The Rivers of Worcestershire: a baseline geomorphological survey

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Project details

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1 Introduction

1.1 Aims of the report

Herefordshire and Worcestershire Earth Heritage Trust (H&WEHT) were provided with funding by Worcestershire County Council to undertake a baseline audit of the soils and fluvial geomorphology of Worcestershire, with a view to identifying potential Regionally Important Geological and Geomorphological Sites (RIGS). This report is concerned with the fluvial geomorphology aspects, specifically

- To determine appropriate drainage basin and stream network properties to define the character of the drainage basins of Worcestershire.
- Conduct an appropriate field survey using River Habitat Survey (RHS) and Geomorphological River Habitat Survey (GeoRHS).
- To identify and record any potential Regionally Important Geological and Geomorphological Sites (RIGS) relating to the drainage system.
- To identify river and river valley areas that may be sensitive to change.
- To identify dry valleys.
- Produce data in electronic format for use in Geographic Information Systems where appropriate.
- Produce a full report to Herefordshire and Worcestershire Earth Heritage Trust.

This report provides details of the approach, method and results of a project undertaken to define and evaluate the geomorphological characteristics of the streams and rivers of Worcestershire. A summary is provided in a separate report. The project was completed in two phases. A desk-based assessment was used to identify catchment characteristics and to select representative sites for the field data collection and analysis. Representative field sites were identified and surveyed and the resulting data were used to further characterise the fluvial geomorphology of Worcestershire's rivers.

2 Method

2.1 Desk based research

Identification of the drainage network of Worcestershire was constructed from map data in the Flood Estimation Handbook (FEH) (CEH, 2006), the network was drawn into a Geographic Information System (GIS) using MapInfo Professional 8. The stream location data are based on Ordnance Survey mapping, although intermittent and culverted drainage pathways are also shown, *e.g.* two culverted streams in Worcester City centre and 'dry valleys' in rural areas.

The river network was drawn in sections between tributary confluences, based on Strahler's Stream Order. This is a method used to describe relative channel network size, headwater streams are designated 1st order, when two 1st order streams meet the stream becomes a 2nd order. This becomes 3rd order when another 2nd order stream joins, although a 1st order stream joining a 2nd order stream makes no change (figure 1). Shreve Stream Order, the number of headwater streams in a catchment, was calculated.

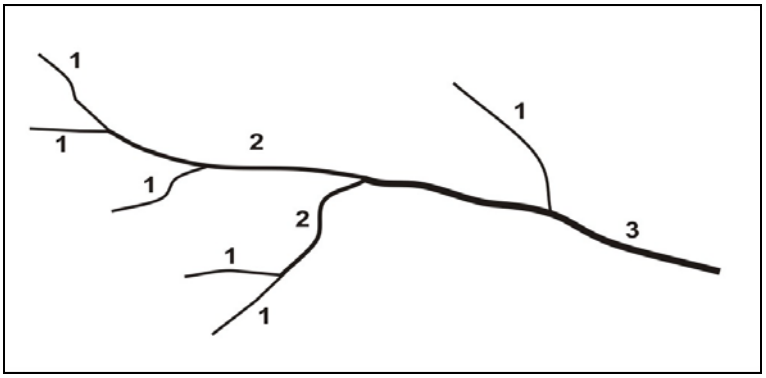


Figure 1. A stream network showing Strahler's Stream Ordering values for each segment. Shreve Stream Order is the sum of the headwater ('1') streams, here a value of six.

The drainage network was mapped beyond the limits of the county boundary for sub-catchments flowing into the county. This acknowledges the fact that administrative boundaries are not based on the river network and stream reaches upstream of the county boundary influence catchment characteristics downstream. For each section of the drainage network, channel length and Strahler stream order were recorded.

Sub-catchments were based on the point where streams joined the Rivers Severn, Avon and Teme or where they flowed out of Worcestershire. The spatial extent of each sub-catchment was drawn with reference to the stream channel extents and identified by a unique code. Three very large sub-catchments, Leigh Brook, River Stour and River Salwarpe, were divided. For each sub-catchment, area, total stream length, Shreve and Strahler Stream orders were calculated.

Channel length, catchment area, altitude, Baseflow Index (an indication of the 'flashiness' or stability of the flow regime) catchment steepness and urban extent were extracted from the Flood Estimation Handbook (FEH) (Appendix 1). Shreve stream order was calculated. Data from many sources was considered and used for sub-catchment characterisation and survey site selection (table 1).

Table 1. Summary of data sets used to characterise sub-catchments and select survey sites in 2006.

Data set	Source	Variables	Sub-catchment characterisation	Survey site selection
Worcestershire County Boundary	Digimap	N/A	No	No
Areas of Outstanding Natural Beauty	MAGIC	Number & area	No	No
Ancient Woodland	MAGIC	Number & area	No	No
Countryside Character Areas	MAGIC	Number & area	No	No
Environmentally Sensitive Areas	MAGIC	Number & area	No	No
Local Nature Reserves	MAGIC	Number & area	No	No
Natural Areas	MAGIC	Number & area	No	No
National Nature Reserves	MAGIC	Number & area	No	Yes
RAMSAR Sites	MAGIC	Number & area	N/A	N/A
Reedbeds	MAGIC	Number & area	No	Yes
Special Areas of Conservation	MAGIC	Number & area	No	Yes
Special Protection Areas	MAGIC	Number & area	No	No
Sites of Special Scientific Interest	MAGIC	Number & area	No	Yes
Wet Woodland	MAGIC	Number & area	No	No
River Habitat Survey	Environment Agency	Habitat Modification Score & Class	Yes	No
Regionally Import Geological and Geomorphological Sites	H&W Heritage Trust	Number & area	No	Yes
Flood Estimation Handbook	Centre for Ecology and Hydrology	See table 3	Yes	No

Fuzzy Discriminate Analysis (Henderson *et al*., 2005) was used to analyse the sub-catchment data. Traditional discriminant analysis assigns cases (*i.e.* sub-catchments) to groups, although in practice all cases belong to all groups by differing proportions. Fuzzy Grouping shows the proportion of membership of all groups, *e.g.* an hypothetical sub-catchment might have the following group membership - Group 1: 80%, Group 2: 12% and Group 3: 8%.

Sub-catchment data was examined using Fuzzy Discriminant Analysis to determine the variables which most strongly influenced the grouping. After each analysis, the variable with the weakest relationship was removed, and the analysis re-run. This was repeated until the strength of the analysis peaked. Each sub-catchment was allocated to the group to which it had the strongest relationship, whilst the strength of the relationships with other groups was utilised in survey site selection.

Sub-catchments were selected for field survey according to the following criteria -

1. strongly representative of groups one, two or three,
2. borderline cases with characteristics of two groups,
3. that exhibit characteristics of all three groups,
4. each of the main rivers,

5. largest - sub-catchment; urban area; Site of Special Scientific Interest (SSSI) area, and National Nature Reserve (NNR) area,
6. sensitivity to change from proposed large scale land-use development,
7. pristine site, and
8. sites with particular Geomorphological interest (*e.g.* RIGS sites).

Results are outlined in section 4.3.3.

2.2 Field survey

Two field survey methods were employed. The River Habitat Survey (RHS) (Environment-Agency, 2003) is an established method of characterising river habitats and comprises ten channel transects along a 500m river reach with a 'sweep-up' of features over the whole reach. Data are analysed in a dedicated computer programme. GeoRHS, is a floodplain geomorphological module, intended to be run alongside RHS. This survey method records the presence of a wider range of in-channel geomorphic features, and pays particular attention to floodplain geomorphology. GeoRHS is currently under development and, to-date the developers have not produced a dedicated analysis tool although initial trials have demonstrated the method is robust (Environment Agency, 2005).

Sites in the lower reaches of each catchment, before the confluence with the first largest tributary, were identified for survey. Consideration was given to access and use of surrounding land.

Data from RHS were analysed using the RHS database, version 3, running in Microsoft Access. Data from GeoRHS were analysed in Fuzzy Grouping because dedicated software is not yet available. GIS data was subsequently converted from MapInfo files to ArcView format, to ensure compatibility, prior to distribution.

3 Desk based research

3.1 Identification of drainage network

Topographically, Worcestershire resembles a bowl with high ground around its perimeter, few rivers flow out of the county (*e.g.* River Cole near Hollywood and Sapey Brook near Clifton on Teme). The network of streams within152 'sub-catchments' in the extended network extends to 2,344km, of which 1,774km are in Worcestershire, (figure 2).

3.1.1 Characterisation of drainage network

In the extended Worcestershire river network, 1,389 stream segments were identified and 1,386 classified. Table 2 shows an example of data extracted from the Flood Estimation Handbook for eight streams with Shreve stream order values. Shreve stream order for the Rivers Severn, Avon and Teme was not calculated due to large extent of these catchments outside Worcestershire, they were assigned notional values to reflect their rank.

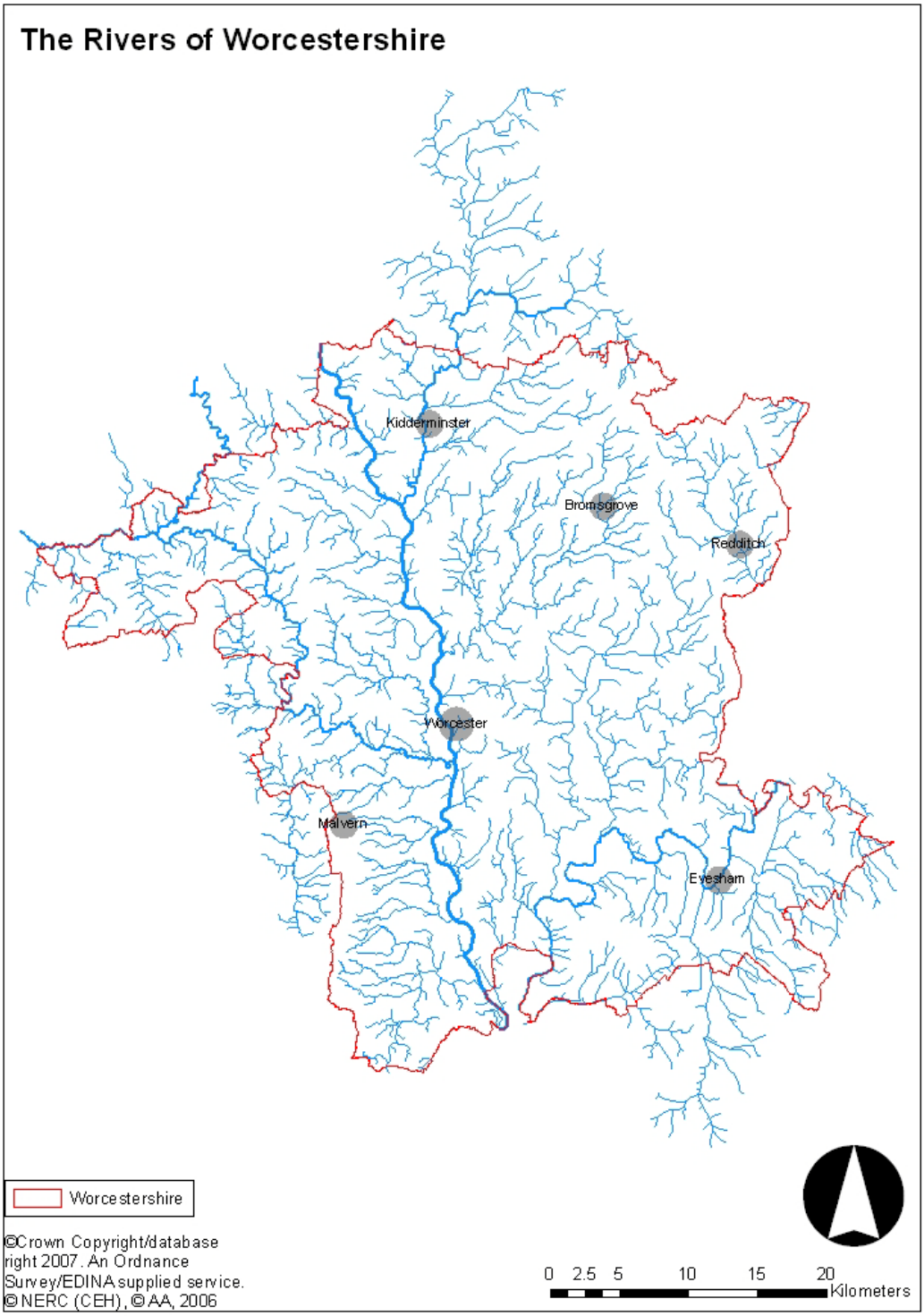


Figure 2. The extended river network of Worcestershire.

Table 2. Eight Worcestershire streams showing physical data used in the desk based research.

River code	River Name	Channel length (km)	Area (km^2)	Altitude mean (m)	Baseflow Index	DPS (Catchment steepness)	1990 Urban extent	Shreve stream order
bw	Bow Brook	148.4	164	61	0.335	33.6	0.0246	62
bd	Badsey Brook	99.34	96.08	77	0.338	42.4	0.0349	44
hd	Hadley Bk	58.33	55.78	68	0.547	35.8	0.0184	23
la	Laughern Bk	52.78	49.14	61	0.516	38.2	0.0419	25
X01	Bockleton Bk	5.99	9.08	137	0.627	5.2	0.0022	3
du	Duck Bk	4.665	4.68	47	0.383	36.5	0.2454	2
t11	Noak Bk	2.056	1.54	103	0.565	102.4	0.0032	1
a31	Bredon Bk	1.257	1.44	39	0.719	35.9	0.1185	1

Most of Worcestershire's rivers are of low Strahler stream order and because area is highly correlated with stream order, most sub-catchments are also small (figure 3).

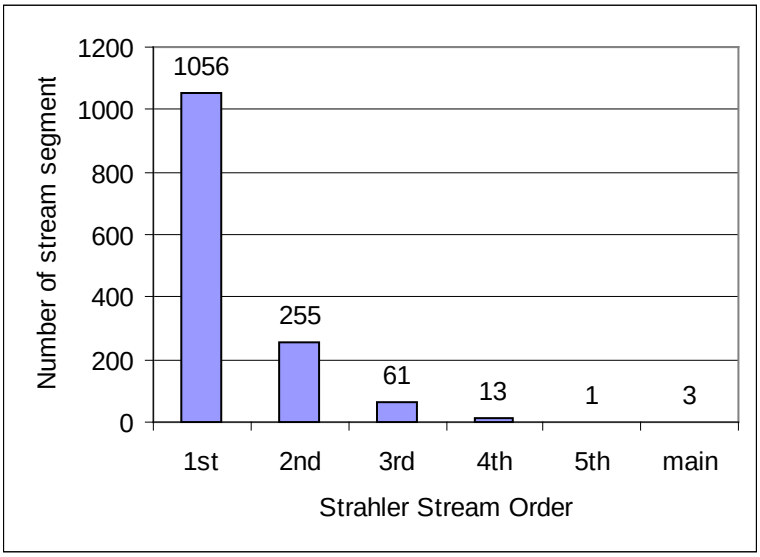


Figure 3. Frequency histogram of Worcestershire (extended) stream segments by Strahler's Stream Order.

Records of 109 River Habitat Surveys (E-A, 2007) in Worcestershire – including the main rivers were examined. Sites are classified by their Habitat Modification Score into five classes, 1 being least modified and 5 highly modified. Figure 4 shows the numbers of sites in each class. Although the RHS survey sites are scattered across the county, the majority are on streams with higher stream orders (figure 5). Although this distorts the overall picture, the results are still worthy of consideration.

