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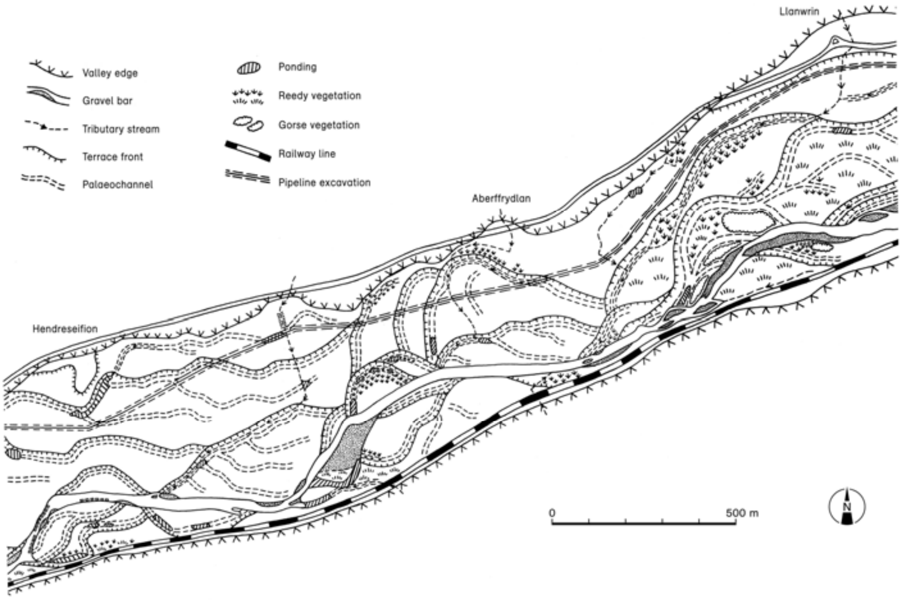
Predictive and investigative modelling of flood risk within Welsh river catchments: a co-funded pilot study

Preliminary Report, March 2004

Urban Geosciences and Geological Hazards Programme

Internal Report IR/04/063



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Countryside Council for Wales

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BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/04/063

Predictive and investigative modelling of flood risk within Welsh river catchments: a co-funded pilot study

Preliminary Report, February 2004

T. H. Sheppard & J. R. Davies

Key words

Flooding; Radiocarbon; Holocene; Fluvial sedimentation; Wales.

Front cover

High-resolution geomorphological map of a floodplain reach in the upper Dyfi river (Courtesy of Eric Johnstone, Aberystwyth University).

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Foreword

This report summarises the preliminary findings arising from the BGS involvement in a 3-year, co-funded project ‘Predictive and investigative modelling of flood risk within Welsh river catchments’. This is a collaborative venture between BGS, the Welsh Assembly Government, the Environment Agency Wales, the Countryside Council for Wales, and the River Basin Dynamics and Hydrology Research Group of the University of Wales Aberystwyth.

This report should be viewed as a working document which will evolve as the project progresses. Future iterations may see significant modification to the initial observations and findings presented below.

Acknowledgements

This report includes text and figures produced by staff at the River Basin Dynamics and Hydraulic Research Group (RBDHRG) at the University of Wales Aberystwyth which the authors are happy to acknowledge. However, the use of this material in this report is at the authors' discretion and the conclusions and recommendations drawn from it are not necessarily endorsed by RBDHRG. This report has benefited from the editorial comments of Dr R. A. Waters.

Contents

Summary

The first three sections of this report detail the rationale project rationale: background and inception of the pilot study (Section 1); specifications and remit of the study as a whole (Section 2), and details BGS' role (Section 3). The remaining sections represent preliminary assessments of methodologies relevant to the modelling of flood risk in Wales: mapping methodologies (Section 4); the Holocene evolution of Welsh river catchments (Section 5); radiocarbon dating techniques and preliminary results (Section 6); the implications of the methodologies, data and interpretation for BGS alluvial mapping methodologies (Section 7), and a preliminary assessment of computer-based forward-modelling of flood risk at Aberystwyth University (Section 8).

