shift away from the baseline conditions. **Sediment Regime** Minimal changes to sediment transport resulting in minimal impacts on species or habitats as a result of changes to suspended sediment concentration or turbidity. Minor impacts to sediment patterns over this area due to either erosion or deposition. **Channel Morphology** Limited impact on channel morphology. **Natural Fluvial Processes** Minimal change in fluvial processes. Any change is likely to be highly localised.
Negligible	Very slight change to the baseline conditions. **Sediment Regime** Negligible changes to sediment transport resulting in negligible impacts on species or habitats as a result of changes to suspended sediment concentration or turbidity. No discernible impact to sediment patterns and behaviour over the development area due to either erosion or deposition. **Channel Morphology** No significant impact on channel morphology in the local vicinity of the proposed site. **Natural Fluvial Processes** No change in fluvial processes operating in the river. Any change is likely to be very localised.

Desk Study

2.2.4 The desk study is designed to utilise existing data sources to provide an insight into current geomorphological conditions and trends in river behaviour. The range of data sources examined during the desk study and the information that they provide is summarised in Table 3.

Table 3 – Data Sources Examined During Desk Study

Data Source	Information Provided
Contemporary Ordnance Survey Mapping	This provides basic contextual information, such as elevation, relative relief and an indication of channel gradient.
Geological Maps (solid and drift plus soils)	Solid and drift geological maps provide an understanding of the likely channel boundary conditions. This, in addition to the soils data, provides an indication of the likely quantity and calibre of sediment released.
Geological Borehole Data	Detailed solid and drift geology data derived from boreholes can be used to augment those provided by geological maps.
Aerial Photography	Aerial photography provides basic contextual information about the site such as land use and vegetation types. In addition, aerial photography provides information on the distribution of geomorphological features such as channel deposits, palaeochannels and sediment sources. In conjunction with field investigations this enables the contemporary and past geomorphological processes to be elucidated.
Land Use Data	Land use data provide an indication of the likely impact of land management practices on the hydrological and sediment regime of the river.
Hydrological Data (where available)	Hydrological data such as bankfull discharge or mean annual flood can be used as the basis of sediment transport calculations to provide an indication of the likely impact of changes to channel morphology, in particular gradient. Flood event hydrographs provide an insight into the mechanism of flooding and the response of the river to rainfall events of different magnitudes and duration. The hydrological response of catchments to rainfall events can influence the nature and severity of erosional and depositional response. Long term (~50 years) flow records provide an indication of the variability in the hydrological regime of the catchment and allow an assessment of the likelihood of future morphological adjustments to be made.
Historical Maps	Comparing a series of historical maps allows changes in river channel planform to be determined over periods of up to 150 years. Such information provides an understanding of the nature of fluvial processes and allows trends in channel behaviour to be elucidated. When compared to long-term hydrological information this can allow insights into the impact of changes in flood frequent and magnitude to be determined.
Existing Topographic Survey (where available)	Cross-sectional surveys provide useful information about the channel structure, such as the width depth ratio, which can be used, in conjunction with field study, to determine the dominant function of differing sections of channel such as zone of net erosion, transport or deposition. Similarly, the long-profile (gradient profile) of the river can also be used to determine the dominant functions (with respect to likely energy levels) of sections of river channel.
River Habitat Survey	This provides useful observational information into the nature of channel condition and materials as well as providing an indication of morphological diversity and the nature and importance of ecological communities (Refer to Freshwater Ecology Appendix A40.9).
Previous Geomorphological Studies	Previous geomorphological studies conducted along these or similar neighbouring watercourses (either reports or academic papers) can provide useful insight into the nature of fluvial processes. When compared to contemporary conditions previous studies can provide a useful comparison to enable changes in baseline conditions to be ascertained enabling trends in river behaviour to be determined.

Field Study

2.2.5 The field study was designed to build on the findings of the desk study to determine the geomorphological forms and processes at each site. The geomorphological information collected during the field study is summarised in Table 4. This field survey was undertaken in June 2006.

2.2.6 The extent of investigation for each watercourse varied according to site conditions. The reaches that were assessed during field investigations varied from a minimum of 200m (i.e. Green Ditch) up to 1km.

Table 4 – Information Obtained During Field Study

Data Source	Information Provided
Geomorphological Mapping	Geomorphological mapping is a well established technique for characterising river channels. This allows: The pattern of existing erosion and deposition to be recorded. The dominant function of differing sections of channel to be determined (sediment source, transfer and sink). The spatial arrangement of morphological forms to be determined, allowing inferences to be made about contemporary and past geomorphological processes enabling the identification of trends in channel behaviour. The impact of past management practices can also be examined enabling inferences to be made about the potential consequences of interference.
Boundary Condition Information	Determining the nature of boundary materials (bed and bank) enables an insight to be gained into the intrinsic controls on patterns of erosion and deposition. This allows the likelihood of morphological adjustments to channel interference to be evaluated.
Space for Time Substitution	This involves examining neighbouring watercourses, with similar geomorphological characteristics, which were subject to past modification such as realignment. This will enable the vulnerability of watercourses to modification to be evaluated and the likely morphological response to be assessed.

2.2.7 Combining the results of the desk and field study enabled the baseline conditions at the site to be determined in terms of sediment regime and fluvial processes together with an understanding of the morphological structure of the river channel. Establishing detailed baseline conditions provided the basis for evaluating the impacts of both construction and operation of the proposed scheme.

2.3 Limitations to Assessment

2.3.1 Mathematical modelling of sediment input, transfer or deposition during road operation or construction was beyond the scope of this assessment due to the lack of available data around which to build the models, for the majority of watercourses. Due to their small size, little additional information would be gained by modelling these watercourses.

2.3.2 The paucity of historical data (flow variation, channel morphology measurements, sediment concentrations in flow) and archive maps for many of the watercourses meant that the baseline conditions were judged on field observations during one site visit, providing an indication of character at a snap-shot of time rather than over a period of time.

2.3.3 In addition, only one site visit means that watercourses were observed under one flow condition (often low-flow) rather than under several flow conditions. Streams and rivers are less dynamic (active) at low flow.

2.3.4 Fieldwork was conducted in the summer when riparian and bank vegetation cover was dense. This often inhibited a full evaluation of the extent of bank erosion. The presence of vegetation on the bank face and bank top implies that the channel is not actively eroding. However, during winter months when banks are less vegetated, the signs of bank erosion are more readily detectible.

2.3.5 The upstream and downstream boundaries were determined by the extent of likely impacts caused by the crossing, and access constraints. The extent of field survey conducted also varied according to these constraints. However, all site investigations considered the channel upstream and downstream of the road over a distance of 200m to 1km. The distance of survey was proportional to the size of the watercourse.

2.3.6 It is not possible to fully assess the impacts of construction before construction contractors have finalised their programme of works, e.g. the location of temporary access roads, timing of construction. However, an assessment has been made of the potential impacts are likely to be caused during construction of the watercourse crossings.

3 Baseline

3.1 Watercourse Descriptions

Megray Burn

3.1.1 Megray Burn is a tributary of the Cowie Water located within a broad ‘v’ shaped valley. The stream has a relatively small catchment and has a relatively steep gradient. The channel is relatively straight throughout its length and this appears to reflect past realignment, particularly in its lower reaches where it is aligned alongside the B979 road. The watercourse is segmented by an online reservoir-like basin, which regulates the flow of the watercourse downstream and incorporates a hydraulic ram, although it is unclear if this remains in operation. At present, the majority of the flow in the lower watercourse originates from a pipe set within the right bank of the channel along the southern margin of the conifer plantation. The source of this flow is not known although it may be spring fed. Land use is predominantly arable, although a section of the watercourse passes through a conifer plantation. The channel has a gravel bed with occasional moss covered cobbles and shows no evidence of active erosion and deposition. The morphology of the channel differs between the section, which flows through arable land and that within the conifer plantation. Where land-use is arable the channel is narrow (0.5-1m wide) and set within a ‘v’ shaped depression approximately 1.5m deep. Within the conifer plantation, the channel is wider (up to 3m) with occasional sediment deposits (fine gravel) and accumulations of woody debris. The lower section of watercourse along side the B979 is extensively culverted although some sections are open.

3.1.2 The extensive modifications to the watercourse, (straightening, culverting and flow regulation) and lack of active fluvial processes, mean the vulnerability of this watercourse to disturbance is low.

Limpet Burn

3.1.3 Limpet Burn is a small stream, draining a small catchment between White Hill and Kempstone Hill, which is extensively wooded. The location of the proposed road crossing is set within a ‘u’ shaped valley, which is an unusual shape for a valley formed by a low order stream. Here the stream is underfit, which means its channel is smaller than would be expected given the size of the valley through which it flows. The valley is approximately 20m deep and has a top width of around 120m wide while the valley floor width is approximately 40m. The valley has a low gradient, which coupled with shape and size, suggests it is an old glacial melt water channel.

3.1.4 The stream channel is narrow (approximately 0.4m wide), with a sand covered bed and a sinuous planform, set within an expanse of waterlogged peaty soil on the floor of the valley. For much of its length, the channel is obscured by thick grasses and rushes on the valley floor. Locally however, where the stream meets the valley sides, occasional clumps of trees are present and at this location the channel is wider (up to 1m). Flow in the channel is diverse, with pools, riffles and runs with occasional chutes occurring where the channel is practically blocked by vegetation. This reflects the high morphological diversity of this natural watercourse. Downstream of the proposed crossing are a series of online ponds used for fishing, which appear to have been artificially constructed by infilling the lower section of the valley to pond flow back upstream. Downstream of these ponds, the gradient of the channel steepens considerably as it descends through a steep gorge, through coastal cliffs and into the North Sea.

3.1.5 As the channel in the location of the proposed road crossing is natural and of high morphological diversity, with a low fine sediment load, it is highly vulnerable to disturbance. In addition, natural low order streams such as this are relatively uncommon in Aberdeenshire due to extensive modification by landowners. In addition, the valley in which the stream is located is an important natural heritage feature (old glacial melt water channel).

Coneyhatch Burn

3.1.6 Coneyhatch Burn is a tributary of Limpet Burn. The stream rises in a peat bog to the south of Fishermyre and flows south through a broad, low gradient valley. The valley floor is filled by peat. The valley is extensively wooded to the south of Coneyhatch (Megray Wood). The channel shows evidence of modification, primarily through straightening throughout its length. In the vicinity of Coneyhatch Farm, in the location of the proposed road crossing, the stream has been over-deepened, potentially in an attempt to improve land drainage. However, the channel has become choked with dense vegetation and the channel shows low morphological diversity and does not exhibit any evidence of active erosion or deposition processes.

3.1.7 The extensive modifications to the watercourse, (straightening and deepening) and lack of active fluvial processes, means the vulnerability of this watercourse to disturbance is low.

Green Burn

3.1.8 Green Burn is a tributary of the Burn of Muchalls, which drains a wetland area. The stream originates to the north of Fishermyre and flows in a south-easterly direction to the east of Fishermyre. The channel in this location appears to be natural. The channel is shallow (0.2-0.3m) and narrow (0.3-0.5m) with a low gradient and sinuosity. The bed morphology is varied, and composed principally of gravel although some cobbles and patches of sand are also present. The banks are generally well vegetated and show no sign of significant erosion. Downstream, the stream passes east under a minor road, through a pipe culvert. To the east of this road, the channel has the form of a straight, and over-deepened ditch, which follows field boundaries in a southerly direction through an area of poorly drained rough grassland. After turning sharply to the left, the burn becomes steeper and flows to the northeast in a straight channel along field boundaries. The channel gradient increases progressively as the stream descends into the valley of the Burn of Muchalls.

3.1.9 The stream in the location of the proposed scheme has a natural form with a morphologically diverse bed. Unmodified low order streams such as this are uncommon in the area around Aberdeen, due to the extensive nature of watercourse modification to aid land drainage, therefore this section of channel is of significance. The channel is of medium vulnerability to future modifications, which are likely to be detrimental to the morphology of the stream.

Green Ditch

3.1.10 Green Ditch is a small tributary of Green Burn located to the north of Fishermyre on the edge of a peat bog. The steam is located in a straight ditch-like channel, which appears to be entirely artificial. This stream has become a drainage ditch and it is unclear whether a pre-existing natural watercourse was present in this location. The channel shows low morphological diversity and does not exhibit any evidence of active erosion or deposition processes.

3.1.11 The artificial nature of the watercourse and lack of active fluvial processes means the vulnerability of this watercourse to disturbance is low.

Allochie Burn

3.1.12 Allochie Burn is a tributary of Back Burn, which is a tributary of the Burn of Muchalls. The stream rises on the north margin of a valley-bottom peat bog to the east of Hill of Muchalls. The watercourse consists of a series of straight ditch-like channels, which appear to have been excavated to improve land drainage. The channel is filled with a dense growth of vegetation, which, in addition to past modifications, has resulted in low morphological diversity. The low gradient of the watercourse and past modification mean that the channel does not exhibit any evidence of active erosive or depositional processes.

3.1.13 The artificial nature of the watercourse and lack of active fluvial processes mean that the vulnerability of this watercourse to disturbance is low.