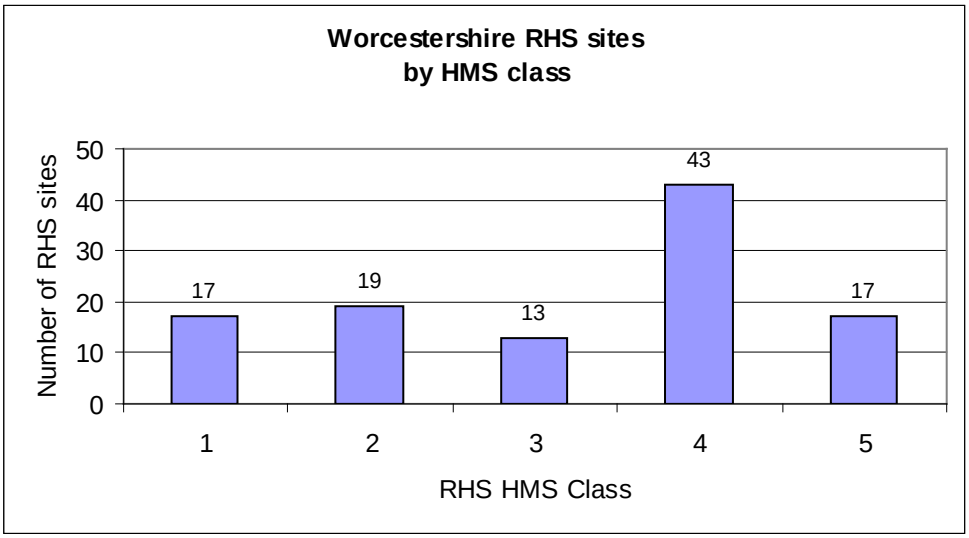


Figure 4. RHS Habitat Modification Classes of Worcestershire Rivers.

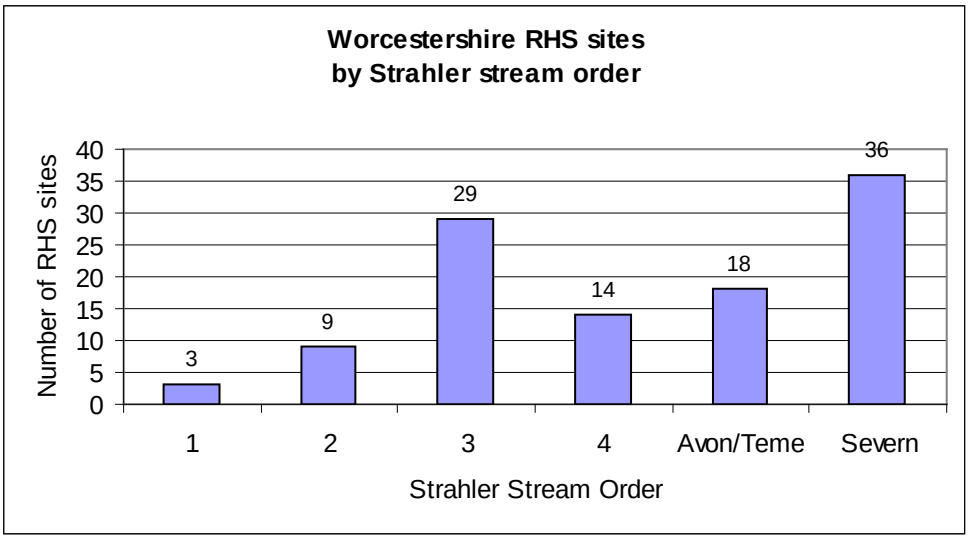


Figure 5. RHS sites on Worcestershire Rivers by Stahler stream order

Frequency histograms of sub-catchment area, gradient, and urban extent are shown in figure 6. Many sub-catchments within the County are small, and because of the topography of the County, also have a low gradient. Urbanisation is shown as a percentage of sub-catchment area, with 29 sub-catchments having no urban area and 92 have less than 5%. A few catchments are more heavily urbanised, with the two most heavily urbanised, S17 (48%) and S18 (47%) in Worcester City Centre.

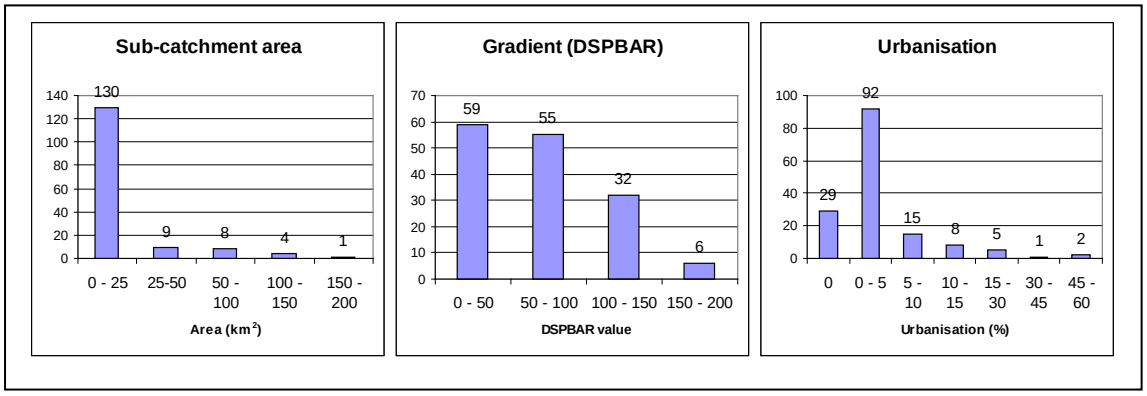


Figure 6. Frequency histograms of sub-catchment area, gradient and urban extent for the extended Worcestershire sub-catchment area.

3.1.2 Characterisation of sub-catchments

The classification of sub-catchments within the County was based on selection of key catchment variables. An iterative process was used to identify the appropriate catchment variables, table 3 shows the variables having the strongest relationship with Fuzzy Discriminant Analysis axes.

Table 3. Variables used to determine sub-catchment groups. Source: FEH – (CEH, 2006); GIS – calculated from GIS programme.

Variable used	Source
Length of stream network in sub-catchment	FEH/GIS
Area of sub-catchment	FEH
Shreve Stream Order	GIS
Mean altitude	FEH
Base Flow Index	FEH
DPS (catchment steepness)	FEH
Urban extent	FEH

The main rivers - Severn, Avon and Teme were identified as belonging to a separate group, and were placed into group four. Fuzzy Discriminant Analysis was used to separate the remaining sub-catchments into three groups. Appendix 2 shows Worcestershire sub-catchments by group.

All sub-catchments are members of all three groups, although by varying proportions, e.g. Sub-catchment A25 is placed in group 1 with a membership weight of 80.06%. However, it also has a membership of group 2 (11.71%) and group 3 (8.23%). Figure 7 shows the discriminant plot of 152 sub-catchments, the three groups are coloured red, yellow and purple. The membership strength to the assigned group is indicated by the transparency of the symbol, the stronger memberships are less transparent.

The strength of the variables used in Fuzzy Discriminant Analysis has been examined by plotting against Axes one and two. Axis one is strongly positively correlated with altitude (R^2 = 0.829) and slope (R^2 = 0.716), urbanisation is negatively correlated (R^2 = 0.12). Axis two is strongly correlated, positively with Shreve stream order (R^2 = 0.931), area (R^2 = 0.921) and channel length (R^2 = 0.92), whilst slope is negatively correlated (R^2 = 0.167). Scatter plots for all variables are shown in appendix 4.

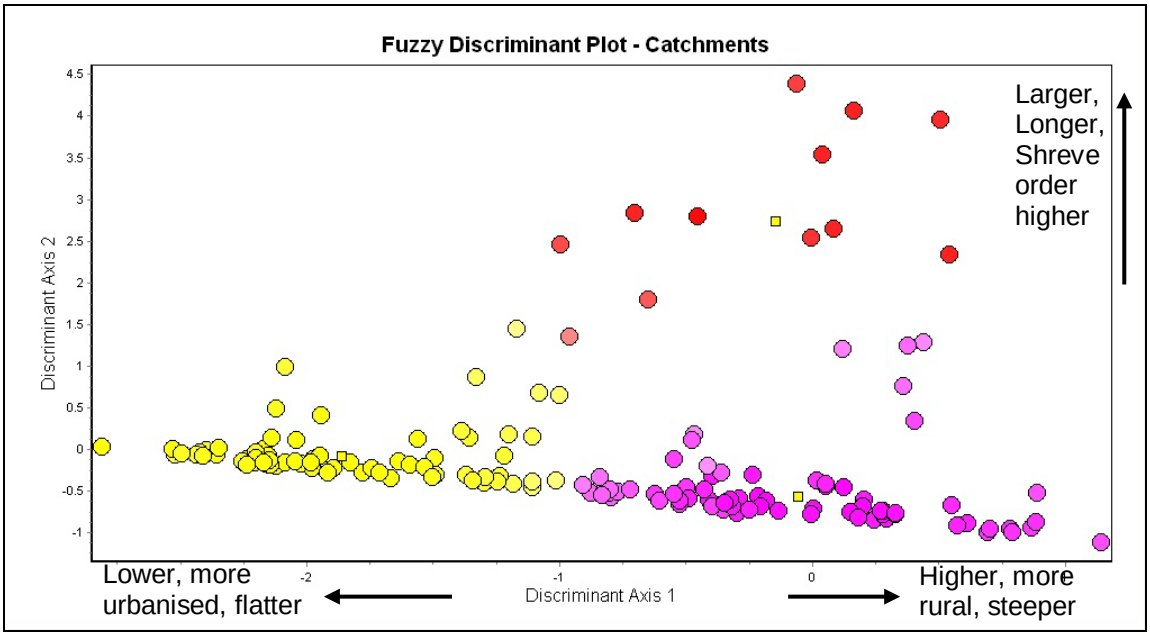


Figure 7. Fuzzy Discriminant plot showing 152 catchments separated into three groups by colour and the degrees of membership to the strongest group by the degree of opaqueness of the symbol.

The characteristics of the three sub-catchment groups are described in table 4, photographs of each type are shown in figure 8.

Table 4. Sub-catchment group descriptions.

	Description
Group 1	Small catchments generally with short channel length at higher altitude and/or gradient. Many are located on the steeper valley sides of the River Teme, with others on the slopes of Bredon Hill.
Group 2	Larger catchments at generally lower altitude and gradient, many on the flood plains of the rivers Severn and Avon.
Group 3	Large catchments with long stream channels and low overall gradients, although some (e.g. Bow Brook, River Stour) rise at relatively high altitude.
Group 4	Main Rivers within whose catchments the sub-catchments are 'nested'.

Group 1 – Pipers Brook

Group 2 – Bushley Brook

Group 3 – Badsey Brook

Group 4 – River Severn

Figure 8. Example photographs of each river group identified in the desk-based survey.

The sub-catchments, river network and the extent of Worcestershire are shown in figure 9, with the sub-catchments shaded by group membership. This shows that group one sub-catchments are located on steeper ground in the Teme valley and on the slopes of Bredon Hill, group two are small catchments predominantly on, and adjacent to the floodplains of the Rivers Severn and Avon, whilst group three comprise the large gently sloping catchments.

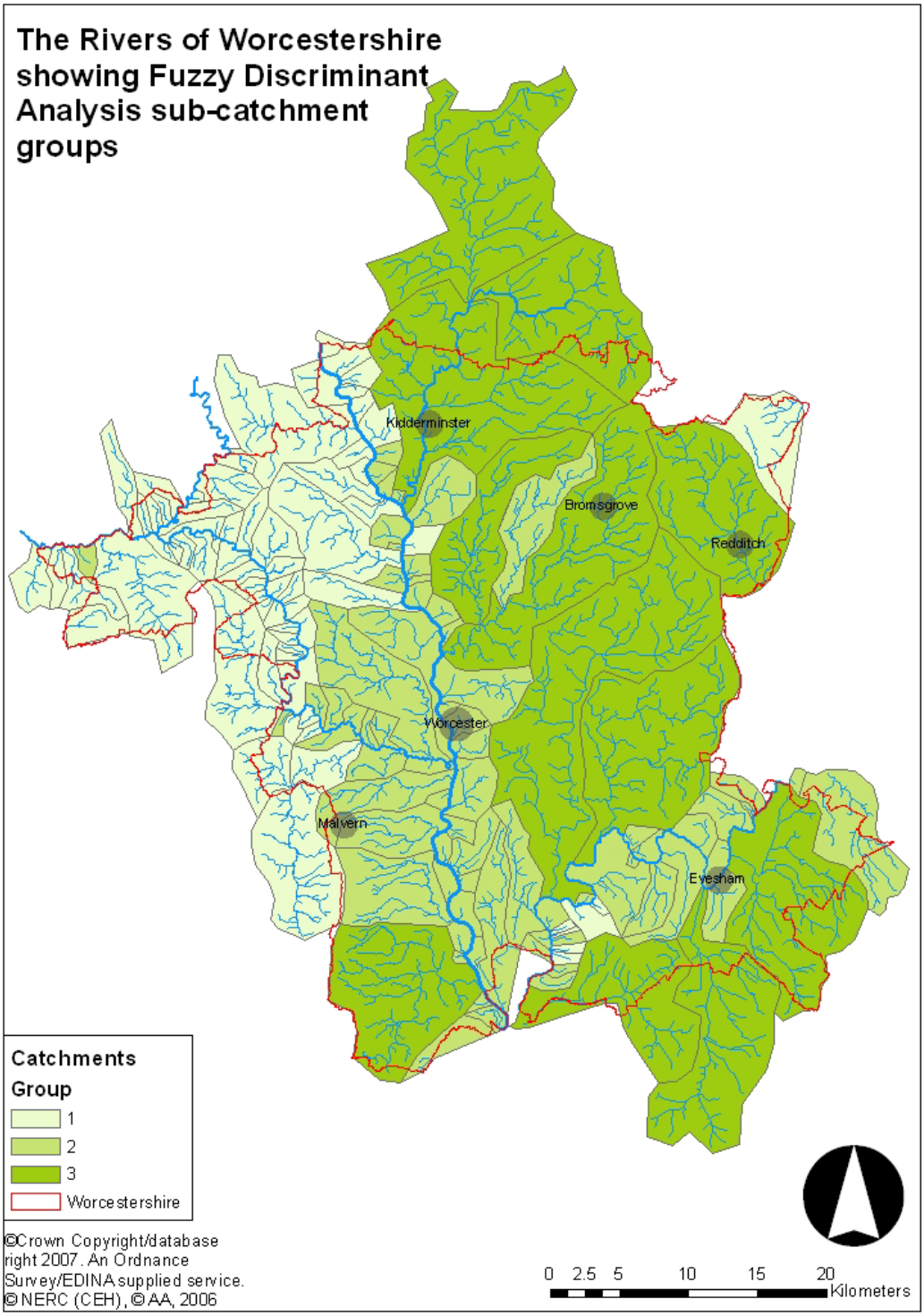


Figure 9. Sub-catchments of the extended Worcestershire stream network shaded by sub-catchment group.

4 Field Survey

4.1 Location

Twenty two sites were surveyed between 14th May and 28th August 2007 (table 5, figure 15) by two experienced surveyors. The fieldwork programme was disrupted by unusually high rainfall and river flows in late June and late July. Both RHS & GeoRHS are conducted at 'summer low flows' broadly equivalent to baseflow conditions, therefore there were periods when flows were too high for surveying.

Table 5. Fieldwork sites surveyed during 2007.

UID	Name	Location	Group	Selection criteria
Severn	R Severn	Upton on Severn (384694 241361)	4	Major river
Avon	R Avon	Cropthorne (400019 245579)	4	Major river / RIGS site
Teme	R Teme	Bransford (379923 253374)	4	Major river
T11	Teme Trib	Noak Farm (373161 260473)	1	Gp1 (98%)
A26	Woolas Bk	East of Eckington (394097 241043)	1	Gp1 (97%) & Mudslide
A31	Bredon Bk	Bredon Village 392615 237102	2	Gp2 (99%)
du	Duck Bk	Battenhall Fields (386040 252924)	2	Gp2 (99%)
bd	Badsey Bk	Offenham Cross (405891 245101)	3	Gp3 (95%)
ar	R Arrow	Arrow Valley Park (405999 266971)	3	Gp3 (86%)
T54	Doddenham Bk	Doddenham (375249 256300)	2	Gp1/2 (44/50%)
S11	Severn Trib	S of Lincomb (381388 267884)	1	Gp1/2 (50/43%)
ky	Kyre Bk	Tenbury Wells (359971 267363)	1	Gp1/3 (50/30%)
hd	Hadley Bk	Harford Hill (386872 262049)	3	Gp3/2 (36/45%)
la	Laugherne Bk	W of Hallow (382541 257986)	2	Gp3/2 (36/45%)
X01	Bockleton Bk	W of Bockleton 357830 262060)	1	Gp1/2/3 (42/32/24%)
bb	Barbourne Bk	Ghulevelt Park (384541 256447)	2	Urban extent
bw	Bow Bk	Tydsley Wood (392688 246198)	3	Largest catchment
do	Dowles Bk	Knowles Meadow (376275 276497)	1	Largest NNR/SSSI
le01	Leigh Bk	Knapp & Papermill (351369 274523)	1	Pristine site
lo	Longdon Bk	Bredon School (385053 236413)	3	Longdon Marsh
po	Powick Bk	Upper Howsell (378826 249279)	2	North Site development
T21	Pipers Bk	Death's Dingle (367000 267750)	3	Tufa deposits

4.2 River Habitat Survey

4.2.1 Habitat Modification and Quality

Data from RHS field surveys were analysed to describe the extent of human modification of river habitats and habitat quality. Results are shown in Table 6 and App 5.

