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JBA Project Code	2020s0819
Contract	Bevis Green
Client	Barratt Homes
Day, Date and Time	27/11/2020
Author	Emma Wright
Reviewer / Sign-off	Matt Hemsworth
Subject	Technical Note

1 Introduction

JBA Consulting was commissioned by Barrett Homes in 2020 to undertake a hydromorphology assessment and conceptual design for the watercourse at the Former Tetrosyle site, Bevis Green, Bury.

1.1 Purpose and scope of study

1.2 Study area

Figure 1-1 displays the site location and the catchment area of the watercourse, which is unnamed and is a tributary of Pigs Lee Brook. The watercourse rises on the southern edge of Harden Moor near Nangreaves and flows primarily south towards the site. The outflow from the reservoir is controlled by a weir in which the channel is culverted and then flows into open channel before discharging into Pigs Lee Brook.



Figure 1-1: Site Location

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2 Desk Based Assessment

2.1 Overview

A desk-based assessment has been undertaken for the catchment of the watercourse. This incorporates nearby main rivers and aims to provide understanding on catchment controls that influence hydromorphology on a local scale. The assessment has utilised available information including historic maps, aerial imagery, and LiDAR data.

2.2 Geology and land use

According to the British Geological Survey (BGS) mapping the watercourse and its upstream catchment is underlain by sandstone and are overlain by till superficial deposits, which are glaciogenic in origin.

The land surrounding to the south-west of the site is heavily urban with residential and commercial buildings. The land use to the north and within the watercourse's catchment is rural with localised areas of small woodland and agricultural land.

2.3 Flow regime

There are no flow gauges present on the watercourse, the closest gauge available is located approximately 3.0km downstream on the River Irwell. The difference in catchment characteristics, namely size, mean the flow gauge (69044 – Irwell at Bury ground) cannot be used to inform the flow regime of the unnamed watercourse.

The watercourse is not gauged; however, in the upper catchment it is characterised with steep topography, which is likely to produce rapid delivery of storm runoff to the watercourse. The urbanised nature of the catchment around the site will further contribute to this. During heavy rainfall events there is the potential for energy to be concentrated over a relatively short time frame, leading to elevated erosion rates in certain reaches.

2.4 Water Framework Directive Status and Water Quality

The unnamed watercourse falls within The Irwell (Rossendale STW to Roch) (ID GB112069064620) which is located within the Croal Irwell Operational Catchment. The waterbody is designated as 'heavily modified'. In the 2016 Cycle 2 assessment, the waterbody was classified as Moderate. There are several reasons why the waterbody is not achieving 'Good' status including both diffuse and point source pollution impacting upon phosphate in the watercourse and local ecology (macrophytes and phytobenthos (combined) and invertebrates).

2.5 Flood Risk

Figure 2-1 displays the Environment Agency Flood Zone Mapping across the site, illustrating that the site is located within Flood Zone 1. Downstream of the site where the watercourse converges with the River Irwell is in Flood Zone 3 which follows the route of the existing watercourse. To the north of the site the Cheesden Brook is within Flood Zone 2 and 3 which follows the route of the watercourse except to the north of the site the is flooding of the floodplain, however, this does not impact upon the unnamed watercourse of the site.

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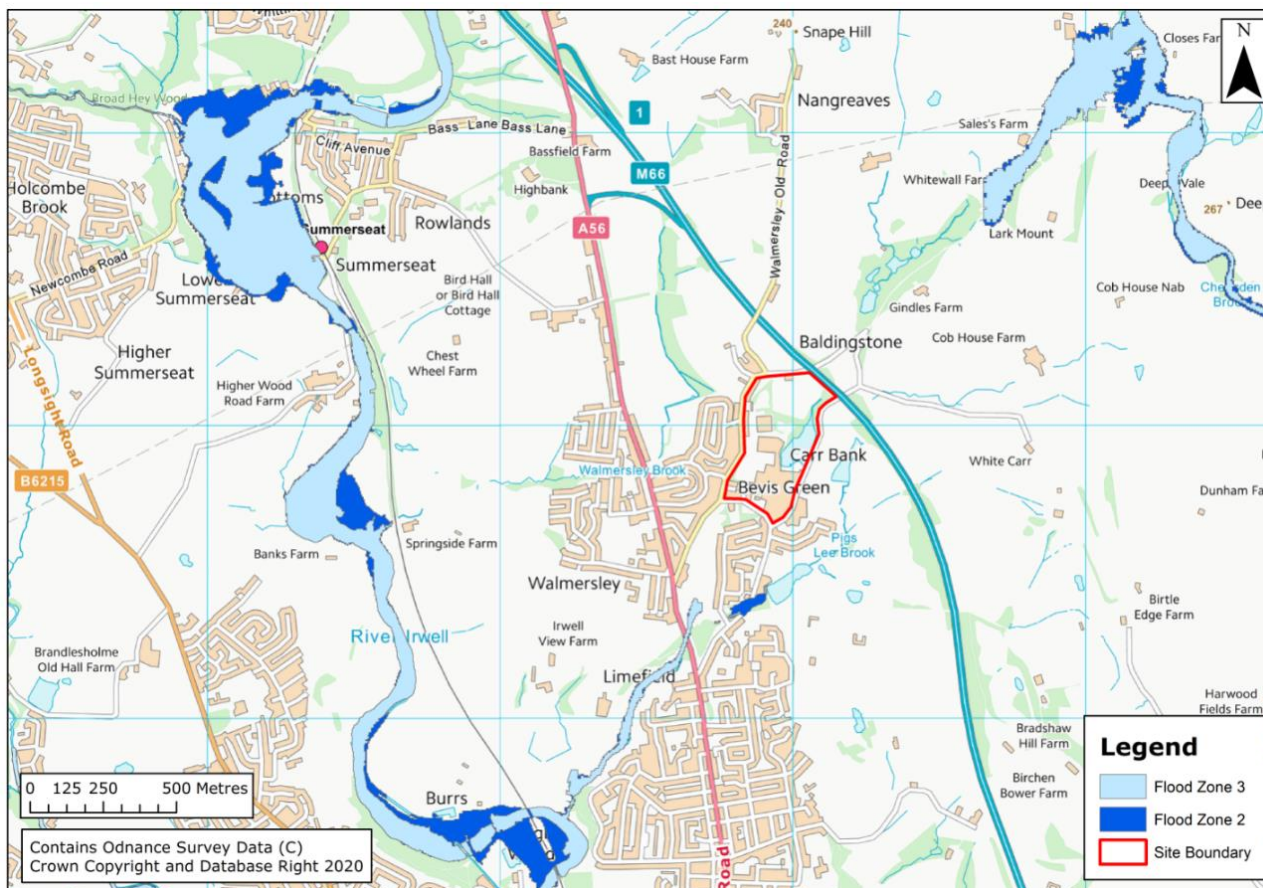


Figure 2-1: Current Flood Risk

2.6 Historic Trend Analysis

A desk-based review of historic maps has been undertaken to develop a historic chronology of the watercourse in response to channel modification over time. This information informs the current state of the channel through the identification of current and historic pressures influencing the watercourse. The assessment can therefore be utilised to predict how the riverine system will potentially develop under different scenarios in the future.

By reviewing the historic Ordnance Survey mapping it is apparent that the watercourse has been altered over time. The first mapping available from 1800, shows the reservoir and several weirs on the watercourse. It is thought the reservoir was originally constructed to supply water to the cotton mill.

Prior to the construction of the M66 the watercourse displayed some sinuosity upstream of the reservoir. The motorway in Bury was constructed between 1973 to 1978, during which the watercourse was straightened. The downstream extent of the watercourse connecting to Pig Lees Brook is entirely culverted, the exact date of which the culverting took place is unknown due to unclear mapping. Upstream of the site the watercourse was modified between 1930 and 1955 with the installation of three ponds controlled by weirs to maintain the water depth. These weirs are still present today.

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3 Walkover Assessment

3.1 Introduction

A walkover assessment was completed on the 15th July 2020 by Rebecca Thrower (geomorphologist) and Emma Wright (geomorphologist) of the watercourse through the site and upstream of the site boundary. The purpose of surveying the watercourse upstream of the site was to identify analogue reaches to gain an understanding of the geomorphic conditions of the river when not confined to culverts.