1 Background

Over the last 2 years the Welsh Assembly Government (WAG) has undertaken discussions and research to underpin the production of a new Technical Advice Note (TAN) on ‘Development and Flood Risk’. The new TAN, circulated for consultation in 2003, upgrades the planning guidelines to be followed by local authorities in Wales when assessing planning applications for developments on Welsh river floodplains, and when formulating their Unitary Development Plans. Dr J. R. Davies was the BGS representative on the WAG advisory group.

The guidance offered by the TAN is underpinned by a Flood Policy Guidance Map for Wales which utilises both EA indicative floodplain mapping data, and the BGS DigMap50 line work for alluvial deposits. These digital datasets are combined to delineate areas perceived to be at high, moderate or low risk of flooding, with the TAN stipulating the planning procedures to be applied in each case. The use of the BGS data marks a significant difference from comparable flood risk maps used to underpin flood risk planning policy in England, which are based exclusively on the EA data.

During the development of the new Welsh TAN, the advisory group visited the River Basin Dynamics and Hydrology Research Group (RBDHRG) at the University of Wales Aberystwyth, where Professor Mark Macklin and his team gave a presentation of recent research being undertaken on river floodplains in the UK, and in Wales in particular. The importance of detailed geomorphological mapping of the type undertaken by the university and BGS was stressed. Such mapping, allied to dating of alluvial features, has revealed just how prone river floodplains are to change, how unstable river channels are, and how young some river terraces are.

RBDHRG have shown that rivers in mid Wales, and in general, are sensitive to climatic variations as well as to changes in land use, and have been affected by quite recent events. Recognising this, they have developed a sophisticated river catchment computer modelling programme called CAESAR (Cellular Automaton Evolutionary Slope And River model). This is unique as it models the whole catchment and simulates not just flood waters but how the river channel and floodplain changes, as well as how slopes and tributaries feed water and sediment into the main trunk river. It has been successfully applied to river catchments in England (Yorkshire Ouse), forecasting changes in erosion, deposition and channel pattern over periods ranging from 1 to 1000 years. Since it utilises the information on past climate and land use, allied to calibrated geomorphological data, to model the effects of future climate change, CAESAR’s ability to predict future topographic changes within each reach of a river catchment has obvious implications for assessing future flood risk.

Subsequently Dr Davies invited representatives of the WAG, EA Wales and CCW to join with BGS and RBDHRG to form a ‘forum on flooding and floodplain related research in Wales’. Arising from the meetings of this group came the idea and proposal for the current co-funded project.

2 Project specifications and methodology

Details of the project funding, timetable and organisation are included in the original proposal and subsequent Memorandum of Agreement signed by all the co-funding partners, both of which are on BGS file.

The study is designed to provide detailed future flood risk models for 7 selected river reaches on four Welsh rivers: the Dee (2 reaches), the Severn (2 reaches), the Dyfi (1 reach) and the Teifi (2 reaches). Five of the reaches lie in areas either undergoing, or soon scheduled for survey as part of the IGS South mapping programme.

The co-funded, 3-year project has a total budget of £354k. The BGS contribution is £90k of which £66k is the nominal cost of surveying the study reaches, and those parts of the catchment of the River Teifi, which lie on the Lampeter Sheet. The balance of £24k is funded from the Urban Geoscience and Geological Hazards Programme (UGGP) and Quaternary Methodologies and Training Project (QMT). This sum attracts an equal amount as part of the co-funding formula, to give a total budget for BGS work on the project, over and above the mapping, of £48k (£16k/year). (All figures at full economic cost).

The BGS project staff are Drs J. R. Davies, T. H. Sheppard and R. A. Waters. Dr Davies acts as project leader for the work undertaken by BGS, but the overall project is administered by the RBDHRG at the University of Wales Aberystwyth. Progress is monitored at 6 monthly meetings of a Project Steering Group made up of representatives of all the co-funding partners. The start date for the project was 1st December 2002.

Details of the project methodology and the role of BGS are given in Appendix 1.