Habitat Modification Scores (HMS) are calculated and categorised into five classes, high class numbers are associated with reaches with higher degrees of modification. A wide range of habitat modification is present in Worcestershire (Table 6). Group one streams exhibited the lowest degree of modification (figure 10) whilst group three streams had a greater degree of modification (all within class 3 or 4). Of the main rivers surveyed (group 4) the Severn and Avon fall in HMS class 4, largely due to embankment, moorings and fishing platforms whilst the Teme is largely unmodified.

Table 6. Habitat Modification and Quality Assessment Scores calculated in the RHS Database for 22 Worcestershire Rivers in 2007.

UID	River name	Group	Habitat Modification Score	Habitat Modification Index class	Habitat Quality Assessment (adjusted)
Teme	Teme	4	0	1	5
po	Powick	2	0	1	45
do	Dowles	1	0	1	57
T21	Pipers	1	0	1	60
A26	Woolas	1	1	1	37
LE01	Leigh	1	1	1	45
X01	Bockleton	1	5	2	52
T54	Dodenham	2	8	2	51
la	Laugherne	2	11	3	30
A	Avon	4	13	3	31
ky	Kyre	1	15	3	42
T11	Noak	1	15	3	46
A31	Bredon	2	17	3	44
lo	Longdon	3	18	3	25
bw	Bow	3	18	3	35
Severn	Severn	4	19	3	19
bd	Badsey	3	20	3	33
hd	Hadley	3	20	3	36
du	Duck	2	27	4	38
ar	Arrow	3	29	4	34
S11	Winnall	1	38	4	33
bb	Barbourne	2	65	5	22

Habitat Quality Assessment scores provide a guide to habitat quality. High scores indicate good quality habitats (figure 10). The River Severn has a low score, 19, attributable to boat moorings, lack of hydraulic diversity and poor bank vegetation complexity, whilst T21 - Pipers Brook, has little modification, complex hydraulics and complex vegetation structure. Group One streams have high HQA scores whilst Group 4 streams have low scores (figure 10). Although the River Teme scores well on habitat modification, intensive agriculture, to the channel edge, reduces the habitat quality resulting in a low habitat score (5).

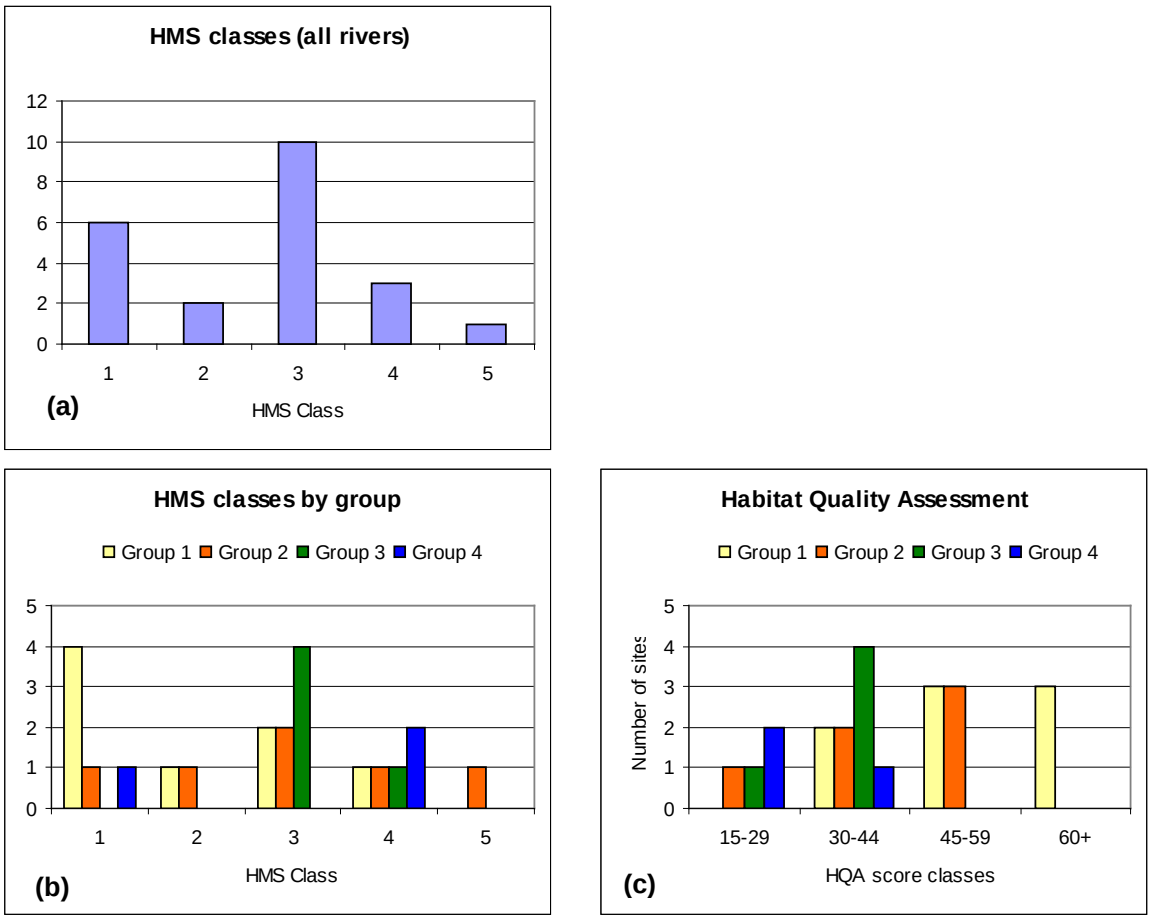


Figure 10. RHS Habitat Modification Score classes and Habitat Quality Assessment scores in Worcestershire Rivers.

4.2.2 Channel substrate and bank material

Seven types of channel substrate were recorded as dominant at the RHS transects (substrate and bank material recorded as not visible have been excluded). 11% were recorded as bedrock (BE), 15% as boulder (BO), 37% gravel/pebble (GP), 8% sand (SA), 3% silt (SI), 20% clay (CL), 6% artificial (AR). Peat (PE) and earth (EA) were not present (figure 11a). By contrast at 70% of transects the dominant bank material recorded was clay (CL) with 10% earth (EA), figure 11b.

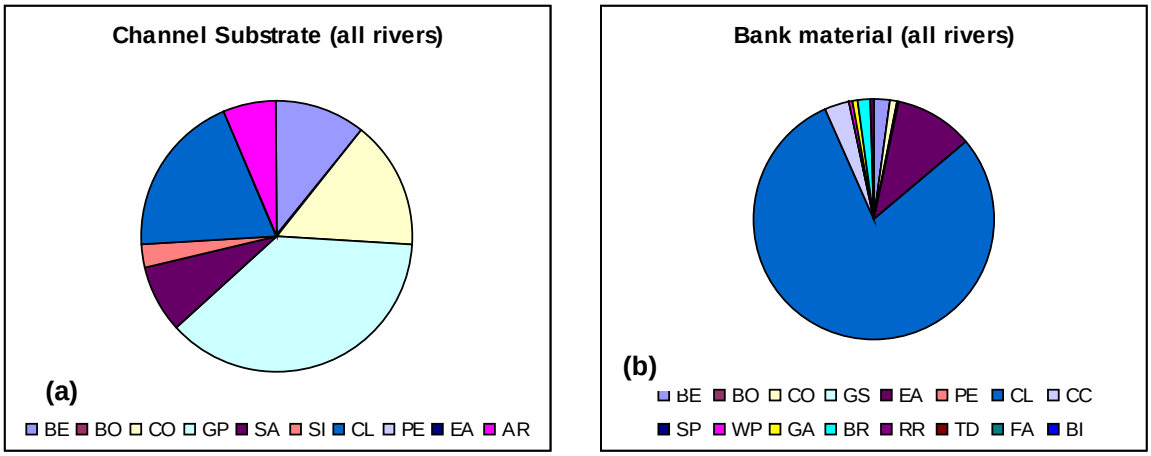
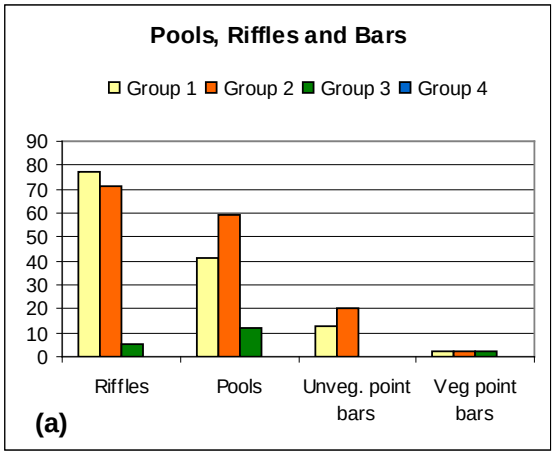


Figure 11. Channel substrate recorded at RHS transects, excluding those recorded as 'not visible'.
Key: BE bedrock; BO boulder; CO cobble; GP gravel/pebble; GS gravel/sand; SI silt; CL clay; EA earth; AR artificial; PE peat; CC concrete; SP sheet piling; WP wooden piling; GA gabion; BR brick/laid stone; RR rip-rap; TD tipped debris; FA fabric; BI Bioengineering.

4.2.3 Pools, Riffles and Bars

The number of pools riffles and bars indicate geomorphological variety which is linked to biodiversity. These features are absent from the main rivers, which exhibit little in-channel morphological diversity, whilst at the other extreme, 26 pools and riffles were recorded in Powick Brook.

Pools riffles and bars are most numerous in groups one and two, with group three streams having small numbers of these features (figure 12a). Similarly unvegetated point bars are more common in groups one and two. These data show that, geomorphologically, groups one and two are more diverse than groups three and four. Histograms of pool and riffle occurrence are presented in figures 12b and 12c, showing that most sites had few pools or riffles (or none) and only a small minority of sites were dominated by large numbers of these features and hence exhibited geomorphological diversity.



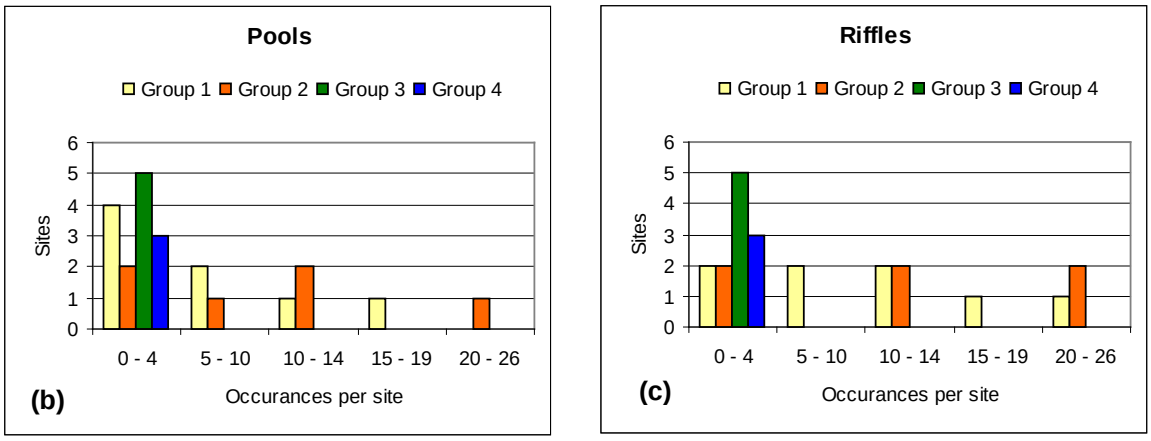


Figure 12. Pool, riffle and bar occurrence in Worcestershire Rivers.

4.3 GeoRHS Survey

4.3.1 Channel slope

Channel slope diminishes from group one to four (table 7), confirming that catchment slope is a driving variable in the selection of catchment group at the desk based phase. In group three Pipers Brook (T21) being particularly steep (6.25^{o}) has been removed from as it is an outlier.

Table 7. Mean channel slope from GeoRHS by group (excluding T21, Pipers Brook).

	Group 1	Group 2	Group 3	Group 4
Mean slope (^{o})	1.1	0.73	0.5	0.33

4.3.2 Active geomorphology

Natural streams are more likely to have active erosional and depositional processes whilst modified rivers will tend to have fewer. Figure 13a shows that the area of active side and point bars decreases from group one to four whilst the extent of engineering works and embankments (by bank length) generally increases in frequency from group one streams to group four main rivers (figure 13b).

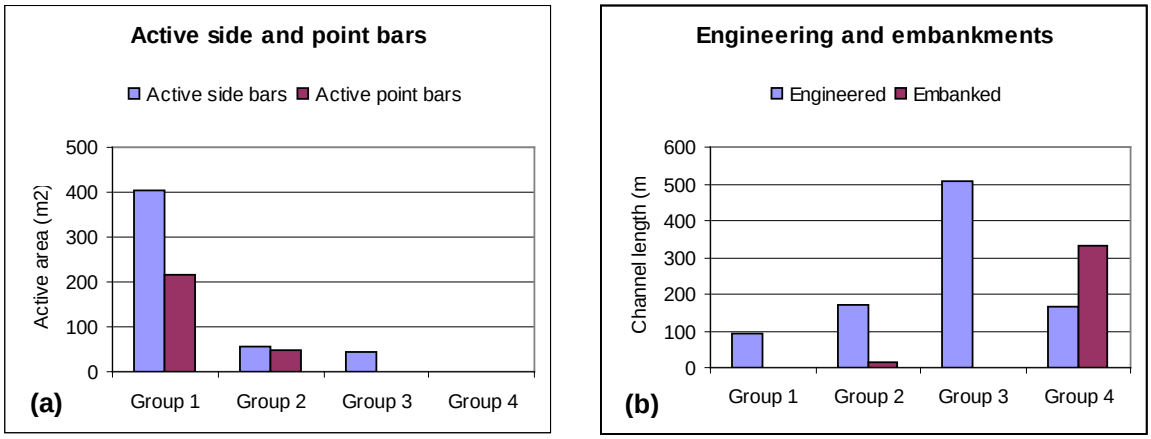


Figure 13. Active deposition and engineering from GeoRHS surveys by cluster.

4.3.3 River Clusters

Analysis of the field survey data using Fuzzy Discriminant Analysis enabled a ***preliminary re-classification*** of Worcestershire's streams and rivers into four different clusters. This is based on RHS scores (HMS and HQA) and 17 GeoRHS variables (table 8), therefore the results are biased towards these survey sites and may not be representative of the whole catchment.

The relationship between fieldwork variables and the roots of the discriminant analysis shows that root 1 (x-axis) is dominated by engineering (R^2 value – 0.971), and that length area, habitat quality, channel depth and stable bars are strongly associated (R^2 values >0.200). Root 2 (y-axis) has weaker relationships, altitude is strongest (R^2 value – 0.341) whilst active point bars, erosion, bankfull width and active side bars have R^2 values >0.100.

Table 8. Field variables used in Fuzzy Discriminant Analysis, with the strength of the relationship between the variable and Discriminant Roots one and two.

