Geomorphological Assessment of channel widening downstream of the confluence of the River Trent and the River Tame

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October 2011

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Revision History

Revision Ref / Date Issued	Amendments	Issued to
29/09/2009	Initial draft	Jonathan Cooper
4/11/2009	Revised draft	Nick Mott & Jonathan Cooper

Contract

This report describes work commissioned by Nick Mott, on behalf of Staffordshire Wildlife Trust, by a letter dated 23rd September 2009. Staffordshire Wildlife Trust's representative for the contract was Nick Mott. George Heritage of JBA Consulting carried out this work.

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Executive Summary

Background and approach

The tendency of the River Trent and its principal tributaries to braid and split to create gravel shoals and islands has been noted by a number of previous studies and the resultant geomorphic variability is seen as very important from a biodiversity perspective. This is particularly the case as long sections of the river are now stable, morphologically uninteresting and unconnected with their floodplain.

The process of shoaling, bar and island development is primarily controlled by flow transport variation with wider shallower reaches exhibiting sediment build up. Such reduced energy zones may be artificially created through channel widening, scalping the floodplain silts to expose the gravels beneath and allowing the river to rework this material together with any inputs delivered from upstream. Staffordshire Wildlife Trust intends to widen the channel of the Trent in the vicinity of the confluence of the River Tame removing approximately 45,000m^3 of floodplain deposits (Figure 1). Gravel shoaling and island development is to be further encouraged through the creation of large woody debris deposits and the retention of vegetated floodplain areas within the widened section.

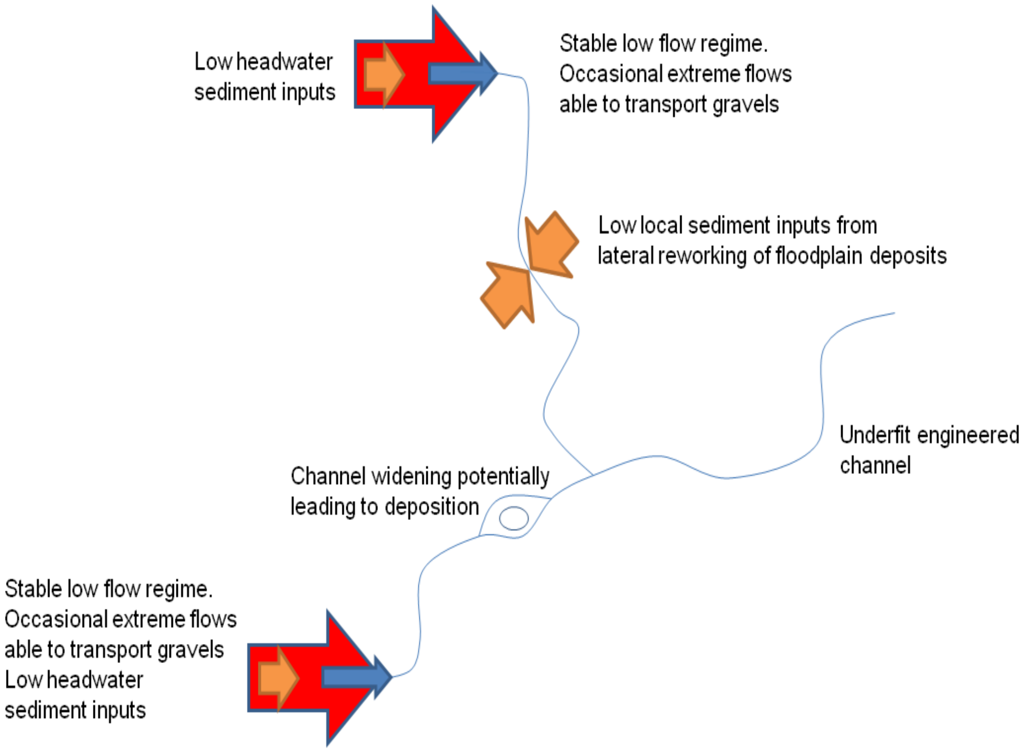
Figure 1 Location of floodplain excavation works on the River Trent at Croxall Lakes.

The impact of the proposed works on river behaviour locally and up and downstream is presently unknown and requires a geomorphological audit of the catchment and a reach based dynamic assessment to assess the potential changes following the proposed works.

Sub-catchment and channel audit.

The process based audit of the River Trent and the major tributaries including the River Tame in the vicinity of Croxall Lakes provided a clear and simple understanding of how the river system functions (Figure 2). It has revealed that the upper Trent and middle Tame have a propensity to alter their form and behaviour in response to climate and anthropogenic influences, switching from single thread, through braided and anastomosing channel types since the end of the last ice age (12ka BP). In particular gravel shoaling and island development have been significant in the historic past. However, at present the river exhibits a stable sinuous single-thread channel with limited gravel shoaling indicating limited active gravel movement. It is also heavily protected against bank erosion preventing lateral migration, floodplain gravel reworking and inputs of coarse material into the river.

Figure 2 A model of system controls and functioning at Croxall Lakes.



Implications for channel dynamics in the vicinity of Croxall Lakes

Although the River Trent has braided during prehistoric times it is clear from the geomorphic audit that the both the River Tame and the River Trent do not presently display any propensity to braid. Channel widening and flow energy reduction has resulted in stable island development in the recent past rather than braiding. At Croxall Lakes the exposure of a large area of unconsolidated river gravels to fluvial action will initially result in sediment reworking across the excavated surface. Flood flows will rationalise the gravels creating bar and shoal features in low energy areas and higher energy chute channels in between. The long term sustainability of this gravel dominated system is questionable, however, as braided channels are characterised by steep channel slopes and high sediment inputs. This section of river has a low slope (0.0001 – 0.0004) and limited active coarse sediment supply and agricultural activity is introducing fine sediment diffusely along the river. ***Provided ther is sufficient flow diversity the widened section is likely to develop as a series of stable vegetated bar features, encouraged by fine sediment deposition.*** Over time these may amalgamate through the periodic trapping of flood derived transported material.

It is unlikely that the predicted deposition and bar stabilisation will have a significant effect on upstream water surface slopes beyond that already exerted by the island immediately upstream of the confluence. ***As a result, the changes imposed on the river at Croxall Lakes will not lead to the development of further depositional zones upstream.*** Some additional deposition may occur in the vicinity of the current upstream island, however the restricted lateral movement posible at this location is likely to limit this. Disruption to the sediment balance downstream of the works at Croxall is likely and there will be a short term reduction in gravels moving downstream as these are deposited at Croxall. The inability of the river to erode its protected banks will to lead to further downcutting of the bed downstream and potential disruption to the development of gravel shoals. ***Provided the morphologic diversity of the widened channel is enhanced through the construction of islands and obstructions then in the longer term it is likely that the reach at Croxall will attain a dynamic stability with the present flow***

regime developing stabilised bars and islands. Once this occurs gravels will again move through the reach to supply the shoals downstream.

Preliminary 1D segmented modelling of the modified reach using HECRAS indicates that the widened area is prone to fine sediment deposition at low flows and that this sediment may be difficult to erode at high flows if it becomes consolidated. Care must be taken during construction to create morphologic diversity across the widened surface encouraging flow variability, erosion and deposition.