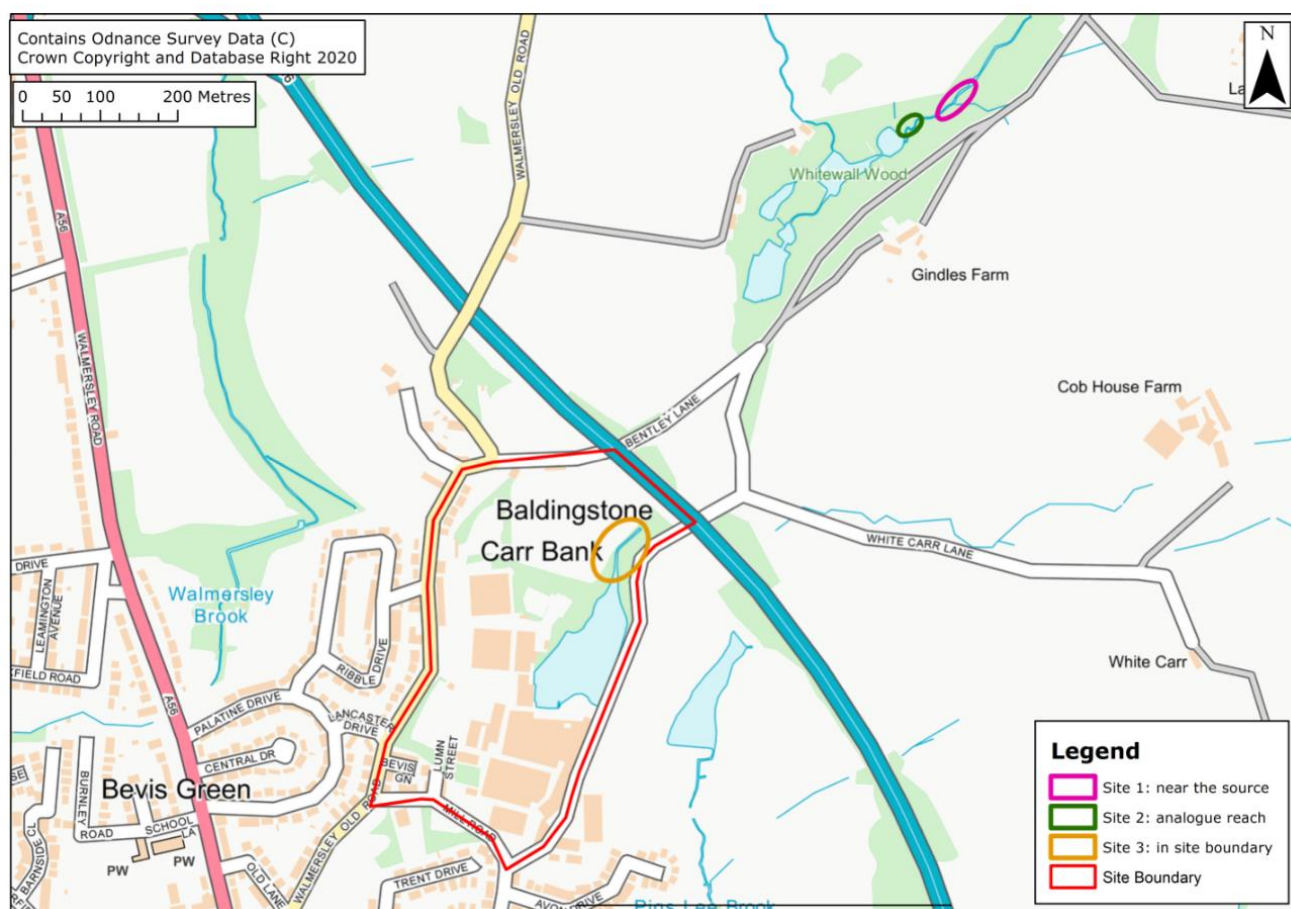


Figure 3-1: Survey Locations

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3.1.1 Upstream of the site: near the source

Upstream of the site (approximately 0.6km) the watercourse is a single thread river that flows through an alluvial channel. At this point in the catchment the watercourse is confined to a steep valley and displays both boulder cascade and cobble step pool morphologies (Figure 3-2). The channel is very narrow, approximately 0.5m wide, and steep with coarse bed material (gravels, cobbles, boulders) indicating an active supply of sediment to the reach. Some bank erosion was evident immediately downstream of the confluence between the two watercourses, where the channel gradient reduces and sediment has been deposited (Figure 3-4). The river is confined by the steep valley and therefore limited floodplain is evident; however, downstream the valley floor widens and this creates some floodplain. The confinement of the valley and lack of floodplain for flows to spill onto concentrates energy in channel and increases the size of the material that can be transported.

The riparian zone consists of a broadleaf woodland providing a large supply woody debris and leaf litter into the channel (Figure 3-4).



Figure 3-2: Upstream steep morphology

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This reach could be used to define characteristics of the new channel if the gradient is to be of similar steepness. Figure 3-3 depicts the long section throughout the site but specifically the step-pool sequences that occur within the steeper gradient. This can be used as an analogue to determine the in-channel features within an area of steeper gradient.

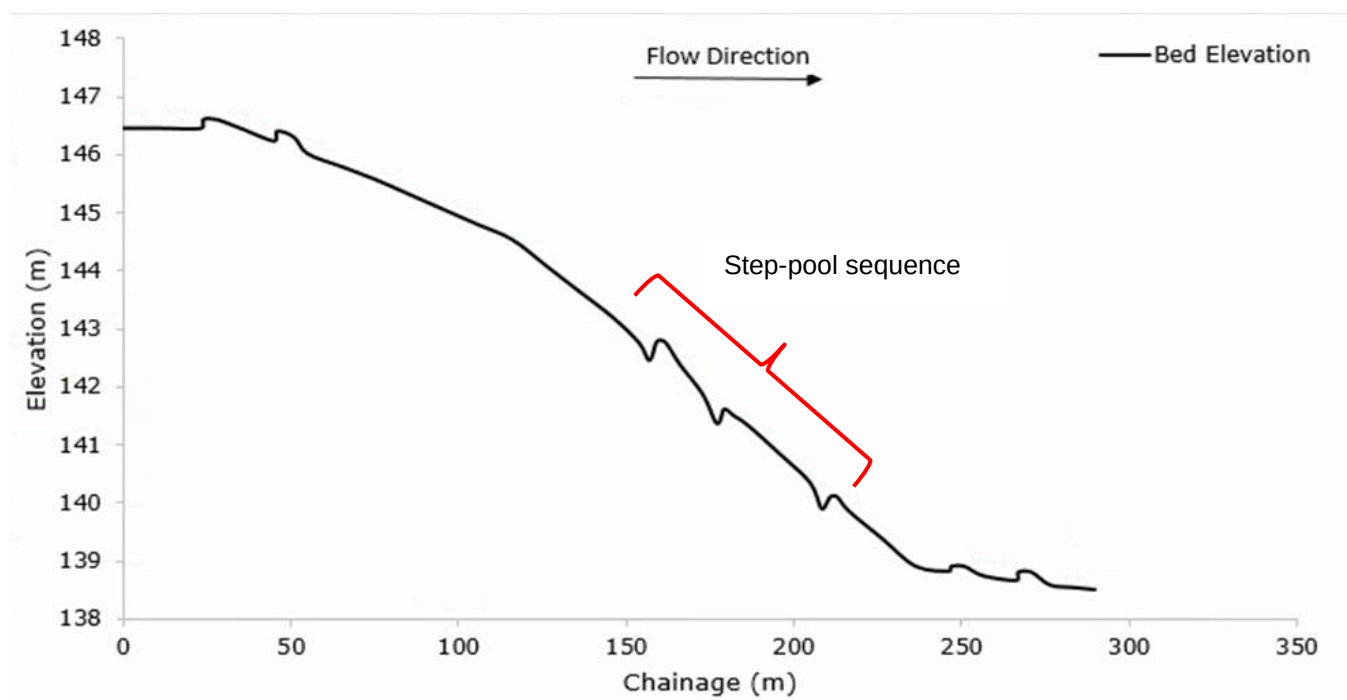


Figure 3-3: Long section to demonstrate the step-pool (step-pool) sequence

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Figure 3-4: Large woody debris supplied into the channel with bank erosion

3.1.2 Upstream of site: Reduced channel gradient

This reach displayed a distinct change in the morphology from the previous reach due to a notable change in gradient and slight widening of the valley floor. The reduced gradient has allowed for a meandering pool riffle morphology. In-channel velocities have reduced as a result of a shallower gradient and enabled greater sediment deposition. Smaller sized coarse sediment is seen throughout with the presence of fine gravels and small cobbles. Small gravels and cobbles are stored in short exposed gravel bars on alternative sides of the channel. These features are typically 0.5m wide and range in length from 1m to 8m. Immediately downstream of the bars, riffles have formed over the submerged part of the bar. Riffles are associated with shallower water depths, locally steeper gradient and increased in-channel velocities due to increased turbulence. These contrast to the deeper areas of channel that are characterised by slower moving pools, which during low flow conditions are typically low energy areas of the channel. Within this reach the river is well connected to its floodplain with shallow bank gradients and heights, which were typically 0.3-0.5m above bed level and at the time of the walkover 0.2-0.25m above the water level (Table 3-2).

Figure 3-5 shows a basic site sketch with the key hydromorphic processes of the reach illustrated. It was determined that this reach and the upstream reach would be used as analogue sites to inform the key hydromorphic features within the new channel construction at the site, therefore incorporating both the higher and lower gradient channel morphologies.

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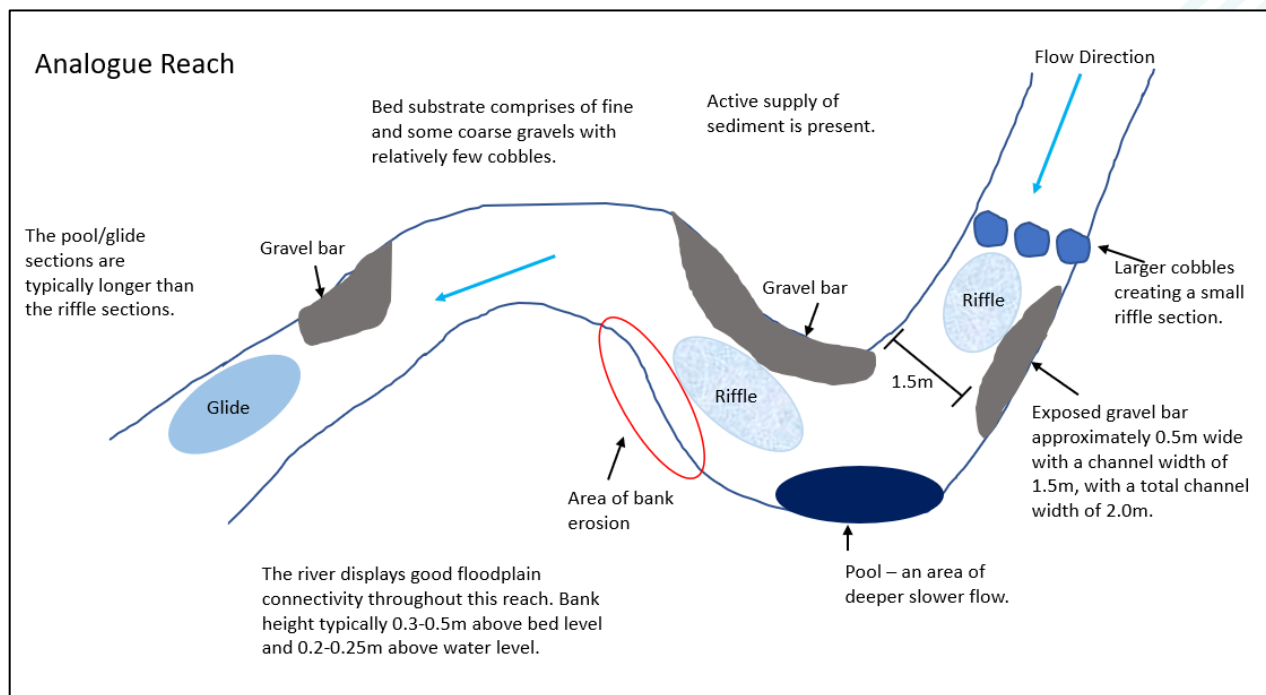


Figure 3-5: Site sketch of the reach to be used as the analogue reach (for lower gradient reaches)

Table 3-1 shows the approximate channel widths, widths and lengths of bar features estimated from the analogue reach, based upon site photographs from Table 3-2 below.