Variable	Root 1	Root 2
GeoRHS Engineered	**0.971**	0.004
GIS length	**0.428**	0.021
FEH area	**0.404**	0.025
RHS Habitat Quality Assessment	**0.360**	0.004
GeoRHS Bankfull depth	**0.235**	0.111
GeoRHS Stable side bars	**0.231**	0.000
FEH altitude	**0.134**	**0.341**
GeoRHS Active Point Bars	0.055	**0.213**
GeoRHS Bankfull width	**0.107**	**0.167**
GeoRHS Erosion	**0.109**	**0.146**
GeoRHS Active side bars	0.049	**0.142**
GeoRHS Slope	0.062	0.070
GeoRHS Buffer zones	0.017	0.068
GeoRHS Channel features	**0.120**	0.048
Strahler Order	**0.122**	0.030
GeoRHS Coarse woody debris jams	0.056	0.029
RHS Habitat Modification Score	**0.199**	0.009
GeoRHS Left floodplain width	0.058	0.007
GeoRHS Active mid-channel bars	0.094	0.005
GeoRHS Ponded	0.030	0.003
GeoRHS Biological	**0.125**	0.001
GeoRHS Embankment	0.048	0.001
GeoRHS Right floodplain width	0.000	0.000

The result of Fuzzy Discriminant Analysis of 19 survey sites, excluding the main rivers, is shown in figure 14. Although the sites have been separated into three clusters, they all belong to all clusters in different proportions; this is indicated by the degree of transparency in the symbols.

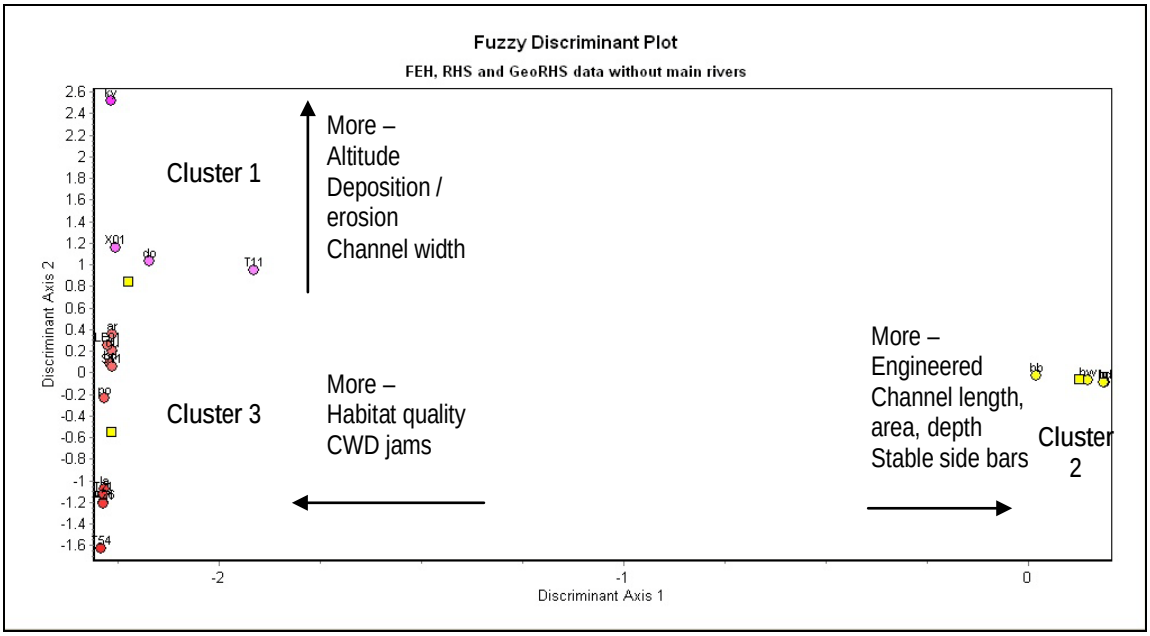


Figure 14. Fuzzy Discriminant Plot of 19 Worcestershire rivers surveyed in 2007 showing the three clusters. The variables with the strongest relationship to the two axes are shown.

Cluster 1 sites are higher, geomorphologically active, smaller, more natural with good habitat quality, cluster 2 are more engineered, large, more stable with poorer habitat quality. Cluster 3 are lower, smaller, more natural with good habitat quality and less erosion (Table 9, figure 11).

Table 9. Membership and descriptions of four river clusters based on Fuzzy Discriminant Analysis of 19 sites surveyed in 2007.

		Description
Cluster 1	Kyre Brook, Bockleton Brook, Dowles Brook, Noak Brook	Higher, geomorphologically active, smaller, more natural, good habitat quality
Cluster 2	Longdon Brook, Barbourne Brook, Bow Brook, Badsey Brook	More engineered, large, more stable, poorer habitat quality,
Cluster 3	Doddenham Brook, Winnall Springs, Hadley Brook, R. Arrow, Laugherne Brook, Leigh Brook, Powick Brook, Duck Brook, Woolas Brook, Bredon Brook.	Lower, smaller, natural, good habitat quality, less erosion.
Cluster 4	Rivers Severn, Avon and Teme	The main rivers, much larger and less diverse, highly modified and engineered.

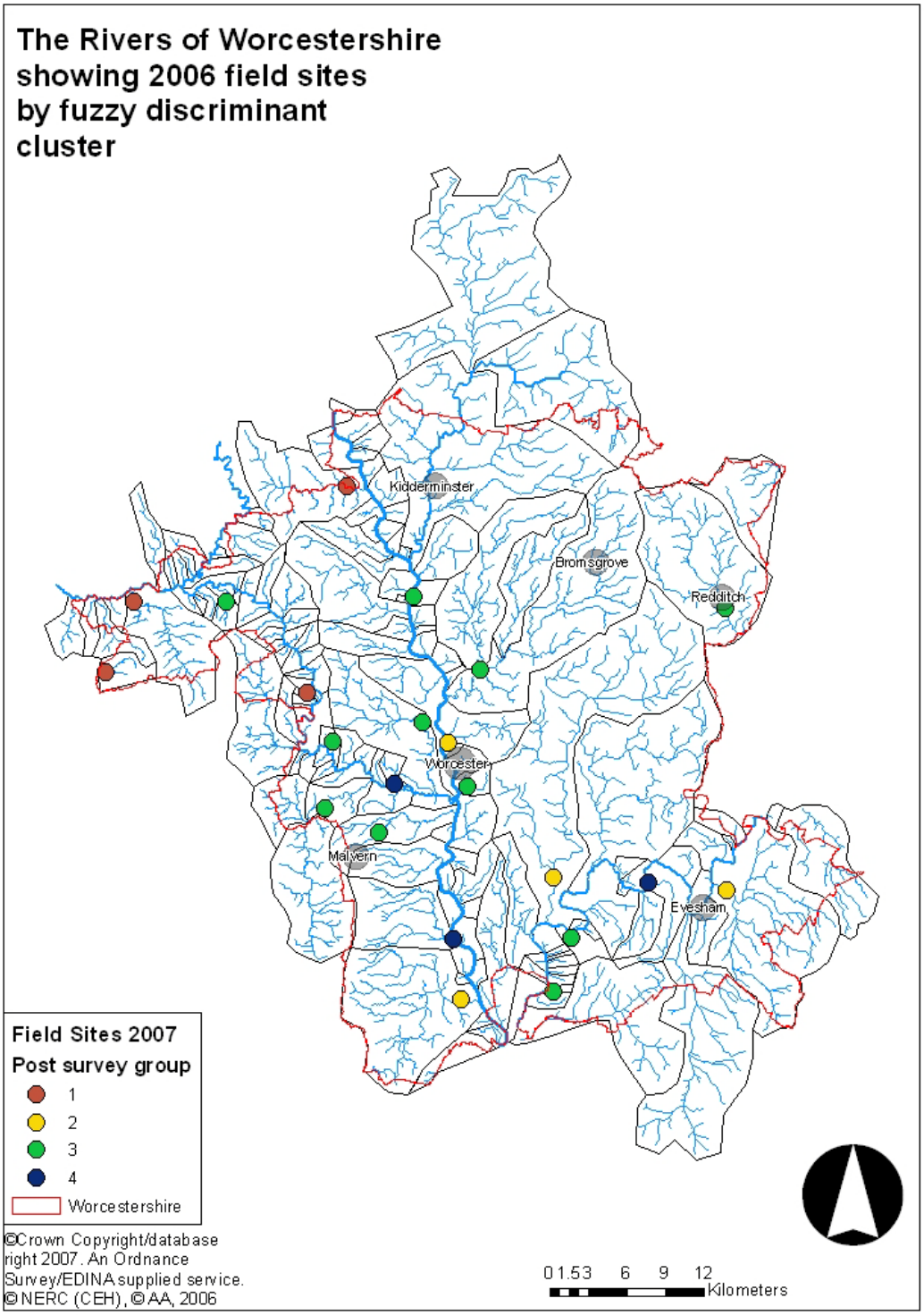


Figure 15. Worcestershire Rivers showing survey sites and associated clusters.

4.4 Indexation of RHS & GeoRHS data

Table 10 shows the variables used to calculate the index, red shading shows negative impacts, green shows positive impacts. The sum of the positive and negative impacts for each unit of measurement - area, length, number of occurrences and Absent/Present/ Extensive - was calculated. To reduce the weight of the length category (where one embankment alone can score 500), the length value was divided by 10, being the number of transects used in the RHS. The four resulting values were summed to produce the index value.

Table 10. Variables used in the index, positive impacts shown in green and negative in red.

Variable	Source	Unit
A10 Engineered	GeoRHS	Length (m)
B Erosion	GeoRHS	Length (m)
B Biological	GeoRHS	Length (m)
B Channel features	GeoRHS	Length (m)
C1 Active Point bars	GeoRHS	Area (m^2)
C2 Active Side bars	GeoRHS	Area (m^2)
C3 Active Mid-channel bars	GeoRHS	Area (m^2)
C4 Active Tributary bars	GeoRHS	Area (m^2)
C10 Berms (unveg)	GeoRHS	Area (m^2)
C16 Waste disposal	GeoRHS	Area (m^2)
C17 Sediment jams/dams	GeoRHS	Area (m^2)
C18 Macrophyte chokes	GeoRHS	Area (m^2)
C19 CWD jams/dams	GeoRHS	Area (m^2)
E3 Active side channels	GeoRHS	Sum 0/1/2
E8 Length of EM	GeoRHS	Length (m)
F1 Channel migration	GeoRHS	Sum 0/1/2
F7 Buffer zone ave. width	GeoRHS	Length (m)
J6 Eroding banks in shallow reaches	GeoRHS	0/1/2
J7 contracted channel at bridges	GeoRHS	0/1/2
J8 recent & extensive dredging/desilting	GeoRHS	0/1/2
K3 Recent cut-offs (dry/wetland)	GeoRHS	0/1/2
K5 Extensive slumping both banks	GeoRHS	0/1/2
K8 Artificial bed stabilisation structures	GeoRHS	0/1/2
Total Major	RHS	Number
Artificial LB Material	RHS	Number
Artificial Bed Material	RHS	Number
Artificial RB Material	RHS	Number
Exposed bedrock	RHS	0/1/2
Exposed boulders	RHS	0/1/2
Veg bedrock/boulders	RHS	0/1/2

The results of this are shown in table 11, where the sites are ranked in increasing order of naturalness based on the index value. Component values are also shown. The order shown reflects the order and magnitude of the site on the natural/modified spectrum. In re-surveys increases in occurrence/length/area of active erosion/deposition or artificial structures would be highlighted by changes in the index value.

Table 11. Results of indexation of 2006 surveys.

UID	River name	Index Score	Absent/ Present/ Extensive	length (/10)	Area (m^2)	Transects
BB	Barbourne Brook	**-115**	-1	-92	0	-22
Severn	River Severn	**-108**	0	-98	0	-10
lo	Bushley Brook	**-96**	0	-96	0	0
Bo	Bow Brook	**-92**	3	-99	4	0
Bd	Badsey Brook	**-84**	2	-96	10	0
Avon	River Avon	**-42**	0	-41	0	-1
s11	Winnall Springs	**-15**	0	-7	0	-8
t11	Noak Brook	**-1**	4	-27	23	-1
Teme	River Teme	**2**	0	2	0	0
ar	River Arrow	**4**	2	-1	8	-5
du	Duck Brook	**8**	0	-3	12	-1
hd	Hadley Bk	**23**	2	15	6	0
A26	Woolas Brook	**27**	2	4	21	0
La	Laugherne Brook	**33**	3	3	27	0
a31	Bredon Brook	**41**	2	10	31	-2
LE01	Leigh Brook	**46**	6	16	24	0
t54	Doddenham Brook	**48**	4	6	39	-1
ky	Kyre Brook	**58**	2	-3	61	-2
T21	Pipers	**108**	3	6	99	0
po	Whippets Brook	**113**	2	3	108	0
X01	Bockleton Brook	**260**	7	11	249	-7
Do	Dowles Brook	**554**	8	32	514	0

4.5 RIGS sites

Twelve previously recorded Regionally Important Geological and Geomorphological Sites (RIGS) have been mapped onto a GIS file. Further GIS files containing 10 sites with RIGS potential and 54 potentially dry valleys have been produced.

RIGS sites were digitised from data provided by H&WEHT, potential RIGS sites were noted during surveys in Worcestershire and potential dry valleys identified from examination of OS 50k maps.

4.6 Sites sensitive to change

Several field sites that were deemed sensitive to change were considered. Powick Brook at Lower Howsell, Malvern was selected due to it's proximity to a large housing development upstream – North Site – and the potential for geomorphic change that may be experienced in future. Other sites with potential for impact include R. Arrow downstream of Redditch, Duck Brook in Worcester and Winnall Springs (S11) near Ombersley all of which are in areas undergoing development.

5 Summary and Conclusions

This study has determined the extent of the river network in, and in the hinterland of, Worcestershire, and placed the sub-catchments into groups reflecting their physical character. The 'main rivers' of the Severn, Avon and Teme dominate the Worcestershire landscape, but in addition there are approximately 1,774km of streams and rivers within the County, organised into 152 sub-catchments.

The desk-based analysis of the main rivers and sub-catchments present within the County enabled a description of their character and a broad classification of four types of stream present. The four groups were subsequently used to identify 22 sites where RHS and GeoRHS field surveys were carried out along 500m reaches at each site. This provided a more detailed description of the geomorphology of a representative sample of Worcestershire's streams and rivers. These are:-

Sub-catchment group	Description
Group 1	Small catchments generally with short channel length and located at higher altitude and/or gradient. Many are located on the steeper valley sides of the River Teme in the west of the County, with others on the slopes of Bredon Hill to the east. Streams and rivers in this group tend to exhibit little or no human modification and have relatively high habitat quality and morphological diversity, with pools, riffles and sediment bars commonly present in the channel.
Group 2	Larger catchments at generally lower altitude and gradient, many on the flood plains of the rivers Severn and Avon. Streams and rivers in this group tend to exhibit some human modification, have intermediate habitat quality and some morphological diversity, with pools, riffles and sediment bars present in the channel.
Group 3	Large catchments with long stream channels and low overall gradients, although some (e.g. Bow Brook, River Stour) rise at relatively high altitude. Streams and rivers in this group tend to be modified, have intermediate habitat quality and limited elements morphological diversity, with pools, riffles and sediment bars present at a small number of sites.
Group 4	Main Rivers with large catchment areas that extend far beyond the County boundaries, i.e. Rivers Severn, Avon and Teme. The sub-catchments that make up the previous three groups are generally 'nested' within these large catchment areas. The River Severn and River Avon are both navigable and tend to exhibit extensive human modification, have low habitat quality and little or no morphological diversity, with pools, riffles and sediment bars rarely present in the channel. The River Teme is not navigable and has less modification and hence has slightly higher habitat quality with some morphological diversity.

Based on these data, a re-classification of river types was proposed into four 'new' clusters. However, we recommend this re-classification be treated as preliminary given the relatively short channel lengths subject to field investigation (11km out of 1,774km) that were used to derive these clusters. Therefore, the results of the desk-based survey

and classification (shown above) are more complete and can be used to describe the County's rivers at the landscape scale at this stage.

However, geomorphological classification of river types is best carried out on field survey data rather than catchment characteristics derived from desk-based (e.g. map) data. With additional field surveys, the preliminary classification of Worcestershire's streams and rivers based on field data could be refined and independently tested. This classification could then supersede the classification based solely on catchment characteristics shown above.

Sites of interest to the H&WEHT have been identified, located and notified to them.

The GIS files accompanying this report provide a broad characterisation of the fluvial geomorphology of Worcestershire and could be used to inform landscape description.

