CREW CENTRE OF EXPERTISE FOR WATERS

Sediment continuity through run-of-river hydropower schemes Appendices

CREW CENTRE OF EXPERTISE FOR WATERS

Sediment continuity through run-of-river hydropower schemes

Richard Williams, Peter Downs, Hamish Moir, Chrystiann Lavarini

Hydro Nation International Centre

The James Hutton Institute

Scottish Government
Riaghaltas na h-Alba
gov.scot

CREW CENTRE OF EXPERTISE FOR WATERS

Published by CREW – Scotland's Centre of Expertise for Waters. CREW connects research and policy, delivering objective and robust research and expert opinion to support the development and implementation of water policy in Scotland. CREW is a partnership between the James Hutton Institute and all Scottish Higher Education Institutes and Research Institutes supported by MASTS. The Centre is funded by the Scottish Government.

Authors: Richard Williams[a], Peter Downs[bc], Hamish Moir[bd], Chrystiann Lavarini[b]

[a] School of Geographical and Earth Sciences, University of Glasgow
[b] cbec eco-engineering UK Ltd, Inverness
[c] School of Geography, Queen Mary University of London
[d] Rivers and Lochs Institute, University of the Highlands and Islands

Steering Group members:
Christopher Bromley, Scottish Environmental Protection Agency
Alasdair Matheson, Scottish Environmental Protection Agency
Kenny Taylor, NatureScot
Angus Tree, NatureScot

Project Manager: Nikki Dodd (2020-21), Rachel Helliwell (2021), Katya Dimitrova-Petrova (2021-22)

Please reference this report as follows: Williams, R.D., Downs, P.W., Moir, H.J. and Lavarini, C. (2022), Sediment continuity through run-of-river hydropower schemes. CRW2019_02. Centre of Expertise for Waters (CREW). Available online at: crew.ac.uk/publications

ISBN number: 978-0-902701-04-5

Dissemination status: Unrestricted

Cover photographs courtesy of: cbec

Contents

Appendix A -sediment management plans in Scottish ROR hydropower schemes

1.0 Sediment Management Plans in Scottish RoR hydropower schemes

The extent to which existing Run-of-River (RoR) hydropower schemes have been developed with sediment management plans to maintain natural sediment transport was evaluated. We were provided with information from NatureScot in the form of CAR Licences and a list of 13 schemes known to include sediment information. SEPA were unable to provide any further information due to data losses associated with a cyber attack to the organisation's electronic data. This was the full extent of data available for this review of sediment management plans and is a key limitation. Without access to more CAR Licences especially, it is difficult to summarise the range of conditions issued by SEPA or the sediment information commonly supplied by developers. Current standard conditions used in CAR licenses are outlined in Section 1.1. Only one scheme had a sediment management plan. However, 12 out of 13 schemes mentioned sediment in an Environment Statement. The Environmental Statement (ES) is part of the planning application process. SEPA would not normally try to control sediment management through the ES, but may provide advice to the planning authority that sediment management, including the possible need for a sediment management plan, would be required. SEPA control the need for sediment management and the way it should be carried out through the CAR licence. A CAR Licence was available for five out of 13 schemes and 3 of these included conditions relating to sediment management. The CAR Licence for the scheme with the sediment management plan was not available. Although it was only possible to review one sediment management plan this provided context as clearly, it is uncommon for sediment management plans to be created. This is an important finding regarding current practise. For each scheme that was reviewed, Table A.1 summarises the scheme's capacity, upstream catchment characteristics, river type and sediment management information. This information was all extracted from the documentation supplied by NatureScot or documentation available via council planning portals, with the exception of upstream catchment area which was in some cases extracted from the Flood Estimation Handbook's catchment descriptors database. The documentation for each scheme is described in Section 1.2.

1.1 Standard Conditions

Existing standard conditions included the following statements:

- Sediment removal shall, if required, be carried out only at or immediately upstream of the location of any of the Authorised Activities.
- The volume of sediment removed shall be the minimum necessary to maintain the efficient operation of the Authorised Activities.
- All reasonable steps shall be taken to avoid increased erosion of sediment within the bed or banks of the affected surface water, both within the worked stretch and downstream of it, as a result of any sediment management.
- Sediment management shall not result in the heightening of either bank of the affected surface water.
- The bed of the channel adjacent to each bank of the affected surface water shall at all times be left undisturbed.
- All reasonable steps shall be taken to prevent the transport of sediments or other matter disturbed by sediment management into waters beyond the worked stretch.
- No sediment management shall be undertaken during periods in which fish are likely to be spawning in the affected surface water nor in the period between any such spawning and the emergence of the juvenile fish without SEPA's prior written approval.

Many of these statements are unclear and these conditions could be revised in line with the recommendations made later in this report.

1.2 Documents Reviewed

Burn of Mar

- Environmental Risk Assessment and Mitigation
- Sediment Management Plan

Slug of Auchrannie

- EIAL_REPORT
- EIAL-VOL_2_Appendices
- Decision Notice
- CAR Licence

Braan

- Environmental Statement Vol 1
- Technical Appendices Part 1
- Decision Notice
- CAR Licence

Camusvrachan

- CAR Licence
- Full Environmental Statement
- Decision Notice

Carie

- ES Volume 2 Part 1
- ES Volume 2 Part 2

Corravachie

- Non-technical summary r1
- Morphology report
- Environmental RA and Mitigation r1

Pirnmill

- Environmental Appraisal Report to Support Planning and CAR Licence Applications
- River Morphology Survey Report

Wester Tullich

- Full Environmental Statement Part 1
- Appendix I – Morphology
- Morphology lDrawing

Ardchullarie

- River Morphology Report
- Environmental Statement
- Decision Notice

Inverhaggernie

- CAR Licence
- Decision Notice

Anie

- Decision Notice
- River Morphology Report
- Environmental Statement

Kinnaird Weir

- Environmental Statement
- CAR Licence

Grudie

- Scheme Design
- Annex B – Schedule of Mitigation
- Geology/Geomorphology Survey
- Non-technical ES Summary