Burn of Muchalls

3.1.14 The source of the Burn of Muchalls is located along the southern margin of Red Moss of Netherley SAC in a series of ditches. For the majority of its length its planform is straight and the channel follows field boundaries. This is indicative of past modification to the watercourses to improve land drainage. In the location of the proposed scheme, the channel, situated in a shallow 'v' shaped valley, is between 1.5m and 2m wide and has a gravel bed with frequent boulders and cobbles. The variation in bed sediment type results in high bed morphological diversity. Glides and riffles are common and larger cobbles and boulders provide areas of turbulence. The water is clear and shows no evidence of fine sediment pollution. In addition, the bed is also free from fine sediment (clay and silt). The banks (approximately 0.5m high) are walled in places, but are generally natural and well vegetated, showing no significant evidence of active erosion. Tree lining occurs locally, particularly downstream of the proposed crossing. Moving progressively downstream, the channel gradient increases and the valley becomes narrower as the watercourse descends towards the North Sea.

3.1.15 The bed of the channel has a good morphological diversity and the banks are generally natural and thus the watercourse supports a diverse ecology. As such, the watercourse is highly vulnerable to activities that may affect the morphology of the stream. The absence of fine sediment in the water column and on the bed means that the watercourse is highly vulnerable to activities that may increase fine sediment inputs.

Burn of Blackbutts

3.1.16 The Burn of Blackbutts is a tributary of the Burn of Muchalls. The watercourse has been heavily modified throughout its length through straightening and deepening. It has been altered to improve land drainage. The proposed scheme would cross the watercourse at its source. At this location, flow appears to be ephemeral and the channel is located in a ditch between fields. The bed of the stream was covered by grasses and the channel is lined by trees and scrub.

3.1.17 The heavily modified nature of the watercourse and the ephemeral nature of the flow in the location of the proposed road crossing indicate that this watercourse is of low vulnerability to modification.

Cookney Ditch

3.1.18 The source of Cookney Ditch is at the foot of the northern slopes of the hill on which the village of Cookney is situated. The stream is located within a straight and over deepened ditch-like channel that is entirely artificial in origin. The ground along the channel margin appears to be formed of material that has been dredged from the channel. Flow appears to be ephemeral. The channel is densely vegetated by grasses and rushes and other wetland plants.

3.1.19 The heavily modified nature of the watercourse and the ephemeral nature of the flow in the location of the proposed road crossing indicate that this watercourse is of low vulnerability to modification.

Stoneyhill Burn

3.1.20 Stoneyhill Burn is a headwater tributary of the Burn of Elsick. This is sourced from an area of lowland peat bog to the east of Red Moss. The upper reaches of the watercourse are of low gradient. This increases downstream as the stream descends towards the Burn of Elsick. The proposed scheme would cross the stream close to its source, in an area of peat bog. The stream at this location flows through a field ditch, which represents previous channel excavation for drainage improvement. The ditch is now choked with vegetation, which completely smothers the channel bed and banks. Flow appears to be ephemeral.

3.1.21 The artificial nature of this watercourse and the ephemeral nature of the flow in the location of the proposed road crossing indicate that this watercourse is of low vulnerability to modification.

Balnagubs Burn

3.1.22 Balnagubs Burn is a headwater tributary of the Burn of Elsick. The source of the watercourse is in gently sloping pasture land to the east of Balnagubs. The watercourse has a low gradient and is aligned along the margins of fields. It has been straightened and deepened. The channel has a trapezoidal cross-section, being wider at the bank top (5m) than the bed (1.5m), and is approximately 1.8m deep. The channel is densely vegetated which encourages ponding of flow and deposition on the bed. The bank tops are lined by rock debris, which is probably composed of material dredged from the channel. The channel shows no evidence of active geomorphological processes such as erosion and deposition and has low morphological diversity.

3.1.23 The heavily modified nature of the watercourse, in the location of the proposed road crossing, means that this watercourse has a low vulnerability to modification.

Tributary of Burn of Elsick

3.1.24 The source of the Burn of Elsick is on the southeast slopes of Berry Top, to the south of North Rothnick. At the location of the proposed crossing, the Burn of Elsick is one of a number of small watercourses that drain the southeast slopes of Stranog Hill and Berry Top, which combine to form the main Burn of Elsick. The watercourse has a low to moderate gradient, is aligned along the margins of fields and appears to have been straightened and deepened. The bank tops are lined by rock debris, which appears to be composed of material dredged from the channel. The channel shows no evidence of active geomorphological processes such as erosion and deposition, and has low morphological diversity.

3.1.25 The heavily modified nature of the watercourse, in the location of the proposed road crossing, means that this watercourse has a low vulnerability to modification.

Whiteside Burn

3.1.26 The source of Whiteside Burn is on the eastern slopes of Berry Top. It is a headwater tributary of the Burn of Elsick. The watercourse has a low gradient and is located along the margins of fields, where it has been straightened and deepened. The watercourse is culverted in several locations where it passes under minor roads and tracks. The channel is densely vegetated and this causes localised ponding of flow. The channel has a gravel-bed, but due to past modification it has low morphological diversity. There is no evidence of active geomorphological processes operating along the watercourse.

3.1.27 The heavily modified nature of the watercourse and low morphological diversity mean that the watercourse has low vulnerability to modification.

Crossley Burn

3.1.28 The source of Crossley Burn is on the southeast slopes of Stranog Hill and it is a headwater tributary of the Burn of Elsick. The watercourse flows through an area of waterlogged rough pasture and follows the field boundaries. The channel is straight and over-deep for its size, which indicates past modification. Given the low gradient of the channel it is unclear whether a distinct channel would have formed here under natural conditions. It is likely that this channel is an artificial drainage ditch excavated to reduce waterlogging of the surrounding land. The channel is densely vegetated by rushes and grasses, which obscure the bed. The banks of the channel are covered by dense vegetation and there is no evidence of bank erosion or coarse sediment deposition along the watercourse.

3.1.29 The artificial nature of this watercourse means that it is of low vulnerability to modification.

Cairns Burn

3.1.30 The source of Cairns Burn is on the southeast slope of Stranog Hill. It is a tributary of the Crossley Burn. The watercourse is straight and follows field boundaries throughout its length. The land in this area is poorly drained pasture land. The channel has a low gradient and it is not clear whether a distinct channel would have been present under natural conditions. It is likely that this channel owes its origin to excavation as a drainage channel rather than being a natural watercourse. The channel is generally filled with vegetation although at some points there is evidence of poaching by cattle.

3.1.31 The artificial nature of this watercourse means that it is of low vulnerability to modification.

Circle Burn

3.1.32 Circle Burn is a short, discontinuous watercourse that is located on the northern slopes of Stranog Hill. From its source, this watercourse follows field boundaries for a distance of approximately 100m before petering out. The watercourse appears to have been modified to follow field boundaries through straightening and deepening. It is likely that prior to this modification the watercourse had the form of an area of frequently waterlogged vegetation-covered ground often referred to as flush. Flow in this watercourse is ephemeral, and the channel shows low morphological diversity and no evidence of active fluvial processes.

3.1.33 The artificial nature of this watercourse means that it is of low vulnerability to modification.

Square Burn

3.1.34 Square Burn is a discontinuous watercourse located on the northern slope of Stranog Hill. The watercourse is straight with occasional bends and follows field boundaries for much of its length. The watercourse appears to have been modified to follow field boundaries through straightening and deepening. Flow in this watercourse is ephemeral and the channel shows low morphological diversity and no evidence of active fluvial processes.

3.1.35 The artificial nature of this watercourse means that it is of low vulnerability to modification.

Wedderhill Burn

3.1.36 The watercourse drains the northern slopes of Wedderhill and is thought to be a tributary of Crynoch Burn, although no clear connection could be found. The watercourse appears to be ephemeral in nature. The channel is generally straight and follows field boundaries. Along much of its length the bed of the channel has been colonised by vegetation. In some sections however, the channel shows evidence of recent vegetation clearance and dredging in an attempt to improve channel capacity. Here the bed of the channel is composed of loose gravel and occasional cobbles with patches of silt. However, due to this disturbance the channel has low morphological diversity and patches of bed are smothered by silt. Much of the spoil from the channel dredging has been tipped along the right bank. The gradient of the watercourse declines as the channel passes into an area of land which is nearly flat. This area is underlain by sand and gravels. At this location, the channel ends and the flow disappears underground. It is unclear if the flow dissipates into the ground through the underlying sands and gravels or drains into a buried drain. From a sediment transport perspective, this burn is not connected to Crynoch Burn.

3.1.37 As the watercourse has been modified by straightening and recent dredging and is not well connected to Crynoch Burn, it has a low vulnerability to modification.

Craigentath Burn

3.1.38 This watercourse also drains the northern slope of Wedderhill and is thought to be a tributary of Crynoch Burn, but again no clear connection was observed. In its upper reaches the channel is generally straight and follows field boundaries. Along much of its length the bed of the channel has been colonised by vegetation. The gradient of the watercourse declines as the channel passes into an area of land that is nearly flat. This area is underlain by sand and gravels. Here the channel ends and the flow disappears underground. It is unclear if the flow dissipates into the ground through the underlying sands and gravels or drains into a buried drain. From a sediment transport perspective, this burn is not connected to Crynoch Burn.

3.1.39 As the watercourse is highly modified and has no clear connection to Crynoch Burn, it is of low vulnerability to modification.

Burnhead Burn and Crynoch Burn

3.1.40 These watercourses have the potential to be affected by both the Fastlink and the Southern Leg sections of the proposed scheme. They are included in the Southern Leg report.

Summary

3.1.41 Table 5 outlines the vulnerability of each watercourse on the basis of the baseline conditions for each watercourse.

Table 5 – Summary of Vulnerability of Watercourses to Change in Baseline Conditions as a Result of Disturbance

Watercourse	Sediment Regime	Channel Morphology	Natural Fluvial Processes	Overall Vulnerability
Megray Burn	Low	Low	Low	**Low**
Limpet Burn	High	High	High	**High**
Coneyhatch Burn	Low	Low	Low	**Low**
Green Burn	Low	Medium	Low	**Medium**
Green Ditch	Low	Low	Low	**Low**
Allochie Burn	Low	Low	Low	**Low**
Burn of Muchalls	High	High	Medium	**High**
Burn of Blackbutts	Low	Low	Low	**Low**
Cookney Ditch	Low	Low	Low	**Low**
Stoneyhill Ditch	Low	Low	Low	**Low**
Balnagubs Burn	Low	Low	Low	**Low**
Tributary of Burn of Elsick	Low	Low	Low	**Low**
Whiteside Burn	Low	Low	Low	**Low**
Crossley Burn	Low	Low	Low	**Low**
Cairns Burn	Low	Low	Low	**Low**
Circle Burn	Low	Low	Low	**Low**
Square Burn	Low	Low	Low	**Low**

Watercourse	Sediment Regime	Channel Morphology	Natural Fluvial Processes	Overall Vulnerability
Wedderhill Burn	Low	Low	Low	**Low**
Craigentath Burn	Low	Low	Low	**Low**

4 Potential Impacts

4.1 General

4.1.1 Potential impacts that could affect watercourses are divided into operational impacts and construction impacts. The operation impacts are those that are long-term and would influence watercourses after the scheme is complete. The construction impacts are shorter-term and would affect the watercourse during the construction phase.

4.1.2 The impact assessment for the operation and construction phases is presented with the assumption of no mitigation.

4.1.3 Unless otherwise stated, the impacts considered are adverse impacts, having an adverse impact on the sediment regime, channel morphology or natural fluvial processes and are assigned based on the criteria set out in Table 2.

4.1.4 The impacts are predominantly direct impacts. Those that are indirect include increased discharge and realignment within the operational impacts. This is discussed further in Chapter 39.9 (Water Environment: Fastlink) and Appendices A39.1 (Surface Water Hydrology) and A39.3 (Water Quality).

Operation Impacts

4.1.5 Table 6 outlines potential impacts on the geomorphology of watercourses during operation of the scheme.

Table 6 – Potential Operational Impacts

Source of Impact	Potential Impact
Suspended Solids **Direct Impact** Increased fine sediment supply from road runoff where road drainage outfalls into a watercourse. The actual volume of sediment generated by the operation of the road would vary between watercourse depending on the length of road from which runoff would be directed into the through drains watercourse.	**Sediment Regime** An increase in transportation (turbidity) and deposition of fine sediment (sedimentation). **Channel Morphology** A reduction of morphological and consequently ecological diversity, due to fine sediment deposition. **Natural Fluvial Processes** A reduction in dynamic processes due to channel sedimentation. For example, the smothering of gravel surfaces, such as bars, by fine sediment can encourage vegetation colonisation, increasing the stability of the feature and changing the nature of associated habitats.
Increased Discharge **Direct Impact** An increase in discharge (flow) along the watercourse during rainfall events may occur as a result of increased surface runoff due to the low infiltration potential of the road surface where road drainage outfalls into a watercourse. This may accelerate the rate of geomorphological processes within the channel and also increase flood risk. Flood risk would also be increased where embankments are constructed across floodplains or where crossing structures constrict the channel reducing flow conveyance. In both cases flood risk is increased by the backing-up of water.	**Sediment Regime** An increase in turbidity and a greater competence to entrain and transport sediment (fine and coarse material) downstream may occur. **Channel Morphology** Erosion of the channel bed and banks is likely to increase. Morphological diversity could be reduced or improved depending on sediment supply. **Natural Fluvial Processes** Adjustment to different flow and sediment regime, for example, a flashier regime would provide more energy for erosion leading to increased lateral migration. This could be a beneficial impact where improvement to morphological diversity results or an adverse impact where an increase in fine sediment supply occurs.
Culverts **Direct Impact** Many of the watercourse crossings are likely to involve culverting the watercourse (Figures 39.3a-f). This section assumes a culvert sized to convey a range of flows would be installed level with the existing watercourse bed, effectively providing artificial bed and banks.	**Sediment Regime** The artificial culvert bed can enhance sediment transfer at high flows. Under normal flows however, sediment could accumulate within the culvert, particularly where the culvert has a low gradient. Where culverts are designed to convey flood events with high return periods, they may have a greater width than the natural channel. This is likely to reduce stream powers leading to sedimentation within the culvert, reducing capacity. This may increase both flood risk and lead to sediment starvation downstream. Where culverting increases channel gradient, scour of the bed and banks at culvert outlets often occurs leading to an increase in the supply of sediment to the watercourse. **Channel Morphology** The morphological diversity within the culvert is greatly reduced due to artificial bed and banks. Interruption of morphological continuity would also segment the watercourse. **Natural Fluvial Processes** Culverts constrain the channel preventing lateral and vertical adjustment. A lack of river corridor (e.g. banks and berms) and in-channel vegetation due to light deficiency is also a detrimental impact.
Outfalls **Direct Impact** Road drainage outfalls are likely to be required on many of the watercourses. In addition to contributing sediment to the watercourse from road runoff (discussed above) the outfall structures themselves may also be vulnerable to scour from flow in the watercourse into which they discharge.	**Sediment Regime** Scour around outfalls will lead to local increases in sediment supply to the watercourse. The magnitude of this is likely to be limited and will be proportional to the size of the watercourse. **Channel Morphology** Scour around outfalls will lead to localised changes in channel morphology.