Site Photo	Channel Width (m)	Channel Width (m)	Bar width (m)	Bar length (m)	Riffle length (m)	Bank height from bed (cm)	Height of Bar feature	Connected to floodplain
1	2	0.5	1.5	5	2	0.4	0.2	Yes, particularly on the left-hand bank
2	1	0.5	0.5	1.5	1.5	0.4	0.2	Yes
3	3	0.5	2.5	8	2	0.5	0.3	Yes
4	1	0.5	0.5	1	-	0.7	0.3	No
5	2	0.5	1.5	2	0.75	0.5	0.2	Yes

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Table 3-2: Site photographs to be used as an analogue reach (for the lower gradient reaches)

Photograph 1



Photograph 2



Photograph 3



Photograph 4



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Photograph 5



3.2 Indicative bar features

A series of indicative cross sections were developed from using the channel measurements from the site visit. These sections provide a guide to the development of the cross sections.

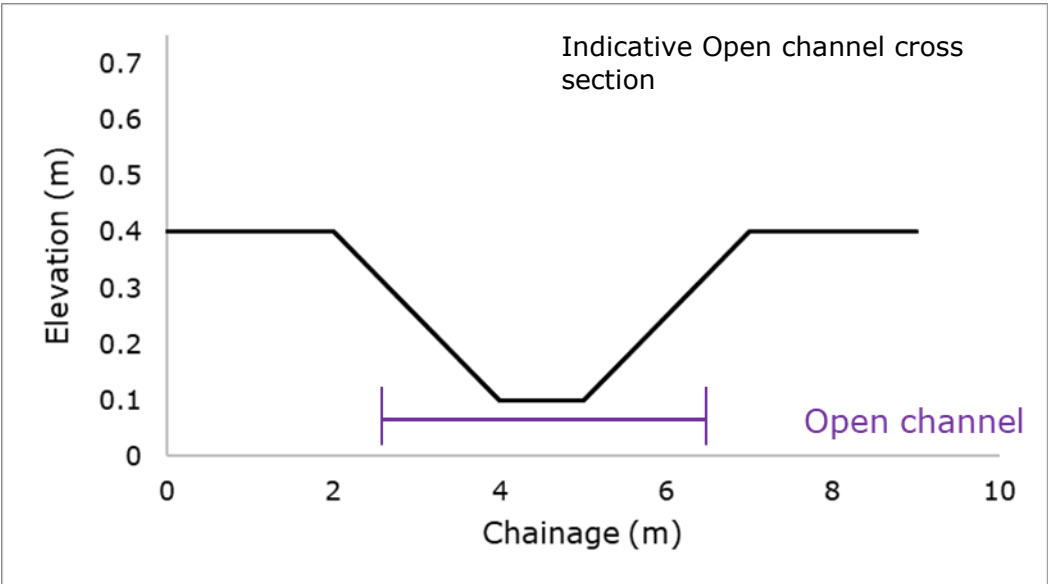


Figure 3-6: Indicative channel section

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Table 3-3: Indicative open channel section

Open channel - Option 1		Open channel - Option 2	
Chainage (m)	Elevation (m)	Chainage (m)	Elevation (m)
0	0.4	0	0.4
2	0.4	3	0.4
4	0.1	4.25	0.1
5	0.1	5	0.1
7	0.4	6.25	0.4
9	0.4	9.25	0.4

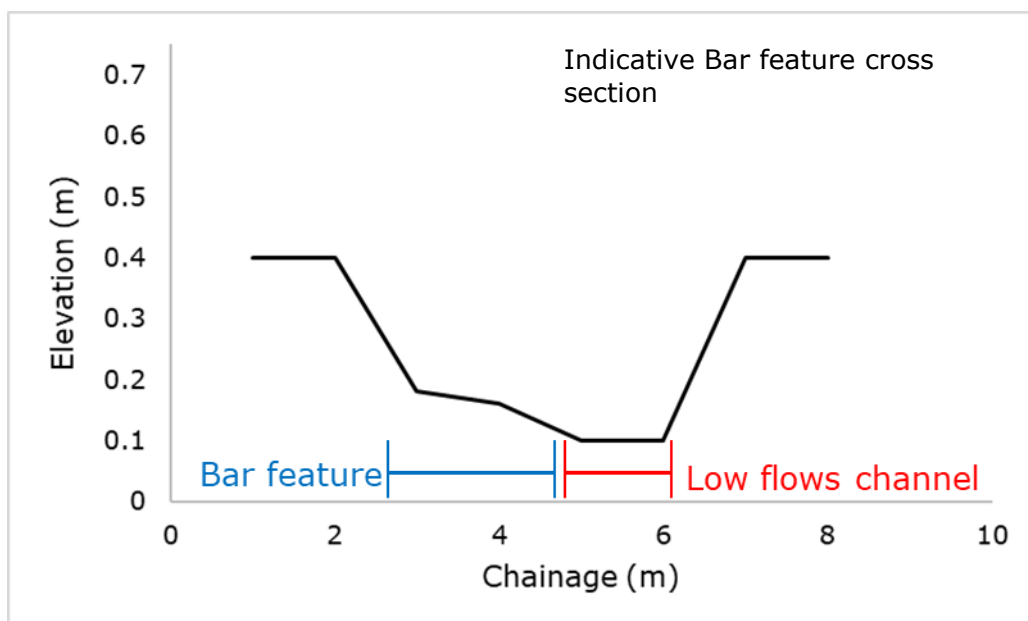


Figure 3-7: Indicative low flows channel section

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Table 3-4: Indicative open channel section

Bar feature - Option 1		Bar feature - Option 2	
Chainage (m)	Elevation (m)	Chainage (m)	Elevation (m)
0	0.4	0	0.4
2	0.4	2	0.4
3	0.18	3	0.2
4.5	0.16	5.5	0.15
5.5	0.1	6	0.1
6	0.1	6.75	0.1
7	0.4	7.75	0.4
10	0.4	9.75	0.4

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4 Low Flows Modelling

4.1 Introduction

This section of the report describes the modelling approach that was undertaken to represent the in-channel features for the new open channel watercourse. The purpose of this modelling was to determine the function of the morphological features and to understand what influence they will have on sediment transport processes, to inform the concept design for the new channel.

4.2 Methodology

4.2.1 Flow Duration Curve

A catchment for the unnamed watercourse has been delineated from the FEH CD-ROM and run through LowFlows 2 software, developed by Wallingford HydroSolutions (WHS). This software estimated the natural flow regime at the location based on a database of hydrologically similar catchments. A Flow Duration Curve (FDC) was developed and used to determine the low flows for the model, key exceedances are shown in Table 4-1.

Table 4-1: Summary of Flow Duration Curve	
Exceedance	Discharge (m ³ /s)
Q10	0.104
Q20	0.065
Q50	0.027
Q70	0.017
Q95	0.007

4.2.2 Baseline Scenario

An existing hydraulic model, supplied by Cole Easdon, was used to develop the concept design for the new channel. The supplied hydraulic model consists of one of the existing configurations with the watercourse culverted underneath the buildings and a post development model with proposed ideas for an open channel.

4.2.3 Post Development Scenario

The low flows model was developed through using the Cole Easdon post development model. To adapt the model for us, several cross sections were modified to incorporate bar and step-pool sequence to represent similar widths and attributes as observed within the analogue reach.

4.3 Model representation

Table 4-2 below depicts how the features were represented in the model, including bar and step-pool sequences.

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Table 4-2: Model Representation	
Feature	Representation
Bar feature	The channel geometry was altered to incorporate bar features into the channel. The length of the bars was determined using similar lengths as observed in the 2nd, pool riffle, analogue reach. The height of the bar features was determined by the water levels, allowing the majority of the bar to be exposed at Q70 whilst submerged at higher flow exceedances, for example Q10.
Step -Pool feature	The channel geometry was altered to incorporate a deeper channel to act as a pool. The depth of the section was increased from the original however the banks remained the same. Whilst immediately downstream of the pool the channel geometry was altered to incorporate a cross section to represent a step, in order to represent some of the features observed in the 1st analogue reach where the gradient is steep. The bed level was raised within this section to provide increased velocities through this section.

4.4 Assumptions and limitations

The hydraulic modelling undertaken for this study is accompanied by some assumptions and limitations, which are discussed below:

- The in-channel roughness values were all set at 0.05, which was considered appropriate to hydraulic conditions observed in the analogue reaches.
- The model was truncated at the weir at Mill Road downstream of the site, as it was anticipated that this structure would not instigate any backflow (due to an 8m drop in bed levels either side of the structure) which may influence on upstream water levels. This was therefore seen as an appropriate location to truncate the model. The model was additionally truncated upstream of the attenuation pond as it was anticipated that this would control the flows downstream into the new channel.

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5 Results

5.1 Introduction

Within this section of the report the results outputted from the post developed hydraulic model are discussed. Table 5-1 reports the model node name and whether it is classified as an open channel section or a bar feature (the difference of which are shown in the next section). These node names are used in the sections below to discuss the velocity, entrainment and shear stress.