Summary of the key findings

- The form of the river at Croxall Lakes is controled by a stable low flow regime and occasional flood flows capable of transporting river gravels.
- ***Sediment rationalisation, bar deposition, stabilisation and vegetative colonisation will occur in the widened reach in preference to wholesale braiding.***
- The river is presently supply limited as regards coarse sediment with low level headwater inputs and only minor floodplain inputs due to bank training. Fine sediment inputs are diffuse but significant. ***As such the development of gravel bars and islands will initially be through the reworking of local exposed gravels only slowly suplemented by upstream inputs.***
- The widened reach at Croxall Lakes is characterised by a low to moderate gradient, low coarse sediment supply and constant fine sediment inputs. ***The propensity of the river to aggrade through fine sediment deposition and consolidation is high and should be mitigated against.***
- The present island upstream of the confluence is unlikely to alter significantly due to the alteration at Croxall as the sediment erosion / deposition system is already in balance and cannot alter significantly due to a stabilised planform.
- Disruption to the sediment dynamics and gravel shoals downstream of Croxall Lakes is likely to be short term and should be restored following stabilisation of the morphology along the widened channel.
- The segmented 1D hydraulic modelling has revealed that a uniform widened channel surface would be prone to sedimentation during summer flows and that, where this becomes consolidated, this material will be resistant to erosion during higher winter flows. ***As such there is a likelyhood that there will be a long term directional change in the geomorphology with sediment continually building up across the widened area.***
- ***The construction of islands and obstructions across the widened surface and in the main channel will concentrate the hydraulic energy in the reach to levels that will permit transport of material up to fine gravel size and should cause some local scour of consolidated fine sediment where flow velocities are maximised.*** The generally low gradient of the reach and shallow nature of most flows do not guarantee this however, and performance will be highly dependent on flood flow frequency and an unchanged fine sediment input level from upstream.
- The outputs from the segmented 1D model are generalised and the reported values may be in error. This is significant given that the current design is subject to continuous diffuse fine sediment inputs and the present energy levels are predicted at the cusp of being unable to remove material of this calibre.
- Despite the generalised outputs of the 1D hydraulic model the hydraulic diversity introduced through island and obstruction construction will generate a variety of eroisonal and depositional environments which will increase habitat and biotic diversity.

Options for further work

The conclusions above are based on qualitative evaluation and generalised flow modelling. A such they only give an indication of likely channel response to the energy distribution within the system. Despite this the propensity for the exposed area to accumulate silt is predicted as high, pointing towards long term directional change as a result of progressive sediment accumulation rather than the development of a self sustaining system of stable islands. The development of a 2D hydraulic model would add considerable detail and confidence to the prediction of channel development. The model data could be used to modify the scheme design and additionally to predict hydraulic habitat distribution and change, demonstrating the likely environmental and ecological benefits of the works in line with Water Framework Directive objectives.

It is essential that valuable information relating to the performance of this project is not lost due to a lack of monitoring. A reactive survey programme to assess scheme performance through morphological change is suggested which will also guide appropriate reactive management activities.

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1 Purpose and scope of study

1.1 Background

The River Trent drains around 10,500 km^2 of central England including 2272km^2 under tidal influence. The river has an almost unique hydrology, experiencing more frequent flooding and more extreme flows compared to other English rivers. Fluvio-glacial deposition in the Trent valley after the last ice age has created a very wide floodplain and terrace sequence composed of gravels overlain by finer flood silts and this sedimentary evidence reveals that since the start of the Holocene (12ka BP) the river has adjusted its form from single-thread through braided and anastomosing in response to changes in the climate. The river is underfit compared to its former floodplain and terrace sequence and has a number of stabilised islands, backwaters and palaeo-channels along its course. Present activity is confined to limited lateral erosion (reworking very extensive fluvio-glacial gravel deposits) and minor gravel shoaling. Fine sediment inputs to the river have increased during historic times due to agricultural intensification.

The tendency of the River Trent and its principal tributaries to braid and split to create gravel shoals and islands is very important from a biodiversity perspective as long sections of the river are now stable, morphologically uninteresting and unconnected with their floodplain. The shoaling process is primarily controlled by flow transport variation with wider shallower reaches exhibiting sediment build up and the creation of shoals and islands. Such reduced energy zones may be artificially created through channel widening, scalping the floodplain silts to expose the gravels beneath and allowing the river to rework this material together with any inputs delivered from upstream. Staffordshire Wildlife Trust intends to widen the channel downstream of the confluence of the River Tame removing 45,000 m^3 of floodplain deposits. Gravel shoaling and island development is to be further encouraged through the creation of large woody debris deposits and the retention of vegetated floodplain areas within the main channel and across the widened section.

The impact of the proposed works on river behaviour locally and up and downstream is presently unknown and requires a geomorphological audit of the catchment and a reach based dynamic assessment to assess the potential changes following the proposed works.

1.2 Aims and objectives

As outlined above the engineering work involves floodplain scalping and river widening, together with selective vegetative island retention and large woody debris installation in order to encourage morphological change and enhance local biodiversity. The aim of this report is to assess the impacts of the works on the geodynamics of the river and an observational and broad scale modelling approach was adopted for the geomorphological appraisal with the aims of:

1. Reporting on a general sub-catchment geomorphic audit designed to develop an understanding of the processes controlling the location and development of the ‘braided’ zone at Croxall Lakes downstream of the confluence of the River Tame with the River Trent.
2. Developing a dynamic model of ‘braided’ zone behaviour and floodplain dynamics predicting likely directions of development in response to flood flows.
3. Assessing the likely impact of the morphological enhancement works on sediment dynamics and channel behaviour up and downstream of the ‘braided’ zone.

2 Methodology

2.1 Sub-catchment geomorphic audit

A process based audit of the R. Trent and the major tributaries in the vicinity of Croxall Lakes has been conducted to provide a clear and simple understanding of how the river system functions. The audit required a walkover survey associated with a review of online aerial imagery and a review of electronic archival sources of catchment changes and river behaviour (aerial photographic evidence, historic flow data, archive planform change information from OS maps and previous studies of the regional geomorphology where available). These will be assessed together with any information provided by the client.

2.2 'Braided' zone modelling

A local qualitative evaluation of the flow and sediment transport processes operating in the 'braided' zone will be conducted through a site based dynamic morphologic audit, leading to the development of a conceptual model of present and modified channel evolution in response to flood flows. The dynamic morphologic audit will concentrate on the reach between the A515 crossing on the R. Trent and Elford village on the R. Tame extending downstream to Edingale village on the R. Trent. A simple segmented 1D hydraulic model will be used to assess the local ability of the river to transport sediment under the following scenarios:

- Scalped floodplain with few large islands.
- Scalped floodplain with many small islands.
- Scalped floodplain with islands and additional in-channel features.

In additiona segmented 1D hydraulic model was developed to investigate hydraulic variation as a result of widening and island and obstruction formation.

2.3 Assessment of river response upstream and downstream

The present and likely future behaviour of the River Trent and the River Tame will be commented upon based on the results of the catchment and dynamic morphologic audits. The knowledge gained will also be applied to making a qualitative assessment of the potential response to the proposed channel widening.

2.4 Deliverables

The following products form part of this final report to the Staffordshire Wildlife Trust:

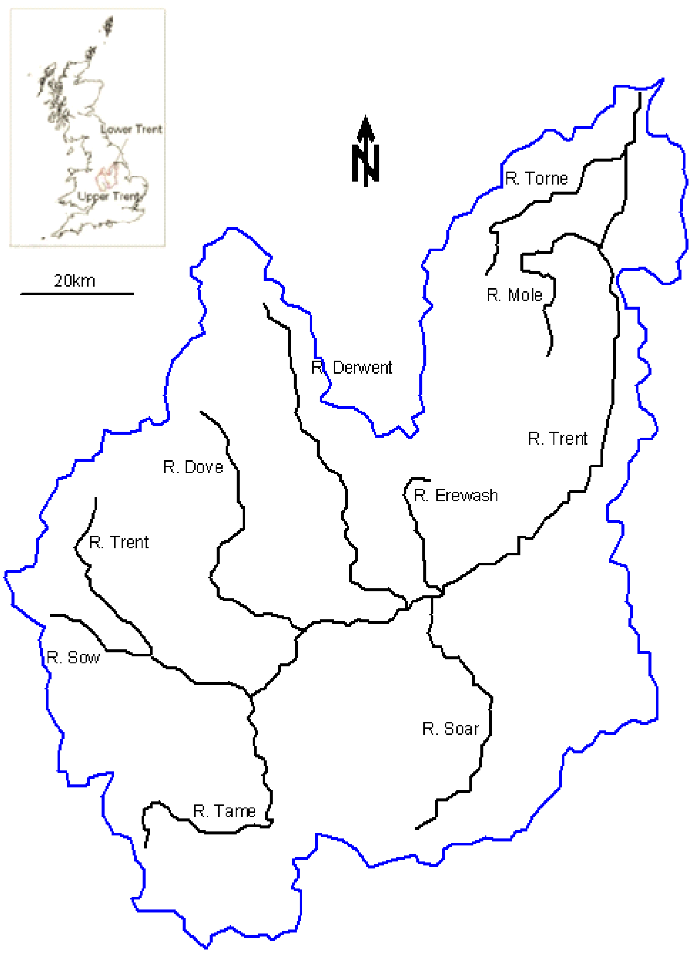
- Sub-catchment process based geomorphology report linked to 'braided' zone function.
- Conceptual dynamic model of the 'braided' zone examining the likelihood of channel change following scheme implementation.
- Indications of potential river response up and downstream of the 'braided' zone.