Source of Impact	Potential Impact
	Natural Fluvial Processes Outfalls provide fixed points along river banks which can alter fluvial process through increases in scour or changes in the rates of bank erosion. In addition, where erosion around an outfall causes the structure to project into the river channel it may lead to localised alterations in flow and patterns of sediment deposition. These impacts are likely to be highly localised and proportional to the size of the watercourse.
Realignments **Direct Impact** The proposed scheme alignment may result in the diversion (realignment) of watercourses (Figures 39.3a-f). This may lead to a change in the geomorphological behaviour of the watercourse over time. This represents an indirect impact of the proposed scheme.	**Sediment Regime** A major change in sediment regime may occur. A new course may result in a change in sediment supply, rate of sediment transfer downstream and depositional zones. Changes in boundary materials through realignment into materials more prone to erosion are likely to increase the volume of sediment supplied to the channel. Increases in channel gradient as a result of realignment would result in an increase in stream power leading to greater erosion rates reducing channel stability, and promoting sedimentation downstream. A reduction in channel gradient however, is likely to lead to increased deposition within the channel, leading to adverse impacts on morphological diversity. **Channel Morphology** Disruption to the channel bed may be short lived and realignment may lead to an improvement in channel morphology. In poor quality streams, realignment provides an opportunity to restore/rehabilitate the watercourse. **Natural Fluvial Processes** As described above, realignments can alter the nature of fluvial processes operating within the reach. An increase in erosion and/or deposition can have feedback effects which can lead to a reduction in channel stability, increasing lateral migration for example. An increase in the rate of channel processes may lead to an increase in morphological quality; however sediment transfer downstream may have adverse consequences.

Construction Impacts

4.1.6 Potential impacts during construction are similar to those that may result during operation, except that they are short-term and generally more severe. There are a higher number of sources of impacts relating to suspended solids, which includes runoff from plant and vehicle washing, excavations, blasting and excavation of road drains, for example. Any requirement for the removal of riparian vegetation for construction may also influence bank stability.

4.1.7 The magnitude of impact is dependent on the nature and schedule of the works. Weather conditions would also influence the severity of impacts. The majority of the impacts would be far more severe if there are intense or prolonged rainfall events during the construction phase.

4.1.8 Table 7 outlines the potential impacts on geomorphology during the construction of the scheme.

Table 7 – Potential Construction Impacts

Source of Impact	Potential Effect
Suspended Solids **Direct Impact** Increased fine sediment supply to watercourses is likely to occur during construction operations. This may result from: • runoff from vegetation free surfaces; • construction and operation of temporary roads; • plant and vehicle washing; • excavations and blasting; • embankment construction; and/or • excavation of road drains.	**Sediment Regime** A possible increase in turbidity and siltation may occur. **Channel Morphology** A reduction in diversity due to increased fine sediment supply and deposition is possible. The ecology of gravel bed rivers would also be severely affected. **Natural Fluvial Processes** An increase in siltation may result.
Vegetation clearance **Direct Impact** Vegetation clearance during construction may reduce the stability of the river channels, increasing the potential for erosion and associated sediment release. Sediment release is likely to be greatest where vegetation clearance is required on slopes and would be particularly significant where woodland clearance is required.	**Sediment Regime** An increase in supply of fine sediment through bank instability, especially during the winter months is possible. **Channel Morphology** Reduced morphological diversity due to bank collapse and sedimentation may occur. **Natural Fluvial Processes** Bank instability due to bank erosion may increase.
Culvert installation **Direct Impact** Culvert installation could cause a major disturbance to the river bed. The majority of the watercourse crossings would involve culverting.	**Sediment Regime** Installation could increase the volume of sediment directly entering the channel and consequently increase turbidity. **Channel Morphology** The channel bed would be severely disturbed in the vicinity of the installation. **Natural Fluvial Processes** Localised erosion and deposition may occur and planform change may be constrained.
Realignments **Direct Impact** The proposed scheme alignment would result in the diversion (realignment) of watercourses. Construction operations may lead to a range of geomorphological impacts.	**Sediment Regime** An increase in sediment supply would occur during cutting a new course. A subsequent increase in channel erosion is likely if the channel is straightened and gradient increased. **Channel Morphology** Bedforms that have developed over a long period of time may be disturbed. The new channel will lack morphological diversity. **Natural Fluvial Processes** Channel instability may be induced due to the new course. Fluvial processes are likely to be exacerbated by realignment, especially in high flows.
Outfalls **Direct Impact** The construction of outfalls within the banks of watercourses may lead to sediment release.	**Sediment Regime** Installation could increase the volume of sediment directly entering the channel and consequently increase turbidity. **Channel Morphology** Construction activities may lead to localised modifications to the channel morphology although this is likely to be highly site specific. **Natural Fluvial Processes** The stability of the river banks may be reduced during installation leading to the potential for higher erosion rates. This is likely to be highly site specific.

4.2 Site Specific Impacts

Operation Impacts

4.2.1 The impacts of the proposed scheme on each watercourse during operation of the scheme would arise from four key changes: the release of suspended sediments, an increase in discharge, culvert installation and realignment. The impact of these changes on the geomorphology of the watercourse is evaluated by assessing the likely impact of these changes on the sediment regime, the existing channel morphology and the nature of contemporary fluvial processes operating.

4.2.2 Table 8 describes the impacts in more detail with specific reference to the individual watercourse.

Table 8 – Potential Impacts on Watercourses During Operation

Watercourse	Potential Impacts	Magnitude
Megray Burn	**Release of Suspended Solids** Fine sediment could accumulate on the bed with an adverse impact on morphology and ecology. However, the limited existing morphological diversity would reduce the impact of this.	**Low**
	Increased Discharge An increase in discharge may lead to accelerated channel erosion increasing fluvial process rates that would cause changes in the sediment regime and channel morphology. However, the limited existing morphological diversity would reduce the impact of this. An increase in sediment transport may however cause reductions in culvert capacity downstream, potentially increasing flood risk.	**Medium**
	Culvert Culverting would reduce the morphological diversity of the river channel. However as this channel is already highly modified this would be of low impact.	**Low**
	Realignment Realigning the watercourse would lead to an increase in channel length, decreasing the channel gradient. As a result, stream power would be lower, increasing the potential for deposition of fine sediment. This could have potential impacts on culvert capacity downstream.	**Medium**
	Outfall Potential sediment release as a result of scour around the outfalls may lead to an increase in sedimentation which could cause a reduction in morphological diversity. As the watercourse has a relatively steep gradient there is potential for scour to occur around the outfall.	**Medium**
Limpet Burn	**Release of Suspended Solids** n/a as road drainage would not outfall into the watercourse.	**n/a**
	Increased Discharge n/a as road drainage would not outfall into the watercourse.	**n/a**
	Bridge A long culvert under the main carriageway may interrupt sediment transfer and significantly alter the channel morphology. The channel morphology at present is extremely good. The loss of morphologically diverse channels in the Aberdeen area is extremely undesirable due to the widespread occurrence of highly modified channels in this area.	**Medium**
	Realignment Due to its sinuosity, the channel will be realigned. This will lead to a change in channel sinuosity, through a slight reduction in the channel length which will increase the channel gradient. An increase in gradient would result in an increase in stream power which in turn, would increase the potential for channel erosion which could lead to channel instability. If instability is created there is likely to an increase in the volume of sediment transferred downstream as the river adjusts to the new conditions. This could potentially have widespread impacts on channel morphology. Ideally, a similar length to the original watercourse should be designed so that the gradient that currently exists at the site could be re-created in the new watercourse. This would reduce the potential for channel adjustment following the realignment as long as the original watercourse currently exhibited minimal adjustment.	**High**

Watercourse	Potential Impacts	Magnitude
Coneyhatch Burn	**Release of Suspended Solids** n/a as water being re-routed into pre-earthworks drainage. **Increased Discharge** n/a as water being re-routed into pre-earthworks drainage. **Culvert** n/a as water being re-routed into pre-earthworks drainage. **Realignment** n/a as water being re-routed into pre-earthworks drainage.	**n/a** **n/a** **n/a** **n/a**
Green Burn	**Release of Suspended Solids** Due to the low gradient, fine material could accumulate on the bed and potentially lead to channel siltation, leading to a decline in the morphological diversity. In addition, fine sediment may also be transferred to the on-line ponds downstream with detrimental impacts of the fisheries value of these ponds. **Increased Discharge** An increase in discharge may lead to accelerated channel erosion increasing fluvial process rates that would cause changes in the sediment regime and channel morphology. **Two Culverts** A long culvert under the main carriageway, and a shorter one under the side road, would interrupt sediment transfer and significantly alter the channel morphology. The channel morphology at present is extremely good. The loss of morphologically diverse low order streams in the Aberdeen area is extremely undesirable due to the widespread occurrence of highly modified channels in this area. **Realignment** This may lead to a change in channel gradient, through a reduction in the channel length. An increase in gradient would result in an increase in stream power which in turn, would increase the potential for channel erosion which could lead to channel instability. If instability is created there is likely to be an increase in the volume of sediment transferred downstream as the river adjusts to the new conditions. This could potentially have widespread impacts on channel morphology. Ideally, a similar length to the original watercourse should be designed so that the gradient that currently exists at the site could be re-created in the new watercourse. This would reduce the potential for channel adjustment following the realignment as long as the original watercourse currently exhibited minimal adjustment. **Outfall** Potential sediment release as a result of scour around the outfalls may lead to an increase in sedimentation which could cause a reduction in morphological diversity. As the watercourse has a low gradient, any sediment supplied is likely to accumulate on the bed. However, the low gradient of the channel means that flow energy is unlikely to be sufficient to lead to significant scour around the outfall.	**High** **High** **High** **High** **Low**
Green Ditch	**Release of Suspended Solids** n/a as watercourse being realigned. **Increased Discharge** n/a as watercourse being realigned. **Culvert** n/a as watercourse being realigned. **Realignment** Realignment will lead to a change in channel length which will increase the channel gradient. An increase in gradient would result in an increase in stream power which in turn, would increase the potential for channel erosion which could lead to channel instability. If instability is created there is likely to be an increase in the volume of sediment transferred downstream as the river adjusts to the new conditions. This could potentially have widespread impacts on channel morphology. However, as this watercourse has a low gradient and low sediment supply the impact of this is likely to be relatively low.	**n/a** **n/a** **n/a** **Low**
Allochie Burn	**Release of Suspended Solids** n/a as water being re-routed into pre-earthworks drainage. **Increased Discharge** n/a as water being re-routed into pre-earthworks drainage. **Culvert**	**n/a** **n/a**

Watercourse	Potential Impacts	Magnitude
	n/a as water being re-routed into pre-earthworks drainage. **Realignment** n/a as water being re-routed into pre-earthworks drainage.	**n/a** **n/a**
Burn of Muchalls	**Release of Suspended Solids** Fine sediment could accumulate on the bed and cause a reduction in morphological diversity of the watercourse, which is currently very good. **Increased Discharge** An increase in discharge may lead to accelerated channel erosion increasing fluvial process rates that would cause changes in the sediment regime and channel morphology. This may lead to an increase in fine sediment supply with adverse consequences for the morphological diversity of the channel. **Bridge** A long bridge under the main carriageway will retain the existing channel morphology. However, the reduction in sunlight under the bridge may reduce the density of vegetation along the banks. This may lead to an increase in bank erosion as the binding effect of vegetation roots would be lost. This in turn may affect sediment transfer downstream and significantly alter the channel morphology. The channel morphology at present is extremely good. **Realignment** n/a **Outfall** Potential sediment release as a result of scour around the outfall may lead to an increase in sedimentation further downstream which could cause a reduction in morphological diversity. As the watercourse has a low gradient any sediment supplied to the reach is likely to accumulate on the bed. However, the low gradient of the channel means that flow energy is unlikely to be sufficient to lead to significant scour around the outfall.	**High** **High** **Low** **n/a** **Low**
Burn of Blackbutts	**Release of Suspended Solids** n/a as water being re-routed into pre-earthworks drainage. **Increased Discharge** n/a as water being re-routed into pre-earthworks drainage. **Culvert** n/a as water being re-routed into pre-earthworks drainage. **Realignment** n/a as water being re-routed into pre-earthworks drainage.	**n/a** **n/a** **n/a** **n/a**
Cookney Ditch	**Release of Suspended Solids** Fine sediment could accumulate on the bed and cause a reduction in morphological diversity of the watercourse, although as the morphological diversity of the watercourse is limited, this is will have a low impact. **Increased Discharge** An increase in discharge may lead to accelerated channel erosion increasing fluvial process rates that would cause changes in the sediment regime and channel morphology. However, the limited existing morphological diversity will reduce the impact of this. **Culvert** There will be two culverts installed which will not reduce the channel length. However as this channel is already entirely artificial this would have low significance. **Realignment** It is anticipated that this realignment will not lead to any change in channel length. Therefore it is anticipated that there will be no change in the channel morphology as a result of realignment.	**Low** **Low** **Low** **Low**
Stoneyhill Ditch	**Release of Suspended Solids** Fine sediment could accumulate on the bed and cause a reduction in morphological diversity of the watercourse. However, as the morphological diversity of the watercourse is limited, this is will have a low impact. **Increased Discharge** An increase in discharge may lead to accelerated channel erosion increasing rates of fluvial processes that would cause changes in the sediment regime and channel morphology. However, the limited existing morphological diversity will reduce the impact of this.	**Low** **Low**