Table A.1. Key. Sediment Considerations in Scottish Run-of-River Hydropower.		
RoR Hydropower Scheme	**Name**	Burn of Mar
	Location	244580, 691550
	Capacity (kW)	500
	Weir Design	Weir with screen, collection chamber, silting chamber. Sluice gate, fish pool, compensation notch. Drain valves and other valves.
Catchment	**Upstream catchment Area (km^2)**	8.5
	QMED (m^3/s)	-
	Sediment Supply	-
	Sediment Source	Valley sides, eroding banks and tributaries.
River Type	**River Upstream of Intake**	Cascade and plane riffle.
	Between Intake - Outfall	Bedrock and cascade.
	Downstream of Outfall	Bedrock and plane-riffle
Sediment Management Information	**Environmental Statement**	Intakes will include scour valve opened periodically. Compensation flow will move material downstream at all times. Tributaries below abstraction will provide sediment. Flood flows are the main vessel of downstream sediment transport and will be unaffected by the scheme. Effect of scheme on sediment movement is negligible.
	CAR Licence	Not Available.
	Sediment Management Plan	Weir crests will be overtopped at high flows allowing fine sediment movement over the Weir crest. Monitoring sediment behind Weir twice per year and following high flow events. Using visual inspection and measuring the depth of the river. Scheduled mechanical removal of sediment behind weir for every 4 years until monitoring inspections decide exact regime. It will be replaced in the watercourse, close to the bank. Monitor and record the volume of sediment moved. Scour valves included at intakes to flush sediment.
	Planning Decision Notice	Available – no information.

RoR Hydropower Scheme	**Name**	Slug of Auchrannie
	Location	327711, 752946
	Capacity (kW)	1400
	Weir Design	River bed wash over weir. Flushing gates.
Catchment	**Upstream catchment Area (km^2)**	172.79
	QMED (m^3/s)	218.9
	Sediment Supply	
	Sediment Source	
River Type	**River Upstream of Intake**	Cascade
	Between Intake - Outfall	Series of small waterfalls
	Downstream of Outfall	Cascade
Sediment Management Information	**Environmental Statement**	Best practise sediment management should be followed. -Likely sediment maintenance will be required. -Weir designed with flushing gates. -Dedicated sediment management plan will not be required. -No details on what best practice guidance will be followed.
	CAR Licence	The monitoring requirements include sediment management according to a sediment management plan.
	Sediment Management Plan	Not Available.
	Planning Decision Notice	-Sediment Management Plan should be included within Den of Airlie SSSI Enhancement Plan.

RoR Hydropower Scheme	**Name**	Braan
	Location	300086, 741464
	Capacity (kW)	1,990
	Weir Design	Weir with adjustable height.
Catchment	**Upstream catchment Area (km^2)**	203.8
	QMED (m^3/s)	113
	Sediment Supply	Sediment supply is low
	Sediment Source	
River Type	**River Upstream of Intake**	Alluvial
	Between Intake - Outfall	Alluvial
	Downstream of Outfall	Rock channels
Sediment Management Information	**Environmental Statement**	Most sediment is moved during high flows. -Weir is adjustable. -Periodic visits to lower the Weir to remove sediment accumulation. -Impact on sediment continuity negligible.
	CAR Licence	Available, but missing Appendix D with sediment management information.
	Sediment Management Plan	Not Available.
	Planning Decision Notice	Available – no information.

RoR Hydropower Scheme	**Name**	Camusvrachan
	Location	261862 749212
	Capacity (kW)	750
	Weir Design	1m height
Catchment	**Upstream catchment Area (km^2)**	5.2
	QMED (m^3/s)	
	Sediment Supply	
	Sediment Source	
River Type	**River Upstream of Intake**	Bedrock valley
	Between Intake - Outfall	Gorge
	Downstream of Outfall	Pool-Riffle
Sediment Management Information	**Environmental Statement**	-Minor changes to sediment transport regime -Best practise. - Sediment management -No details on what best practice guidance will be followed.
	CAR Licence	Standard (Bank) of conditions. -Refer to Appendix 1
	Sediment Management Plan	Not Available.
	Planning Decision Notice	Available – no information.

RoR Hydropower Scheme	**Name**	Carie
	Location	261845, 755425
	Capacity (kW)	500
	Weir Design	V-notch
Catchment	**Upstream catchment Area (km^2)**	7.1
	QMED (m^3/s)	
	Sediment Supply	
	Sediment Source	Channel banks above the intake
River Type	**River Upstream of Intake**	Wide alluvial channel
	Between Intake - Outfall	Bedrock step-pools
	Downstream of Outfall	Alluvial and bedrock, low gradient
Sediment Management Information	**Environmental Statement**	-Scour valve at weir. -Sediment Management Plan should be drawn up. -Enforce downstream river banks with rock armour -Periodic extraction of sediment accumulated.
	CAR Licence	Not Available.
	Sediment Management Plan	Not Available.
	Planning Decision Notice	Not Available.

RoR Hydropower Scheme	**Name**	Pirnmill
	Location	187494 ,644506
	Capacity (kW)	500
	Weir Design	V notch, compensation and hands-off flow, coanda screen.
Catchment	**Upstream catchment Area (km^2)**	3.17
	QMED (m^3/s)	
	Sediment Supply	High sediment load
	Sediment Source	Down-cutting of the bed and lateral erosion of banks. Bank failure.
River Type	**River Upstream of Intake**	Cascade
	Between Intake - Outfall	Plane-riffle and cascade
	Downstream of Outfall	Cascade
Sediment Management Information	**Environmental Statement**	-Intake design will allow sediment in high flow to pass over. -Coanda-type screen should be included in weir face. -Minimise weir and water heigh falling over weir. -Intake position will minimise erosion and sedimentation. - Sediment management should avoid fish spawning and emergence. -Prevent downstream scouring by placing intake in stable bedrock reach.
	CAR Licence	Not Available.
	Sediment Management Plan	Not Available.
	Planning Decision Notice	Available – no information.

