UNIVERSITY OF TRENTO - Italy
Faculty of Engineering

SLAD BROOK PILOT:

Hydrological Modelling and Flood Alleviation Solutions

Ilaria Pretto

Water21
(Department of Vision21 Ltd)
30 St Georges Place
Cheltenham
GL50 3JZ

01242 224321

1 Introduction

1.1 Aims of this Report

The aim of this study is to analyse the hydrology and topology of the Slad Brook in order to implement long-term, naturalistic, soft-engineered permanent solutions for flooding problems here (and also inform flood alleviation for other local watercourses). The will be based on a comprehensive analytical study of the causes that lead to the flooding. The opportunity to identify, create and exploit additional water resource storage capacity will be also considered.

The main objectives of this study are:

- Flood risk management
- Sediment management
- Water quality improvement
- Habitat creation
- Water resource storage and utilization.

By focusing on flood moderation, within related aspects of land management, this pilot will demonstrate much lower cost, mutually inclusive solutions, with high social benefit, and significant agricultural diversification. Also, enabling new economic/ecologic resource creation with a global relevance, all these would reinforce the holistic nature of our approach.

It is important to understand the legal situation, and investigate the issue of responsibility, clearly one of the main issues linked to implementation of solutions. Landowners are responsible for any watercourse that verges onto or runs through their property, so any solution to be adopted must firstly be explained and agreed with the landowner. They are not responsible in law for the flood consequences of rainfall run-off from their property however; we seek to identify economic & biodiversity based solutions that encourage landowner implementation in order to retain run-off to alleviate flood risk on an opportunity basis.

Water21 is working on behalf of SBAG (Slad Brook Action Group) and RBAG (Ruscombe Brook Action Group), two community groups created one year and three years ago respectively in order to improve water course quality and to alleviate flooding problems. Further local community groups are arising locally.

The solutions will be applied in the Slad Valleys with partnership involvement of:

- University of Gloucestershire, in particular Professor Lindsey McEwen and the Cartographer Caroline MacIntosh
- Environment Agency
- Stroud District Council
- Gloucestershire County Council
- Local Parish Councils

1.2 Background

In our contemporary era, water problems are becoming one of the biggest issues. We see apparently increasing frequency of catastrophic flooding, and significantly, also often associated problems with lack of water availability (drought) in the same areas as flooding – both within the UK and all around the world.

During summer 2007 the UK was shocked by two major flood events occurring respectively in June and July. The geographical, physical and economic effects were on a scale not seen for sixty years.

The summer 2007 flooding was caused by heavy rainfall (well in excess of 1/100 year return periodicity) as a combination of multiple flash (surface) floods accumulating into whole major river floods. This occurs when a high volume of rainfall falls in an area which is unable to drain away effectively. The problem is clearly bigger in urban areas, where much of the land is impermeable, and the greatest economic damage also tends to occur.

Both the Pitt Review and the House of Commons, Environment, Flood and Rural Affairs Committee Flood (EFRACOM) Report stated that they strongly support greater use of SUDS (Sustainable Urban Drainage Systems) such as swales and balancing ponds, but both also that there is lack of clarity about the ownership, responsibility and especially maintenance, which is delaying wider implementation.

In the UK, watercourses are generally owned by a number of riparian owners. If the watercourse is designated as 'Main River', the Environment Agency has permissive powers to undertake maintenance and recover the costs from the riparian owners. For non-main rivers, the relevant Local Authority has an equivalent power.

This Pilot aims to demonstrate that implementing natural processes, within a mostly 'soft-engineered' context to mitigate flood risk is both feasible in terms of volumetric capacity required to contain likely flood events but actually highly beneficial from economic, biodiversity and social points of view.

We will seek to identify different naturalistic methods for upstream flood alleviation within in the Brook catchment, located in the Cotswold Aquifer. It will also consider several key water quality & quantity problems that affect the Cotswold Aquifer and in turn, the local Stroud Watercourses, including Slad Brook. These are all recent problems, arising in the last 30/40 years, and they should be central to the flood alleviation plan. These water quality and quantity problems are:

- Over-abstraction by water companies for municipal supply. Low summer base flows severely affect many Cotswold streams, including Slad, during many summers.
- Significant increase in siltation and topsoil losses resulting from arable farming that appears to be slowly percolating through the fissured limestone. This process takes a long time, in the scale of many decades. It appears that these silts can travel long distances, even several miles underground.
- Poor aquifer recharge (and increased runoff, flooding) resulting from arable farming.
- Contamination of the aquifer by nitrates and pesticides.

The regulatory and legislative context for flood alleviation within the UK is unclear and a key issue identified following 2007 floods was a lack of responsibility by any single authority. A 2009 Flooding & Water Act is proposed to resolve this situation. However existing legal criteria (UK Statute Law & International Conventions) do provide an ample framework to support the community based approach being developed in this report. These are :

- **UK Water Acts** : Determine (together with other international free trade conventions) an obligation to provide water sector competition wherever feasible. The dispersed upstream attenuation of water resources in the context of this study enables a proliferation of players in this sector. Enabling multiple landowners to partake in the provision of a robust, dispersed water infrastructure at low cost in accordance with overwhelming consumer preference for this.

- **Water Framework Directive (WFD)** : Aim of achieving 'pre human intervention' qualitative and quantitative standards for EU surface waters provides a novel challenge to conventional municipal water infrastructure operation and planning; whose 'normal' implementation would directly counter any such standard. The application of naturalistic water management in an holistic manner provides a novel opportunity for flood resolution.

- **Convention on Biological Diversity (CBD)** : Important criteria for protecting and enhancing ecological factors are defined within the UK Biodiversity Action Plan (BAP).

- **Agenda 21** : Chapter 18 specifically notes that priority must be accorded to flood prevention and control measures, (as well as sedimentation control). Requiring integrated water resources management based on the perception of water as an integral part of the ecosystem.

Important principles in defining the means for resolution of flood risk flood were pronounced by Sir Michael Pitt (speaking at the Critical National Infrastructure Conference, 16 April 2008), he stated:

- Start with the needs of those individuals and communities who have suffered flooding or are at risk.
- Change will only happen with strong and more effective leadership across the board.
- We must be clear about who does what.
- We must be willing to work together and share information.

Sir Michael also stated "we should be as serious about flooding as we are when it comes to terrorism … yet this is not always the case … it still does not seem to get treated with the respect or priority it deserves as a problem."

The Water21 approach to flood resolution is in accordance with Sir Michael's pronouncement, specifically by focusing on the needs of those at risk and defining the least cost and quickest means of resolving such risk.

Before implementing any engineered techniques, an estimation of the flood frequency and volumetric capacities required for attenuation is required. Flood frequency estimation can be considered as flood risk assessment. This estimation is substantial in supporting the decision to improve the defenses to reduce the frequency of inundation. The mapping of flood risk areas is also required in order to advise landowners and their properties.

1.3 Methodology

The first step in this work is to consult with a number of stakeholders. These are public opinion from the community action groups, (SBAG, RBAG) and public authorities (Environmental Agency, Severn Trent Water, Parish Councils, Stroud District Council, Gloucestershire Country Council). This consultation will identify and map the problematic areas, collect historical information and obtain the specific data to be able to analyze the hydrological characteristics of the two catchments.

The second step is to analyze the hydrological gauges such as river flow, river level, groundwater level and rainfall across the catchments using the Flood Estimation Handbook (FEH) software in order to estimate flow hydrographs for a 1 in 150 year-return period flow.

The third step is to run the Hydraulic Model, HEC-RAS, which models the hydraulics of water flow through the brook in order to identify the whole area that is under flooding risk.

The fourth step is to propose naturalistic solutions, as for example naturalistic impoundments, swales, SUDS and reed-beds in order to minimize the flooding risk and at the same time to improve the water quality.

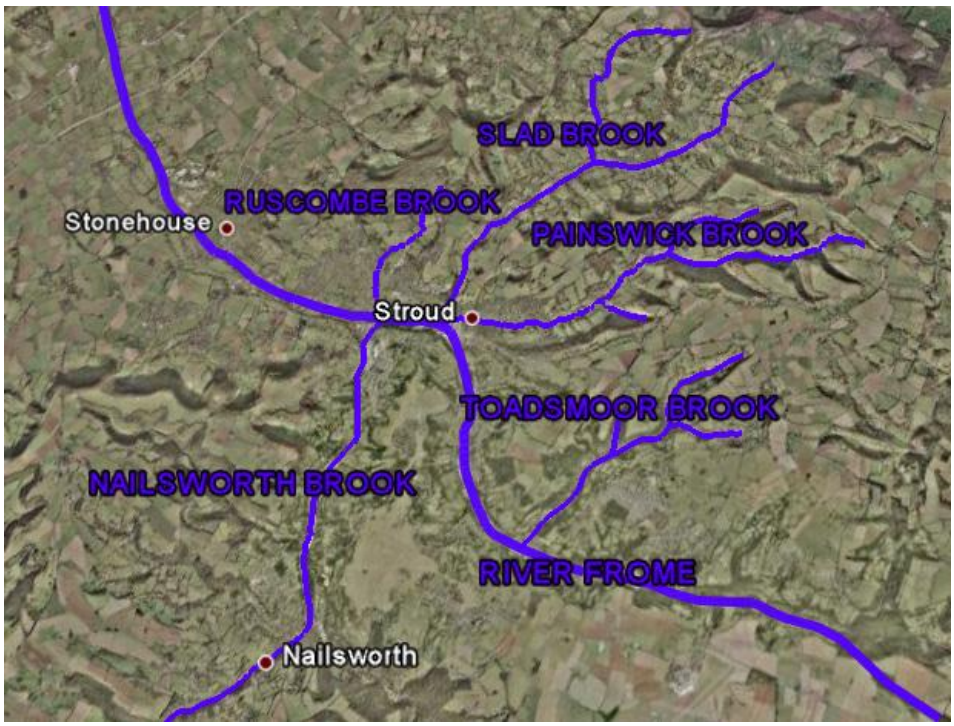
The fifth step is to run the HEC-RAS model with the solution implemented in order to have an output on the effect of the solution.

1.4 Locations

Slad Brook is part of the Five Valleys. The Five Valleys are a group of valleys in Gloucestershire, England, which converge on the town of Stroud at the western edge of the Cotswolds.

The valleys are as follows:

1. The Frome Valley
2. The Nailsworth Valley
3. The Toadsmoor Valley
4. The Slad Valley
5. The Painswick Valley



1.4.1.1 Figure: The Five Valleys [Google Earth]

1.4.2 Ruscombe brook

1.4.2.1 Figure: Ruscombe Brook's aerial view [Google Earth]

Ruscombe Brook is another small tributary catchment that can benefit from the upstream attenuation model the Slad study explores. It has its source in three springs in Ruscombe. It wends its way down in the valley to meet the Randwick tributary before cutting along hidden backways to The Lawns lake opposite Tricorn House and then into the Stroudwater canal. The Ruscombe Brook catchment is about 3 Km^2 and can be classified overall as rural. The upper parts of the catchment are open farmland, whereas the lower portion is partly urbanised.

Severe flooding occurred in the Ruscombe Valley the 1960s and any rainfall here contributes to flood risk further downstream the Frome catchment. Attenuation

solutions proposed for Slad can thereafter be applied in Ruscombe (and the other tributary catchments of the 'Five Valleys').

A lack of flow data for the Ruscombe Brook has prevented studies here presently.

List of the other identified problems:

- Cattle drinking area at Puckshole: steep banks and fast flowing water following heavy rain causes erosion and silt generation.
- Above Puckshole the brook is covered over by brambles and fallen trees for a length of about 150m. The plan is to consider the impact of this vegetation on the water course.
- Puckshole: the road here is located over a culvert, and about 3 times a year, flooding occurs over the road. Many makeshift solutions for the culvert head gratings have caused problems as they are never cleaned, replaced or improved.
- Silting problems arise at the top end of the brook, manifesting at Puckshole and onwards downstream to Albert Terrace and the Lawns at the lower end. The plan is to investigate the origins of the silt.
- Hamwell Leaze is the only floodable area planned at present (*see appendix 1*) and some sediment is deposited here during storm events. It is important to consider consider sedimentation effects at this location this location. Furthermore, it is important to consider the improvement of both human and wildlife enjoyment and promote diverse habitat.

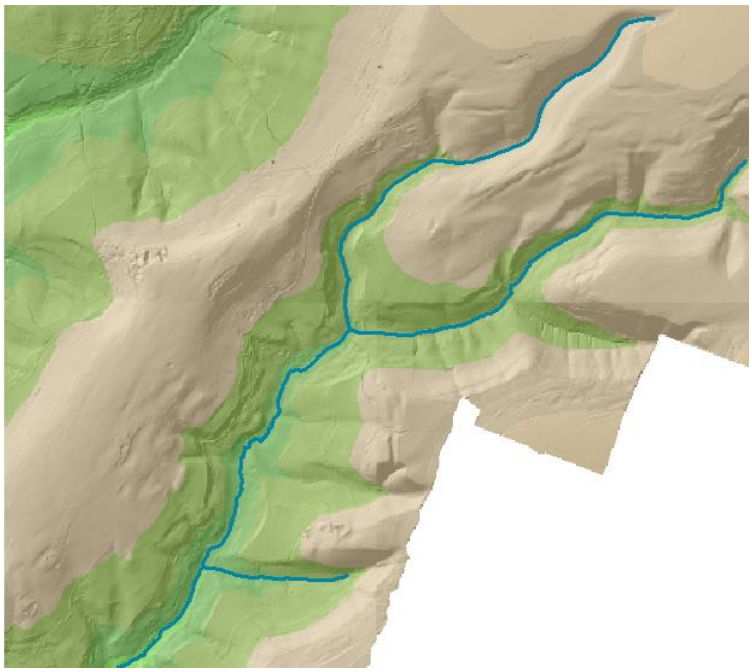
Further requests:

- Identify where the most significant catchments of run-off from impermeable surfaces enter the brook.
- Identify the main areas of watercourse erosion.
- Identify any soil erosion problems from land in the catchment.
- Identify inadequate culverts and screens.
- Identify the leaking sewers, either into the ground or into the brook

[Source: personal survey and consultation with members of the RBAG]

1.4.3 Slad brook

1.4.3.1 Figure: Slad brook's aerial view [Google Earth]



1.4.3.2 Figure: Hill-shade and elevation map (upstream part)

The town name 'Stroud' derives from ancient word "Ströd", which means "a marshy place with brushwood (willow - Salix)". The loss of these natural wetlands profoundly altered the hydraulic response of local watercourses to rainfall, heightening flood (and drought) risk, as well as loss of water quality benefits. The Slad Brook comprised extensive ströd, well into the 18th century. Any flood attenuation plans here should restore both the hydrologic and ecologic benefits of these where feasible (WFD).

Stroud is central within the catchments of the River Frome, near to the confluence of the five valleys. Joining the main Frome valley from Chalford are the Slad and Painswick Brooks within the town, whilst just below the town, the Nailsworth and Ruscombe Brooks merge. These watercourses are fed by springs which evolve from rock horizons in the Cotswold Scarp slopes.

The valley has a long history of involvement in the milling industry; whose ability to operate relied on a system of river water storage and control, presently there are presently no such significant facilities. In fact, a formerly extensive system of watercourse management has been lost, this may be a contributory factor to present flood risk.

"The watercourse contains many artifacts of the ancient milling industry such as the disused sluice gate behind Captain Barton Close and the culverted former mill streams underneath the Mill Apartments on Lansdown Road and underneath New Mills Estate Business Park on Libbys Drive."

[*Haswall Report 'Slad Brook Flood Study'*]

Due to the porosity of the limestone rocks, and the historically well charged aquifer, the streams used to be notable for their very constant flows, however this situation has currently been lost. The Slad Brook catchment is 14.95 Km^2 and can be classified overall as rural. The upper parts of the catchment are open farmland whereas the lower portion is heavily urbanised by the town of Stroud.

1.5 Geology

1.5.1 General introduction

Between about 185 and 140 million years ago, during the Jurassic period, a vast limestone belt was created, stretching between Lincolnshire and the Dorset coast. The Cotswolds, a region of ambiguous boundaries, is usually held to constitute the highest part of this belt, a plateau which rises from the east in Oxfordshire and descends in a dramatic escarpment to the west, within sight of Stroud.

During the Jurassic period, a shallow sea covered the area, in which a sequence of sediments settled into alternating layers or 'strata' of clay, sand and limestone. Although the beds of sediment were each laid down on a virtually horizontal level, subsequent processes have resulted in shifts in the terrain, so that, in places, strata of quite diverse ages and substance have ended up next to each other. The whole Cotswold plateau has been tilted, so that the west has risen up, while the east has sunk. Erosion and climatic changes have also played their part in shaping the landscape.

In the past, the whole Cotswold formation was known as The Oolite, due to the prevalence of this form of limestone throughout the region. Limestone, and in particular oolitic limestone, is extremely permeable, and where it meets beds of impervious clay, water is driven out in the form of springs. Hence the Cotswolds are riddled with streams and brooks as well as rivers. These have been highly active in the formation of the topography, carving deep and complex valleys into the 'Oolite' plateau, a process which continues and means that the landscape is ever changing.

Due to its porous nature, oolitic limestone is 'soft' when it is newly extracted and may be easily worked. The mass of oolite is in two basic layers, separated by a narrow bed of Fullers Earth: the older, deeper layers being known as the 'Inferior Oolite' and the upper layers as 'Great Oolite'.

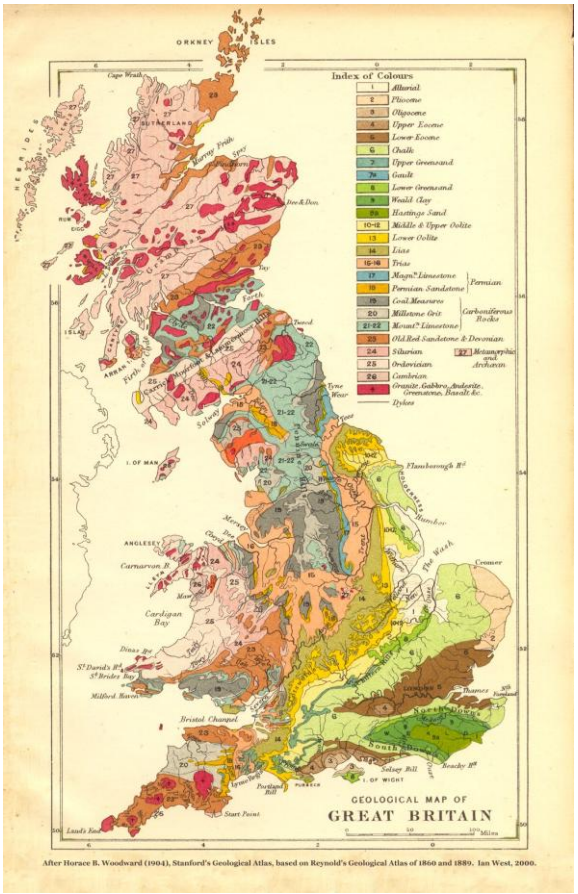
The tilt of the Cotswolds means that the lower layers, the 'Inferior Oolite', are exposed along the western escarpment, where they are more easily accessible than in the eastern Cotswolds. The hills encircling Stroud were particularly rich in good quality Lower Inferior Oolite stones, known by masons as 'Freestones', due to the ease with which they can be cut and dressed. Among these is Lower Freestone, of which the fine Painswick Stone is a variety, and Lower Limestone, the eldest of the strata, of which there is a large outcrop at Frocester Hill. Upper Freestone is of poorer quality, mostly used for burning, to create lime mortars and plasters. In Stroud, though, it was sufficiently good to be used for many of the town's 'rock-faced' rusticated buildings.

The Severn Vale has been subject to very different geological processes. Though also formed in the Jurassic period, later ages have seen the geology of the Vale strongly influenced by the River Severn and its smaller tributaries, including the river Frome.

The Vale is essentially a large flood plain. Successive floods and changes in the course of the rivers have left the older, Lower Lias, rocks covered with alluvial silts, pebbles and clays, the residue of the materials found on the riverbeds.

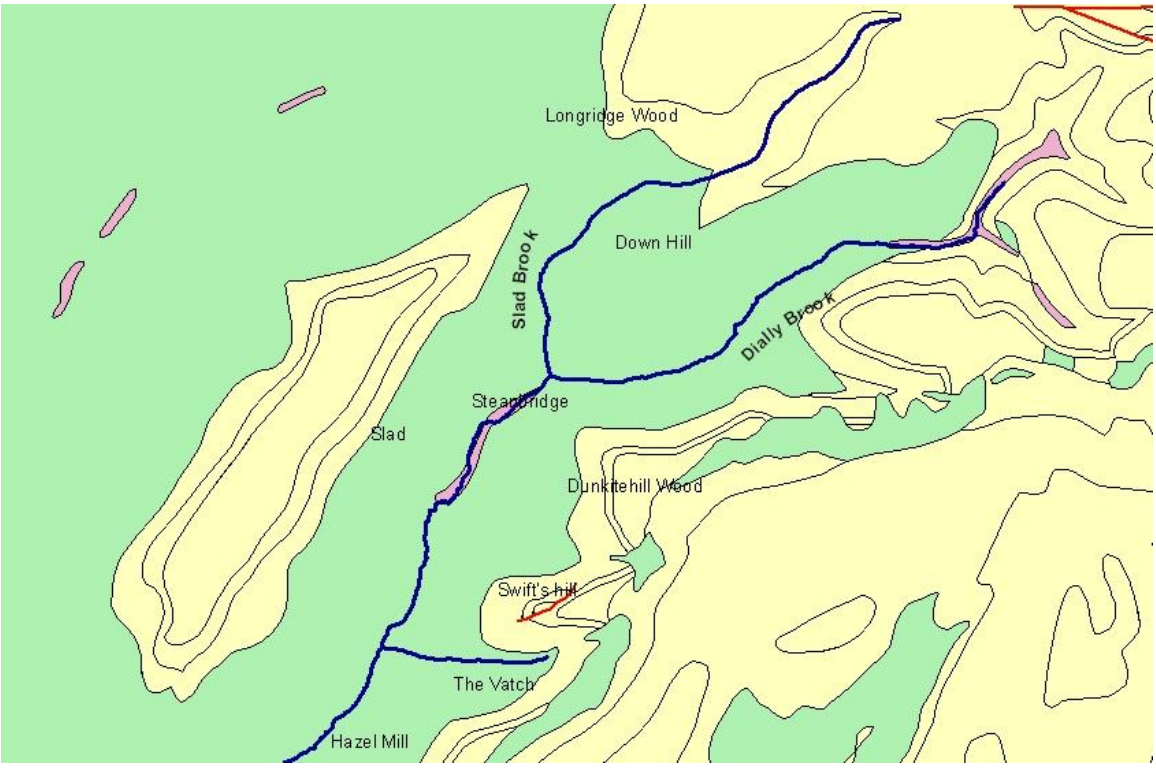
Clay is predominant in the Severn Vale below Stroud. Its impermeable intractable nature has meant that the river Frome has not formed deep narrow incisions into the landscape, but has instead created a broad and shallow river valley.

The clay has proved useful in lining the floors of millponds and canals in the area. It is also ideal for brick making, providing a building material in an area lacking an abundant supply of stone.
[Source: http://www.stroud.gov.uk/info/planning/39_chap4_Vol2_overview_draft_may08.pdf]



1.5.1.1 Figure: UK geological map

1.5.2 Slad brook



1.5.2.1 Figure: Slad brook's geological map

In the Stroud area the valley bottoms are mostly in Lias clays that dip east. In the Pliocene period the Severn Plain and the whole valley did not exist. The hilltops, now common, were higher, and the streams followed very similar courses but higher up in shallow valleys.

The upper and mid Severn ran north into the Irish Sea. The Frome flowed into the Thames joining the Rhine and then into the North Sea. The Usk and Monnow ran into the Avon in Bristol, which also joined the Thames. There may have been a cave system taking water from the much smaller Severn Plain into the Bristol Channel.

The Pleistocene Ice Age changed all this as the hill tops were lowered and covered in snow fields for most of the year, followed by brief annual thaws. The Avening, Chalford and Slad valleys show progressive lines of capture, with the water now flowing westward into the newly enlarged Severn Plain. All those valleys follow lines of geological weakness, which, acted upon by melting snow, formed cataracts instead of the more normal form of river formation. The valley sides show hanging valleys and solifluxion, and surface landslips still occur, showing the ground is still not truly stable. Even some of the hill masses are slowly moving. All

quarries show gulls or lizzens, and that frost penetration reached a depth of at least ten feet.

The upper Slad Valley is intersected by three infantile combes, eroded from the plateau, but in which the recession of the ice age denied the water to form the valley type to be seen in and below Slad. This unusual landscape can be seen in several valley heads in the area.

Below Slad note that there are more valleys entering on the north than on the south, and that one would expect cambering to occur on the south. There are also hanging valleys on the south indicative of the deprivation of water from melting snow at an early stage. The linear valley profile (apparently not yet drawn) will show variable slopes in the valley bottom caused by the presence of rock or harder clay. These govern the rate of flow, and also the position, in later times, of mills and road crossings. Roads can be historically linked with the Neolithic Jurassic Way and the Roman route from Gloucester to Circencester.

Note the different forms of water treatment at Steanbridge, The Vatch, Peghouse, Lansdown Road, Gloucester St. clay pit, and at the Thames & Severn Canal.

[Sources: written document by Lionel F.J. Walrond and personal research through bibliography]

1.6 Historical data: the milling industry usage

1.6.1.1 Figure: Detail from Cloth Mills in Gloucestershire 1750-1820

In the beginning of the 18th century the milling industry was very prosperous. In Slad Brook there were 11 woollen mills. They were (from downstream to upstream):

- Badbrook Mill
- Little Mill
- New Mill
- Peghouse Mill
- Wades Mill
- Hazel Mill
- Upper Vatch Mill
- Vatch Mill
- Wyatts Mill
- Lower Steanbridge Mill
- Upper Steanbridge Mill

1.6.1.2 Figure: Detail from Cloth Mills in Gloucestershire 1840[15]

1.6.1.3 Figure: Detail from Cloth Mills in Gloucestershire 1849[15]

1.6.1.4 Figure: Detail from Cloth Mills in Gloucestershire 1867[15]

Brief history and actual state of the mills:

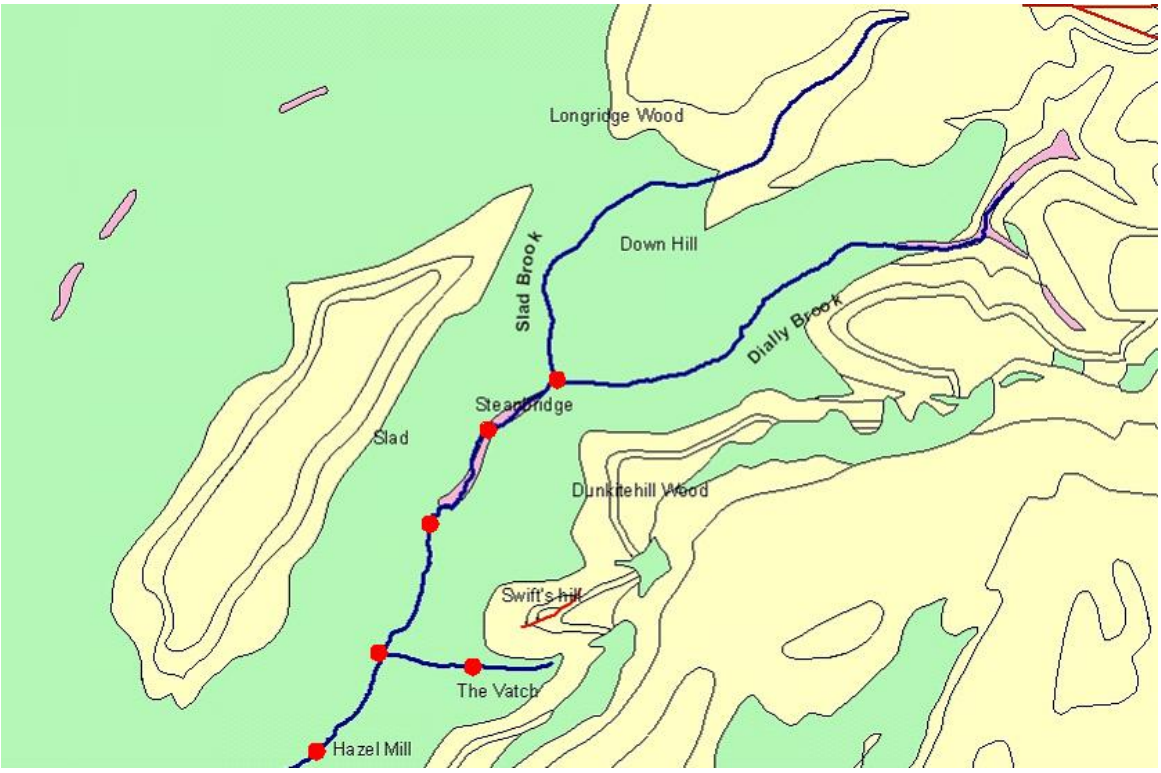
- *Badbrook Mill:* The site is now covered.
- *Little Mill:* The mill was surrounded by a pond, that after 1863 was drained, and the mill demolished.
- *New Mill:* The power for this mill was both water and stream, and presumably there was an artificial leat from Peghouse Mill. New Mills Court and a small part of the mills still remain.
- *Peghouse or Woodlands Mill:* The old mill and associated buildings have been demolished. There was a 22 kW steam engine and the water-wheel generated 7.5 kW.
- *Wade's Mill:* No record of fulling at this mill has been found.
- *Hazel Mill:* This small mill is now used for storage. It is a three-storey stone building with dormer windows. The wheel was fed by a long leat.
- *The Vatch Mill complex:* Vatch Mill was probably a fulling mill by the early seventeenth century. In 1776 a spring of water rising at "Buddings" was turned through "Rack Hill" and the mill pond at Vatch Mill. In 1827 the mill was burnt down and rebuilt. The mill contained 3 steam engines which produced 50 kW and

2 water-wheels of 9 kW each. The Vatch House and its gardens was a pond with two small buildings, one of which appears to be astride a water-course.