Watercourse	Potential Impacts	Magnitude
	Culvert Culverting would reduce the morphological diversity of the channel. However, the watercourse is already highly modified and the ephemeral nature of the channel in the location of the proposed crossing point means that there is little existing morphological diversity. **Realignment** It is anticipated that this realignment will not lead to any change in channel length. Therefore it is anticipated that there will be no change in the channel morphology as a result of realignment.	**Low** **Low**
Balnagubs Burn	**Release of Suspended Solids** n/a as road drainage would not outfall into the watercourse. **Increased Discharge** n/a as road drainage would not outfall into the watercourse. **Culvert** Culverting would reduce the morphological diversity of the channel. However as this channel is already highly modified this would be of low significance. **Realignment** As the channel is already straight and realigned in this location, further realignments would cause no change in stream length or planform. However, some extent of bed grading would need to take place to culvert the stream.	**n/a** **n/a** **Low** **Low**
Tributary of Burn of Elsick	**Release of Suspended Solids** Fine sediment could accumulate on the bed, causing a reduction in the capacity of the channel and the efficiency of flow. In addition, deposition of fine sediments is also likely to increase weed growth in the channel that would reduce channel capacity and increase maintenance requirements. However the existing channel is of low morphological diversity and is already choked with dense grasses and rushes. **Increased Discharge** An increase in discharge, associated with a 16% increase in catchment area caused by the road, may lead to accelerated channel erosion; leading to localised increases in deposition on the bed downstream of the erosion. The low channel gradient and dense vegetation growth in the location of the proposed crossing would prevent significant erosion from occurring. **Culvert** Culverting would reduce the morphological diversity of the channel. However as this channel is already highly modified this would be of low magnitude. **Realignment** As the channel is already straight and realigned in this location, further realignments would cause no change in stream length or planform. However some extent of bed grading would need to take place to culvert the stream. **Outfall** Potential sediment release as a result of scour around the outfall may lead to an increase in sedimentation further downstream which could cause a reduction in morphological diversity. As the watercourse has a low gradient any sediment supplied is likely to accumulate on the bed. However, the low gradient of the channel means that flow energy is unlikely to be sufficient to lead to significant scour around the outfall.	**Low** **Medium** **Low** **Low** **Low**
Whiteside Burn	**Release of Suspended Solids** n/a as road drainage would not outfall into the watercourse. **Increased Discharge** n/a as road drainage would not outfall into the watercourse. **Culvert** Culverting would reduce the morphological diversity of the channel. However as this channel is already highly modified this would be of low significance. **Realignment** As the channel is already straight and realigned in this location, further realignments would cause no change in stream length or planform. However some extent of bed grading would need to take place to culvert the stream.	**n/a** **n/a** **Low** **Low**
Crossley Burn	**Release of Suspended Solids** n/a as road drainage would not outfall into the watercourse. **Increased Discharge** n/a as road drainage would not outfall into the watercourse. **Culvert**	**n/a** **n/a**

Watercourse	Potential Impacts	Magnitude
	Culverting would reduce the morphological diversity of the channel. However, as this channel is already highly modified this would be of low significance. **Realignment** As the channel is already straight and realigned in this location, further realignments would cause no change in stream length or planform. However some extent of bed grading would need to take place to culvert the stream.	**Low** **Low**
Cairns Burn	**Release of Suspended Solids** n/a as road drainage would not outfall into the watercourse. **Increased Discharge** n/a as road drainage would not outfall into the watercourse. **Culvert** n/a as channel being realigned to avoid road. **Realignment** Although realignment may lead to a change in the gradient, the ephemeral nature of the flow and low gradient would limit the likelihood of an adverse erosional response.	**n/a** **n/a** **n/a** **Low**
Circle Burn	**Release of Suspended Solids** n/a as water being re-routed into pre-earthworks drainage. **Increased Discharge** n/a as water being re-routed into pre-earthworks drainage. **Culvert** n/a as water being re-routed into pre-earthworks drainage. **Realignment** n/a as water being re-routed into pre-earthworks drainage.	**n/a** **n/a** **n/a** **n/a**
Square Burn	**Release of Suspended Solids** n/a as water being re-routed into pre-earthworks drainage. **Increased Discharge** n/a as water being re-routed into pre-earthworks drainage. **Culvert** n/a as water being re-routed into pre-earthworks drainage. **Realignment** n/a as water being re-routed into pre-earthworks drainage.	**n/a** **n/a** **n/a** **n/a**
Wedderhill Burn	**Catchment Severance** Although Wedderhill Burn is not being directly taken into the pre-earthworks drainage network it is losing 100% of its catchment due to catchment severance. This is ultimately likely to result in the loss of this watercourse through the drying out of the present channel. However, as this watercourse appears to be ephemeral in nature, vegetated and of low morphological diversity, this is unlikely to have a significant impact on the geomorphological processes. In addition, as no clear connection could be found to the Crynoch Burn, this will not have any downstream consequences on this watercourse.	**Negligible**
Craigentath Burn	**Release of Suspended Solids** n/a as road drainage would not outfall into the watercourse. **Increased Discharge** n/a as road drainage would not outfall into the watercourse. **Culvert** Culverting would reduce the morphological diversity of the channel. However, as this channel is already highly modified this would be of low significance. **Realignment** As the channel is already straight and realigned in this location, further realignments would cause no change in stream length or planform. However, some extent of bed grading would need to take place to culvert the stream.	**n/a** **n/a** **Low** **Low**

Construction Impacts

4.2.3 Impacts during road construction would generally occur as a result of the release of suspended sediments, vegetation clearance, culvert installation and the activities associated with the construction of the realigned channel. The impact of these changes on the geomorphology of the watercourse is evaluated by assessing the likely impact of these changes on the sediment regime, the existing channel morphology and the nature of contemporary fluvial processes operating.

4.2.4 Table 9 outlines the potential impacts on watercourses that could result during construction of the proposed scheme.

Table 9 – Potential Impacts on Watercourses During Construction

Watercourse	Potential Impact	Magnitude
Megray Burn	**Release of Suspended Solids** Construction works would provide a high sediment supply, which may enter the channel. Downstream, sedimentation would lead to reductions in morphological quality and potentially reductions in the capacity of culverts downstream increasing flood risk.	**High**
	Vegetation Clearance Clearing trees, in the plantation, could lead to bank instability and increased fine sediment input, particularly as ground vegetation cover is thin. Marginal vegetation in the open section provides bank stability and filters surface runoff, trapping fine sediment. If this vegetation were removed, more sediment would be likely to enter the channel directly.	**High**
	Culvert Installation Installation would disturb the bed and release plumes of fine sediment. If this sediment is deposited culverts downstream this may lead to a reduction in capacity and an increase in flood risk.	**High**
	Realignment Excavating both the new course and potentially a temporary realignment would lead to a temporarily high sediment supply during construction operations. The resulting increase in sediment delivery would probably lead to channel sedimentation downstream, reducing morphological quality with potential adverse effects on aquatic ecology.	**High**
	Outfall Construction of the outfall structure may lead to a release of sediment into the watercourse. However, the low morphological quality of this watercourse and highly localised nature of the impact will limit the impact of this.	**Low**
Limpet Burn	**Release of Suspended Solids** Construction works would provide a high sediment supply, which may enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality and changes to channel capacity, which may increase the frequency of out of channel flow. The transfer of fine sediment from the construction site to the online lakes would lead to a reduction in the water quality of the lakes with potentially adverse impacts on the fisheries within these waterbodies.	**High**
	Vegetation Clearance Marginal vegetation provides bank stability and filters surface runoff, trapping fine sediment. If this vegetation is removed, more sediment is likely to enter the channel directly. The removal of trees and vegetation along the valley sides would also increase the likelihood of significant fine sediment inputs to the stream. If vegetation clearance operations coincide with heavy rains it is possible that slope failures may occur, leading to very high rates of sediment supply.	**High**
	Culvert Installation Installation would require the channel to be realigned.	**High**
	Realignment Excavating both the new course and potentially a temporary realignment could lead to a temporarily high sediment supply during construction operations. The resulting increase in sediment delivery is likely to lead to channel sedimentation downstream, reducing morphological quality and also inflicting adverse effects on the online ponds.	**High**
Coneyhatch Burn	**Release of Suspended Solids** Construction works would provide a high sediment supply which may enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality. However as the existing channel is characterised by low	**Low**

Watercourse	Potential Impact	Magnitude
	morphological diversity this would be of limited significance. **Vegetation Clearance** Marginal vegetation provides bank stability and filters surface runoff trapping fine sediment. Were this vegetation to be removed, more sediment would enter the channel directly, leading to the impacts described above. In addition, channel vegetation filters fine sediment carried in the water column, and removal of this vegetation would release fine sediment stored on the bed. This reduces the potential for trapping fine sediment in the water column. However, as the existing channel is characterised by low morphological diversity this would have a limited significance. **Routing into Pre-Earthworks Drainage** Diverting the watercourse into pre-earthworks drainage would lead to a considerable disturbance to the channel during construction. This would cause a temporary release of fine sediment into the water column which may be transported downstream. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. **Realignment** n/a as water being re-routed into pre-earthworks drainage.	**Low** **Low** **n/a**
Green Burn	**Release of Suspended Solids** Construction works could provide a high sediment supply which may enter the channel and reduce water quality. Downstream, sedimentation, which will be encouraged by the low gradient of this watercourse, will also lead to reductions in morphological quality and changes to channel capacity which may increase the frequency of out of channel flow. In addition, sediment is also likely to accumulate in the existing small culvert under the existing minor road. This would reduce culvert capacity and flow efficiency and potentially increase the risk of flooding in this location. **Vegetation Clearance** Marginal vegetation provides bank stability and filter surface runoff trapping fine sediment. If this vegetation were removed, more sediment would enter the channel directly, leading to the impacts described above. **Culvert Installation** Installation would disturb the bed and release plumes of fine sediment. In addition, culvert installation would also require a realignment of the stream. **Realignment** Excavating both the new course and potentially a temporary realignment could lead to a temporarily high sediment supply during construction operations. The resulting increase in sediment delivery would be likely to lead to channel sedimentation downstream. **Outfall** Construction of the outfall structure may lead to a release of sediment into the watercourse. The morphologically diverse nature of this watercourse means that potential sediment release during outfall construction may lead to a reduction in morphological quality. .	**High** **High** **High** **High** **High**
Green Ditch	**Release of Suspended Solids** Construction works could provide a high sediment supply, which may enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality. However as the existing channel is characterised by low morphological diversity this would have a limited impact. **Vegetation Clearance** Marginal vegetation provides bank stability and filter surface runoff trapping fine sediment. Where this vegetation is removed, more sediment would enter the channel directly, leading to the impacts described above. In addition, channel vegetation filters fine sediment carried in the water column; removal of this vegetation would release fine sediment stored on the bed and reduce the potential for trapping fine sediment in the water column. **Realignment** Excavating both the new course and potentially a temporary realignment could lead to a temporary high sediment supply during construction. The resulting increase in sediment delivery is likely to lead to channel sedimentation downstream. However, as the existing channel is characterised by low morphological diversity this would be of limited significance.	**Low** **Low** **Low**
Tributary of Burn of Elsick	**Release of Suspended Solids** Construction works could result in the release of a high sediment supply that may enter	**Low**