5.1 Electronic data

The following data are provided in electronic format (shapefiles) on a CD attached to this report:

1. Worcestershire (extended) stream network including includes main rivers showing length and Strahler stream order,
2. Worcestershire sub-catchments with Shreve stream order and original catchment groups (excludes main rivers).
3. Field sites surveyed during 2007 with Strahler Stream Order and post survey clusters.
4. Known locations of peat in Worcestershire.
5. Known RIGS sites.
6. Potential RIGS sites.
7. Potentially dry valleys.

6 Recommendations for further work

1. ***Further streams should be surveyed*** using RHS and GeoRHS; particularly headwater streams (*i.e.* lower Strahler order streams). These are currently under represented in the field data set.

2. The collection of additional field survey data would enable ***refinement and independent testing of the preliminary classification of Worcestershire's streams and rivers*** based on field data that we have established. This could subsequently used as the preferred classification system for the geomorphology of the County's rivers and streams.

3. Rivers and streams are naturally dynamic entities, and respond to changes that may occur both within the channel upstream, and on the land surface that occupies the catchment. As such, changes in channel morphology can provide important information on the 'health' of a river system, which in turn may impact biodiversity, e.g. plant, macroinvertebrate and fish populations. It is recommended that ***a number of existing sites (that include examples from each river 'type', as well as key 'natural' sites and those downstream from ongoing development) should be monitored on a routine basis to evaluate the status and detect change in the health of Worcestershire's streams and rivers***.

7 References

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Environment Agency (2005) *A Refined Geomorphological and Floodplain Component River Habitat Survey (GeoRHS)*. Environment Agency, Bristol.

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Henderson, P.A., Seaby, R.M.H., and Somes, J.R. (2005). *Fuzzy Grouping, version 2*. Pisces Conservation Ltd., Lymington, Hampshire, UK. www.pisces-conservation.com

Appendix 1

Data extracted from FEH –

River	River Name	Area (km^2)	Altitude (mean, m)	Aspect (mean)	Aspect variation	Baseflow Index	Longest drainage path	Urban extent (1990)
bw	Bow Brook	164	61	168	0.14	0.335	44.7	0.0246
st00	R. Stour (lower)	148.79	112	251	0.1	0.635	27.73	0.1639
sa	R. Salwarpe	144.99	81	223	0.15	0.570	32	0.04
st01	R. Stour (upper)	133.6	114	253	0.07	0.587	27.95	0.1639
pi	Piddle Brook	106.36	57	247	0.16	0.313	29.41	0.0173
bd	Badsey Brook	96.08	77	315	0.37	0.338	17.99	0.0349
is	R. Isbourne	95.57	124	330	0.26	0.476	24.12	0.0189
st02	R. Stour (upper)	89.28	137	289	0.13	0.548	22.84	0.2983
ar	R. Arrow	87.96	131	154	0.22	0.425	19.43	0.0844
lo	Longdon Bk	80.03	39	77	0.17	0.417	18.22	0.0072
ca	Carrant Bk	65.4	77	242	0.16	0.399	19.29	0.0223
hd	Hadley Bk	55.78	68	169	0.18	0.547	22.32	0.0184
le03	Leigh Bk (upper)	50.27	131	292	0.17	0.548	16.12	0.014
la	Laughern Bk	49.14	61	116	0.3	0.516	22.77	0.0419
do	Dowles Bk	46.33	125	64	0.14	0.637	16.24	0.0055
ky	Kyre Bk	44.43	124	344	0.17	0.598	14.98	0.01
a18	Noleham Bk	39.69	63	347	0.31	0.349	15.93	0.0186
sp	Sapey Bk	39.41	134	99	0.22	0.579	14.74	0.0082
di	Dick Bk	37.95	116	95	0.22	0.653	14.85	0.0123
hn	Hanley Bk	35.4	61	87	0.53	0.397	14.16	0.0335
eb	Elmbridge Bk	32.06	75	184	0.3	0.379	18.78	0.0212
rp	Ripple Bk	28.93	24	176	0.14	0.408	18.84	0.0194
po	Powick Bk	21.56	68	63	0.37	0.419	14.71	0.0361
cl	Clevelode Bk	21.36	59	80	0.43	0.358	10.39	0.138
co	R. Cole	20.41	161	89	0.36	0.321	12.04	0.0619
bo	Bourne Bk	20.36	27	241	0.22	0.275	10.95	0.0081
bb	Barbourne Bk	18.16	43	308	0.11	0.441	10.57	0.1072
le02	Leigh Bk(upper)	16.89	110	86	0.26	0.581	7.37	0.0088
ha	Hadley Bk	16.33	56	277	0.15	0.808	8.25	0.0405
gr	Grimley Bk	15.96	52	87	0.28	0.531	9.92	0.0093
le01	Leigh Bk (lower)	12.49	110	352	0.08	0.555	8.63	0.012
a23	Comberton Bk	12.46	61	346	0.37	0.529	7.67	0.0223
X02		12.1	187	142	0.46	0.546	11.3	0.0089
a22	Cropthorne Bk	12.04	66	29	0.41	0.491	6.87	0.0213
wi	Witley Bk	11.76	91	92	0.33	0.663	9.18	0.0071
ke	Kempsey Bk	10.56	33	261	0.49	0.438	6.2	0.033
gl	Gladder Bk	10.53	123	98	0.24	0.631	8.81	0.0132
t27	Westbrook	10.5	135	3	0.34	0.575	9.15	0.0024
a21	Merry Bk	10.39	52	70	0.32	0.342	12.07	0.0179
X01	Bockleton Bk	9.08	137	5	0.26	0.627	6.27	0.0022
t62		8.79	123	219	0.26	0.515	5.43	0.0034
ss	Severn Stoke Bk	8.61	28	233	0.35	0.598	7.13	0.0144
a20	Four Pools Bk	8.31	38	329	0.33	0.266	4.86	0.0803
r06		7.54	142	287	0.29	0.550	5.46	0.0238
a08	Harvington Bk	6.79	67	103	0.43	0.441	6.87	0.0398
t02		6.45	42	46	0.45	0.377	8.13	0.0239
s06		6.38	70	183	0.32	0.832	5.17	0.0723
s62	Earnswood Bk	5.76	103	57	0.32	0.668	3.93	0.0009
t08		5.24	111	143	0.46	0.574	6.49	0.0198
t63		4.89	135	222	0.42	0.494	5.49	0.0041

du	Duck Bk	4.68	47	214	0.42	0.383	5.29	0.2454
r04		4.65	115	261	0.22	0.555	6.4	0.003
a06		4.54	65	184	0.25	0.305	4.16	0.0366
s02	Arley Bk	4.43	111	216	0.62	0.649	3.71	0.0025
r03		4.26	113	142	0.29	0.562	5.03	0.0023
s58		4.19	48	106	0.32	0.865	3.9	0.087
t22		4.09	156	0	0.52	0.582	4.83	0.0052
a10		3.85	57	117	0.51	0.566	5.35	0.0013
t50		3.78	102	30	0.42	0.575	4.66	0.0003
a32	Bredon Bk	3.55	35	237	0.35	0.594	6.14	0.0789
s18		3.44	41	243	0.5	0.471	3.64	0.4775
t51		3.32	43	211	0.6	0.503	4.62	0.0102
s15		3.25	44	201	0.28	0.716	3.39	0.0385
t19	Hanley Bk	3.19	134	71	0.52	0.580	3.83	0.0123
s59		3.12	86	96	0.32	0.708	4.9	0.0368
t20	Lower House Sm	2.98	153	51	0.45	0.591	4.33	0.0013
a04		2.84	33	214	0.8	0.631	3.72	0.088
r07		2.84	140	297	0.34	0.600	2.96	0.0004
s03	Eyemore Bk	2.76	126	261	0.56	0.645	3.03	0.0035
s56	Shrawley Bk	2.74	53	97	0.36	0.606	3.1	0.0187
t54	Dodderham Bk	2.69	50	154	0.35	0.371	4.85	0.0177
t61		2.54	122	267	0.51	0.540	3.64	0.0005
t59		2.52	117	242	0.49	0.604	3.38	0
t55		2.48	68	171	0.4	0.413	3.03	0.0035
a05		2.39	23	206	0.65	0.690	3.11	0.0362
s12		2.38	61	251	0.55	0.816	2.85	0
t17	Noverton Bk	2.35	131	71	0.53	0.574	3.29	0.0032
t18	Rectory Bk	2.31	132	71	0.53	0.574	3.22	0.0032
a26	Woolas Bk	2.28	107	334	0.59	0.383	3.02	0.0033
t66		2.27	94	175	0.34	0.587	3.71	0
s50	Bushley Bk	2.25	24	99	0.29	0.512	4.03	0.0563
s07		2.15	49	269	0.36	0.887	2.86	0.0361
s61	Bewdley Bk	2.15	99	54	0.42	0.735	3.35	0.0653
t03		2.09	61	56	0.42	0.417	3.11	0.037
a27	Eckington Bk	2.06	26	247	0.77	0.512	2.55	0.1033
t23	Bonfire Bk	2.06	126	342	0.5	0.564	3.65	0
s14		1.88	54	229	0.54	0.822	3.32	0.0088
r02		1.75	95	153	0.47	0.625	3.08	0
s53		1.65	19	106	0.54	0.778	2.83	0.062
t64		1.64	95	209	0.55	0.552	3.22	0.013
a25		1.63	135	341	0.74	0.492	2.46	0.01
s11		1.63	66	257	0.45	0.824	2.61	0.0346
t53		1.57	44	177	0.59	0.367	2.57	0.0048
a33		1.54	78	253	0.7	0.589	3.67	0
s04		1.54	96	252	0.62	0.628	3.11	0.0057
t11	Noak Bk	1.54	103	111	0.52	0.565	3.18	0.0032
t60		1.53	88	220	0.52	0.558	2.83	0.0008
t26	Berrington Bk	1.49	89	338	0.34	0.563	2.35	0.0152
a31		1.44	39	258	0.58	0.719	3.29	0.1185
t56		1.42	69	256	0.52	0.682	2.81	0.0062
t05		1.41	75	53	0.5	0.412	2.8	0.0049
s08		1.4	51	215	0.63	0.879	2.52	0.125
a03		1.38	15	150	0.59	0.619	2.51	0.0045
t52		1.37	36	169	0.62	0.488	3.94	0
t25	Haresbrook	1.32	93	360	0.42	0.559	2.05	0.0009
s23		1.3	15	201	0.59	0.814	2.7	0.0173
s22		1.28	21	234	0.66	0.613	2.53	0.0016

t15		1.27	139	48	0.58	0.585	2.05	0
a28	Clatsmore Bk	1.24	71	284	0.72	0.383	3.26	0
a24		1.23	33	3	0.32	0.400	1.72	0
a29		1.23	59	267	0.87	0.555	3.08	0.06
s10		1.21	38	175	0.57	0.869	2.43	0.4274
r01		1.19	89	142	0.38	0.629	2.69	0
s19		1.19	29	256	0.77	0.580	2.96	0.0032
t14		1.17	115	59	0.69	0.613	2.43	0.0245
s20		1.15	18	223	0.47	0.804	2.93	0.0033
a01		1.11	34	129	0.39	0.465	3.79	0.0057
a09		1.08	35	121	0.7	0.712	2.43	0.0951
s54		1.06	22	110	0.73	0.748	1.74	0.0023
t06		1.06	71	346	0.53	0.508	1.95	0.0012
t58		1.03	119	233	0.57	0.630	2.6	0
s05	Trimpley Bk	1.02	125	222	0.61	0.576	2.4	0.0061
t04		1.02	78	70	0.56	0.401	2.59	0
t12		1.02	102	111	0.58	0.563	2	0
s55		1	28	75	0.68	0.579	2.61	0.1122
t24		0.98	108	343	0.54	0.562	2.13	0
t07		0.96	65	27	0.42	0.599	2.99	0.0092
t09		0.96	72	120	0.45	0.569	2.07	0
t13		0.94	136	61	0.59	0.585	2.53	0.0185
t65		0.94	98	188	0.49	0.547	2.23	0.0013
s52		0.93	23	88	0.54	0.644	2.21	0
s01		0.92	103	262	0.83	0.670	1.86	0
a30		0.88	78	245	0.74	0.480	3.47	0.0256
t16		0.88	124	64	0.63	0.570	1.63	0.02
s17	Noverton Bk	0.83	23	287	0.35	0.719	2.66	0.4834
t21	Pipers Bk	0.8	83	15	0.65	0.564	1.4	0
t57		0.8	118	236	0.54	0.645	2.44	0
r05		0.79	106	272	0.36	0.567	1.6	0
s21		0.77	31	285	0.62	0.373	1.69	0.0603
a19		0.76	43	356	0.5	0.320	2.05	0.1016
t01		0.76	38	66	0.69	0.790	2.32	0.1443
t10		0.76	87	86	0.48	0.568	2.48	0
s13		0.71	62	250	0.67	0.827	1.87	0
a02		0.7	33	128	0.42	0.568	2.01	0
a07		0.68	51	122	0.26	0.441	1.87	0.0519
s16		0.66	40	235	0.57	0.704	2.2	0
s60	Ribbesford Bk	0.66	102	75	0.52	0.680	1.29	0.0019
s51		0.63	38	89	0.57	0.470	1.71	0.012
s09		0.59	35	207	0.79	0.852	2.11	0.2884
a40		0.57	86	272	0.86	0.509	2.72	0
s57		0.55	53	72	0.53	0.833	1.56	0.0516

Appendix 2. Classification of 152 Worcestershire sub-catchments and three main rivers into four groups.

UID	NAME	Group	UID	Name	Group	UID	Name	Group	UID	Name	Group
A25	Comberton bk	1	A01	Avon Tr	2	ar	River Arrow	3	Avon	Avon	4
A26	Woolas Bk	1	A02	Strensham Bk	2	bd	Badsey Bk	3	Severn	Severn	4
A28	Clatsmore Bk	1	A03	Avon Tr	2	bw	Bow Bk	3	Teme	Teme	4
A30	Bredons Norton Bk	1	A04	Avon Tr	2	ca	Carrant Bk	3			
A33	Bredons Norton Bk	1	A05	Avon Tr	2	hd	Hadley Bk	3			
a40	Avon Tr	1	A06	Avon Tr	2	is	Isbourne Tr	3			
co	R Cole	1	A07	Avon Tr	2	lo	Longdon Bk	3			
di	Dick Bk	1	A08	Harvington Tr	2	pi	Piddle Bk	3			
do	Dowles Bk	1	A09	Avon Tr	2	sa	Salwarpe	3			
gl	Gladder Bk	1	A10	Avon Tr	2	st00	Stour lower	3			
ky	Kyre Br	1	A18	Noleham Bk	2	st01	Stour upper	3			
le01	Leigh lower	1	A19	Avon Tr	2	st02	Stour east	3			
le02	Cradley Bk	1	A20	Four Pools Bk	2						
le03	Leigh upper	1	A21	Merry Bk	2						
R01	Knighton Bk	1	A22	Cropthorne Bk	2						
R02	Bickley Br	1	A23	Comberton Bk	2						
R03	Trapnell Br	1	A24	Avon Tr	2						
R04	Rea Tr	1	A27	Eckington Bk	2						
R05	Rea Tr	1	A29	Bredons Norton	2						
R06	Rea Tr	1	A31	Bredon Bk	2						
R07	Bayton Bk	1	A32	Bredon Tr	2						
S01	Severn Tr	1	bb	Barbourne Bk	2						
S02	Arley Bk	1	bo	Bourne Bk	2						
S03	Eyemore Bk	1	cl	Clevlode Bk	2						
S04	Severn Tr	1	du	Duck Br	2						
S05	Trimpley Bk	1	eb	Elmbridge tr	2						
S06	Severn Tr	1	gr	Grimley Bk	2						
S11	Lincombe	1	ha	Hartlebury Bk	2						
S59	Arley Bk	1	hn	Hanley Brook	2						