Table 5-1: Model node labels	
Cross section type	Mode Node Label
PLB352	Open channel
PLB387	Bar feature
PLB427	Open channel
PLB468	Open channel
PLB508	Open channel
PLB508_PO1	Pool (lowered bed level)
PLB508_PO2	Open channel
PLB508_R1	Step (raised bed level)
PLB508_R2	Open channel
PLB548	Open channel
PLB588	Open channel
PLB628	Open channel
PLB641	Open channel

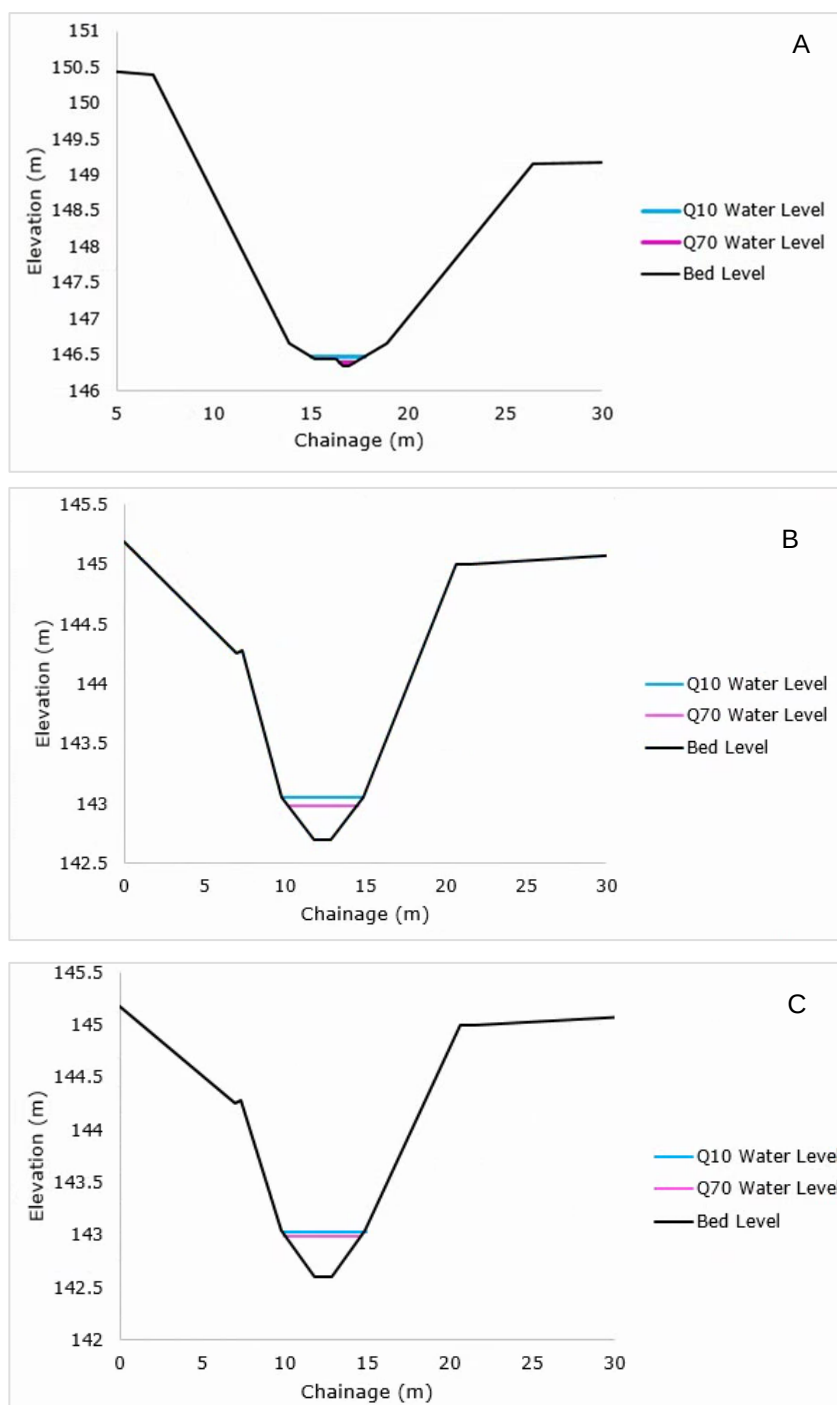
5.2 Water Levels

Table 5-2 depicts a cross sections within the model including both the open channel, with the bar features and in areas of step-pool sequences. The water levels within the bar cross section (A) shows that within a higher flow exceedance (Q10) the bar features are fully submerged, whilst at a lower exceedance they are exposed as per the design criteria. The cross section that contains a pool (B) shows the water levels are greater because the channel is narrower. Cross section (C) depicts the step has raised water levels compared to the open channel sections.

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Table 5-2: Model water levels



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5.3 Channel Velocities

Velocities throughout the site have been extracted from the hydraulic model. Figure 5-1 shows the channel velocities with the open river channel sections without the presence of any in-channel features. The data shows that the gradient steepens, as shown in the long section in Figure 5-2, there is a correlated increase in the in-channel velocities. As the bed gradient become shallower these velocities reduce. It is anticipated to observe erosional process occurring in the steeper sections where the velocities are high, whilst where the gradient becomes shallower it is anticipated to observe a more depositional environment. The Hjulström curve depicts the relationship between the size of the sediment and the velocity that is required to either transport it, erode or deposit it. Within the Q10 flows the velocities range from 0.3-0.7m/s. The calculated entrainment values for the same event would be capable of entraining, transporting and deposition of small gravels between 6-38mm.

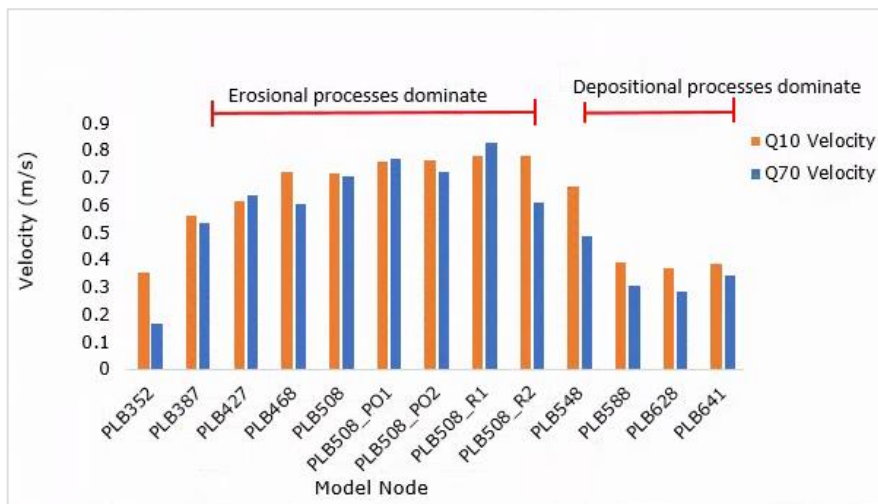
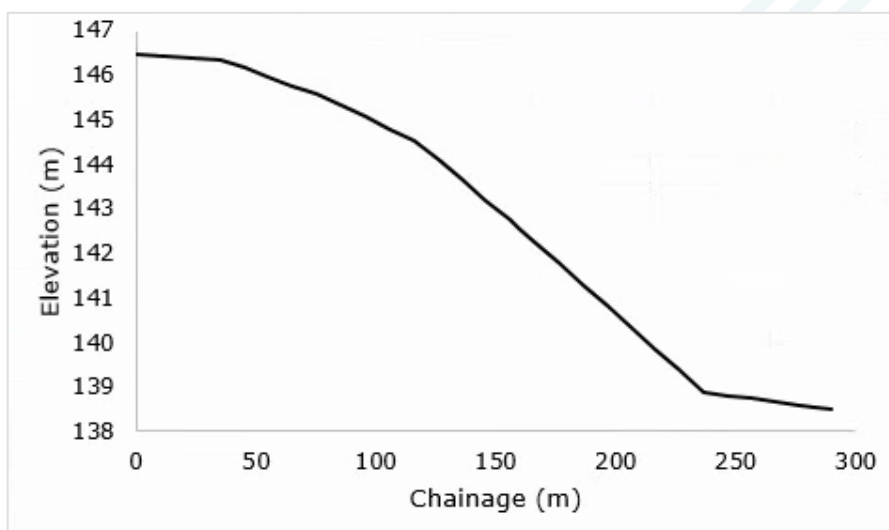


Figure 5-1: Velocities across the site (Baseline) sequence*

* *Note not to scale, total model length is 289m and the distance between the model nodes vary.



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Figure 5-2: Long section

5.3.1 In channel features present

The hydraulic model was developed to include the addition of a step-pool sequence within the stepper sections of the long profile to represent the bed conditions observed upstream from the site. These features have also been introduced to manage the high velocities shown in Figure 5-1, which could lead to a highly erosive channel if left designed as a uniform channel. In the shallower gradient areas at the start and end of the reach, a bar feature has been included to determine the influence this would have on the in-channel velocities.

Figure 5-3 shows the results of this scenario in terms of modelled velocities.

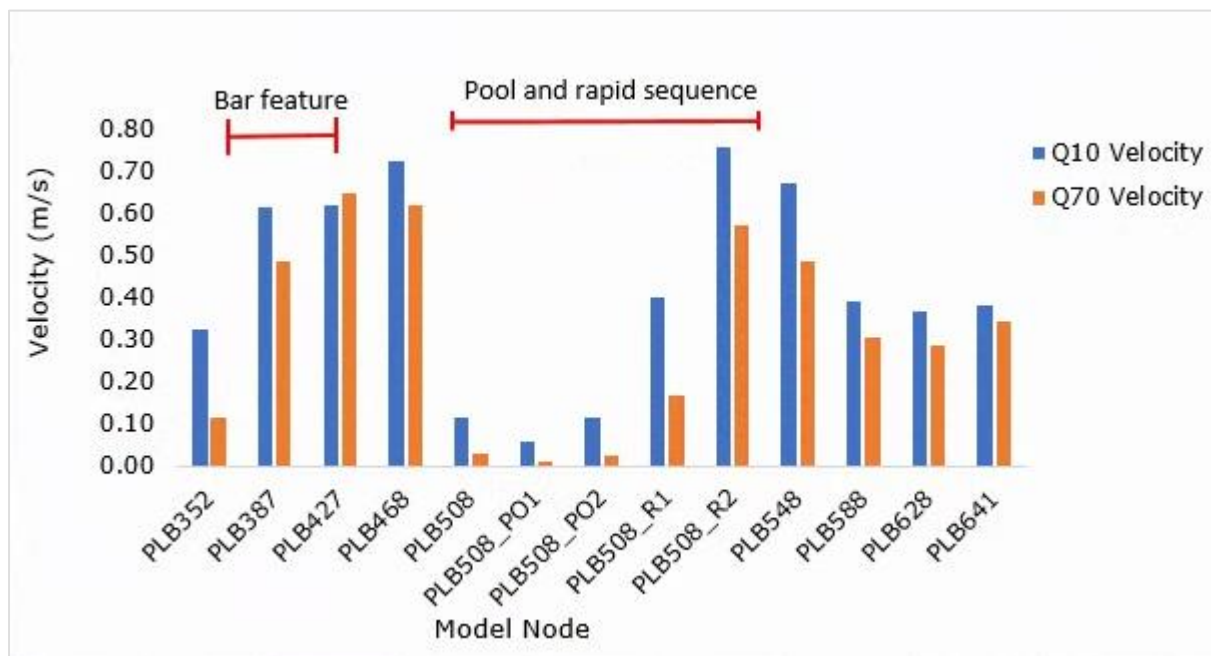


Figure 5-3: Velocities across the site (post development) sequence*

*Note not to scale, total model length is 289m and the distance between the model nodes vary.

