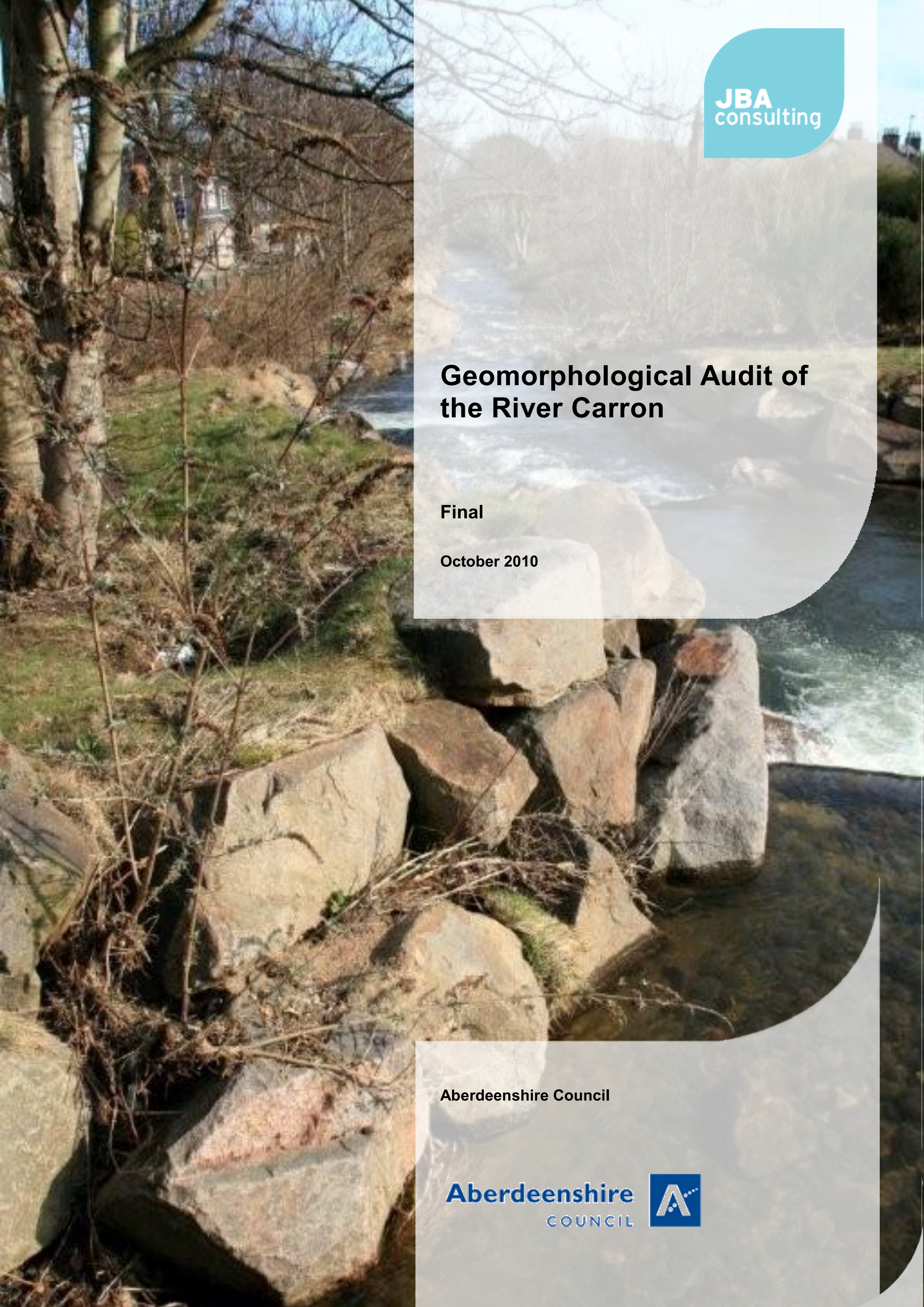

Geomorphological Audit of the River Carron

Final

October 2010

Aberdeenshire Council

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Contract

This report describes work commissioned by Steve McFarland, on behalf of Aberdeenshire Council, by Purchase Order No. NS 1150718. Aberdeenshire Council's representative for the contract was Steve McFarland. George Heritage of JBA Consulting carried out this work.

