2 Restoration of channel/floodplain features

2.1 Background

The river basins of the New Forest are drained by a complex network of rivers, streams and drains. Since the 1870's, well over half the total length of main streams and first order tributaries have been modified to some extent by drainage schemes to improve areas for forestry or grazing. For example, studies undertaken by Southampton University during the Life 3 project found that 78% of surveyed channel in the Black Water and 44% along the Highland Water have been modified in the past. Even so, the rivers and stream still represent an excellent example of a relatively undisturbed lowland river system.

Channel and floodplain form is a result of the processes of erosion, deposition and sediment transport over time. The processes are naturally constrained by the geology and topography of the catchment and the way in which the river responds to changes in climate and hydrology. The natural form of many New Forest streams is a sinuous meandering channel of variable width and depth that is laterally, relatively stable and contains pools, riffles and debris dams. However, a number of streams throughout the New Forest catchments have been modified by straightening, deepening and removal of debris dams which changes the natural balance and dynamics of geo-morphological features due to increased energy generated in a canalised system.

The gradient, channel width and depth all influence the energy and erosive and depositional power of a river or stream. The gradient of most of the New Forest streams is relatively low ranging from 1% - 0.6%. The majority of channels are less than 5m wide with shallow flows. Channels wider than 7m and more than 1m deep are limited to the lowest reaches of the Lymington & Beaulieu rivers. The streams with the steepest gradients are generally the Hampshire Avon tributaries which drain down from the highest areas of the Forest.


Example of a straightened stream section

Natural debris dams can have a significant influence on channel width resulting in a greater variation in widths than might be found on a non-forested stream.

Distinct areas of floodplain border the natural channels of the Forest streams and display a typical range of floodplain features such as:

- ephemeral channels - (sinuous, linear scour features around 50cm wide and 5-50cm deep)
- pools and hollows
- wake deposits - material deposited behind obstacles such as trees, tussocks and woody debris
  abandoned channels – old river channels left in one part of the floodplain when the river moved laterally elsewhere

- woody debris, trees & vegetation
- shallow man made drainage channels in streamside lawns and woodlands

Even where the channels have been over deepened and flooding is less frequent remnant features can often be discerned.

The New Forest streams are fed by a combination of mires, bogs and surface water run-off and through flow. Many of the streams typically have a mean daily flow rate of less than 0.5 m3s-1 during dry weather (Langford, 1996) and flows can be considerable lower during periods of summer drought. Typical hydrographs for flows measured at the gauging stations on the Dockens Water and the Lymington River are shown in Figure 2.1 which give values for two contrasting streams. The rivers and streams are characterised by their flashy nature and can rise rapidly in response to heavy or prolonged rainfall. The influence of river restoration on flood flows is discussed further in Chapter 3. Flood peaks tend to pass through quickly and during out of bank events although the total magnitude of the flow cannot always be recorded. During the summer months those streams fed by well developed seepage steps or mires continue to flow although at a much reduced level with only a few centimetres depth of water. However, a number of streams, particularly the Hampshire Avon Tributaries are seasonally dry or reduced to a series of small pools separated by dry gravel bars or small trickles under the surface gravel. Often only the deeper pools scoured out behind debris dams or on the inside of meanders contain any water.

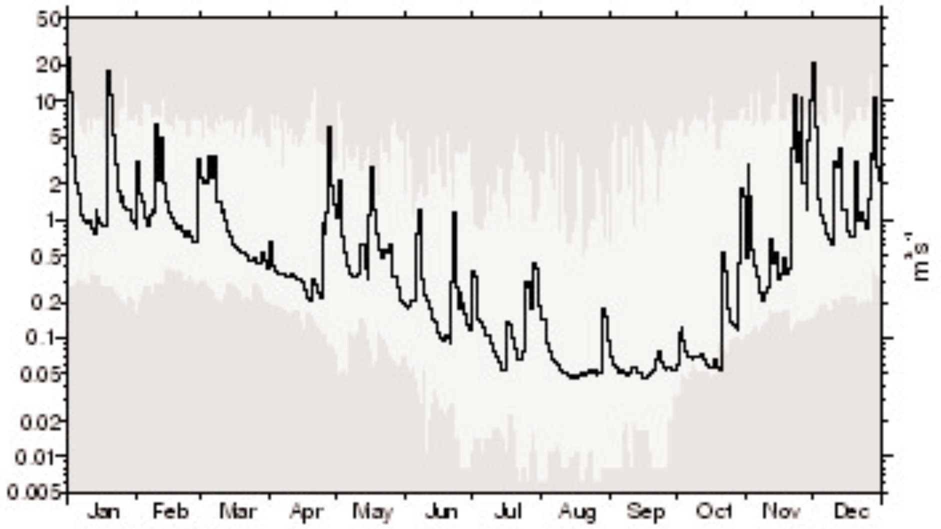
Flow patterns are characterised by glides (slow flowing water), riffles (medium flowing water) and runs (fast flowing water). Life 3 studies in the Blackwater and Highland Water sub-catchments found that glides tend be to the most common form of flow followed by riffles and runs (refer to Figure 2.2.). Pools (still water) are noticeably rare in modified reaches being replaced by glides or runs. Pools where they occur are usually found at meander bends apices. Cascades and small water falls also occur at the faces of debris dams. Canalisation tends to affect the flow type in that it reduces the number of pools.

Bank material is made up of clay, fines, sand and gravel. The banks tend to be dominated by cohesive, fine-grained material incorporating gravel as individual clasts or as a layer of basal gravels. Where the bed of the river has been lowered either artificially or as a result of incision, the underlying valley gravels have sometimes been exposed, but the overlying layer of fines is nearly always present and often covers more than half the bank face. Where no bed level changes have occurred, the banks are usually composed of more than 75% fines. The typical composition of bed material making up the banks of the Highland Water and Black Water is shown in Figure 2.3.

Figure 2.1: Annual Average Monthly Flow Hydrographs

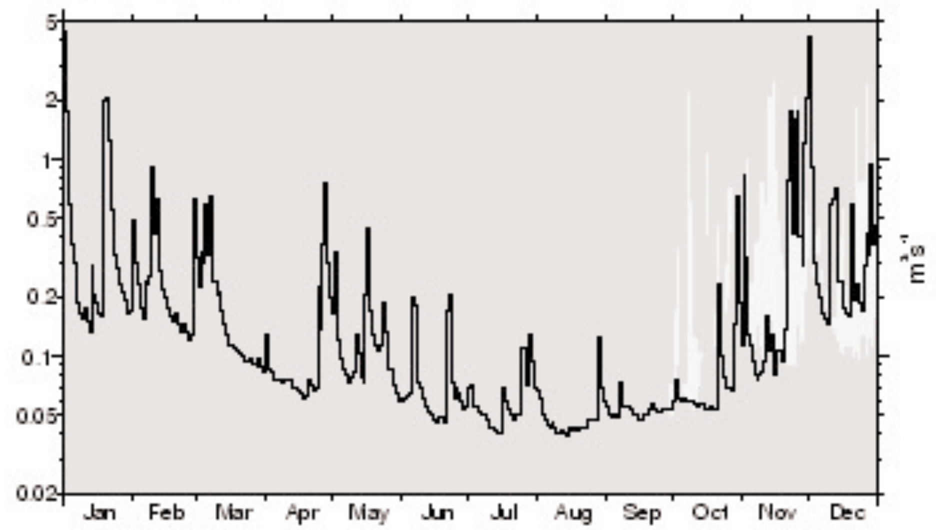
a) Lymington River – Brockenhurst

Max. and min. daily mean flows from 1960 to 2003 excluding those for the featured year (2003; mean flow: 1.09 m^3s^{-1})



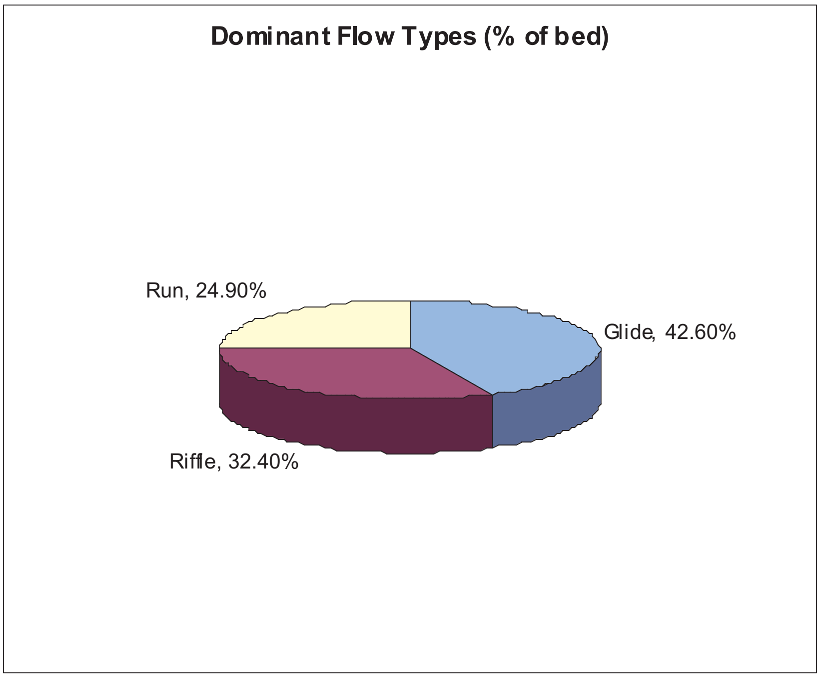
b) Dockens Water – Moyles Court

Max. and min. daily mean flows from 2001 to 2003 excluding those for the featured year (2003; mean flow: 0.22 m^3s^{-1})



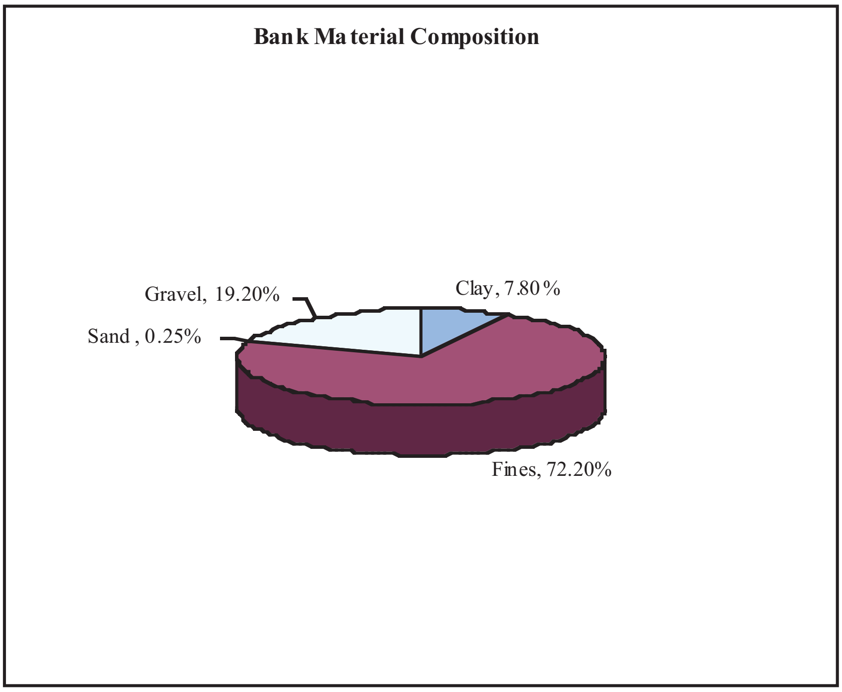
Source: Centre of Ecology & Hydrology

Figure 2.2: Flow types



Source: Geodata Institute

Figure 2.3 Bank Material Composition



Source: Geodata Institute

Life 3 studies found that coarse gravel forms the majority of bed substrate (around 75%) intermingled with fine gravel (24%) in a lesser amount. Despite sands and clays being a dominant feature of the local geology, fines (<1%) are virtually negligible indicating that few low energy areas occur within the main channel. It is also possible that the fine sediment load is transported to the lower reaches of the rivers where conditions are more favourable for deposition or washed out onto the floodplain during flood events.

Southampton University's monitoring work on sediment transport in the Highland Water catchment suggests that:

- Bed load transport is dominated by fine gravels and coarse sand
- Critical discharge for the onset of bed load motion is in the order of 0.25 m3s-1 or 35% of bank full discharge.
- The majority of bed load is derived from upstream bars and pools
- Riffles typically have stable gravel surfaces over which finer bed load is transported.
- Bed load transport rates are poorly correlated with discharge owing to supply exhaustion and the unsteady nature of the transport process Bed load yields in semi natural reaches are low in comparison with other UK rivers due to the relatively low gradient, stable banks and relatively low stream power available for transport.

However, comparison between a channelised and semi-natural reach of the Highland Water showed a 5 to 7-fold increase in bedload yield in the channelised reach for a range of flood events. This is thought to be due to:

- Greater confinement of higher flows within the channelised section (3.5 cumecs compared to 2.2 cumecs in the semi-natural reach)
- Increased slope due to lack of meanders
- Greater stream power for sediment transport due to higher width:depth ratios

Suspended sediment transport is characterised by the rapid rise and exhaustion of fine silts and clays with concentrations reaching around 1700 mgl-1 during high magnitude events. Flood yields may reach 176 tonnes though the typical flood yield is around 5-20 tonnes. Over bank sedimentation is highly variable and depends on a number of factors including the presence of debris dams and exit pathways onto the floodplain. Once on the floodplain, deposition rates are strongly influenced by vegetation patterns and micro topography of the floodplain surface. Floodplain deposits are dominated by fine silts with high organic matter content.

A natural feature found along New Forest streams is debris dams. Debris dams are important features along the Forest streams, particularly in wooded catchments where large woody debris occurs on the floodplain. Debris dams are generally made up of naturally fallen woody debris and/or cut logs from forestry operations. Debris dams have a number of different forms as highlighted in Table 2-1. Debris dams are of significance because they:

- Influence the morphology of the channel including the pool-riffle sequence, roughness of the channel, bank stability and locations of sediment deposition. This variation in stream morphology is important in maintaining the diversity of aquatic life characteristic of New Forest streams.
- Act as sediment and gravel traps
- Promote over bank flow in localised areas to the benefit of floodplain habitats Hold back and thus slow up the rate of downstream flow particularly during peak discharges. The rate of water attenuation can be significant in the Forest streams given their flashy nature. For example, it

was found that over a distance of 4028m the presence of 93 dams delayed the progress of small flood peaks by 100 minutes and large flood peaks by 10 minutes (Gregory et al, 1985)

- Provides food for invertebrates and shelter for fish

Table 2-1 : Debris Dam Forms

Classification	Form	Hydraulic Influence
High Water Dam	Tree fallen across channel	Minor hydraulic influence during over bank flow
Partial Dam	Small accumulation of debris that partly spans the channel	Slightly disrupts flow hydraulics and usually reduced cross-sectional area
Complete Dam	Debris accumulation spans the channel	Affects hydraulics but does not pond water
Active Dam	Accumulation that spans the channel	Ponds Water
Other	Compiled from non-woody debris e.g. clay plug	Variable

Source: Geodata 2003

The New Forest streams have been undergoing modification since the 1870's (possibly even as early as the 1840's) with further large scale modifications through the 1950's-70's which have resulted in canalisation of many of the channels and associated loss of meanders leading to:

- Over deepening and over widening of the river channels resulting in increased energy and erosive power in the flow system which leads to changes to natural in channel morphology and width/depth ratio.