Watercourse	Potential Impact	Magnitude
	the channel and reduce water quality. Downstream, sedimentation could also lead to reductions in morphological quality. However, as the existing channel is characterised by low morphological diversity this would be of limited significance.	
	Vegetation Clearance Marginal vegetation provides bank stability and filters surface runoff trapping fine sediment. Were this vegetation to be removed, more sediment would enter the channel directly, leading to the impacts described above.	**Low**
	Culvert Installation Installation would disturb the bed and release plumes of fine sediment. However, as the existing channel is characterised by low morphological diversity this would be of limited significance.	**Low**
	Realignment Excavating for realignment during culvert installation may result in temporary high sediment supply during construction operations. The resulting increase in sediment delivery would probably lead to channel sedimentation downstream.	**Low**
	Outfall Construction of the outfall structure may lead to a release of sediment into the watercourse. However, the low morphological quality of this watercourse and its heavily modified nature in the location of the proposed road crossing means that there will be little impact on morphology.	**Low**
Whiteside Burn	**Release of Suspended Solids** Construction works could result in the release of a high sediment supply that may enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality. However, as the existing channel is characterised by low morphological diversity this would be of limited significance.	**Low**
	Vegetation Clearance Marginal vegetation provides bank stability and filters surface runoff, trapping fine sediment. Were this vegetation to be removed, more sediment would enter the channel directly, leading to the impacts described above. In addition, channel vegetation filters fine sediment carried in the water column; removal of this vegetation would release fine sediment stored on the bed and reduce the potential for trapping fine sediment in the water column.	**Low**
	Culvert Installation Installation could disturb the bed and release plumes of fine sediment. However as the existing channel is characterised by low morphological diversity this would be of limited significance.	**Low**
	Realignment Excavating for realignment during culvert installation may result in temporary high sediment supply during construction operations. The resulting increase in sediment delivery would probably lead to channel sedimentation downstream.	**Low**
Crossley Burn	**Release of Suspended Solids** Construction works could result in the release of a high sediment supply that may enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality. However, as the existing channel is characterised by low morphological diversity this would have be of limited significance.	**Low**
	Vegetation Clearance Marginal vegetation provides bank stability and filters surface runoff, trapping fine sediment. Were this vegetation to be removed, more sediment would enter the channel directly, leading to the impacts described above. In addition, channel vegetation filters fine sediment carried in the water column; removal of this vegetation would release fine sediment stored on the bed and reduce the potential for trapping fine sediment in the water column.	**Low**
	Culvert Installation Installation would disturb the bed and release plumes of fine sediment. However as the existing channel is characterised by low morphological diversity this would be of limited significance.	**Low**
	Realignment Excavating for realignment during culvert installation may result in temporary high sediment supply during construction operations. The resulting increase in sediment delivery is likely to lead to channel sedimentation downstream.	**Low**
Cairns Burn	**Release of Suspended Solids** Construction works could result in the release of a high sediment supply that may then enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality. However, as the existing channel is	**Low**

Watercourse	Potential Impact	Magnitude
	characterised by low morphological diversity this would be of limited significance. **Vegetation Clearance** Marginal vegetation provides bank stability and filters surface runoff trapping fine sediment. Were this vegetation to be removed, more sediment would enter the channel directly, leading to the impacts described above. In addition, channel vegetation filters fine sediment carried in the water column, removal of this vegetation would release fine sediment stored on the bed and reduce the potential for trapping fine sediment in the water column. **Culvert Installation** n/a as watercourse being realigned to avoid the road. **Realignment** Excavating both the new course and potentially a temporary realignment would lead to a temporarily high sediment supply during construction operations. The resulting increase in sediment delivery is likely to lead to channel sedimentation downstream. However, as the existing channel is characterised by low morphological diversity these activities would be of limited significance.	**Low** **n/a** **Low**
Circle Burn	**Release of Suspended Solids** Construction works could result in the release of a high sediment supply that may enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. **Vegetation Clearance** Marginal vegetation provides bank stability and filters surface runoff, trapping fine sediment. Were this vegetation to be removed, more sediment would enter the channel directly, leading to the impacts described above. In addition, channel vegetation filters fine sediment carried in the water column, removal of this vegetation would release fine sediment stored on the bed and reduce the potential for trapping fine sediment in the water column. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. **Routing into Pre-Earthworks Drainage** Diverting the watercourse into pre-earthworks drainage would lead to a considerable disturbance to the channel during construction. This would cause a temporary release of fine sediment into the water column, which may be transported downstream. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. **Realignment** n/a as water being re-routed into pre-earthworks drainage.	**Low** **Low** **Low** **n/a**
Square Burn	**Release of Suspended Solids** Construction works could result in the release of a high sediment supply that may enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. **Vegetation Clearance** Marginal vegetation provides bank stability and filters surface runoff, trapping fine sediment. Were this vegetation to be removed, more sediment would enter the channel directly, leading to the impacts described above. In addition, channel vegetation filters fine sediment carried in the water column; removal of this vegetation would release fine sediment stored on the bed and reduce the potential for trapping fine sediment in the water column. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. **Routing into Pre-Earthworks Drainage** Diverting the watercourse into pre-earthworks drainage would lead to a considerable disturbance to the channel during construction. This would cause a temporary release of fine sediment into the water column, which may be transported downstream. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. **Realignment** n/a as water being re-routed into pre-earthworks drainage.	**Low** **Low** **Low** **n/a**
Wedderhill Burn	**Release of Suspended Solids** Construction works could result in the release of a high sediment supply that may enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. As there is no	**Negligible**

Watercourse	Potential Impact	Magnitude
	channel connection to Crynoch Burn sediment would not be transferred to this watercourse. **Vegetation Clearance** Vegetation clearance associated with road construction at the source of the stream would be likely to lead to an increase in sediment supply to the stream. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. As there is no channel connection to Crynoch Burn sediment would not be transferred to this watercourse.	**Negligible**
Craigentath Burn	**Release of Suspended Solids** Construction works could result in the release of a high sediment supply that may enter the channel and reduce water quality. Downstream, sedimentation would also lead to reductions in morphological quality. However, as the existing channel is characterised by low morphological diversity this would be of limited significance. As this stream is a tributary of Crynoch Burn, an increase in the concentrations of suspended solids may have adverse consequences for this watercourse, which is designated as an SAC. However, there is no channel connection to Crynoch Burn so sediment would not be transferred to this watercourse.	**Low**
	Vegetation Clearance Marginal vegetation provides bank stability and filters surface runoff, trapping fine sediment. Were this vegetation to be removed, more sediment would enter the channel directly, leading to the impacts described above. In addition, channel vegetation filters fine sediment carried in the water column; removal of this vegetation would release fine sediment stored on the bed and reduce the potential for trapping fine sediment in the water column.	**Low**
	Culvert Installation Installation would disturb the bed and release plumes of fine sediment. However as the existing channel is characterised by low morphological diversity this would be of limited significance.	**Low**
	Realignment Excavating for realignment during culvert installation may result in temporary high sediment supply during construction operations. The resulting increase in sediment delivery would be likely to lead to channel sedimentation downstream.	**Low**

4.3 Summary of Impacts

Operational Impacts

4.3.1 Potential impacts that are likely to result during operation of the proposed scheme have been described in terms of sediment regime, channel morphology and natural fluvial processes (Table 6). The main issues that have been identified are the potential for increased discharge and high fine sediment supply, the use of culverts, the impacts of realignments and outfalls on watercourses.

4.3.2 An increase in discharge from road surface runoff is often associated with an increase in fine sediment supply to watercourses, resulting from accelerated bank erosion and channel instability. An increase in fine sediment supply accumulates on the bed when the flow velocity subsides and acts to reduce morphological diversity. Fine sediment deposition is particularly detrimental in gravel bed watercourses that are used by migratory fish for spawning.

4.3.3 An increase in discharge may also lead to a greater risk of flooding. Some of the watercourses currently exhibit flashy hydrological regimes. Greater surface runoff and less infiltration could exacerbate this flood risk. An increase in the frequency and magnitude of flood flows would increase the rate of geomorphological processes of both erosion and deposition. This would be likely to have particularly adverse impacts along Limpet Burn and Burn of Muchalls.

4.3.4 The majority of the watercourses require either a single culvert or a number of culverts. In cases where the channel is artificial and/or has been historically straightened and displays poor morphology, the significance of operational impacts are minimal. Adverse impacts on natural fluvial processes such as erosion and deposition and features such as pool and riffle sequences can occur when the bed is replaced by an artificial substrate. The channel section through the culvert will lack bank and riparian features (and all vegetation due to lack of light) which has direct implications on the ability of the river to laterally migrate and maintain the sinuosity. Culverts interrupt the continuity of a watercourse, often prohibiting fish and wildlife migration.

4.3.5 Culverts straighten the channel, constraining lateral migration and increasing the gradient, which may lead to instability. The impact of culverts would be greatest where the existing channel gradient is relatively steep and where protected sites exist downstream.

4.3.6 A number of watercourses would be realigned in order to install a culvert. If the channel geometry, gradient and sinuosity of the new alignments are not appropriate, it may take a long period of time for a channel to adjust to its new course. The impacts of this would include bank erosion, bed incision and channel deposition downstream.

4.3.7 Outfall structures will be installed on a number of watercourses. Depending on the type of outfall structure constructed, these may be vulnerable to scour from flow in the watercourse into which they discharge.

Construction Impacts

4.3.8 As with operational impacts, many of the impacts associated with construction would be generic to every site, although the severity of the impact would differ according to the individual baseline conditions and the scale of works in the vicinity of the watercourse.

4.3.9 One major impact on watercourses would be the increased availability of fine sediment associated with activities such as embankment construction, cutting excavations, temporary access roads, vehicle washing. The installation of culverts would also have a direct impact by disturbing the morphology of the channel bed, destabilising the banks and releasing more fine sediment.

4.3.10 The high fine sediment volume entering the channel during construction may lead to channel siltation and the possibility of excessive channel vegetation growth if there is a sustained period of low flow. Fine sediment would have a detrimental effect on the gravel bed streams through the smothering of spawning gravels. In addition, sediment that enters the channel can be stored within the watercourse for a long period of time, if it cannot be flushed downstream due to obstruction in the form of channel vegetation. This may prolong the impact on aquatic ecology (refer to Appendix A40.9). The turbidity of the water would also likely be high, with adverse effects on water quality.

4.3.11 Culvert installation would likely result in short-lived, but potentially severe impacts on watercourses. Long lengths of channel would be disturbed releasing sediment downstream. The banks and surrounding floodplain could also be destabilised. The sediment loading could be greatly increased and the morphological diversity greatly reduced during and after installation. The recovery time of the channel would depend on how dynamic the watercourse is (how much energy it has), which partly depends on flow velocity.

4.3.12 The construction of outfall structures that would be installed on a number of watercourses have the potential to result in localised modifications to channel morphology, although this is likely to be highly site specific. The stability of the river banks may be reduced during outfall installation leading to the potential for higher rates of erosion. Sediment release during the installation of outfalls could lead to increased sedimentation further downstream.

5 Mitigation

5.1 Generic Mitigation

Operation Mitigation

5.1.1 A number of generic mitigation measures can be implemented to reduce the potential impacts that would be associated with the operation of the proposed scheme. These are described in Table 10.

Table 10 – Operational Mitigation Measures

Source of Impact	Mitigation Measure	Type of Mitigation
Suspended Solids	Avoid direct drain outlets from road into watercourse.	Prevention (avoidance)
	Where road drainage will be routed into watercourses this will be treated using: filter drains, treatment ponds and detention basins. Further details about these options are included in the Water Quality Appendix A39.3.	Reduction
Increased discharge (and flooding)	Avoid direct drain outlets from road into watercourse.	Prevention
	Detention basins will be provided where road drainage is to be routed into watercourses. These store road runoff and release it gradually into watercourse to prevent an increase in discharge. The detailed designs for these detention basins vary according to location and are described further in the Water Quality Appendix (A39.3).	Reduction
	Avoid building structures (e.g. embankments) on the floodplain as these may constrict flow during floods and lead to a backing-up of flow, potentially increasing flooding upstream.	Prevention
Crossing Structures (Culverts)	A number of options are available for watercourse crossing structures, these are: Build a bridge across the watercourse. Divert the watercourse. Culvert the watercourse.	Prevention Offset Reduction
	The DMRB gives a number of "cases" for water crossings requiring culverts:	
	Case 1: Culvert barrel with dimensions derived for flood flow conditions.	Reduction
	Case 2: Culvert with depressed invert to allow for inclusion of stream bed material within the barrel.	Reduction
	Case 3: Bottomless arch culvert to retain natural stream bed.	Reduction
	Case 4: Provision of a low flow channel within the culvert invert.	Reduction
	Case 5: Provision of baffles within the culvert to increase roughness.	Reduction
Realignments	Ensure the realignment (planform, geometry, sinuosity and morphological features) is appropriate by including input from a geomorphologist.	Reduction (this also represents an opportunity to improve the morphological status of watercourses in the immediate vicinity of the road)

Source of Impact	Mitigation Measure	Type of Mitigation
Outfalls	Ensure that the outfall is correctly positioned to limit the potential for scour around the culvert. This involves ensuring that the outfall does not cause a significant alteration to flow patterns which may lead to turbulence and/or excessive deflection of flow towards the bed or banks of the channel. The outfall must not project out into the channel and should not be located where flow converges with river banks causing higher shear stresses or where active bank erosion is occurring.	Reduction
	Ensure that adequate scour protection measures are provided around the outfall. Details of best practice are identified in CIRIA C697 (2007).	Reduction

<u>Crossing Structures</u>

5.1.2 Depressed invert culverts will be used to convey the majority of the watercourse along the alignment under the road. The culverts will be designed to convey flows of up to 1 in 200 year return flow. Depressed invert culverts are culverts where the invert (base) is installed at an elevation below the existing watercourse bed to allow a natural bed structure to reform. This reduces the impact of the culvert on morphological structure and continuity as well as reducing the impact of the culvert on sediment transport processes. However, these culverts inhibit lateral channel changes (erosion) and also lead to the artificial straightening of the river channel (increased channel gradient). This may lead to increases in stream power, leading to scour both within the culvert and at the culvert outlet. Bench features will be installed either side of the wetted channel and be sized relative to the current channel dimensions to provide wildlife access (refer to Appendix A39.9). The installation of these culverts requires in-channel works.