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Purpose

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Contents

List of Figures

List of Tables

1. Purpose and scope of study

1.1 Background

The River Carron flows through the coastal town of Stonehaven on the east coast of Scotland south of Aberdeen. The town suffered extensive flood damage during 2009 as the engineered channel capacity was exceeded, particularly around Green Bridge, Low Wood Road and Carron Terrace. Following the flooding several potential issues were raised with regard to flood capacity along the river through Stonehaven including in-channel sedimentation, excessive bankside vegetation growth, lack of upstream flood storage and engineered channel modifications (weirs, bridges, structural encroachments etc.). JBA Consulting were commissioned to comment on the affect that these issues are having on long term channel capacity considering the stability of the channel as regards erosion and sedimentation. This report contains the findings of a geomorphological audit of the river and catchment informing on these issues.

1.2 Catchment character

The River Carron rises in the hills around the Brae of Glenbervie flowing for approximately 15 kilometres before discharging into the sea at Stonehaven. Much of the $43km^2$ catchment is composed of Devonian Old Red Sandstone sedimentary deposits overlain by a variety of glacial tills, sands and gravels. The main channel drains generally to the east with short, steep tributaries joining principally from the north (in particular Cheyne Burn). Two tributaries join the main river from the south in the vicinity of Stonehaven, namely Toucks Burn and the Burn of Glaslaw. Isostatic rebound following the last glaciation has resulted in channel incision reworking the glacial and fluvio-glacial deposits and creating limited areas of lowland floodplain. The upper catchment is covered in plantation forest and pastoral farmland and the lower reaches of the main river are extensively engineered throughout its course through Stonehaven.

1.3 River character

The main River Carron may be classified as moderately active sinuous single thread displaying a cobble and gravel bed and the morphologic features associated with the temporary storage of this material (riffles, point bars, lateral bars etc.). The tributary channels appear steep but are generally stable, flowing through confined wooded valley's. The river has been extensively altered over time through Stonehaven resulting in a single thread channel that in places is wider than natural sections upstream. The banks are well protected by a variety of revetment types and a number of ad-hoc structures presently encroach across the bed of the river. Grade control structures in the form of log and boulder weirs influence the character and hydraulics of the river and tributary in the vicinity of Green Bridge.

The combined effects of the channel alterations has disrupted the sediment balance in the river through the town and concerns have been expressed that the sediment deposits seen at several along the river may be leading to localised flooding during extreme flow events.

1.4 Study aims

This report details the findings of a geomorphological audit of the River Carron catchment linked to a dynamic assessment of the watercourse through Stonehaven. Controls on channel sedimentation are investigated and their effect on the flood capacity of the river are considered.

2. Methodology

2.1 Catchment geomorphic audit

It is necessary, even with localised erosion and deposition problems, to consider the relationship of a watercourse with its catchment, otherwise there is a significant risk of failing to identify the causes and controls related to the sedimentation issue. Changes occurring to a river are a function of both local controls on flow pattern and energy concentration and other wider catchment controls on flow magnitude, frequency and sediment transport.

A study of the dynamic fluvial geomorphology of a catchment provides an integrated perspective, as well as a rigorous understanding of the physical processes by which the river channel is formed and alters. This approach also recognises and assesses the importance of history and site-specific conditions, critical to the success of river engineering and management. This understanding can be achieved through desk and field based survey methodologies which follow broad SEPA / Environment Agency guidelines[1]. Sources of information include web based aerial photographic evidence, planform change information from Ordnance Survey maps and a limited walkover survey of the upper catchment.

2.2 Geodynamic and hydromorphic assessment

A reach based assessment of the geodynamics of the River Carron (again following SEPA / Environment Agency guidelines) will identify the causes of local instability along the Carron in the reach between the A90 road bridge and the river mouth. Key areas susceptible to channel change will be identified and areas at risk from fluvial erosion or deposition will be highlighted. The assessment will allow the nature and approximate rate of change of any erosion and deposition to be qualified. It will also generate an insight into the potential upstream and downstream channel response to any form of intervention in order to control erosion, deposition, flooding and channel instability in the future. Additionally, a hydromorphic assessment will be conducted for the river, concentrating on the reach through the town.