Table 5-3: Comparison of velocity's		
	Q10 Velocity	
Model Node	Baseline	Post Development
PLB352	0.35	0.32
PLB387	0.56	0.61
PLB427	0.62	0.62
PLB468	0.72	0.72
PLB508	0.72	0.11
PLB508_PO1	0.76	0.06

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PLB508_PO2	0.76	0.11
PLB508_R1	0.78	0.4
PLB508_R2	0.78	0.75
PLB548	0.67	0.67
PLB588	0.39	0.39
PLB628	0.37	0.37
PLB641	0.38	0.38

Velocities throughout the site have been extracted from the hydraulic model. Table 5-3 (red text highlights an in-channel feature) shows a comparison of velocities between the baseline and the post development results during Q10 flows. It shows within the steeper gradient where the pool has been modelled there is a decrease in the in-channel velocities as a result of deeper water, with a substantial increase in velocities through the step-pool due to the steeper gradient associated with these features. For the Q10 flow results around the bar feature in the lower gradient area, the velocities are higher which can be attributed to the way the model calculates an average velocity for the cross section and in bar features, the flow depths over the bar are shallower than then open channel. In addition, there is a narrower flow channel which increases water depth attributing to higher velocities.

The variation in velocity between sections and between different flow events will help to maintain and provide diverse geomorphic conditions, significantly improving upon the existing culverted watercourse.

5.4 Sediment transport

The shear stress and entrainment values were determined for the modelled cross sections for the site, using the Shields equation. Entrainment is the value in which the maximum size of sediment can be transported during a particular flood or low flow event. Figure 5-4 depicts the entrainment values at both Q10 and Q70 flow exceedances for the post development. The graph shows that the typical grain size that is mobilised and entrained during Q10 flows ranges from 6-38mm, which represent flows that are exceeded only 10% of the time and are therefore relatively high flows (compared to other low flows), suggests the new channel would be capable of sustaining bedform development. This is regarded as a positive outcome as bedform development leads to diverse morphology and creates in-channel habitat, such as those observed in the analogue reaches upstream.

Velocity is used in the calculation of shear stress and so the results share similar trends. Figure 5-4 shows that typically there is a greater size of sediment which is entrained within the open channel compared to those with a bar feature present. This indicates that at Q10 flows, larger sediment would be entrained and transported through the open channel sections, which are deeper and slightly narrower than the overall channel with the bar features. Whereas at bar feature cross-section, the slight reduction in maximum grain size entrainment would mean coarser sediment is deposited. This enables bars to form as they are created through depositional processes. Immediately downstream of the bar features there is the potential for riffles to form as an extension of the bar and which would provide flow diversity within the channel.

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Immediately upstream of the modelled step-pool on the steeper section, there is a drop in the shear stress and entrainment associated with the pool feature, as a result in the reduced flow velocity. The modelled step-pool sequence is shown to reduce velocities overall when compared to the results without them in. This will help manage velocities in the reach which is seeking to mimic the high gradient slope observed in the headwater streams.

The recorded entrainment values outputted from the hydraulic model, is comparable to observations made on the walkover assessment of the analogue reach. Small gravels were observed typically within the open channel, with larger, coarser gravels identified on the exposed bar features. Whilst, further upstream in areas of steeper gradients step-pool sequences dominated observing very coarse bed material (gravels, cobbles, boulders) indicating an active sediment supply.

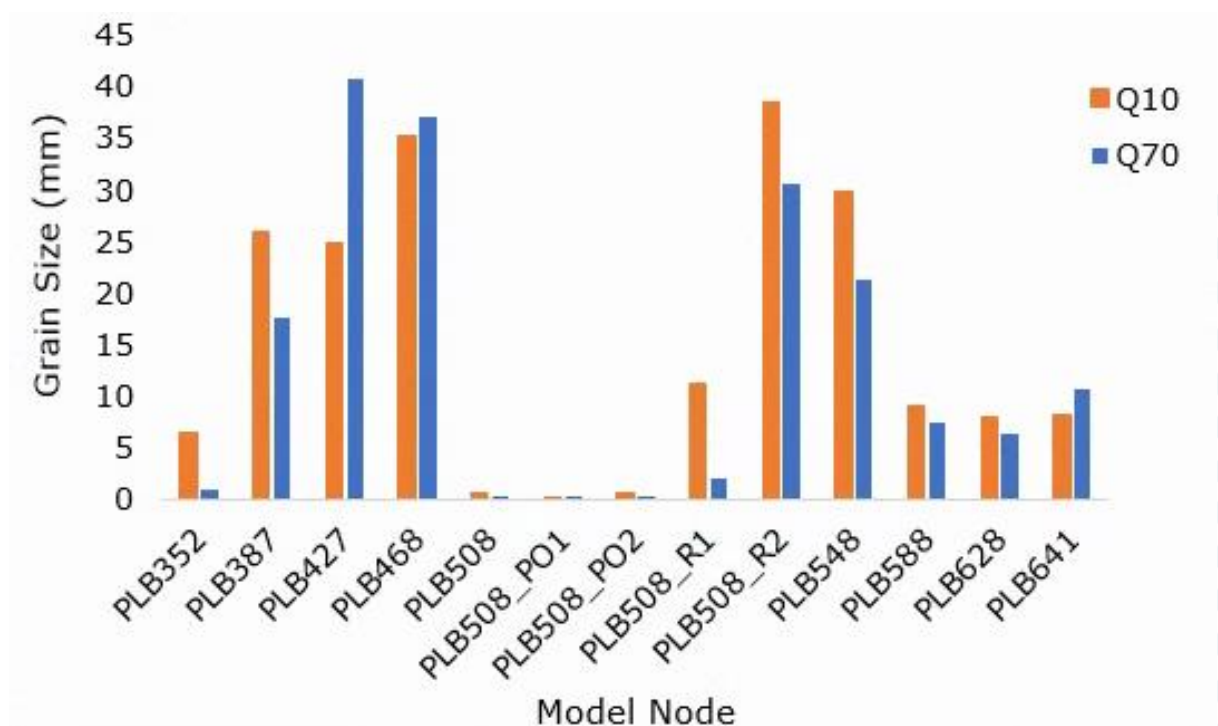


Figure 5-4: Entrainment values across the site*

*Note not to scale, total model length is 289m and the distance between the model nodes vary.

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5.5 Design risks

When designing a new channel or when considering modifications to an existing channel, there are a number of risks that need to be considered to develop an appropriate design. The following risks have been identified:

- Inappropriate sizing of the channel which could lead to a degraded system that does not support hydromorphic processes: To mitigate this risk analogue sites have been identified and used to inform the shape of the new channel. Hydraulic modelling has been used to test the appropriateness of the channel shape and size under low flow conditions.
- Uncontrolled or excessive erosion that could impact infrastructure or destabilise the bed: The steeper channel profile required by the client has the potential to generate high energy that could lead to instability in the reach, particularly if sediment supply to the reach is limited by the reservoir and modifications upstream. To mitigate this, features are recommended in the concept design to control erosion and mimic morphological units found in steep channels (i.e. rapid and step pools).
- Uncontrolled or excessive erosion that could impact infrastructure through bank erosion: Bank erosion is a residual risk that will need to be considered in future design work. The conceptual design has involved working with natural processes to produce a functioning channel, within the constraints of the site. Some bank erosion may therefore occur on the outside of small bends within the channel; monitoring will be required to ensure bank erosion is not excessive and does not threaten the stability of infrastructure within the development.

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6 Indicative Drawings

6.1 Introduction

Following on from the hydraulic modelling a series of indicative drawings were developed to demonstrate the in-channel bar features geometry, which met the design criteria of the bars being fully submerged at Q10 and exposed during lower flows for example at Q70, and developing slower in-channel velocities through the pool, but increased velocities over the step-pool sections.

The indicative cross sections are provided within DRV-JBAU-XX-00-DR-EN-0001-S3-P02-Indicative_Cross_Sections. Within the indicative drawings it outlines the long section marked with the locations for the different in-channel features, such as step-pool sequences and bar features. The step-pool sequences are located within areas of steeper bed gradient as these processes are anticipated to be dominated by erosional processes. Whilst in shallower bed gradients it is anticipated to have more depositional environments allowing the formation of bars. River sections where the bar is present the channel is typically wider which encourages deposition during higher flows and develops a varied channel morphology. It additionally displays how the cross sections developed for the hydraulic modelling compare to the original cross sections within the model provided.

6.2 CDM Regulation 2015

This report provides conceptual design parameters and information for the new channel associated with the Bevis Green site. If these are taken forward to detailed design and implementation all work will need to follow the framework and fulfil the obligations outline in the Construction (Design and Management) Regulation 2015 (CDM Regulations). At this early stage, JBA Consulting has not been designated as the Principal Designer but have acted as a designer. When progressing the designs further, the client should assess where the nature and scale of the works are likely to be notifiable under CDM regulations (the criteria for it being notifiable is that the construction phase will last more than 30 working days or shifts and has more than 20 persons on site, or will involve more than 500 person days or shifts).

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Client	Barratt Homes
Day, Date and Time	27/11/2020
Author	Emma Wright
Reviewer / Sign-off	Matt Hemsworth
Subject	Technical Note

7 Conclusions

A hydraulic model has been developed to include in-channel features to improve the geomorphic conditions of the watercourse from its existing culvert. A geomorphology assessment was undertaken to understand hydromorphic processes operating in the watercourse and an analogue site was identified upstream. The concept design for the new channel has been based on this analogue site.

Bar features were hydraulically modelled to narrow the channel width and create an area of deeper flow during low flow conditions. Water levels were shown to submerge the bar feature during a Q10 event whilst at a lower flow extent, such as Q70, the bars were exposed with all the flow contained within the low flows channel. The calculated entrainment values showed a Q10 event would be capable of entraining and transporting small gravels (6-38mm), whilst smaller sediment sizes could be transported during a Q70 event.

This sediment mobilisation is similar to observations made during the site walkover. Velocities and shear stress were found to be lower in areas where bar features were present in the model, indicating higher rates of deposition in these parts of the channel. Immediately downstream of the bars, an increase in velocities and entrainment was shown, indicating the potential for riffle features to develop which would encourage greater geomorphic diversity within the channel.