3 Sub-catchment geomorphic audit

3.1 General description

The fluvial River Trent drains a catchment of 8228km^2 and is made up of a number of large subcatchments including the River Sow, River Tame, River Dove, River Derwent, River Soar and River Erewash (Figure 3). The underlying geology is mixed, consisting of Millstone grit, Carboniferous limestone and Sherwood sandstone and Triassic mudstones overlain in the Trent valley by extensive floodplain alluvium. The catchment is presently highly urbanised containing much of the connurbations of Birmingham, Nottingham, Derby, Leicester and Stoke.

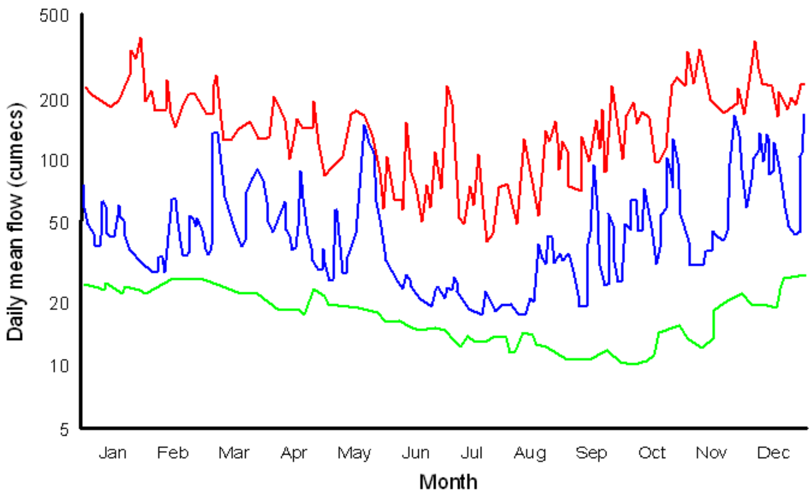
Figure 3 Map of the Trent catchment showing the location of Croxall Lakes.



3.2 Influences on the confluence of the River Tame with the River Trent

Upstream of the Trent-Tame confluence the system is quite complex, with the upper Trent and Sow systems draining relatively steep narrow valleys that are cut into permeable limestone before flowing over a wider lower gradient floodplain of relatively impermeable loamy soils. The wide valley of the River Tame is dominated by an impermeable mudstone-floodplain alluvium sequence and loamy soils, resulting in a relatively low gradient river system. Flood response time is moderated in the steeper limestone catchments by the permeable nature of the bedrock, however the lower gradient reaches of the Trent and Tame are relatively impermeable and respond quite quickly to precipitation (The flood response time of the River Tame is approximately 11 hours). Aside from Blithfield reservoir there are no significant flow storage areas and urbanisation in the Tame catchment in particular further reduces flood response time. Low flows in the Tame are strongly influenced by effluent inputs and show a diurnal fluctuation in discharge. As a result of these influences the flow at the confluence of the Trent and Tame (Figure 4) is characterised by variable low flows (20-40m^3s^{-1}) interspersed by flood flows that rapidly rise to peaks approaching 500m^3s^{-1} (greater than would be expected for an unmodified catchment). The modified channel was modelled using summer base flows of 20m^3s^{-1}, median flows of 50m^3s^{-1} and estimated bankfull flow of 130m^3s^{-1}.

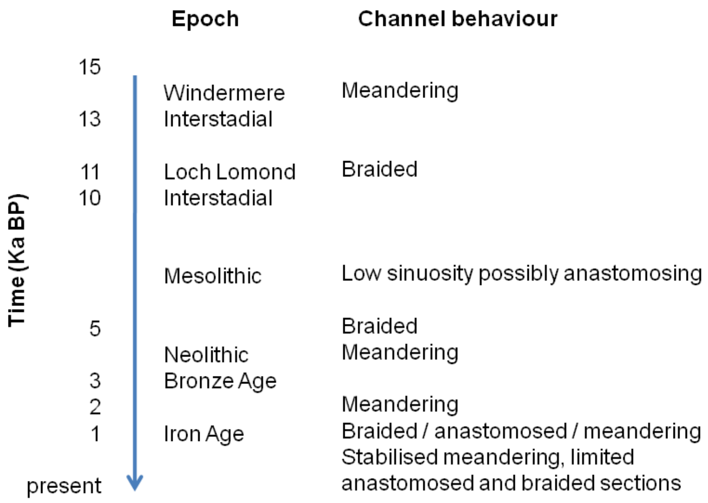
Figure 4 Mean daily average flows for the River Trent at Shardlow (red -max, blue - mean, green -minimum).



3.3 Historic channel behaviour

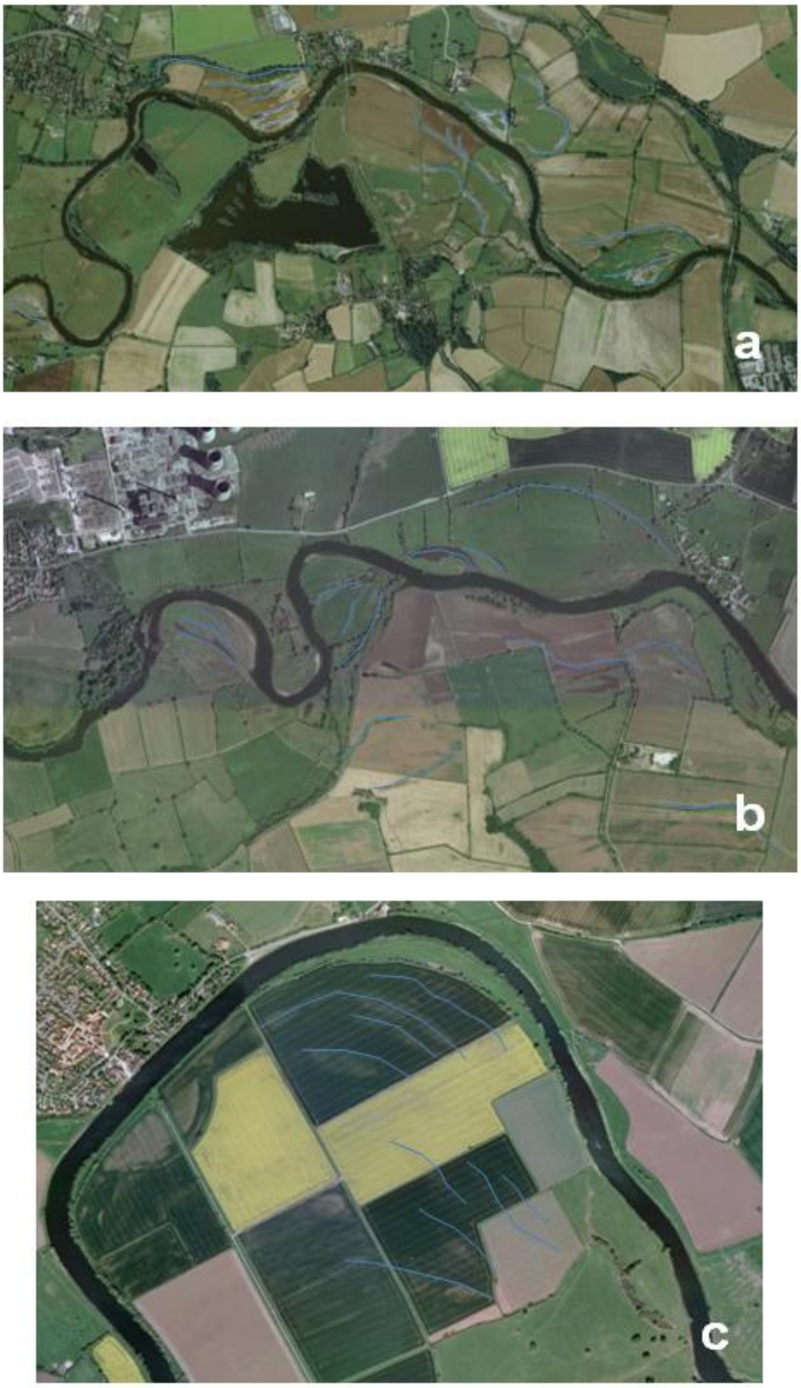
Previous studies of the behaviour of the River Trent reveal a complex set of responses to changes in climatic and catchment drivers since the Holocene (12ka BP) with the channel exhibiting periods of braiding and more stable anastomosing behaviour as well as the more familiar single thread meandering (Figure 5). There is also ample evidence to suggest that the anastomosing channel behaviour was strongly linked to forested floodplain conditions. General stability is suggested for the period following the enclosures in England (14th – 16th Century onwards).