- *Wyatt's Mill:* Only the foundations can now be traced, but the long embanked pond still exists.
- *Lower Steanbridge:* The mill was standing in 1895 but has since been demolished. It was fed by a leat which led from a pond higher up the valley.
- *Steanbridge Mill:* The mill appears to be of early eighteenth century date and is now converted into a house. The bank of the large pond can still be traced although it has been drained for many years.

[Source: [11]]

It would also be interesting to analyse the historical map (see attachments) and to localise the ancient milling ponds.



1.6.1.5 Figure: Geological map and ancient milling usage in the upstream part

Local flooding: historical analysis

Year	Month	Details
1900	December	Severe and prolonged flooding from the River Stroud to Saul near the confluence with the Severn as well as on some tributaries.
1900	December	Snowmelt caused flooding in the River Frome catchment.
1903	June	Chipping Sodbury- Summer storms caused an estimated 1.50 in. to fall in 45 minutes. One house and stable were flooded [Little Avon].
1907	July	Gloucestershire Frome - severe flooding resulted from intense summer thunderstorms, which mainly affected the Nailsworth Stream and the River Slad.
1907	July	Severe flooding from intense summer thunderstorms, which mainly affected the Nailsworth Stream and the River Slad.
1910	August	Summer storms affected the River Cam causing surrounding meadows from a tributary of the River Cam to flood three times in less than two hours due to the sudden and intense rainfall.
1929	December	Snowmelt caused flooding in the River Frome catchment. Prolonged flooding from Stroud to Saul near the confluence with the Severn as well as on some tributaries.
1931	August	Flooding resulted from intense summer thunderstorms, which mainly affected the Nailsworth Stream and the River Slad.
1931	unknown	Flood levels from the Frome at Nailsworth were 20" higher than 1820 levels.
1947	March	Spring floods affected Gloucester causing serious flooding on the railway system around Gloucester. Venues include the Docks Branch, which crossed a bridge across the Eastern Channel of the Severn, and Over Junction, where a bridge crossed the Western Channel.
1960	unknown	Major floods in Gloucester.
1964	unknown	Flooding of the River Frome, which affected numerous properties and the floodplain area.
1965	December	Extensive and prolonged flooding occurred due to packed snow melting rapidly, with flooding from the River Frome affecting numerous

		properties and the floodplain area. Entered Twice.
1965	unknown	Major floods in Gloucester.
1965	December	Severe and prolonged flooding from Stroud to Saul near the confluence with the Severn as well as on some tributaries. Entered Twice
1968	July	Flooding recorded in the Cinderford Brooks, Lyd, Frome, Cam, Nailsworth Stream, Little Avon and River Twyver catchments.
1979	May & December	Flooding from the River Frome.
1990	February	Major floods in Gloucester.
1991	March	Flood events recorded in the Whaddon Brook, Dimore Brook, Shorne Brook, and Frome catchments.
1992	January	Extensive flooding in the River Frome catchment. Other catchments affected include the Whaddon Brook, Dimore Brook, Shorn Brook, River Cam, and Wicksters Brook.
1993	January	Property affected by flooding in the Lyd, Cam and Nailsworth Stream catchments.
1994	January	Flooding from River Frome.
1995	February	Flood events recorded in the Whaddon Brook, Dimore Brook, Shorn Brook, River Cam, Wicksters Brook, and River Frome catchments.
1998	January & March	Flood events recorded in the River Cam and River Frome catchment.
2000	October	Police in Gloucestershire considered evacuations in Dursley and Cam after flooding.
2001	February	Property affected by flooding in the River Cam, Wicksters Brook, River Frome, Slad Brook, and Nailsworth Stream. Flooding also reported in the Little Avon and River Twyver catchments.
2003	January	Extensive flooding in the Frome catchment.
2004	August	Property affected by flooding the River Cam, Wicksters Brook, River Frome, Slad Brook, and Nailsworth Stream catchments. Flooding also reported in the Little Avon and River Twyver catchments.
2006	October	Roads were blocked, windows blown out during lightning strikes and

		heavy rainfall. Two cars had to be abandoned on flooded roads under railway bridges, one on Tredworth Road in Gloucester and another in Stroud.

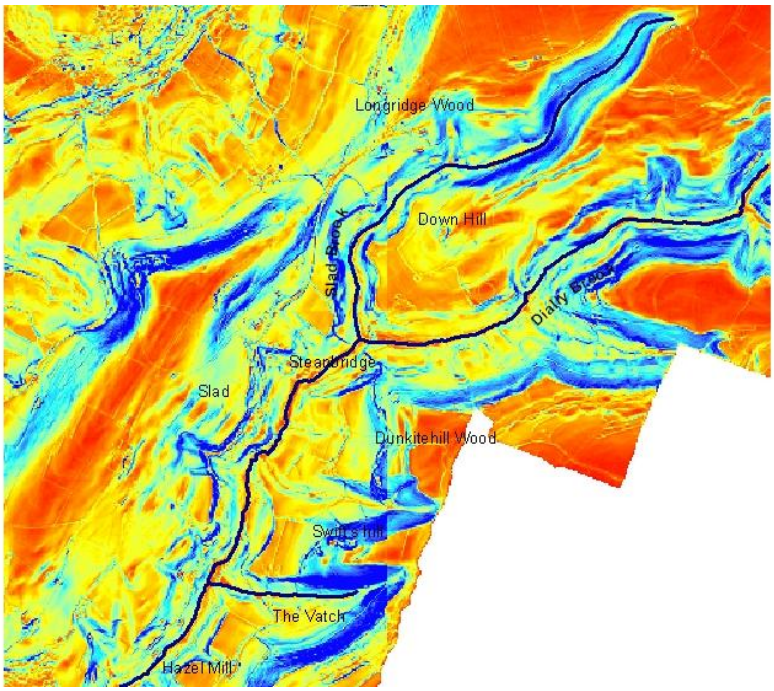
1.6.1.6 *Table: http:// www.environment-agency.gov.uk/commondata/acrobat/draft_cfmp4_1684747.pdf*

- At Gloucester was the most violent rain ever known, lasting 3 hours, with very little intermission, by which the principal streets were above 3 feet deep in water, so that most of the cellars were filled, & many of the shops. At Stroud & Painswick, several mills were much damaged, large trees & hedges carry'd away & walls thrown down by the torrent; some had 30 ton of coal wash'd away, others their furnaces carry'd out of the stacks, & a bridge called Dodbridge was forced up; the damage computed at several thousand pounds.
  [Source: Gentleman's Magazine 2/9/1750]

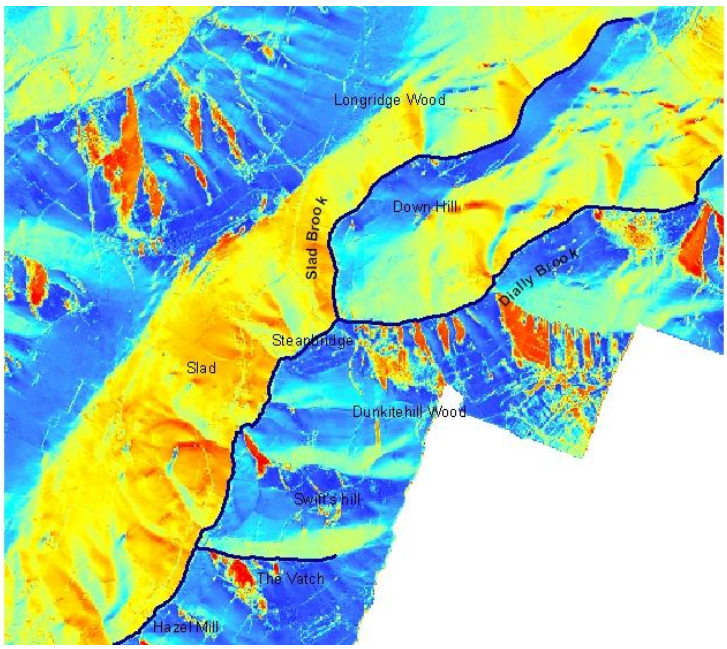
2 Topographic analysis

2.1 Introduction

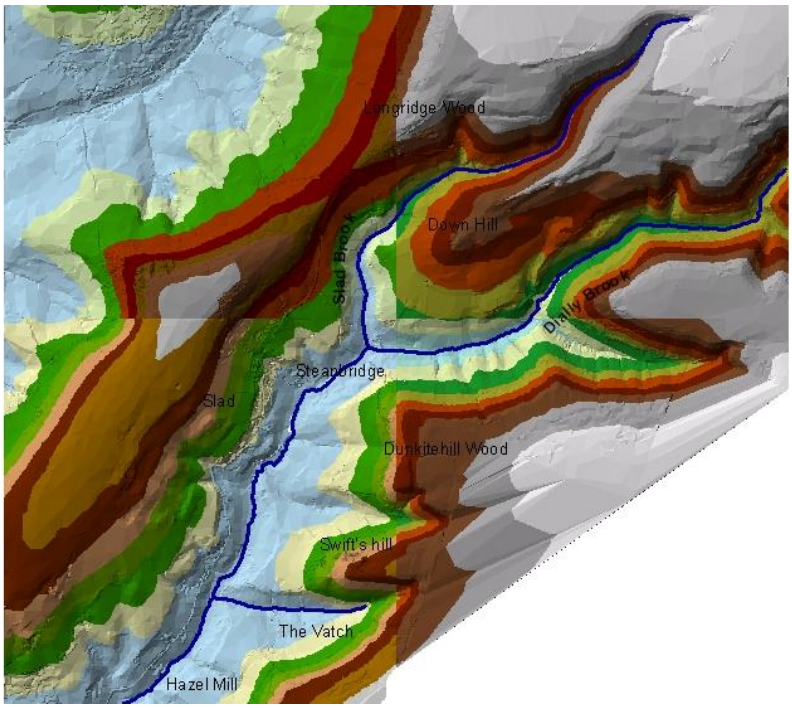
These valleys are steep sided, gradually descending from the high ground of the Cotswolds towards the Severn Vale. Both have several smaller valleys branching from them. Most of the hillsides overlooking the length of the study area are capped with common land. The relationships between the landscape, transport links and the built environment can be best appreciated when viewed from the heights of Minchinhampton, Rodborough and Selsley Commons. Beyond Dudbridge, much of the Lower Frome valley is predominately rural: quiet lanes are surrounded by water-meadows containing networks of ditches and drains bordered by pollard willow and elder trees. The land has a variety of uses from orchards, pasture and arable fields to managed parkland with mature specimen trees. The lack of stone in the Severn Vale has strongly influenced the overall look of the area. Fields are bounded by hedges and many village gardens are enclosed with iron railings or walls constructed from bricks made locally. As the valleys thread away from the stretches of industrial development between Stroud and Brimscombe, and Rodborough and Nailsworth, they become steeper and narrower. The landscape becomes predominately rural and more densely wooded. Settlements are small and scattered and the remnants of mill sites retain their historic isolation.
[Source: http://www.stroud.gov.uk/info/planning/39_chap4_Vol2_overview_draft_may08.pdf]



2.1.1.1 Figure: Slope map



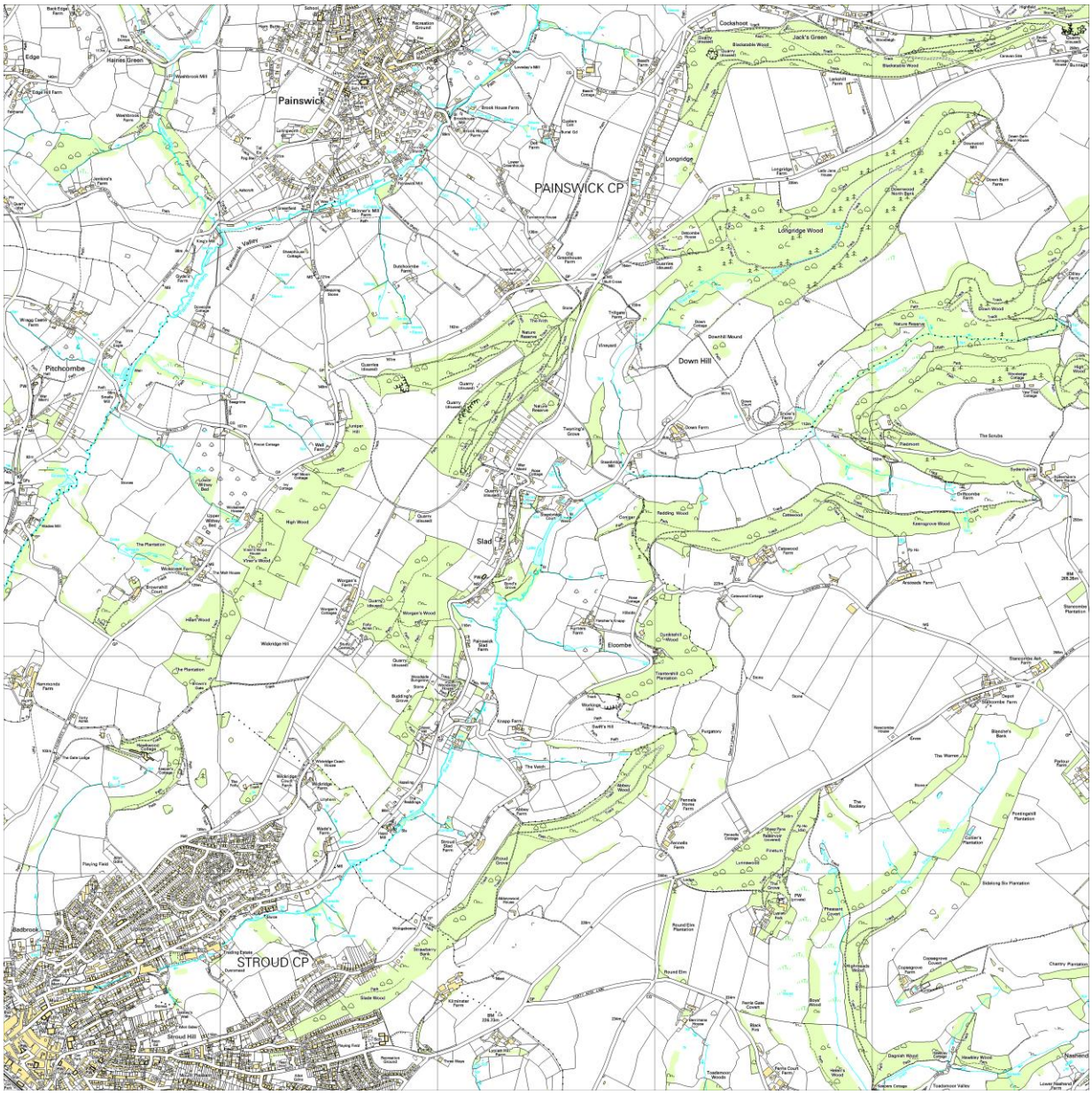
2.1.1.2 Figure: Aspect map



2.1.1.3 Figure: Elevation Map

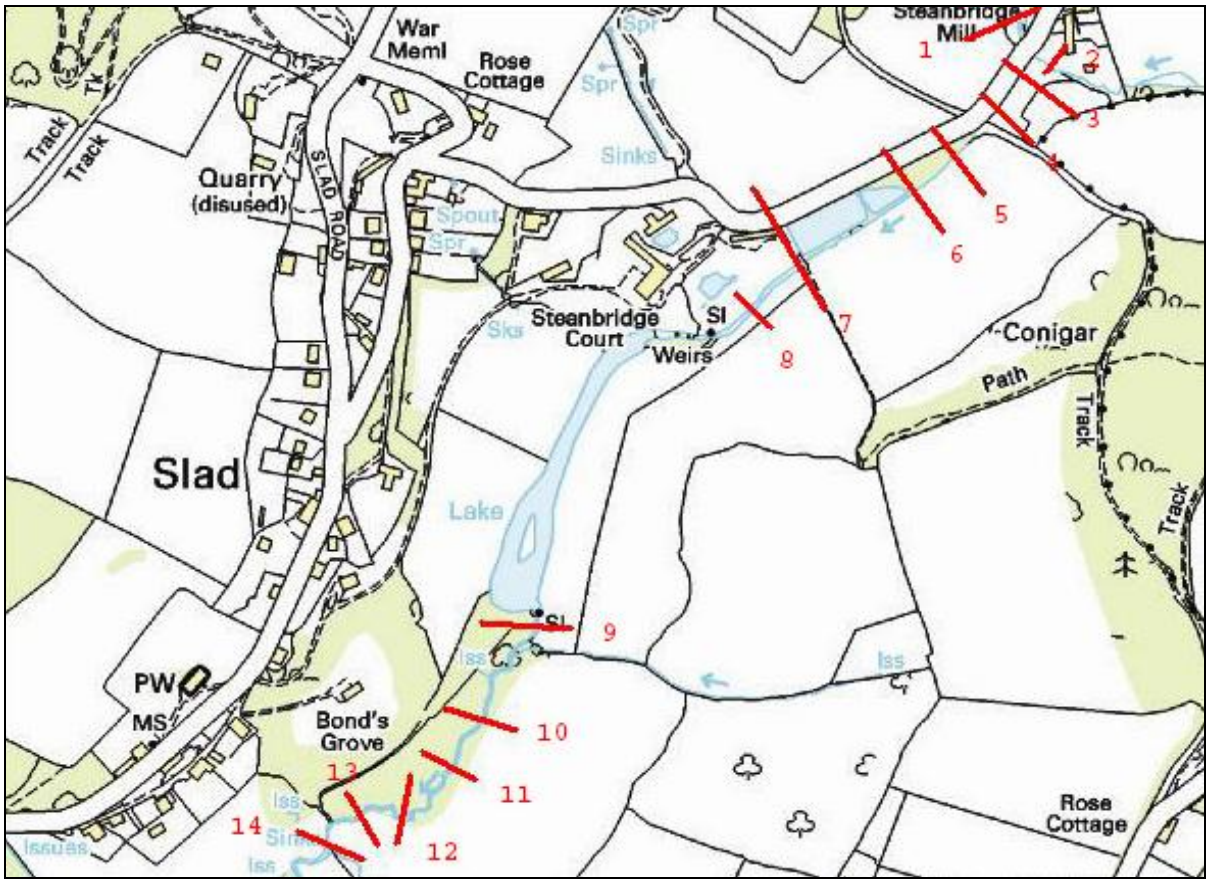
2.2 Survey

A topographic survey has been undertaken in order to detect the cross-section, basic data for the hydraulic modelling. A cross section was measured approximately every 100 meters between Steanbridge, Slad Farm, and The Vatch.

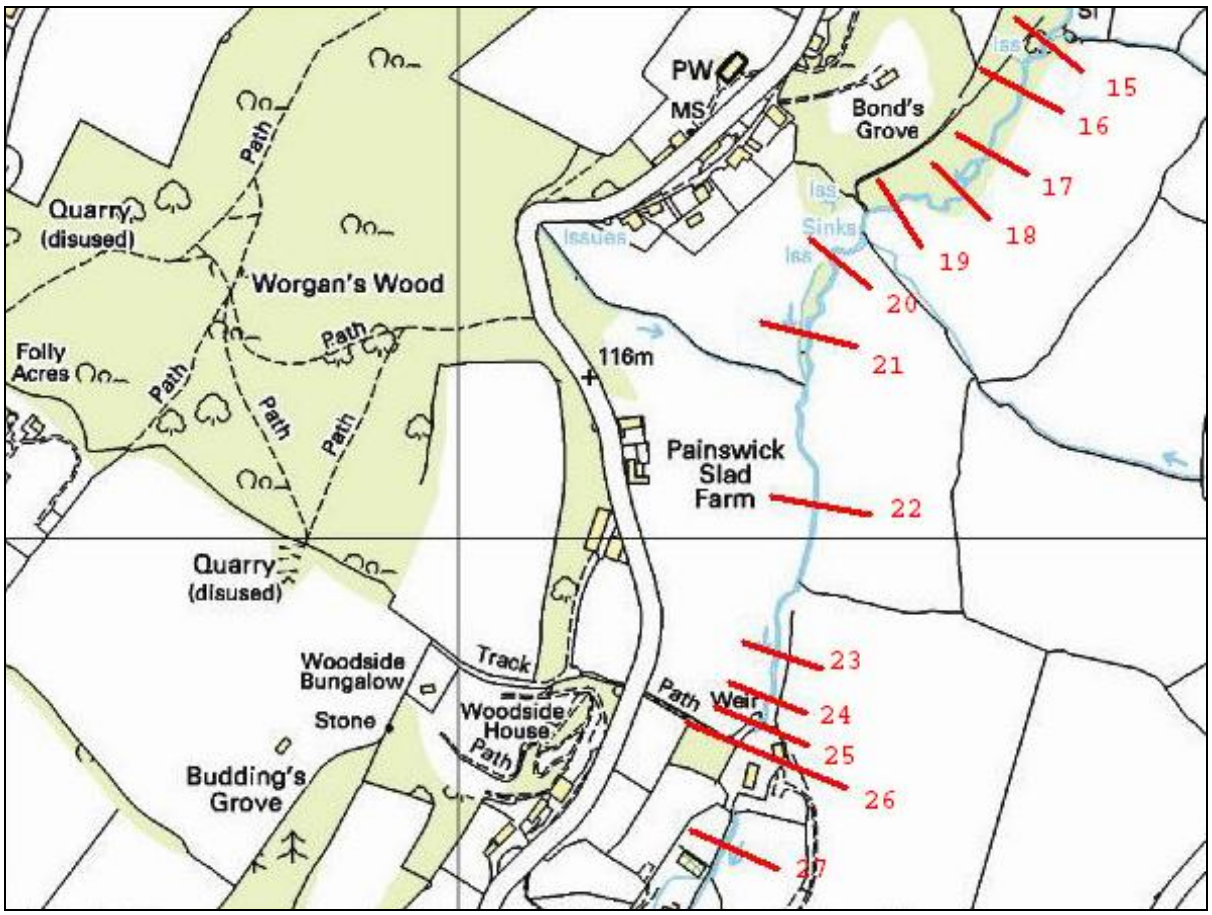


2.2.1.1 Figure: Ordnance Survey 1:10000 Map

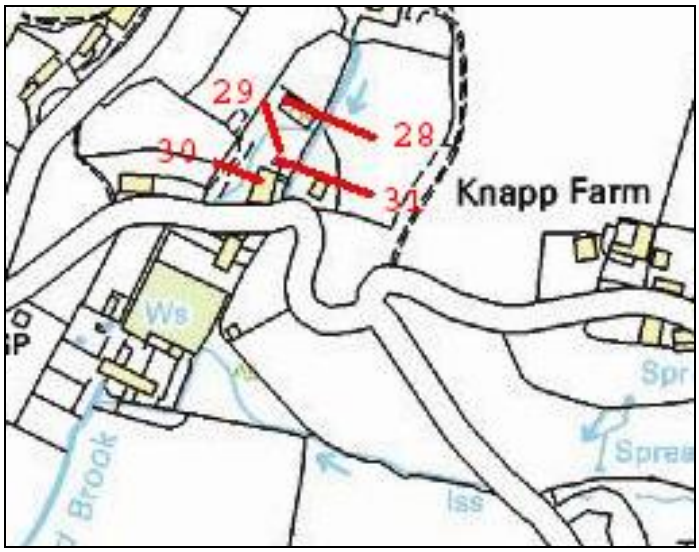
A cross section was taken from the right to the left of the brook. The cross sections with white background are not geo-referenced (for more details check the Excel sheet) whilst the cross section with light blue background are. For the z coordinate of each cross section, it is advisable to relate the above image to lidar data.



2.2.1.2 Figure: Localization of the cross sections (1)



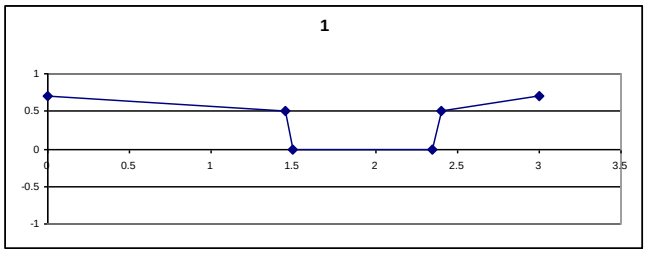
2.2.1.3 Figure: Localization of the cross sections (2)



2.2.1.4 Figure: Localization of the cross sections (3)

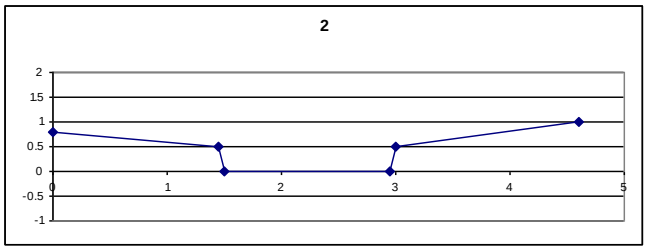
1

x [m]	y [m]
0	0.7
1.45	0.5
1.5	0
2.35	0
2.4	0.5
3	0.7



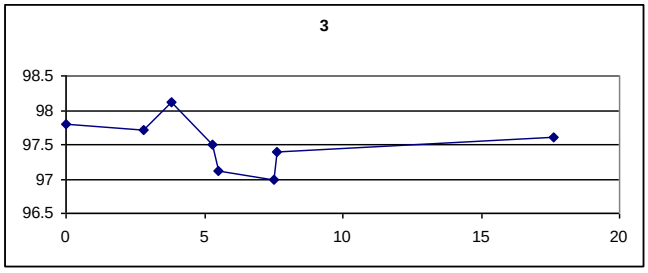
2

x [m]	y [m]
0	0.8
1.45	0.5
1.5	0
2.95	0
3	0.5
4.6	1



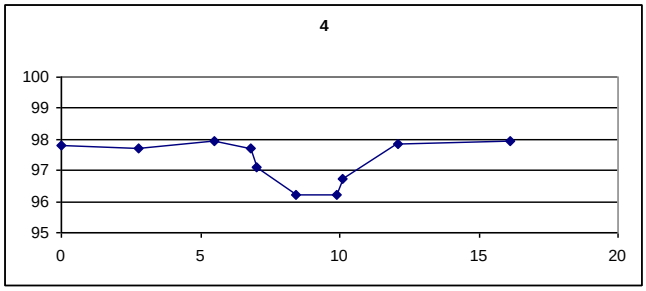
3

x [m]	y [m]
0	97.79
2.8	97.71
3.8	98.11
5.3	97.51
5.5	97.11
7.5	97
7.6	97.4
17.6	97.6



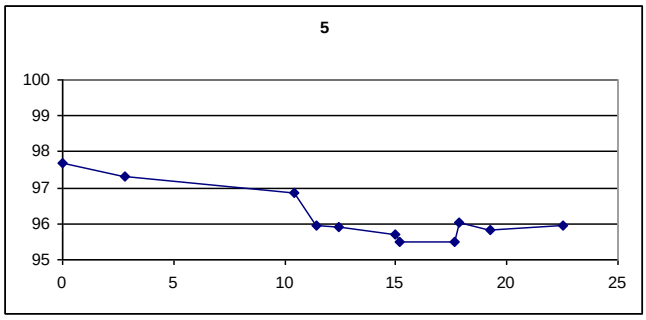
4

x [m]	y [m]
0	97.82
2.8	97.73
5.5	97.93
6.8	97.7
7	97.12
8.45	96.22
9.9	96.22
10.1	96.75
12.1	97.83
16.1	97.93



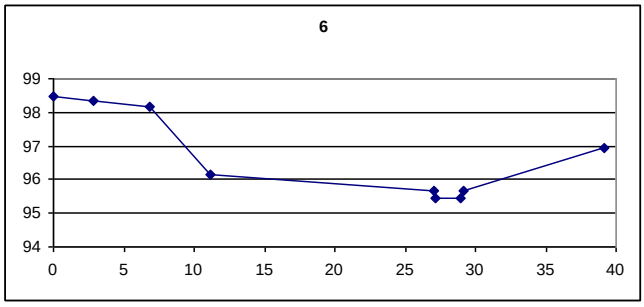
5

x [m]	y [m]
0	97.7
2.8	97.33
10.4	96.84
11.4	95.94
12.4	95.89
14.95	95.69
15.15	95.5
17.65	95.48
17.85	96.02
19.25	95.81
22.55	95.97



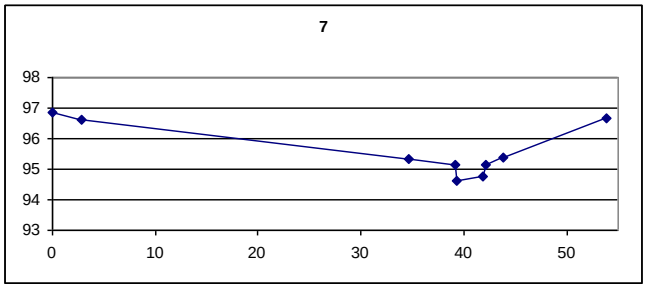
6

x [m]	y [m]
0	98.46
2.8	98.36
6.8	98.16
11.2	96.16
27	95.66
27.2	95.46
28.96	95.46
29.16	95.66
39.16	96.96