Information gathered from the geodynamic assessment and hydromorphic assessment will allow a model of local system function to be developed helping to understand the river behaviour and suggest sustainable flood mitigation measures for the reach locally.

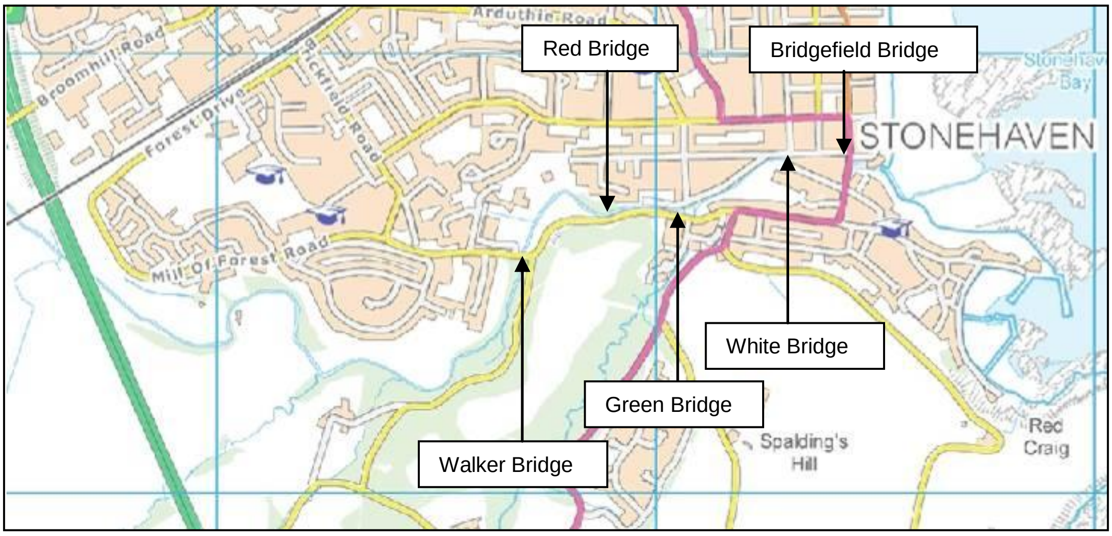
[1] River Geomorphology: a practical guide. EA Guidance Note 18, October 1998.

3. Catchment Geomorphic Audit

3.1 General Description

The catchment of the River Carron is generally low lying with much of the area under arable or pasture. The main river has developed a generally restricted floodplain reworking the extensive glacial tills, sands and gravels. Steeper short tributary channels, occupying stable confined valleys, join the main channel at regular intervals, principally from the north. The river is constrained by engineering works through Stonehaven and is crossed by several bridges, often associated with channel widening. A number of weirs also exist under and downstream of Green Bridge (Figure 3-1).

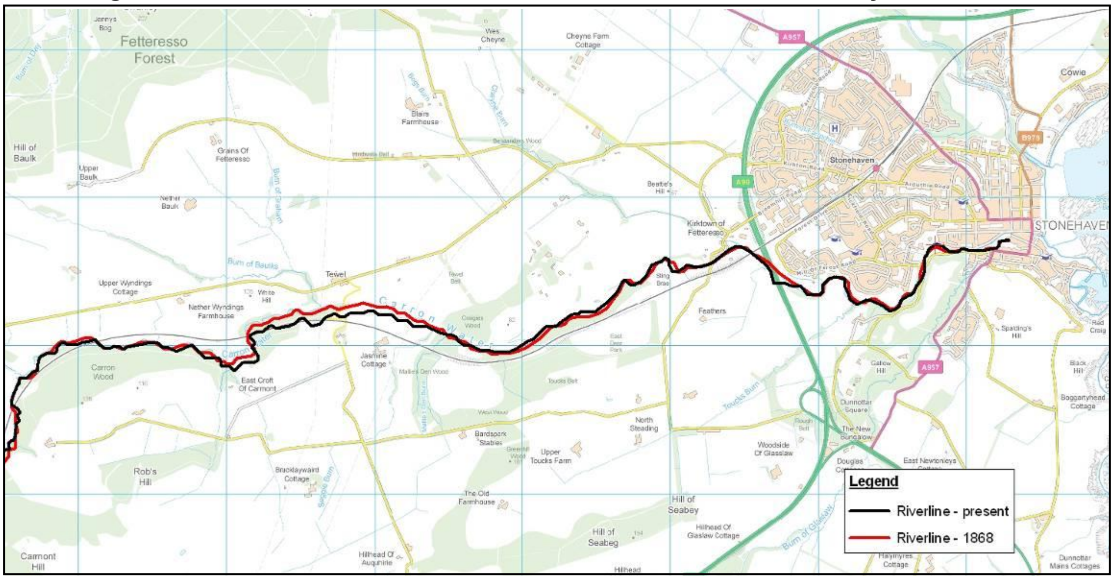
Figure 3-1: Structures along the River Carron through Stonehaven