Figure 5 Channel change on the River Trent since the last Ice Age (12ka).



Analysis of web based imagery of the River Trent reveals widespread palaeo-channel preservation across the floodplain indicating considerable pre-historic movement of the river with channels in various states of preservation suggesting that lateral movement was once common across the floodplain before engineering works effectively constrained the river to its present course (Figure 6).

Figure 6 Example floodplain palaeo-features along the River Trent.



Gravel shoaling and island development has also been recorded on the main river most notably in the 1700s, again river training works in the recent past has reduced lateral activity and bar / island development.

3.4 Contemporary channel behaviour

Published studies of the River Trent and the River Tame indicate that both presently display no gross instability, flowing along a quasi-fixed course. Islands have reduced in their occurrence from 13 in the mid 19th Century to 4 at present and shoaling is much reduced. Connectivity with the floodplain has been lowered through channel dredging and flood embanking disrupting the hydrological regime and affecting the geomorphological and ecological dynamics of floodplain palaeochannels.

A review of web based aerial imagery indicates that coarse sediment movement along the channels is occuring, with evidence of present day shoaling and bar development along several reaches and associated with channel widening at weirs (Figure 7). Islands remain confined to a few locations close to tributary junctions and these are stable and of considerable age with no evidence of embrionic island development along the watercourse.

Figure 7 Example contemporary sediment accumulations along the River Trent.

Channel splitting remains relatively common along the rivers linked to natural and engineered sections (Figure 8). However, evidence of braiding is completely absent from the main channel along the lower Tame and Middle Trent and may reflect the relative lateral inactivity of the present channel, delivering only a very reduced supply of reworked floodplain gravels to the river for periodic flood driven transport and low flow deposition as gravel bars.

Figure 8 Anastomosing of the River Trent north west of Newark on Trent.

3.5 The geodynamics of the Trent – Tame confluence

The River Tame joins the River Trent close to Croxall Lakes Nature Reserve, both rivers are quite diverse in this vicinity (Figure 9) displaying floodplain palaeo-channel features (Figure 9a), a number of islands (Figure 9b) and anastomosing channels (Figure 9c). Despite this diversity there are few in-channel features along much of the length of both watercourses.

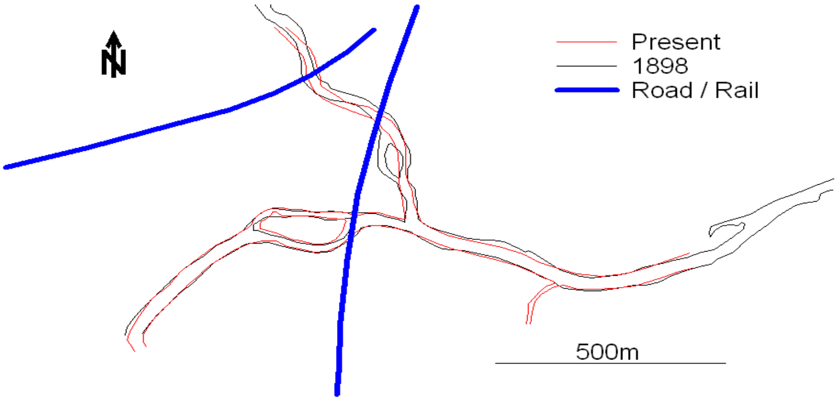
Figure 9 Palaeo-channel activity and in-channel island development close to Croxall Lakes.

Notably a large stable vegetated island has formed just upstream of the confluence of the River Tame with the River Trent and incipient gravel shoaling is evident at the confluence (Figure 10). This would indicate gravel movement through the reach both in the past and more recently. The banks of both rivers appear stable and vegetated.

Figure 10 Detail of the river channel at the confluence of the River Tame and the River Trent at Croxall Lakes.

Comparison of the 1898 and present 1:10,000 Ordnance Survey maps of the confluence indicate that there has been only very minor planform change on the River Trent and that a small island has been lost. This is likely to have been due to engineering rather than natural river rationalisation. The large island feature was present in much the same form as it exists today with no further downstream extension or lateral bank destabilisation (Figure 11).

Figure 11 Historic channel movement in the vicinity of Croxall Lakes.



3.6 Summary

- The upper Trent and middle Tame have a propensity to alter their form and behaviour in response to climate and anthropogenic influences.

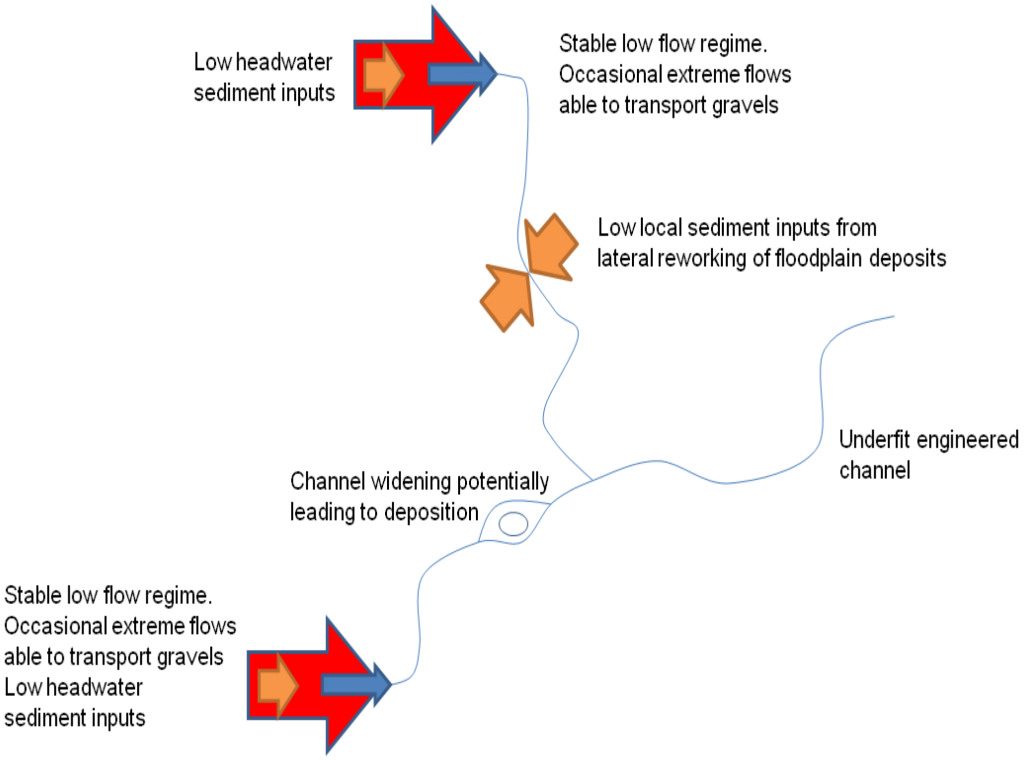
- Gravel shoaling and island development were more significant in the historic past that at present.
- The current river exhibits a stable sinuous single-thread with little evidence of braiding although gravel shoaling is apparent indicating some active gravel movement.
- Extensive lateral migration and floodplain gravel reworking is apparent from palaeo-channel evidence, this is presently severely restricted due to bank protection.
- The flow regime of the Tame and Trent are characterised by an tendency for more extreme events compared to other temperate river systems across England.
- Channel widening and / or a reduction in local flow energy encourages deposition of material in transport.