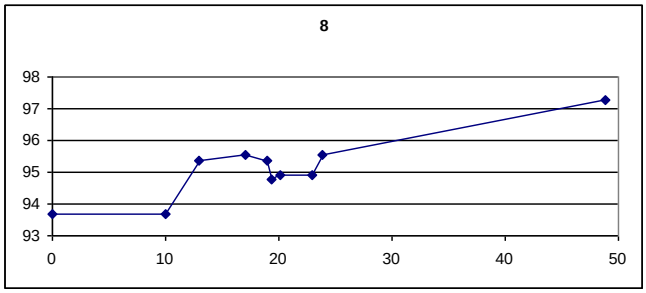
7

x [m]	y [m]
0	96.84
2.8	96.64
34.6	95.35
39.1	95.16
39.3	94.6
41.9	94.75
42.1	95.13
43.9	95.36
53.9	96.66



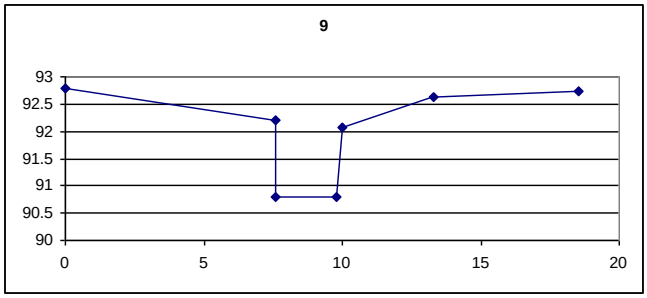
8

x [m]	y [m]
0	93.66
10	93.66
13	95.37
17	95.54
19	95.37
19.3	94.78
20.1	94.91
22.9	94.91
23.9	95.56
48.9	97.28



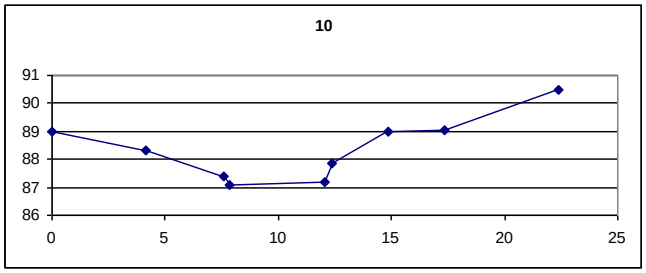
9

x [m]	y [m]
0	92.786
7.6	92.216
7.61	90.796
9.81	90.806
10.01	92.076
13.31	92.626
18.51	92.746



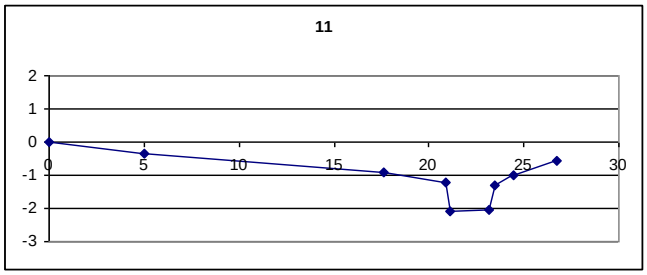
10

x [m]	y [m]
0	89.004
4.16	88.314
7.56	87.374
7.86	87.074
12.06	87.184
12.36	87.834
14.86	88.974
17.36	89.054
22.36	90.484



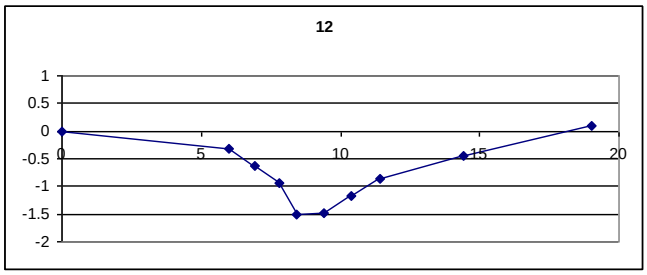
11

x [m]	y [m]
0	0
5	-0.34
17.6	-0.92
20.85	-1.21
21.15	-2.08
23.15	-2.03
23.45	-1.31
24.45	-0.99
26.75	-0.56



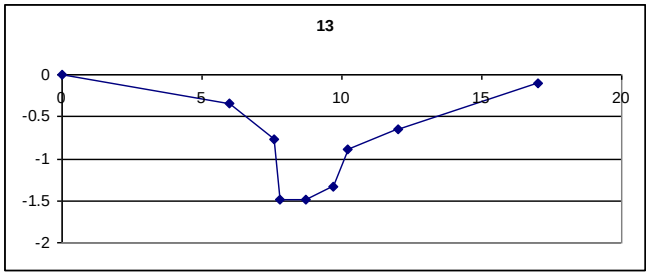
12

x [m]	y [m]
0	0
6	-0.32
6.9	-0.64
7.8	-0.93
8.4	-1.5
9.4	-1.49
10.4	-1.18
11.4	-0.85
14.4	-0.44
19	0.09



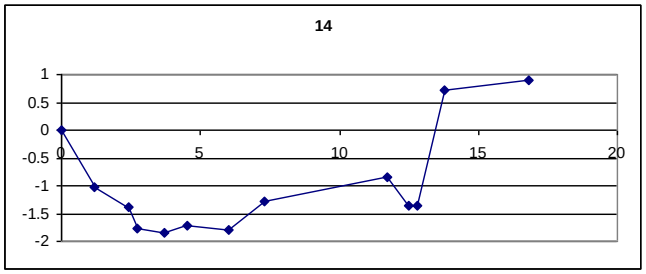
13

x [m]	y [m]
0	0
6	-0.34
7.6	-0.77
7.8	-1.48
8.7	-1.49
9.7	-1.33
10.2	-0.89
12	-0.65
17	-0.11



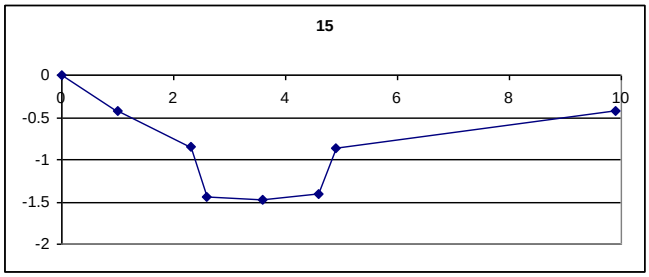
14

x [m]	y [m]
0	0
1.2	-1.02
2.4	-1.38
2.7	-1.77
3.7	-1.85
4.5	-1.72
6	-1.79
7.3	-1.29
11.7	-0.84
12.5	-1.36
12.8	-1.36
13.8	0.71
16.8	0.91



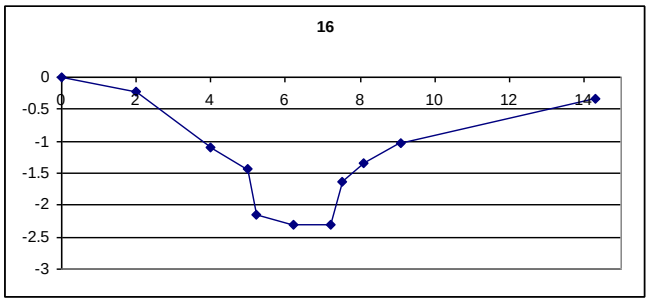
15

x [m]	y [m]
0	0
1	-0.43
2.3	-0.85
2.6	-1.44
3.6	-1.48
4.6	-1.41
4.9	-0.86
9.9	-0.43



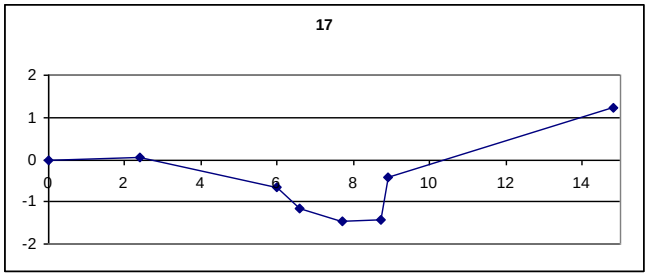
16

x [m]	y [m]
0	0
2	-0.23
4	-1.09
5	-1.43
5.2	-2.15
6.2	-2.3
7.2	-2.3
7.5	-1.64
8.1	-1.35
9.1	-1.03
14.3	-0.33



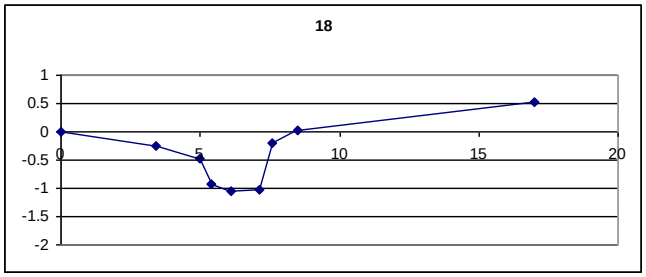
17

x [m]	y [m]
0	0
2.4	0.05
6	-0.65
6.6	-1.15
7.7	-1.45
8.7	-1.43
8.9	-0.41
14.8	1.24



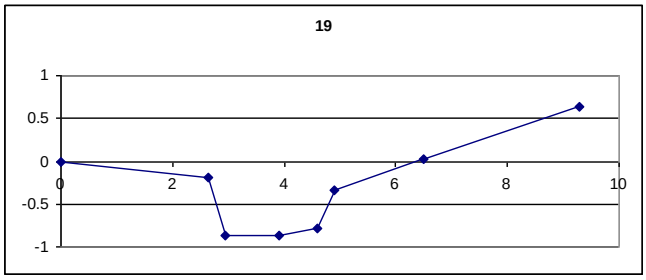
18

x [m]	y [m]
0	0
3.4	-0.25
5	-0.48
5.4	-0.92
6.1	-1.04
7.1	-1.02
7.6	-0.21
8.5	0.02
17	0.52



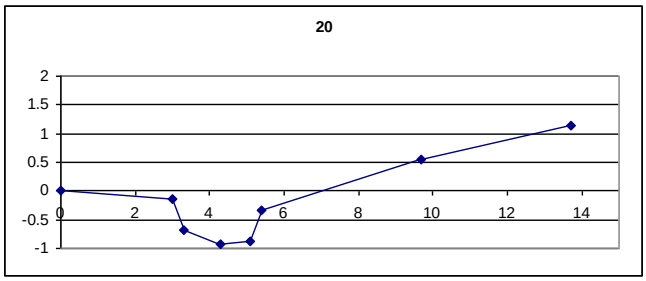
19

x [m]	y [m]
0	0
2.64	-0.19
2.94	-0.86
3.9	-0.87
4.6	-0.79
4.9	-0.34
6.5	0.02
9.3	0.64



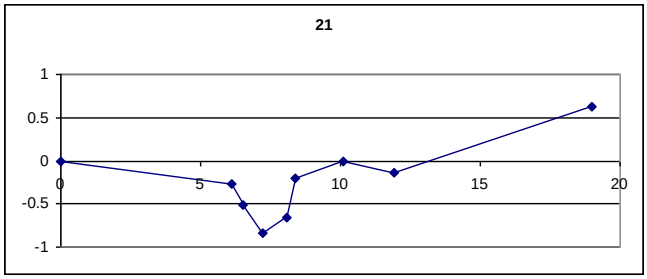
20

x [m]	y [m]
0	0
3	-0.15
3.3	-0.67
4.3	-0.92
5.1	-0.88
5.4	-0.33
9.7	0.54
13.7	1.13



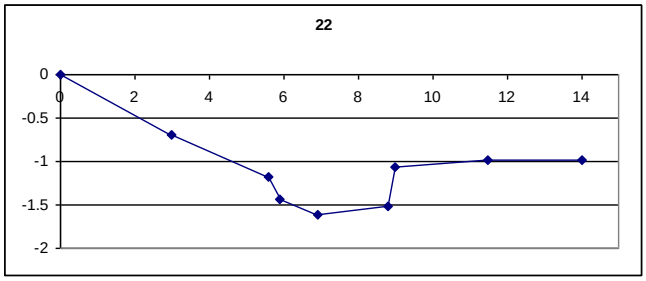
21

x [m]	y [m]
0	0
6.1	-0.27
6.5	-0.51
7.2	-0.83
8.1	-0.66
8.4	-0.21
10.1	0
11.9	-0.14
19	0.62



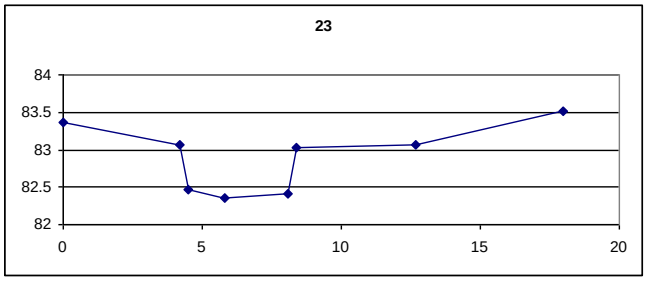
22

x [m]	y [m]
0	0
3	-0.7
5.6	-1.18
5.9	-1.44
6.9	-1.62
8.8	-1.51
9	-1.06
11.5	-0.99
14	-0.98



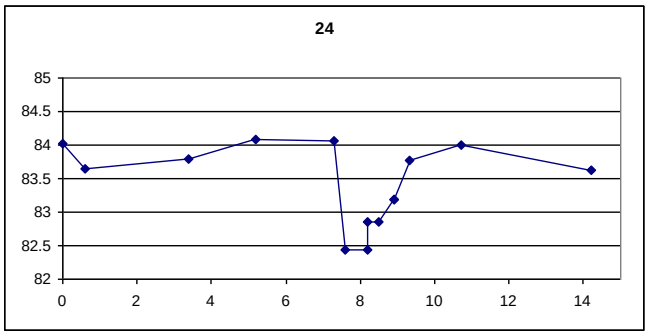
23

x [m]	y [m]
0	83.358
4.2	83.058
4.5	82.468
5.8	82.358
8.1	82.418
8.4	83.028
12.7	83.068
18	83.518



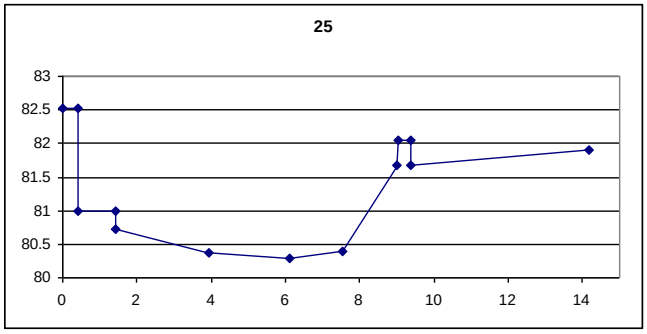
24

x [m]	y [m]
0	84.029
0.6	83.649
3.4	83.799
5.2	84.079
7.3	84.069
7.6	82.429
8.2	82.429
8.21	82.859
8.51	82.859
8.91	83.179
8.92	83.179



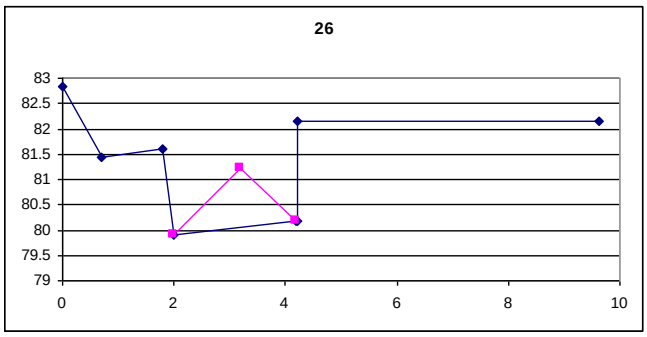
25

x [m]	y [m]
0	82.53
0.4	82.53
0.41	80.99
1.41	80.99
1.42	80.73
3.92	80.37
6.12	80.28
7.52	80.39
9.01	81.67
9.02	82.05
9.37	82.05
9.38	81.67
14.18	81.91



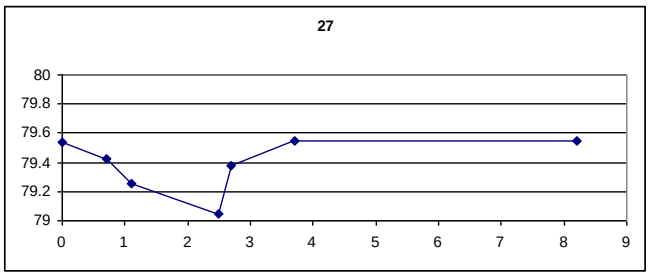
26

x [m]	y [m]
0	82.83
0.7	81.43
1.8	81.6
2	79.91
4.2	80.19
4.21	80.19
4.22	82.14
9.62	82.14
9.62	82.96
2	79.91
3.2	81.21
4.2	80.19



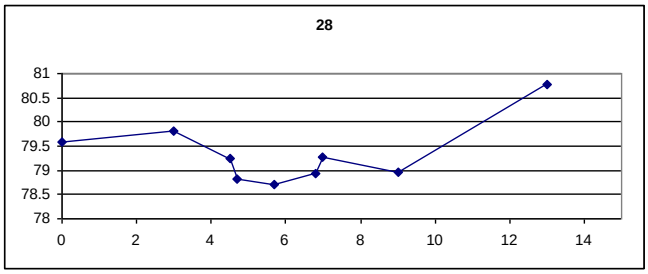
27

x [m]	y [m]
0	79.541
0.7	79.421
1.1	79.251
2.5	79.051
2.7	79.381
3.7	79.551
8.2	79.551



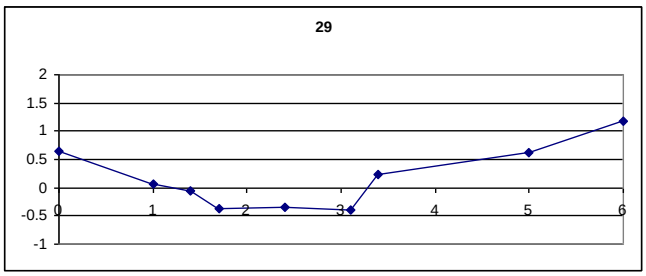
28

x [m]	y [m]
0	79.597
3	79.807
4.5	79.247
4.7	78.807
5.7	78.707
6.8	78.927
7	79.267
9	78.957
13	80.787



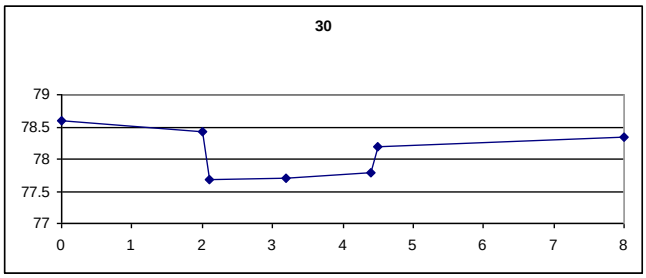
29

x [m]	y [m]
0	0.65
1	0.06
1.4	-0.05
1.7	-0.37
2.4	-0.35
3.1	-0.39
3.4	0.23
5	0.63
6	1.18



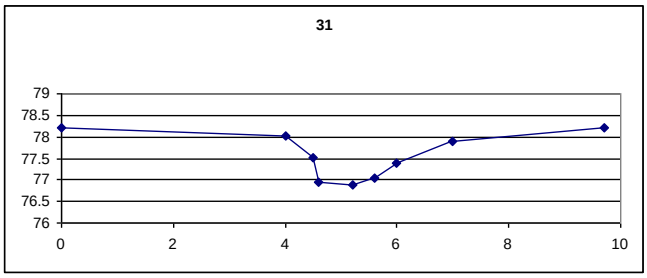
30

x [m]	y [m]
0	78.597
2	78.427
2.1	77.687
3.2	77.697
4.4	77.777
4.5	78.197
8	78.337



31

x [m]	y [m]
0	78.207
4	78.027
4.5	77.517
4.6	76.937
5.2	76.887
5.6	77.057
6	77.377
7	77.907
9.7	78.217



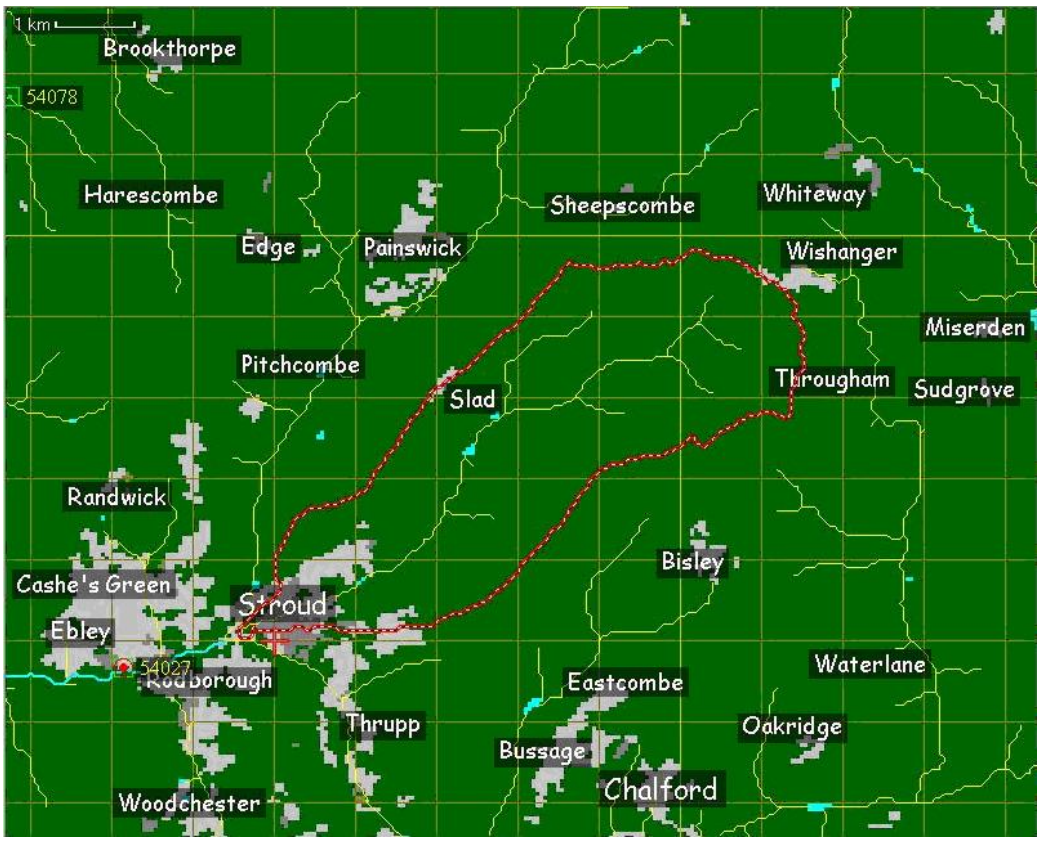
2.2.1.5 Table: cross-sections

3 Hydrological analysis

The hydrology is the main aspect to be considered in this study as it is necessary to calculate the volume of water to be dispersed upstream. The discharge which exceeds the channel capacity is termed 'flood discharge'. Flood does much of the work of shaping river channels and valleys through erosion and deposition.

3.1 Whole Catchment

Catchment descriptors are measures that seek to capture key features of the drainage basin.



3.1.1.1 Figure: FEH-Whole catchment

The whole catchment has an area of 14.96 Km^2 .

Comparing the index URBEXT 1990 of 0.0279 with the URBEXT 2000 of 0.0381 we can evidence that the catchment's urbanisation is slightly growing. The URBEXT index measures the urban extent, and according to the FEH [*Volume 1, p.21*] it is essentially rural if below 0.025 and slightly urbanised if below 0.050. Overall, in both the cases, the FEH suggested that a "rural version" is applicable when applying both the statistical method and the rainfall-runoff method.

DESCRIPTORS	MEANING	VALUE
NGR	National Grid Reference	SO 84594 05108
IHDTM NGR	Integrated Hydrological Digital Terrain Model	GB 384550 205050
DTM AREA	Catchment Area (Km^2)	14.97
ALTBAR	Mean height	181
ASPBAR	Mean ASP	252
ASPVAR	Variance ASP	0.22
BFIHOST	Baseflow index estimated from soil type	0.769
DPLBAR	Mean Drainage Path Length	5.47
DPSBAR	Mean Drainage Path Slope	169.4
FARL	Index of flood attenuation due to reservoirs and lakes	0.97
PROPWET	Index of proportion of time that soil is wet	0.33
RMED-1H	Median annual maximum rainfall (1 hour time)	10.3
RMED-1D	Median annual maximum rainfall (1 day time)	35.4
RMED-2D	Median annual maximum rainfall (2 day time)	46.7
SAAR	1961-90 standard-period annual maximum rainfall (mm)	814
SAAR4170	1941-70 standard-period annual maximum rainfall (mm)	886
SPRHOST	Standard percentage runoff estimated from soil type	16.15
URBEXT1990	Extent of urban and suburban cover (year 1990)	0.0279
URBEXT2000	Extent of urban and suburban cover (year 2000)	0.0381

Easting	384600	Northing	205100	
Area	14.96			
FARL	0.97	RMED-1H	10.3	
PROPWET	0.33	RMED-1D	35.4	
ALTBAR	181	RMED-2D	46.7	
ASPBAR	252	**SAAR**	814	
ASPVAR	0.22	SAAR4170	886	
BFIHOST	0.769	SPRHOST	16.15	
DPLBAR	5.42	URBCONC	0	
DPSBAR	169.5	**URBEXT1990**	0.0275	slightly urbanised
LDP	9.38	URBLOC	0	
C	-0.02688	C(1km)	-0.028	
D1	0.38643	D1(1km)	0.405	
D2	0.40593	D2(1km)	0.386	
D3	0.2463	D3(1km)	0.259	
E	0.29696	E(1km)	0.301	
F	2.42401	F(1km)	2.393	

3.1.1.2 Table: FEH parameters and descriptors

3.1.2 Key location springs

DESCRIPTORS	1st main spring	2nd main spring (DillayBrook)	1st confluence (1st spring)	1st confluence (2nd spring)	1st+2nd spring
NGR	SO 88891 09053	SO 90406 09201	SO 87856 07852	SO 87902 07852	SO 87858 07812
IHDTM NGR	GB 388900 209050	GB 390350 209200	GB 387850 207850	GB 387900 207800	GB 387850 207800
DTM AREA	0.5	0.67	1.67	6.17	7.83
BFIHOST	1	0.85	0.883	0.863	0.867
DPLBAR	0.52	0.64	1.56	2.58	2.42
DPSBAR	166.4	134.2	189.6	173.3	176.6
FARL	1	1	1	1	1
PROPWET	0.33	0.33	0.33	0.33	0.33
SAAR	826	848	815	840	835
SPRHOST	2	13.1	8.38	11.7	11.01
URBEXT2000	0	0	0	0	0

3.1.2.1 Table: FEH parameters for the main springs

3.1.3 Ebley station-donor catchment

Characteristic of the gauging station can be founded at:
http://www.environment-agency.gov.uk/hiflowsuk/stations/54027

DESCRIPTORS	Ebley station on river Frome (54027)
NGR	SO 83302 04593
IHDTM NGR	GB 383300 204600
DTM AREA	196.25
BFIHOST	0.739
DPLBAR	12.23
DPSBAR	124.5
FARL	0.95
PROPWET	0.32
SAAR	828
SPRHOST	20.39
URBEXT2000	0.0303

3.1.3.1 Table: Ebley station parameters

Flow value (discharge) estimation

The average Q_{med} (medium value for the discharge) can be calculated in different ways, depending on the available data.

It basically can be calculated using four different methods:

1. From flood data
2. From catchment descriptors
3. By data transfer
4. Other statistical methods

In Slad Brook there is no flow gauging station, which is the reason why the only two methods that can be used to calculate it are based on a donor or analogue catchment or use of the catchment descriptors.

The nearest flow gauge is located at Ebley on the river Frome. Even if comparing the catchment descriptors this basin can appear suitable, this area is definitely too big and seems not advisable to utilize the flood data from this catchment to calculate the Q_{med} of Slad valley.

To prove this first assumption the Q_{med} for Frome gauging station will be calculated and later compared with the result obtained using the catchment descriptors. This method calculates Qmed by linking these different descriptors: area, average annual rainfall (SAAR), soil drainage type (SPRHOST and BFIHOST) and storage attenuation (FARL) [*p.13 volume 3 of FEH*].

It is also advisable to execute a direct survey to measure it, and in this case, it must be considered that the value obtained is not representative of the average value of the year, but only for the specific season when the data is collected.

Location	Qmed from catchment descriptors (m^3/s)	Qmed forn annual maximum data (m^3/s)
Ebley	12.71	11.07
End of the Slad catchment	1.16	-
Fist confluence (1+2)	0.40	-
End of the first spring	0.07	-
End of the second spring	0.34	-
Beginning of the first spring	0.003	-
Beginning of the second spring	0.05	-
Down Stean Bridge	0.59	-
Down Stean Bridge2	0.75	-
Swift Hill	0.12	-
EA proposal	1.00	-

3.1.3.2 Table: Q_{med} for the different cross-sections

[*NOTE: applied the theory described in page 16 of The Revitalised FEH*]

Pooling Group selection

[Note: reference can be sourced in Chapter 6 of Volume 3 of FEH]

The pooling group selection to estimate a long return-period flow is advisable when the aquifer is not gauged or the gauged data is too short a timescale to provide reliable estimations. The FEH recommendation is therefore to pool data from groups of similar catchments.