S60	Ribbesford Bk	1	ke	Kempsey Bk	2						
S61	Bewdley Bk	1	la	Laugherne Bk	2						
S62	Earnswood Bk	1	po	Powick Bk	2						
sp	Sapey Bk	1	rp	Ripple Bk	2						
T04	Teme Tr	1	S07	Severn Tr	2						
T05	Teme Tr	1	S08	Severn Tr	2						
T06	Teme Tr	1	S09	Severn Tr	2						
T08	Teme Tr	1	S10	Severn Tr	2						
T09	Teme Tr	1	S12	Severn Tr	2						
T10	Teme Tr	1	S13	Severn Tr	2						
T11	Teme Tr	1	S14	Severn Tr	2						
T12	Teme Tr	1	S15	Severn Tr	2						
T13	Teme Tr	1	S16	Severn Tr	2						
T14	Teme Tr	1	S17	Severn Tr	2						
T15	Shelsley Walsh	1	S18	Severn Tr	2						
T16	Teme Tr	1	S19	Severn Tr	2						
T17	Noverton Brook	1	S20	Severn Tr	2						
T18	Rectory Brook	1	S21	Severn Tr	2						
T19	Hanley Bk	1	S22	Ryall Bk	2						
T20	Lwr House St	1	S23	Severn Tr	2						
T21	Pipers Bk	1	S50	Bushley Bk	2						
T22	Highwood St	1	S51	Severn Tr	2						
T23	Bonfire Bk	1	S52	Severn Tr	2						
T24	Rochford Bk	1	S53	Severn Tr	2						
T26	Berrington Bk	1	S54	Severn Tr	2						
T27	Westbrook	1	S55	Severn Tr	2						
T29	Teme Tr	1	S56	Shrawley Bk	2						
T55	Teme Tr	1	S57	Severn tr	2						
T56	Teme Tr	1	S58	Astley Bk	2						
T57	Teme Tr	1	ss	Severn Stoke Bk	2						
T58	Teme Tr	1	T01	Teme Tr	2						
T59	Teme Tr	1	T02	Bransford Trib	2						

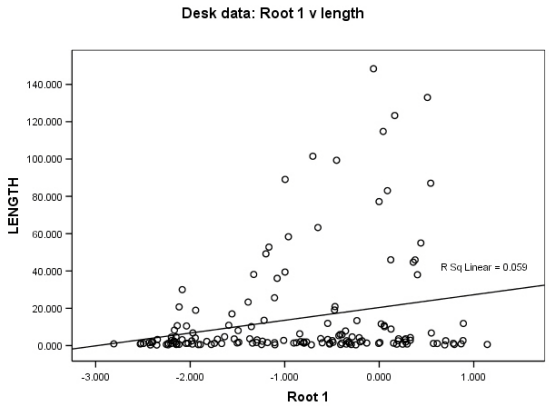
T60	Crundeland	1	T03	Hayley Dingle	2						
T61	Poolhouse Bk	1	T07	Teme Tr	2						
T62	Frith Common St	1	T25	Haresbrook	2						
T63	Teme Tr	1	T50	Cotheridge Bk	2						
T64	Teme Tr	1	T51	Teme Tr	2						
T65	Teme Tr	1	T52	Teme Tr	2						
T66	Teme Tr	1	T53	Broad Green Br	2						
wi	Witley Bk	1	T54	Dodderham Bk	2						
X01	Bockleton Br	1	X00	Corse St	2						

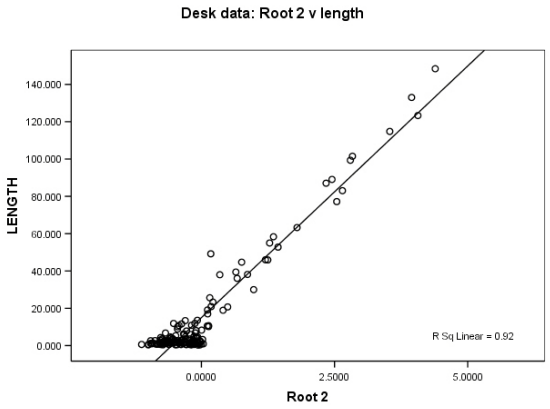
Appendix 3

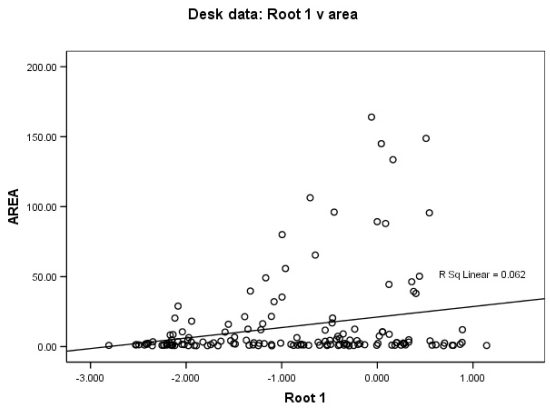
Sites selected for field survey, with group and selection criteria.

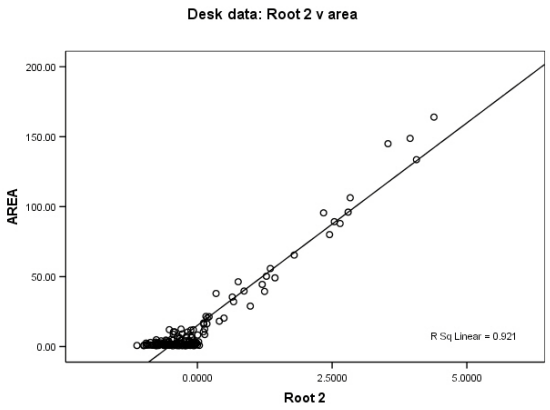
UID	Name	Location	Group	Selection criteria
Severn	R Severn	N of Upton	4	Major river
Avon	R Avon	Cropthorne	4	Major river / RIGS site
Teme	R Teme	Bransford	4	Major river
T11	Teme Trib	Noak Farm	1	Gp1 (98%)
A26	Woolas Bk	East of Eckington	1	Gp1 (97%) & Mudslide
A31		Bredon Village	2	Gp2 (99%)
du	Duck Bk	Battenhall Fields	2	Gp2 (99%)
bd	Badsey Bk	Offenham Cross	3	Gp3 (95%)
ar	R Arrow	Arrow Valley Park	3	Gp3 (86%)
T54	Doddenham Bk	Doddenham	2	1/2 (44/50%)
S11	Winnall Springs	S of Lincomb	1	1/2 (50/43%)
ky	Kyre Bk	Tenbury Wells	1	1/3 (50/30%)
hd	Hadley Bk	S of A4133	3	3/2 (36/45%)
la	Laugherne Bk	W of Hallow	2	3/2 (36/45%)
X01	Bockleton Bk	W of Bockleton	1	1/2/3 (42/32/24%)
bb	Barbourne Bk	Alongside canal?	2	Urban extent
bw	Bow Bk	Tydsley Wood	3	Largest catchment
do	Dowles Bk	Knowles Meadow	1	Largest NNR/SSSI
le01	Leigh Bk	Knapp & Papermill	1	Pristine site
lo	Longdon Bk	Bredon School	3	Longdon Marsh
po	Powick Bk	Upper Howsell	2	North Site development
T21	Pipers Bk	Death's Dingle	3	Tufa deposits

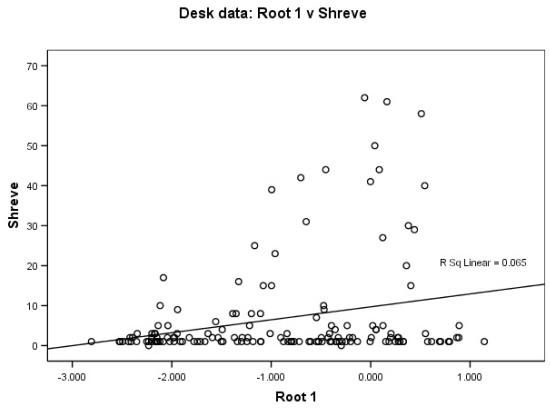
Appendix ***. Scatter plots of desk-based sub-catchment variables against discriminant roots (axis one and two).

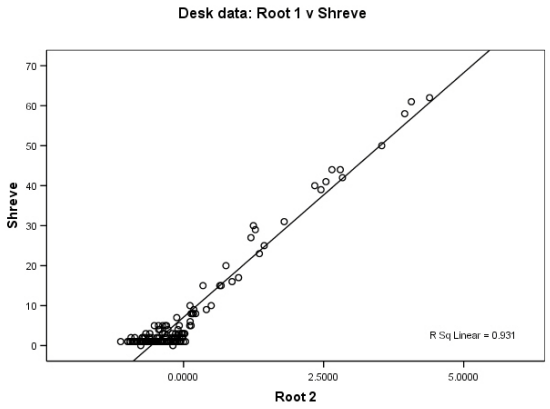




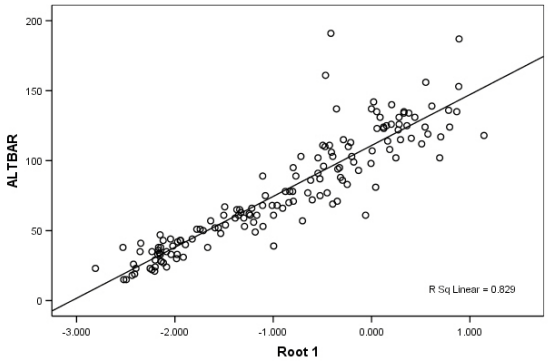








Desk data: Root 1 v Altitude



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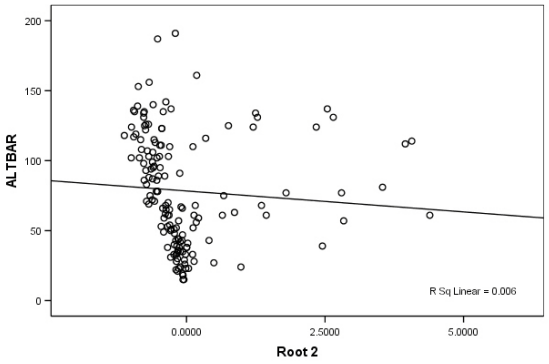
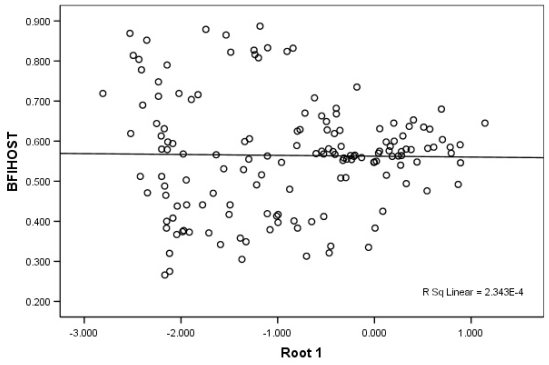


Desk data: Root 1 v BFI



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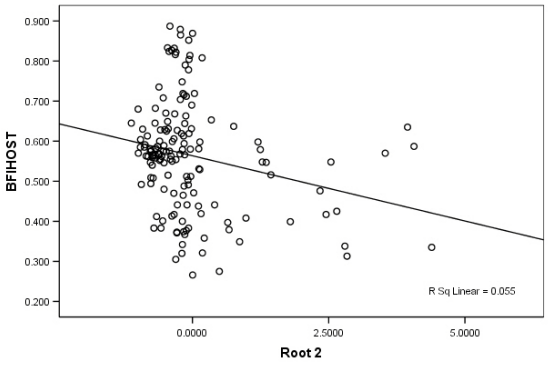
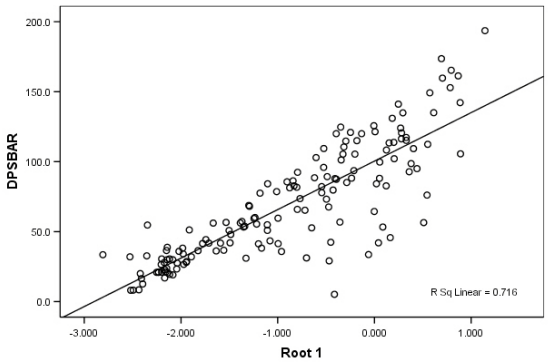


Desk data: Root 1 v DPS (Catchment steepness)



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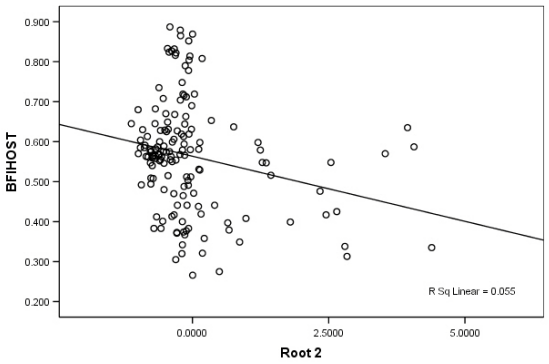
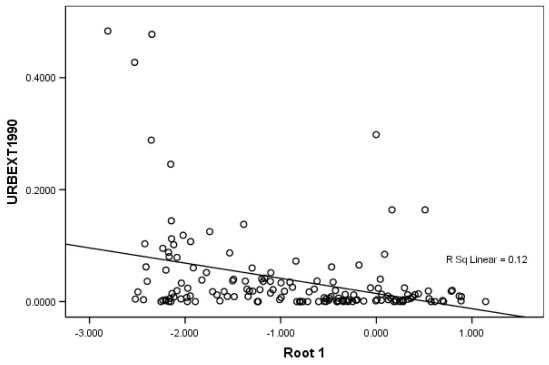
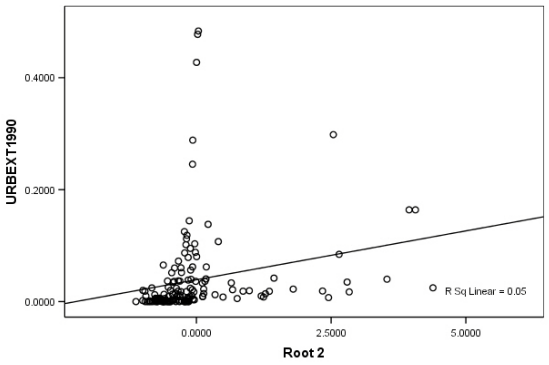


Desk data: Root 1 v Urban extent (1990)



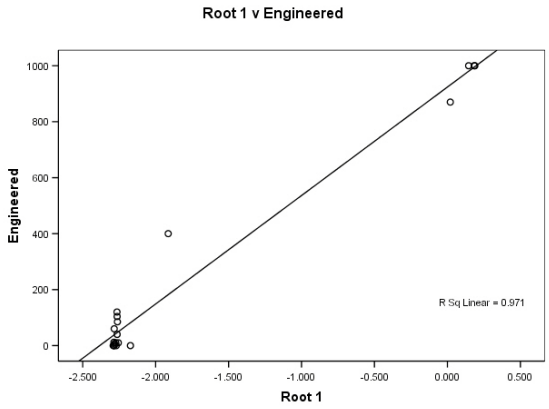
Desk data: Root 2 v Urban extent (1990)

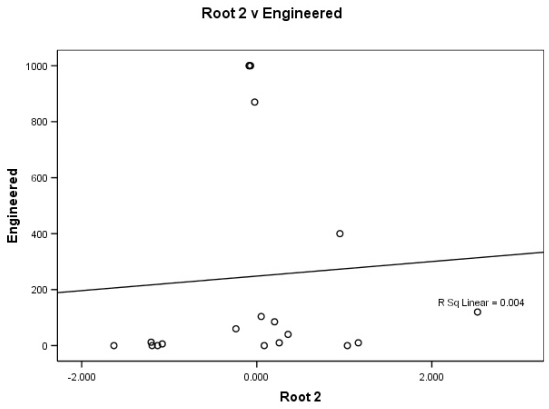


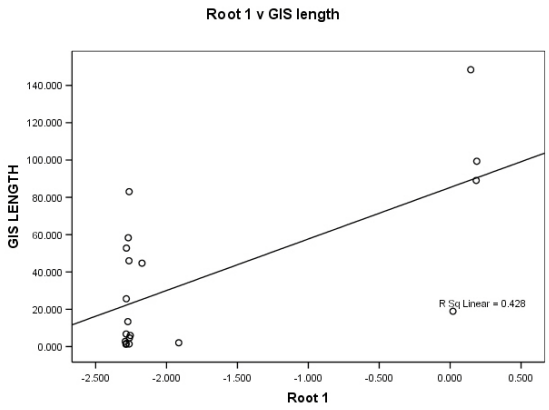
Appendix 5. Results of RHS analysis – HMS & HQA scores.