4 Development of a dynamic channel response model and implications for 'braid' development at Croxall Lakes.

4.1 A general model of river function in the vicinity of Croxall Lakes

The present behaviour of the rivers Trent and Tame close to Croxall Lakes is controlled by an essentially stable flow regime punctuated by occasional more extreme flows. The majority of flows are unable to affect system stability delivering only minor amounts of gravel from headwater sources and releasing limited material through floodplain reworking due to extensive bank training structures. Deposition of sediment has occurred where the watercourses widen or where flow energy is reduced locally, however, the level of deposition is not sufficient to cause the channel to switch from a single thread system with islands to a multi-thread braided channel. The rivers are currently supply limited and have overdeepened in response to an inability to migrate laterally creating a rather monotonous morphologically uniform channel. Evidence of contemporary transport exists in the form of embryonic gravel shoals along sections of the River Trent downstream (Figure 12).

Figure 12 A model of system controls and functioning at Croxall Lakes.

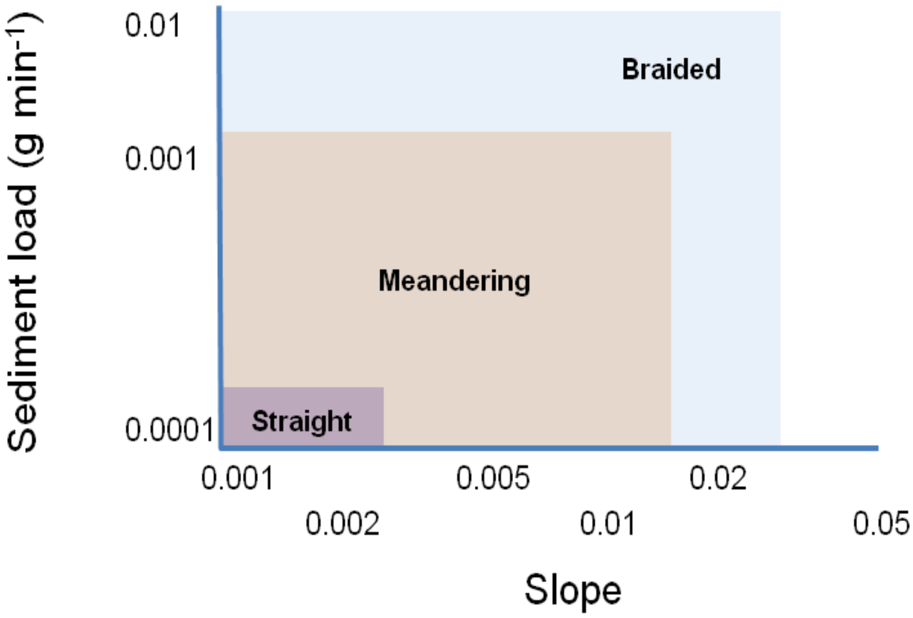


It is proposed that the right bank floodplain in the vicinity of the Tame Trent confluence be widened by up to 100m along the 450m between the railway line and the River Mease. Removal of alluvuium down to the level of the present river gravels will involve the translocation of around 45,000m^3 of material retaining isolated trees as islands and installing large woody debris across the newly exposed river bed (Figure 13).

Figure 13 Location of floodplain excavation works on the River Trent at Croxall Lakes.

Although the River Trent has braided during prehistoric times it is clear from the geomorphic audit that the both the River Tame and the River Trent do not presently display any propensity to braid. Channel widening and flow energy reduction has resulted in island development in the recent past rather than braiding. The exposure of a large area of unconsolidated river gravels to fluvial action will result in sediment reworking across the excavated surface. Flood flows will rationalise the gravels creating bar and shoal features in low energy areas and cutting chute channels in between. The long term sustainability of the system is questionable, however, as braided channels are characterised by steep channel slopes and high sediment inputs (Figure 14). This section of river has a low slope and limited active coarse sediment supply. This contrasts with the effect of agricultural activity which is introducing fine sediment diffusely along the river. As such the widened section is likely to develop a series of stable vegetated bar features, encouraged by fine sediment deposition, which over time may amalgamate through the periodic trapping of flood derived transported material.

Figure 14 River type and sediment load / channel gradient controls.

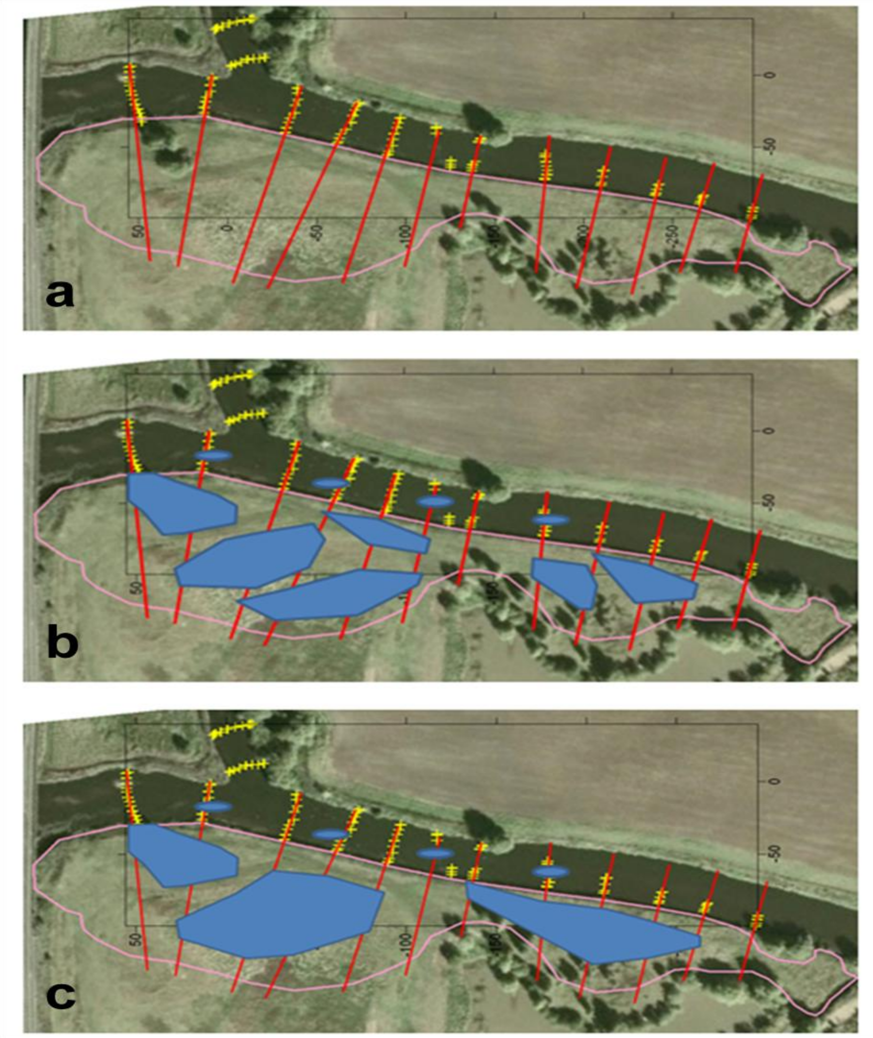


4.2 Segmented modelling of the river works at Croxall Lakes.

A segmented 1D hydraulic model of the reach between the railway bridge and the confluence of the River Mease was constructed for the purpose of obtaining general values of flow depth and velocity for summer base flows of $20m^3s^{-1}$, median flows of $50m^3s^{-1}$ and bankfull flow of $130m^3s^{-1}$ under the following scenarios:

- Unchanged channel.
- Complete removal of floodplain sediment down to 10cm below summer low flow levels (Figure 15a)
- Construction of several smaller islands across the scraped floodplain area, main channel unmodified (Figure 15b)
- Construction of several smaller islands across the scraped floodplain area, smaller debris / island feature in the main channel (Figure 15b)
- Construction of large islands across the scraped floodplain area, main channel unmodified (Figure 15c)
- Construction of large islands across the scraped floodplain area, smaller debris / island feature in the main channel (Figure 15c)