The number of stations to include in the pooling group is estimated to be the minimum number that provide data for 5T times the target return period, T.

After several simulations, it was decided to utilise a pooling group of 200 years and then refine it by comparing manually with several indexes in order to try to have an homogeneous pooling group.

The selection of the similar catchments is automatically made comparing the size (AREA), wetness (SAAR) and soil proprieties (BFIHOST) in the first instance, and later also by examining other additional indicator and flood peak data.

The heterogeneity measure stated that the auto-created pooling group was strongly heterogeneous, so a manual review of the pooled group was required.

The methodology to obtain the flood frequency hydrograph for a pooling group analysis will be explained in detail for the whole catchment analysis and will be later quickly repeated reporting only the results for the other points of interest.

The stations that have been removed manually are the following:

- 30005 was removed for the AREA index too high
- 29009 was removed for the BFIHOST index too low
- 54034 was removed for the BFIHOST index too low
- 52025 was removed for the BFIHOST index too low
- 48802 was removed for the SAAR too high
- 39029 was removed for the FARL index too low
- 39035 was removed for the FARL index too low
- 27056 was removed for the PROPWET index too high
- 54044 was removed because too discordant with the average of the L-moments
- 29002 was removed because too discordant with the average of the L-moments
- 44003 was removed because too discordant with the average of the L-moments
- 41015 was removed because too discordant with the average of the L-moments

[*See p.130 of Volume 3 of FEH for the theory of L-moments*]

After this removal the final statement for the heterogeneity calculated by the software was that "the pooling group is possibly heterogeneous and a review of pooling group is optional ".

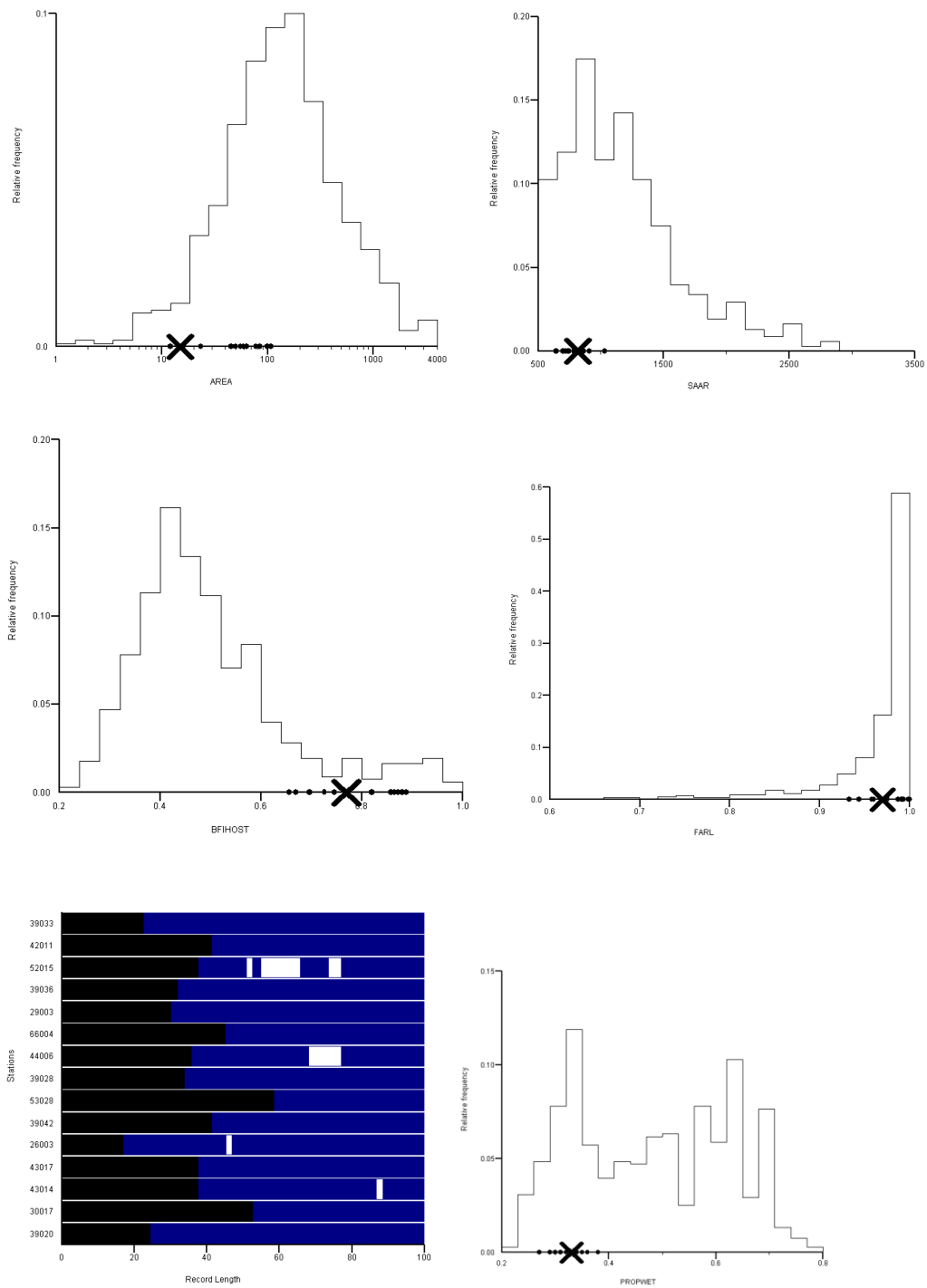
The stations included in the pooled group are finally:

- 39033 Winterbourne at Bangor
- 42011 Hamble at Frogmill
- 52015 Land Yeo at Wraxall Bridge
- 39036 Law Brook at Albury
- 29003 Lud at Louth
- 66004 Wheeler at Bodfari
- 44006 Sydling Water at Sydling st Nicholas
- 39028 Dun at Hungerford
- 53028 at Middlehill
- 39042 Leach at Priory Mill Lechlade
- 26003 Foston Beck at Foston Mill
- 43017 West Avon at Upavon
- 43014 East Avon at Upavon
- 30017 Witham at Colsterworth
- 39020 Coln at Bibury

3.1.3.3 Figure: Location of the Donor Catchments

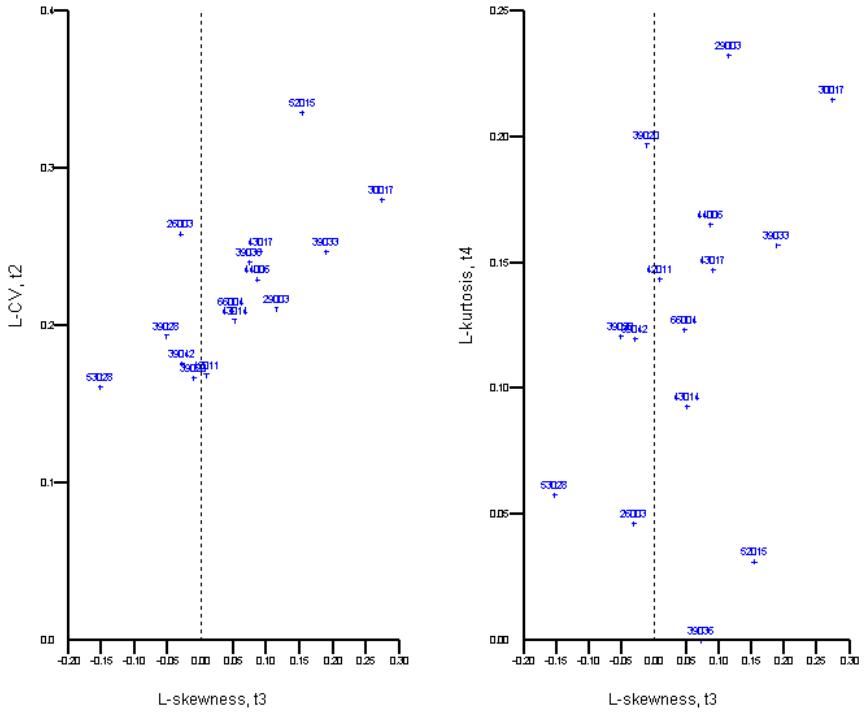
The total amalgamated data gives 488 years of acquired data that is slightly inferior of the suggested value of 500 years, but is still considered acceptable.

The following graphs show the comparison between the principal indicators of the pooling group stations.

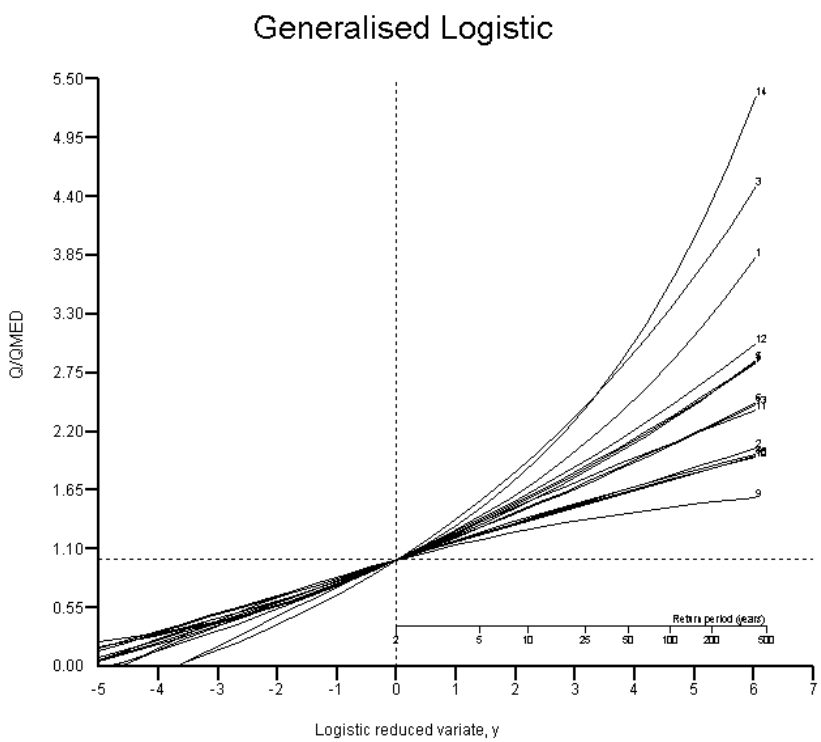


3.1.3.4 Figure: Graphs of the Indicators

The Generalised Logistic distribution, which is fitted by L-moments, is recommended by the FEH. [*See p.141 of Volume 3 of FEH for more theory on the Generalised Logistic distribution*]. The Generalised Logistic will be used to generate the flood growth curve.



3.1.3.5 Figure: L-moments



3.1.3.6 Figure: Generalised Logistic Curve

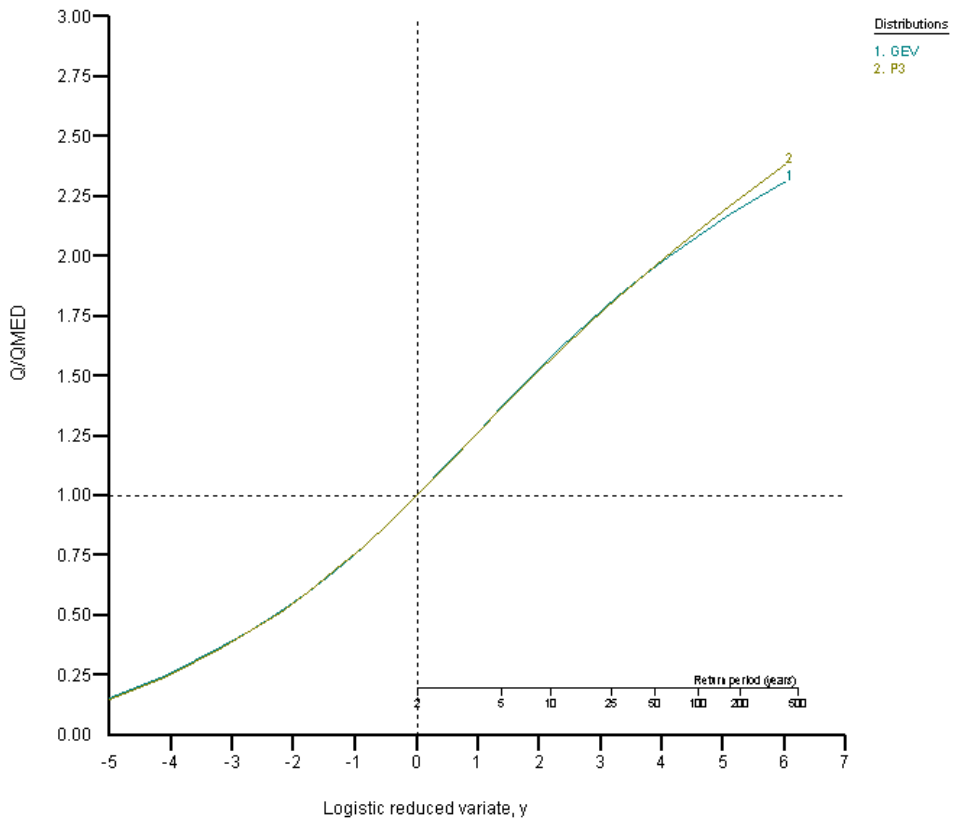
3.1.4 Flood Frequency curve

A growth curve for the pooling group is derived in order to be combined with the Q_{med} to produce the flood frequency curve.

For the kind of data object of this study it results that the acceptable distributions are the Generalised Extreme Value and Pearson Type III.

Return Period	Estimated Peak Flow (using P3)
1 in 2 years	1.00
1 in 5 years	1.365
1 in 10 years	1.572
1 in 25 years	1.805
1 in 50 years	1.963
1 in 100 years	2.019
1 in 200 years	2.247

3.1.4.1 Table: Peak Flow for the Flood Frequency curve



3.1.4.2 Figure: Flood Frequency Curve

Flood Growth Curve

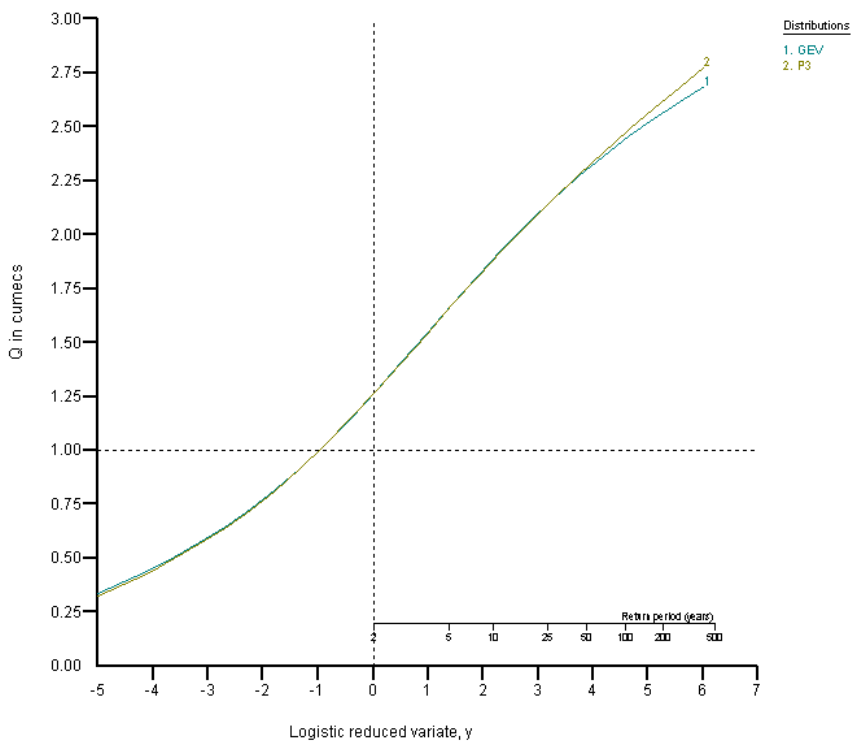
The generalised logistic distribution was used to generate the flood growth curve by multiplying the curve factors for Q_{med} for every location. The estimates of the peak flow for the design event was so determined.

In constructing the flood frequency curve, the WINFAP-FEH software strongly recommend an abstraction from Annual Maximum Flow. We are not in possession of this data, which is why the study will be carried on without this data. It should be noted that the results that will be obtained must be considered only as a rough estimation which is a high margin of error.

The resultant growth curve with the associated fittings is shown below.

Return Period	Estimated Peak Flow (using P3)
1 in 2 years	1.258
1 in 5 years	1.658
1 in 10 years	1.885
1 in 25 years	2.140
1 in 50 years	2.313
1 in 100 years	2.474
1 in 200 years	2.625

3.1.4.3 Table: Peak Flow for the Flood Growth curve



3.1.4.4 Figure: Flood Growth Curve

3.1.5 Hydrograph

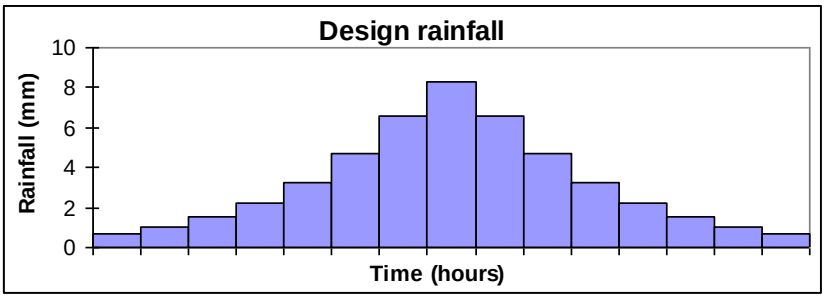
To develop a design hydrograph fitting the statistical estimation of flood peak, the revitalised FSR/FEH method was used.

This software, also provided by the CEH, is directly linked to the FEH software as it imports the catchment descriptors in order to estimate a design rainfall.
The parameters used to calculate the designed rainfall were:

- Duration, D=Tp*(1+SAAR/1000) = 5.7 hr
- Time step, Ts = 0.38 hr (note that D/Ts must be integer odd)
- Return Period, Tr = 100 yr
- Seasonal corrector factor SCF = 0.73
- Areal Reduction factor ARF = 0.95

And implementing the calculation, the result was:

- FEH DDF Model rainfall = 69.9 mm
- Design rainfall = 48.5 mm
- Peak rainfall = 8.3 mm



The design hydrograph was also obtained from the catchment descriptors parameters and the other following model parameters calculated by the software:

- Design rainfall parameters:
  - Return period (yr) = 100
  - Duration (hr) = 5.7
  - Timestep (hr) = 0.38
- Loss model parameters:
  - Cmax (mm) = 607
  - Cini (mm) = 50
  - α factor = 0.83
- Routing model parameters:
  - Tp (hr) = 3.13
  - Up = 0.65
  - Uk = 0.8
- Baseflow model parameters:
  - BL (hr) = 53.2
  - BR = 1.89
  - BF0 (m3/s) = 0

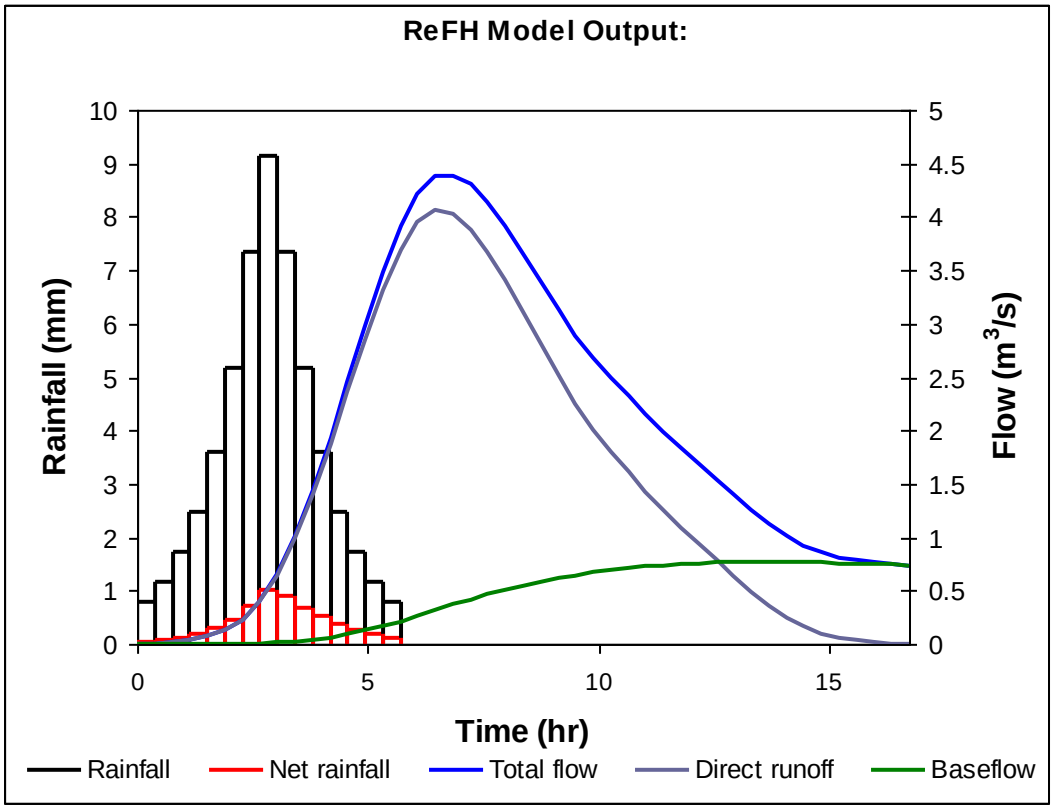
A summary of the whole characteristic is given below:

- FEH DDF rainfall (mm) = 69.9
- Design rainfall (mm) = 48.5

- Peak rainfall (mm) = 8.3
- Peak flow (m3/s) = 3.9

Series	Design Rainfall	Net rainfall	Direct runoff	Baseflow	Total flow
Units	mm	mm	m3/s	m3/s	m3/s
0.00	0.802	0.053	0.000	0.000	0.000
0.38	1.172	0.080	0.003	0.000	0.003
0.76	1.708	0.121	0.013	0.000	0.013
1.14	2.483	0.184	0.033	0.000	0.033
1.52	3.593	0.284	0.069	0.001	0.070
1.90	5.165	0.446	0.130	0.002	0.132
2.28	7.324	0.707	0.229	0.005	0.234
2.66	9.153	1.008	0.388	0.009	0.397
3.04	7.324	0.906	0.638	0.016	0.653
3.42	5.165	0.692	0.985	0.027	1.011
3.80	3.593	0.507	1.405	0.043	1.448
4.18	2.483	0.363	1.874	0.064	1.938
4.56	1.708	0.256	2.365	0.092	2.457
4.94	1.172	0.178	2.853	0.127	2.980
5.32	0.802	0.123	3.310	0.168	3.478
5.70	0.000	0.000	3.697	0.214	3.910
6.08	0.000	0.000	3.959	0.264	4.223
6.46	0.000	0.000	4.060	0.316	4.376
6.84	0.000	0.000	4.023	0.368	4.391
7.22	0.000	0.000	3.881	0.419	4.300
7.60	0.000	0.000	3.666	0.466	4.132
7.98	0.000	0.000	3.401	0.511	3.911
8.36	0.000	0.000	3.107	0.551	3.658
8.74	0.000	0.000	2.801	0.587	3.388
9.12	0.000	0.000	2.505	0.618	3.124
9.50	0.000	0.000	2.242	0.646	2.888
9.88	0.000	0.000	2.008	0.670	2.678
10.26	0.000	0.000	1.799	0.691	2.490
10.64	0.000	0.000	1.606	0.709	2.315
11.02	0.000	0.000	1.426	0.724	2.150
11.40	0.000	0.000	1.255	0.737	1.992
11.78	0.000	0.000	1.091	0.748	1.839
12.16	0.000	0.000	0.933	0.756	1.689
12.54	0.000	0.000	0.779	0.762	1.541
12.92	0.000	0.000	0.630	0.766	1.396
13.30	0.000	0.000	0.488	0.768	1.256
13.68	0.000	0.000	0.358	0.769	1.126
14.06	0.000	0.000	0.246	0.767	1.013
14.44	0.000	0.000	0.160	0.764	0.925
14.82	0.000	0.000	0.099	0.761	0.860
15.20	0.000	0.000	0.057	0.756	0.814
15.58	0.000	0.000	0.030	0.752	0.782
15.96	0.000	0.000	0.014	0.747	0.760
16.34	0.000	0.000	0.005	0.741	0.746
16.72	0.000	0.000	0.001	0.736	0.737
Totals	53.647	5.909	5.909	1.796	7.705

3.1.5.1 Table: Hydrograph parameters

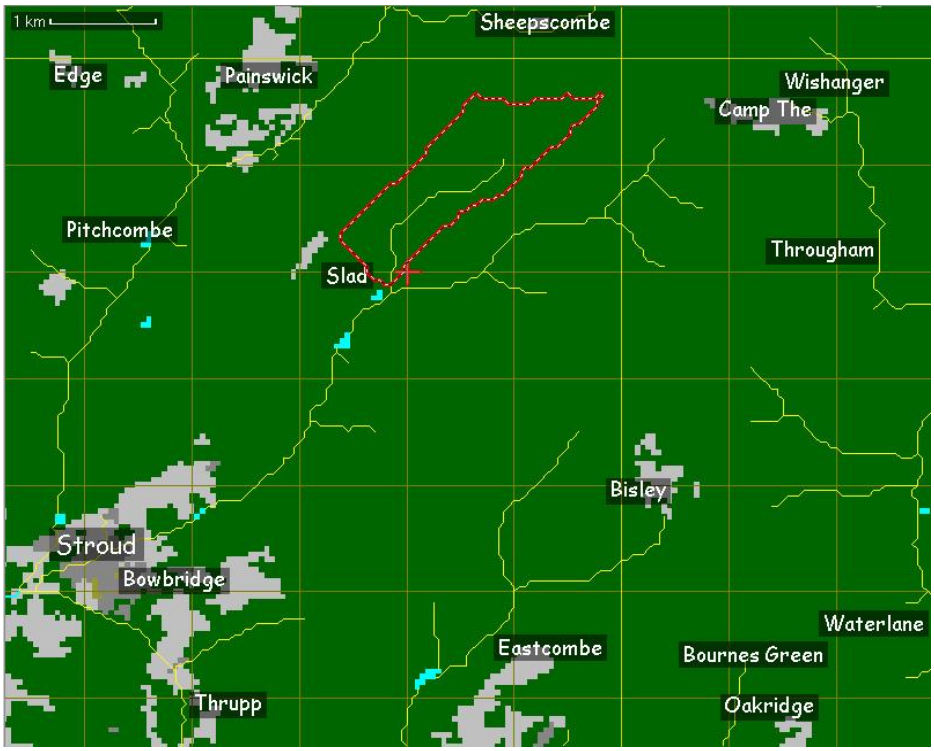


3.1.5.2 Figure: Hydrograph

From the hydrograph above, the direct runoff is easily recognisable. The direct runoff is the runoff caused by and directly following a rainfall; it forms the major part of the flood hydrograph and excludes base flow. The base flow is that part of the stream discharge that is not attributable to direct runoff from precipitation or melting snow; it is usually sustained by groundwater. The amount of base flow a stream receives is closely linked to the permeability of rock or soil in the watershed. Base flow is important because impervious surfaces created by development will inhibit water from infiltrating into the ground as it did prior to development. Over time this will draw down the groundwater elevation, which in turn affects spring activity, which feeds the river. In short the river's base flow will decrease over time if springs are not replenished by infiltration; which is why base flow is a key indicator to monitor.

3.2 First spring

3.2.1 Catchment descriptors



3.2.1.1 Figure: FEH-Slad spring

The First Spring catchment has an area of 1.63 Km^2.

Easting	387850	Northing	207900	
Area	1.63			
FARL	1	RMED-1H	10.3	
PROPWET	0.33	RMED-1D	35	
ALTBAR	198	RMED-2D	46.1	
ASPBAR	192	SAAR	815	
ASPVAR	0.41	SAAR4170	877	
BFIHOST	0.886	SPRHOST	8.23	
DPLBAR	1.53	URBCONC	0	
DPSBAR	190.9	URBEXT1990	0	essentially rural
LDP	3.08	URBLOC	0	
C	-0.02678	C(1km)	-0.026	
D1	0.38196	D1(1km)	0.385	
D2	0.41085	D2(1km)	0.411	
D3	0.24534	D3(1km)	0.238	
E	0.29685	E(1km)	0.295	
F	2.42211	F(1km)	2.428	

3.2.1.2 Table: FEH parameters

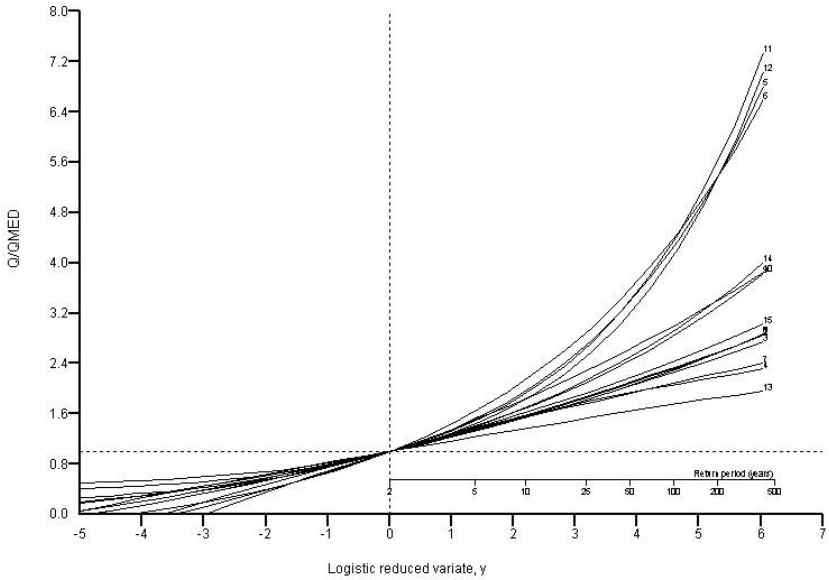
3.2.2 Pooling group selection

After this removal the final statement for the heterogeneity calculated by the software was that "the pooling group is possibly heterogeneous and a review of pooling group is optional".