As part of its contribution to the project BGS has supplied the RBDHRG with DigMap50 data for the whole of Wales under license. This data will be used to characterise the hyrogeological properties of the study catchments within the CEASAR modelling programme. Details of the use of BGS DigMap 50 within the project data are given in Appendix 2.

As a separate but closely allied initiative, BGS is also funding an University Collaboration Advisory Committee (UCAC) project with Professor Macklin and his team, to undertake radiocarbon (^{14}C) dating of alluvial deposits within the study catchments. The results of this study will feed directly into the main project, allowing alluvial surfaces within the study catchments to be correlated and calibrated in time, and underpinning an improved understanding of how Welsh alluvial systems have evolved during the post-glacial period.

3 Aims and remit for BGS

The overarching aim of the project is to gauge the value of the CAESAR catchment modelling software as a potential tool for forward-modelling of flood risk in the river catchments of Wales. The WAG view this as the next phase of its flood risk related research anticipating that the results of the study will underpin the next generation of flood risk policy maps for Wales. However, in pursuing this central objective, there are a series of secondary aspirations directly relevant to various BGS research programmes, notably Integrated Geoscience Surveys (South) and the UGGP:

i) The project offers an opportunity for BGS to make an informed assessment of the merits and limitations of a variety of surveying techniques and topographic datasets (DTM, GPS, LiDAR, NextMap) used in the context of floodplain mapping. It also allows us to compare and contrast our surveying methods with those used by the RBDHRG.

ii) The detailed maps of alluvial features produced for the study catchments may allow BGS to upgrade its alluvial linework for these rivers.

iii) The project will provide information on the evolution of Welsh river catchments from late Pleistocene times onwards, on the chronology of erosional and depositional events, and on the intra- and extra-basinal factors which promoted them. These insights will inform the debate about how BGS interprets and labels alluvial deposits and landforms inside the Devensian limit, and how we depict them on our maps.

iv) The project will improve BGS understanding of the range and implications of future climate change scenarios used for predictive modelling.

v) Critically, the project will allow BGS to make an informed judgement about the application of our floodplain mapping in the context of assessing future flood risk.

vi) It will allow us to evaluate the modelling technique developed by the RBDHRG and to assess its possible applications within BGS.

The catchments and reaches studied as part of the project all lie **inside the Devensian Limit** and the conclusions and recommendations arising from the study will relate primarily to such systems.

4 Comparison of RBDHRG and BGS floodplain mapping

4.1 MAPPING TECHNIQUES

Both RBDHRG and BGS floodplain mapping methodologies are principally based on recognition of discrete geomorphological features (terraces, palaeochannels, etc), which are considered to record the history and evolution of floodplain systems. The essential differences of approach concern nomenclature, the degree of detail, and technical issues of scale and representation on the mapface.