RoR Hydropower Scheme	**Name**	Corravachie
	Location	248050, 873000
	Capacity (kW)	-
	Weir Design	Low profile concrete weir, scour valve, compensation pipe, plunge pool.
Catchment	**Upstream catchment Area (km^2)**	6.4
	QMED (m^3/s)	
	Sediment Supply	
	Sediment Source	Loose valley sides
River Type	**River Upstream of Intake**	Cascade
	Between Intake - Outfall	Bedrock
	Downstream of Outfall	Braided/Meandering
Sediment Management Information	**Environmental Statement**	-Intake will include scour valve or flushing pipe to periodically flush out material upstream of intake. -Compensation flow left in river will move material downstream. -Flood flows are the main method of sediment transportation and these will be unaffected by the scheme. -Overall impact on sediment movement is negligible.
	CAR Licence	Not Available.
	Sediment Management Plan	Not Available.
	Planning Decision Notice	Not Available.

RoR Hydropower Scheme	**Name**	Wester Tulluch
	Location	268598, 737143
	Capacity (kW)	100
	Weir Design	Low profile concrete, compensation pipe, plunge pool, scour pipe, screen, collection and silting chambers.
Catchment	**Upstream catchment Area (km^2)**	2.5
	QMED (m^3/s)	
	Sediment Supply	Low supply
	Sediment Source	Cascade valley or loos valley sides
River Type	**River Upstream of Intake**	Cascade
	Between Intake - Outfall	Bedrock/cascade
	Downstream of Outfall	Cascade
Sediment Management Information	**Environmental Statement**	- Intake will include scour valve or flushing pipe to periodically flush out material upstream of intake. - Compensation flow left in river will move material downstream -Flood flows are the main method of sediment transportation and these will be unaffected by the scheme. - Morphology is cascade and bedrock so sediment transfer is limited. -Overall impact on sediment movement is negligible.
	CAR Licence	Not Available.
	Sediment Management Plan	Not Available.
	Planning Decision Notice	Available – no information.

RoR Hydropower Scheme	**Name**	Ardchullarie
	Location	258413, 713715
	Capacity (kW)	100
	Weir Design	1-2m concrete weir, coanda screen on downstream side. Notch structure for hands-off and compensation flow.
Catchment	**Upstream catchment Area (km^2)**	2.81
	QMED (m^3/s)	
	Sediment Supply	High sediment load
	Sediment Source	Channel banks, landslides.
River Type	**River Upstream of Intake**	Cascade
	Between Intake - Outfall	Step Pool
	Downstream of Outfall	Plane bed
Sediment Management Information	**Environmental Statement**	-Weir will allow sediments to be washed over. -Weir will be similar size to bedrock outcrops. -Morphological impacts are insignificant.
	CAR Licence	Not Available.
	Sediment Management Plan	Not Available.
	Planning Decision Notice	-Flushing of sediment from intake weir including coanda screen undertaken monthly but not during fish spawning October – May.

RoR Hydropower Scheme	**Name**	Inverhaggernie
	Location	238528, 728410
	Capacity (kW)	650
	Weir Design	
Catchment	**Upstream catchment Area (km^2)**	6.27
	QMED (m^3/s)	
	Sediment Supply	
	Sediment Source	
River Type	**River Upstream of Intake**	
	Between Intake - Outfall	
	Downstream of Outfall	
Sediment Management Information	**Environmental Statement**	Not Available.
	CAR Licence	-Standard (Bank) of conditions. -Refer to Appendix 1
	Sediment Management Plan	Not Available.
	Planing Decision Notice	Not Available.

RoR Hydropower Scheme	**Name**	Anie
	Location	259496, 710394
	Capacity (kW)	66
	Weir Design	1.5m concrete weir. coanda screen, notch with compensation and hands-off flow.
Catchment	**Upstream catchment Area (km^2)**	1.22
	QMED (m^3/s)	
	Sediment Supply	High sediment load
	Sediment Source	Upper catchment bank erosion
River Type	**River Upstream of Intake**	Cascade
	Between Intake - Outfall	Cascade/Step Pool
	Downstream of Outfall	Plane bed
Sediment Management Information	**Environmental Statement**	-Highest flood flows will still occur with abstraction and these are the main morphological process. -Unlikely there will be any noticeable impact on river morphology.
	CAR Licence	Not Available.
	Sediment Management Plan	Not Available.
	Planning Decision Notice	-Flushing of sediment from intake weir should happen monthly but not during fish spawning (October – May).

RoR Hydropower Scheme	**Name**	Kinnaird Weir
	Location	362574, 758298
	Capacity (kW)	100
	Weir Design	Existing Weir
Catchment	**Upstream catchment Area (km^2)**	501.24
	QMED (m^3/s)	
	Sediment Supply	
	Sediment Source	
River Type	**River Upstream of Intake**	
	Between Intake - Outfall	
	Downstream of Outfall	
Sediment Management Information	**Environmental Statement**	-All fine sediment will pass over the weir or through the turbine. -No height alterations will be made to the existing weir therefore, no additional sediment will be deposited upstream of the weir.
	CAR Licence	-Standard (Bank) of conditions. -Refer to Appendix 1
	Sediment Management Plan	Not Available.
	Planning Decision Notice	Not Available.

RoR Hydropower Scheme	**Name**	Grudie
	Location	19590, 865844
	Capacity (kW)	2000
	Weir Design	Low concrete weir, concrete spillway, oanda screen, v-notch for hands-off and compensation flow, plunge pool.
Catchment	**Upstream catchment Area (km^2)**	22.1
	QMED (m^3/s)	
	Sediment Supply	
	Sediment Source	Collapsed upper channel banks, glacial drift, lower channel banks.
River Type	**River Upstream of Intake**	Upland boulder bed
	Between Intake – Outfall	Bedrock Gorge, waterfalls.
	Downstream of Outfall	Sinuous planform
Sediment Management Information	**Environmental Statement**	-Schedule of Mitigation. -Sediment management plan will be developed. -Scour valve will be operated. -Digger may be used to mechanically extract the sediment upstream of the intake and deposit this downstream of the weir. -Sediment will be retuned in accordance with the CAR Licence and SEPA Good Practice avoiding fish spawning and emergence. - ES Summary -Long-term geomorphological impact reduced by requirement for sediment management plan leading to moderate significant geomorphological change.
	CAR Licence	Screening form available but this contains no information on sediment.
	Sediment Management Plan	Not Available.
	Planning Decision Notice	Available but no information on sediment.