- Loss of meanders and overall reduction in stream length causes water to run through the shortened channel section more rapidly. In addition, over deepening and bank-side spoil reduces the opportunity for out of bank flow and flooding of the floodplain.

- Prevention of natural flooding means that more energy is concentrated within the river channel itself resulting in increased erosion and transport of gravel. These gravels are deposited further downstream where the channel gradient reduces. This can result in the reduction of the channel capacity downstream, which in turn may cause drainage problems elsewhere.

- As the river tries to adapt to its new lowered stream bed level it creates headward erosion, often into the valley mires.

A key purpose of HLS funded river restoration projects has been to reverse these effects and restore a natural functioning river system.

2.2 Restoration Objectives

River restoration is seeking to restore:

- Natural width/depth ratios through bed level raising and restoration of natural channels to reduce the energy in the channel and promote re-connection with floodplain during times of flood flow

- Restoring meanders to slow the flow and increase the channel length

- Flow conditions which promote a more diverse substrate and in-channel morphology which in turn creates habitat niches for macrophytes, macro-invertebrates and fish.

2.3 HLS Monitoring Sites

In order to monitor the geomorphological status of New Forest streams pre and post restoration a series of MoRPh surveys have been conducted. The Modular River Physical or MoRPh survey was originally developed for Citizen Scientists to support the Catchment Based Approach and river stewardship for Catchment Partnerships. It is now being used more widely for river assessment and monitoring

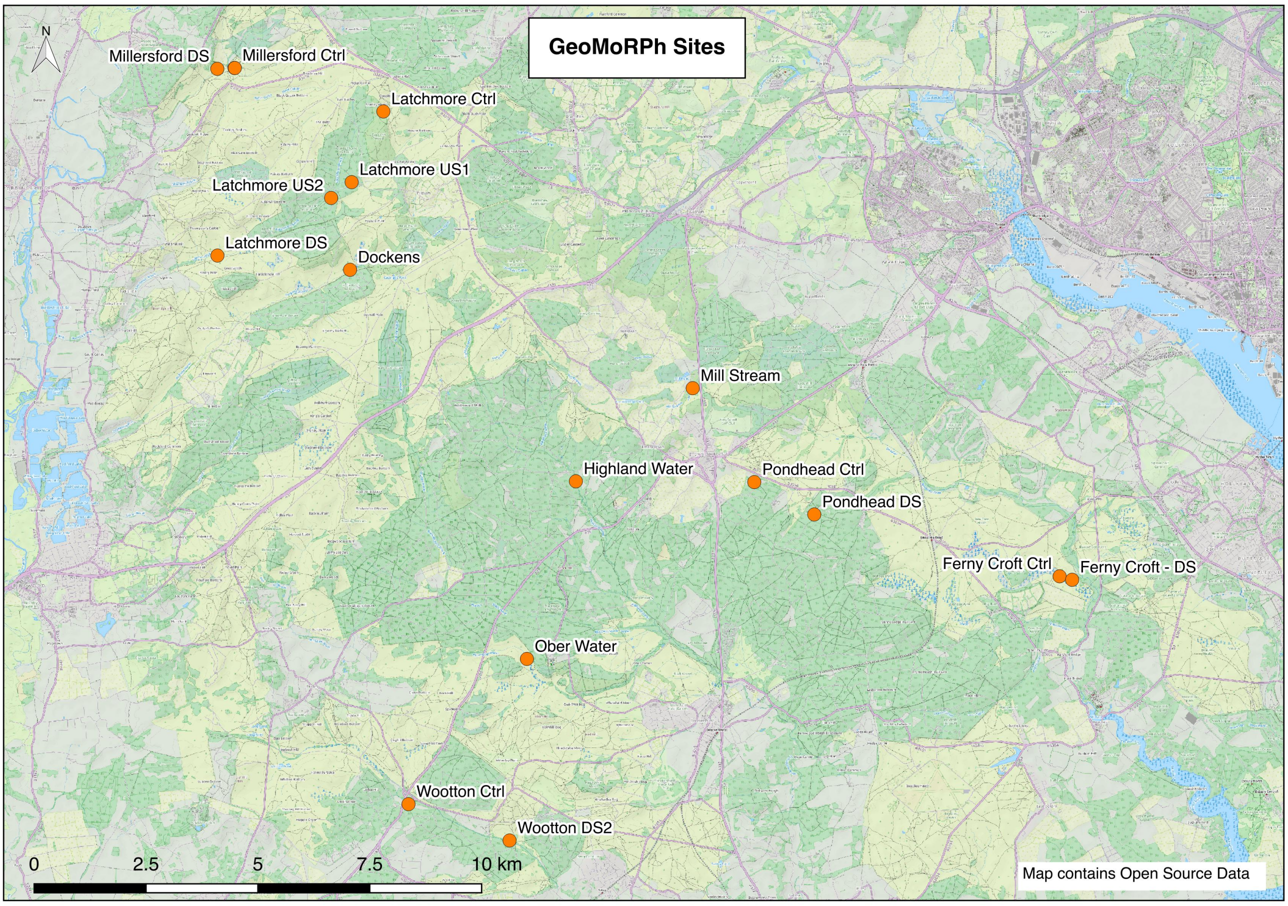
The MoRPh survey is one part of the Modular River Survey suite of scaled assessment techniques that have been designed to promote understanding of the way rivers function across a hierarchy of spatial scales within river catchments. The MoRPh module survey is designed to characterise the river channel, banks (or generally steeper areas next to the active channel) and immediate bank tops (adjacent flatter areas) to 10 m from the bank top edge. A 10m distance from the bank top edge is chosen to enclose features (particularly vegetation) on the bank top that may provide habitat for river organisms or may act as a pressure on the river ecosystem. To capture the locations, spacing, and geographical arrangement of these geomorphic features in sufficient detail to make hydrogeomorphologically robust interpretations, at least 10 contiguous MoRPh physical habitat surveys are needed to support a full MultiMoRPh or sub-reach assessment.

The HLS MoRPh surveys have been carried out at 18 sites by the HLS Monitoring Officers as shown in Table 2-2 and Figure 2.4. Ten transects/adjacent modules have been conducted at each site (MoRPh 10 Surveys). From the data recorded at each transect, fourteen high-level morphological indices have been generated to monitor the geomorphological baseline and changes resulting from river restoration. These indices record channel characteristics, bank/riparian zone characteristics and human influences.

Table 2-2: MoRPh Survey Sites

Site	Section	Grid Reference (M1)	Habitat Type	Habitat Condition	Survey Year	Survey Type
Ferny Croft	Control	SU3774405555	Transitional Mire	good	2019	Control
Ferny Croft	Downstream	SU3798505390	Transitional Mire	degraded	2017	Pre_Restoration
Ferny Croft	Downstream	SU3798205423	Transitional Mire	restored	2018, 2019	Post Restoration
Dockens	Benchmark	SU2198412341	Open Habitat	good	2019	Benchmark
Highlands Water	Benchmark	SU 26987 07625	Woodland Stream	good	2019	Benchmark
Latchmore	Upstream_1	SU2272715941	Woodland Stream	degraded	2019	Pre_Restoration
Latchmore	Control	SU2203714235	Woodland Stream	degraded	2019	Control
Latchmore	Upstream_2	SU2154814036	Woodland Stream	degraded	2019	Pre_Restoration
Latchmore	Downstream	SU1908112649	Open Habitat	degraded	2019	Pre-Restoration
Mill Stream	Benchmark	SU2955909635	Woodland Stream	good	2019	Benchmark
Millersford	Control	SU1942516786	Open Habitat	degraded	2019	Control
Millersford	Downstream	SU1906016850	Open Habitat	degraded	2019	Pre_Restoration
Pondhead	Control	SU3087707665	Woodland Stream	degraded	2019	Control
Ober Water	Benchmark	SU2583303717	Open Habitat	good	2019	Benchmark
Wootton	Control	SU2320400442	Woodland Stream	degraded	2019	Control
Wootton	Downstream_Section_2 (B-C)	SZ2540599599	Woodland Stream	restored	2018, 2019	Post_Restoration
Wootton	Downstream_ section 2 (B-C)	SZ2539799603	Woodland Stream	restored	2017	Pre_Restoration

Figure 2.4 – Map of survey locations



2.4 Methodology

Each reach of river channel forming the survey has been divided into 10 Morph modules/cross-sections and measurements repeated annually, at the same time of year. The data is used to inform the calculation of indices which show how the river is functioning. Many of the indices use an abundance scoring system where:

P = present (5-33%)
E = extensive (>33%)
T= trace (< 5%)

A number of measurements and observations encompassing physical dimensions, materials, vegetation cover/type, geomorphological/fluvial features and anthropogenic factors are taken of the channel, bank face/channel margin and bank top/flood plain (to within 10 m of the bank) in order to calculate the following indices.

Channel characteristics

- INDEX 1: Number of flow types
- INDEX 2: Highest energy extensive flow type
- INDEX 3: Number of bed material types
- INDEX 4: Coarsest extensive bed material particle size
- INDEX 5: Average bed material size (phi units)
- INDEX 6: Average bed material particle size class
- INDEX 7: Extent of bed siltation
- INDEX 8: Channel physical habitat complexity
- INDEX 9: Number of aquatic vegetation morphotypes

Riparian (Bank Face and Bank Top) characteristics

- INDEX 10: Riparian physical habitat complexity
- INDEX 11: Riparian vegetation complexity

Human pressures and impacts

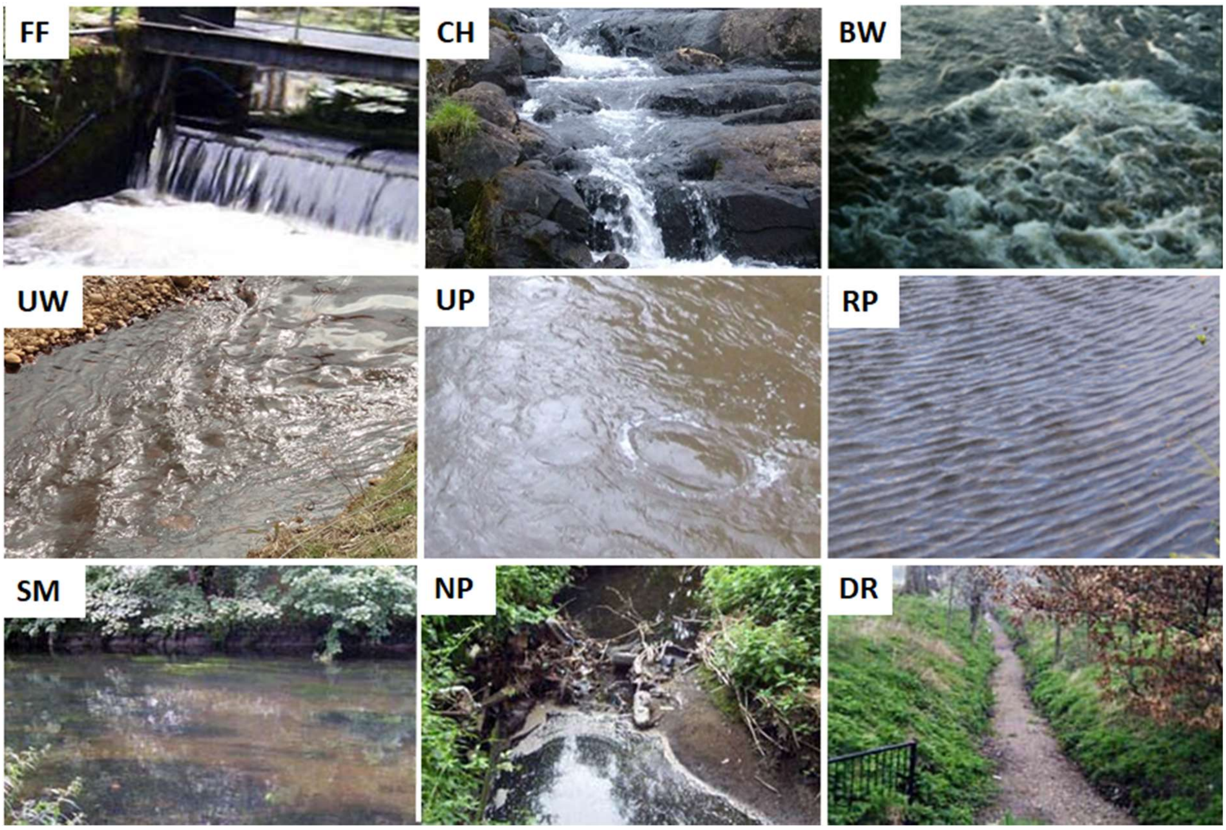
- INDEX 12: Degree of human pressure imposed by land cover on the bank tops
- INDEX 13: Channel reinforcement INDEX 14: Extent of non-native invasive plants

The indices are calculated as follows:

INDEX 1: Number of flow types

The number of flow types (Figure 2.5) that have been recorded as P or E in any of the 10 MoRPhs (maximum possible value is 9)

Figure 2.5: Flow Types



FF – Free fall (near vertical falling water with open air behind the falling water and so no direct contact with river bed,

CH – Chute flow (steep water surface with some air gaps behind the water but mainly water is contact with river bed – there are three chutes in the downstream sequence in the picture) (Source: www.freeimageslive.co.uk free_stock_image watercascade3897jpg).

BW – Broken standing waves (waves on the water surface that occupy a fixed position in the river channel and have a foaming / breaking crest),

UW – Unbroken standing waves (waves on the water surface that occupy a fixed position in the river channel and do not have a foaming / breaking crest),

UP – Upwelling (formed by water rising up to the water surface and then spreading sideways in all directions like the surface of slowly boiling water),

RP – Ripples (small waves on the water surface that are not in fixed locations but move gradually – usually in a downstream direction),

SM – Smooth (near featureless water surface but water clearly moving downstream as witnessed by movements of leaves on the water surface)

NP – no perceptible flow (water not clearly moving – often occurs when water is ponded back by a weir, wood jam, etc.)

DR – dry channel (no water in the channel).