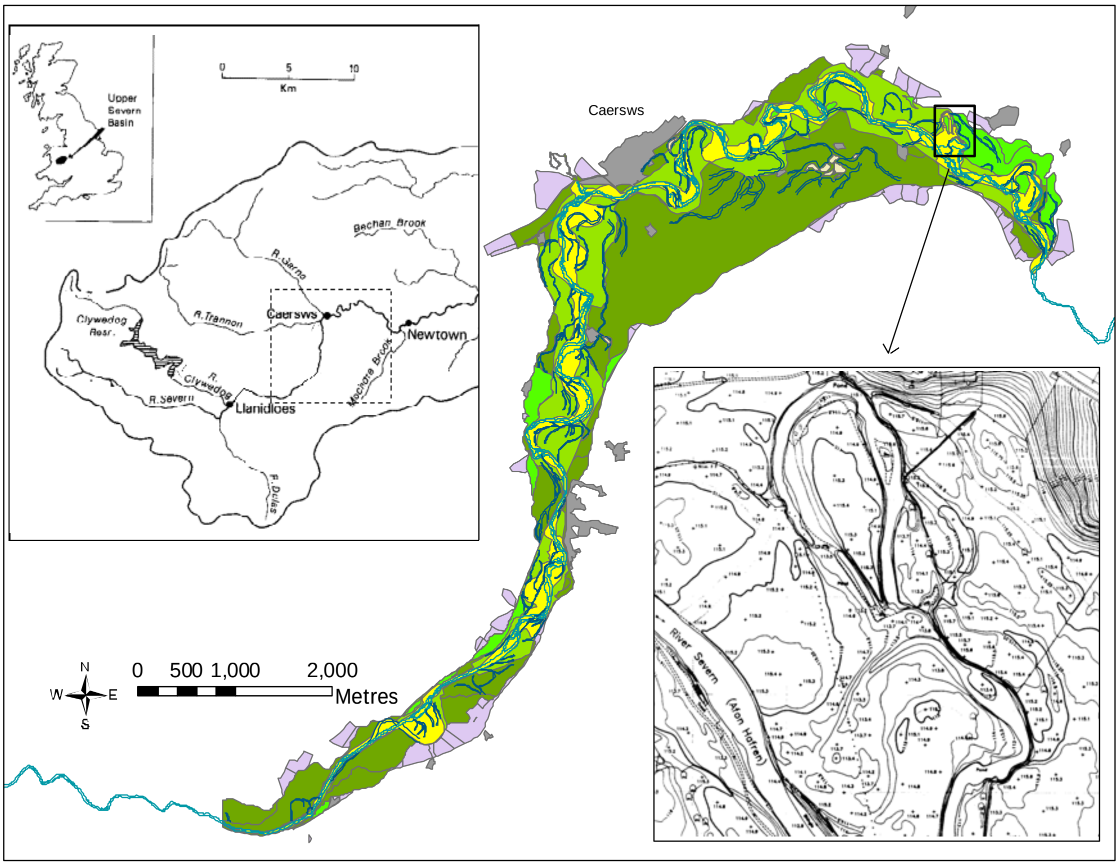

Figure 1. RBDHRG high resolution geomorphic map produced for the Upper Severn SSSI centred around Caersws with the shading corresponding to different Holocene alluvial units. The inset shows an example of the high resolution topographic data produced, here with contour lines at 0.2m.

RBDHRG pay significantly more attention to features which record past drainage patterns and which might influence modern drainage and flooding patterns. Whereas BGS surveyors only record the most obvious palaeochannels on their field slips, and even these are rarely shown on our published maps, RBDHRG surveyors go to great lengths to identify as much of the earlier drainage network as possible, mapping quite subtle features (sinuous depressions, boggy ground, etc) and these features are routinely shown on their final maps (Figure 1). They also recognise the importance of anthropogenic features (field drains, ditches, etc) in modifying and controlling the hydrology of the alluvial tract and consequently carefully map the positions of such features and the nature of any flow within them. This is not general BGS practice unless the features are significant enough to be classified as artificial ground.

From a practical point of view, a very significant difference between the two methodologies lies in the scale of map needed to record and represent the features recognised by RBDHRG. BGS practice is to map in the field at 1:10000 scale or exceptionally 1:25000. The features recognised and mapped by UWA (standing water, isolated reed patches, anastomosing drainage networks, etc) are simply not representable at those scales. UWA routinely survey at ~1: 7500 although they produce field slips by photocopying and enlargement of OS 10k maps and use different scales depending on the nature of the floodplain to be surveyed.

RBDHRG also use a number of ancillary mapping techniques including heavy use of air photography (AP). Particular use is made of historic AP datasets in order to chart changes of active river systems through time.

4.2 TOPOGRAPHIC DATASETS

As part of the current project RBDGRG and BGS are also investigating the use of LIDAR and GPS data to aid in the detailed geomorphological mapping of the floodplains, and this appears to be particularly beneficial where the floodplain morphology is complex and difficult to interpret both on the ground and from air photographs. The merits of these datasets will be assessed as a future part of the project.

During the surveying of the Teifi catchment, BGS surveyors have been assessing the use of NextMap data. The results of this evaluation are given in Appendix 3.