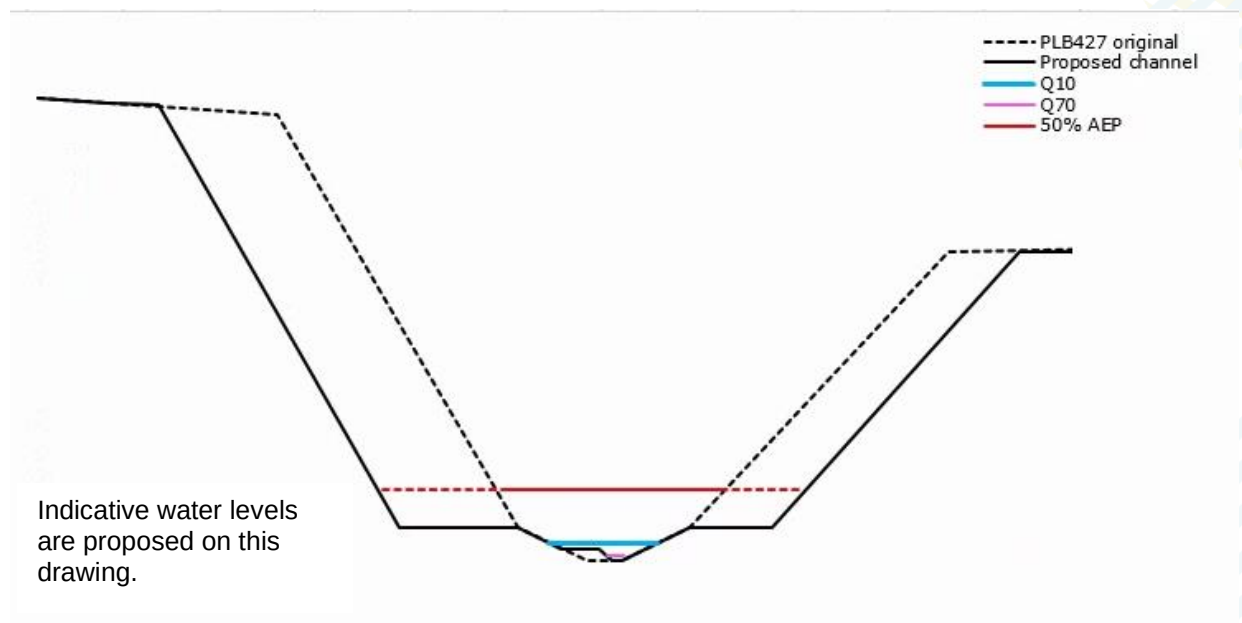
8 Recommendations

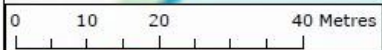
It is recommended that the following should be completed at the next stage:

- Advancement of the concept proposals during the detailed design stage - it is assumed this will be undertaken by Barratt Homes.
- It may be required to conduct further flood risk modelling of the new design to ensure the proposed channel does not increase flood risk to adjacent properties.
- A Water Framework Directive assessment would be required to obtain the relevant permits.
- Larger flows (such as the 50% AEP) should not be contained within the channel as this disconnects the channel from its floodplain and concentrates high energy within the channel, which can lead to exacerbated erosion. It is understood that space is limited; however, by designing the channel so that the upper bank profiles are set back and larger flows are able to spill onto a second stage of the channel, would allow for some riparian connectivity within the limited river corridor. This would also provide additional flood storage capacity during flood flows without impacting upon the gradient of slopes on both banks, as the figure below demonstrates.

NOTE TO FILE

JBA Project Code 2020s0819
Contract Bevis Green
Client Barratt Homes
Day, Date and Time 27/11/2020
Author Emma Wright
Reviewer / Sign-off Matt Hemsworth
Subject Technical Note

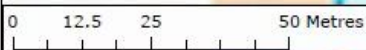
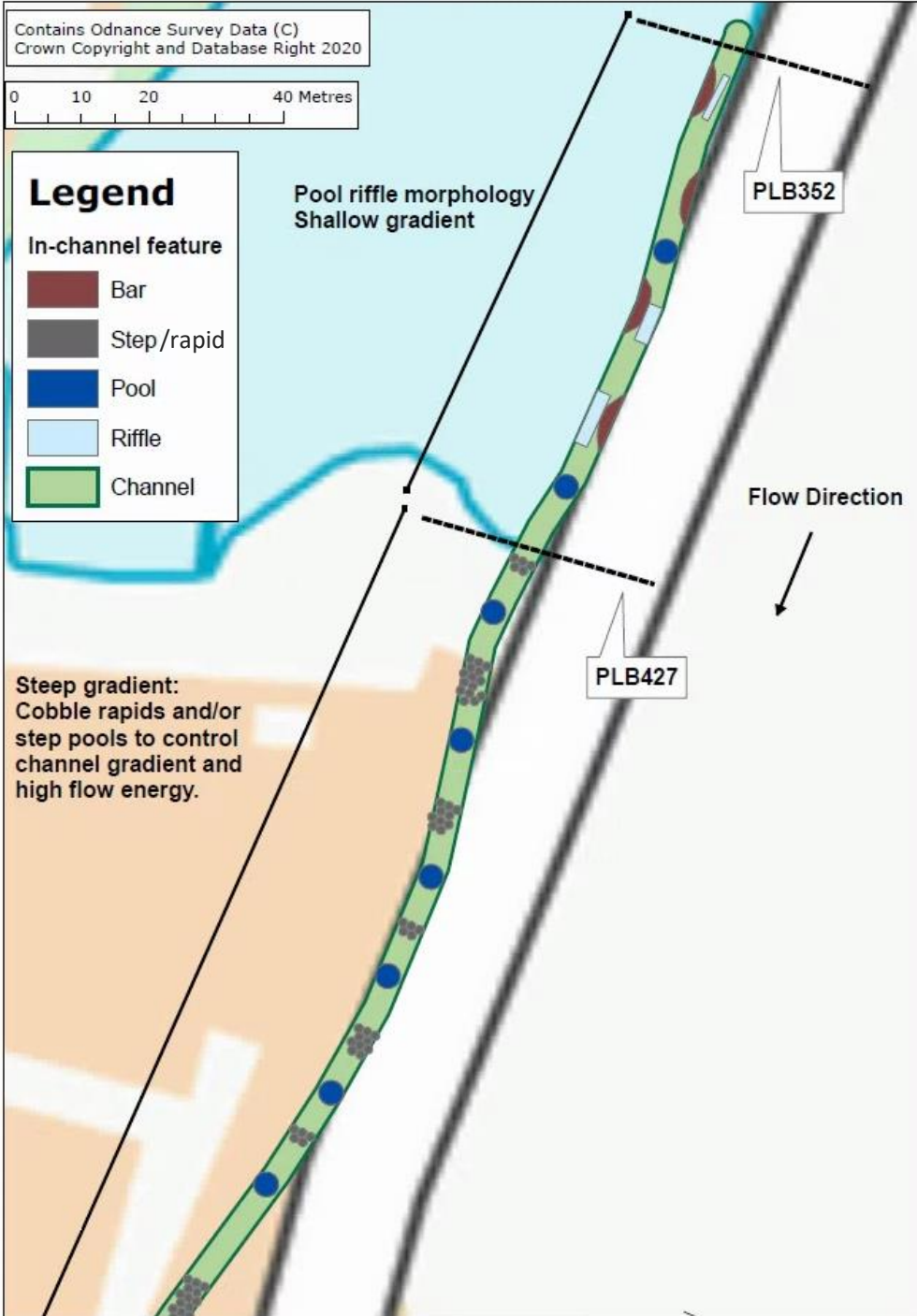




Legend

In-channel feature

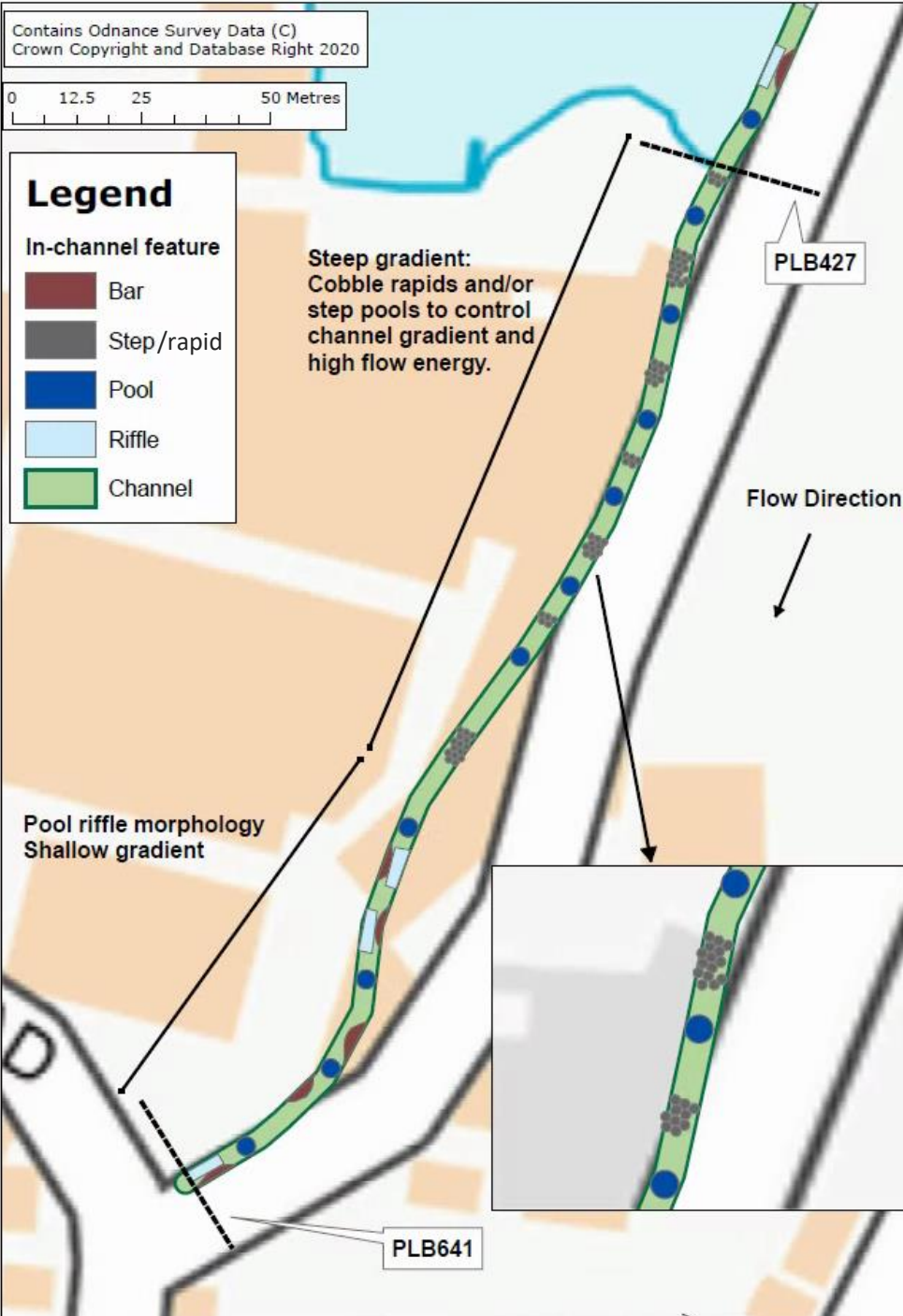
- Bar
- Step/rapid
- Pool
- Riffle
- Channel



Legend

In-channel feature

- Bar
- Step/rapid
- Pool
- Riffle
- Channel



Bevis Green – Conceptual Plan view

This document presents a concept design comprising of an indicative plan for the new channel with example placement of morphological features. Further hydraulic modelling and analysis will be needed as part of a detailed design stage to determine the placement and size of in-channel features (including size of sediment) to progress the design for implementation.