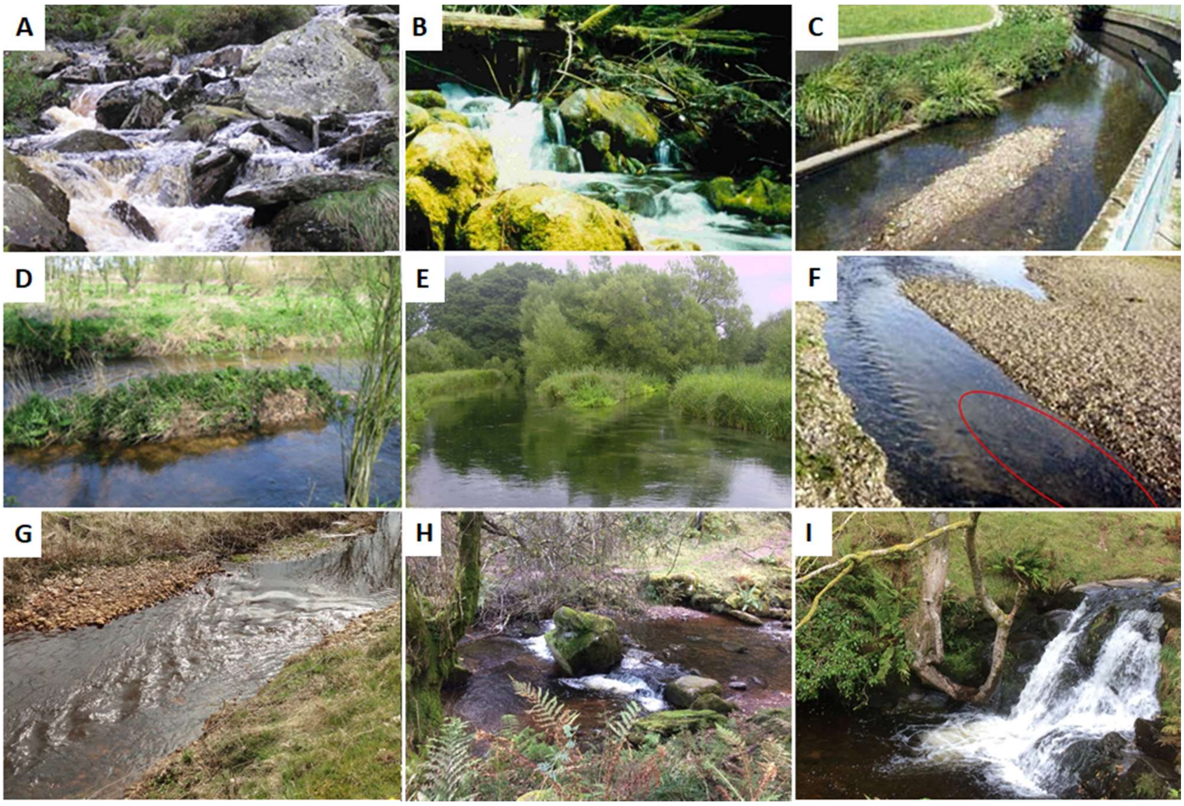
INDEX 2: Highest energy extensive flow type

The highest energy flow type recorded as E (i.e. in the order Freefall > Chute > Broken standing wave > Unbroken standing wave > Upwelling > Chaotic flow > Rippled > Smooth > No perceptible flow > Dry).

INDEX 3: Number of bed material types

NumBedMat: Number of channel bed natural materials sediment types (the number of types that are P or E – potential maximum 9, likely maximum 6). Sediment types are shown in Figure 2.6

Figure 2.6: Sediment Types



A – (i) exposed unvegetated boulders / rocks (i.e. < 50% vegetation cover)
(ii) a cascade (sequence of chutes and broken standing waves),
B – (i) exposed vegetated (i.e. > 50% vegetation/moss cover) boulders / rocks
(ii) a cascade (sequence of chutes and broken standing waves),
C – Unvegetated mid channel bar (i.e. < 50% vegetation cover),
D – Vegetated mid channel bar bank (> 50% vegetation cover). Note rounded shape with an upper surface that is much lower than the level of the channel bank tops),
E – Island (similar to vegetated mid channel bar but note the more tabular shape with a flatter upper surface and steeper sides than a vegetated mid channel bar and an upper surface that is close to the level of the surrounding bank tops),
F – Pool (locally deep area with smooth / rippled water surface),
G – Riffle (area of locally shallow water over a coarse cobble / gravel river bed with (un)broken standing waves),
I – Step (near-vertical mix of chute flow and some free fall less than 2 m high, usually in bedrock/boulder rivers)
H – Waterfall (near-vertical mix of mainly free fall with some chute flow over 2 m high, usually in bedrock/boulder rivers).

INDEX 4: Coarsest extensive bed material particle size

Excluding bedrock, organic and peat, the coarsest bed material recorded as E (i.e. one of the following in the order Boulder > Cobble > Gravel-pebble > Sand > Silt > Clay)

INDEX 5: Average bed material size and INDEX 6: Average bed material particle size class

Use only P and E observations of the following 6 bed material sizes: Boulder, Cobble, Gravel-pebble, Sand, Silt, Clay. For each record the abundance as 1 for P and 4 for E.

Average bed material size = ((-9*Boulder abundance) + (-7*Cobble abundance) + (-1.5*Gravel abundance) + (1.5*Sand abundance) + (6*Silt abundance) + (9*Clay abundance)) / (Boulder abundance + Cobble abundance + Gravel abundance + Sand abundance + Silt abundance + Clay abundance)

The index is expressed in approximate phi units. To aid interpretation, these units translate into approximate particle sizes (Average bed material particle size class) as shown in Table 2.3.

Table 2-3: Particle Sizes

Particle size description	**Minimum value (phi units)**	**Maximum value (phi units)**
Boulder		-8
Cobble	>-8	-6
Gravel-pebble	>-6	-1
Sand	>-1	+4
Silt	>+4	+9
Clay	>+9	

INDEX 7: Extent of bed siltation

Using the following table of abundance scores add the scores for ‘continuous silt layer’ and ‘patchy thin silt layer’ to give an overall indication of the ‘extent of bed siltation’ (maximum possible value is 15) – refer to Table 2-4

Table 2-4: Silt Abundance Scores

Silt Type	**T**	**P**	**E**
Patchy thin silt layer	0.5	2	5
Continuous silt layer	1	4	10

INDEX 8: Channel physical habitat complexity

The index value ranges from 1 (minimal complexity) to 10 (extremely high complexity) and is calculated as a weighted average of 4 sub-indices as follows (round down to nearest integer value):

NumBedMat (i.e. Index 1): Number of channel bed natural materials sediment types that are P or E – likely maximum 6)

NumFlow: Number of water surface flow types that are Present or Extensive - likely maximum is 6)

NumBedFeat: Number of types of natural bed features, subsection 'Channel bed - Natural physical features': score 1 for each that is observed as P or E or count>0 – maximum 10)

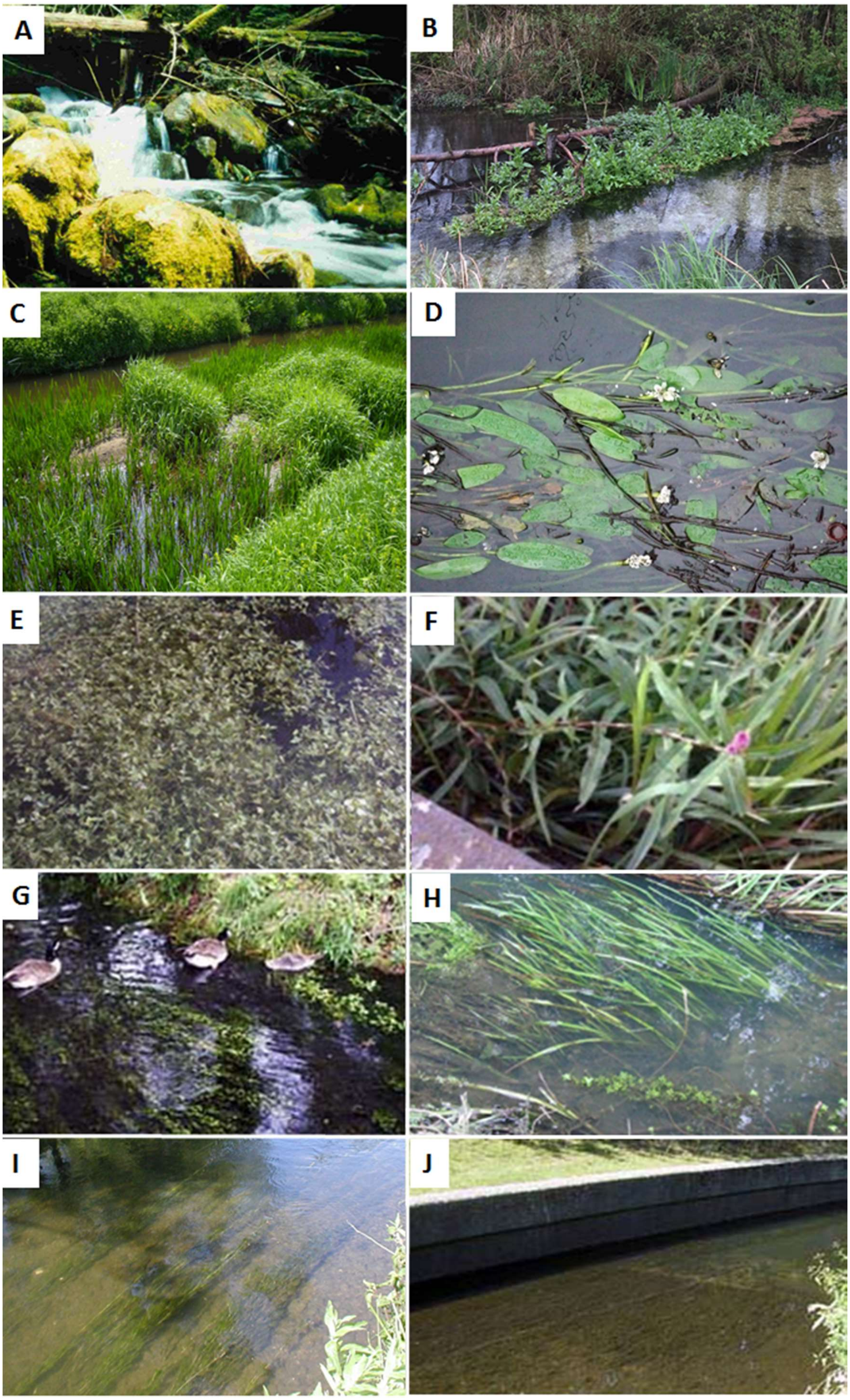
NumVegInteraction: Number of ways in which vegetation is interacting with wetted channel (from section 4.4, subsection 'Vegetation interacting with the wetted channel': score 1 for each that is observed as P or E apart from large wood dams and fallen trees entirely/predominantly which score 2 if count>0 – maximum 8)

Channel physical habitat complexity = ((NumBedMat + NumFlow + NumBedFeat + NumVegInteraction)/3)

INDEX 9: Number of aquatic vegetation morphotypes

This index illustrates the number of aquatic vegetation morphotypes that are present (Figure 2.7). The index value is an integer ranging from 0 (no aquatic vegetation) to 10 (all aquatic vegetation morphotypes are present). Score 1 each for every plant morphotype that is P or E (maximum 10 types, ranging from liverworts/mosses/lichens to filamentous algae) based on observations (i) on the channel bed sheet and (ii) the bank face sheet (subsection 'Aquatic vegetation at the bank-water margin', where 5 of the types can also be recorded). Only score each morphotype once.

Figure 2.7: Vegetation Types



INDEX 10: Riparian Physical Habitat Complexity

This index represents the number and extent of riparian physical habitats found within the survey site, accumulating those related to wood, water-related features on the bank top, physical features on the bank face and water's edge, and natural bank profiles. The index value ranges from 0 (extremely low complexity) to 10 (extremely high riparian physical habitat complexity across both banks). It is made up of the following components:

WoodHab: is the extent of wood-related habitat features calculated for each bank separately (i.e. LeftBankWoodHab, RightBankWoodHab and is the total of the scores from the following table, summed for the bank top (subsection 'Terrestrial vegetation') and the bank face ('Terrestrial vegetation on bank face'). Maximum score = 22 for each bank. Divide by 2.2 to give a final score in the range 0 to 10 for each bank.

Table 2-5: Woody Habitat

Feature	**P**	**E**
Large wood(sections 2.2 and 3.4)	2	4
Fallen trees(sections 2.2 and 3.4)	2	4
Exposed tree roots (section 3.4)	2	4
Discrete organic accumulation (section 3.4)	1	2

BankTopWatFeat: is the number and extent of water-related habitats on the bank top. It is calculated for each bank separately (i.e. LeftBankTopWatFeat, RightBankTopWatFeat and is the total of the scores on the following table from the bank top. Maximum score = 12 for each bank. Divide by 1.2 to give a final score in the range 0 to 10 for each bank.

Table 2-6: Bank Top Water Features

Feature	P	E
Pond (disconnected)	1	2
Pond (connected)	1	2
Side channel	1	2
Wetland (short non-woody vegetation)	1	2
Wetland (tall non-woody vegetation)	1	2
Wetland (shrubs and trees)	1	2

BankFaceNatFeat: is the number and extent of natural physical features on the bank face and along the water's edge. It is calculated for each bank separately (i.e. LeftBankFaceNatFeat, RightBankFaceNatFeat and is the total of the scores on the following table from the bank face (Natural physical features). Maximum score = 27 for each bank. Divide by 2.7 to give a final score in the range 0 to 10 for each bank.

Table 2-7: Bank Face Features

Feature	P	E
Vegetated side bar (> 50% veg cover)	1	3
Unvegetated side bar (< 50% veg cover)	1	3
Toe	1	3
Berm	1	3
Bench	1	3
Stable cliff (> 0.5 m)	1	2
Eroding cliff (> 0.5m)	1	3
Animal burrows	1	1
Marginal backwater	1	3
Tributary confluence	3	

BankProfile: is the number and extent of natural bank profiles. It is calculated for each bank separately (i.e. LeftBankProfile, RightBankProfile. Assign a score of 3 to each natural bank profile type (only score natural profiles, i.e. vertical (V), vertical with top overhang (Vo), undercut (Vu), vertical with toe (Vt), steep (St), gentle (Gt), composite (Cm)). If both dominant and subdominant profiles are natural, the maximum potential score is 6 for each bank. The above scores are combined into an integrated index of Riparian Physical Habitat Complexity:

Riparian Physical Habitat Complexity = (LeftBankWoodHab + RightBankWoodHab + LeftBankTopWatFeat + RightBankTopWatFeat + LeftBankFaceNatFeat + RightBankFaceNatFeat + LeftBankProfile + RightBankProfile)/(7.2)

INDEX 11: Riparian Vegetation Complexity

This index represents the number and extent of riparian vegetation morphotypes found within the survey site. The index value is rounded down to an integer ranging from 0 (completely bare banks) to 10 (highly complex vegetation across both banks).

To calculate the index, vegetation is scored separately for the bank top (section 2.2, subsection 'Terrestrial vegetation') and bank face (subsection 'Terrestrial vegetation on bank face') of each bank according to the following table.

The scores for the vegetation types are summed for the top and face of each bank and then the two bank scores are summed giving a potential maximum score of 60 across both banks, although more than 50 is very unlikely. The total is then divided by 4 to provide an index value ranging from 0 (bare banks) to 10 (highly complex and well-developed vegetation).

Table 2-8: Vegetation Types

Vegetation type	T	P	E
Mosses (etc.)	1	2	4
Short/creeping herbs/grasses	1	1	1
Tall herbs/grasses	1	2	3
Scrub or shrubs	1	2	3
Saplings or trees	1	2	4

INDEX 12: Degree of human pressure imposed by land cover on the bank tops

The index indicates the degree of human pressure imposed by land cover on the bank tops. The index value is rounded down to an integer ranging from 0 (minimal modification/pressure) to 10 (high modification/pressure). Score the artificial ground cover recorded on each bank top by summing the dominant and subdominant cover (section 2.1) according to the following table.