The stations included in the pooled group are: 39036, 44006, 33054, 43806, 42005, 41015, 26003, 29003, 39033, 33032, 42009, 42008, 39042, 42006, and 43017.

3.2.2.1 Figure: Location of the Donor Catchments

That summed together give 509 years of acquired data.



3.2.2.2 Figure: Generalised Logistic Curve

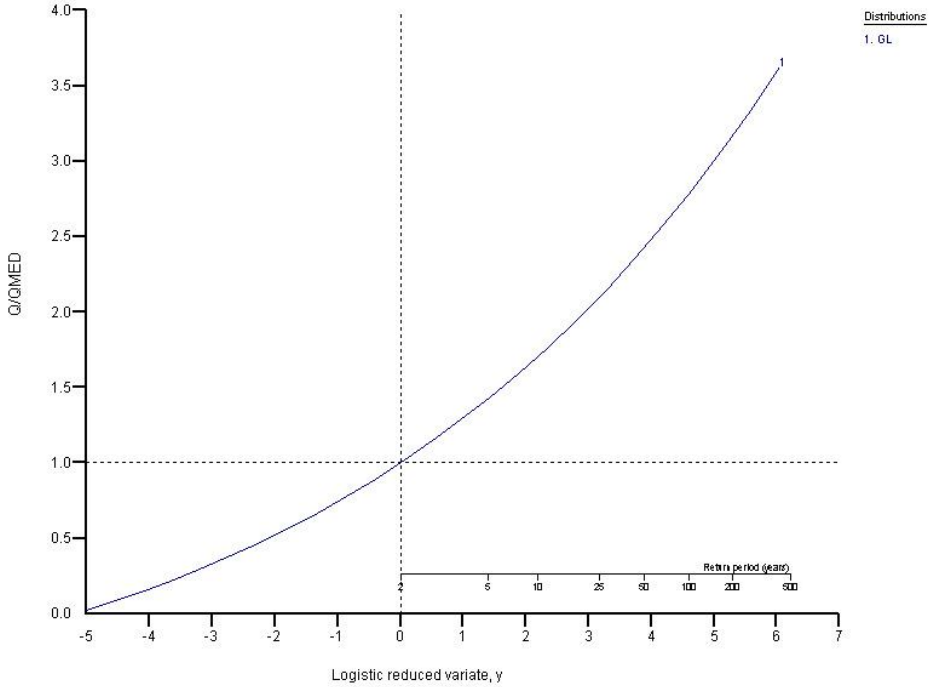
3.2.3 Flood Frequency Curve

A growth curve for the pooling group is derived in order to be combined with the Q_{med} (0.7 m^3/s) to produce the flood frequency curve.

With the type of data available to this study it results in acceptable distributions for the Generalised Logistic Study.

Return Period	Estimated Peak Flow (using GL)
1 in 2 years	1.00
1 in 5 years	1.430
1 in 10 years	1.708
1 in 25 years	2.102
1 in 50 years	2.427
1 in 100 years	2.780
1 in 200 years	3.168

3.2.3.1 Table: Peak Flow for the Flood Frequency curve

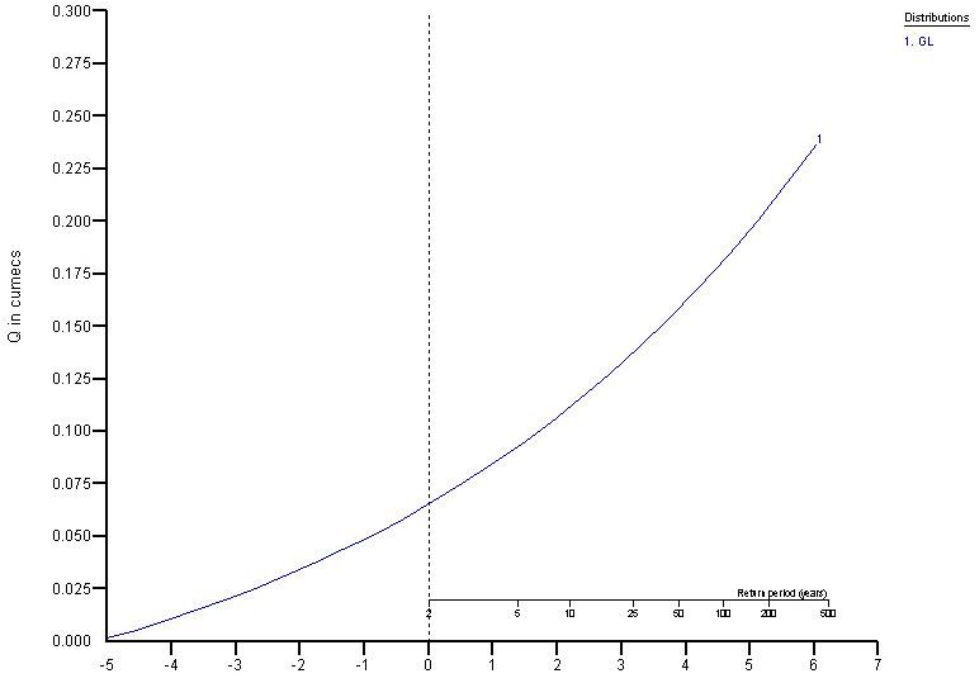


3.2.3.2 Figure: Flood Frequency Curve

3.2.4 Flood Growth Curve

Return Period	Estimated Peak Flow (using GL)
1 in 2 years	0.065
1 in 5 years	0.093
1 in 10 years	0.112
1 in 25 years	0.137
1 in 50 years	0.159
1 in 100 years	0.182
1 in 200 years	0.207

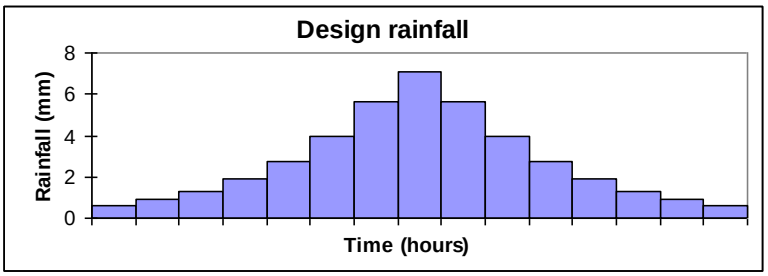
3.2.4.1 Table: Peak Flow for the Flood Growth curve



3.2.4.2 Figure: Flood Growth Curve

3.2.5 Hydrograph

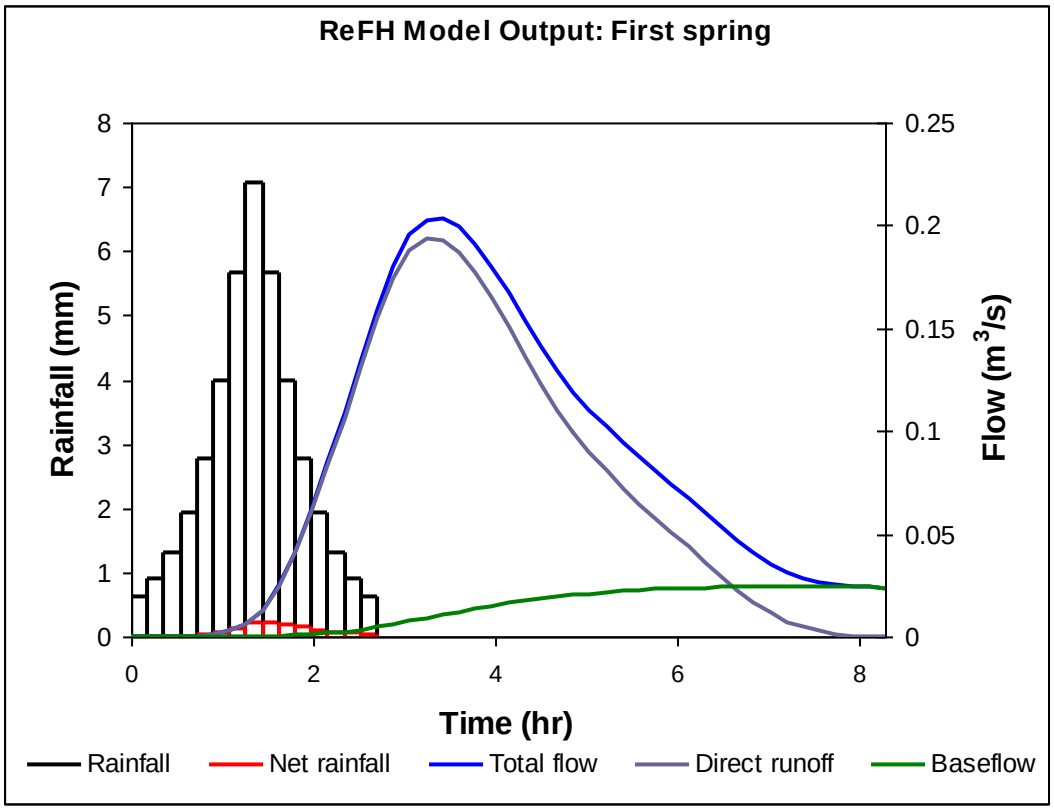
To develop a design hydrograph fitting the statistical estimation of flood peak, the revitalised FSR/FEH method was used.



Series	Design Rainfall	Net rainfall	Direct runoff	Baseflow	Total flow
Units	mm	mm	m3/s	m3/s	m3/s
0.00	0.619	0.000	0.000	0.000	0.000
0.18	0.905	0.001	0.000	0.000	0.000
0.36	1.319	0.004	0.000	0.000	0.000
0.54	1.917	0.010	0.000	0.000	0.000
0.72	2.774	0.025	0.000	0.000	0.000
0.90	3.989	0.055	0.001	0.000	0.001
1.08	5.655	0.117	0.002	0.000	0.003
1.26	7.068	0.211	0.006	0.000	0.006
1.44	5.655	0.221	0.013	0.000	0.013
1.62	3.989	0.183	0.025	0.000	0.025
1.80	2.774	0.141	0.041	0.001	0.041
1.98	1.917	0.104	0.060	0.001	0.061
2.16	1.319	0.075	0.083	0.002	0.084
2.34	0.905	0.053	0.106	0.002	0.109
2.52	0.619	0.037	0.131	0.003	0.134
2.70	0.000	0.000	0.154	0.005	0.159
2.88	0.000	0.000	0.174	0.006	0.180
3.06	0.000	0.000	0.188	0.007	0.195
3.24	0.000	0.000	0.193	0.009	0.202
3.42	0.000	0.000	0.193	0.011	0.203
3.60	0.000	0.000	0.187	0.012	0.199
3.78	0.000	0.000	0.177	0.014	0.191
3.96	0.000	0.000	0.165	0.015	0.180
4.14	0.000	0.000	0.151	0.016	0.167
4.32	0.000	0.000	0.136	0.017	0.154
4.50	0.000	0.000	0.122	0.018	0.141
4.68	0.000	0.000	0.110	0.019	0.129
4.86	0.000	0.000	0.099	0.020	0.119
5.04	0.000	0.000	0.089	0.021	0.110
5.22	0.000	0.000	0.080	0.021	0.102

5.40	0.000	0.000	0.072	0.022	0.094
5.58	0.000	0.000	0.065	0.022	0.087
5.76	0.000	0.000	0.057	0.023	0.080
5.94	0.000	0.000	0.050	0.023	0.074
6.12	0.000	0.000	0.043	0.024	0.067
6.30	0.000	0.000	0.036	0.024	0.060
6.48	0.000	0.000	0.029	0.024	0.053
6.66	0.000	0.000	0.023	0.024	0.047
6.84	0.000	0.000	0.017	0.024	0.041
7.02	0.000	0.000	0.011	0.024	0.036
7.20	0.000	0.000	0.007	0.024	0.031
7.38	0.000	0.000	0.004	0.024	0.029
7.56	0.000	0.000	0.002	0.024	0.027
7.74	0.000	0.000	0.001	0.024	0.025
7.92	0.000	0.000	0.000	0.024	0.024
8.10	0.000	0.000	0.000	0.024	0.024
8.28	0.000	0.000	0.000	0.024	0.024
Totals	41.426	1.236	1.236	0.248	1.484

3.2.5.1 Table: Hydrograph parameters



3.2.5.2 Figure: Hydrograph

3.3 Second spring – Dillay Brook

3.3.1 Catchment descriptors

3.3.1.1 Figure: FEH-Dillay Brook

The Second Spring catchment has an area of 6.17 Km^2 .

Easting	387900	Northing	207800	
Area	6.17			
FARL	1	RMED-1H	10.4	
PROPWET	0.33	RMED-1D	35.3	
ALTBAR	216	RMED-2D	47	
ASPBAR	275	SAAR	840	
ASPVAR	0.24	SAAR4170	901	
BFIHOST	0.863	SPRHOST	11.7	
DPLBAR	2.58	URBCONC	0	
DPSBAR	173.3	URBEXT1990	0.0018	essentially rural
LDP	4.45	URBLOC	0	
C	-0.02729	C(1km)	-0.026	
D1	0.38244	D1(1km)	0.385	
D2	0.41837	D2(1km)	0.411	
D3	0.24946	D3(1km)	0.238	
E	0.29725	E(1km)	0.295	
F	2.42976	F(1km)	2.428	

3.3.1.2 Table: FEH parameters

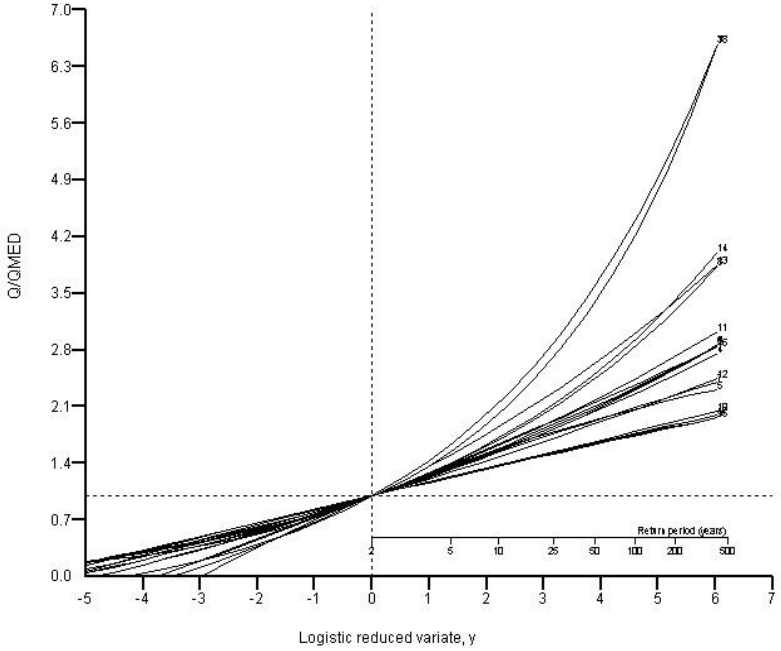
3.3.2 Pooling group selection

After this removal the final statement for the heterogeneity calculated by the software was that "the pooling group is possibly heterogeneous and a review of pooling group is optional".

The stations included in the pooled group are: 39036, 44006, 41015, 33054, 43806, 29003, 26003, 39033, 39042, 42011, 43017, 43014, 33032, 42006, 39020, 43010, 43012, and 44003.

3.3.2.1 Figure: Location of the Donor Catchments

That summed together give 584 years of acquired data.



3.3.2.2 Figure: Generalised Logistic Curve

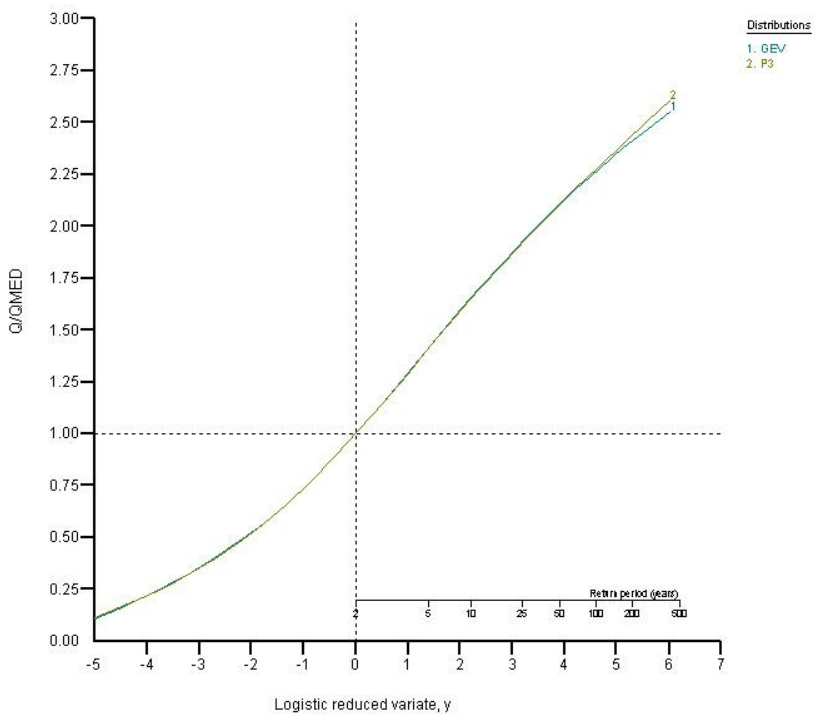
3.3.3 Flood Frequency Curve

A growth curve for the pooling group is derived in order to be combined with the Q_{med} to produce the flood frequency curve.

For the kind of data object of this study it results that the acceptable distributions are the Generalised Extreme Value and Person Type III.

Return Period	Estimated Peak Flow (using P3)
1 in 2 years	1.00
1 in 5 years	1.409
1 in 10 years	1.647
1 in 25 years	1.918
1 in 50 years	2.104
1 in 100 years	2.278
1 in 200 years	2.443

3.3.3.1 Table: Peak Flow for the Flood Frequency curve

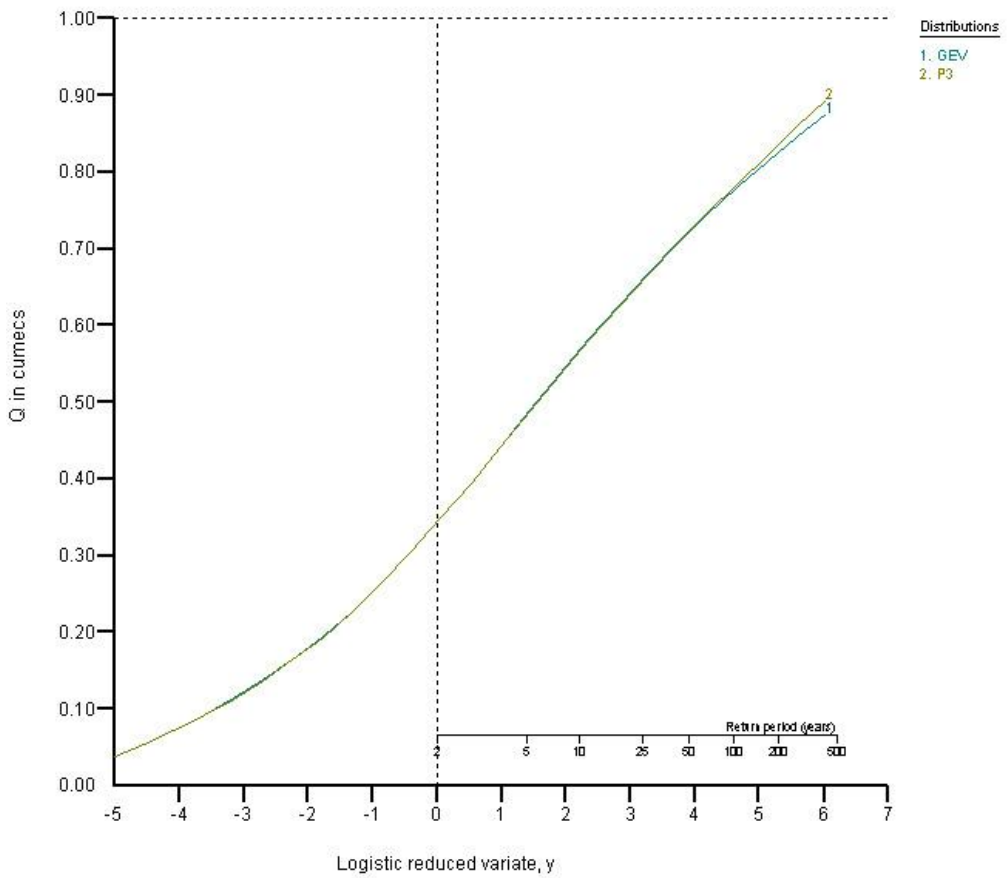


3.3.3.2 Figure: Flood Frequency Curve

3.3.4 Flood Growth Curve

Return Period	Estimated Peak Flow (using P3)
1 in 2 years	0.343
1 in 5 years	0.483
1 in 10 years	0.564
1 in 25 years	0.657
1 in 50 years	0.721
1 in 100 years	0.781
1 in 200 years	0.837

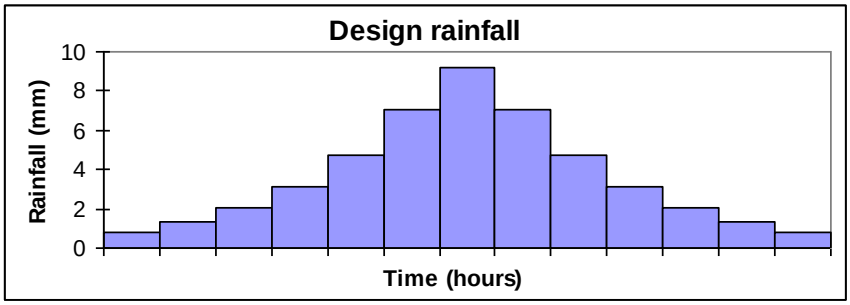
3.3.4.1 Table: Peak Flow for the Flood Growth curve



3.3.4.2 Figure: Flood Growth Curve

3.3.5 Hydrograph

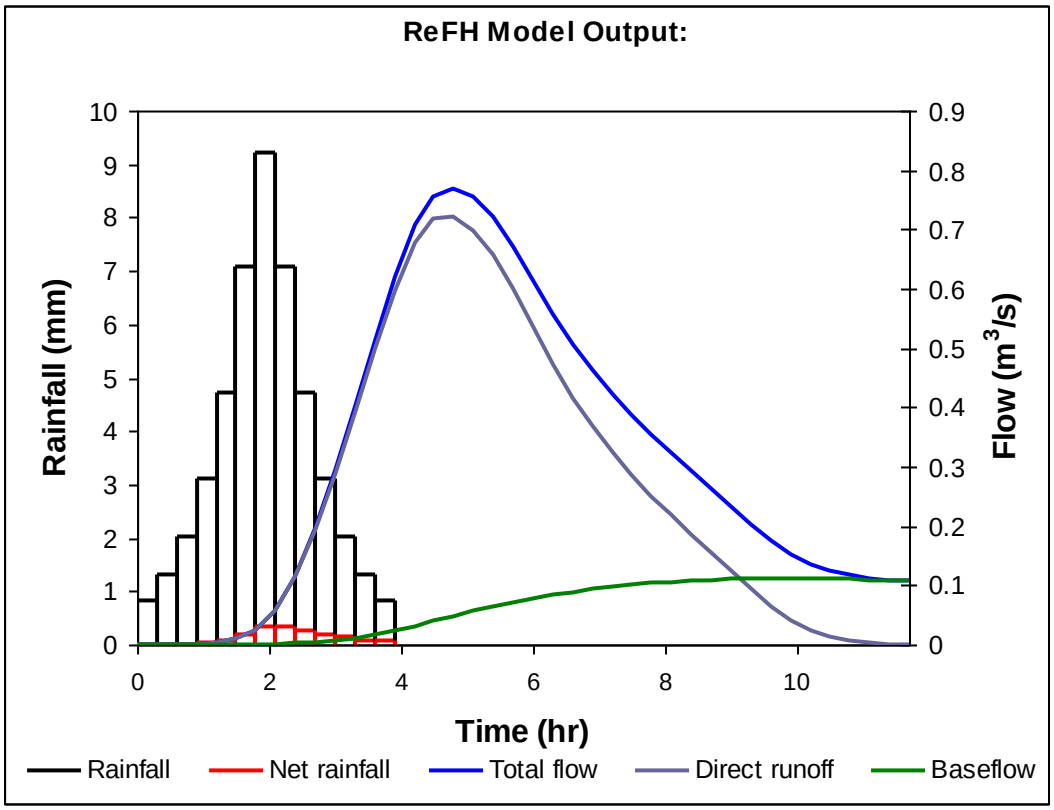
To develop a design hydrograph fitting the statistical estimation of flood peak, the revitalised FSR/FEH method was used.



Series	Design Rainfall	Net rainfall	Direct runoff	Baseflow	Total flow
Units	mm	mm	m3/s	m3/s	m3/s
0.0	0.842	0.002	0.000	0.000	0.000
0.3	1.304	0.005	0.000	0.000	0.000
0.6	2.012	0.012	0.000	0.000	0.000
0.9	3.091	0.030	0.001	0.000	0.001
1.2	4.714	0.074	0.004	0.000	0.004
1.5	7.084	0.172	0.010	0.000	0.010
1.8	9.226	0.335	0.025	0.000	0.025
2.1	7.084	0.343	0.057	0.001	0.058
2.4	4.714	0.269	0.114	0.002	0.116
2.7	3.091	0.194	0.193	0.004	0.196
3.0	2.012	0.134	0.287	0.007	0.293
3.3	1.304	0.090	0.390	0.011	0.401
3.6	0.842	0.060	0.497	0.016	0.514
3.9	0.000	0.000	0.598	0.023	0.621
4.2	0.000	0.000	0.676	0.031	0.707
4.5	0.000	0.000	0.717	0.039	0.756
4.8	0.000	0.000	0.722	0.048	0.770
5.1	0.000	0.000	0.699	0.056	0.755
5.4	0.000	0.000	0.656	0.064	0.720
5.7	0.000	0.000	0.600	0.072	0.672
6.0	0.000	0.000	0.536	0.078	0.615
6.3	0.000	0.000	0.473	0.084	0.557
6.6	0.000	0.000	0.416	0.089	0.505
6.9	0.000	0.000	0.367	0.094	0.461
7.2	0.000	0.000	0.324	0.097	0.422
7.5	0.000	0.000	0.286	0.100	0.386
7.8	0.000	0.000	0.251	0.103	0.354
8.1	0.000	0.000	0.218	0.106	0.323
8.4	0.000	0.000	0.186	0.107	0.293
8.7	0.000	0.000	0.154	0.109	0.263

9.0	0.000	0.000	0.123	0.110	0.233
9.3	0.000	0.000	0.093	0.111	0.204
9.6	0.000	0.000	0.065	0.111	0.176
9.9	0.000	0.000	0.042	0.111	0.153
10.2	0.000	0.000	0.025	0.111	0.136
10.5	0.000	0.000	0.014	0.110	0.124
10.8	0.000	0.000	0.006	0.110	0.116
11.1	0.000	0.000	0.002	0.109	0.112
11.4	0.000	0.000	0.001	0.109	0.109
11.7	0.000	0.000	0.000	0.108	0.108
Totals	47.320	1.720	1.720	0.427	2.147

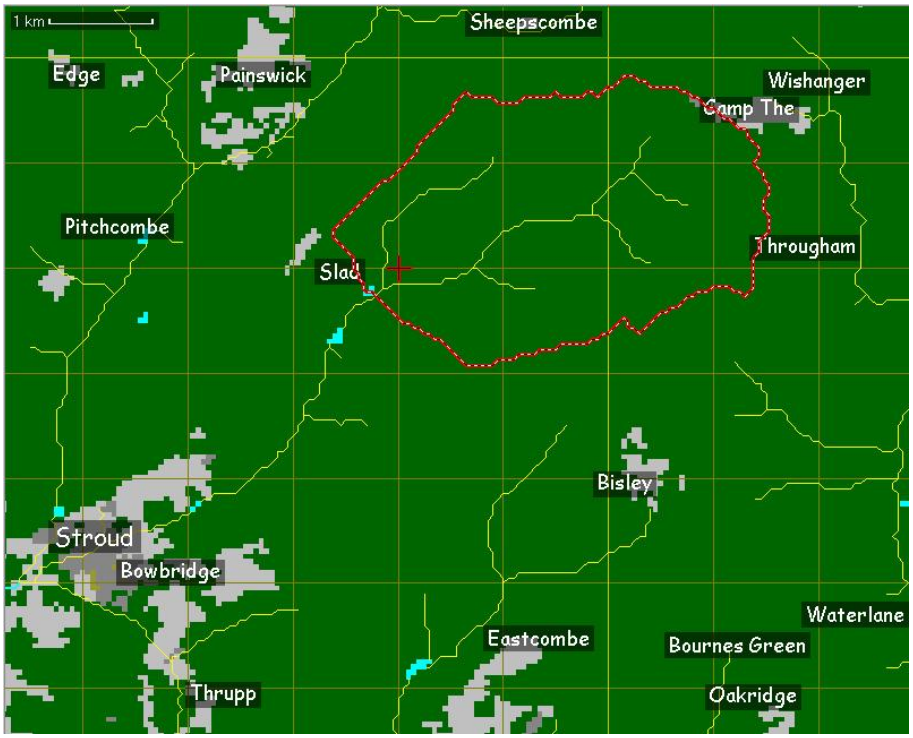
3.3.5.1 Table: Hydrograph parameters



3.3.5.2 Figure: Hydrograph

3.4 First and Second Spring

3.4.1 Catchment descriptors



3.4.1.1 Figure: FEH-First and Second Spring

The catchment has an area of 7.86 Km^2 .