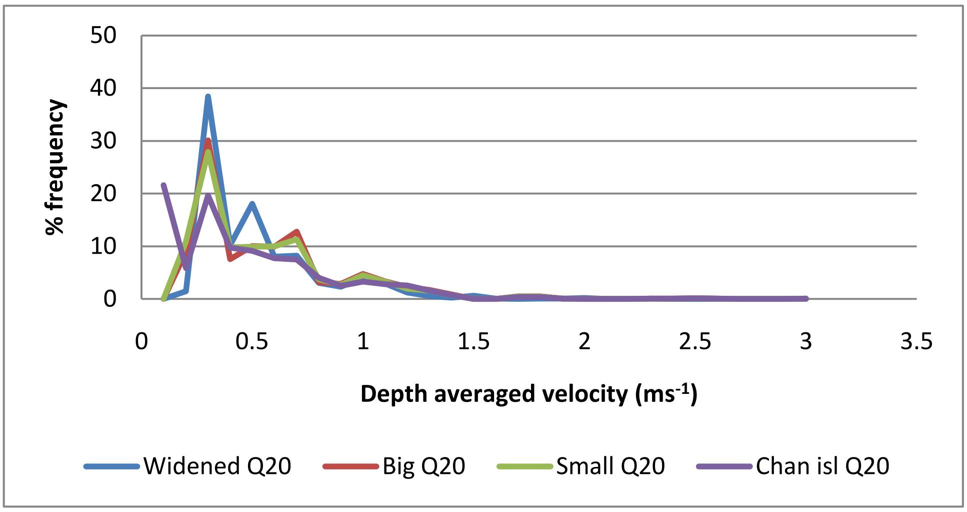
Figure 15 Morphologies evaluated using a 1D segmented hydraulic model.



The basic model was constructed from 2 cross-sections located on the main river Tame and a further 12 sections surveyed on the River Trent (Figure 15). Intermediate sections were interpolated at 10m intervals between survey locations. Cross-sections were modified to simulate the widened channel and island features and main channel obstructions were added to determin their effect on flow velocity and depth. Data from the gauging station on the River Trent at Shardlow were used to determin appropriate summer base flow, median flow and bankfull flow for the site. The resulting hydraulic outputs from the model runs were then utilised to assess the potential for sediment movement through the modified reach.

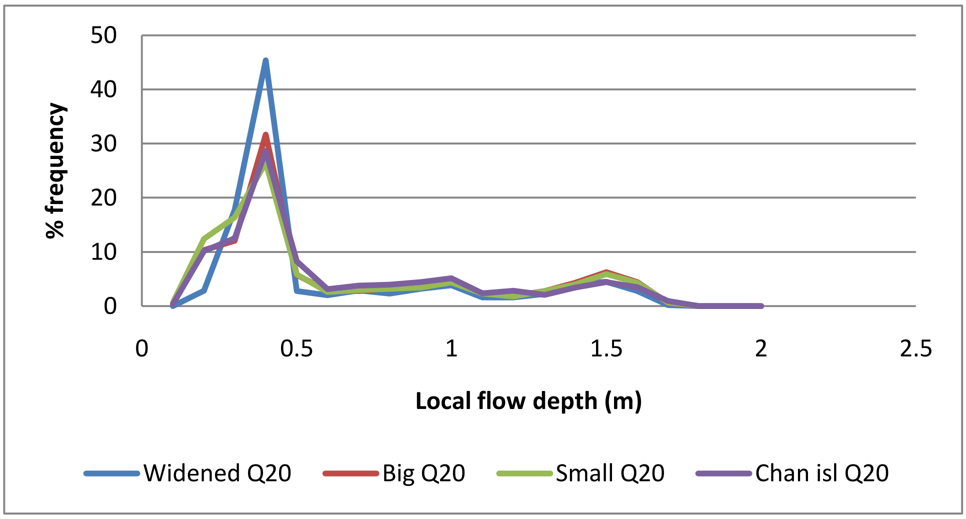
Modelling of the velocity distribution likely during summer low flows (Figure 16) Indicates that a widened channel with no island / bar features will exhibit uniform velocities around 0.4ms^{-1} across the scalped surface with main channel flows largely unaffected. The introduction of large islands reduces the dominance of low flow velocities over the ecalped area introducing heterogeneity and increasing the area of more moderate velocities (between 0.5 and 1.0ms^{-1}). Smaller more frequent islands increased the area of flows between 0.7 and 1.0ms^{-1}, however flows around 0.5ms^{-1} are unaffected. The introduction of additional main channel obstructions locally increases flow velocity and increases heterogeneity for flows exceeding 1.0ms^{-1}.

Figure 16 Effect of channel widening and island formation on summer flow velocities (20m^{3}s^{-1}).



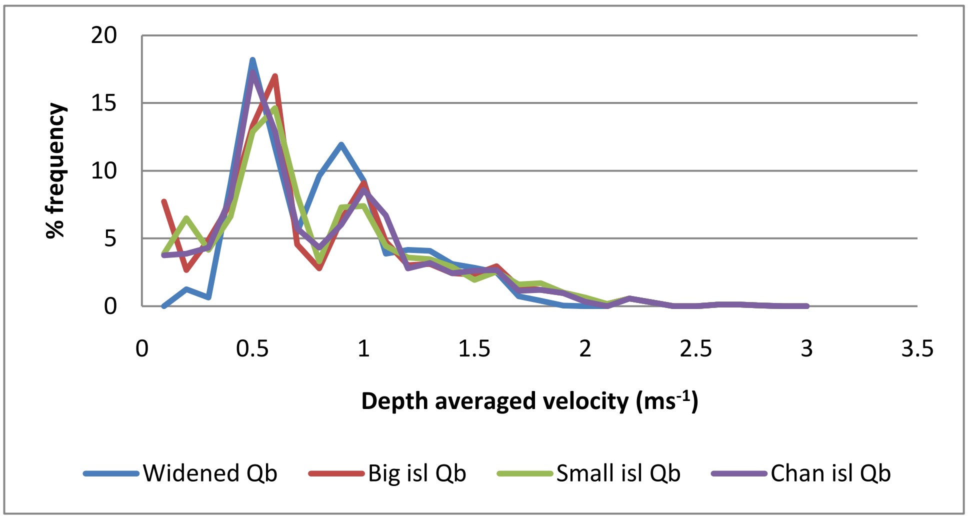
Modelling of the depth distribution likely during summer low flows (Figure 17) Indicates that a widened channel with no island / bar features will exhibit uniform depths around 0.2m across the scalped surface with main channel flow depth largely unaffected. The introduction of large or small islands increases flow depth heterogeneity. The introduction of additional main channel obstructions has little extra affect on flow depths.

Figure 17 Effect of channel widening and island formation on summer local flow depths (20m^{3}s^{-1}).