2.0 SEPA license conditions relating to sediment management

This review provides background context for the project covering the planning process and existing sediment management licence conditions in place for Scottish RoR Hydropower Schemes.

Two main forms of authorisation are required to construct and operate a new RoR hydroelectric power scheme in Scotland. First, for hydropower schemes under 50 MW capacity, consent is required from the local planning authority under the Planning Scotland Act. In addition, if the scheme is located in a sensitive environment or generates over 500 kW, the developer is required to undertake an Environmental Impact Assessment (EIA) under the Town and Country Planning and Environmental Impact Assessment (Scotland) Regulations 2011. If an EIA is required, the developer must subsequently produce an Environmental Statement (ES) summarising the EIA findings and submit this alongside the planning application. The ES and planning application are then both made available for public review (SNH 2015). Second, under the Water Environment (Controlled Activities) (Scotland) Regulations 2011 (CAR), all developers of hydropower schemes in Scotland must be granted Controlled Activities Regulation (CAR) authorisation from SEPA (Robson 2013, SEPA *n.d*). CAR authorisation was introduced to regulate previously uncontrolled water activities under the Water Environment and Water Services (Scotland) Act 2003 (Robson 2013). There are three types of CAR authorisation available which are based on the amount of risk an activity presents to the water environment: (i) General Binding Rules (GBRs; low risk)), (ii) Registration (moderate risk) and (iii) Licenses (high risk). GBRs do not require an application or registration instead they are a set of rules that, if fulfilled, ensures the proposed activity to comply with SEPA regulations. Registrations require the activity to be registered with SEPA, providing details of the activity alongside compliance with mandatory rules. Lastly, both simple and complex Licences exist depending upon their environmental risk which require an application before authorisation is granted. This enables site-specific conditions to be created which will protect the water environment (SEPA 2019b). CAR authorisation is necessary for any RoR Hydropower development in Scotland because the scheme will include water abstraction and creation of an impoundment, which are high risk activities. All impoundment activities associated with hydropower schemes require a simple or complex licence (SEPA 2019b). Within the CAR Licence, a typical hydropower project will be required to submit "Form A –Responsible Person Other Contacts and Site Details" and "Form D – Abstractions and Impoundments" (SEPA 2019b).

Before submitting a CAR Licence application for a hydropower scheme, SEPA/NatureScot advises developers to assess the suitability of the proposal using the Guidance for Developers of RoR Hydropower Schemes (SEPA, 2015). Checklists provided in this guidance are necessary to understand if the scheme will avoid significant detrimental impacts on the water environment. CAR authorisation can only be obtained if the checklist criteria is met and submitted with the application. In addition, the guidance describes practicable mitigation measures which should be incorporated into all RoR hydropower developments to minimise the adverse impacts on the water environment. It is good practise for the developer to assess the activities potential impact on sediment continuity, downstream habitat, morphology and erosion (SEPA 2019a). The mitigation measures outlined in the guidance include preventing significant disturbance to the downstream sediment supply that may occur if sediment accumulates upstream of the intake. Ensuring natural sediment transport continues after construction of the impoundment is vital for maintaining river habitats and preventing downstream bed and bank erosion (SEPA 2015). The guidance states that to mitigate any adverse impacts, sediments accumulated behind the intake should be returned to the river by: designing an intake which allows sediment to be transported naturally over the weir during high flows; including and operating scour valves; and/or mechanically excavating and reintroducing accumulated sediment downstream. The guidance also outlines the best practise for mechanically returning sediment downstream which should be done at a suitable location as close downstream of the intake as possible. Sediment reintroduction should occur:

- during high flow conditions;
- during periods other than those during which fish are likely to be spawning and the period between spawning and emergence of the juvenile fish;
- at locations that will not create an accumulation of sediment likely to impede the free passage of migratory fish; and
- as close to within 10 metres downstream of the intake as possible (SEPA 2015).

Sediment management is then included within the CAR Licence application in the impoundment activities section in Form D, Section 4. Point 4.16 necessitates a description of maintenance plans during the scheme's operation. The CAR Licence Applicant Guidance denotes that this may include description of the operation of scour valves that are designed to flush through sediment accumulated behind the weir. Point 4.17 requires sediment management information; the guidance highlights that this section requires a statement denoting if there will be or will not be any sediment management at the impoundment (SEPA 2014). Alongside points 4.16 and 4.17, as part of the general requirements, the developer should provide photographs of the proposed hydropower scheme location and at least one upstream and downstream view of the

affected river reach. These are required for SEPA staff to assess the morphological river type which is important when they are issuing a hydropower CAR Licence (SEPA *n.d*). However, despite it being good practise, the developer is not required to include any detailed sediment management proposals within their CAR application.