Table 2-9: Human Pressure Features

	P	E
Fp Pedestrianised, footpath	2	4
Tr Transport infrastructure	5	10
Ic Buildings (commercial / industrial)	4	8
Re Buildings (residential)	4	8
Sy Storage area	4	8
Ld Landfill area	5	10
Ar Arable agriculture / allotments	3	6
Pv Permanently vegetated agriculture (e.g. pasture, orchard)	1	1
Pr Permanently vegetated recreation (e.g. playing fields)	1	1
Pw Plantation woodland	1	1
Ow Artificial open water (e.g. canal, reservoir)	1	1

If dominant and subdominant artificial cover types are present, the maximum score = 20 for each bank. Sum the scores for the two banks (maximum 40) and divide by 4 to give a final score in the range 0 to 10.

INDEX 13: Channel reinforcement

The index indicates the extent and strength of reinforcement of the river banks and bed. The index ranges from 0 (no reinforcement) to 10 (fully reinforced with concrete and/or sheet piling).

For each bank (section 3.2, subsection 'Bank face reinforcement'):

ReinfVertExt (Reinforcement vertical extent), top = 1, bottom = 1.5, whole = 2 (maximum of 2 for each bank)

(i.e. LeftBankReinfVertExt, RightBankReinfVertExt)

For each bank (section 3.2, subsection ‘Bank face reinforcement’):ReinfLatExt (Reinforcement lateral extent), T = 0.5, P = 1, E = 2 (maximum of 2 for each bank) (i.e.LeftBankReinfLatExt, RightBankReinfLatExt(right bank))

For the bed (subsection ‘Channel bed reinforcement’): BedReinfExt (bed reinforcement extent), T = 1, P = 2, E = 4 (maximum of 4)

For each bank and the bed (section 3.2, subsection ‘Bank face reinforcement’ and section 4.1, subsection ‘Channel bed reinforcement’)LeftBankMatType, RightBankMatType, BedMatType are the dominant reinforcement material types for the left bank, right bank and channel bed scored from the following table (maximum of 5 for each bank and for the bed)

INDEX 14: Extent of non-native invasive plants

The index indicates the number and extent of invasion by the 4 most common non-native invasive plants along British rivers. The index value ranges from 0 (no nuisance plants) through 5 (extensive invasion) to approximately 10 (extensive and diverse invasion).

The 4 species may be recorded on the bank top (section 2.2), bank face (section 3.4) and channel bed (section 4.4). This gives 12 possible location-species combinations, each of which should be scored 1 for Trace, 2 for Present and 4 for Extensive, giving a maximum possible but, in practice, unrealistic total of 48. In reality, no more than one species is likely to be extensive in each of the three locations, giving a maximum feasible score of 30 if all species are present at all 3 locations (bank top, bank face, bed).

Therefore, the index is calculated by adding scores of 1 (for T), 2 (for P) and 4 (for T) for the extent of each species at each of the 3 locations and then adding the scores for all 4 species together and dividing by 4 to give a score of 0 (no species at any of the 3 locations) or 1 to 10 (or thereabouts) where species are present to some degree.

Table 2-10: Channel Reinforcement Features

Code	Reinforcement type	Score
CC	Concrete	5
CB	Concrete & brick / laid stone (cemented)	4
BR	Brick / laid stone (cemented)	4
SP	Sheet piling	5
WP	Wood piling / panels	3
BW	Builders waste / hard core (tipped)	2
RR	Rip-rap (large laid stone, uncemented)	3
GA	Gabions	2
WS	Willow spiling	1
RE	Planted reeds	0
BC	Biotextiles / coir	0
WO	Washed out reinforcement	0

Channel reinforcement = (LeftBankReinfVertExt * LeftBankReinfLatExt * LeftBankMatType) + (RightBankReinfVertExt * RightBankReinfLatExt * RightBankMatType) + (BedReinfExt*BedMatType)) / (6)

2.5 Analysis & Discussion of Results

Forestry England have calculated the Index Values (Appendix A) and generated a series of graphs to illustrate the results. As part of this discussion the Index values have been evaluated for unrestored, benchmark and restored sites to show any differences in the functioning of the fluvial systems. The bench mark sites are located on the Dockens Water, Highland Water, Mill Stream and Ober Water are regarded as being in good condition and analysis of these sites help to provide typical bench mark values which it is hoped restored streams should be achieving.

2.5.1 Index 1 - Flow Types

Figure 2.8 shows the number of flow types recorded at all sites, Figure 2.9 shows flow types at bench mark sites while Figures 2.10 to 2.14 give a breakdown across individual sites.

Results show that the number of flow types found in New Forest streams typically varies between 1 and 4 types. Two survey sections have recorded 0 suggesting the stream bed was dry at the time of survey. The average number of flow types recorded is as follows:

Unrestored sites – 2.11
Benchmark sites – 2.14
Restored sites – 2.16

The graphs (Figures 2.10 to 2.13) suggest there is a reasonable variability in flow types at all sites although flow types are marginally more diverse at both benchmark and restored sites. The number of flow types appear to alter from year to year irrespective of whether restoration has taken place or not and are likely to be influenced by water levels at the time of survey. However, Millersford (Figure 2.14) is the least diverse site in terms of flows with minimal flow variability within the MoRPh modules with the control site having between 1 and 2 flow types and the downstream section which requires restoration only demonstrating 2 flow types over its entire reach.