5.1.3 Depressed invert culverts are generally appropriate where channel morphology is already influenced by past modifications, but bed morphology is of good quality. Where the majority of the section of watercourse affected by the road is natural, the provision of bridges is recommended, where possible. In addition, bridges are most appropriate where the channel is steep and has a sinuous planform as channel straightening associated with culverting may increase stream powers and lead to scour problems.

5.1.4 Existing culverts that would be located close to the proposed scheme can have an impact on the effectiveness of mitigation. Inappropriately designed culverts currently in place can act as a barrier to sediment or wildlife movement. Where appropriate, it may be possible to upgrade these structures to maximise the values achieved by the mitigation measures associated with the proposed scheme.

<u>Realignments</u>

5.1.5 Realignment designs will be based upon the following principles:

- In general, the new alignments will have similar channel dimensions (width and depth) as the existing channels that they are replacing. Where necessary, changes in gradient will be compensated for by varying the channel sinuosity (planform), width and depth.
- The bed of the new channel will be formed using sediment sized to match the existing bed. Where possible an alternating sequence of pools, riffles and runs will be sited appropriately. These features are represented in natural watercourses and will help provide optimum habitat conditions for salmonids.

5.1.6 Prior to construction of these realignments, further geomorphological investigations are recommended where watercourse have a medium to high vulnerability to assess:

- sinuosity and channel cross-sectional dimensions required to minimise subsequent re-adjustments (these may vary along the watercourse); and

- specific requirements for bank and bed protection measures.

5.1.7 It is anticipated that additional geomorphological assessments will be submitted to SEPA, as required, as part of the CAR application for each realignment.

Construction Mitigation

5.1.8 A number of generic mitigation measures will be implemented to reduce the impact of the operation of the road scheme and are presented in Table 11.

Table 11 – Construction Mitigation Measures

Source of Impact	Mitigation Measure	Type of Mitigation
Suspended Solids	Provide barriers between earth working and watercourses to prevent sediment washing into the watercourse.	Reduction
	Avoid positioning stockpiles near the channel bank	Prevention
	Cover the stockpiles when not in use.	Reduction
	Contain the stockpiles with bunds or sediment fences.	Reduction
	Use a sediment trap (settling lagoons) to treat surface runoff.	Reduction
	Do not wash vehicles near watercourses.	Prevention
	Avoid creating access roads adjacent to the channel.	Prevention
	Plant and machinery not to ford any channels.	Prevention
	Limit the use of temporary culverts.	Prevention
	Where possible use temporary bridges rather than culverts to cross watercourses.	Prevention
	Provide adequate barriers (sediment fences) along the sides of bridges to prevent sediment from being washed into the watercourse from the road surface.	Prevention
	Connect drains to watercourses only on completion	Reduction
	Ensure there is an adequate space (exclusion zone) between earthworks (embankments and cuttings) and watercourses, to limit the transfer of sediment into them.	Reduction
	When drilling boreholes for blasting, ensure that dust release is limited by damping with water or through providing dust boxes or other barriers.	Reduction
	During blasting operations ground conditions must be carefully examined to determine the quantity of explosives required to fracture the rock. This will help to minimise the risk of fly rock.	Reduction
Vegetation Clearance	Limit the clearing of vegetation on the channel banks and riparian zone.	Reduction
	Use seeded geotextile mats to encourage re-vegetation after works on or near the banks.	Prevention
Culvert Installation (including upgrades)	Use temporary realignment to reduce the impact on installation on watercourses.	Reduction
	Use temporary bridges rather than culverts to cross watercourses.	Prevention
	Use culverts designed to avoid disturbance to the channel bed.	Prevention
	Minimise the length of channel disturbed.	Reduction
	Divert flow through a pipe or lined channel to bypass the channel works to enable the culvert to be installed into a dry channel.	Reduction
	Where depressed invert culverts are to be installed, use new, appropriately sourced and sized sediments to form the bed of the new culvert.	Reduction
Pre-earthworks drainage	Construction mitigation measures for the construction of pre-earthworks drainage systems are described in the Water Quality Appendix.	Reduction
Realignments	Limit the use of temporary realignment channels.	Prevention
	Ensure the realignment and length (course, geometry, sinuosity, and morphological features) is appropriate by including input from a geomorphologist.	Reduction
	Use new appropriately sourced and sized sediments to form the bed of the new sections of channel.	Reduction
	Do not allow flow in the new channel until construction is complete.	Reduction

Source of Impact	Mitigation Measure	Type of Mitigation
Outfalls	Ensure that construction if outfall is not conducted during periods of high flow as the disturbed an exposed river banks will be vulnerable to erosion.	Reduction
	Where possible provide sediment fences to prevent sediment being washed into the watercourse.	Reduction
	Where possible avoid excavating into the river banks and limit the extent of disturbance.	Reduction

5.1.9 A detailed method statement for construction activities in the vicinity of each watercourse will be produced and agreed with SEPA. This will contain the measures to be implemented to minimise the impacts of construction on a site by site basis.

Crossing Structures

5.1.10 The construction of depressed invert culverts (Case 2) and the upgrading of any existing culverts, will require extensive in-channel works. During culvert installation, flow must be diverted around the channel works, either in a lined open channel or through a pipe. This will allow channel works to be conducted in conditions that will assist the minimisation of sediment release during construction. To reduce erosion risk, flow will only be re-routed into the new culvert once channel works are completed.

5.1.11 To ensure morphological continuity and prevent localised changes in bed elevation, such as the evolution of knickpoints, the channel bed in depressed invert culverts will be formed prior to the routing of flow through the culvert. Bed sediments will not be transferred from the existing channel, as transferring channel bed sediment may release fine sediments and pollutants stored beneath the bed armour (coarse sediments forming the top layer of the bed sediments). The new bed will be formed of locally sourced material (perhaps from excavation works elsewhere along the route) of the same size as the dominant particle size (excluding silt accumulations) in the pre-existing gravel channel. No fine sediment will be placed in the new channels.

5.1.12 The long-term stability of the bed sediments in depressed invert culverts will depend upon stream power within the culvert. Where the gradient of the culvert is high, stream powers may lead to scouring within the culverts and the loss of these bed sediments to downstream depositional areas. Problems associated with stream power are most likely to occur where culverting has involved the straightening of previously sinuous watercourses. To minimise the risk of scour, it may be necessary to install baffles within the culvert to dissipate flow energy and to stabilise the bed sediments. In addition, it may be necessary to install scour protection on the bed of the channel at the culvert outlet, to dissipate energy and prevent scour.

5.1.13 Clear span bridges or buried structures, such as those proposed for Limpet Burn and the Burn of Muchalls, are advantageous as these do not require in-channel work during installation and will help preserve the morphology and materials of the existing watercourse. Where sinuous watercourses are to be culverted, some channel realignment may be required, involving a reduction in sinuosity. This reduction in sinuosity would increase stream powers and can lead to an increase in erosion, and/or incision, potentially leading to increases in sediment conveyance and deposition downstream. Where possible, watercourse realignment will be avoided through wide culverts or the use of bridges.

5.1.14 Bare channel banks created during culvert installation will be covered by geotextile matting, where appropriate, to limit the potential for erosion. This is important because these new banks will be vulnerable to scour, particularly at the culvert outlet. Geotextile matting will limit the potential for both fluvial scour, geotechnical failure and rainfall induced runoff erosion of the exposed banks. The geotextile matting will be seeded to promote vegetation colonisation and to ensure rapid stabilisation.

Temporary Realignments

5.1.15 Temporary watercourse realignments will be constructed with a great deal of care to prevent these from becoming sources of sediment. The temporary channel will be fully lined using geotextiles to prevent erosion of the bed and banks. Where possible, the realignment will have approximately the same channel length as the exiting watercourse in order not to increase the channel gradient. An increase in channel gradient can promote an increase in stream power that could lead to scour downstream.

5.1.16 Works in the vicinity of temporary realignment will be carefully managed to avoid the risk of accidental spillage into the watercourse. All pumps will have drip trays or bunding to minimise seepage. Site road crossings will consist of piped section sufficiently long to provide a road together with strips of ground either side to provide a barrier between the road and open channel sections.

5.1.17 Sediment control measures will be placed at the downstream end of the temporary realignment to intercept sediment delivered to the temporary realignment as a result of construction activities.

Watercourse Realignments

5.1.18 Further detailed site specific assessments are likely to be required for each watercourse realignment once the construction methods have been finalised, but the approach will be based upon the following principles:

- In order to limit the potential for bank erosion, new banks of the realignments will be appropriately graded.
- Covering newly formed banks along the new alignment with geotextile matting (where deemed necessary) will also reduce the potential for erosion by physically holding the newly exposed channel bank sediments together. This will limit the potential for both fluvial erosion and runoff induced erosion on the exposed banks during rainfall. The geotextile matting will be seeded to promote vegetation colonisation and thus ensure rapid stabilisation of this new section of watercourse.
- It is essential that no flow is routed through the new, realigned channel during construction. The channel will be complete, including the new culverts, prior to the diverting of water – and no further in-channel works will be conducted. The new channel will be constructed by moving progressively upstream, to minimise the risk of flow switching into the new channel during high flow events, prior to completion.
- Bed sediments will not be transferred from the existing channel as this would necessitate a temporary realignment during sediment transfer. Bed sediments will not be taken from the existing channel, as transferring channel bed sediment may release fine sediments and pollutants stored beneath the bed armour (coarse sediments forming the top layer of the bed sediments). Bed sediments will be appropriately sized (and shaped) gravels derived from a local source. The use of gravel sized sediments will provide voids within the channel bed which will act as a sediment sink to fine material, allowing a reduction in sediment transfer downstream where any localised readjustment (erosion) occurs following the diversion of flow.
- It is likely that when flow is routed through the new channel alignment there will be a period of adjustment during which some sediment release can be expected. The new channel will be monitored regularly and where signs of instability are observed, such as erosion or incision, appropriate remediation measures will be undertaken.
- It is recommended that works be carried out in early spring in lower flow conditions, enabling vegetation to establish over the summer.

5.2 Site Specific Mitigation

Operation Mitigation

5.2.1 In addition to these generic mitigation measures, site specific mitigation measures will be required as a result of local conditions and site specific factors. These mitigation measures focus on watercourse crossings and realignments. Watercourses that would be diverted into pre-earthworks drainage are not considered in this section.

Crossing Structures

5.2.2 The varied geomorphology of watercourses means that the minimum requirements of each watercourse crossing design varies. As such, different crossing structures are required (Table 12).

Table 12 – Crossing Structures

Watercourse	Crossing Structures
Megray Burn	Case 2 Depressed Invert Box Culvert and extension of existing culvert
Limpet Burn	Bridge - Buried Structure underbridge with a 12.5m span
Green Burn	Two Case 2 Depressed Invert Box Culverts
Burn of Muchalls	Bridge - Buried structure underbridge with a 15m span
Cookney Ditch	Two Case 2 Depressed Invert Box Culverts
Stoneyhill Ditch	Case 2 Depressed Invert Box Culvert
Balnagubs Burn	Case 2 Depressed Invert Box Culvert
Tributary of Burn of Elsick	Case 2 Depressed Invert Box Culvert
Whiteside Burn	Case 2 Depressed Invert Box Culvert
Crossley Burn	Case 2 Depressed Invert Box Culvert
Craigentath Burn	Case 2 Depressed Invert Box Culvert

5.2.3 A number of watercourse realignments would also be required and are listed in Table 13.

Table 13 – Watercourse Realignments

Watercourse	Realignment
Megray Burn	Realignment of 951m required, with a 49m increase in channel length.
Limpet Burn	Realignment of 123m required, with a 1m reduction in channel length.
Green Burn	Realignment of 342m required, with an 8m decrease in channel length.
Green Ditch	Realignment of 36m required, with a 59m reduction in channel length.
Balnagubs Burn	Realignment of 117m required with no change in channel length.
Tributary of Burn of Elsick	Realignment of 150m required with no change in channel length.
Whiteside Burn	Realignment of 121m required with no change in channel length.
Crossley Burn	Realignment of 161m required with no change in channel length.
Craigentath Burn	Realignment of 216m required with no change in channel length.
Cairns Burn	Realignment of 192m required, with a 40m decrease in channel length.
Stoneyhill Ditch	Realignment of 203m with no change in channel length.
Cookney Ditch	Realignment of 244m required with no change in channel length.

Megray Burn

5.2.4 The realignment of this watercourse would lead to an increase of approximately 49m to the length of the reach. This will lead to a change in the overall gradient of this section of watercourse. However, the change in gradient will not occur uniformly along the reach. To route the watercourse into the culvert under the road, a locally steep section of watercourse will be required. Consideration will be given at this location to ensure that increased flow velocities associated with this steep section do not lead to an increase in channel erosion or initiate channel incision. The banks will be appropriately graded and, where necessary, protected using suitable erosion protection measures. Similarly, the bed should be protected by using a combination of coarse bed sediments, to limit the potential for entrainment, or through the provision of hard steps using boulders to dissipate flow energy. Further information regarding erosion prevention will be provided in the Controlled Activities Regulations (CAR) application.

Limpet Burn

5.2.5 The realignment of the watercourse will not involve a significant change in channel length (1 metre reduction) and this will limit the potential for channel adjustment following construction. The new channel should have the same dimensions as the existing watercourse (width and depth), bed composition and morphology.

Construction Mitigation

Megray Burn

5.2.6 The channel realignment will be conducted off-line and preferably in dry conditions. The construction works will have to be carefully managed to ensure that they do not result in sediment release to the watercourse. The new alignment should be completed prior to the re-routing of flow into the channel. To achieve this, it may be necessary to construct the realignment in phases.