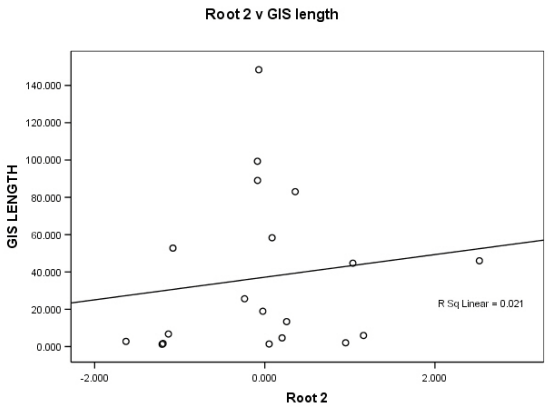
UID	River name	Group	HMS	HMI class	HQA flow (95-97)	HQA flow (94)	HQA Channel Substrate	HQA Channel Features	HQA Bank Features	HQA Bank Vegetation Structure	HQA Point Bars	HQA Channel Vegetation	HQA Land Use	HQA Trees	HAQ Special Features (95-97)	HQA Score	HQA (adjusted
Teme	Teme	4	0	1	4	3	1	0	1	12	0	0	0	8	0	26	5
po	Powick	2	0	1	7	6	6	2	6	12	2	0	0	11	5	51	45
do	Dowles	1	0	1	11	8	6	3	8	12	0	1	9	10	5	65	57
T21	Pipers	1	0	1	9	7	6	2	8	12	0	1	14	10	5	67	60
A26	Woolas	1	1	1	9	8	3	0	3	12	0	0	0	11	5	43	37
LE01	Leigh	1	1	1	8	5	6	2	5	12	0	0	4	11	5	53	45
X01	Bockleton	1	5	2	9	6	7	4	8	12	1	0	3	11	5	60	52
T54	Dodenham	2	8	2	9	7	5	3	7	12	1	2	3	11	5	58	51
la	Laugherne	2	11	3	8	6	1	0	0	11	0	0	1	11	0	32	30
A	Avon	4	13	3	4	3	1	0	5	11	0	6	0	4	0	31	31
ky	Kyre	1	15	3	9	6	4	0	9	9	1	0	2	11	12	45	42
T11	Noak	1	15	3	11	7	7	0	8	11	0	6	0	7	5	55	46
A31	Bredon	2	17	3	10	6	6	0	5	12	0	2	2	11	0	48	44
lo	Longdon	3	18	3	3	3	1	0	1	12	0	3	1	4	0	25	25
bw	Bow	3	18	3	6	5	3	1	3	12	0	4	0	7	0	36	35
Severn	Severn	4	19	3	3	3	1	0	0	11	0	0	0	4	0	19	19
bd	Badsey	3	20	3	4	3	3	0	4	12	0	1	2	8	0	34	33
hd	Hadley	3	20	3	7	5	2	0	6	12	0	2	0	9	5	43	36
du	Duck	2	27	4	7	6	8	0	2	12	0	2	0	8	9	39	38
ar	Arrow	3	29	4	8	5	3	0	4	11	0	1	1	9	0	37	34
S11	Winnall	1	38	4	7	6	3	0	0	12	0	2	4	6	0	34	33
bb	Barbourne	2	65	5	7	5	3	0	5	6	0	0	0	3	0	24	22

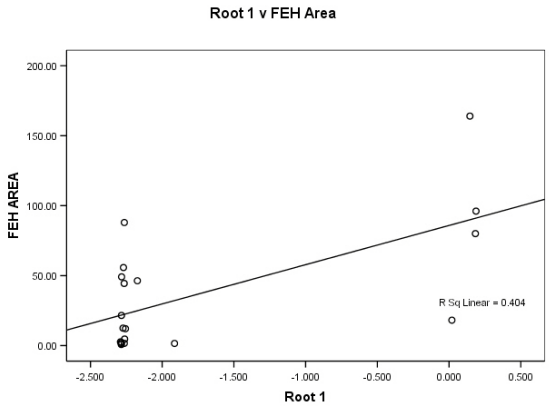
Appendix 4. Scatter-plots of fieldwork variables against Fuzzy Discriminant Analysis