Figure 2.8

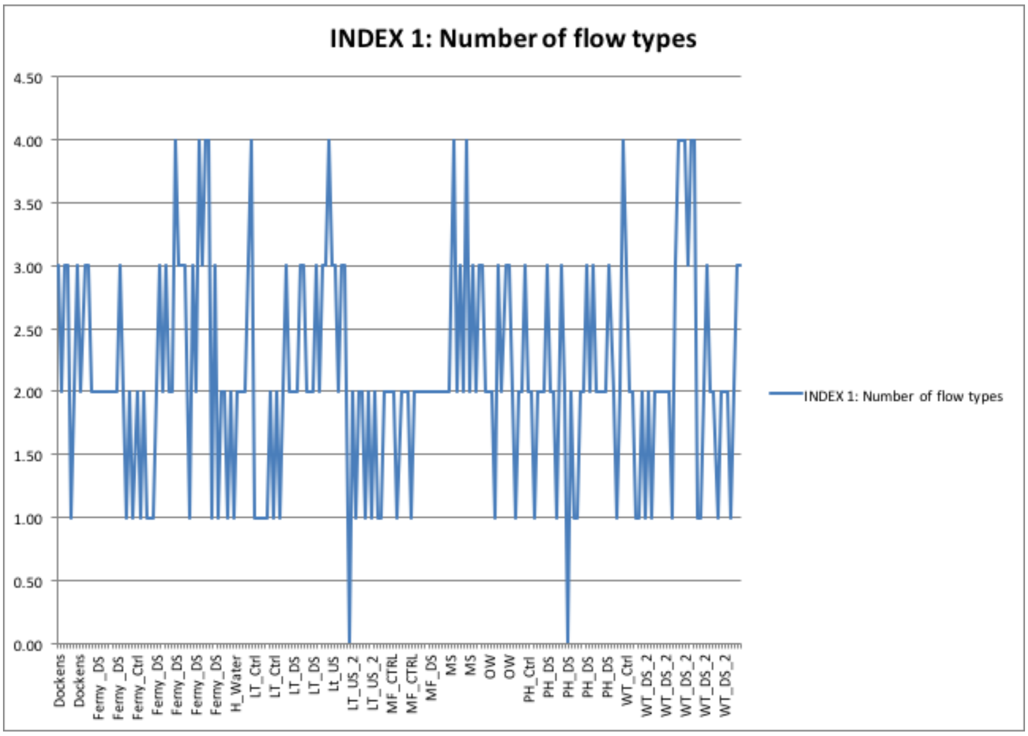


Figure 2.9

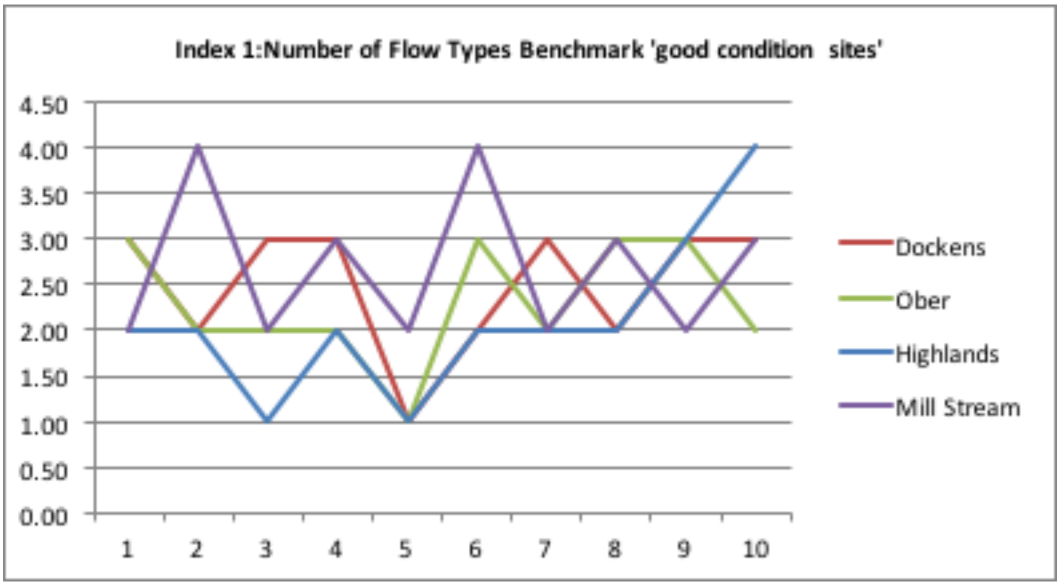


Figure 2.10

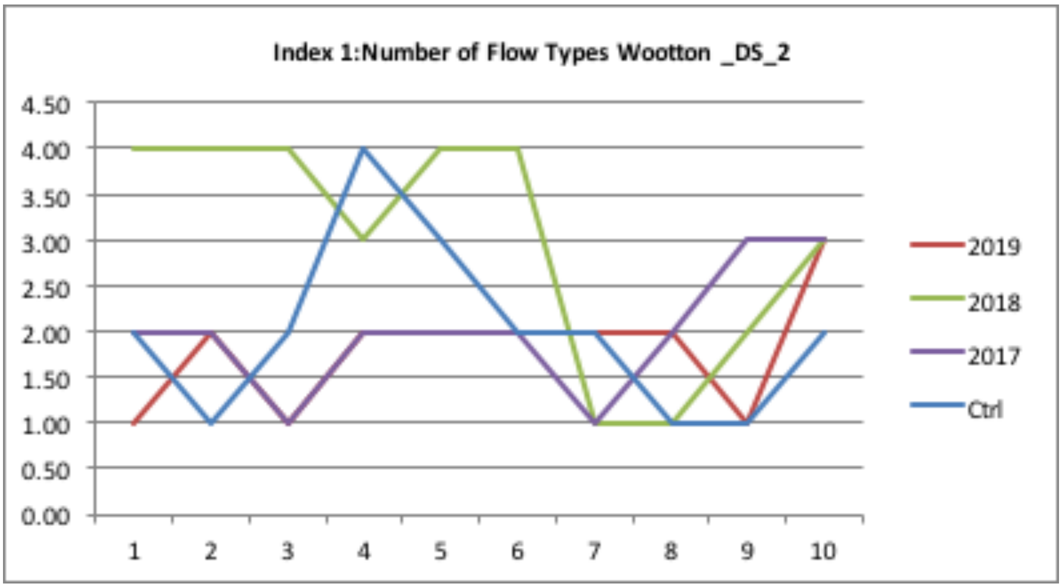


Figure 2.11

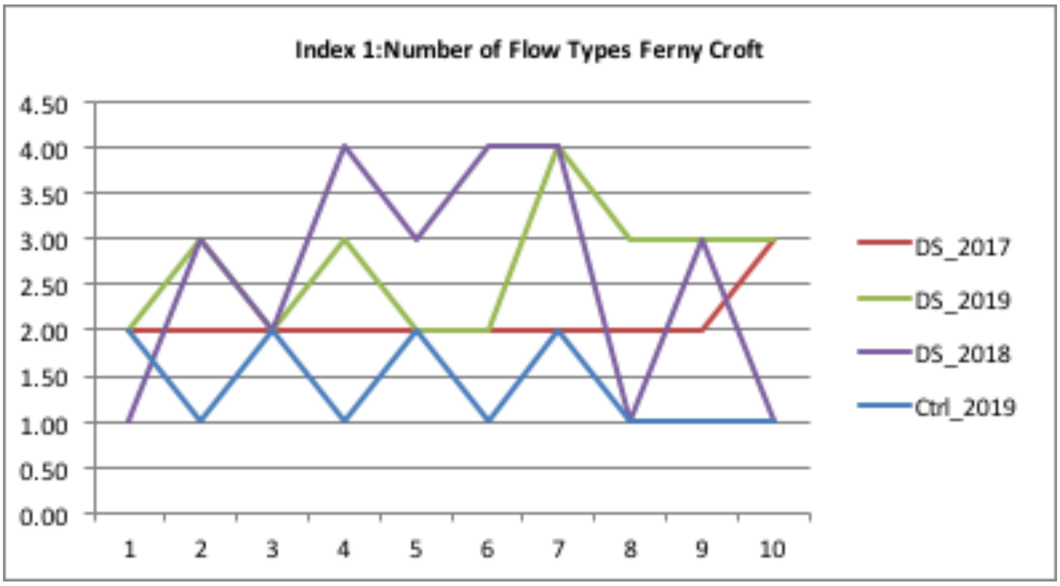


Figure 2.12

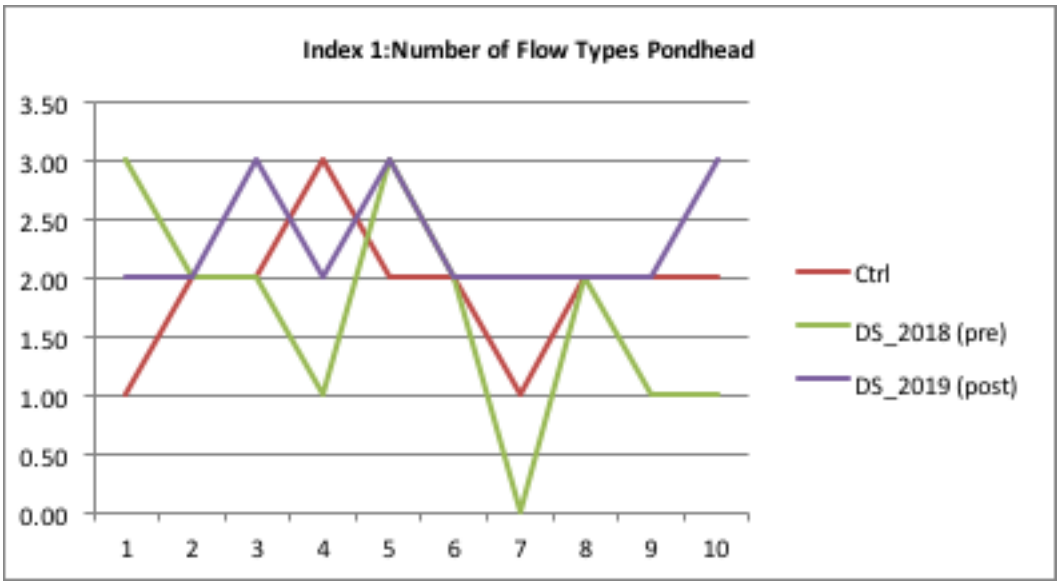


Figure 2.13

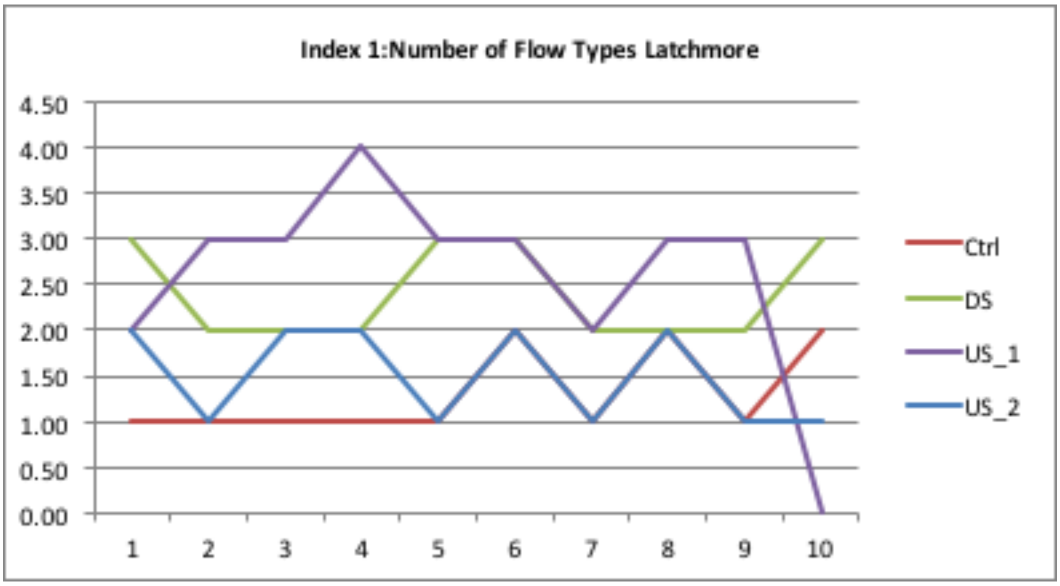
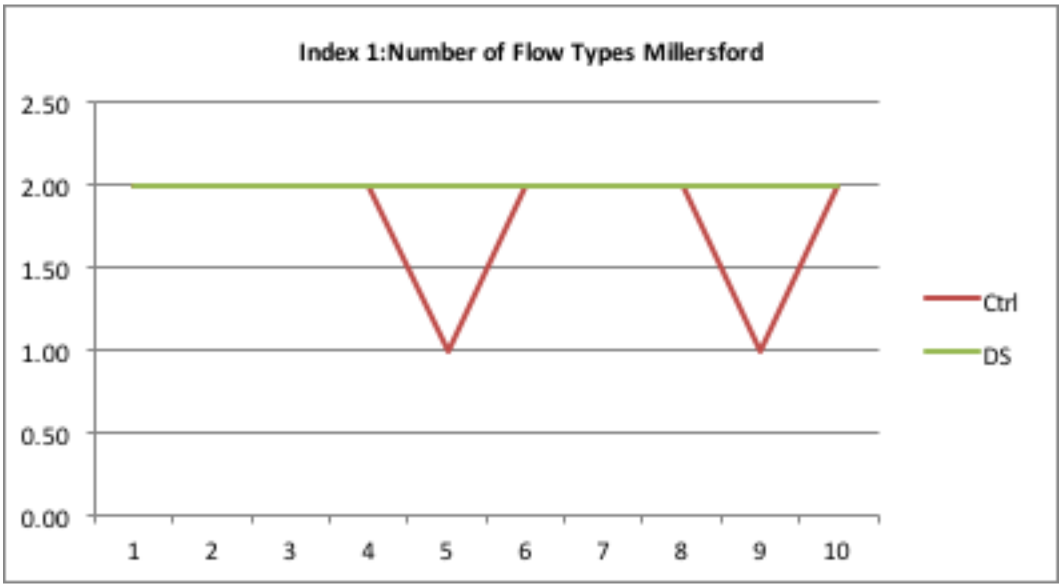


Figure 2.14



2.5.2 Index 2 – Flow Strength Types

Figure 2.15 shows a breakdown of the highest energy flow types recorded across all sites. The highest energy flow type was primarily recorded at restored sites (Ferny Croft and Wootton). The lowest flow recorded was no perceptible flow at Latchmore - control, Millersford -control and Pondhead (pre restoration). By far the most common flow type recorded is smooth followed by rippled and unbroken standing waves. Upwelling is rarely recorded and was only noted at Wootton (post restoration). Broken standing waves are also uncommon and were only recorded at Highland Water and Wootton (post restoration - 2018). It should be noted that the flow type will vary according to water levels in the channel at the time of survey which probably accounts for some of the changes in the proportion of flow types noted at Wootton post restoration.

Figure 2.16 shows the variations in highest flow types recorded between unrestored, benchmark and restored sites. It can be seen that the flow types are more diverse in the restored sites compared to the unrestored sites. Unrestored sites are dominated by two flow types - smooth flow and ripples. There is also a smaller proportion of no perceptible flow and unbroken standing waves. The highest flow categories of chutes and broken standing waves form a very small proportion of flows types. Benchmark sites display three key flow types – smooth, rippled and unbroken standing waves and a small proportion of broken standing waves. Restored sites appear to have a high proportion of chutes and unbroken standing waves along with a diversity of other flow types including upwelling although unbroken standing waves and smooth flow are the dominant flow types.

Figure 2.15

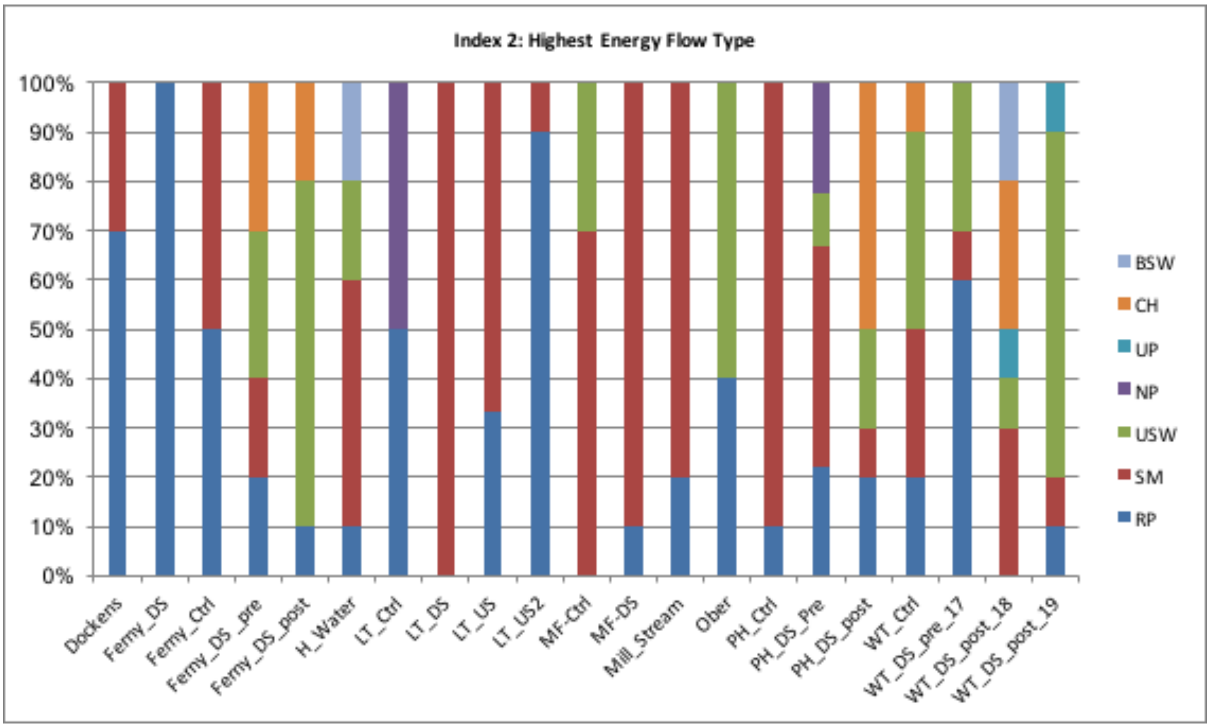
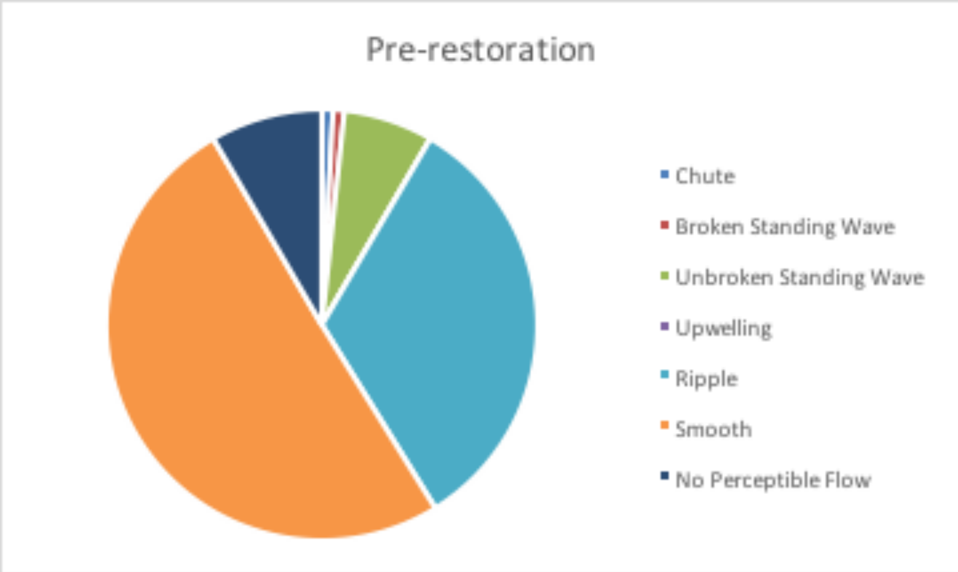
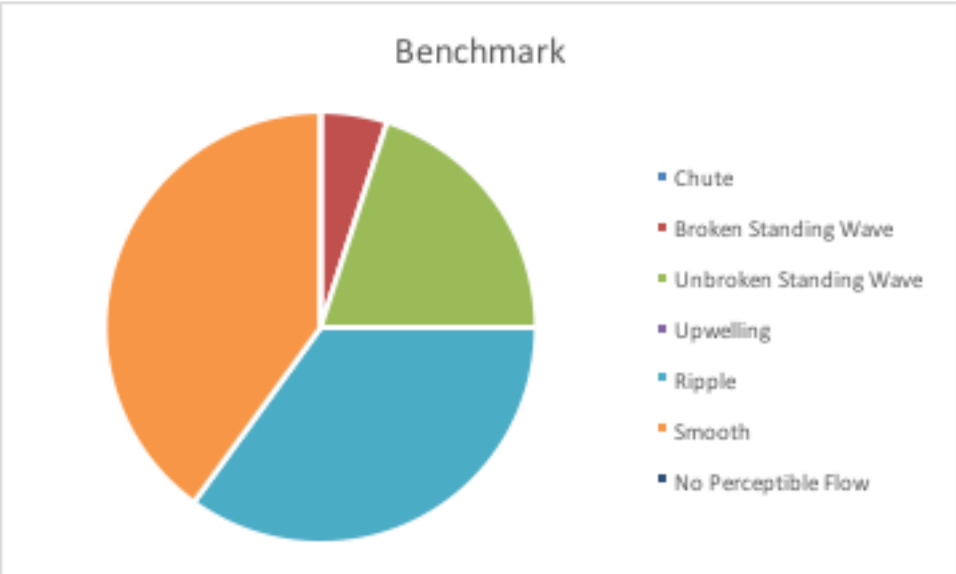
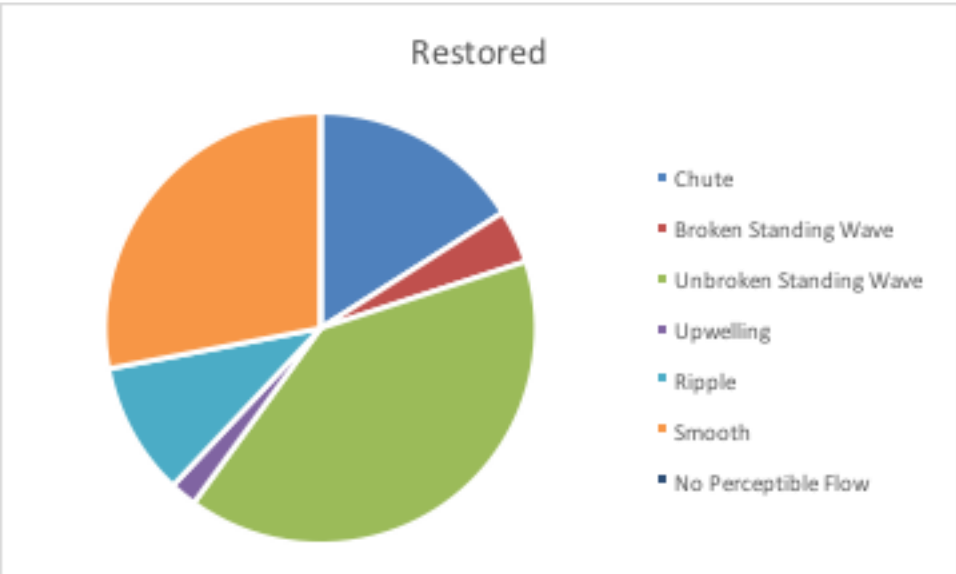


Figure 2.16: Flow Types







2.5.3 Index 3, 4, 5, 6 & 7 - Bed Material Types

Up to seven bed material types have been recorded at New Forest MoRPh sample sites (Figure 2.17). MoRPh sections along the Latchmore Brook (upstream)(9.4/5) & Highland Water (6.2/3 & 6.9/10) show the greatest diversity in bed materials, closely followed by sections along the Ober Water. The overall median across all sites bed material types is 3 and the averages for sites of different restoration status are as follows:

Unrestored – 3.00 types
Benchmark – 3.08
Restored – 3.09

Figure 2.17

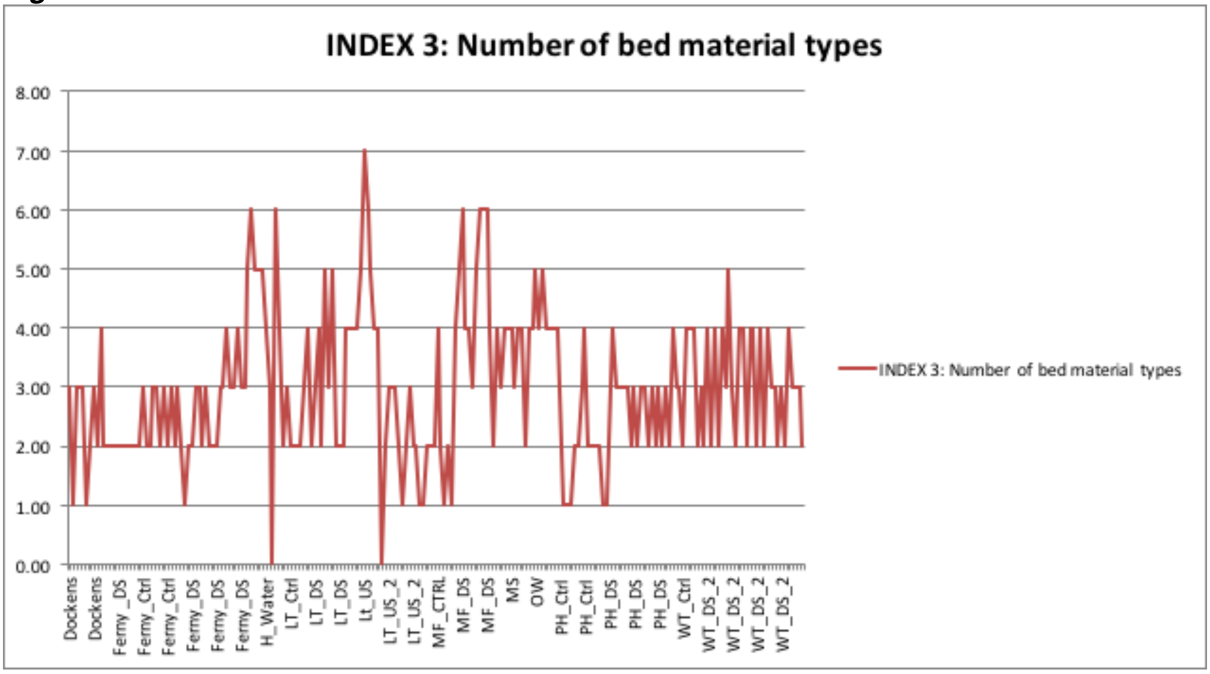


Figure 2.18 & 2.19 show that gravel/pebble sized particles dominate the substrate in most streams and indeed some individual MoRPh section are entirely composed of gravel/pebble, notably Ferny Croft and Wootton.