Limpet Burn

5.2.7 The channel realignment will be conducted off-line and preferably in dry conditions. However, the proposed realignment crosses the existing watercourse. The construction works will be carefully managed to ensure that they do not result in sediment release to the watercourse. The new alignment should preferably be completed prior to the re-routing of flow into the channel. To achieve this, it may be necessary to construct the realignment in phases.

5.3 Mitigation Summary

Operation Mitigation

5.3.1 The application of the mitigation measures that have been recommended at all crossing points will reduce the impacts of the operation of the road (Table 10).

5.3.2 Open channel realignments (Megray Burn, Limpet Burn, Green Burn, Cairns Burn, and Green Ditch) will be carefully designed using the geomorphological principles described previously. Following completion, the morphological response of all watercourse realignments will be monitored for a period of at least one year. This is essential, as the realigned channels will undergo some morphological re-adjustment following realignment. This will be monitored to ensure this does not have an adverse effect on the ecology and geomorphology of the channel. A monitoring plan would be detailed once the designs for the works have been determined.

5.3.3 Outfalls will be correctly positioned to limit the potential for scour. This involves positioning the outfall so that it does not cause a significant alteration to flow patterns which may lead to turbulence and/or excessive deflection of flow towards the bed, or banks, of the channel. The outfall must not project out into the channel and should not be located where flow converges with channel banks which could create high shear stresses, or where active bank erosion is occurring. It is important to ensure that adequate scour protection measures are provided around the outfall. Details of best practice are identified in CIRIA C697 (2007). Further information describing the design and operation of the outfalls will be provided in the CAR application for each watercourse.

Construction Mitigation

5.3.4 A range of generic mitigation measures have been recommended which can be applied at all crossing points, to reduce the impact of the construction of the road (Table 11).

5.3.5 During in-channel works, flow will be diverted around the construction operations within an appropriately sized temporary realignment (diversion channel) lined with geotextiles to prevent bank erosion (if appropriate).

5.3.6 Watercourse alignments will be constructed and completed prior to the switching of flow through the new course, which will prevent fine sediment release into watercourses during construction. However, it is likely that when flow is routed through the new channel alignment there will be a period of adjustment during which some sediment release can be expected. It is essential that the new channel is monitored regularly and where signs of excessive instability are observed, such as erosion or incision, appropriate remediation measures are undertaken.

5.3.7 The construction of outfalls during periods of low flow will limit the amount of sediment released and the potential for erosion from vulnerable river banks. The use of sediment fences will prevent sediment being washed into the watercourse. Avoiding excavation into channel banks and limiting the extent of disturbance will reduce the extent of sediment released into the watercourses. Further details of the construction of each outfall will be provided in the CAR application.

5.3.8 Prior to construction of realignments, further geomorphological investigations may be required to determine the:

- sinuosity and channel cross-sectional dimensions required to minimise subsequent re-adjustments (these may vary along the watercourse); and
- specific requirements for bank and bed protection measures.

6 Residual Impacts

6.1 Operational Residual Impacts

6.1.1 The long-term predicted residual impacts remaining once the mitigation described has been successfully implemented for operation are provided in Table 14. With the effective implementation of mitigation, the anticipated impacts are predominantly negligible.

Table 14 – Generic Residual Impacts for Operation

Source of Impact	Residual Impact (with mitigation)
Suspended Solids **Direct Impact**	**Sediment Regime** Treatment of the road drainage using filter drains, detention basins and treatment ponds will prevent significant quantities of suspended sediment from being released into watercourses. Sediment removal efficiencies are variable, filter drains remove 80%-90% of suspended solids and treatment ponds have removal efficiencies of between 65% and 90%. Removal efficiency is partly dependant on discharge. During flood events for example, efficiencies will be towards the lower end of the range while during periods of low flows removal efficiency will be greatest. During high flows the suspended sediment is naturally high. The residual impact would be Negligible. **Channel Morphology** Overall, the proposed scheme would have a Negligible impact resulting in limited fine sediment release. It would also have a Negligible impact on channel morphology. **Natural Fluvial Processes** Overall, changes to the sediment regime would be Negligible. They would be insufficient to produce any noticeable change in the nature of fluvial processes operating on watercourses in the study area and the residual impact would be Negligible for most watercourses.
Increased discharge **Indirect Impact**	**Sediment Regime** The storage of road discharge in detention basins prior to gradual release into the watercourse will prevent the proposed scheme resulting in significant impacts on the hydrological regime of watercourses in the study area. Overall, the residual impacts on the sediment regime through changes in erosion or deposition rates of watercourses in the study area would be Negligible. **Channel Morphology** Overall, the road would nave no appreciable impact on the hydrological regime of most of the affected watercourses in the study area and changes in channel morphology would be Negligible. **Natural Fluvial Processes** Similarly as the provision of detention basins would limit changes in the discharge and sediment regimes of most of the watercourses in the study area, the changes in natural fluvial processes would be also be Negligible.

Source of Impact	Residual Impact (with mitigation)
Outfall	**Sediment Regime** Ensuring that each outfall is appropriately located and that best practice design guidance is adhered to (CIRIA C697) will limit the potential for scour around the structure. In addition, this will ensure that associated increases in sediment supply would result in a negligible impact on each watercourse affected. **Channel Morphology** Ensuring that each outfall is designed and located in accordance with best practice will limit the impact of the outfall on channel morphology. This highly localised modification to the bank will have a negligible impact on the morphology of each watercourse as a whole. **Natural Fluvial Processes** Ensuring that each outfall is designed and located in accordance with best practice will prevent interference with flow. This will reduce the likelihood that changes in rates of erosion and deposition within the section of the watercourse will occur ensuring that the modification has a negligible impact on each watercourse. Further information describing the design and operation of the outfalls will be provided in the CAR application for each watercourse.

6.2 Generic Construction Residual Impacts

6.2.1 A series of mitigation measures have been recommended, which would reduce the impact of the construction phase of the proposed scheme on watercourses (Table 11). The residual impact of these recommendations are applicable to all watercourses are summarised in Table 15. The predicted residual impacts are likely to be temporary in nature and most would be negligible.

Table 15 – Generic Residual Impacts During Construction

Impact	Residual Impact (with mitigation)
Vegetation Clearance **Direct Impact**	**Sediment Regime** The range of mitigation measures required at each crossing point would reduce the potential for vegetation clearance to lead to an increase in sediment supply. Vegetation clearance would generally have a negligible effect on the sediment regime of the channel. **Channel Morphology** As changes to the sediment regime resulting from construction and vegetation clearance would be low or negligible they would be insufficient to produce any noticeable change in the channel morphology operating on the watercourse and the residual impact would be negligible for all watercourses. **Natural Fluvial Processes** As changes to the sediment regime resulting from construction and vegetation clearance would be low or negligible they would be insufficient to produce any noticeable change in the nature of fluvial processes operating on the watercourse and the residual impact would be negligible for all watercourses.
Loss of Watercourse to Pre-earthworks **Direct Impact**	Generic residual impacts following mitigation measures for the construction of pre-earthworks drainage systems are described in the Water Quality Appendix A39.3.
Outfall installation	Ensuring that the construction of the outfall is appropriately timed and that barriers, such as sediment fences, are provided to prevent sediment being transferred into the watercourse will enable the impact on watercourse to be limited. Further details of the construction of each outfall will be provided in the CAR application.

6.3 Site Specific Residual Impact Assessment

Operational Residual Impacts

6.3.1 The residual site specific operational impacts of the scheme on each watercourse following the application of mitigation measures are outlined below in Table 16. Residual impacts associated with outfalls (Table 16) have not considered on a site-by-site basis for this assessment. The selection of specific locations will occur in consultation with SEPA and other relevant authorities. Those watercourses that would be diverted into pre-earthworks drainage are not considered in this section as they will no longer exist.

Table 16 – Site Specific Residual Impacts During Operation

Watercourse	Magnitude (without mitigation)	Source of Residual Impact	Residual Impact Magnitude
Megray Burn	Medium	Depressed Invert Box Culvert and Realignment: As this watercourse is already modified, walled, straightened and locally culverted, the installation of a depressed invert culvert would not lead to detrimental impacts on the sediment regime or morphological structure of this watercourse Ensuring that the realignment is designed according to the generic and site specific mitigation measures will limit the impact of the realignment on geomorphological processes within the channel. Detailed geomorphological considerations will also be provided in the Controlled Activities Regulations (CAR) application for this watercourse.	**Low**
Limpet Burn	High	Bridge and Realignment: The use of a bridge (buried structure) means that disruption to morphological processes and the character of the bed and banks of the burn would be limited. The bridge would be installed along a section that currently exhibits good, natural morphological diversity, and good connectivity to the floodplain in the form of continuous wetlands. Ensuring that the channel realignment replicates the dimensions and morphology of the natural sections of this watercourse will hep to limit the impact of this on the geomorphological processes. However, as there would only be limited light penetration beneath the structure vegetation growth would be limited. This would increase the potential for bank erosion to occur along the realignment during high flows, although the scale of this is likely to be limited.	**Low**
Green Burn	High	Two Depressed Invert Box Culverts and Realignment: The provision of depressed invert culverts allows the bed to be formed from appropriately sourced natural sediments, and ensures that the continuity of bed morphology and sediment transfer is maintained. The channel would be realigned over a distance of 342 m. However, the realignment would primarily affect the section of the watercourse which is currently heavily modified.	**Low**
Green Ditch	Low	Realignment: As Green Ditch appears to be an artificial watercourse and thus realignment of this reach would have a negligible impact. The low gradient of the watercourse in this area means that despite the substantial shortening caused by realignment it would not have a significant impact on the geomorphology of the watercourse.	**Negligible**
Burn of Muchalls	High	Bridge: The construction of a bridge would avoid direct impacts on the Burn of Muchalls.	**Negligible**

Watercourse	Magnitude (without mitigation)	Source of Residual Impact	Residual Impact Magnitude
Cookney Ditch	Low	Two Depressed Invert Box Culverts and Realignment: The watercourse in the location of the proposed culvert is already straight and of low morphological diversity. Culverting this section of watercourse would have a negligible impact on the morphological diversity of the watercourse and the new culvert would ensure continuity of bed morphology. A 244m length of channel would be realigned. However, this would be vertical/bed realignment and unlikely to cause change in an already straightened channel with a low gradient.	**Negligible**
Stoneyhill Ditch	Low	Depressed Invert Box Culvert and Realignment: The watercourse in the location of the proposed culvert is straight and of low morphological diversity. Culverting this section of watercourse would have a negligible impact on the morphological diversity of the watercourse and the new culvert would ensure continuity of bed morphology. A 203m length of channel would be realigned. However, this would be vertical/bed realignment and unlikely to cause change in an already straightened channel with a low gradient.	**Negligible**
Balnagubs Burn	Low	Depressed Invert Box Culvert and Realignment: The watercourse in the location of the proposed culvert is already straight and of low morphological diversity. Culverting this section of watercourse would have a negligible impact on the morphological diversity of the watercourse and the new culvert would ensure continuity of bed morphology. A 117m length of channel would be realigned. However, this would involve vertical/bed realignment and unlikely to cause change in an already straightened channel with a low gradient.	**Negligible**
Tributary of Elsick Burn	Low	Depressed Invert Box Culvert and Realignment: The watercourse in the location of the proposed culvert is straight and of low morphological diversity. Culverting this section of watercourse would have a negligible impact on the morphological diversity of the watercourse and the new culvert would ensure continuity of bed morphology. A 150m length of channel would be realigned. However, this would involve vertical/bed realignment and is unlikely to cause change in an already straightened channel with a low gradient.	**Negligible**
Whiteside Burn	Low	Depressed Invert Box Culvert and Realignment: The watercourse in the location of the proposed culvert is already straight, culverted in a number of places, and of low morphological diversity. Culverting a further section of this watercourse would have a negligible impact on the overall morphological quality, and the new culvert would ensure continuity of bed morphology. A 121m length of channel would be realigned. However, this would involve vertical/bed realignment and is unlikely to cause change in an already straightened channel with a low gradient.	**Negligible**
Crossley Burn	Low	Depressed Invert Box Culvert and Realignment: The watercourse in the location of the proposed culvert is already straight and of low morphological diversity. Culverting this section of watercourse would have a negligible impact on the morphological diversity of the watercourse and the new culvert would ensure continuity of bed morphology. A 161m of length of channel would be realigned. However, this would involve vertical/bed realignment and is unlikely to cause change in an already straightened channel with a low gradient.	**Negligible**
Cairns Burn	Low	Realignment: The realignment would not lead to any significant deviation from baseline conditions as the channel is a small, straight field drain.	**Negligible**
Wedderhill Burn	Negligible	Catchment Severance As the watercourse is ephemeral, has low morphological diversity and is not directly connected to Crynoch Burn, this would have a negligible impact.	**Negligible**

Watercourse	Magnitude (without mitigation)	Source of Residual Impact	Residual Impact Magnitude
Craigentath Burn	Low	Depressed Invert Box Culvert and Realignment: The watercourse in the location of the proposed culvert is already straight and of low morphological diversity. Culverting this section of watercourse would have a negligible impact on the morphological diversity of the watercourse and the new culvert would ensure continuity of bed morphology. A 216m length of channel would be realigned. However, this would involve vertical/bed realignment and is unlikely to cause change in an already straightened channel with a low gradient.	**Negligible**

Construction Phase Impacts

6.3.2 The residual impacts of the scheme on each watercourse, following the application of mitigation measures during construction, are outlined below in Table 17.