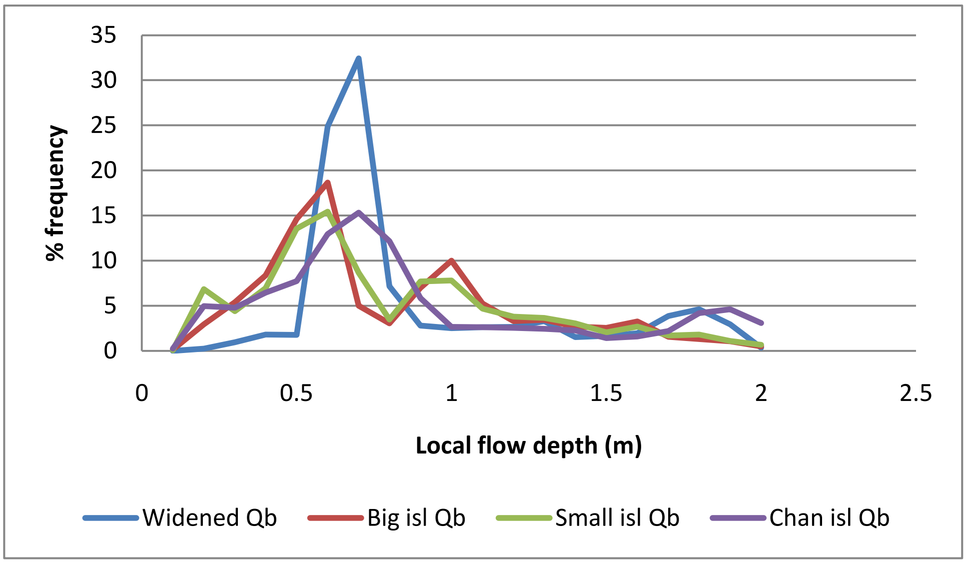
Modelling of the velocity distribution likely under median flow conditions (Figure 18) Indicates that a widened channel with no island / bar features will exhibit uniform velocities around $0.5ms^{-1}$ across the scalped surface with main channel flows largely unaffected. The introduction of large or small islands reduces the dominance of low flow velocities over the ecalped area introducing heterogeneity and increasing the area of more moderate velocities (between 0.7 and $1.1ms^{-1}$). The introduction of additional main channel obstructions locally increases flow velocity and increases heterogeneity for flows exceeding $1.5ms^{-1}$.

Figure 18 Effect of channel widening and island formation on median discharge local flow velocities ($50m^3s^{-1}$).



Modelling of the depth distribution likely during median flow conditions (Figure 19) Indicates that a widened channel with no island / bar features will exhibit uniform depths around 0.6m across the scalped surface with main channel flow depth largely unaffected. The introduction of main channel obstructions, large islands or small islands increases flow depth range and heterogeneity.

Figure 19 Effect of channel widening and island formation on median discharge local flow depths (50m3s-1).



Typical verlocity and flow depth distributions are shown in Figure 20 and

Figure 21 for summer and median flows respectivley. Predicted flow velocities across the widened area are given in

Table 1 including values modelled at the estimated bankfull discharge of 130m^3s^{-1}.

Table 1 Typical velocity values across the scraped surface of the River Trent at Croxall Lakes with and without islands and obstructions.

	Scraped channel	Scraped channel with islands and obstructions
Summer flow	0.2ms^{-1}	0.21ms^{-1}
Median flow	0.32ms^{-1}	0.36ms^{-1}
Bankfull flow	0.44ms^{-1}	0.52ms^{-1}

Figure 20 Summer discharge (20m^{3}s^{-1}) velocity profiles for the widened River Trent at Croxall Lakes with and without islands and obstructions.

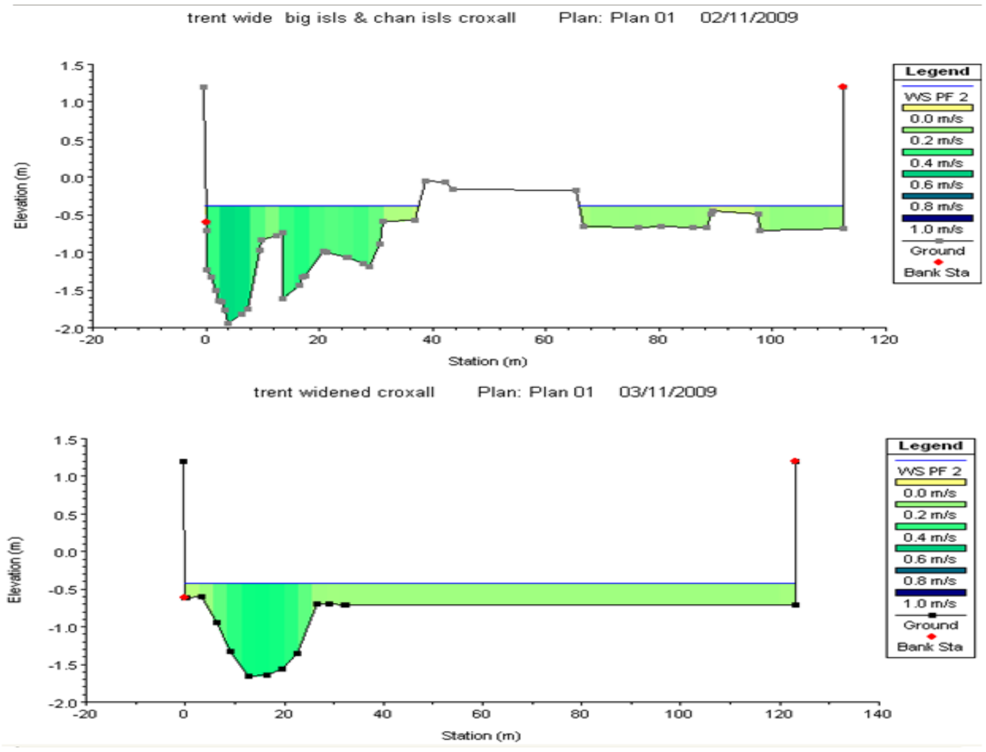
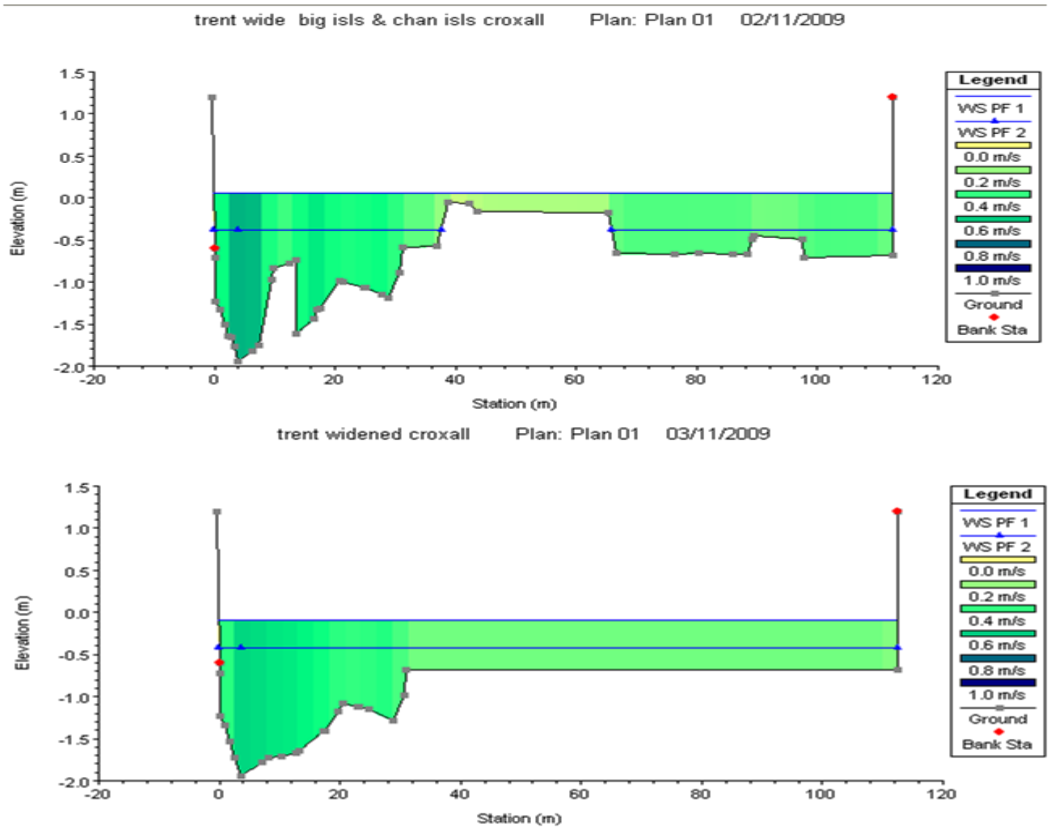