Flow velocity is highly influential in transporting particles and determining the dominant substrate. It was noticeable that flow types can vary from year to year across the same site. For example, Figure 2.10 shows flow types at Wootton. At this site flow types were quite variable across the same MoRPh modules when comparing the 2018 and 2019 surveys (both post restoration) with more higher flow types being recorded in 2018. At the same time, it can be seen from Figure 2.18 that in 2018 Wootton (downstream) comprised reasonable proportions of silt, sand and gravel whereas by 2019 gravel/pebble was entirely dominant. This suggests that the higher flows experienced in 2018 may have flushed some of the finer particles sizes through the system. However, it should be noted that as the river had recently been restored and a new substrate introduced the river will have been reworking and moving substrate around in the process of finding its natural equilibrium.

Figure 2.18

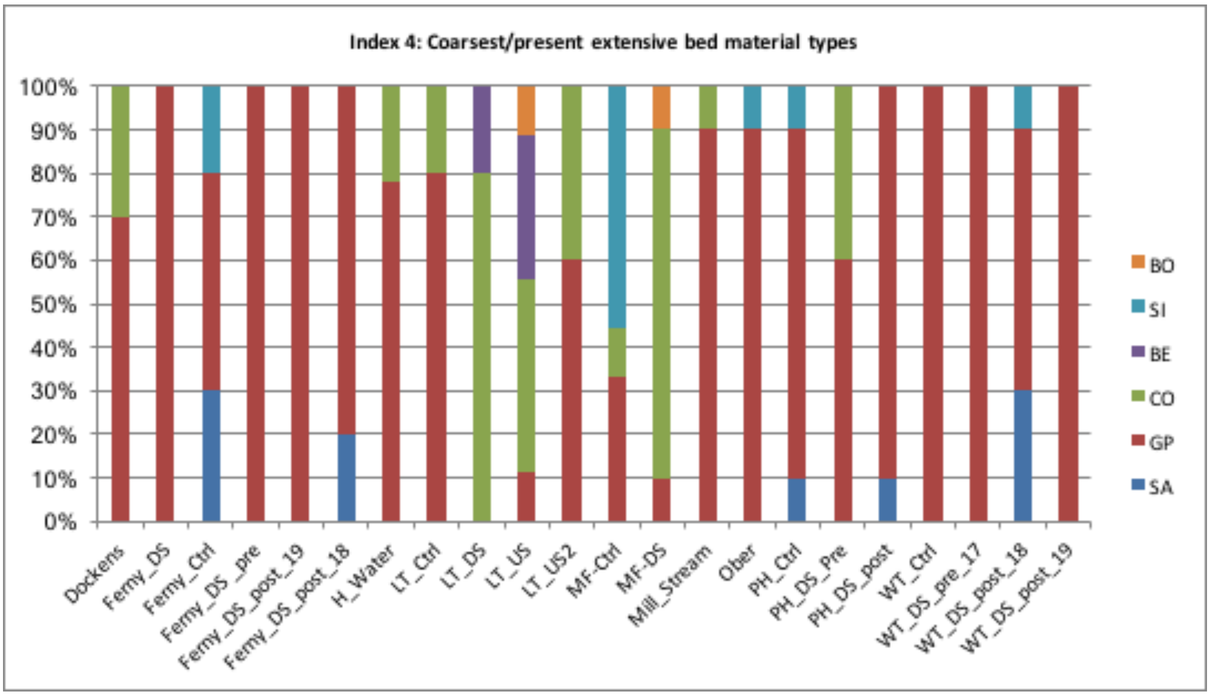
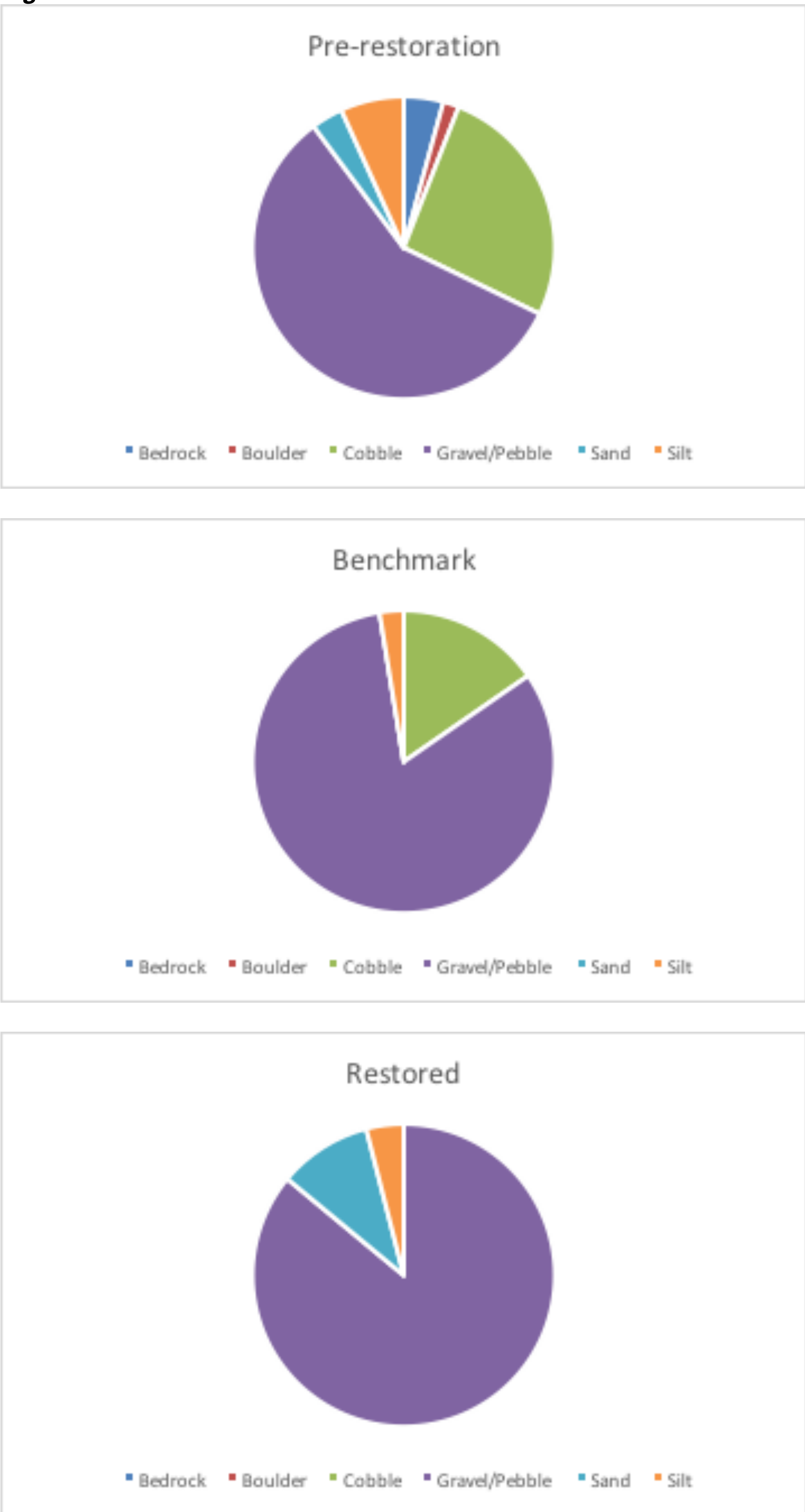


Figure 2.19 shows the average proportion of the coarsest present/extensive bed material type present at sites pre and post restoration and at bench mark sites. What is immediately apparent is that the substrate present at pre-restoration sites is more indicative of high energy flows with a higher proportion of bedrock, boulder and cobble although all substrate types are present.

The substrate at benchmark sites is indicative of a lower energy fluvial environment than the pre-restoration sites with the substrate being composed almost entirely of gravel/pebble with a proportion of cobble and silt.

The substrate at the restored sites suggests the lowest fluvial energy as the coarsest substrate is gravel/pebble with a smaller proportion of sand and silt. Slight caution is required with the interpretation of results at this early stage in the restoration process as the substrate is artificially introduced into the restored channels as part of the restoration process and the river may well still be reworking the bed material and it may develop a coarser profile over time. However, the substrate profiles fit with the fact that most of the restored streams overtop with their banks during flood flows taking the energy out of the channel and reducing the sediment transport potential.

Figure 2.19


Pre-restoration
Bedrock
Boulder
Cobble
Gravel/Pebble
Sand
Silt
Benchmark
Bedrock
Boulder
Cobble
Gravel/Pebble
Sand
Silt
Restored
Bedrock
Boulder
Cobble
Gravel/Pebble
Sand
Silt

When comparing the average alluvial bed material size (Index 5), the results are as follows:

Pre-restoration – 0.35 phi
Benchmark – 0.31phi
Restored – 0.33 phi

Given the results above this is not surprising as it is indicative of gravel/course sand dominated substrate.

Figure 2.20 shows how the average alluvial bed material size/class varies between individual sites. The bed material is dominated by gravel/pebble and sand with a smaller proportion of silt. Indeed 68% of the sample sites had no silt contributing to the average alluvial bed material size. From Figure 2.20 it is also possible to observe how the restored streams rework the bed material profile over time. For example, in the case of Ferny Croft in 2017 the average size of bed material was entirely comprised of sand. In 2018, immediately post restoration the material profile comprised 20% gravel/pebble, 50% sand, 30% silt. In 2019, the profile comprised 40% gravel/pebble and 60% sand with the silt having been transported out of the survey reaches. Looking at the flow type graphs for Ferny Croft it can be seen that there were more higher flow types recorded in 2018 than 2019.

A similar pattern can be observed for Wootton with no silt being present pre-restoration (20% gravel/pebble, 80% sand), immediately post restoration in 2018 the profile was 10% gravel/pebble, 60% sand and 30% silt. By 2019 it was 30% gravel/pebble and 70% sand with the silt component having been transported out of the system.