5 Evolution of Welsh river catchments

The principal late Quaternary events/processes which have influenced Welsh river systems are summarised in Figure 2a. Alluvial deposits and landforms within river catchments in mid and north Wales date from the Devensian glaciation to the present day, a period of around 20 000 years. Meltwaters released during the retreat of Devensian ice deposited extensive spreads of glaciofluvial outwash in many of the main river valleys. In the first few thousand years following deglaciation these deposits were reworked as rivers sought to regain their pre-glacial thalwegs. This late Pleistocene period (and the processes) of readjustment of the landscape following glaciation is termed paraglacial and was a time of massive erosion and sediment redistribution (Figure 2b). Glacio-isostatic uplift gave added impetus to this process of regrading and served, initially, partly to offset the effects of the post-glacial eustatic rise in sea level. Isostatic rebound may still be on going today, but its main impact had been felt well before the rapid rise in sea level to its present day elevation attained around 5000 years ago. Climatic changes associated with the late Pleistocene Windermere Interstadial followed by the Loch Lomond Readvance, which was marked by the return of periglacial conditions to much of Wales, also influenced the flux of sediment within river catchments and marked the beginning of a series of similarly influential climatic fluctuations recorded throughout the Holocene.

The Holocene deposits of Welsh floodplains record a long history of inundite deposition, with long-term variations leading to the alternation of flood-prone and flood-poor periods. Macklin & Lewin (2003) recently assessed the ^{14}C data for the Holocene alluvial record and identified 14 significant periods of flooding, demonstrating a correlation between these flood events and periods of wetter climate recorded by mire deposits (Hughes et al., 2000). From the higher-resolution part of the Holocene ^{14}C record (4Ka BP to present) Macklin & Lewin (2003) identified a persistent centennial-scale climatic variability (the so-called '100-year flood event), which they considered the principal control on alluviation in the British Holocene. Major flood episodes related to periods of cold, wet climate are recorded at 10 420 ca. yr. BP (calendar years before present), 8100-7520 ca. yr. BP, 3940-1940 ca. yr. BP and 1070-400 ca. yr. BP and represent a longer-term climatic control on alluviation. This record suffers from an anthropogenic blurring or overprint. Woodland clearances initiated around 4500 ca. yr. BP coinciding with the development of Bronze-Age agriculture have increased runoff, which in turn increases the frequency and magnitude of flooding. The increased severity of flooding experienced, particularly in upland catchments in the last 4500 years may be related to this activity. A further consequence of this activity is greater sediment runoff and thus greater preservation potential of alluvial units younger than c. 4500 ca. yr. BP, and the exponential increase in clearances following c. 2000 ca. yr. BP is reflected in the skewing of the alluvial record towards the preservation of relatively young Holocene alluvial units in upland catchment areas (e.g. Lewin & Macklin, 2003).