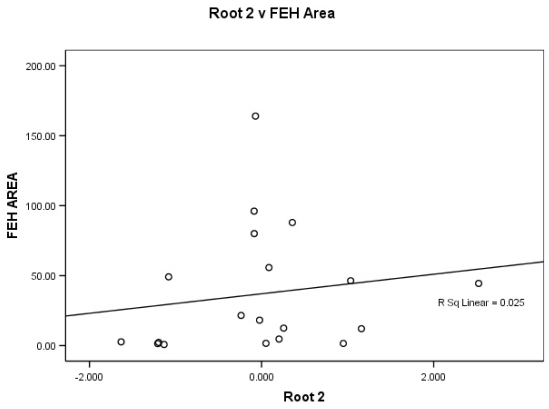




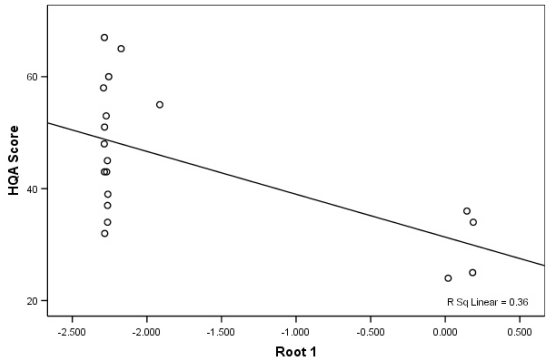




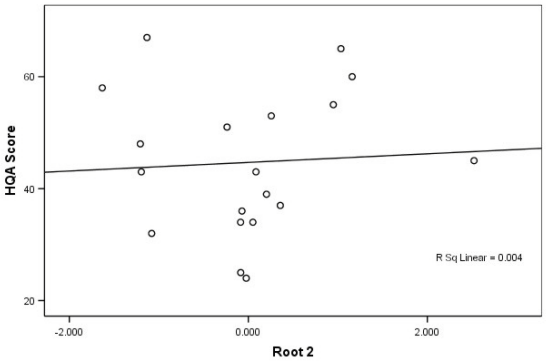




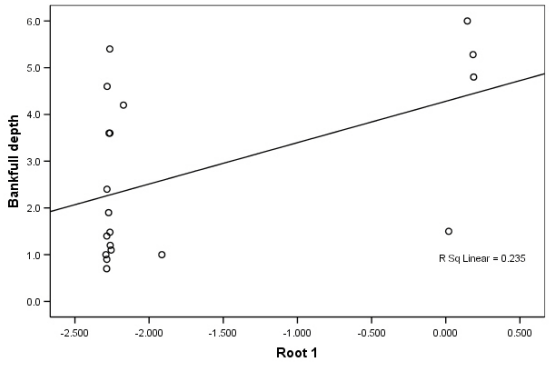
Root 1 v RHS HQA Score



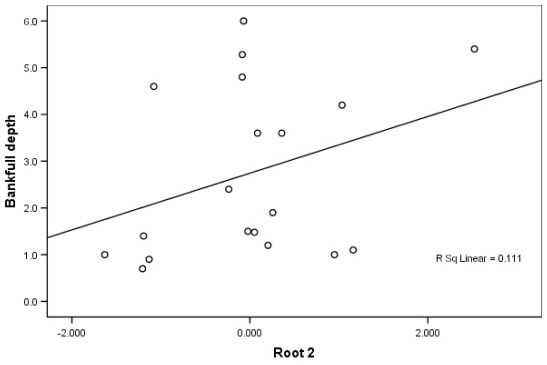
Root 2 v RHS HQA Score



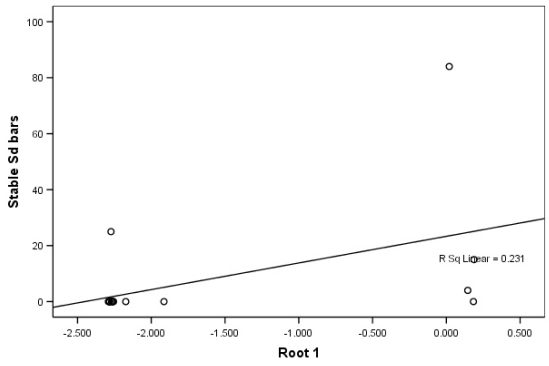
Root 1 v Bankfull depth



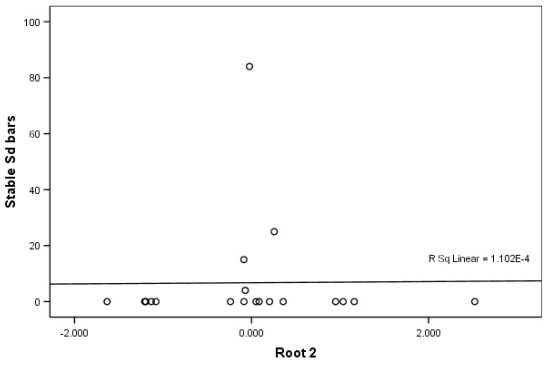
Root 2 v Bankfull depth



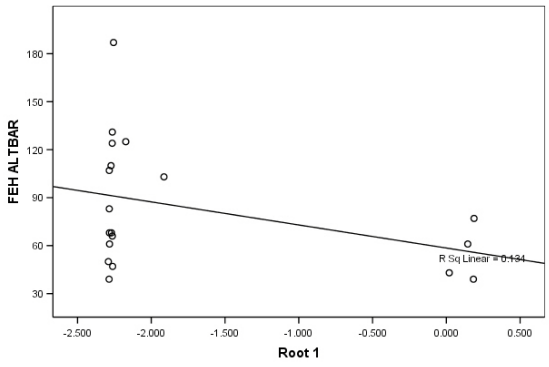
Root 1 v Stable side bars



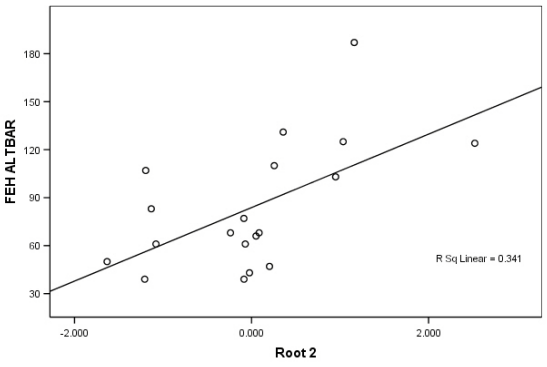
Root 2 v Stable side bars



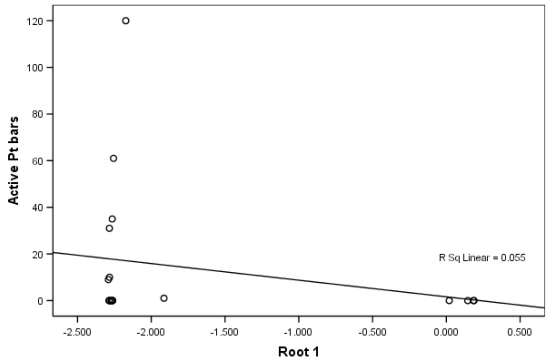
Root 1 v FEH Altitude



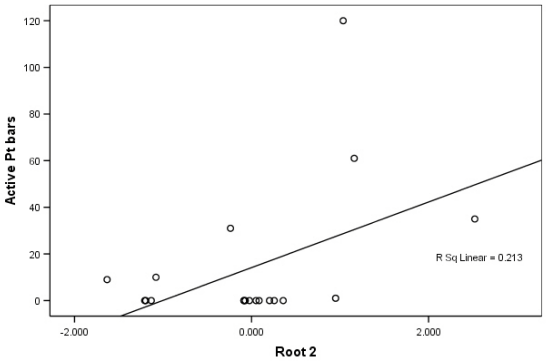
Root 2 v FEH Altitude



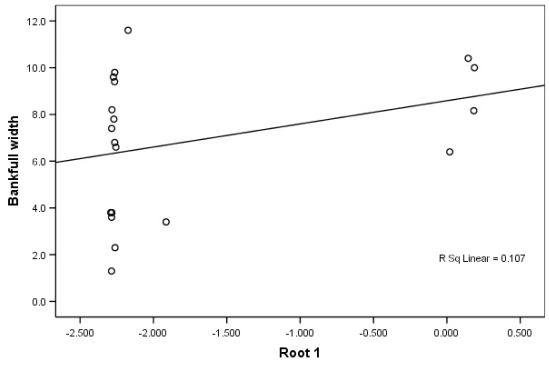
Root 1 v Active point bars



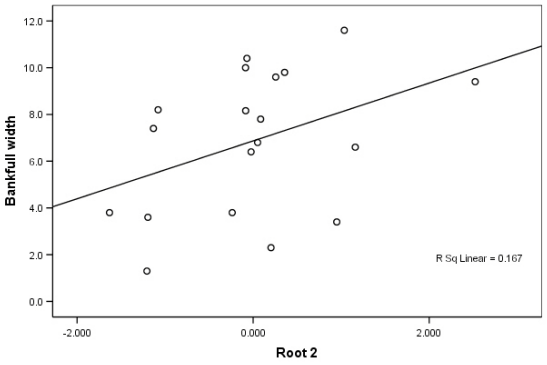
Root 2 v Active point bars



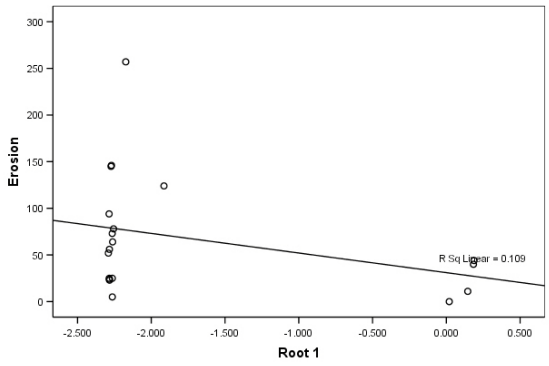
Root 1 v Bankfull width



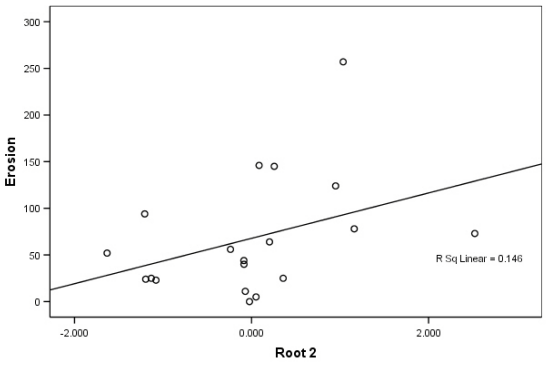
Root 2 v Bankfull width



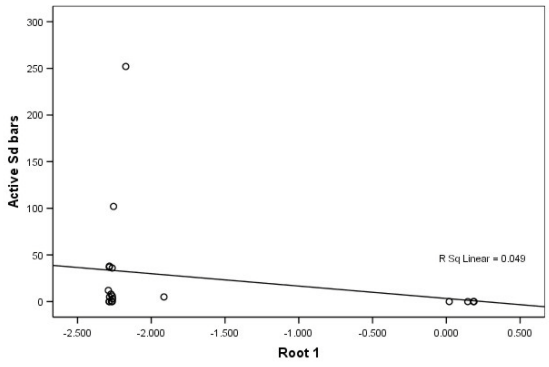
Root 1 v Erosion



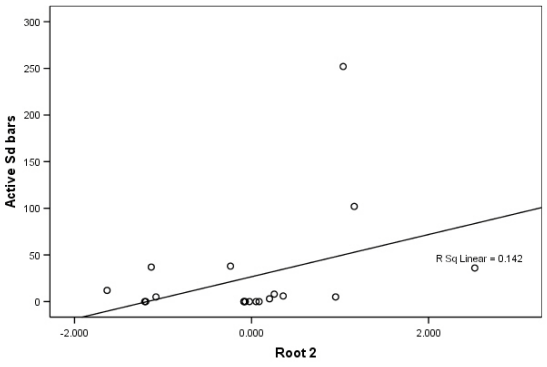
Root 2 v Erosion



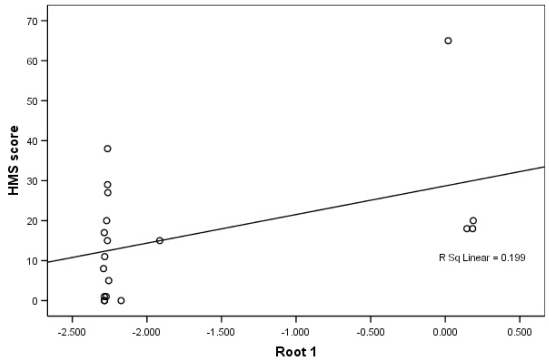
Root 1 v Active side bars



Root 2 v Active side bars



Root 1 v RHS HMS Score



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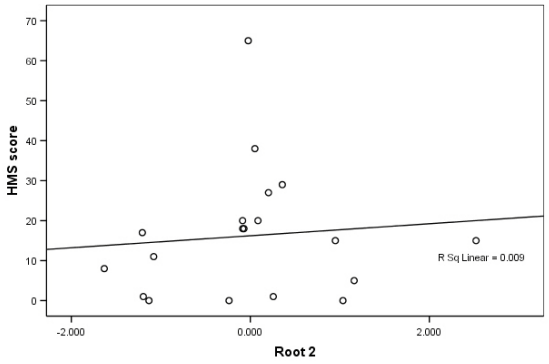
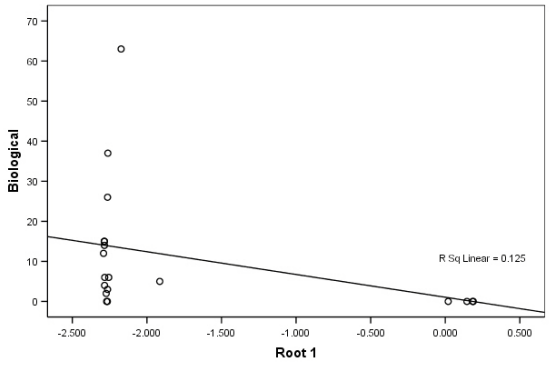
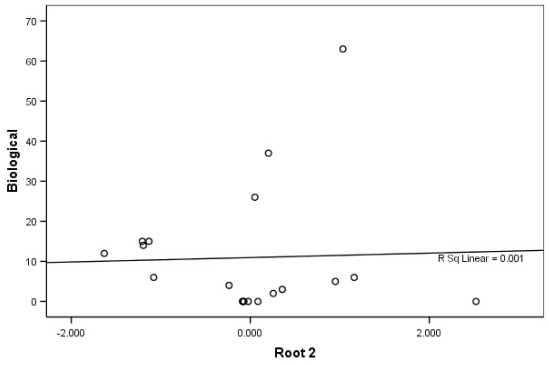


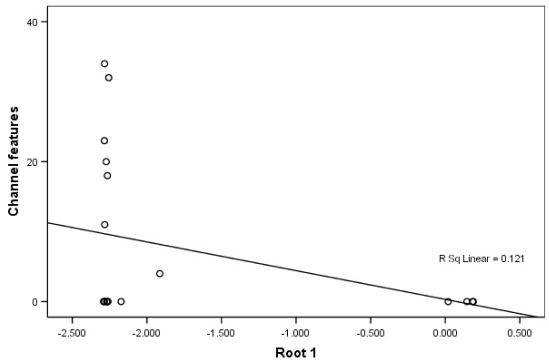
Root 1 v Biological



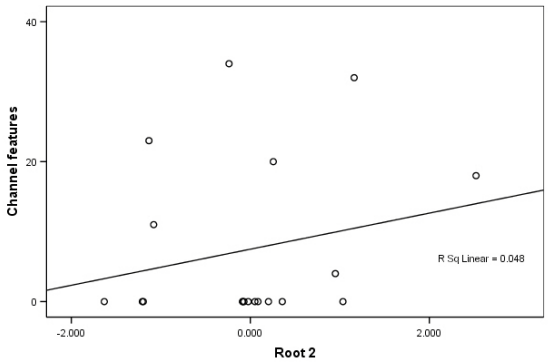
Root 2 v Biological



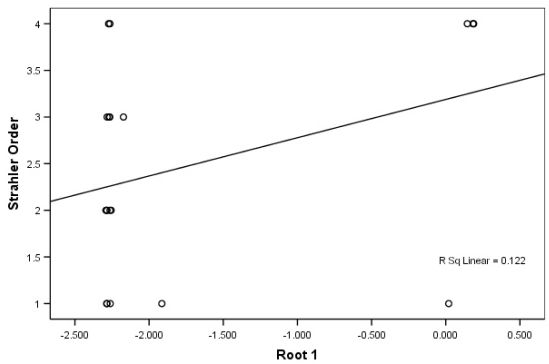
Root 1 v Channel features



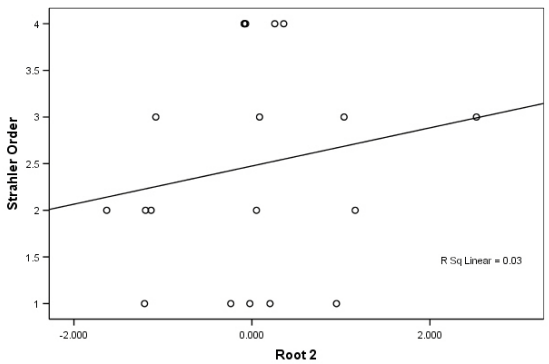
Root 2 v Channel features



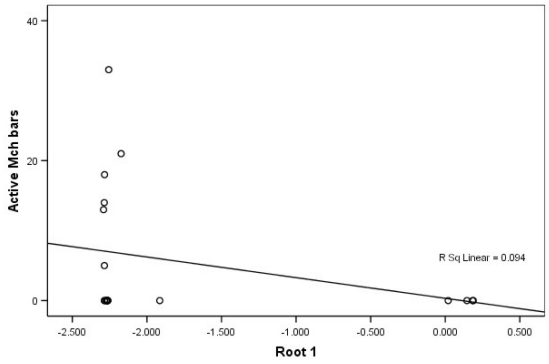
Root 1 v Strahler Order



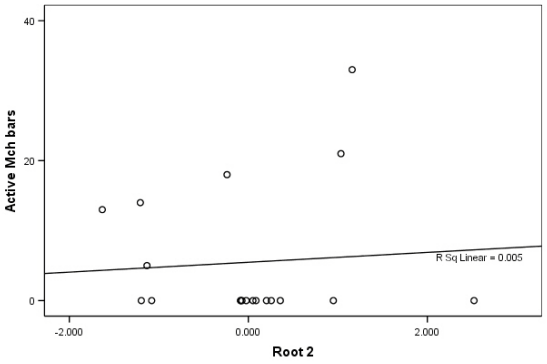
Root 2 v Strahler Order



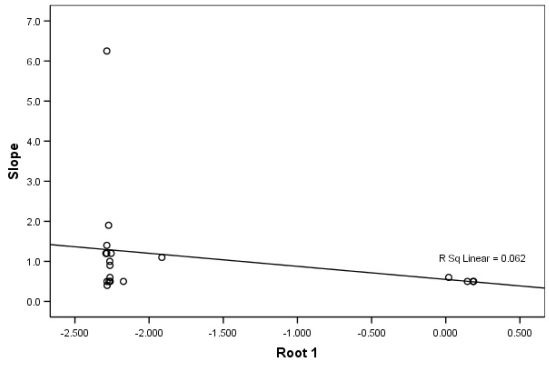
Root 1 v Active Mid-channel bars



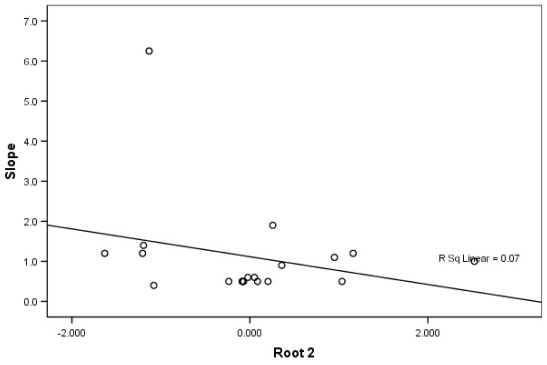
Root 2 v Active Mid-channel bars



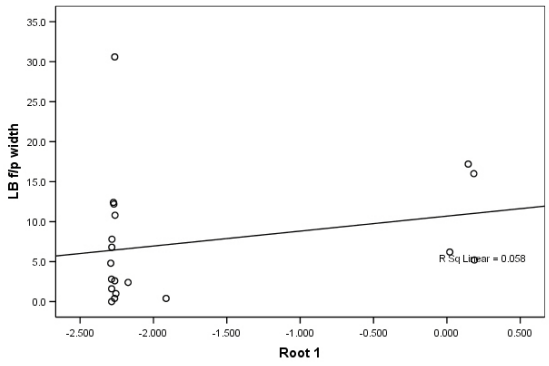
Root 1 v Slope



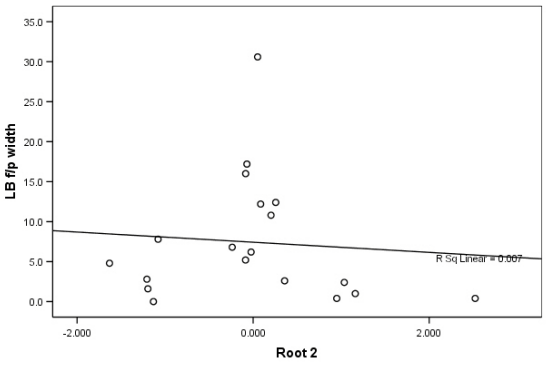
Root 2 v Slope



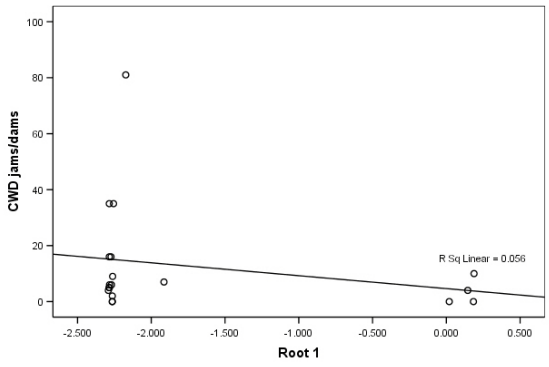
Root 1 v left floodplain width



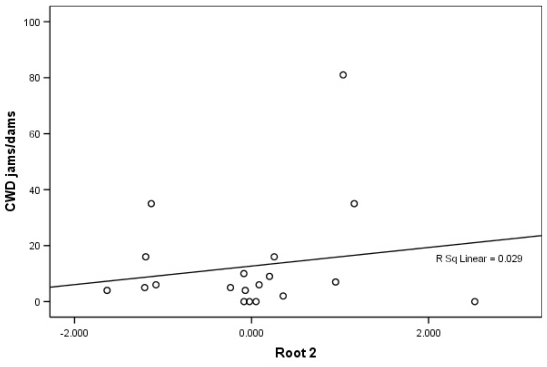
Root 2 v left floodplain width



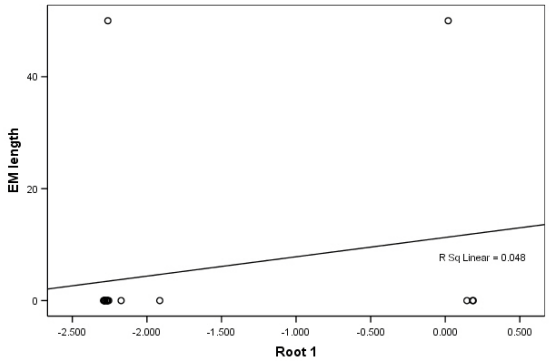
Root 1 v CWD jams/dams



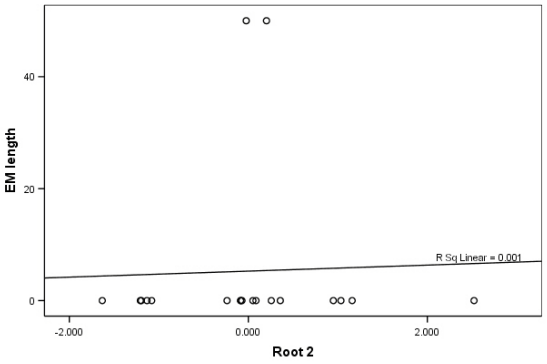
Root 2 v CWD jams/dams



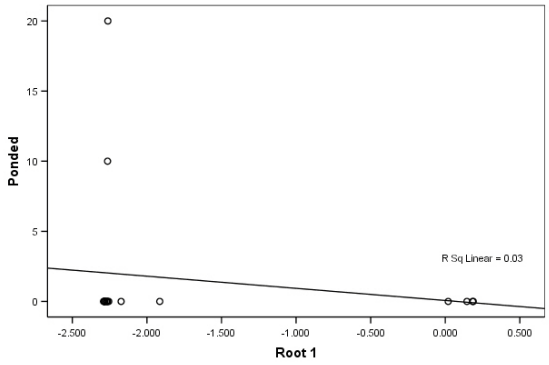
Root 1 v Embankment length



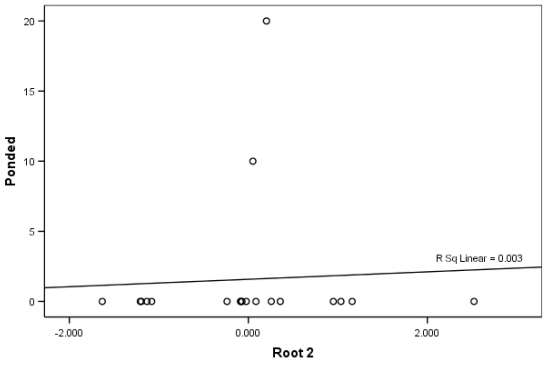
Root 2 v Embankment length



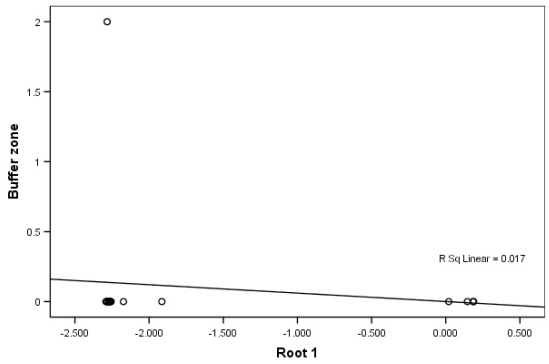
Root 1 v Ponded (%)



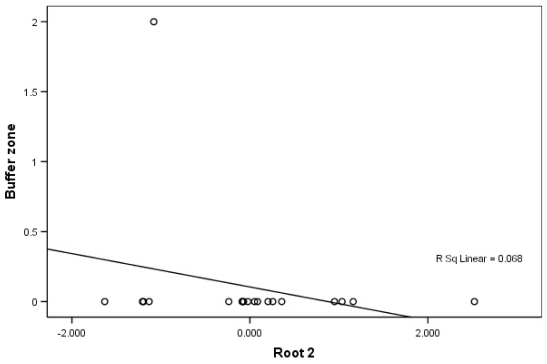
Root 2 v Ponded (%)



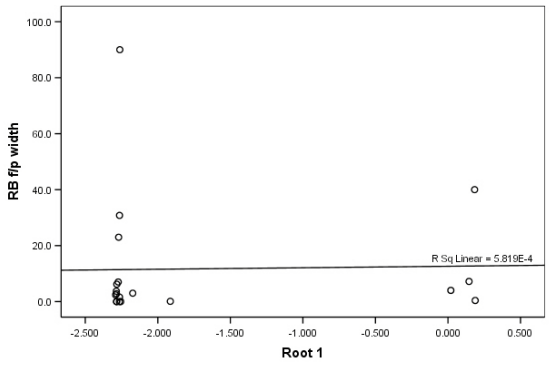
Root 1 v Buffer Zone length



Root 2 v Buffer Zone length



Root 1 v Right floodplain width



Root 2 v Right floodplain width