3.2 Historic channel behaviour

The river through Stonehaven is highly engineered and channel movement is restricted by revetment works along much of the banks. Outside of the town the river flows through the wooded Mill of Forest and mixed pastoral and arable farmland further upstream. The current Ordnance Survey map for the area has been compared with the 1868 survey (Figure 3-2). It is clear that there has been some channel movement in the middle alluvial reaches over the last 150 years. Although some of this may be the result of survey error the geomorphological walkover survey and aerial photography of the river (Figure 3-3) supports longer term and continuing local channel activity.

Figure 3-2: Channel movement on the River Carron over the last 150 years



Contains Ordnance Survey data. © Crown copyright and database right 2010.

Figure 3-3: Contemporary and palaeo evidence of channel activity on the middle reaches of the River Carron

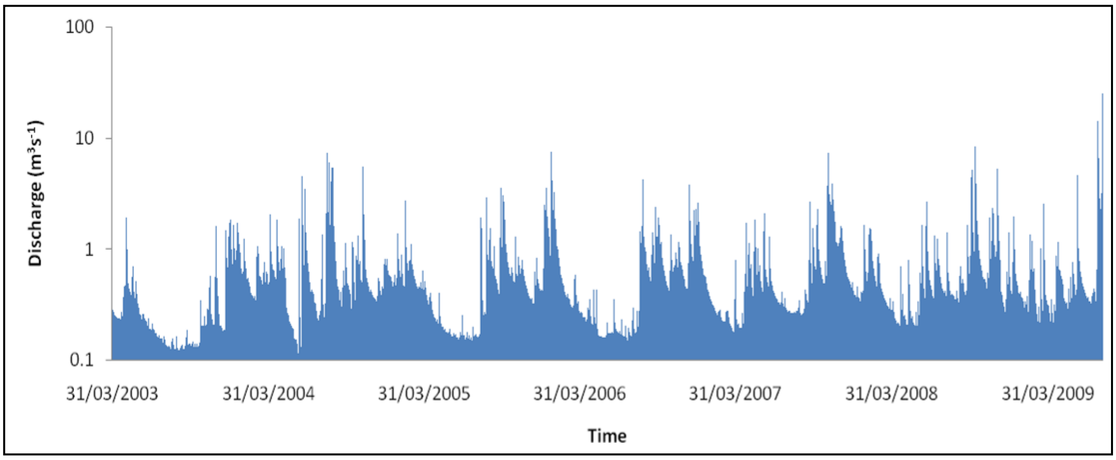
Images © 2009 Google, Map Data © 2009 Tele Atlas.

3.3 Contemporary conditions

3.3.1 Hydrology

There are only limited flow records for the River Carron (Figure 3-3). This flow record suggests that flows of the order of $10m^3s^{-1}$ are equalled or exceeded annually during the winter with rarer exceptional flows exceeding $20m^3s^{-1}$. Low flows exceed $1m^3s^{-1}$ 90% of the time. Hydraulic modelling of the urban channel[2] suggests that flows of around $20m^3s^{-1}$ are sufficient to exceed the channel capacity at several points through the town, with the reach above Green Bridge particularly susceptible to flooding.

Figure 3-4: Gauged daily flow data for the River Carron at Stonehaven.



Empirical stable channel dimensions linking alluvial channel shape to the hydrological regime suggests that for the River Carron, which drains a catchment of $43km^2$, bankfull flow is of the order of $4.5m^3s^{-1}$. This equates to a stable channel width of around 7m, corresponding to the present channel dimensions above the town[3]. Much of the channel through Stonehaven exceeds this width. A natural depth of around 0.5m would be characteristic of a river this width. It should be recognised that these dimensions are only a general guide as there is considerable variation in the datasets used to derive the relationships. However, significant deviation away from these values are usually associated with enhanced river response as the sediment system adjusts to restore the dimensions linked to the catchment characteristics.