Once the application is submitted, the Coordinating Officer at SEPA will determine the outcome. They can aid their decision using the *Sector Specific Guidance: Hydropower* and the *Regulations for Impoundments and Abstractions* documents. The Regulations for Impoundments and Abstractions demonstrates that a CAR application is assessed against several tests to conclude if the activity may breach environmental standards. Most hydropower projects will lead to a failure of environmental standards of the water environment. However, the socio-economic benefits and mitigation steps if outlined in the application, can allow the licence to be granted (SEPA *n.d*). This is relevant to sediment management conditions as the impoundment is likely to have an impact on the water environment with regards to sediment continuity. As part of the Environmental Standards tests, there is a Mitigation Test which includes sediment management. The test assess whether the application has provided information on sediment continuity and if sediment management has been addressed to minimise downstream erosion (SEPA 2019a). Provided an application is successful in passing all the tests, a CAR Licence for the hydropower project can then be granted. Otherwise, the socio-economic benefits and justifications must be provided and outweigh the environmental impacts for a CAR licence to be granted. Once granted, SEPA will issue a licence document with a set of licence conditions to be complied with (SEPA 2018). This includes Sediment Management licence conditions where necessary. The appropriate conditions will depend on the outcomes of the environmental standards tests, the size and location of the scheme, the impacted river morphology and the impoundment design. Generally, SEPA currently take the view that if the impoundment is less than 1m in height, the volume will quickly be filled and allow sediment to pass over leading to no significant impacts to sediment continuity. If the impoundment is over 1m then appropriate conditions should be issued in the licence (Alasdair Matheson 2021, Personal Communication, 23 April 2021).

If the impoundment is likely to have a significant impact on sediment movement site-specific conditions may be issued. Additionally, in cases where the risk to the water environment is high the conditions will specify that a Sediment Management Plan is required. The CAR Licence Applicant guidance states that any sediment management plan created should include a description of the location, quantity and frequency of sediment removal from the impoundment waters. It should also indicate the time of year of removal and describe re-introduction of the sediment (SEPA 2019b). A Sediment Management Plan may also be requested by SEPA if site-specific monitoring is needed. The plans should be submitted to SEPA within 6 months of an issued licence and may include data returns for the volume of sediment removed (SEPA 2018).

Finally, sediment management may also be recommended by the EIA report. The EIA includes an analysis of the morphological impact of a hydropower scheme on the river and if this is likely to be significant or not. It may recommend a Sediment Management Plan is drawn up to mitigate significant impacts on sediment continuity and or downstream erosion. Ultimately, sediment management is an activity controlled under CAR though so the regulation of sediment management, including the need for and enforcement of a sediment management plan, should be part of the CAR Licence process.

To conclude, this review has summarised the authorisation required for creating a RoR hydropower scheme and the sediment management mitigation measures which should be incorporated into RoR developments and assessed in the pre-application stage. It has also reviewed the sediment management licence conditions issued by SEPA when authorising a CAR application for a hydropower scheme. It is important to understand that accessing a larger selection of issued CAR Licences was not possible and the list of standard conditions may not be exhaustive. From this review, some problems with the existing process have been highlighted:

1. It is unclear what information the developer should supply regarding morphology/sediment management in the CAR Licence application. The developer is encouraged to assess the impacts of the scheme on sediment continuity, morphology and erosion and incorporate mitigation measures into the scheme as described by the *Guidance for Developers of RoR Hydropower Schemes*. However, a licence application can be submitted with no sediment management information supplied by the developer. As described by the *CAR Applicant Guidance Notes,* the developer has to state only if there will or will not be sediment management.
2. The guidance available for SEPA officers regarding when a sediment management plan is required is not clear. The diagram within *Sector Specific Guidance: Hydropower*, shown in Figure 2.1, is not logical. Impoundments less than 1m high are lower risk than those over 1m high yet the diagram suggests that the higher risk impoundments can be dealt with using standard conditions whereas the lower risk impoundments require site specific conditions or a sediment management plan. This should be the other way round. The sediment assessment procedure referenced in the right hand box on the second row of the diagram also does not exist in the Regulatory Method (WAT-RM-01) (SEPA, 2019a). Therefore, it is unclear in which situations a sediment management plan or site-specific licence conditions are necessary and when the standard conditions are suitable.

Recommendations to address these problems will be made during Objective 6 of this project, to aid the development of a clear set of guidance and best practise for sediment management at RoR hydropower schemes in Scotland.