Figure 2.20

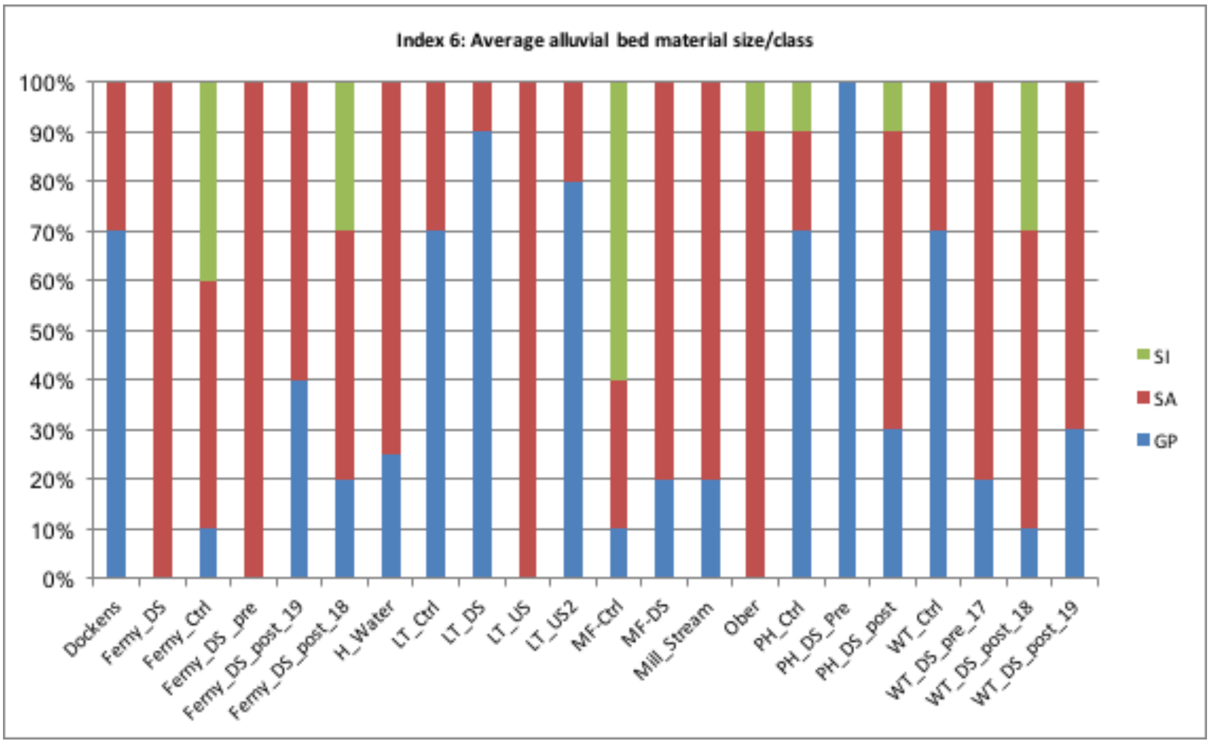


Figure 2.21

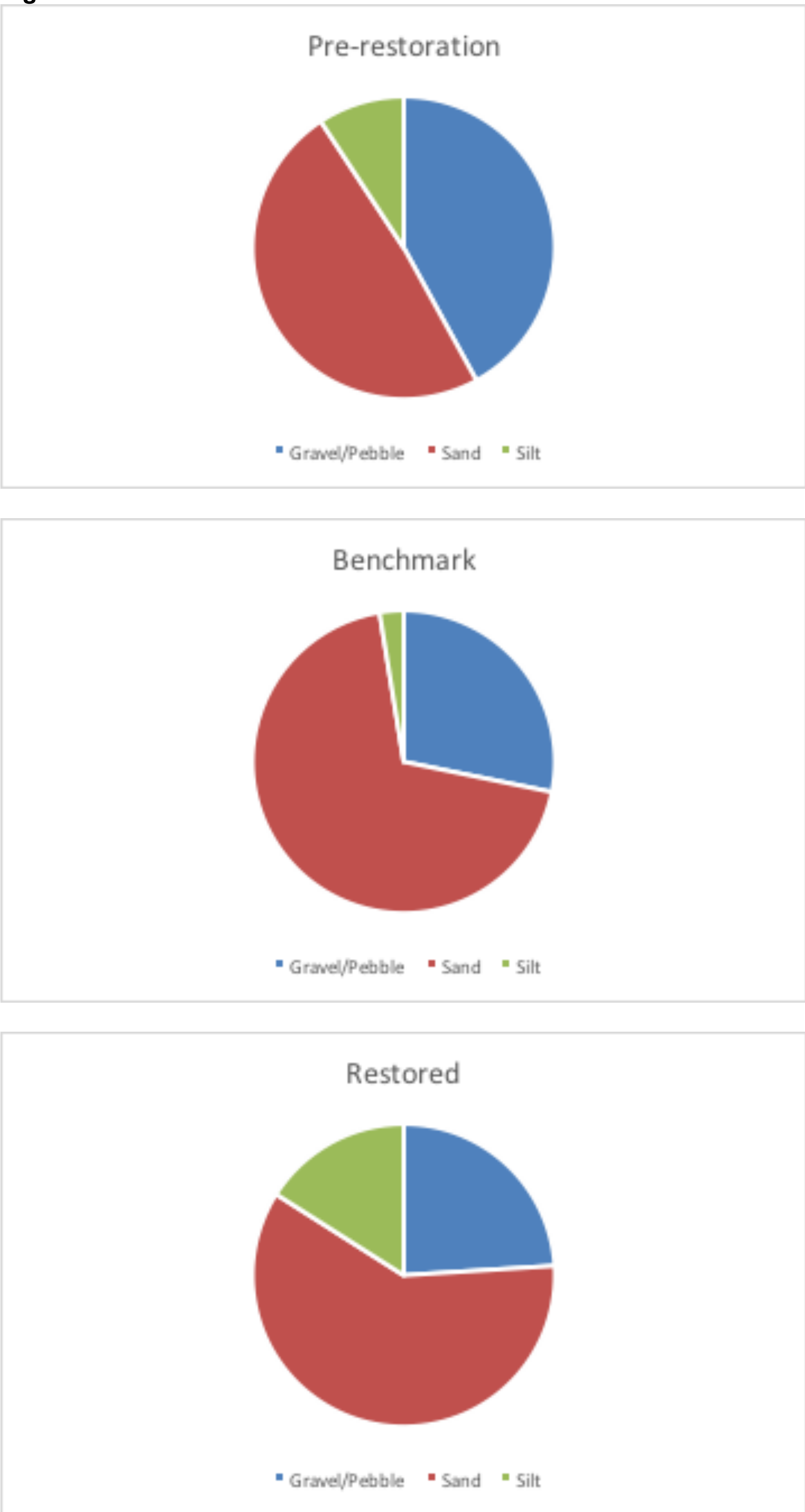
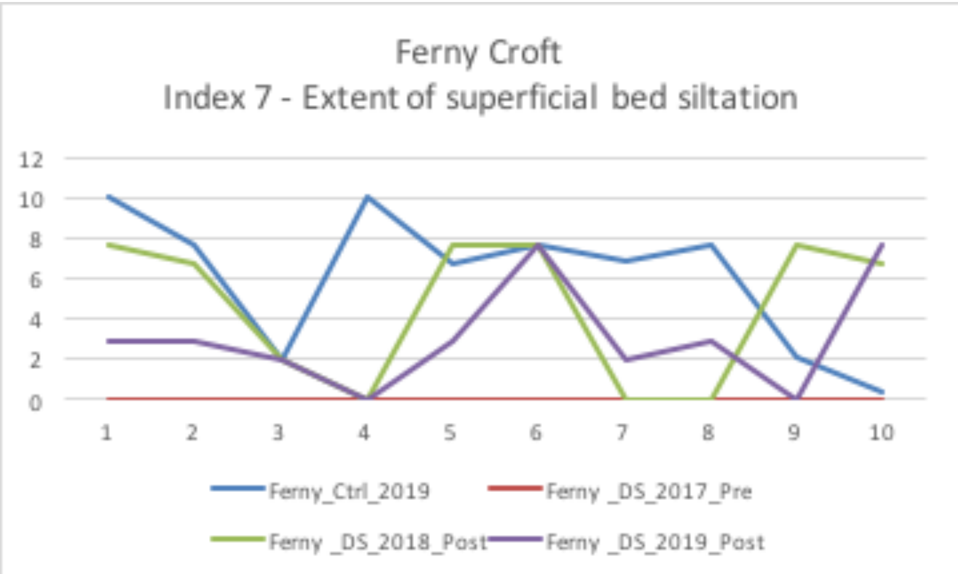

Pre-restoration
Gravel/Pebble
Sand
Silt
Benchmark
Gravel/Pebble
Sand
Silt
Restored
Gravel/Pebble
Sand
Silt

Figure 2.21 gives a breakdown of the average alluvial bed material size/class at pre-restoration, benchmark and restored sites. In can clearly be seen from the proportions of sediment types that the highest energy flows are present in the pre-restoration sites due to the higher proportions of gravel/pebble compared to the bench mark and restored sites. The sediment profile for the restored sites is indicative of the lowest energy profiles with more diverse flow environments compared to the results for the pre-restoration and restored sites.

Index 7 – Extent of superficial bed siltation shows that the only site that records any degree of siltation is Ferny Croft which has values ranging from 0 to 10.05 (refer to Figure 2.22) with the highest values being recorded at the control site. Interestingly, the presence/impact of silt is also noted in the analysis of macro-invertebrates (Chapter 5). The pattern of the graph lines for 2018 and 2019 suggest that silt is moving down through the system.

Figure 2.22



2.5.4 Index 8 - Channel physical habitat complexity

The channel physical habitat complexity score gives a good indication of the variability of channel complexity as it brings together the channel bed material types, water surface flow types, bed features and vegetation interaction with the channel, for example debris dams and fallen trees. The higher the complexity of the channel the greater the potential for diversity of habitat niches. The average channel physical habitat complexity index scores are as follows:

Unrestored – 3.67
Benchmark – 3.59
Restored- 3.73

The graphs shown in Figures 2.23 to 2.29 show how variable the streams are along their reaches and how they change from year to year. Rivers are dynamic in nature and substrate, flow patterns and vegetation interactions such as debris dams shift through time. Therefore, the diversity of individual MoRPh sections can vary significantly from year to year.

Figures 2.30 to 2.32 show the average overall channel physical habitat complexity and riparian habitat complexity (Index 10) for Ferny Croft, Wootton and Pondhead. Variations can be seen from year to year and it is likely the scores for channel physical habitat complexity have fallen marginally because silt has been washed out of the system as noted in section 2.5.3. However, some caution is required in drawing too many assumptions from the average score as some MoRPh sections are very diverse compared to some that are less so, as can be seen from the graphs but the average scores mask this point. Riparian physical habitat complexity scores are likely to have fallen post restoration due to vegetation clearance as part of the works and the impact of the work itself on the riparian zone. For most sites vegetation recovery is still on-going and further monitoring over future years should reveal future changes.