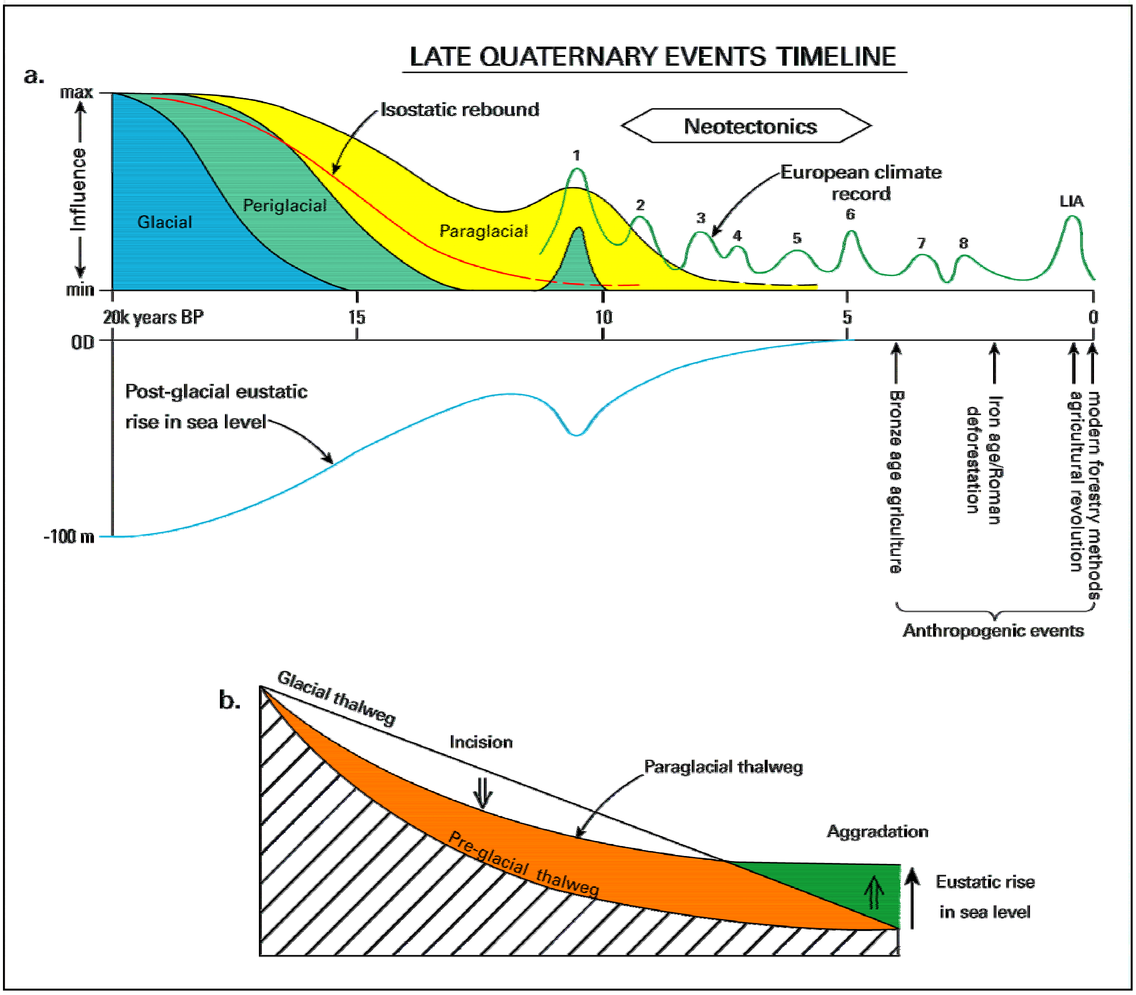

Figure 2. a) Major late Quaternary events which have influenced the evolution of Welsh river catchments. b) Principal effects of paraglacial regrading.

6 Radiocarbon dating results

6.1 RIVER DYFI

A coring programme was undertaken to recover organic material from alluvial sediments for radiocarbon dating in the Dyfi valley. The programme incorporated eight sites that are representative of the upland, piedmont and lowland environments found in the valley. Over thirty organic samples were collected and, based on their geomorphological and sedimentological context, six were selected for radiocarbon dating.

Two organic samples were taken from the upland sites at Minllyn and Dugoed and yielded dates of 1960±40 and 3430±40 yrs BP, respectively (see Table 1). The first sample was taken from the fourth highest terrace in a sequence of six, which lay approximately 4-5 m above the present channel. The sample was recovered at 57 cm depth, 10 cm from the top of a fining upwards sequence. The older sample from the Dugoed site was recovered from the sixth highest terrace in a sequence of seven. The surface of the terrace lies approximately 7-8 m above a tributary channel and the sample was taken from 82 cm depth at the top of a fining upward sequence.

In the piedmont reach only one sample was processed because relatively little organic material was found in significant sedimentological contexts. The dated sample was taken at Rhydygwiail from the third highest terrace of four, which lay approximately 3 m above the channel. The sample yielded a date of 710±40 yrs BP and was recovered at 134 cm depth from an organic-rich seam that capped a fining upward sequence.