3.3.2 Hydromorphology

The present main channel is generally characterised by a moderate energy single thread gravel-bed channel occasionally splitting through wooded areas of the floodplain (Figure 3-3). The upper reaches are cobble bed step-pool channels with only extremely limited wooded floodplain (Figure 3-5a). Even though the headwaters are confined (Figure 3-5b) sediment supply is low as current geomorphic activity is negligible. Occasional areas of valley infill exist in the upper catchment (Figure 3-5c), these are relic features and erosion of these deposits is negligible. Further downstream the bed material grades into gravels (Figure 3-5d) as the channel flows through its middle reaches. The catchment gradient drops and valley slopes become lower. Much of the area is farmed (Figure 3-5e).

[2] Stonehaven Channel Capacity Study, JBA Consulting, July 2010.
[3] Petit, F. and Pauquet, A. (1997), Bankfull Discharge Recurrence Interval in Gravel-bed Rivers. Earth Surface Processes and Landforms, 22: 685–693

Figure 3-5: Characteristics of the River Carron in the upper reaches of the catchment.

Occasional outcrops of bedrock create steeper narrower sections of channel with higher energy flows (Figure 3-6a) and localised gravel bars acting as temporary stores of sediment during low flows (Figure 3-6b). Step pools again dominate. The river has reworked some of the abundant fluvio-glacial deposits in the lower catchment upstream of Stonehaven creating areas of floodplain with high terraces (Figure 3-6c & d). Erosion of the floodplain and terrace material (Figure 3-6e & f) releases slugs of mixed sediment into the main channel for transport downstream. Often the fluvio-glacial deposits are of considerable thickness and even small areas of localised erosion can generate equivalent volumes of sediment to the bar forms that have developed in the channel through Stonehaven.

Figure 3-6: Characteristics of the River Carron in the middle reaches of the catchment.

In summary sediments that are presently building up as bars in the channel through Stonehaven are principally sourced from localised erosion of fluvio-glacial deposits in the lower reaches of the river. This type of erosion is occurring at many locations and control of these sources through bank protection would be difficult. It is also likely that any attempt at upstream erosion control would only serve to shift the loci of erosion to other unprotected lengths of river bank creating new supply zones for the gravel bars in Stonehaven. It should also be noted that, although the bars appear permanent, they are in fact cycling sediment down the river. The sediment is stored temporarily before eventually being transported to the river mouth and replaced by newer material. At the mouth the sediment is contributing to the delta of gravels on the beach and supplying coastal sediment transport processes.

4. Urban channel dynamic assessment

4.1 Engineering

Practically the entire river downstream of Walker Bridge (Figure 3-1) has been altered to provide flood channel capacity through Stonehaven. Low masonry walls and alder lined banks exist between Walker Bridge and Green Bridge. Here the river is approximately 8m wide increasing to around 10m immediately upstream of Green Bridge. The channel displays a series of pools and coarse gravel riffles grading into a lateral bar feature on the left bank close to Green Bridge (Figure 4-1a). These are natural features characteristic of this type of river and given no change in the planform of the river or flow and sediment regime will continue to form in the same places if removed. The gravels are likely to develop to an equilibrium height. For the riffles this will correspond roughly to the low flow water level, the lateral bar (Figure 4-1b) will be exposed at low flows extending up to a maximum of around 0.5m from the general bed level.

Given the widespread sources of gravel material upstream and the natural propensity for deposition in the vicinity of Green Bridge the removal of material under and upstream of the Bridge will necessarily be an ongoing maintenance process. It should be noted, however, that engineered in-channel structures in the vicinity of the bridge are encouraging sedimentation. The presence of a log weir immediately downstream of the bridge (Figure 4-1c) coupled with historic local widening of the channel is creating a low energy zone under and upstream of the bridge during low and moderate flows. Deposition is likely in these low energy areas and the sediments are presently being colonised and stabilised by emergent vegetation. Removal of the log weir will improve flood conveyance and general channel capacity through the bridge and will result in a reduced need for dredging along this reach.