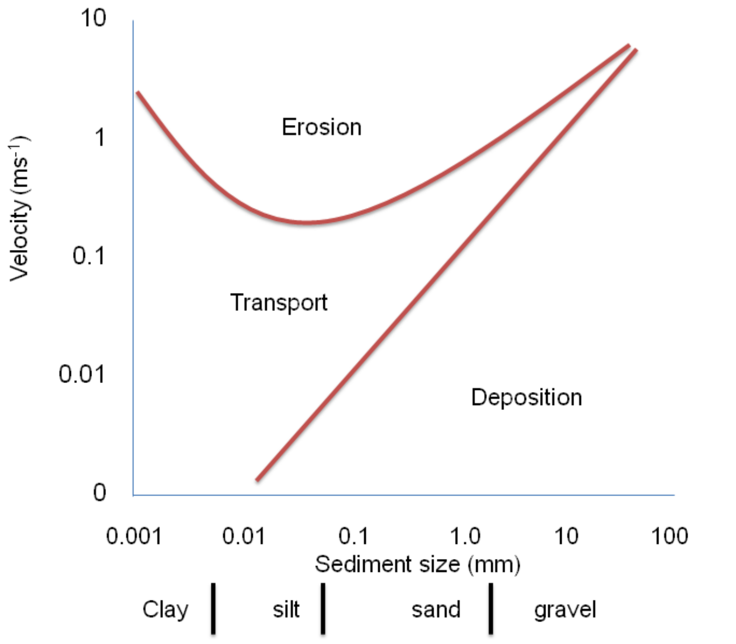
Figure 21 Median discharge (50m^{3}s^{-1}) velocity profiles for the widened River Trent at Croxall Lakes with and without islands and obstructions.



The general effect of the proposed work on sediment transport may be assessed by means of the Hjulstrom curve (Figure 22). It is clear that whilst the addition of island features and obstructions increases flow velocity and depth diversity and range it only increases flow energy across the widened area by 5cms^{-1} during median flows and 8cms^{-1} at bankfull flow. However the effect of this increase could be significant. Summer flows of around 20cms^{-1} across the widened surface are capable of transporting coarse sands and below (<2mm), however, such velocities would not erode any cohesive deposits and sediment build up is likely. The increase in velocities at median and bankfull flows to around 40cms-1 allows fine gravels and below to be transported (<4mm) and is capable of erosing silty sands preventing the rapid and wisespread build up of fine material.

This situation is improved by the addition of island features and obstructions with a general decrease in flow velocities over islands and an increase along the intervening channels where flow becomes concentrated. As such islands and obstructions should be constructed to enhance the overall sustainability of the works.

Figure 22 Threshold velocity values for sediment erosion and deposition.



4.3 Assessing the likely impact of the morphological enhancement works on sediment dynamics and channel behaviour up and downstream of the 'braided' zone

It is unlikely that the predicted deposition and bar stabilisation will have a significant effect on upstream water surface slopes beyond that already exerted by the island immediately upstream of the confluence. As such the changes imposed on the river at Croxall Lakes will not lead to the development of further depositional zones upstream. Some additional deposition may occur in the vicinity of the current upstream island, however the restricted lateral movement posible at this location is likely to limit this. Disruption to the sediment balance downstream of the works at Croxall is likely and there will be a short term reduction in gravels moving downstream as these are deposited at Croxall. The inability of the river to erode its protected banks is likely to lead to further downcutting of the bed downstream and potential disruption to the development of gravel shoals. In the longer term it is likely that the widened reach at Croxall will attain a dynamic stability with the present flow regime as stabilised bars and islands develop. Once this occurs gravels will again move through the reach to supply the shoals downstream.

4.4 Summary

- The form of the river at Croxall Lakes is controled by a stable low flow regime and occasional flood flows capable of transporting river gravels.
- The river is presently supply limited as regards coarse sediment with limited headwater imnputs and only minor floodplain inputs due to bank training. Fine sediment inputs are diffuse but significant.
- The widened reach at Croxall Lakes is characterised by a low to moderate gradient, low coarse sediment supply and constant fine sediment inputs.

- Sediment rationalisation, bar deposition, stabilisation and vegetative colonisation will occur in the widened reach in preference to wholesale braiding.
- The present island upstream of the confluence is unlikely to alter significantly due to the alteration at Croxall as the sediment erosion / deposition system is already in balance and cannot alter significantly due to a stabilised planform.
- Disruption to the sediment dynamics and gravel shoals downstream of Croxall Lakes is likely to be short term and should be restored following stabilisation of the morphology along the widened channel.
- The segmented 1D hydraulic modelling has revealed that a uniform widened channel surface would be prone to sedimentation during summer flows and that this material will be resistant to erosion during higher winter flows where this becomes consolidated. As such there is a likelyhood that there will be a directional change in the geomorphology with sediment continually building up across the widened area.
- The construction of islands and obstructions across the widened surface and in the main channel will concentrate the hydraulic energy in the reach to levels that will permit transport of material up to fine gravel size and should cause some local scour of consolidated fine sediment where flow velocities are maximised. The generally low gradient of the reach and shallow flows do not guarantee this however, and performance will be highly dependent on flood flow frequency and unchanged fine sediment input levels from upstream.
- The outputs from the segmented 1D model are generalised and the reported values may be in error. This is significant given that the current design is subject to continuous diffuse fine sediment inputs and the present energy levels are predicted at the cusp of being unable to remove material of this calibre.
- Despite the failings of the 1D hydraulic model the hydraulic diversity introduced through island and obstruction construction will generate a variety of eroisonal and depositional environments which will increase habitat and biotic diversity.

5 Conclusions

5.1 General behaviour of the River Trent

The River Trent drains a large catchment in UK terms (8228km^2) and is made up of a number of large subcatchments Flood response time is moderated in the steeper limestone catchments by the permeable nature of the bedrock, however the lower gradient reaches of the Trent and Tame are relatively impermeable and respond quite quickly to precipitation. The flow regime of the Tame and Trent are characterised by an tendency for more extreme events compared to other temperate river systems across England.

The upper Trent and middle Tame have a propensity to alter their form and behaviour in response to climate and anthroprogenic influences. The current river exhibits a stable sinuous single-thread with little evidence of braiding although gravel shoaling is apparent indicating some active gravel movement, this activity was more significant in the historic past. This is also the case with lateral migration and floodplain gravel reworking which is apparent from palaeo-channel evidence but is presently severely restricted due to bank protection.

5.2 Likely response of the River Trent to the proposed widening at Croxall Lakes

The form of the river at Croxall Lakes is controled by a stable low flow regime and occasional flood flows capable of transporting river gravels and channel widening and / or a reduction in local flow energy will encourage deposition of material in transport particularly as the reach has a low to moderate gradient and constant fine sediment inputs. The segmented 1D hydraulic modelling has revealed that a uniform widened channel surface would be prone to sedimentation during summer flows and that this material will be resistant to erosion during higher winter flows where this becomes consolidated. As such there is a likelyhood that there will be a directional change in the geomorphology with sediment continually building up across the widened area. The construction of islands and obstructions across the widened surface and in the main channel will concentrate the hydraulic energy in the reach to levels that will permit transport of material up to fine gravel size and should cause some local scour of consolidated fine sediment where flow velocities are maximised. The generally low gradient of the reach and shallow flows do not guarantee this however, and performance will be highly dependent on flood flow frequency and unchanged fine sediment input levels from upstream. The hydraulic diversity introduced through island and obstruction construction will, however, generate a variety of eroisonal and depositional environments which will increase habitat and biotic diversity.

The present island upstream of the confluence is unlikely to alter significantly due to the alteration at Croxall as the sediment erosion / deposition system is already in balance and cannot alter significantly due to a stabilised planform. Similarly disruption to the sediment dynamics and gravel shoals downstream of Croxall Lakes is likely to be short term and should be restored following stabilisation of the morphology along the widened channel.

5.3 Options to mitigate against widespread sedimentation at Croxall Lakes

The predicted response of the River Tame to the proposed channel widening are based on qualitative evaluation and generalised flow modelling. A such they only give an indication of likely channel response to the energy distribution within the system. However, it appears very likely that widespread fine sediment accumulation will occur in preference to the development of a self sustaining system of stable islands. The present design requires refinement to prevent this happening and the development of a 2D hydraulic model would add considerable detail and confidence to the prediction of channel development. The model outputs could be used to modify the scheme design and additionally to predict hydraulic habitat distribution and change, demonstrating the likely environmental and ecological benefits of the works in line with Water Framework Directive objectives.