Easting	387800	Northing	207750	
Area	7.86			
FARL	1	RMED-1H	10.4	
PROPWET	0.33	RMED-1D	35.2	
ALTBAR	212	RMED-2D	46.8	
ASPBAR	251	SAAR	835	
ASPVAR	0.22	SAAR4170	896	
BFIHOST	0.865	SPRHOST	11.1	
DPLBAR	2.48	URBCONC	0	
DPSBAR	176.7	URBEXT1990	0.0014	essentially rural
LDP	4.57	URBLOC	0	
C	-0.026	C(1km)	-0.026	
D1	0.38236	D1(1km)	0.385	
D2	0.41672	D2(1km)	0.411	
D3	0.24851	D3(1km)	0.238	
E	0.29715	E(1km)	0.295	
F	2.42815	F(1km)	2.428	

3.4.1.2 Table: FEH parameters

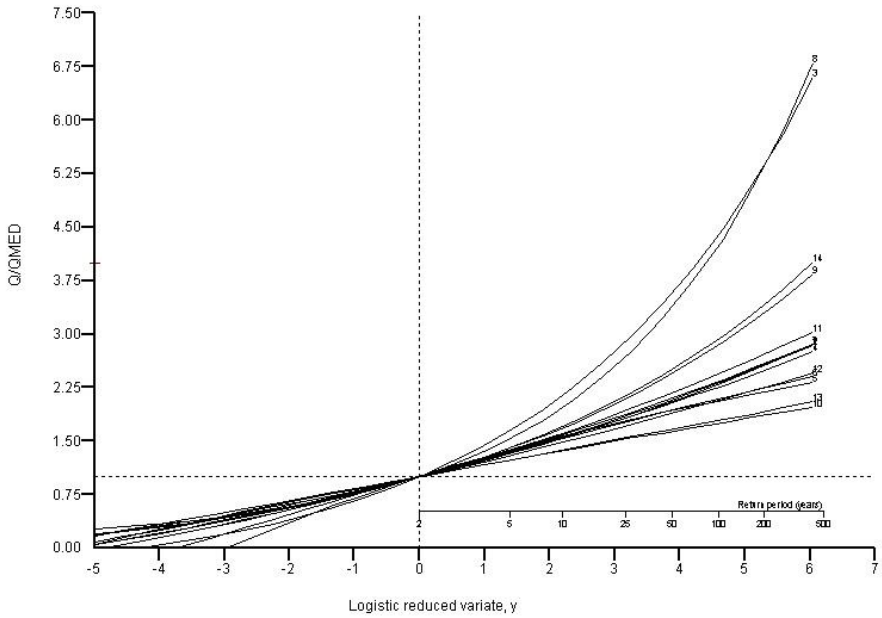
3.4.2 Pooling group selection

After this removal the final statement for the heterogeneity calculated by the software was that "the pooling group is possibly heterogeneous and a review of pooling group is optional".

The stations included in the pooled group are: 39036, 44006, 41015, 33054, 43806, 29003, 26003, 42005, 39033, 39042, 43017, 43014, 42011, and 42006.

3.4.2.1 Figure: Location of the Donor Catchments

That summed together give 472 years of acquired data.



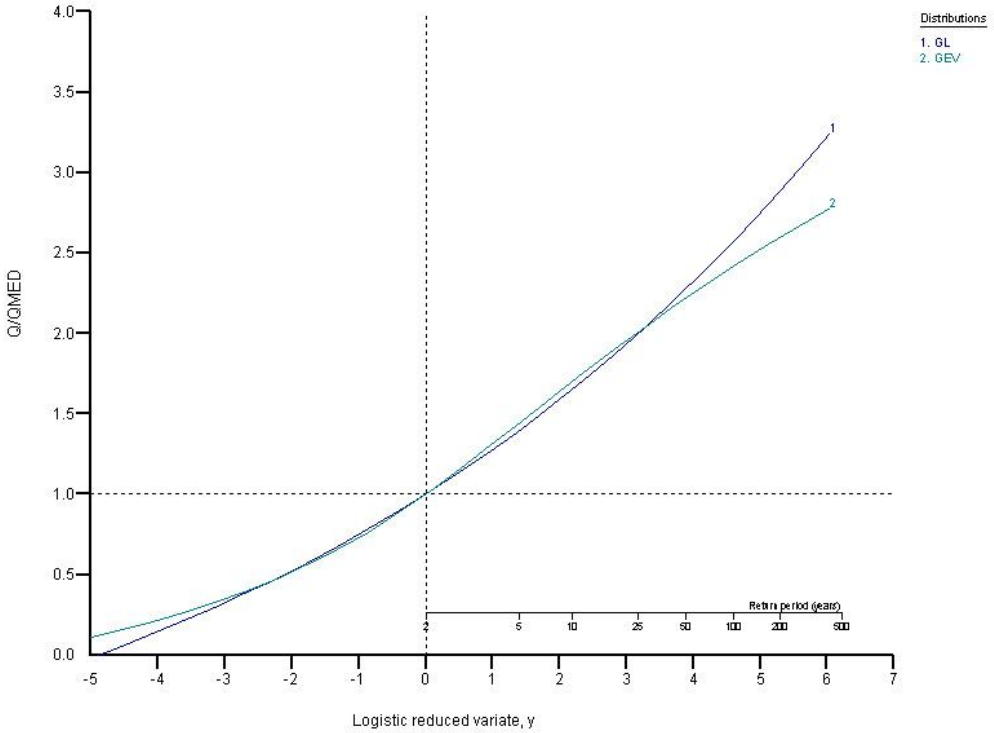
3.4.2.2 Figure: Generalised Logistic Curve

3.4.3 Flood Frequency Curve

A growth curve for the pooling group is derived in order to be combined with the Q_{med} (0.408 m^3/s) to produce the flood frequency curve.

Return Period	Estimated Peak Flow (using GL)
1 in 2 years	1.000
1 in 5 years	1.394
1 in 10 years	1.654
1 in 25 years	2.000
1 in 50 years	2.277
1 in 100 years	2.571
1 in 200 years	2.886

3.4.3.1 Table: Peak Flow for the Flood Frequency curve

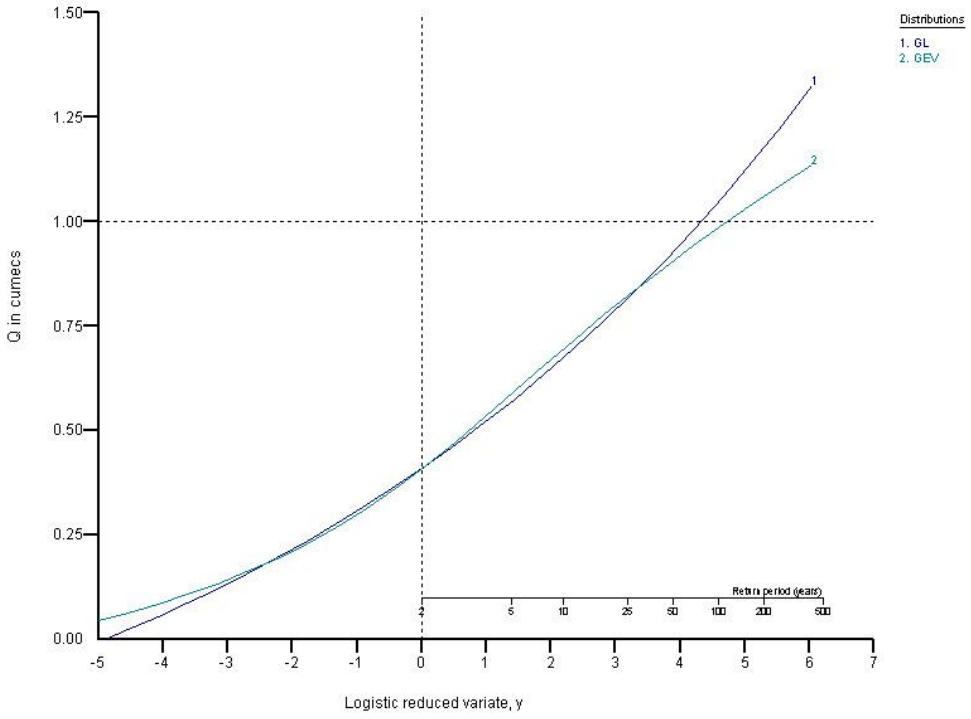


3.4.3.2 Figure: Flood Frequency Curve

3.4.4 Flood Growth Curve

Return Period	Estimated Peak Flow (using GL)
1 in 2 years	0.408
1 in 5 years	0.588
1 in 10 years	0.696
1 in 25 years	0.821
1 in 50 years	0.908
1 in 100 years	0.987
1 in 200 years	1.062

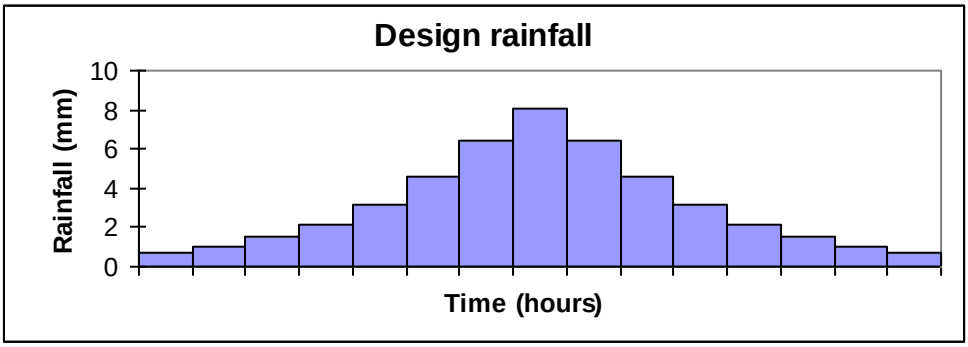
3.4.4.1 Table: Peak Flow for the Flood Growth curve



3.4.4.2 Figure: Flood Growth Curve

3.4.5 Hydrograph

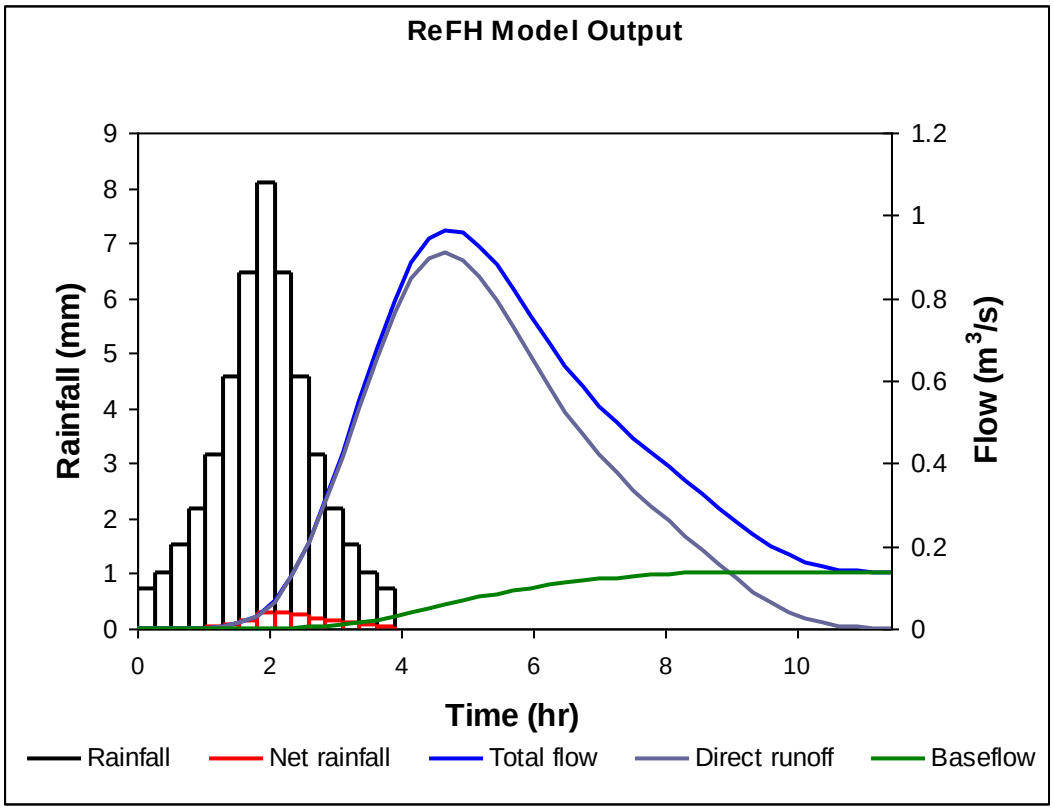
To develop a design hydrograph fitting the statistical estimation of flood peak the revitalised FSR/FEH method was used.



Series	Design Rainfall	Net rainfall	Direct runoff	Baseflow	Total flow
Units	mm	mm	m3/s	m3/s	m3/s
0.00	0.708	0.000	0.000	0.000	0.000
0.26	1.034	0.002	0.000	0.000	0.000
0.52	1.508	0.006	0.000	0.000	0.000
0.78	2.191	0.014	0.001	0.000	0.001
1.04	3.171	0.033	0.002	0.000	0.002
1.30	4.558	0.073	0.005	0.000	0.005
1.56	6.463	0.156	0.013	0.000	0.013
1.82	8.078	0.282	0.030	0.000	0.030
2.08	6.463	0.295	0.065	0.001	0.066
2.34	4.558	0.245	0.124	0.002	0.126
2.60	3.171	0.188	0.206	0.004	0.209
2.86	2.191	0.139	0.305	0.006	0.311
3.12	1.508	0.100	0.416	0.010	0.426
3.38	1.034	0.070	0.535	0.015	0.550
3.64	0.708	0.049	0.654	0.022	0.675
3.90	0.000	0.000	0.764	0.029	0.793
4.16	0.000	0.000	0.849	0.038	0.887
4.42	0.000	0.000	0.897	0.047	0.944
4.68	0.000	0.000	0.908	0.057	0.965
4.94	0.000	0.000	0.890	0.066	0.956
5.20	0.000	0.000	0.850	0.075	0.925
5.46	0.000	0.000	0.795	0.084	0.878
5.72	0.000	0.000	0.729	0.091	0.820
5.98	0.000	0.000	0.657	0.098	0.756
6.24	0.000	0.000	0.587	0.105	0.692
6.50	0.000	0.000	0.524	0.110	0.634
6.76	0.000	0.000	0.469	0.115	0.584
7.02	0.000	0.000	0.420	0.119	0.539
7.28	0.000	0.000	0.376	0.123	0.499
7.54	0.000	0.000	0.335	0.126	0.461

7.80	0.000	0.000	0.296	0.129	0.425
8.06	0.000	0.000	0.260	0.131	0.391
8.32	0.000	0.000	0.224	0.133	0.358
8.58	0.000	0.000	0.189	0.135	0.324
8.84	0.000	0.000	0.154	0.136	0.290
9.10	0.000	0.000	0.120	0.137	0.257
9.36	0.000	0.000	0.088	0.137	0.226
9.62	0.000	0.000	0.061	0.137	0.198
9.88	0.000	0.000	0.040	0.137	0.177
10.14	0.000	0.000	0.024	0.137	0.161
10.40	0.000	0.000	0.014	0.136	0.150
10.66	0.000	0.000	0.007	0.136	0.143
10.92	0.000	0.000	0.003	0.135	0.138
11.18	0.000	0.000	0.001	0.135	0.135
11.44	0.000	0.000	0.000	0.134	0.134
Totals	47.345	1.653	1.653	0.401	2.055

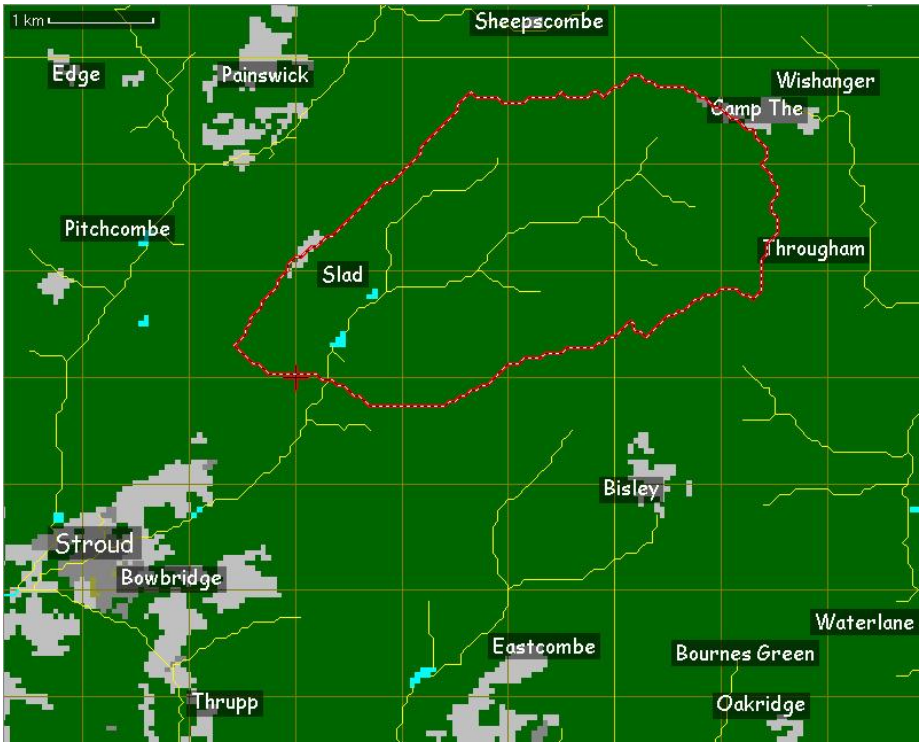
3.4.5.1 Table: Hydrograph parameters



3.4.5.2 Figure: Hydrograph

3.5 Painswick Farm

3.5.1 Catchment descriptors



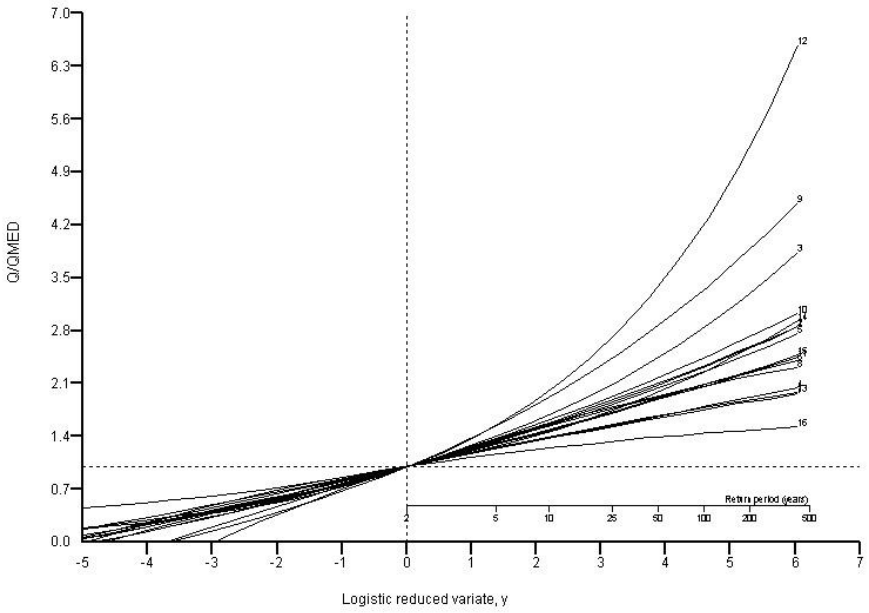
3.5.1.1 Figure: FEH-Painswick Farm catchment

The catchment has an area of 9.78 Km^2 .

3.5.2 Pooling group selection

After this removal the final statement for the heterogeneity calculated by the software was that "the pooling group is possibly heterogeneous and a review of pooling group is optional ".

Amalgamated together, the data gives 492 years of acquired data.



3.5.2.1 Figure: Generalised Logistic Curve

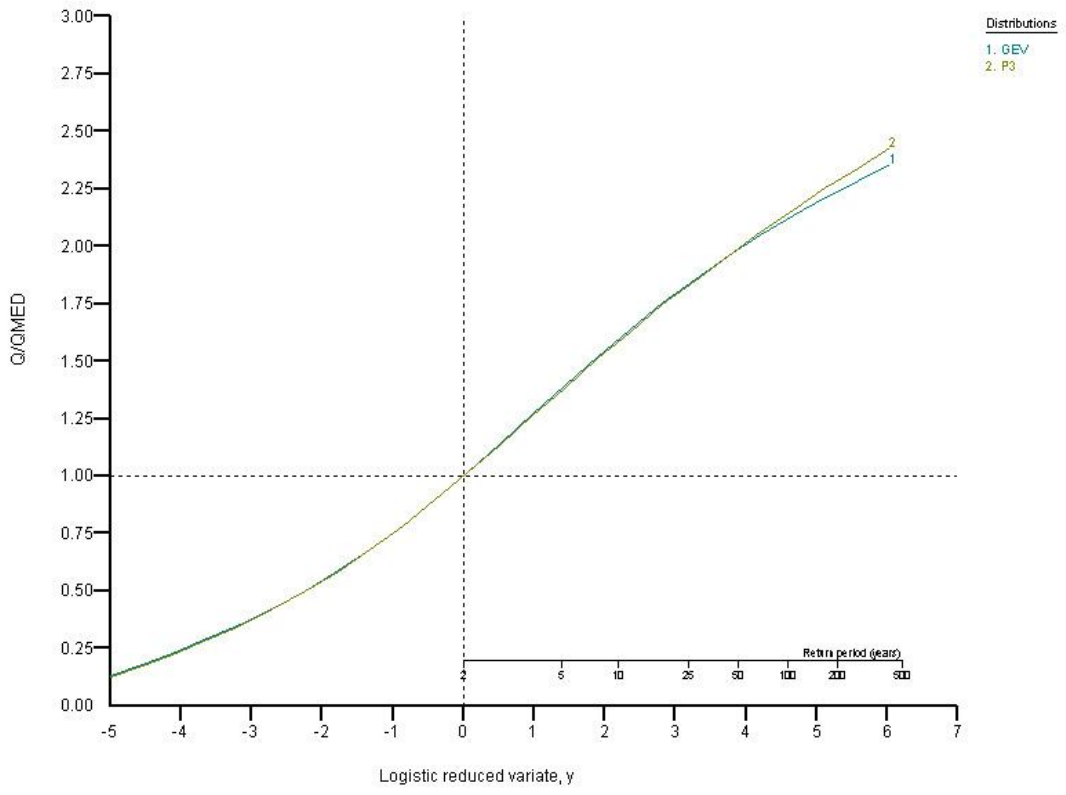
3.5.3 Flood Frequency Curve

A growth curve for the pooling group is derived in order to be combined with the Qmed (0.577 m^3/s) to produce the flood frequency curve.

For the kind of data object of this study it results that the acceptable distributions are the Generalised Extreme Value and the Pearson Type III.

Return Period	Estimated Peak Flow (using GEV)
1 in 2 years	1.000
1 in 5 years	1.382
1 in 10 years	1.598
1 in 25 years	1.835
1 in 50 years	1.988
1 in 100 years	2.124
1 in 200 years	2.244

3.5.3.1 Table: Peak Flow for the Flood Frequency curve

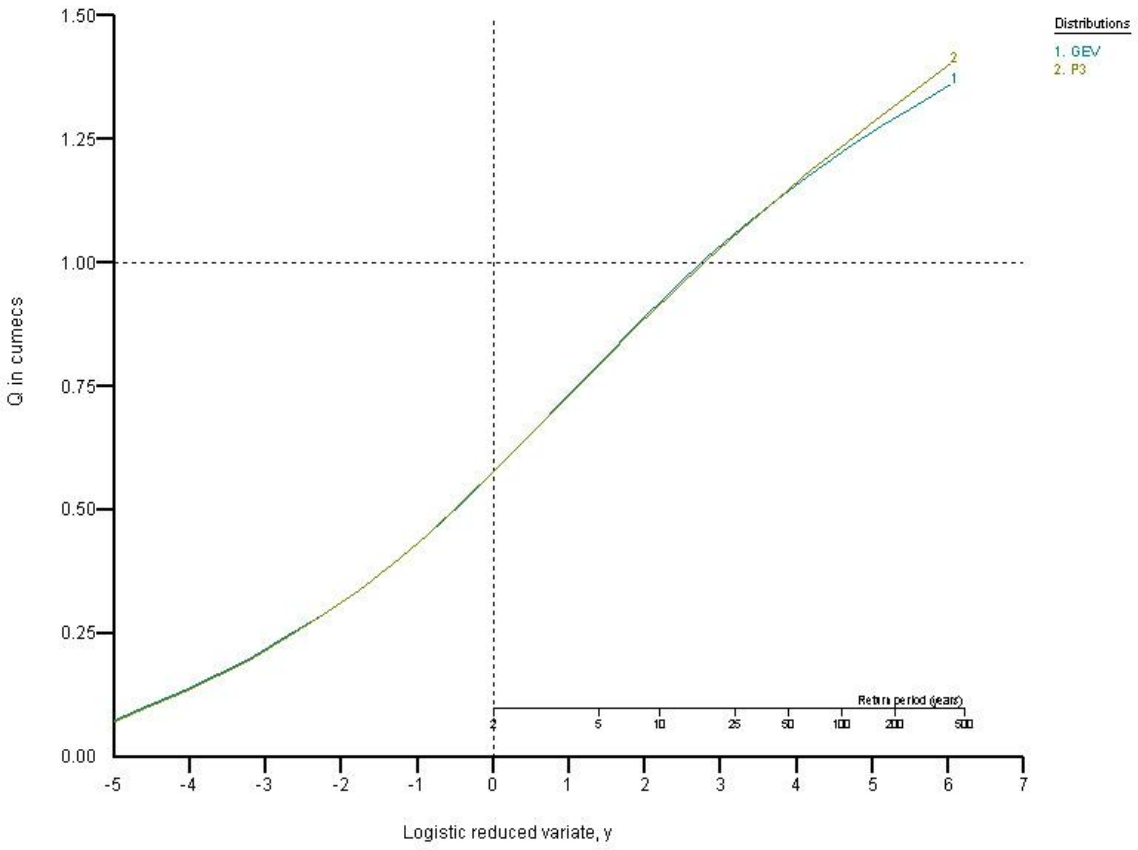


3.5.3.2 Figure: Flood Frequency Curve

3.5.4 Flood Growth Curve

Return Period	Estimated Peak Flow (using GEV)
1 in 2 years	0.557
1 in 5 years	0.798
1 in 10 years	0.923
1 in 25 years	1.060
1 in 50 years	1.148
1 in 100 years	1.226
1 in 200 years	1.295

3.5.4.1 Table: Peak Flow for the Flood Growth curve



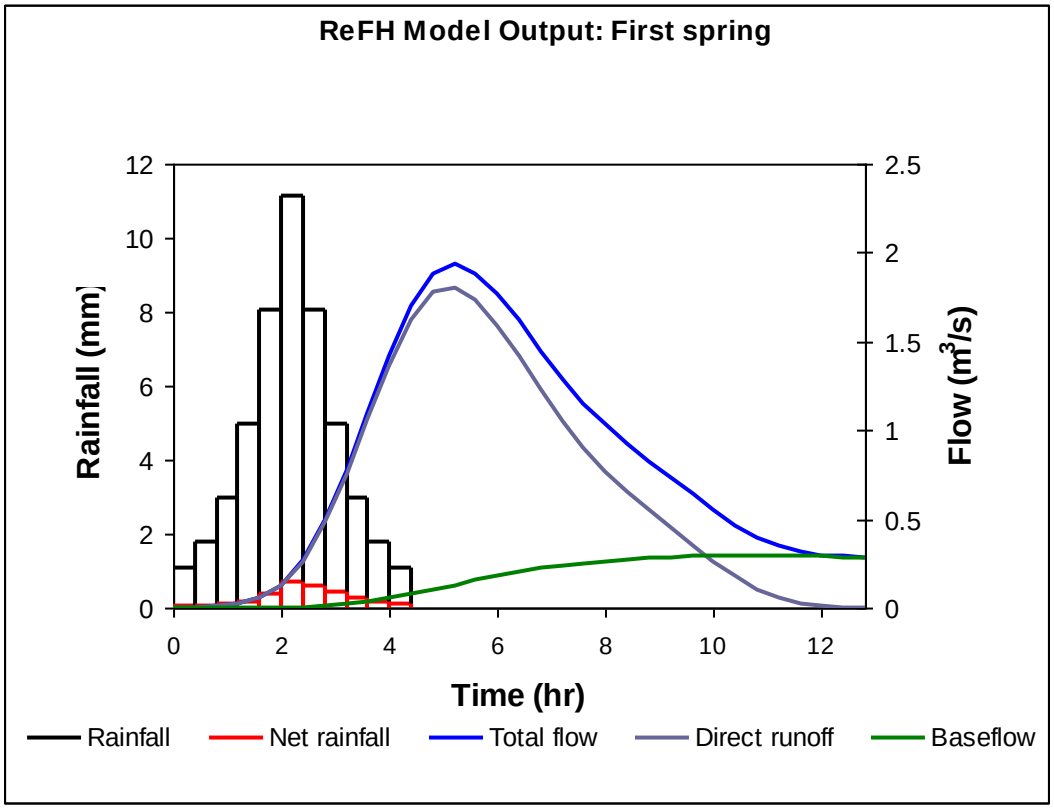
3.5.4.2 Figure: Flood Growth Curve

3.5.5 Hydrograph

To develop a design hydrograph fitting the statistical estimation of flood peak was used the revitalised FSR/FEH method.