The single span bridge structure itself is having no impact upstream at low and moderate flows and as such is not influencing depositional processed locally. Immediately downstream of the bridge a series of boulder weirs and boulder 'island' have been constructed to control flow energy levels through this extremely steep reach Figure 4-1c). The engineered structures appear to have been very successful and are becoming naturalised through the deposition of finer material in low energy zones and associated with colonising vegetation.

Channel capacity has been increased in the reach between Green Bridge and White Bridge through the scalping of the right bank meander bend (Figure 4-1d) and the general raising of the banks. Where the channel has been significantly widened under White Bridge there has been considerable deposition of mixed sediments that are now colonised by ruderal vegetation (Figure 4-1e). Deposition here is likely to continue as the channel seeks to attain a smaller equilibrium channel shape. Flood modelling of this reach suggests that there is presently adequate capacity in the vicinity of White Bridge. As such it is recommended that the gravel shoals be retained.

The river between White Bridge and Bridgefield Bridge is constrained by hard engineering. The channel is over-wide at around 12m although this is reduced in a number of locations by the piecemeal construction of lateral structures to gain garden areas for riverside residents (Figure 4-1f). Even though the main channel displays no significant bar deposits the garden features themselves are significantly reducing flood flow capacity through the bottom of the town. Although no historic supporting evidence has been found it is suggested that these gardens would have been constructed on lateral bar deposits present in the over-wide channel. Removal of these features is recommended to improve flood conveyance. Their removal would most likely lead to the reformation of gravel bars, however, they will not build up to occupy the same channel capacity as the present gardens.

Downstream of Bridgefield Bridge tidal influences are encouraging the deposition of silts over bankside riprap. Present fluvial flows are limiting this build up to the extreme channel margins (Figure 4-1g). River flows are also able to maintain a well defined channel between the emplaced boulders at the channel mouth (Figure 4-1h). Periodic build-up of litoral sands and gravels at the mouth are flushed through during high flows and deposited as a fan of coarser material across the beach face.

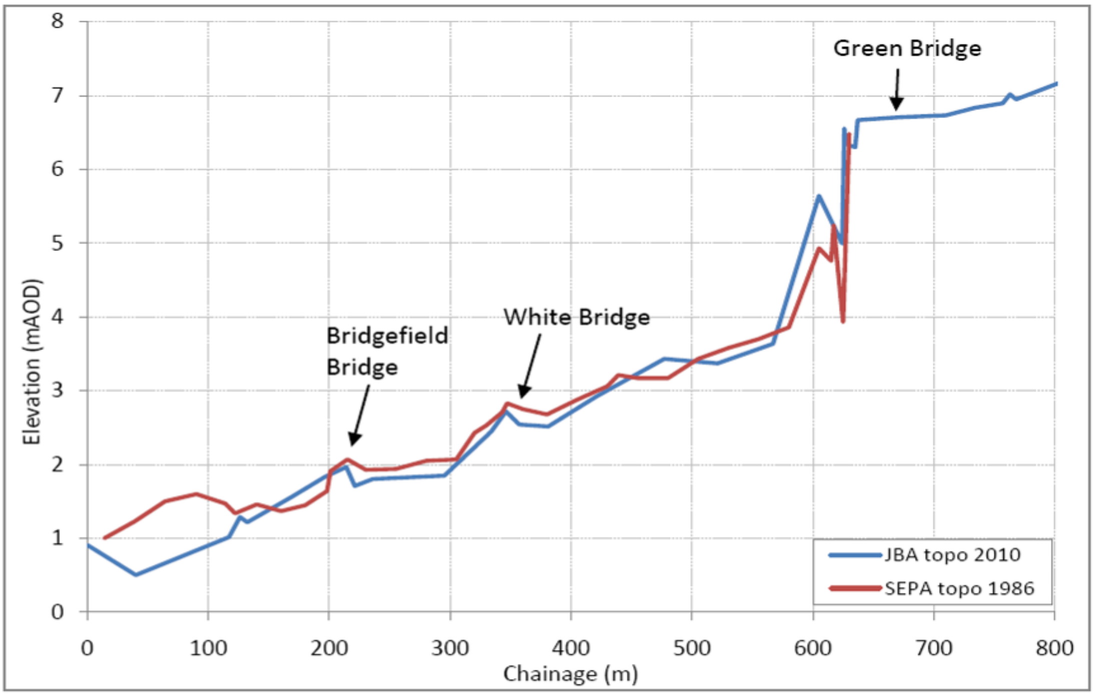
Figure 4-1: Characteristics of the River Carron through Stonehaven.