Three radiocarbon dates were obtained for the lowland reach of the Dyfi. The first of these dates, 2010±40 yrs BP, was taken from a palaeochannel on the highest terrace of four at Hendreseifion, which lies about 4 m above the channel. The dated charcoal was sampled at 232 cm depth, lay 15 cm above a fining upward sequence and was overlain by 200 cm of fine material. The adjacent terrace, the third highest of the four, that lies approximately 3 m above the channel, yielded a date of 650±40 yrs BP. The sample was recovered at 127 cm depth from a thin organic-rich layer that capped a sequence of clast-supported gravels. The third dated sample was taken a short distance upstream at Aberffrydlan where a series of three terraces was inset against the other valley floor terraces. The highest of these surfaces, which lies about 2.5 m

Sample Location	Grid Reference	Sample Type	Lab. ID Number	Conventional ^{14}C Age (yr BP)	Calibrated ^{14}C Age (2 sigma)	Calibrated ^{14}C Age (Calendar Years)
Minllyn	SH 860 131	Charcoal	170554	1960±40	BP 1995 – 1830	BC 45 – AD 120
Dugoed	SH 861 126	Charcoal	169567	3430±40	BP 3820 – 3580	BC 1870 - 1630
Rhydygwiail	SH 828 056	Wood	170553	710±40	BP 695 – 640 or BP 585 – 570	AD 1255 – 1310 or AD 1365 – 1380
Aberffrydlan	SH 774 027	Wood	170550	640±40	BP 665 – 545	AD 1285 – 1405
Hendreseifion	SH 769 027	Charcoal	170551	2010±40	BP 2050 – 1875	BC 100 – AD 75
Hendreseifion	SH 771 026	Charcoal	170552	650±40	BP 670 – 545	AD 1280 - 1405

Table 1. New Dyfi Valley Radiocarbon Dates.

Sample Location	Grid Reference	Sample Type	Lab. ID Number	Conventional ^{14}C Age (yr BP)	Calibrated ^{14}C Age (2 sigma)	Calibrated ^{14}C Age (Calendar Years)
Mathafarn	SH 802 038	Wood	152058	390±50	BP 520 – 310	AD 1430 – 1640
Pennal	SN 705 995	Wood	152060	380±50	BP 520 – 310	AD 1430 – 1640
Pennal	SN 704 992	Wood	152059	3330±70	BP 3710 – 3390	BC 1760 – 1440

Table 2. Existing Dyfi Valley Radiocarbon Dates.

above the channel, yielded a date of 640±40 yrs BP. The sample was taken at 238 cm depth from a clay layer 15 cm above a fining upward sequence and was overlain by 200 cm of organic-rich fines.

6.1.1 Preliminary interpretation of River Dyfi results

The new radiocarbon dates, when combined with dates gathered from earlier research (see Table 2), give an insight into late Holocene fluvial development in the Dyfi valley. The upland reach dates, for example, indicate that the Dyfi has been exposed to high rates of incision in the last 4000 years. This process has led to channel entrenchment and stabilization and has also helped to preserve the SSSI-designated river terraces. In the lowland reach the dates indicate that much, if not all, of the valley floor has been reworked by the river in the last 2000 years. Thick layers of fine sediment found in the lowland reach also indicate that significant amounts of overbank sedimentation have occurred in this period.

The ages of samples from different parts of the valley also strongly correspond indicating that individual terraces can be traced for long distances downstream. The corresponding dates also give a strong indication of when the Dyfi was most geomorphologically active. Four distinct periods of enhanced fluvial activity seem to be apparent in the Dyfi terrace record: cal BP 3820 – 3390; cal BP 2050 – 1830; cal BP 695 – 545; cal BP 520 – 310.

6.2 RIVER SEVERN

Geomorphological mapping of the Caesws reach of the River Severn has identified five main morphological units: alluvial units 1 to 4 (river terraces) and the contemporary gravel bars of the present day river channel (Figure 1). Three ^{14}C dates have been obtained from organic material found within alluvial unit 3 sediments exposed in channel bank sections (Table 2). In conjunction with archaeological evidence, these dates have allowed the probable age of deposition of the various alluvial units to be determined (Table 3).