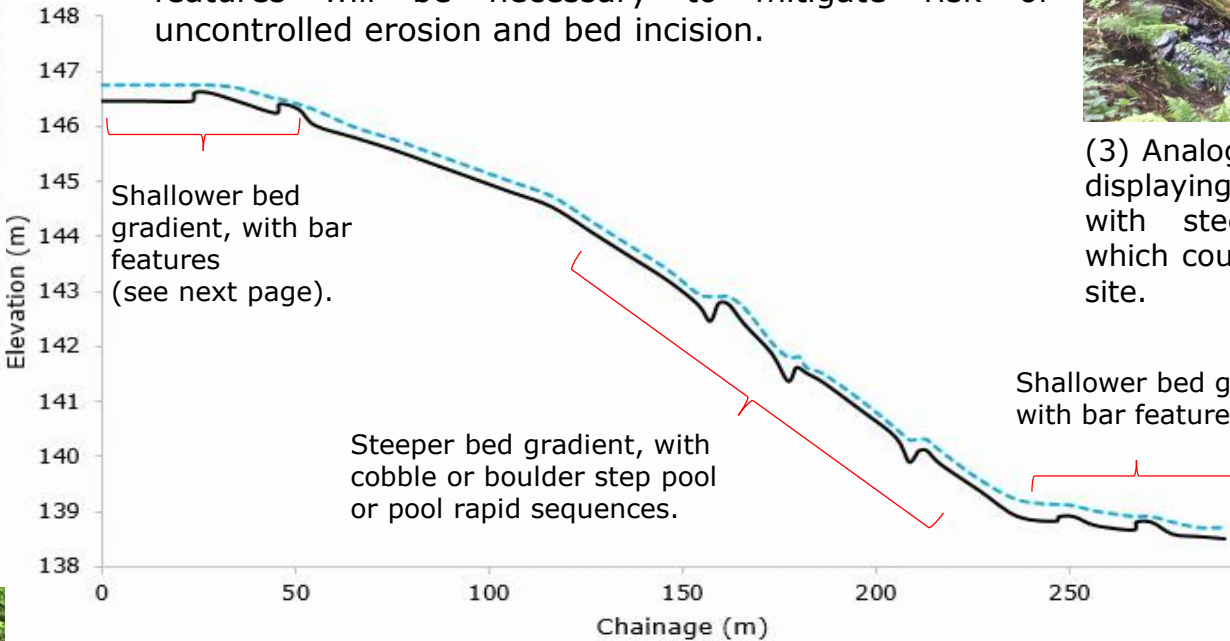
Revision Ref/Date	Amendments
P02 -2 nd December 2020	Draft – Issued for Comment
Drawn: E. Wright 27/11/2020	
Checked: R Thrower 02/12/2020	
Approved: M Hemsworth 02/12/2020	
Project Reference: 2020s0819	



(1) Analogue reach displaying a step-pool morphology with steeper bed gradient. A similar concept could be achieved at the site, but with a wider channel as required.



The shallower bed gradient at either end of the new channel will reduce in-channel velocities and allow for depositional processes to dominate. It is anticipated that bar features will form (2), reducing the channel width and introducing morphological diversity.



Within areas of steeper bed gradient, features mimicking either step pool or cascade morphology should be created along this reach. Coarser bed material will form the step or rapid (areas of raised bed level) whilst material upstream of the rapid will be scoured out to form a pool, with increased water depths and reduced in-channel velocities. It is expected to see sediment deposition within the pool as a result. Erosional processes will dominate throughout this reach. Appropriate placement and sizing of features will be necessary to mitigate risk of uncontrolled erosion and bed incision.



(3) Analogue reach photograph displaying a cascade channel with steeper bed gradient, which could be achieved at the site.



(4) Typical sediment identified downstream of the step pool/ cascade reaches, predominately consisting of coarse gravels.

Bevis Green – Long Section Plan

Indicative long-section plot with example placement of morphological features to control gradient and limit high velocities. To be developed further as part of a detailed design stage.

Revision Ref/Date	Amendments
P02 -2 nd December 2020	Draft – Issued for Comment

Drawn: E. Wright 27/11/2020
Checked: R Thrower 02/12/2020
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Project Reference: 2020s0819

**Bevis Green –
Indicative
Plan of Pool
Riffle sections**

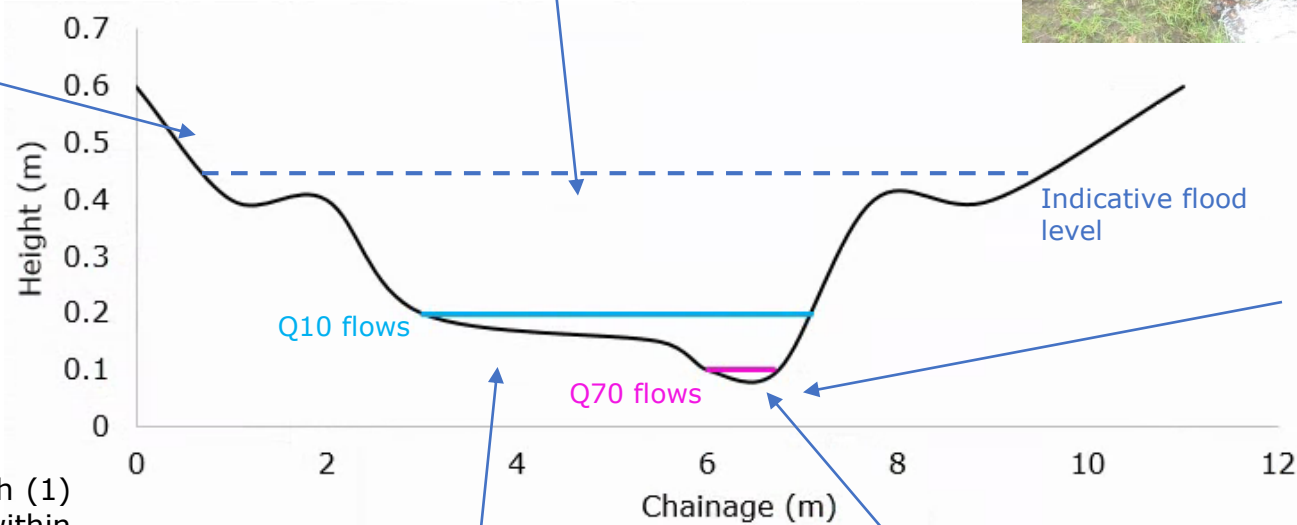
Indicative cross-section showing the typical channel shape within the shallower gradient sections of channel. To be developed further as part of a detailed design stage.

Revision Ref/Date	Amendments
P02 -2 nd December 2020	Draft – Issued for Comment

Drawn: E. Wright 27/11/2020
Checked: R Thrower 02/12/2020
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In-channel bar features will provide both hydromorphological and ecological benefits. These features will only be submerged during certain low flow conditions and dry during the rest, providing channel complexity and different habitats as observed in the analogue site upstream (1 and 2).

The gradient of this slope will depend on the difference between the desired bed level and proposed site ground levels.



The flows at Q70 will be contained within the low flows channel (pink line), whilst larger flow events such as Q10 will submerge the bar (blue line).

Analogue reach photograph (1) displaying a bar feature within an area of gentler gradient.



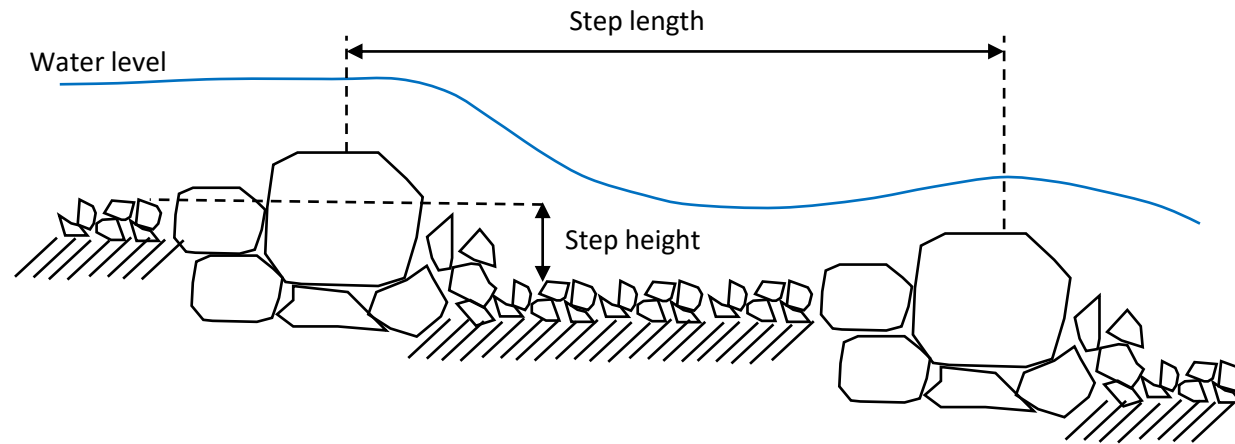
Bank heights are relatively shallow which is representative of the analogue reach and is important for maintaining a hydraulic connection to the riparian zone during larger flows.