Series	Design Rainfall	Net rainfall	Direct runoff	Baseflow	Total flow
Units	mm	mm	m3/s	m3/s	m3/s
0.0	1.073	0.027	0.000	0.000	0.000
0.4	1.798	0.050	0.002	0.000	0.002
0.8	2.997	0.094	0.008	0.000	0.008
1.2	4.956	0.186	0.024	0.000	0.024
1.6	8.066	0.384	0.057	0.001	0.058
2.0	11.111	0.692	0.127	0.002	0.129
2.4	8.066	0.621	0.264	0.005	0.269
2.8	4.956	0.431	0.480	0.011	0.492
3.2	2.997	0.279	0.755	0.021	0.776
3.6	1.798	0.174	1.060	0.035	1.094
4.0	1.073	0.106	1.363	0.053	1.416
4.4	0.000	0.000	1.624	0.076	1.700
4.8	0.000	0.000	1.779	0.102	1.881
5.2	0.000	0.000	1.805	0.129	1.934
5.6	0.000	0.000	1.730	0.156	1.886
6.0	0.000	0.000	1.591	0.180	1.771
6.4	0.000	0.000	1.414	0.202	1.617
6.8	0.000	0.000	1.224	0.221	1.445
7.2	0.000	0.000	1.049	0.237	1.286
7.6	0.000	0.000	0.900	0.251	1.150
8.0	0.000	0.000	0.771	0.262	1.033
8.4	0.000	0.000	0.656	0.271	0.927
8.8	0.000	0.000	0.550	0.278	0.828
9.2	0.000	0.000	0.450	0.284	0.733
9.6	0.000	0.000	0.353	0.288	0.641
10.0	0.000	0.000	0.260	0.290	0.551
10.4	0.000	0.000	0.175	0.292	0.467
10.8	0.000	0.000	0.105	0.292	0.397
11.2	0.000	0.000	0.057	0.291	0.348
11.6	0.000	0.000	0.027	0.289	0.317
12.0	0.000	0.000	0.011	0.287	0.298
12.4	0.000	0.000	0.003	0.285	0.288
12.8	0.000	0.000	0.000	0.283	0.283
Totals	48.893	3.044	3.044	0.791	3.836

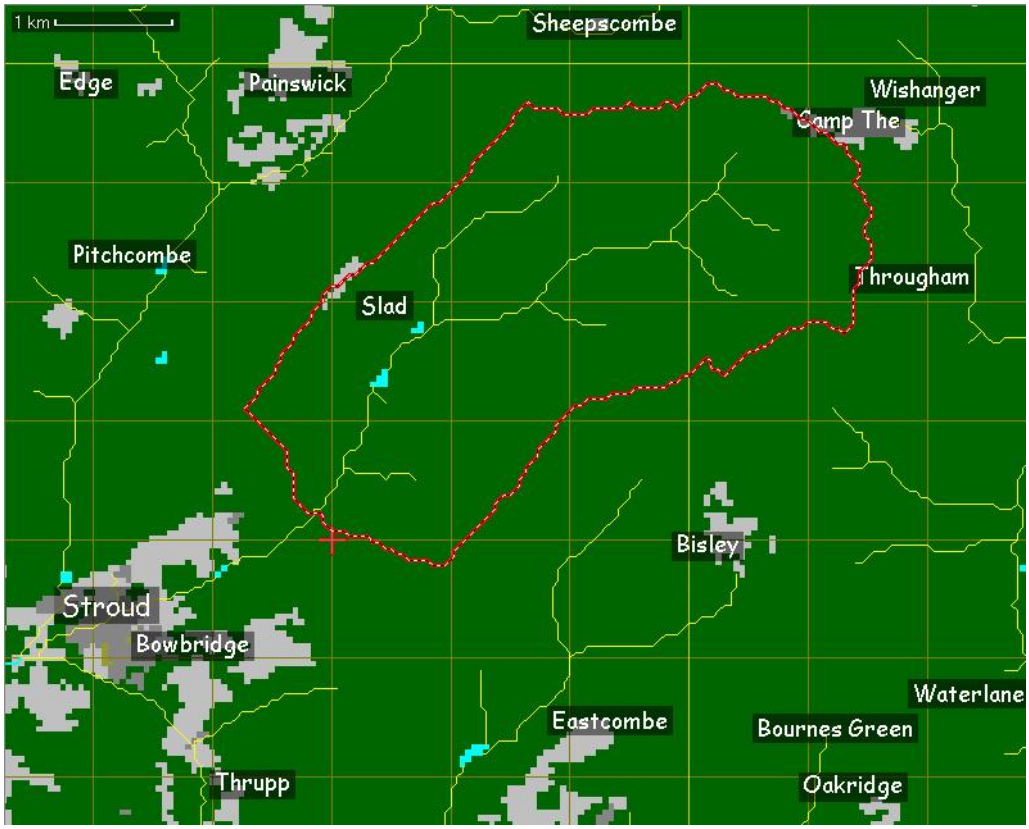
3.5.5.1 Table: Hydrograph parameters



3.5.5.2 Figure: Hydrograph

3.6 Hazel Mill

3.6.1 Catchment descriptors



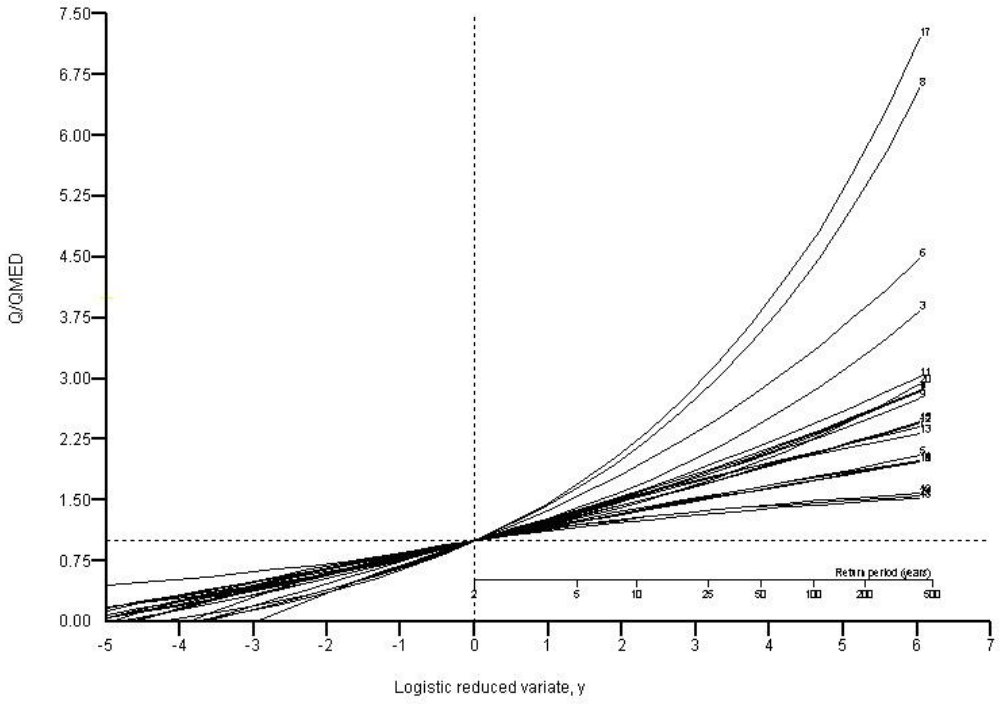
3.6.1.1 Figure: FEH-Hazel Mill catchment

The catchment has an area of 11.51 Km^2.

3.6.2 Pooling group selection

After this removal the final statement for the heterogeneity calculated by the software was that "the pooling group is possibly heterogeneous and a review of pooling group is optional".

Amalgamated together, the data gives 642 years of acquired data.



3.6.2.1 Figure: Generalised Logistic Curve

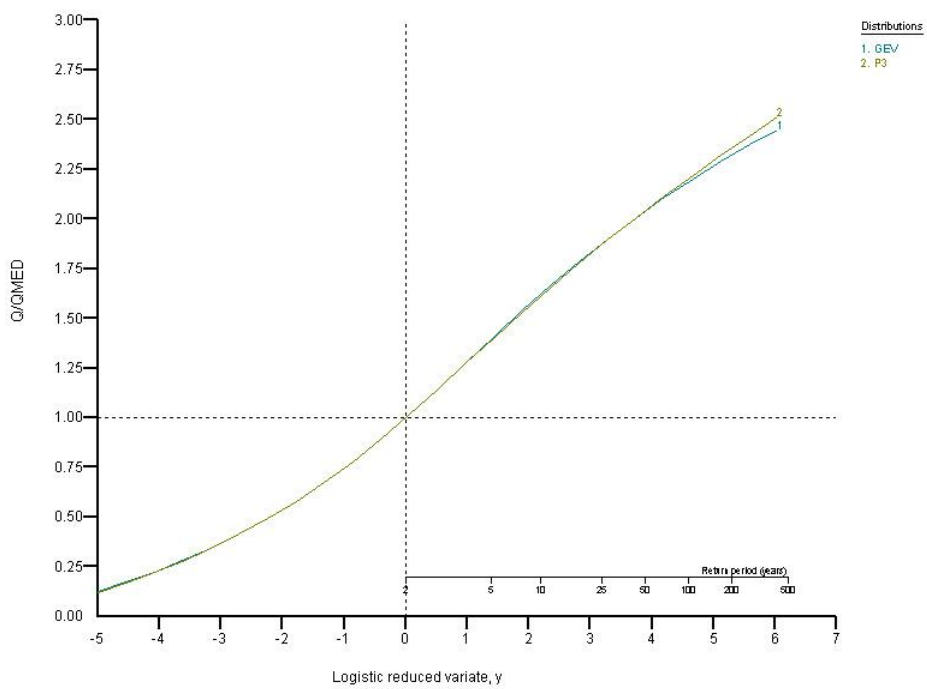
3.6.3 Flood Frequency Curve

A growth curve for the pooling group is derived in order to be combined with the Qmed (0.748 m^3/s) to produce the flood frequency curve.

For the kind of data object of this study it results that the acceptable distributions are the Generalised Extreme Value and the Pearson Type III.

Return Period	Estimated Peak Flow (using GEV)
1 in 2 years	1.000
1 in 5 years	1.396
1 in 10 years	1.624
1 in 25 years	1.876
1 in 50 years	2.042
1 in 100 years	2.189
1 in 200 years	2.321

3.6.3.1 Table: Peak Flow for the Flood Frequency curve

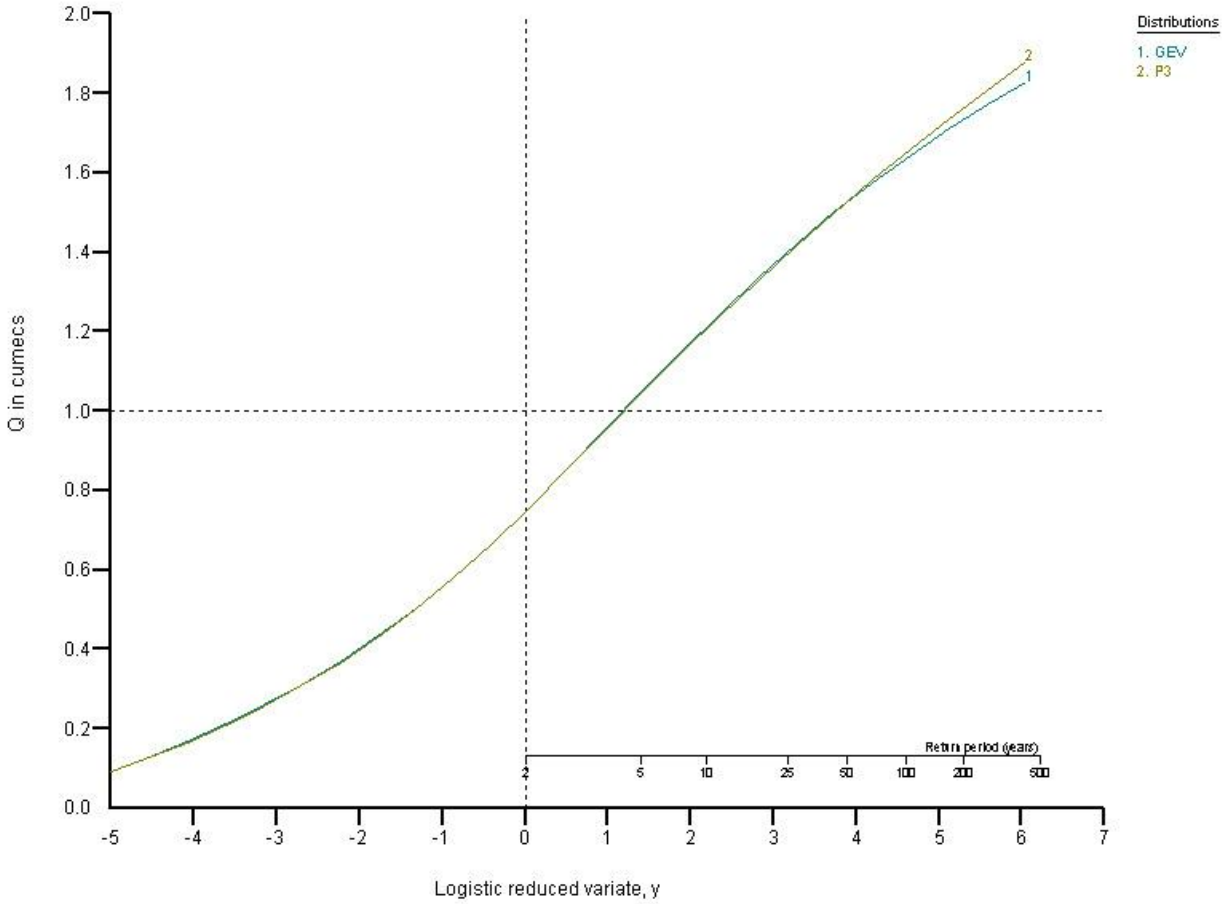


3.6.3.2 Figure: Flood Frequency Curve

3.6.4 Flood Growth Curve

Return Period	Estimated Peak Flow (using GEV)
1 in 2 years	0.748
1 in 5 years	1.044
1 in 10 years	1.214
1 in 25 years	1.403
1 in 50 years	1.527
1 in 100 years	1.637
1 in 200 years	1.736

3.6.4.1 Table: Peak Flow for the Flood Growth curve



3.6.4.2 Figure: Flood Growth Curve

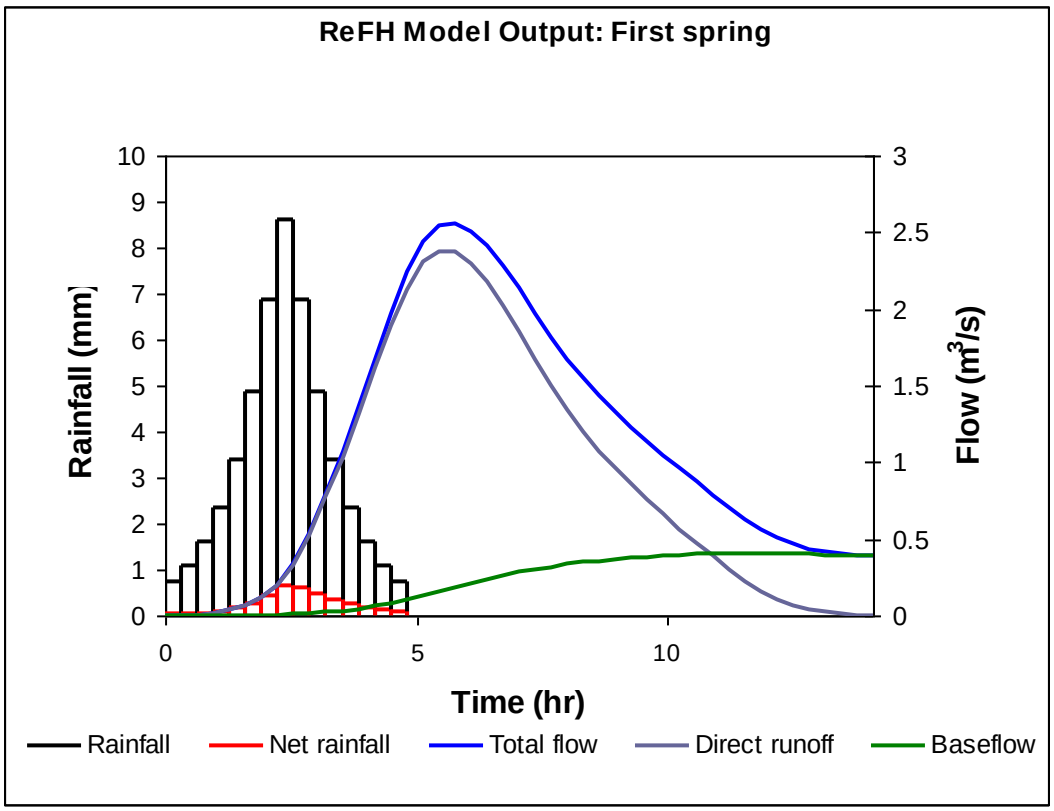
3.6.5 Hydrograph

To develop a design hydrograph fitting the statistical estimation of flood peak was used the revitalised FSR/FEH method.

Series	Design Rainfall	Net rainfall	Direct runoff	Baseflow	Total flow
Units	mm	mm	m3/s	m3/s	m3/s
0.00	0.753	0.027	0.000	0.000	0.000
0.32	1.101	0.042	0.001	0.000	0.001
0.64	1.605	0.064	0.006	0.000	0.006
0.96	2.332	0.100	0.016	0.000	0.016
1.28	3.375	0.160	0.033	0.000	0.033
1.60	4.852	0.261	0.063	0.001	0.064
1.92	6.880	0.434	0.113	0.002	0.115
2.24	8.598	0.646	0.196	0.004	0.200
2.56	6.880	0.600	0.331	0.007	0.338
2.88	4.852	0.468	0.524	0.012	0.536
3.20	3.375	0.347	0.763	0.020	0.783
3.52	2.332	0.250	1.034	0.030	1.064
3.84	1.605	0.177	1.323	0.044	1.367
4.16	1.101	0.124	1.614	0.061	1.675
4.48	0.753	0.086	1.891	0.081	1.973
4.80	0.000	0.000	2.132	0.105	2.237
5.12	0.000	0.000	2.303	0.130	2.434
5.44	0.000	0.000	2.380	0.157	2.537
5.76	0.000	0.000	2.372	0.185	2.556
6.08	0.000	0.000	2.299	0.211	2.510
6.40	0.000	0.000	2.179	0.237	2.415
6.72	0.000	0.000	2.027	0.260	2.287
7.04	0.000	0.000	1.855	0.282	2.137
7.36	0.000	0.000	1.675	0.301	1.975
7.68	0.000	0.000	1.498	0.318	1.816
8.00	0.000	0.000	1.340	0.333	1.673
8.32	0.000	0.000	1.201	0.346	1.547
8.64	0.000	0.000	1.076	0.357	1.433
8.96	0.000	0.000	0.962	0.367	1.329
9.28	0.000	0.000	0.856	0.376	1.232
9.60	0.000	0.000	0.755	0.383	1.139
9.92	0.000	0.000	0.659	0.389	1.048
10.24	0.000	0.000	0.566	0.394	0.961
10.56	0.000	0.000	0.476	0.398	0.874
10.88	0.000	0.000	0.387	0.401	0.788
11.20	0.000	0.000	0.302	0.403	0.705
11.52	0.000	0.000	0.224	0.403	0.627
11.84	0.000	0.000	0.156	0.403	0.559
12.16	0.000	0.000	0.102	0.402	0.505
12.48	0.000	0.000	0.064	0.401	0.465

12.80	0.000	0.000	0.037	0.399	0.436
13.12	0.000	0.000	0.020	0.397	0.417
13.44	0.000	0.000	0.009	0.395	0.404
13.76	0.000	0.000	0.003	0.393	0.396
14.08	0.000	0.000	0.000	0.391	0.391
Totals	50.395	3.786	3.786	1.019	4.805

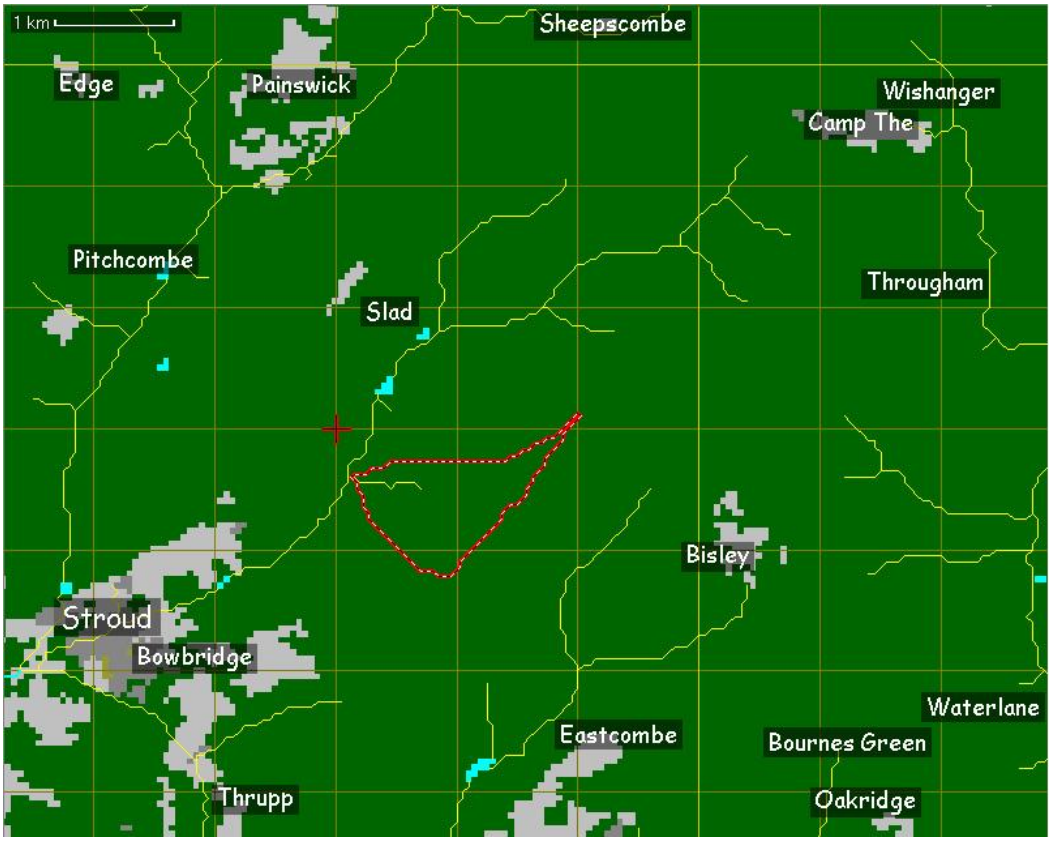
3.6.5.1 Table: Hydrograph parameters



3.6.5.2 Figure: Hydrograph

3.7 The Vatch

3.7.1 Catchment Descriptors



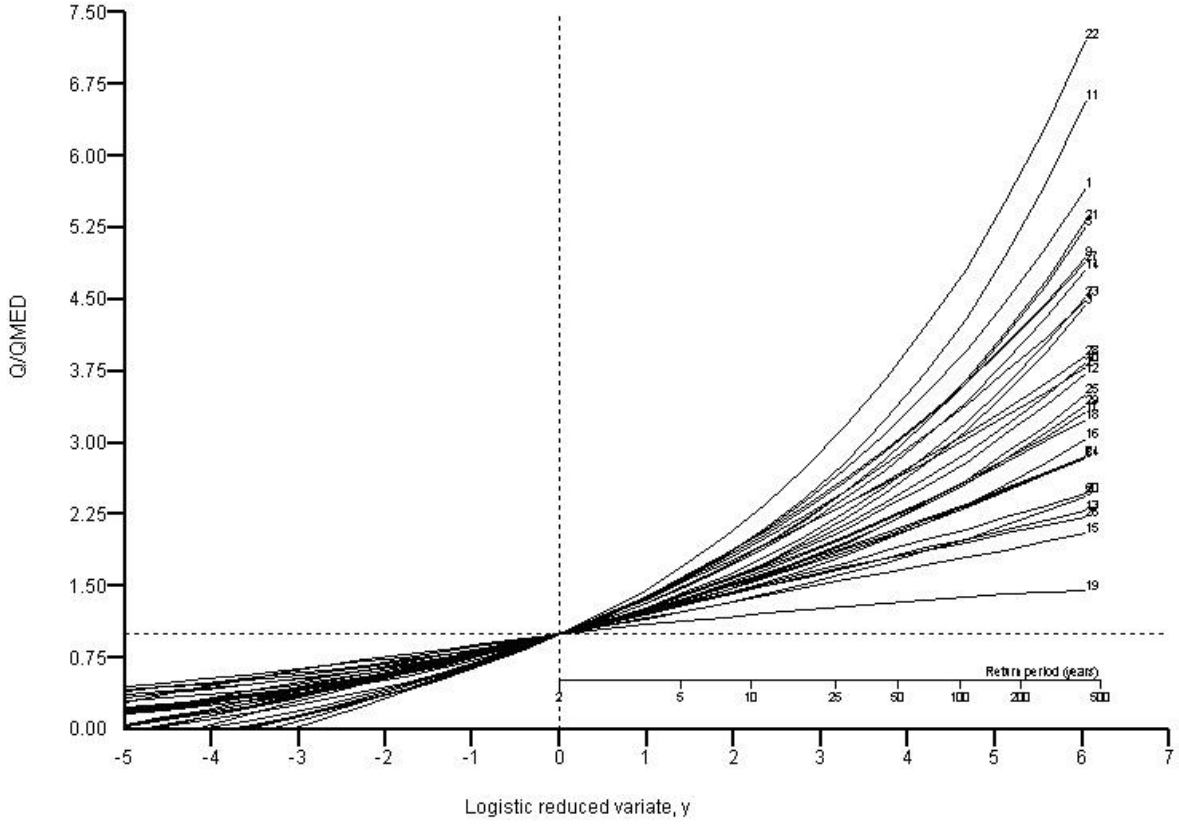
3.7.1.1 Figure: The Vatch catchment

The Vatch Brook's catchment has an area of 0.98 Km^2 .

3.7.2 Pooling group selection

After this removal the final statement for the heterogeneity calculated by the software was that "the pooling group is possibly heterogeneous and a review of pooling group is optional".

Amalgamated together the data gives 788 years of acquired data.



3.7.2.1 Figure: Generalised Logistic Curve

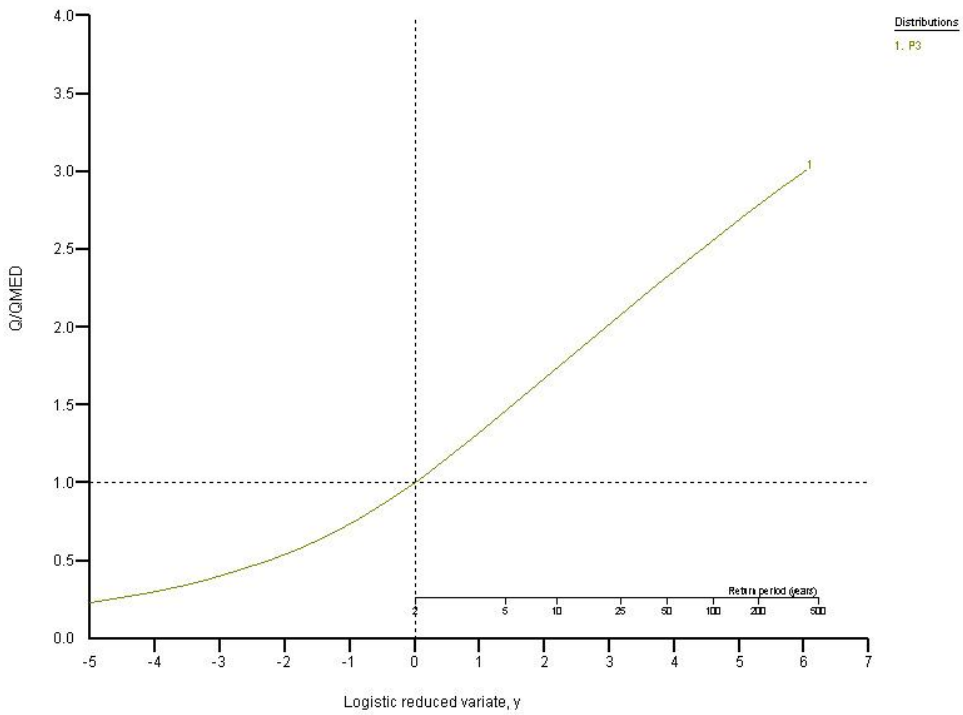
3.7.3 Flood Frequency Curve

A growth curve for the pooling group is derived in order to be combined with the Q_{med} (0.120 m^3/s) to produce the flood frequency curve.