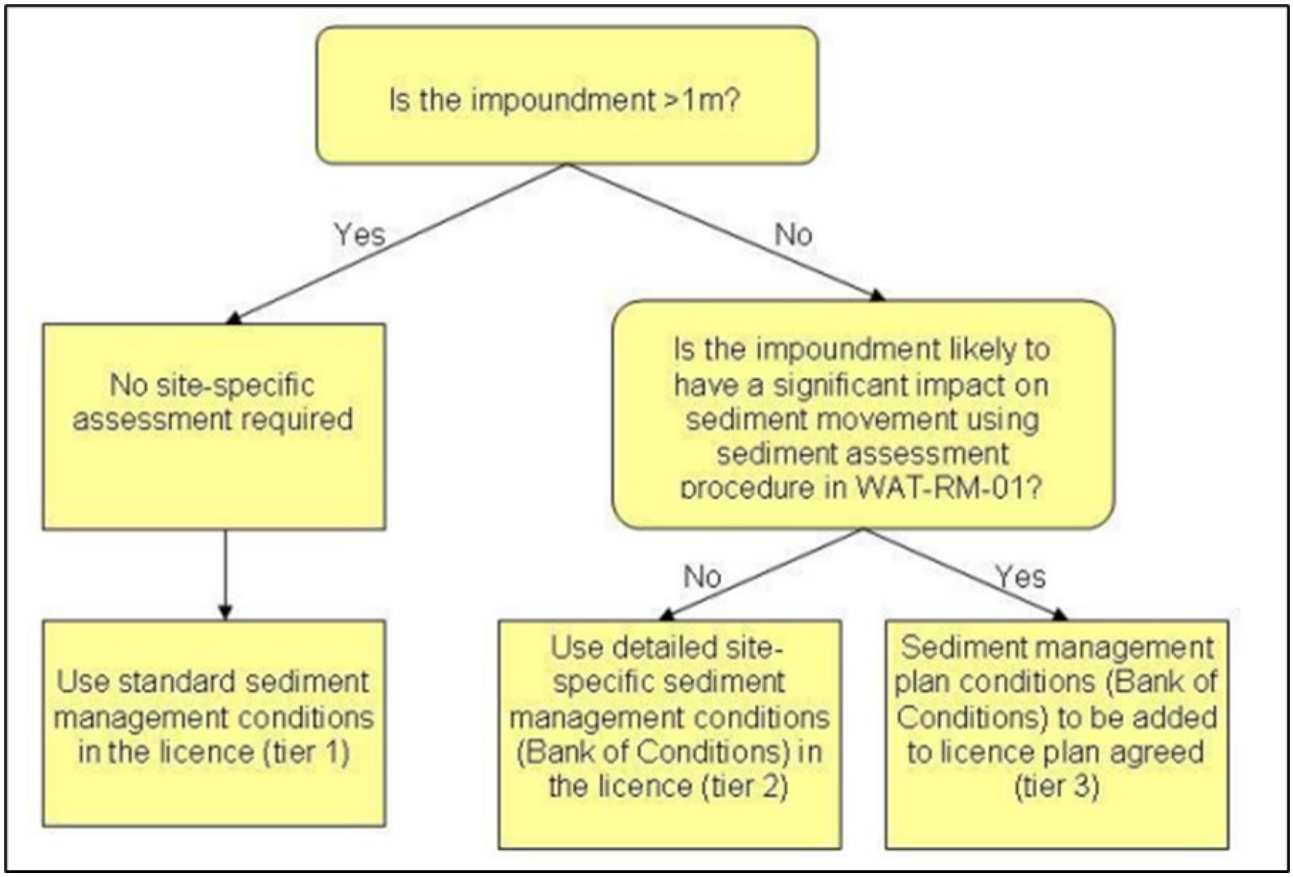

Figure 2.1. Tiered Approach to appropriate sediment management conditions as set out in Sector Specific Guidance: Hydropower (SEPA, 2018). The figure would make more sense if the first 'Yes' and 'No' arrows are switched around or the ">1m" in the first box is changed to "<1m".

3.0 References

Robson, A. L. (2013) Implications of small-scale run-of-river hydropower schemes on fish populations in Scottish streams, unpublished thesis University of Hull.

SEPA (2014) Water Environment (Controlled Activities) (Scotland) Regulations 2011 Licence Applicant Guidance General Guidance Notes.

SEPA (2015) Guidance for developers of run-of-river hydropower schemes.

SEPA (2018) Sector-specific Guidance: Hydropower.

SEPA (2019a) Regulatory Method (WAT-RM-01) Regulation of Abstractions and Impoundments, 4.3.

SEPA (2019b) The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended) A Practical Guide,

SEPA (n.d) Guidance for applicants on supporting information requirements for hydropower applications.

SNH (2015) Hydroelectric Schemes and the Natural Heritage.

Appendix B - Upstream and downstream characteristics of sediment accumulation

1.0 Upstream and Downstream Characteristics of Sediment Accumulation

The literature analysed prior to producing the review in Section 2 of the main report, and full details of this data is provided in Table 1.1 of this appendix.

Table B.1. Key modelling, experimental and field studies literature informing understanding of impacts related to RoR Hydropower Projects

Weir Height (m)	Impacted Reach (m)	Slope (%)	Location	Geomorphological Setting	Lithological Setting	Grainsize (mm)	Sediment Accumulation behind RoR Weir	Upstream Effects	Downstream Effects	Study
Low head impoundments										
Physical Study										
5 Scale 1:20	N/A	0.5	Muerz River, Austria	Medium-sized gravel bed river	N/A	14 – 120 (used in study)	All sediment loads accumulate at head of reservoir.	Delta Formation. Water level raised.	Coarse gravel for spawning fish potentially locked in delta.	Sindelar et al. (2020)
Modelling and Field Studies										
2.5	N/A	0.48	White Cray Creek and Red Cray Creek Watersheds, Northern Delware USA.	Alluvial-bedrock , pools and riffles, narrow floodplains, forested riparian zones.	Cambrian and Ordovician metamorphic rock.	0.6-3 (Upstream impoundment)	Reservoir behind dam 25% filled with sand and gravel.	Sediment Ramp.	Large mid-channel gravel bar immediately downstream of dam.	Pearson and Pizzuto (2015)
2.3, 1 2 Weirs	N/A	-1.3 -0.3	River Dalligan and River Duag, Ireland.	-Coarse bedded, riffle-pool, outcropping bedrock, dense vegetation. -Meandering cobble bed stream.	-Ordovician volcanic rocks. Devonian sandstones, conglomerates, mudstones at headwaters. -Tournaisian limestone, Devonian sandstones at headwaters.	35-164 (Tracers used in River Dalligan) 40-115 (Tracers used in River Duag)		Sediment Ramp	Supply-limited conditions. Bed material coarsens.	Casserly et al. (2020)

Weir Height (m)	Impacted Reach (m)	Slope (%)	Location	Geomorphological Setting	Lithological Setting	Grainsize (mm)	Sediment Accumulation behind RoR Weir	Upstream Effects	Downstream Effects	Study
Field Studies										
1.2-2.3 7 Weirs	N/A	2, 6	Bocq River, Waalonia Belgium	Single thread, sinuous channel, pools and riffles, forested riparian zones.	Underlying bedrock Upper Devonian sandstone, carboniferous limestone. Patches of Oligocene sands in limestone valleys.	73 (Average trapped in the reservoirs)	25-50% of reservoirs storage capacity filled with bedload. Central reservoir biggest accumulation of coarser bedload.	Sediment Ramp	The coarsest grainsize particles are trapped upstream in the reservoir.	Peeters et al. (2020)
1.5 – 5.1 7 Weirs	N//A	0.2 – 3	Upper Connecticut watershed, USA.	Riffle-pools and plane-bed units. Coarse sediment, very low fine-grained suspended sediment.	Paleozoic-age metamorphic and igneous rocks.	15-81 (Tracers used in the study)	Gravel temporarily deposited in reservoir.	Sediment Ramp	N/A	Magilligan et al. (2021)
1.8-3 4 Weirs	N/A	0.013-0.07	Vermillion River, Little Wabash, Yellow Creek. River, North Fork, Illinois USA.	Vermillioni River valey bottom fluvial and glaciofluvial deposits sand and gravel. Surficial unconsolidated sand, gravel and sandy till glacial deposits over bedrock.	Unconsolidated sedimentary glacial material overlying bedrock sedimentary Silurian, Devonian, Mississippian and Pennsylvanian age (Resources 1999).	0.37-64.3 (Upstream North Fork) 1.39-40.4 (Upstream Vermillion) 13-33.8 (Upstream Yellow Creek) 9-49,65 (Upstream Little Wabash)	Minor trapping of fine sediment.	N/A	Bed material coarsening. Flushing of fine material.	Csiki and Rhoads (2014)