Narrower low flows channel adjacent to the bar to encourage fine sediment to be transported downstream, as seen in the analogue reach. Generally, the channel is wider with bar features (compared with 'open channel' section) to encourage deposition during higher flows and varied channel morphology.



Bevis Green – Indicative Step Pool

This document presents a concept design comprising of an indicative plan for the new channel. Further hydraulic modelling and analysis will be needed as part of a detailed design stage to determine the placement and size of in channel features including size of sediment) to progress the design for implementation



The spacing and size of step pools should be variable, in order to maintain a natural sediment flux, particularly during flood flows. Designs should avoid uniform dimensions for the step pools.

Revision Ref/Date	Amendments
VO – December 2020	Draft – Issued for Comment
Drawn: E. Wright	
Checked: R. Thrower	
Approved: M. Hemsworth	
Project Reference: 2020s0819	

[illegible]

Cross section Reference	Parameter	Return Event								
		1:2yr	1:10yr	1:30yr	1:50yr	1:75yr	1:100yr	1:100yr +35%	1:100yr + 70%	1:1000 yr
CH427										
Cobble rapid / step pool	Peak Water Level (mAOD)	145.92	146.009	146.056	146.08	146.106	146.123	146.199	146.28	146.299
	Peak Water Depth (m)	0.35	0.439	0.486	0.51	0.538	0.553	0.629	0.71	0.729
	Wetted Perimeter (m)	5.322	5.829	6.097	6.234	6.393	6.479	6.923	7.373	7.481
	Wetted Area (m2)	1.51	1.64	1.915	2.06	2.234	2.328	2.825	3.389	3.527
	Peak Velocity (m/s)	1.139	1.346	1.457	1.504	1.545	1.583	1.731	1.874	1.907
	Shear Stress	48.41973838	67.80825032	76.59091511	80.24251789	83.11380444	86.44618801	99.07447469	111.6021113	114.5939793
	Critical Shear (entrainment mm)	66.47478987	93.09301004	105.1506092	110.1638442	114.1057938	118.6807772	136.0179775	153.2169968	157.3244909
	Sediment type which can be entrained	All sediment up to Cobbles	All sediment up to Cobbles	All sediment up to Cobbles	All sediment up to Cobbles	All sediment up to Cobbles	All sediment up to Cobbles	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders
CH468										
Cobble rapid / step pool	Peak Water Level (mAOD)	144.843	144.919	144.958	144.978	145	145.016	145.082	145.153	145.17
	Peak Water Depth (m)	0.313	0.389	0.428	0.448	0.47	0.486	0.552	0.623	0.64
	Wetted Perimeter (m)	5.122	5.522	5.727	5.832	5.948	6.032	6.379	6.752	6.842
	Wetted Area (m2)	0.964	1.364	1.58	1.693	1.829	1.915	2.315	2.769	2.883
	Peak Velocity (m/s)	1.362	1.625	1.769	1.83	1.888	1.931	2.124	2.312	2.352
	Shear Stress	79.38724753	103.2150651	117.8930076	124.0408446	129.5185819	134.051316	155.1143259	176.4497991	180.9657804
	Critical Shear (entrainment mm)	108.9896553	141.7025368	161.8536814	170.2939618	177.8142717	184.0371997	212.954315	242.2454914	248.4454197
	Sediment type which can be entrained	All sediment up to Cobbles	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders
CH508										
Cobble rapid / step pool	Peak Water Level (mAOD)	143.059	143.131	143.172	143.19	143.211	143.226	143.292	143.364	143.379
	Peak Water Depth (m)	0.309	0.381	0.422	0.44	0.461	0.476	0.542	0.614	0.629
	Wetted Perimeter (m)	5.093	5.482	5.703	5.801	5.914	5.995	6.351	6.74	6.821
	Wetted Area (m2)	0.943	1.32	1.545	1.648	1.769	1.856	2.255	2.715	2.814
	Peak Velocity (m/s)	1.389	1.669	1.808	1.873	1.938	1.981	2.178	2.364	2.409
	Shear Stress	83.01708924	109.8103787	123.8979624	130.8779419	137.7318531	142.2705593	164.2945999	185.5812012	191.18652
	Critical Shear (entrainment mm)	113.9730149	150.7571519	170.0978009	179.6805182	189.0901582	195.3212854	225.5577863	254.7818671	262.4773319
	Sediment type which can be entrained	All sediment up to Cobbles	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders	All sediment up to Boulders
CH548										
Cobble rapid / step pool	Peak Water Level (mAOD)	141.131	141.197	141.24	141.258	141.277	141.291	141.356	141.422	141.438
	Peak Water Depth (m)	0.311	0.377	0.42	0.438	0.457	0.471	0.536	0.602	0.618
	Wetted Perimeter (m)	5.113	5.531	5.802	5.916	6.036	6.125	6.536	6.953	7.054
	Wetted Area (m2)	0.954	1.301	1.541	1.646	1.757	1.841	2.246	2.681	2.791
	Peak Velocity (m/s)	1.382	1.668	1.788	1.839	1.902	1.945	2.095	2.244	2.272</

Cross section Reference	Parameter	Return Event								
		1:2yr	1:10yr	1:30yr	1:50yr	1:75yr	1:100yr	1:100yr +35%	1:100yr + 70%	1:1000 yr
CH588										
Pool riffle	Peak Water Level (mAOD)	139.365	139.548	139.675	139.734	139.811	139.866	140.116	140.41	140.481
	Peak Water Depth (m)	0.465	0.648	0.775	0.834	0.911	0.966	1.216	1.51	1.581
	Wetted Perimeter (m)	6.095	7.25	8.051	8.424	8.91	9.257	10.835	12.691	13.139
	Wetted Area (m2)	1.806	3.004	3.953	4.427	5.076	5.562	7.998	11.342	12.227
	Peak Velocity (m/s)	0.745	0.77	0.773	0.773	0.774	0.774	0.775	0.774	0.775
	Shear Stress	20.41770303	19.50457504	18.57557822	18.15951656	17.72323384	17.41154717	16.29902377	15.25315457	15.0878221
	Critical Shear (entrainment mm)	28.03118241	26.7775616	25.5021547	24.9309494	24.33198288	23.90407256	22.37670455	20.94084517	20.71386251
	Sediment type which can be entrained	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels
CH628										
Pool riffle	Peak Water Level (mAOD)	139.197	139.457	139.61	139.677	139.762	139.822	140.086	140.389	140.461
	Peak Water Depth (m)	0.617	0.877	1.03	1.097	1.182	1.241	1.506	1.809	1.881
	Wetted Perimeter (m)	6.866	8.359	9.238	9.623	10.112	10.451	11.957	13.355	13.685
	Wetted Area (m2)	2.754	4.679	5.983	6.593	7.402	7.984	10.838	14.502	15.427
	Peak Velocity (m/s)	0.493	0.494	0.494	0.494	0.495	0.495	0.494	0.494	0.495
	Shear Stress	8.082570021	7.262118656	6.917501026	6.78899336	6.667792465	6.573528049	6.184253375	5.822840729	5.773961113
	Critical Shear (entrainment mm)	11.09644871	9.970062371	9.496941589	9.320515189	9.154120156	9.024705841	8.490276019	7.99409759	7.926991441
	Sediment type which can be entrained	All sediment up to Medium gravels	All sediment up to Medium gravels	All sediment up to Medium gravels	All sediment up to Medium gravels	All sediment up to Medium gravels	All sediment up to Medium gravels	All sediment up to Medium gravels	All sediment up to Medium gravels	All sediment up to Medium gravels
CH641										
	Peak Water Level (mAOD)	139.151	139.423	139.582	139.65	139.737	139.798	140.067	140.373	140.446
	Peak Water Depth (m)	0.651	0.923	1.082	1.15	1.237	1.298	1.567	1.873	1.946
	Wetted Perimeter (m)	4.866	6.206	6.99	7.325	7.754	8.055	9.381	10.889	11.249
	Wetted Area (m2)	2.032	3.446	4.427	4.881	5.493	5.942	8.122	10.998	11.476
	Peak Velocity (m/s)	0.664	0.665	0.666	0.665	0.665	0.665	0.666	0.667	0.666
	Shear Stress	14.46642795	13.19525557	12.66718244	12.4170543	12.16627716	12.00318793	11.41351791	10.87473739	10.80600755
	Critical Shear (entrainment mm)	19.86075907	18.11558406	17.39059977	17.0472023	16.70291383	16.47901088	15.66946105	14.92977672	14.83541848
	Sediment type which can be entrained	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Coarse gravels	All sediment up to Medium gravels	All sediment up to Medium gravels	All sediment up to Medium gravels

PHI - mm COVERSION $\phi = \log_2 (d \text{ in mm})$ $1\mu\text{m} = 0.001\text{mm}$			Fractional mm and Decimal inches	SIZE TERMS (after Wentworth, 1922)	SIEVE SIZES		Intermediate diameters of natural grains equivalent to sieve size	Number of grains per mg		Settling Velocity (Quartz, 20°C)		Threshold Velocity for traction cm/sec	
ϕ	mm				ASTM No. (U.S. Standard)	Tyler Mesh No.		Quartz spheres	Natural sand	Spheres (Gibbs, 1971) cm/sec	Crushed cm/sec	(Nevin, 1946)	(modified from Hjulstrom, 1939)
-8	200	256	10.1"	BOULDERS ($\geq -8\phi$) COBBLES								200	1 m above bottom
-7	100	128	5.04"									150	
-6	50	64.0	2.52"	2 1/2"	2"							100	
-5	40	53.9		2.12"	2"							90	
-5	30	45.3		1 1/2"	1 1/2"							80	
-5	20	33.1	1.26"	1 1/4"	1.05"							70	
-4	10	32.0		1.06"								60	
-4	10	26.9	0.63"	3/4"	.742"							50	
-3	5	22.6		5/8"	.525"							40	
-3	5	17.0	0.32"	1/2"	.371"							30	
-2	4	16.0		7/16"								20	
-2	4	13.4	0.16"	3/8"	3							10	
-1	2	11.3		5/16"								9	
0	1	9.52	0.08"	.265"								8	
0	1	8.00	mm									7	
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0	1	1.41											
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