For the kind of data object of this study it results that the acceptable distributions is the Pearson Type III.

Return Period	Estimated Peak Flow (using P3)
1 in 2 years	1.000
1 in 5 years	1.458
1 in 10 years	1.744
1 in 25 years	2.086
1 in 50 years	2.328
1 in 100 years	2.560
1 in 200 years	2.785

3.7.3.1 Table: Peak Flow for the Flood Frequency curve

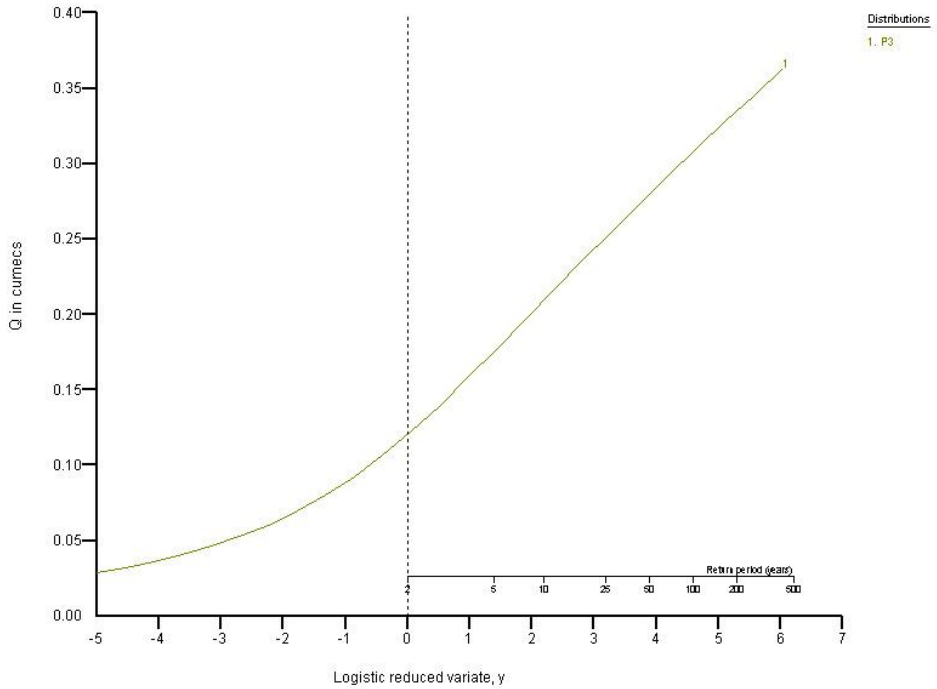


3.7.3.2 Figure: Flood Frequency Curve

3.7.4 Flood Growth Curve

Return Period	Estimated Peak Flow (using P3)
1 in 2 years	0.120
1 in 5 years	0.176
1 in 10 years	0.210
1 in 25 years	0.280
1 in 50 years	0.308
1 in 100 years	0.335
1 in 200 years	0.370

3.7.4.1 Table: Peak Flow for the Flood Growth curve



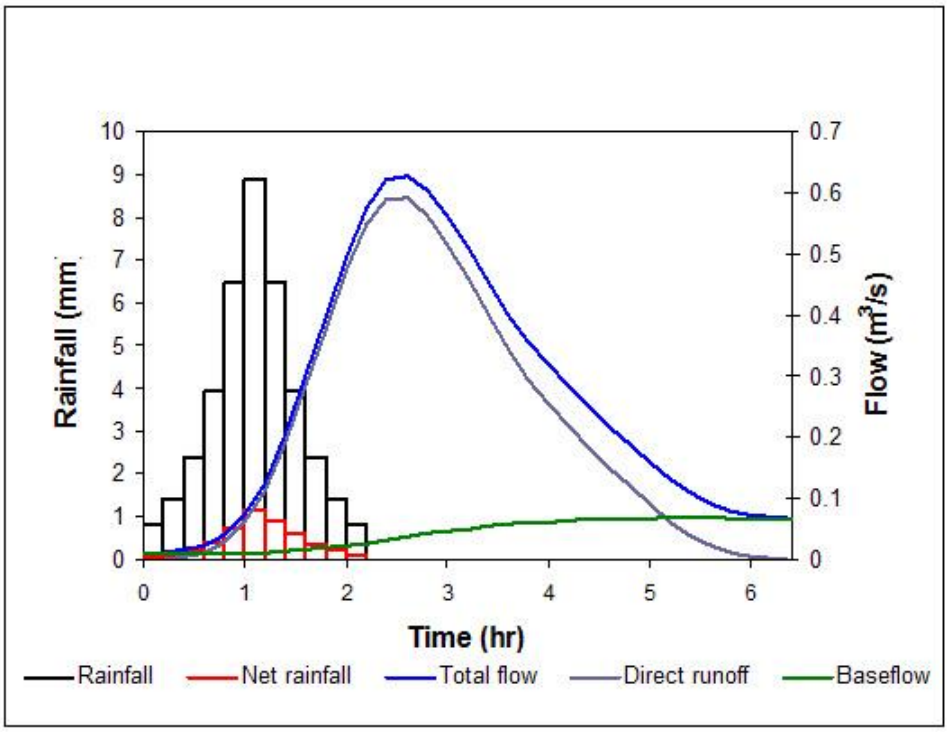
3.7.4.2 Figure: Flood Growth Curve

3.7.5 Hydrograph

To develop a design hydrograph fitting the statistical estimation of flood peak was used the revitalised FSR/FEH method.

Series	Design Rainfall	Net rainfall	Direct runoff	Baseflow	Total flow
Units	mm	mm	m3/s	m3/s	m3/s
0.0	0.859	0.084	0.000	0.012	0.012
0.2	1.438	0.144	0.001	0.012	0.013
0.4	2.397	0.248	0.005	0.012	0.016
0.6	3.964	0.433	0.013	0.012	0.025
0.8	6.451	0.763	0.030	0.012	0.042
1.0	8.886	1.170	0.060	0.012	0.073
1.2	6.451	0.936	0.114	0.013	0.127
1.4	3.964	0.611	0.192	0.014	0.206
1.6	2.397	0.383	0.284	0.016	0.300
1.8	1.438	0.235	0.380	0.019	0.400
2.0	0.859	0.142	0.472	0.023	0.495
2.2	0.000	0.000	0.547	0.027	0.575
2.4	0.000	0.000	0.589	0.032	0.621
2.6	0.000	0.000	0.590	0.038	0.627
2.8	0.000	0.000	0.561	0.043	0.604
3.0	0.000	0.000	0.515	0.047	0.562
3.2	0.000	0.000	0.459	0.051	0.510
3.4	0.000	0.000	0.399	0.055	0.454
3.6	0.000	0.000	0.343	0.058	0.401
3.8	0.000	0.000	0.295	0.061	0.356
4.0	0.000	0.000	0.254	0.063	0.317
4.2	0.000	0.000	0.218	0.065	0.282
4.4	0.000	0.000	0.183	0.066	0.249
4.6	0.000	0.000	0.151	0.067	0.218
4.8	0.000	0.000	0.120	0.068	0.188
5.0	0.000	0.000	0.090	0.069	0.159
5.2	0.000	0.000	0.063	0.069	0.132
5.4	0.000	0.000	0.040	0.069	0.109
5.6	0.000	0.000	0.022	0.069	0.092
5.8	0.000	0.000	0.011	0.069	0.081
6.0	0.000	0.000	0.005	0.069	0.074
6.2	0.000	0.000	0.002	0.068	0.070
6.4	0.000	0.000	0.000	0.068	0.068
Totals	39.105	5.150	5.150	1.065	6.215

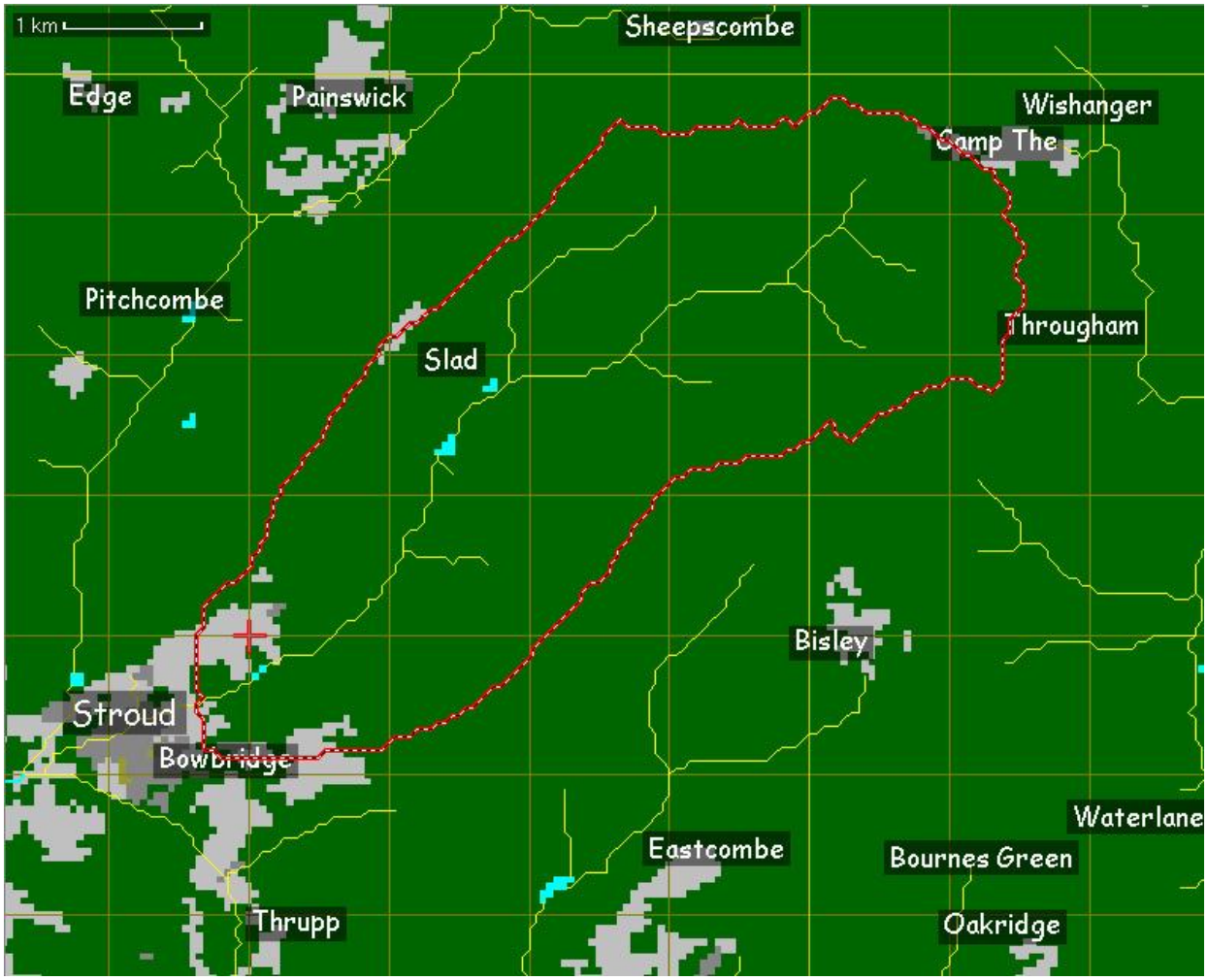
3.7.5.1 Table: Hydrograph parameters



3.7.5.2 Figure: Hydrograph

3.8 EA proposal

3.8.1 Catchment's descriptors



3.8.1.1 Figure: FEH-EA proposal

The catchment has an area of 13.87 Km^2 .

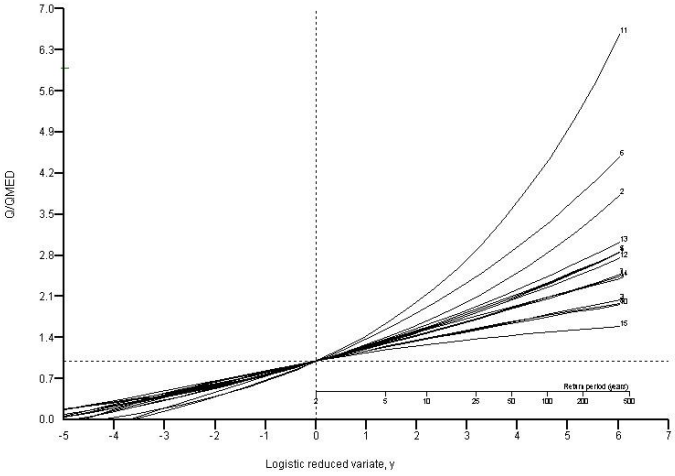
3.8.2 Pooling group selection

After this removal the final statement for the heterogeneity calculated by the software was that "the pooling group is possibly heterogeneous and a review of pooling group is optional".

The stations included in the pooled group are: 39036, 39033, 42011, 52015, 29003, 44006, 66004, 39028, 26003, 39042, 53028, 41015, 43017, 43014, and 53028.

3.8.2.1 Figure: Location of the Donor Catchments

Amalgamated together, the data gives 486 years of acquired data.



3.8.2.2 Figure: Generalised Logistic Curve

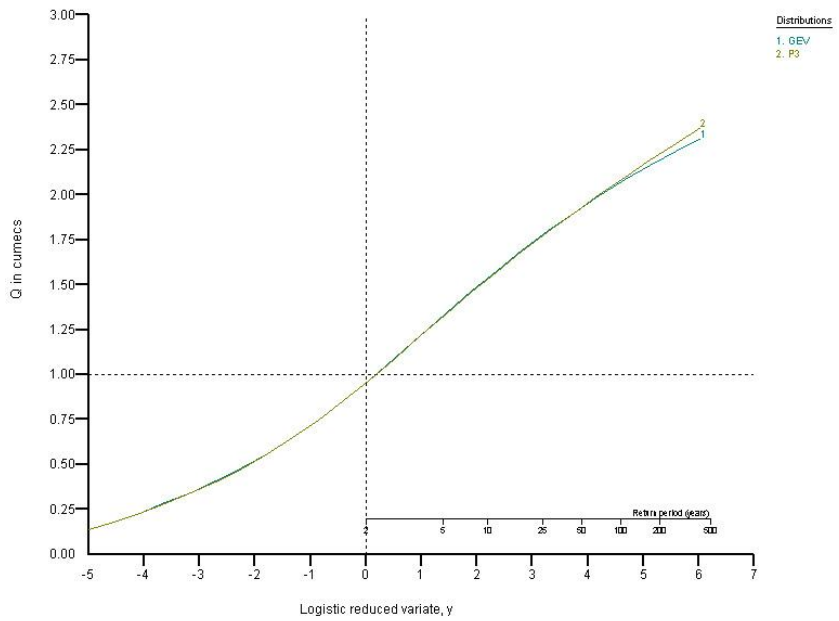
Flood Frequency Curve

A growth curve for the pooling group is derived in order to be combined with the Qmed (1.001 m^3/s) to produce the flood frequency curve.

For the kind of data object of this study it results that the acceptable distributions are the Generalised Extreme Value and Pearson Type III.

Return Period	Estimated Peak Flow (using P3)
1 in 2 years	0.956
1 in 5 years	1.322
1 in 10 years	1.532
1 in 25 years	1.771
1 in 50 years	1.934
1 in 100 years	2.086
1 in 200 years	2.230

3.8.2.3 Table: Peak Flow for the Flood Frequency curve

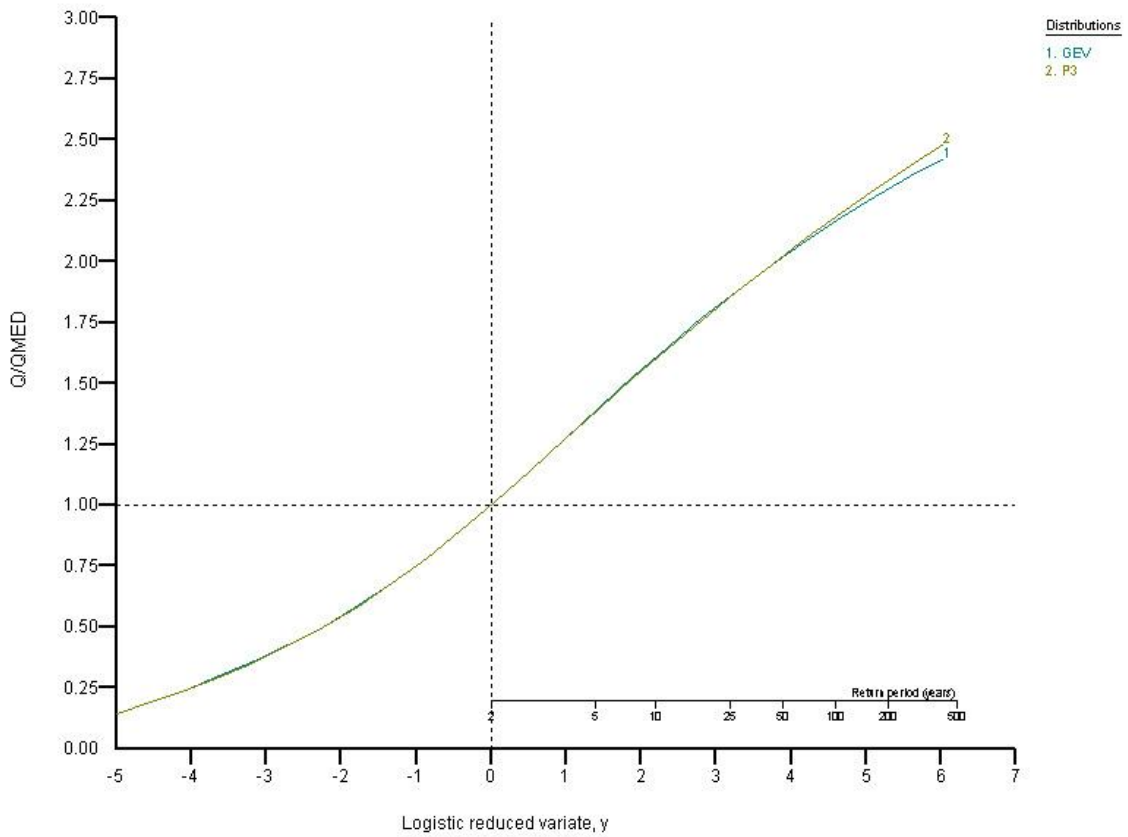


3.8.2.4 Figure: Flood Frequency Curve

3.8.3 Flood Growth Curve

Return Period	Estimated Peak Flow (using P3)
1 in 2 years	1.000
1 in 5 years	1.383
1 in 10 years	1.603
1 in 25 years	1.853
1 in 50 years	2.024
1 in 100 years	2.183
1 in 200 years	2.333

3.8.3.1 Table: Peak Flow for the Flood Growth curve



3.8.3.2 Figure: Flood Growth Curve

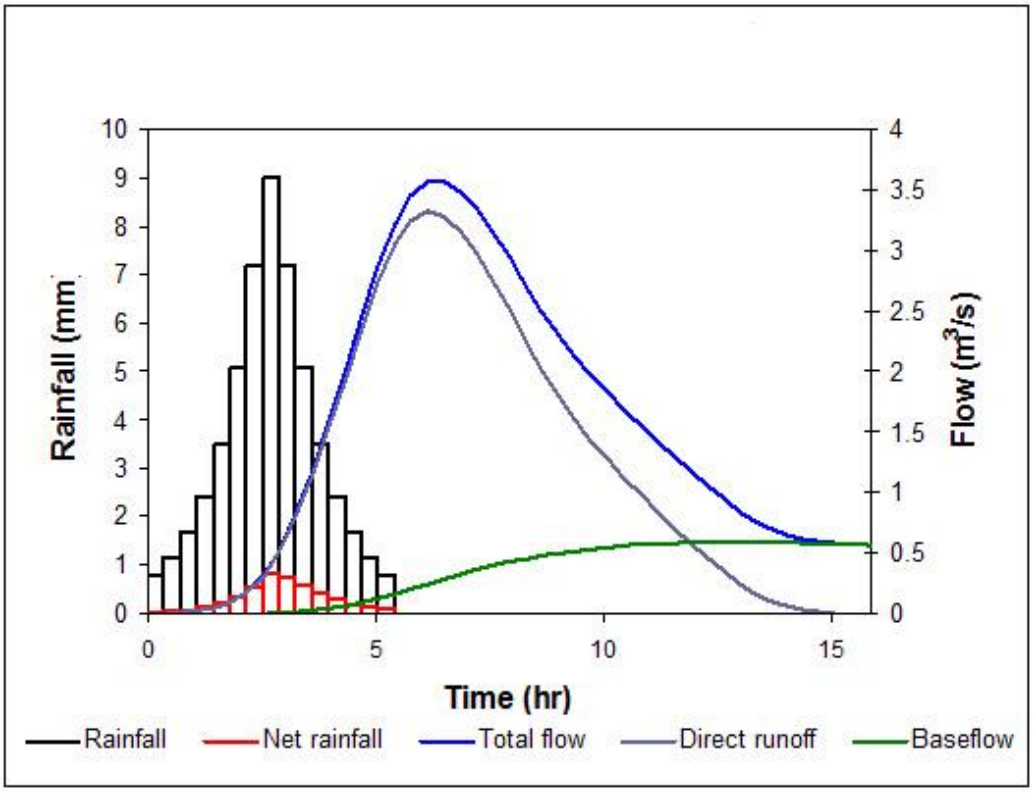
3.8.4 Hydrograph

To develop a design hydrograph fitting the statistical estimation of flood peak was used the revitalised FSR/FEH method.

Series	Design Rainfall	Net rainfall	Direct runoff	Baseflow	Total flow
Units	mm	mm	m3/s	m3/s	m3/s
0.000	0.787	0.041	0.000	0.000	0.000
0.360	1.150	0.062	0.002	0.000	0.002
0.720	1.677	0.094	0.010	0.000	0.010
1.080	2.437	0.144	0.025	0.000	0.026
1.440	3.526	0.226	0.054	0.001	0.055
1.800	5.069	0.360	0.101	0.002	0.103
2.160	7.187	0.581	0.180	0.004	0.184
2.520	8.983	0.843	0.308	0.007	0.315
2.880	7.187	0.768	0.510	0.012	0.522
3.240	5.069	0.591	0.795	0.020	0.815
3.600	3.526	0.436	1.142	0.033	1.175
3.960	2.437	0.313	1.531	0.050	1.580
4.320	1.677	0.221	1.939	0.072	2.011
4.680	1.150	0.154	2.346	0.099	2.445
5.040	0.787	0.107	2.725	0.131	2.856
5.400	0.000	0.000	3.042	0.167	3.209
5.760	0.000	0.000	3.249	0.206	3.455
6.120	0.000	0.000	3.321	0.247	3.569
6.480	0.000	0.000	3.281	0.288	3.569
6.840	0.000	0.000	3.155	0.327	3.482
7.200	0.000	0.000	2.970	0.365	3.334
7.560	0.000	0.000	2.745	0.399	3.144
7.920	0.000	0.000	2.497	0.430	2.927
8.280	0.000	0.000	2.243	0.458	2.701
8.640	0.000	0.000	2.002	0.482	2.483
9.000	0.000	0.000	1.788	0.503	2.291
9.360	0.000	0.000	1.598	0.522	2.120
9.720	0.000	0.000	1.427	0.538	1.964
10.080	0.000	0.000	1.269	0.551	1.820
10.440	0.000	0.000	1.120	0.563	1.683
10.800	0.000	0.000	0.979	0.573	1.552
11.160	0.000	0.000	0.844	0.581	1.424
11.520	0.000	0.000	0.713	0.587	1.300
11.880	0.000	0.000	0.585	0.591	1.177
12.240	0.000	0.000	0.463	0.594	1.057
12.600	0.000	0.000	0.348	0.596	0.944
12.960	0.000	0.000	0.246	0.595	0.842
13.320	0.000	0.000	0.164	0.594	0.758
13.680	0.000	0.000	0.104	0.592	0.696

14.040	0.000	0.000	0.062	0.589	0.651
14.400	0.000	0.000	0.034	0.586	0.620
14.760	0.000	0.000	0.017	0.582	0.599
15.120	0.000	0.000	0.007	0.579	0.585
15.480	0.000	0.000	0.001	0.575	0.576
15.840	0.000	0.000	0.000	0.571	0.571
Totals	52.647	4.939	4.939	1.451	6.390

3.8.4.1 Table: Hydrograph parameters



3.8.4.2 Figure: Hydrograph

4 Storage volume

4.1 Volume calculation

From each hydrograph (time recurrence of 150 years) was calculated the volume of water for storage. All the data can be found in the accompanying data folder.

The first table shows the volume calculated in each site, assuming that there has not been previous storage along the brook. Also, is given a rough estimation of the length of the storage pond, considering it with a right-angle triangle shape.

	Qmed [m^3/s]	Volume [m^3]	Height [m]	Width [m]	Area [m^2]	Lenght [m]
First Spring	0.07	1062.27	1.5	10	7.5	141.64
Dially Brook	0.34	4342.00	1.5	20	15	289.47
1+2	0.40	5721.17	1.5	20	15	381.41
Painswick Farm	0.59	18076.07	3	20	30	602.54
Hazel Mill	0.75	27119.07	3	10	15	1807.94
The Vatch	0.12	3840.56	1.5	10	7.5	512.07
EA proposal	1.00	44094.27	3	40	60	734.90
Whole catchment	1.16	60988.24	3	40	60	1016.47

4.1.1.1 Table: Volume calculation 1

The second table shows the volume calculated deducting the volume that has been stored upstream, step by step. It should be noted that overall there is an overestimation of the volumes as the hydrographs have not been recalculated after deducting the volume.

	Qmed [m^3/s]	Volume [m^3]	Height [m]	Width [m]	Area [m^2]	Lenght [m]
First Spring	0.07	1062.27	1.5	10	7.5	141.64
Dially Brook	0.34	4342.00	1.5	20	15	289.47
1+2	0.40	5721.17	1.5	20	15	381.41
Painswick Farm	0.59	13734.08	3	20	30	457.80
Hazel Mill	0.75	13384.99	3	10	15	892.33
The Vatch	0.12	3840.56	1.5	10	7.5	512.07
EA proposal	1.00	30709.27	3	40	60	511.82
Whole catchment	1.16	30278.96	3	40	60	504.65

4.1.1.2 Table: Volume calculation 2

5 Suggestions for the hydraulic analysis

5.1 Hec-Ras

The following ASCII files of the Study Area were provided by the Environment Agency:

- V0050761
- V0050765
- V0055477
- V0055483
- V0055488
- V0055487
- V0055484

Each file was imported in ArcMap and converted in a readable raster file The Hillshade map and the Slope and Aspect maps were also created.

The Coordinate System used is the following:

- Coordinate System: British National Grid
- Projection: Transverse Mercator
- Datum: D_OSGB_1936
- False Easting: 400 000, 000
- False Northing: -100 000, 000
- Central meridian: -2, 000
- Scale factor: 0, 999 601
- Latitude of origin: 49, 000
- Linear unit: Meter (1 000)
- Angular Unit: Degree (0, 017 453 295)
- EPSG Code: EPSG:27700

The ASCII files were therefore joined using the program "Global Mapper" and from the unique output file was created the TIN raster file.

From the website www.edina.ac.uk/digimap, the geological map and the historical maps were downloaded. Some of those maps were provided in .NTF format. They were therefore converted in .dwg and .dxf using AutoCad program.

6 Conclusions

6.1 Personal considerations

The hydraulic simulation was not completed as the internship was shortened by 1 month, having completed the first stage of volumetric modelling that confirms the feasibility of upstream flood attenuation in the Slad Valley.

The input geometry file for the HEC-RAS program was partly created but not yet finished. The Arc-GIS extension of Geo HEC-RAS was used to create it. All the necessary data can be found with the accompanying data in the HEC-RAS folder.

Also, due to some problems in having stable computer space and software, the maps used could have been better exported and analysed.

6.2 The problem of the culverts

Since the year 2000 the culvert at the lower end of Slad Road has repeatedly failed to carry the volume of water passing through the brook.

This has resulted in residents and businesses being flooded either through their drainage system (ground and foul water) or through flood water entering from street level. On four occasions since 2000 Slad Road has been closed due to flood water.

Since July 2007 residents of Stroud have had water from the brook enter their properties due to the pressure caused by water trying to enter the culvert while the brook is in spate. This has occurred after the culvert was cleared of accumulated debris by the EA.

It would appear that there are several causes of this dramatic increase in flood incidents. When the culvert was constructed in the late 19th / early 20th Century there existed in the Slad Valley and its tributaries, a number of working mill ponds which would have acted to attenuate heavy water flow. Also, within Stroud itself the increase in hard standing has caused an increase in the volume of surface water entering the culvert. This double effect, coupled with a perceived increase in 'storm' events has resulted in the culvert failing on an almost annual basis.

There is also some historic evidence that the current culvert is one of a pair which were used by the old Dye Mill which stood on the site of Badbrook Hall. The culvert we see today was used to provide water for the dye process while the main body of water was diverted into a separate channel.

[Souce: Sarah Lunnon, SBAG]

Bibliography

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