4.2 Local channel behaviour

Comparison of the long section of the River Carron conducted by JBA Consulting[4] and the 1986 channel survey (Figure 4-2) highlight the local depositional zones present in the reach between Green Bridge and Bridgefield Bridge (Unfortunately the 1986 survey did not extend upstream of Green Bridge). General sedimentation along the river appears to be an ongoing issue and this will continue to be the case due to the disruption to the sediment transport regime caused by channel engineering enhancing the ability of the channel to accumulate material at over-widened sites. Given the volume of sediments being released into the river upstream and then transported through to the town sedimentation may be viewed as inevitable under the present regime. Trapping of sediment upstream would reduce the need for removal through the town but may lead to further instability as the river picks up material from the bed of the urban channel leading to bed lowering and / or armouring and associated bank erosion.

Overall it should be noted that the deposition of material on the bed of the channel through the town, although initially quite rapid, would slow down as the river regains a local sediment transport equilibrium. In particular riffle sites will stabilise and are unlikely to impact significantly on flood capacity, occupying only a small volume of the river and increasing channel roughness only marginally at high flows. The bar deposit upstream of Green Bridge is likely to develop to a height of around 0.5m above the general bed level and will become vegetated reducing flood capacity at a critical point in the river. Removal of the log weir under the bridge will serve to increase low and intermediate flow energy levels upstream encouraging riffle development rather than bar deposition, thus increasing flood capacity. This will not impact on the rock weirs downstream. The improved flood conveyance achieved by removing the log weir accompanied by the local morphological switch from bat to riffle deposition should mean that no maintenance dredging will be necessary through this reach.

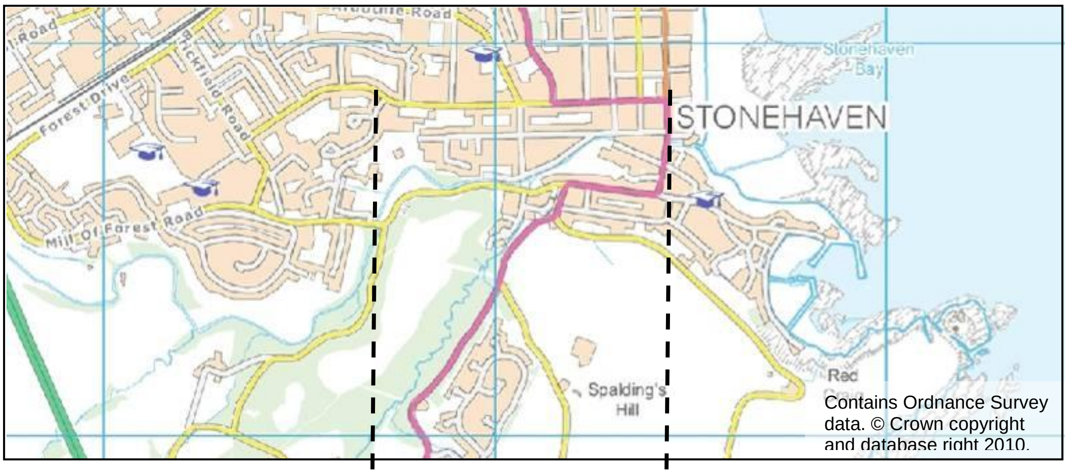
Figure 4-2: Comparison long sections of the River Carron through Stonehaven (1986 and 2010).



[4] Stonehaven Channel Capacity Study, JBA Consulting, July 2010.

Channel widening, particularly around White Bridge is also creating a lower energy zone leading to deposition and a loss of channel capacity. Narrowing the channel here would reduce gravel build-up but it is likely that the re-engineered channel would not display an increased channel capacity as a result due to the narrowing. Similarly the local channel narrowing created by the construction of raised garden areas in the town display a flat channel bed as the present low flow dimensions are closer to the stable shape for the river. Removal of the gardens will lead to bar deposition but these units would not occupy the same channel volume as the present structures. Controls and current river response is summarised in Figure 4-3. Table 4-1 lists recommended actions to improve sediment management on the river and likely related benefits.