Weir Height (m)	Impacted Reach (m)	Slope (%)	Location	Geomorphological Setting	Lithological Setting	Grainsize (mm)	Sediment Accumulation behind RoR Weir	Upstream Effects	Downstream Effects	Study
High head impoundments										
Modelling Study										
N/A	N/A	0.76-0.86	US Pacific Northwest and British Columbia.	Bedrock, boulder upper reach and alluvial plane. Bar pool downstream reach.	Plutonic and gneissic rock of Middle Jurassic to Eocene, metamorphic rocks. Younger mid-cretaceous overlap middle Jurassic through early cretaceous marine clastic rocks (Bustin et al. 2013).	23-69 (Sediment parameters input to morphodynamic model)	Assumes 100% of bedload sediment is trapped. For a period of time before transport is resumed.	N/A	Bed material coarsening. Spawning gravel missing downstream.	Fuller et al. (2016)
Field Studies										
5.5	3700	2.52	Hailing River, Northern China	Large, mountain river, riffle-pool.	Mesozoic granites, Cenozoic sediments.	2-230 (Average upstream)		N/A	Cobble composition decreased, sand increased. Low suspended sediment load. Poor habitat conditions. Unstable banks, poor riparian vegetation. Macroinvertebrate effected.	Wang et al. (2016)

Weir Height (m)	Impacted Reach (m)	Slope (%)	Location	Geomorphological Setting	Lithological Setting	Grainsize (mm)	Sediment Accumulation behind RoR Weir	Upstream Effects	Downstream Effects	Study
Field Studies										
1 – 57 15 Weirs	N/A	0.9-57	Pennsylvania and Maryland	Single thread coarse-grained rivers with forested riparian zones. Planar, cobble, boulder beds, half of reaches have exposed bedrock.	Appalachian Plateau.	17.98 0.564 33.372 155.528 9.99 34.812 22.375 27.219 49.626 77.019 9.176 0.80 25.563 1.588 18.262 32.168 22.375 39.736 (All Upstream)	Cobbles and smaller sediments trapped in reservoir.	N/A	Bed material coarsens.	Skalak et al. (2009)
N/A	N/A	3	Ain River, Bienne River and Fier river, Northern Prealps, France.	Bedrock gorges, medium gravel bed, bedrock gorges cascade.	Middle Jurassic limestone, Holocene deposits, part of Alpine foreland.	N/A	Reservoir sedimentation.	Metal sediment contamination. Ecotoxic risk to reservoir biota and downstream species.	N/A	Fanny et al. (2013)

1.1 References in Table B.1

Casserly, C. M., Turner, J. N., O'Sullivan, J. J., Bruen, M., Bullock, C., Atkinson, S. and Kelly-Quinn, M. (2020) Impact of low-head dams on bedload transport rates in coarse-bedded streams, *Science of the Total Environment*, 716, 136908.

Csiki, S. J. C. and Rhoads, B. L. (2014) Influence of four run-of-river dams on channel morphology and sediment characteristics in Illinois, USA, *Geomorphology*, 206, 215-229.

Fanny, C., Virginie, A., Jean-François, F., Jonathan, B., Marie-Claude, R. and Simon, D. (2013) 'Benthic indicators of sediment quality associated with run-of-river reservoirs', *Hydrobiologia*, 703, 149-164.

Fuller, T. K., Venditti, J. G., Nelson, P. A. and Palen, W. J. (2016) Modeling grain size adjustments in the downstream reach following run-of-river development, *Water Resources Research*, 52, 2770-2788.

Magilligan, F. J., Roberts, M. O., Marti, M. and Renshaw, C. E. (2021) The impact of run-of-river dams on sediment longitudinal connectivity and downstream channel equilibrium, *Geomorphology*, 376, 107568.

Pearson, A. J. and Pizzuto, J. (2015) Bedload transport over run-of-river dams, Delaware, U.S.A, *Geomorphology*, 248, 382-395

Peeters, A., Houbrechts, G., Hallot, E., Van Campenhout, J., Gob, F. and Petit, F. (2020) Can coarse bedload pass through weirs?, *Geomorphology*, 359, 107131.

Sindelar, C., Gold, T., Reiterer, K., Hauer, C. and Habersack, H. (2020) Experimental Study at the Reservoir Head of Run-of-River Hydropower Plants in Gravel Bed Rivers. Part I: Delta Formation at Operation Level, *Water*, 12, 2035.

Skalak, K., Pizzuto, J. and Hart, D. D. (2009) Influence of Small Dams on Downstream Channel Characteristics in Pennsylvania and Maryland: Implications for the Long-Term Geomorphic Effects of Dam Removal 1, *Journal of the American Water Resources Association*, 45, 97-109.

Wang, H., Chen, Y., Liu, Z. and Zhu, D. (2016) Effects of the "Run-of-River" hydro scheme on macroinvertebrate communities and habitat conditions in a Mountain River of Northeastern China, *Water*, 8, 31, 1-16.

1.2 Additional bibliography

Anderson, D., Moggridge, H., Warren, P. and Shucksmith, J. (2015) 'The impacts of 'run-of-river' hydropower on the physical and ecological condition of rivers', Water and Environment Journal, 29(2), 268-276.

Baumgartner, M. T., Piana, P. A., Baumgartner, G., & Gomes, L. C. (2020). Storage or run-of-river reservoirs: exploring the ecological effects of dam operation on stability and species interactions of fish assemblages. Environmental management, 65(2), 220-231.