Figure 2.23

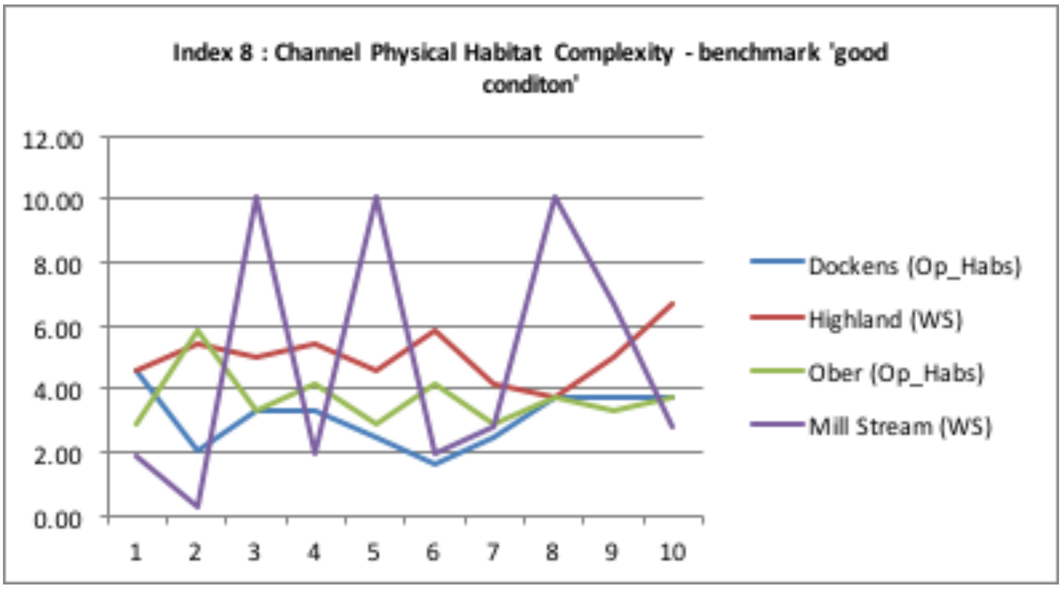


Figure 2.24

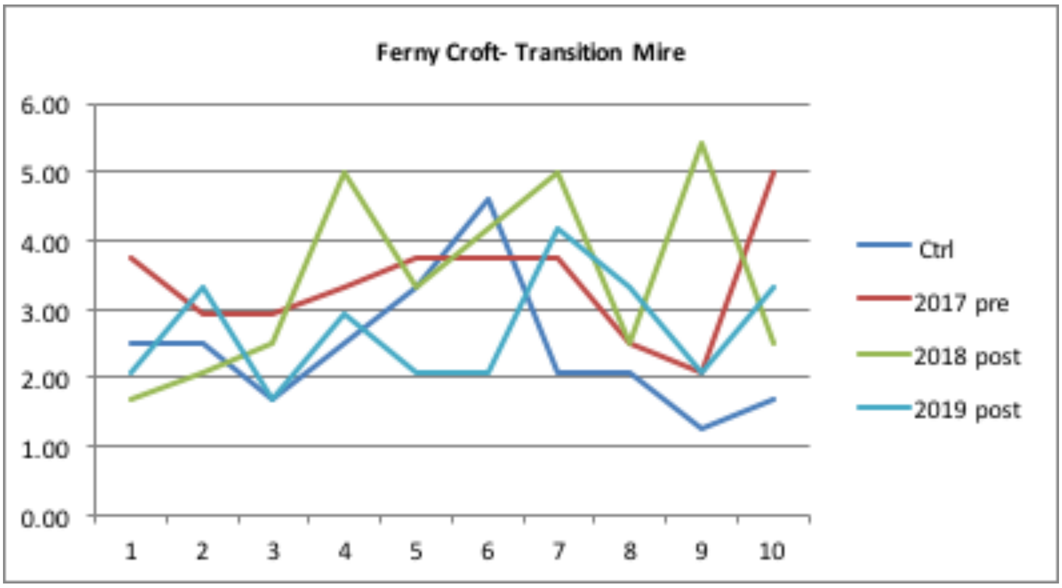


Figure 2.25

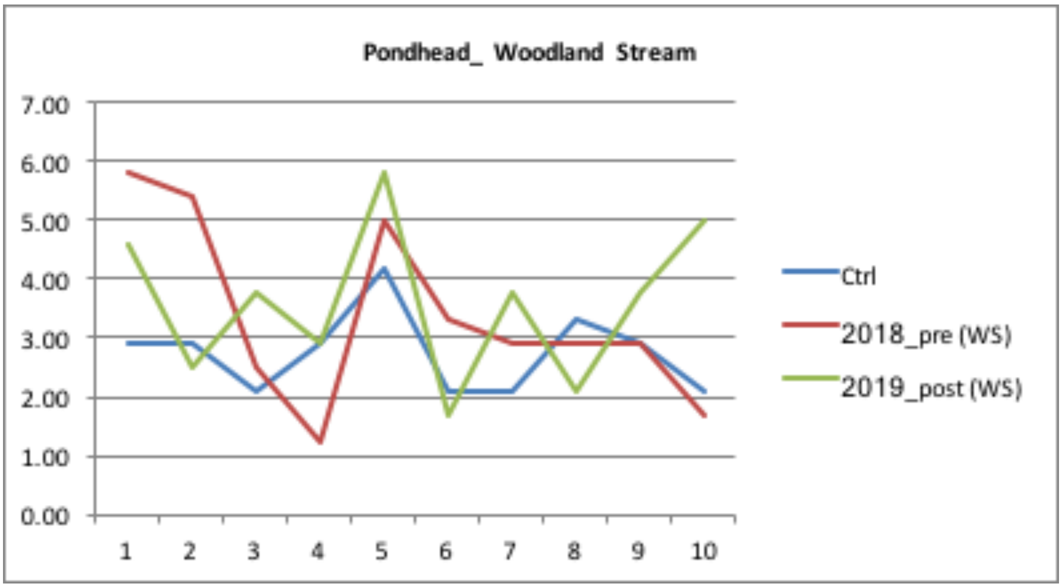


Figure 2.26

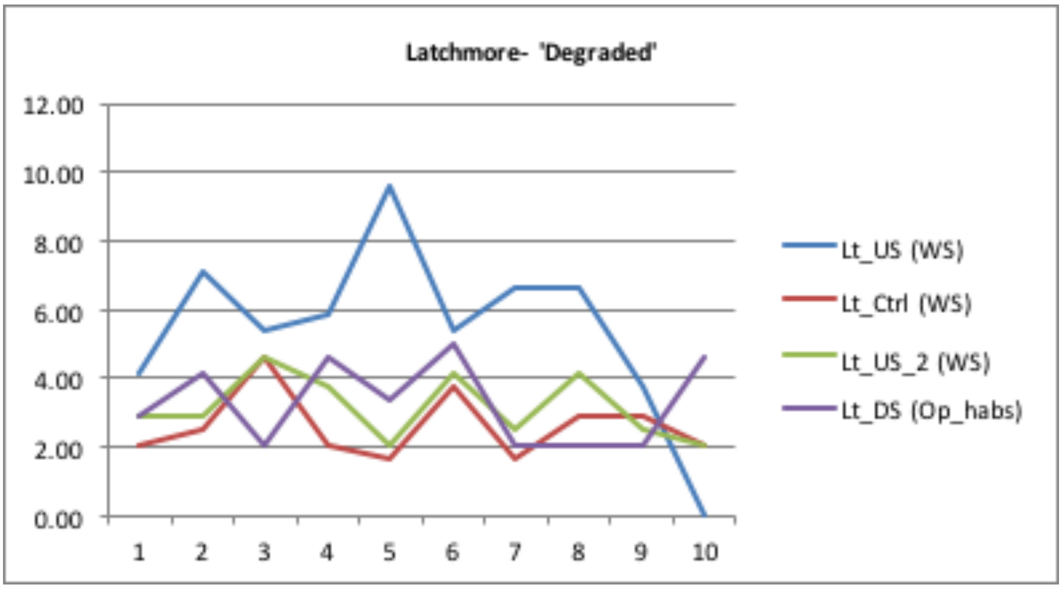


Figure 2.27

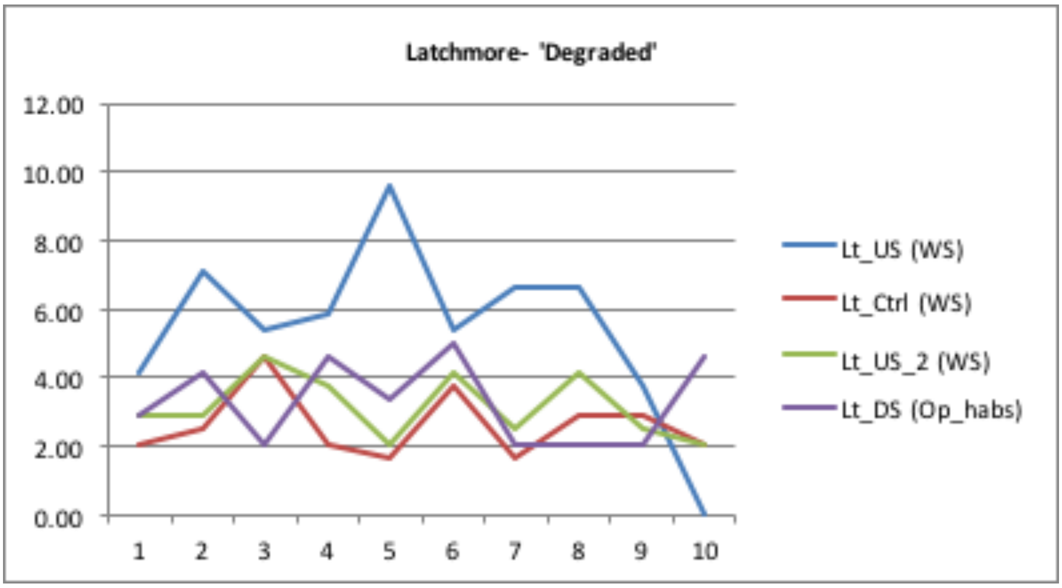


Figure 2.28

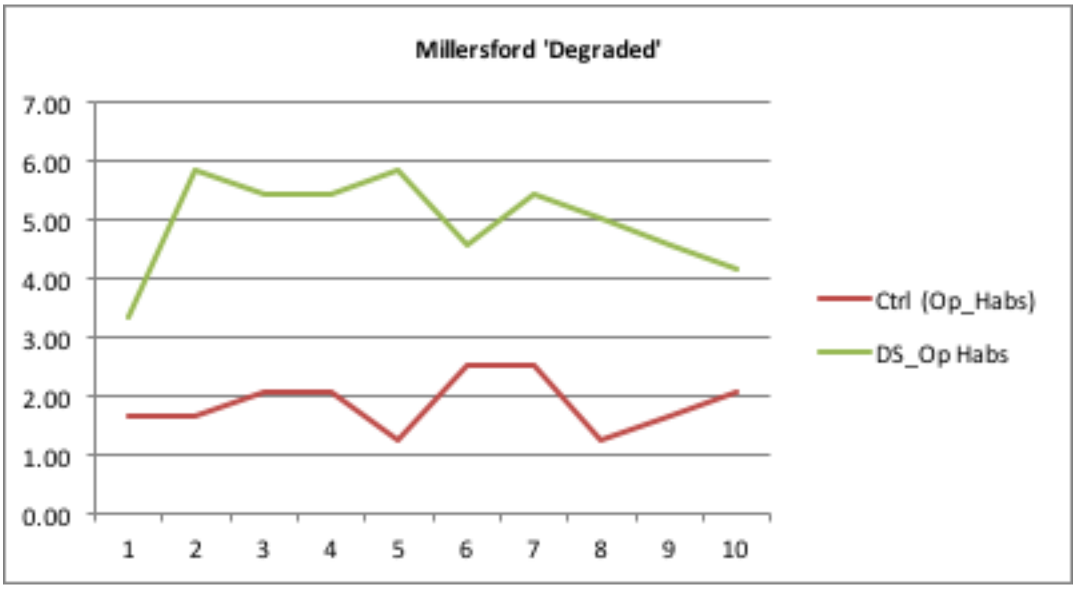


Figure 2.29

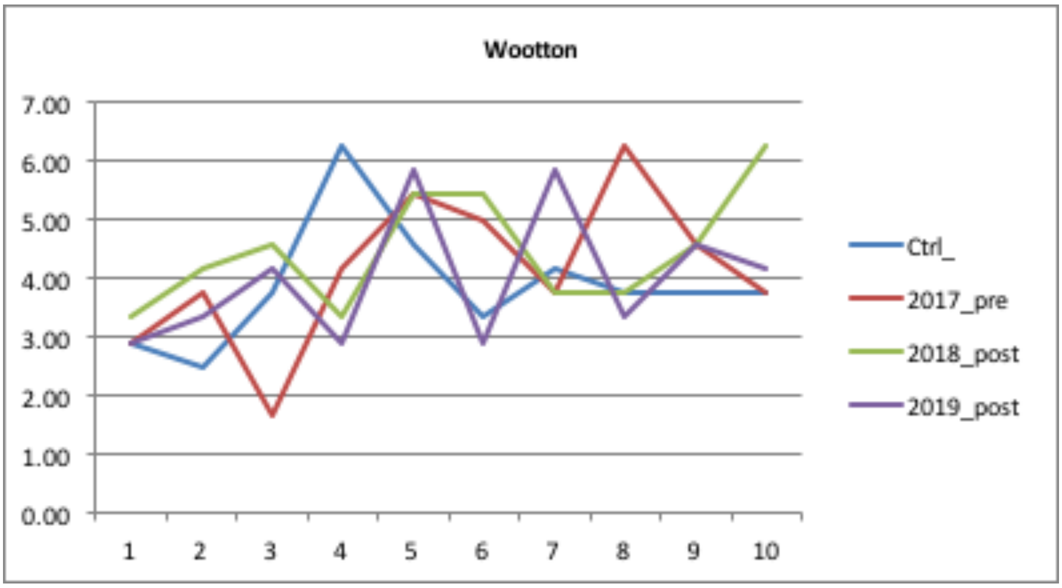


Figure 2.30

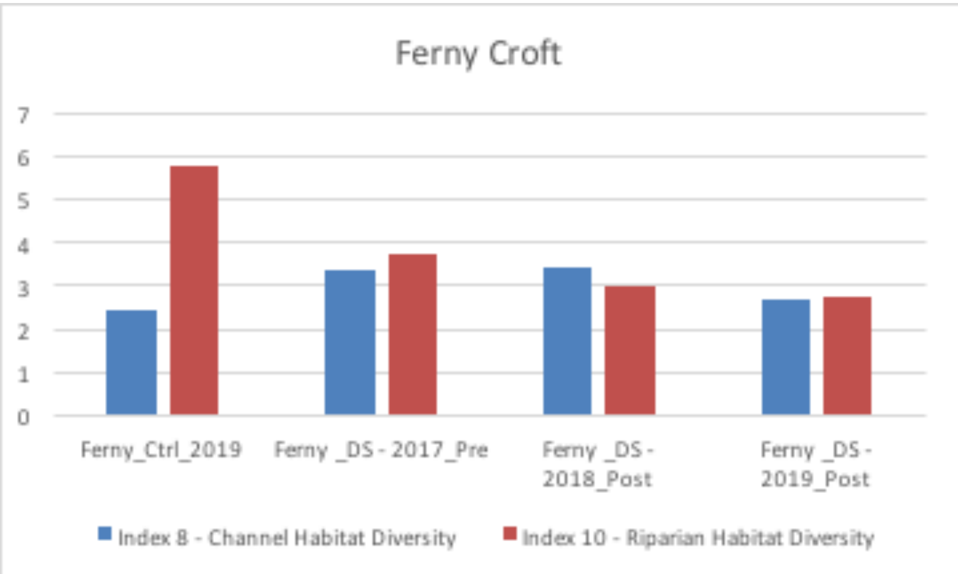


Figure 2.31

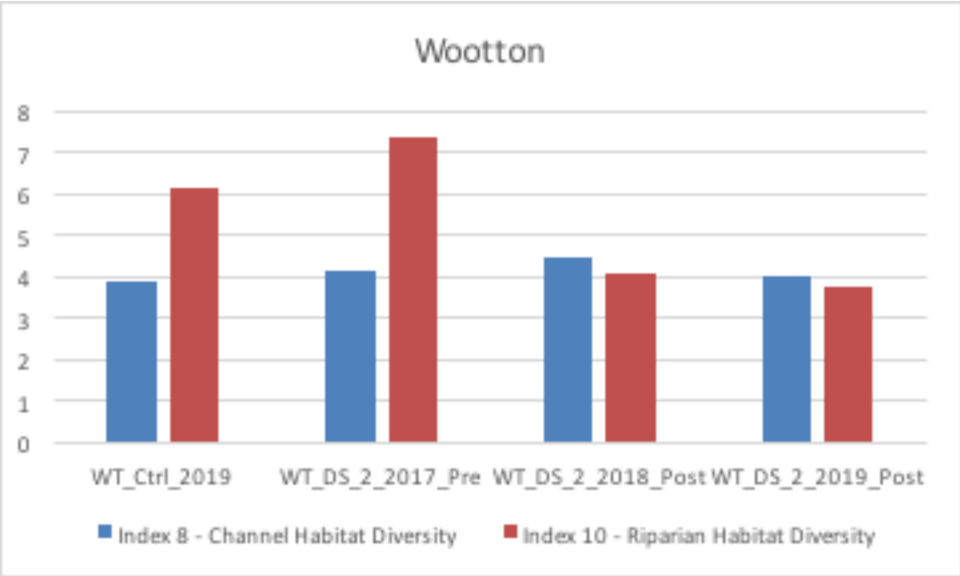
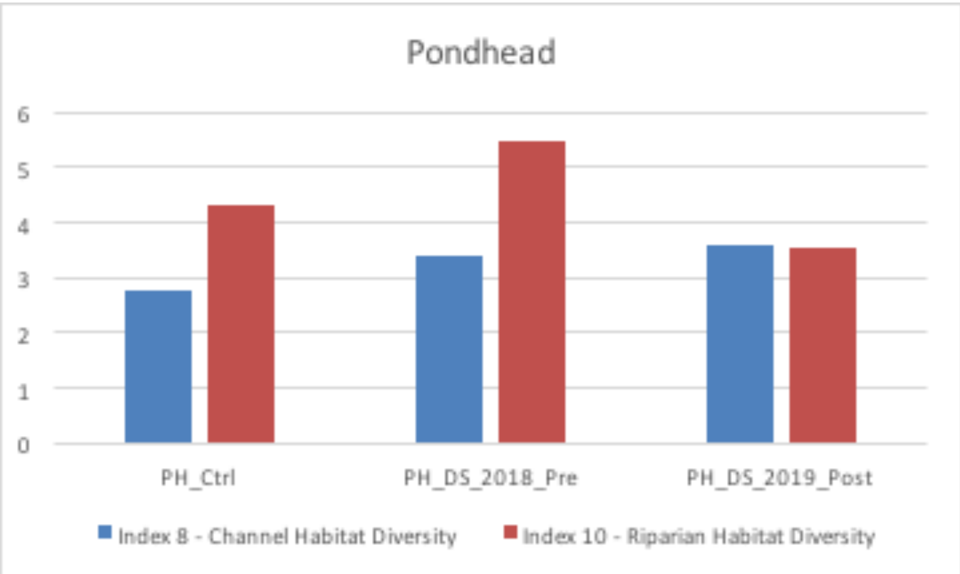


Figure 2.32



2.5.5. Index 9 to 14

Detailed analysis has not yet been undertaken by Forestry England of the remaining Indices (9 to 14) but a brief evaluation of the Index values to look at the differences between unrestored, benchmark and restored sites is set out below.

Index 9 Number of aquatic vegetation morphotypes

Unrestored – 2.4
Benchmark – 2.83
Restored – 2.19

Between 0 and 9 morphotypes were recorded across the New Forest streams. Bench marks sites have the highest average scores in terms of aquatic vegetation morphotypes and restored sections have the lowest. Due to the flow environment and substrate character aquatic vegetation is not a dominant feature in New Forest streams. As restored sites have only been completed in the last few years it is possible that vegetation has not yet become as established. Further monitoring will hopefully pick up increases in the score as sites stabilise.

Of the restored sites, Ferny Croft was the highest scoring site with Index score of up to 5 and 6 and this may be related to the fact that it has higher levels of siltation and a lower energy environment which allows vegetation to colonise more readily.

Index 10 – Riparian physical habitat complexity

Unrestored 4.71
Benchmark – 4.57
Restored – 4.55

As noted earlier, riparian physical habitat complexity scores are likely to have fallen post restoration due to vegetation clearance as part of the works and the impact of the work itself on the riparian zone. For most sites vegetation recovery is still on-going and further monitoring over future years will reveal future changes.

Index 11 – Riparian vegetation structural complexity

Unrestored – 4.47
Benchmark – 4.16
Restored – 4.19

The same comments apply as those for Index 10.

Index 12 – Human pressure

Unrestored – 0.98
Benchmark – 0.86
Restored – 1.12

Human pressure is generally low at most sites.

Index 13 – Channel reinforcement

No channel reinforcement recorded at any of the MoRPh survey locations.

Index 14 – Non-native invasive plant extent

The only sites where a very low score of non-native plant extent has been recorded is at the Wootton control site (0.1 to 0.15) and Millersford – DS (0.05)

2.6 Conclusions

Modular River Physical surveys (MoRPh) carried out on the New Forest stream are very useful for revealing the characteristics of the fluvial environment and for highlighting changes in hydro-geomorphology and general habitat availability. The results reveal:

- The dynamic character of the streams and how fluvial geomorphological elements change from year to year in response to flow dynamics. It is also clear to see why the New Forest streams are considered an excellent example of a relatively undisturbed lowland river system.

- It is clear that river restoration using bed level raising and restoration of meanders to slow the flow and promote reconnection with the floodplain is taking energy out of the channel. This is revealed by analysis of flow types and bed material types.

- For most indices, the average overall scores for the restored sections generally exceed both the bench mark sites and the unrestored sites suggesting that the rivers are becoming more complex which will in turn increase the habitat niches for in-stream aquatic communities.

- The only indices where restored sites fall slightly below benchmark sites and unrestored sites is in relation to aquatic morphotypes, riparian physical habitat and vegetation complexity. This may be because the sites have been recently restored and the bankside habitat is still recovering and evolving. Future MoRPh surveys will no doubt reveal if this is the case. However, it is notable that benchmark sites also fall below unrestored sites.

- There is little evidence of human pressure through bank top land cover, channel reinforcement or the introduction of non-natives.

It can be concluded that the HLS Restoration Objective Traffic Light Status is **Green** with monitoring results suggesting that river restoration does appear to meeting its aims and objectives in terms of:

- Reducing the energy in the channel through the restoration of channel morphology including bed level raising and restoration of natural channels which allows the river to reconnect with the floodplain during flood flows thus reducing the energy and erosive power of the flow in channel

- Restoring meanders to slow the flow and increase the channel length

- Re-establishing flow conditions which promote a more diverse substrate and in-channel morphology which in turn creates habitat niches for macrophytes, macro-invertebrates and fish