Table 17 –Site Specific Residual Impacts During Construction

Watercourse	Magnitude (without mitigation)	Source of Residual Impact	Residual Impact Magnitude
Megray Burn	High	Depressed Invert Box Culvert and Realignment: Road construction and culvert installation would require temporary watercourse realignment and ultimately permanent watercourse realignments. This would lead to some disturbance along the watercourse corridor, involving vegetation clearance and vehicle movements. This activity would have an impact on the natural and diverse morphology of the watercourse. No flow will be routed along the new course during construction would limit the quantity of fine sediments released. The effective implementation of generic and site specific mitigation measures would limit the impact of the realignment. Further more detailed consideration of construction practices will also be provided in the Controlled Activities Regulations (CAR) application for this watercourse.	**Low**
Limpet Burn	High	Bridge and Realignment: The construction of a major bridging structure would have significant impacts on the Limpet Burn and surrounding valley. Due to the difficult access, steep valley sides and wet ground, the movement of plant during construction is likely to involve significant vegetation clearance and ground stabilisation. This would introduce sediment into the watercourse. However, the use of sediment fencing will limit the potential for sediment laden runoff to enter the water column. With mitigation in place, it is considered to be unlikely that any sediment would reach the fishery ponds downstream.	**Low**
Green Burn	High	Two Depressed Invert Box Culverts and Realignment: Road construction and culvert installation would require temporary watercourse realignment and ultimately permanent watercourse realignments. This would lead to disturbance along the watercourse corridor, involving vegetation clearance and vehicle movement. This activity would affect the natural and diverse morphology of the watercourse. No flow will be routed along the new watercourse during construction to limit the quantity of fine sediments released in this phase of the works.	**Low**
Green Ditch	Low	Realignment The effective implementation of generic and site specific mitigation during construction of the realignment would minimise the risk of sediment transfer downstream. Therefore, the proposed modifications to this heavily modified watercourse would have a negligible impact.	**Negligible**

Watercourse	Magnitude (without mitigation)	Source of Residual Impact	Residual Impact Magnitude
Burn of Muchalls	High	Bridge: The construction of a bridge would not involve any in-channel works in this location, which would ensure that construction of the crossing would have a minimal impact on the Burn of Muchalls. Sediment fences will be used to prevent the transfer of sediment from disturbed ground into the watercourse by surface runoff.	**Negligible**
Cookney Ditch	Low	Two Depressed Invert Box Culverts and Realignment: Ensuring that the realignment for culverting does not convey flow prior to the completion of the culverts would limit the impact of construction to a negligible level.	**Negligible**
Stoneyhill Ditch	Low	Depressed Invert Box Culvert and Realignment: Ensuring that the realignment for culverting does not convey flow prior to the completion of the culverts would limit the impact of construction to a negligible level.	**Negligible**
Balnagubs Burn	Low	Depressed Invert Box Culvert and Realignment: Ensuring that the realignment for culverting does not convey flow prior to the completion of the culverts would limit the impact of construction to a negligible level.	**Negligible**
Tributary of Elsick Burn	Low	Depressed Invert Box Culvert and Realignment: Providing a temporary flow diversion and ensuring that channel works are completed before flow is routed along the watercourse will minimise the risk of any temporary increase in sediment supply. Any sediment releases that mau occur as a result of accidental spillage or failure of mitigation measures are likely to be of short duration and would have a negligible impact on this watercourse.	**Negligible**
Whiteside Burn	Low	Depressed Invert Box Culvert and Realignment: Providing a temporary flow diversion and ensuring that channel works are completed before flow is routed along the watercourse would minimise the risk of temporary increases in sediment supply occurring. Any sediment releases that do occur as a result of accidental spillage or failure of mitigation measures are likely to be of short duration and would have a negligible impact on this watercourse.	**Negligible**
Crossley Burn	Low	Depressed Invert Box Culvert and Realignment: Ensuring that the realignment for culverting does not convey flow prior to the completion of the culverts would limit the impact of construction to a negligible level.	**Negligible**
Cairns Burn	Low	Realignment: Constructing the realignment prior to the diversion of flow would limit the impact of the realignment to small scale readjustments. This would thus have a negligible impact on the sediment regime of the watercourse.	**Negligible**
Wedderhill Burn	Negligible	Catchment Severance As the watercourse is ephemeral, has low morphological diversity and is not directly connected to Crynoch Burn, this would have a negligible impact.	**Negligible**
Craigentath Burn	Low	Depressed Invert Box Culvert and realignment: Ensuring that the realignment for culverting does not convey flow prior to the completion of the culverts would limit the impact of construction to a negligible level.	**Negligible**

7 Summary

7.1.1 This technical appendix has focused on the degree to which the operation and construction of the scheme would affect the fluvial geomorphology of the watercourses that would be crossed by the road.

7.1.2 The road would cross watercourses that range in size from small ephemeral watercourses, such as field drains, for example, Cookney Ditch, through to larger streams, for example, the Burn of Muchalls.

7.1.3 The baseline geomorphological characteristics of watercourses vary considerably, according to the size of the watercourse, its topography and the degree of anthropogenic modification.

7.1.4 During operation, impacts would include changes to sediment load (primary increases in suspended solids), increases in discharge, and changes to channel morphology and fluvial processes as a result of crossing structures (mainly culverts) and realignments. During construction, common impacts would be changes to sediment load, vegetation clearance, culvert installation and channel realignment.

7.1.5 Operational impacts would be long-term (permanent) impacts, while those resulting from construction would be short term (temporary impacts) limited to the period of construction.

7.1.6 The magnitude of impacts has been determined by comparing the range of potential consequences associated with operation and construction of the road with baseline conditions of each watercourse, primarily its geomorphological status (morphological diversity and range of fluvial processes), and the proximity of the watercourse in relation to the proposed scheme.

7.1.7 Although fluvial geomorphology does not include any receptors, changes to the fluvial geomorphology have consequences for water quality and ecological receptors and these are considered in Appendix A39.3 and A40.9, respectively.

7.1.8 The effective implementation of appropriate mitigation measures will limit the impact of the proposed scheme on the fluvial geomorphology of watercourses.

7.1.9 For the operational phase, treatment ponds will be used to treat road drainage by trapping fine sediment, while detention basins will limit the impact of the road on the hydrological regime of watercourses. Crossing structures have been designed to reflect the quality of watercourses with bridges over watercourses exhibiting good morphological diversity while depressed invert culverts are to be utilised where lesser quality watercourses are crossed.

7.1.10 In a number of instances, watercourse realignments have been included in the design to ensure that the proposed scheme would result in a limited impact at locations where watercourse crossings may otherwise be highly damaging to the fluvial geomorphology and dependant receptors. Channel realignment also provides an opportunity to improve the geomorphological quality of modified watercourses, primarily through improvements in morphological diversity. Such improvements would also be beneficial for the water quality and ecology of watercourses (Appendix A39.3 and A40.9).

7.1.11 During construction, the application of construction site best practice will limit the potential for sediment release into watercourses. Mitigation measures have also been described to limit the impact of channel works required during culvert installation and watercourse realignment.

7.1.12 The adoption of these mitigation measures during the design and construction phases will ensure that the road scheme generally has a negligible or low impact on the fluvial geomorphology of the affected watercourses.

8 References

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9 Glossary

Adjustment	the modification of river channel morphology, both vertically and in planform, through erosion and deposition, which occurs in response to a modification to a channel caused by external factors such as human interference, climate or land use.
Bar	a general term referring to a depositional feature, usually formed of gravel deposited in a river.
Berm	permanent deposits that have developed on the margin of the channel consisting of bench like features which effectively create a two-stage channel.
Boulder	particle of diameter > 256 mm “human head” size and above.
Buffer Strip	an area of land between the river channel and cultivated land that is uncultivated and often fenced off.
Channel Capacity	the volume of water that can be contained within a given section of river channel.
Catchment	the total area of land that drains into any given river.
Channel	the course of a river including the bed and banks.
Clay	particle of diameter < 0.002mm.
Coarse sediment	sediment of grain diameter greater than 2 mm.
Cobble	particle of diameter 64mm to 256mm, approximately “fist” sized.
Competence	the ability of a river to transport sediment. Generally competence will increase as flows and velocities increase.
Continuity	relates to how continuous the flow or sediment transfer is within a particular watercourse. Culverts often break the continuity through promoting deposition.
Conveyance	how water is transported downstream (e.g. volume, speed).
Culvert	artificial structure, often concrete, for carrying water underground or under bridges.
Debris dam	coarse woody debris blocking the channel and causing water to pond back
Discharge	the volume of water flow per unit time usually expressed in cubic metres per second ($m^3 s^{-1}$)
Dynamic rivers	rivers with high energy levels; which are prone to change their channel characteristics relatively rapidly.
Embankment	artificial flood bank built for flood defence purposes, which can be flush with the channel or set back on the floodplain.
Entrainment	the point at which the sediment is picked up before being transported downstream.
Ephemeral stream	usually low order, water only during and immediately after heavy rainfall.
Erosion	the process by which sediments are mobilised and transported by rivers.
Equilibrium	where erosion and deposition are balanced. This is achieved through morphological adjustment which maintains sediment transport continuity.

EU Water Framework Directive:	Under this Directive, Member States must achieve “good ecological potential” in modified systems and prevent deterioration in the status of surface waters. Ecological status is to be assessed using a number of parameters, including hydromorphological (or fluvial geomorphological and hydrological) quality elements:
Hydrological regime	the quality and connection to groundwater reflect totally or neat totally undisturbed conditions.
River continuity	the continuity of the river is not disturbed by human activities and allows the undisturbed migration of aquatic organisms and sediment transport.
Morphological conditions	channel patterns and dimensions, flow velocities, substrate conditions and the structure and condition of the riparian zone correspond totally or nearly totally to undisturbed conditions. (Source: EU Directive 2000/60/EC – The Water Framework Directive).
Exclusion zone	an area of land beside the river which is out of bounds during construction operations. In the AWPR case, the zone includes the 5 m width from the river bank which forms the SAC and a further 4 m totalling 9 m.
Feedback	the linkage between elements of a system.
Fine sediment	sediment of grain diameter finer than 2 mm.
Flood	a high river flow following rainfall or snowmelt where a river flows out of its channel, sometimes affecting human activity.
Floodplain	area of the valley bottom inundated by water when a river floods.
Flow regime	description of how the flow in a river varies over time and how frequently and for how long high flows (floods) and low flows (during droughts) occur.
Fluvial erosion	erosion carried out by a river, including toe scour and cliff erosion.
Fluvial	the branch of geomorphology that describes the characteristics of river systems and examines the processes sustaining them.
Geomorphology	the study of features and processes operating upon the surface of the Earth.
Geotextile	fabric membrane used for bank stabilisation, usually to aid re-vegetation.
Gravel	particle of diameter between 2 mm and 64 mm.
Hydraulic	the force exerted by flowing water.
Hydrological	referring to the flow of water, specifically its routing and speed.
Incised channel	where the riverbed is well below the floodplain due to downwards erosion (incision).
In-stream	that part of the channel covered by water in normal flow conditions.
Internal controls	controls which are components of the river system such as bed and bank materials, gradient and channel morphology.
Load	the amount of sediment that is being carried by the river.
Meander	a bend in the river formed by natural river processes e.g. erosion and deposition.
Mid-channel bars	gravel or other shallow deposits in the middle of straight sections of watercourse.
Migration	lateral movement of channel across floodplain through bank erosion and deposition.

Modification	channel features that have been created by management interventions and often involve river engineering.
Poaching	trampling by livestock.
Point bar	gravel or other shallow sediment deposition on the inside of bends.
Pool	discrete areas of deep water, typically formed on the outside of meanders.
Reach	a length of an individual river which shows broadly similar physical characteristics.
Realignment	alteration of the planform channel (often by straightening) to speed up flows and reduce flood risk.
Re-naturalising	a formally modified channel that is adjusting to represent a more natural channel in terms of geometry and vegetation.
Reprofiling	reshaping a bank to improve its stability and potential habitat value (usually by reducing the angle of the slope).
Resectioning	alteration of the cross-sectional profile of a channel, often to speed up flows and reduce flood risk.
Riffle	a shallow, fast flowing section of water with a distinctly disturbed surface forming upstream-facing unbroken standing waves, usually over a gravel substrate.
Riparian	land on the side of the river channel.
River corridor	land to either side of the main river channel, including associated floodplain(s),
Rock armour	angular stone placed to protect eroding banks.
Runoff	surface flow after rain which entrains and transports fine sediment from the slope to the channel.
Salmonid	the family of fish species that includes the salmon, trout and char
Sedimentation	the accumulation of sediment (fine or/and coarse) which was formerly being transported.
Scour	erosion caused resulting from hydraulic action.
Side bars	gravel or other shallow deposits along the edges of straight sections of river channels
Siltation	deposition of fine sediment (comprising mainly silt) on the channel bed often promoting vegetation growth if it is not flushed downstream regularly.
Sink	a deposit of sediment in the channel – the location where sedimentation is occurring.
Sinuous	a channel displaying a meandering course. High sinuosity relates to a channel with many bends over a short distance; low sinuosity is often used to describe a fairly straight channel.
Source	where sediment is supplied to a river channel.
Suspended solids	typically fine sediment which is transported in suspension.
Toe (of the riverbank)	where the riverbed meets the bank
Turbidity	a density flow of water and sediment (suspended solids).
Two stage channel	a channel containing a bench like feature or features (berms) which create a low flow channel within a wider high flow channel.

Woody Debris	accumulations of woody material derived from trees, usually fragments of the branches, trunk and roots.