Bilotta, G. S., Burnside, N. G., Gray, J. C., & Orr, H. G. (2016). The effects of run-of-river hydroelectric power schemes on fish community composition in temperate streams and rivers. PLoS One, 11(5), e0154271.

Bilotta, G. S., Burnside, N. G., Turley, M. D., Gray, J. C., & Orr, H. G. (2017). The effects of run-of-river hydroelectric power schemes on invertebrate community composition in temperate streams and rivers. PloS one, 12(2), e0171634.

Brackley, R. (2016) Interactions between migrating salmonids and low-head hydropower schemes, unpublished thesis University of Glasgow.

Brandt, S. A. (2000) 'Classification of geomorphological effects downstream of dams', Catena, 40(4), 375-401

Cantelli, A., Paola, C. and Parker, G. (2004) Experiments on Upstream-Migrating Erosional Narrowing and Widening of an Incisional Channel Caused by Dam Removal. Water Resources Research, 40, W03304. https://doi.org/10.1029/2003WR002940

Casserly, C. M., Turner, J. N., JJ, O. S., Bruen, M., Bullock, C., Atkinson, S. and Kelly-Quinn, M. (2021) 'Effect of low-head dams on reach-scale suspended sediment dynamics in coarse-bedded streams', J Environ Manage, 277, 111452.

Casserly, C. M., Turner, J. N., O'Sullivan, J. J., Bruen, M., Bullock, C., Atkinson, S. and Kelly-Quinn, M. (2020) 'Impact of low-head dams on bedload transport rates in coarse-bedded streams', Sci Total Environ, 716, 136908.

Csiki, S. and Rhoads, B. L. (2010) 'Hydraulic and geomorphological effects of run-of-river dams', Progress in Physical Geography: Earth and Environment, 34(6), 755-780.

Csiki, S. J. C. and Rhoads, B. L. (2014) 'Influence of four run-of-river dams on channel morphology and sediment characteristics in Illinois, USA', Geomorphology, 206, 215-229.

Fanny, C., Virginie, A., Jean-François, F., Jonathan, B., Marie-Claude, R. and Simon, D. (2013) 'Benthic indicators of sediment quality associated with run-of-river reservoirs', Hydrobiologia, 703(1), 149-164.

Fencl, J. S., Mather, M. E., Costigan, K. H. and Daniels, M. D. (2015) 'How big of an effect do small dams have? Using geomorphological footprints to quantify spatial impact of low-head dams and identify patterns of across-dam variation', PLoS One, 10(11), e0141210.

Fuller, T. K., Venditti, J. G., Nelson, P. A. and Palen, W. J. (2016) 'Modeling grain size adjustments in the downstream reach following run-of-river development', Water Resources Research, 52(4), 2770-2788.

Gibeau, P., Connors, B. M. and Palen, W. J. (2017) 'Run-of-River hydropower and salmonids: potential effects and perspective on future research', Canadian Journal of Fisheries and Aquatic Sciences, 74(7), 1135-1149.

Ibisate, A., Díaz, E., Ollero, A., Acin, V. and Granado, D. (2013) 'Channel response to multiple damming in a meandering river, middle and lower Aragón River (Spain)', Hydrobiologia, 712(1), 5-23.

Kondolf, G. M., Gao, Y., Annandale, G. W., Morris, G. L., Jiang, E., Zhang, J., Cao, Y., Carling, P., Fu, K. and Guo, Q. (2014) 'Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents', Earth's Future, 2(5), 256-280.

Magilligan, F. J., Roberts, M. O., Marti, M. and Renshaw, C. E. (2021) 'The impact of run-of-river dams on sediment longitudinal connectivity and downstream channel equilibrium', Geomorphology, 376.

Pearson, A. J. and Pizzuto, J. (2015) 'Bedload transport over run-of-river dams, Delaware, U.S.A', Geomorphology, 248, 382-395.

Peeters, A., Houbrechts, G., Hallot, E., Van Campenhout, J., Gob, F. and Petit, F. (2020) 'Can coarse bedload pass through weirs?', Geomorphology, 359, 107131.

Robson, A. L. (2013) Implications of small-scale run-of-river hydropower schemes on fish populations in Scottish streams, unpublished thesis University of Hull.

SEPA (2010). Engineering in the water environment: good practice guide - Sediment management. 1st edition, 1-56.

SEPA (2018) Supporting Guidance (WAT-SG-74). Sector-specific Guidance: Hydropower. V3.0, 1-42.

Simons, D. B. and Şentürk, F. (1992) Sediment transport technology: water and sediment dynamics, Water Resources Publication.

Sindelar, C., Gold, T., Reiterer, K., Hauer, C. and Habersack, H. (2020) 'Experimental Study at the Reservoir Head of Run-of-River Hydropower Plants in Gravel Bed Rivers. Part I: Delta Formation at Operation Level', Water, 12(7), 2035.

SNH (2015) Hydroelectric Schemes and the Natural Heritage. v1, 1-28.

Vazquez-Tarrio, D., Tal, M., Camenen, B. and Piegay, H. (2019) 'Effects of continuous embankments and successive run-of-the-river dams on bedload transport capacities along the Rhone River, France', Sci Total Environ, 658, 1375-1389.

Wang, H., Chen, Y., Liu, Z. and Zhu, D. (2016) 'Effects of the "Run-of-River" hydro scheme on macroinvertebrate communities and habitat conditions in a Mountain River of Northeastern China', Water, 8(1), 31

CREW CENTRE OF EXPERTISE FOR WATERS

CREW Facilitation Team

Hydro Nation International Centre

James Hutton Institute

Craigiebuckler

Aberdeen AB15 8QH

Scotland UK

Tel: +44 (0)1224 395 395

Email: enquiries@crew.ac.uk

www.crew.ac.uk

Hydro Nation International Centre

The James Hutton Institute

Scottish Government
Riaghaltas na h-Alba
gov.scot

CREW is a partnership between the James Hutton Institute and Scottish Higher Education Institutes and Research Institutes.
The Centre is funded by the Scottish Government.