Figure 4-3: Behaviour of the River Carron through Stonehaven



Sediment source zone

Local erosion of fluvio-glacial sediment sources supplying material for sedimentation through the town.

Limited existing floodplain, channel slightly entrenched reducing connectivity and allowing peak flows through to Stonehaven.

Weirs
Local sediment sinks

Heavily modified channel with disrupted sediment regime.

Ample sediment supply to the channel in the town.

Repeated build up of gravels where channel is widened and behind weirs.

Ad-hoc in-channel structures reducing capacity locally.

Very limited options to further enlarge channel capacity.

Option to improve sediment transport continuity through modification of weir structure at Green Bridge

Tidal influence

Main zone of tidal influence (may extend upriver during high tides). Some local silt build-up.

Flood flows able to maintain sediment free channel mouth.

Table 4-1 Recommended actions to control sedimentation and improve flood conveyance on the River Carron through Stonehaven.

Action	Benefits	Additional Maintenance
Removal of log weir at Green Bridge	Improved river gradient Loss of bar morphology in favour of lower impact riffle development	None anticipated
Removal of bar sedimentation at Green Bridge	Improved channel capacity Creation of site for riffle development	None anticipated
Retention of the present Green Bridge structure	No engineering costs	None anticipated
Retention of the multiple rock weirs downstream of Green Bridge	No engineering costs	None anticipated
Retention of the gravel shoals in the vicinity of White Bridge	Minor ecological value	Weed cutting to avoid development of woody vegetation
Excavation of 2 stage flood channel downstream of Green bridge where possible	Improved flood capacity through town Improved amenity value of the river	Grass cutting
Removal of in-channel structures downstream of White Bridge	Improved flood capacity through town Development of more natural in-stream morphology	Monitor gravel bar development and remove periodically if channel capacity is severely impacted

5. Summary and recommendations

The following statements regarding sediment management and flood control relate to general conditions operating on the river. Extreme events do occur and result in disequilibrium conditions. These events are not predictable and may result in changes to the river, including excessive sedimentation, which require intervention to restore flood capacity. The proposed actions are summarised in Figure 5-1.

Figure 5-1: Recommended actions for the River Carron through Stonehaven

Recommended Actions for the River Carron through Stonehaven

- a Dredge bar deposits in conjunction with log weir removal.
- b Remove log weir structure.
- c Retain boulder weir complex.
- d Create 2stage high flow channel where space allows.
- e Retain gravel shoals under bridge. Periodic weed cutting.
- f Remove in-channel structures on left bank.
- g Remove in-channel structures on left bank. Monitor bar sedimentation.

5.1 Controls on sedimentation

- Sediment supply to the River Carron through Stonehaven is presently largely from the local erosion of extensive fluvio-glacial deposits through the middle reaches of the river.
- Present supply zones are plentiful and control of source zones would meet with limited success as new erosion points develop.
- Fixed sedimentation zones exist along the river through Stonehaven associated with semi-natural riffle sites, inner bank bars and over-wide sections of engineered channel.
- Bar deposits will continue to build up to a height of around 0.5m from the bed.
- Riffle areas will not build up above the low flow water surface.

- Artificial channel narrowing of the channel is reducing channel area and flood capacity, removal would lead to bar sedimentation but these deposits will be smaller than the present structures.

5.2 Opportunities to improve sediment continuity and flood capacity

- Construction of an upstream gravel trap is not recommended due to the reactive nature of the river downstream and the likelihood of bed degradation and bank erosion.
- Weir removal/lowering at Green Bridge will lead to a reduction in upstream sedimentation and improved flood capacity.
- Creation of a 2 stage channel at flow constriction points will maintain the low flow transport regime whilst increasing flood capacity locally.
- Removal of Ad-hoc structures in the river will increase flood capacity and improve downstream conveyance. Bar development is likely but these will be smaller than the original obstructions.
- Dredging results in the rapid re-deposition of gravel deposits. The rate of accumulation will slow as the river attains a quasi steady-state sediment transport equilibrium. It is anticipated that following the above works that dredging would be unnecessary unless a major flood deposited large amounts of material through the town.

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