Sample number	Grid Reference	Sample type	Lab. ID number	Conventional ^{14}C age (years BP)	Calibrated age (2 sigma)
S1	SO 0464 9221	Wood	Beta-145823	1680 +/- 60 BP	AD 230 to 530
S2	SO 0545 9289	Wood	Beta-145824	1260 +/- 50 BP	AD 660 to 890
S3	SO 0719 9130	Wood	(unavailable)	1020 +/- 60 BP	AD 900 to 1120

Table 3. Radiocarbon (^{14}C) dates obtained from organic material within alluvial unit sediments exposed in channel-bank sections.

Alluvial unit	Maximum and minimum surface height above local riffle elevation (m)	Surface area in km^2 and as a percentage of total floodplain surface	Probable age of alluvial deposition
Unit 1	5 – 4	0.31 (3%)	Late Devensian
Unit 2	4 – 2.5	5.9 (57%)	Pre- Bronze Age
Unit 3	2.7 – 1.5	2.3 (22%)	Post-AD 230-530 to AD 1840
Unit 4	2.2 – 1.5	1.2 (11%)	c. 1840 to present
Gravel bars	1.7 – 0.5	0.15 (1.5%)	Present

Table 4. Alluvial unit surface height above river bed elevation measured at channel riffle sites, surface area and age of alluvial deposition.

6.2.1 Preliminary interpretation of River Severn results

Channel incision into alluvial unit 1 and deposition of alluvial unit 2 were probably associated with a change in sedimentation style from coarse-gravel outwash deposition in a braided river environment to predominantly fine grained, single-channel, overbank deposition. Deposition of alluvial units 3 and 4 appears to be related to a number of environmental controls, including the climatic deterioration associated with the Little Ice Age, metal mining in the headwaters and the improvement of land for grazing during the nineteenth century. The relative contribution of these factors to floodplain development, however, is unknown. During the last *c*. 160 years channel engineering has altered both the lateral and vertical position of the channel. Although the direct impacts on the channel were localised, the impacts of such activity appears to have affected the reach in both downstream and upstream directions. The impact of historic lateral channel change (anthropogenically and naturally induced) has promoted channel incision in the upper and lower parts of the reach, with channel aggradation occurring in the vicinity of Caersws. Anthropogenically induced channel change, from direct and indirect intervention, during the last *c*. 160 years, may have had a greater impact upon river floodplain development than natural processes (e.g. climatic).

6.3 FUTURE SAMPLING

Two further samples have been obtained from the Dyfi reaches are awaiting processing, and further sampling of both the Severn and Teifi reaches is planned this summer.

7 Implications for BGS alluvial mapping

RBDHRG classify alluvial landforms rather differently to BGS. They number alluvial surfaces in topographic sequence, but with the highest (and oldest) surface as terrace (or alluvial unit) number 1. This is because they are primarily concerned with calibrating the heights and ages of alluvial *surfaces* as a record of the catchment's post-glacial evolution. This is in marked contrast to BGS maps which seek to depict *deposits*, and herein lies a fundamental difference with major implications for the way BGS maps and labels alluvial sequences.

The data obtained from the Dyfi illustrate the implications of this difference in approach. RBDHRG view river terraces in the upper Dyfi as essentially erosional benches, the products of paraglacial incision, with a veneer of fluvial sediment. Where terraces are cut in earlier glaciofluvial deposits, these materials may occur at shallow depth beneath a thin spread of reworked gravel, with the older glacial material commonly cropping out in the faces of the terraces. Normally in mid Wales, BGS would map the whole of each terrace feature as a separate River Terrace Deposit, or include the whole of terrace sequence as a unit of undivided River

Terrace Deposits. The upper Dyfi landforms suggest a far more complex reality in which a suite of perched, late Pleistocene to early Holocene paraglacial terraces can be distinguished from late Holocene features developed in response to more recent climatic and anthropogenic events (Figures 2 and 3).

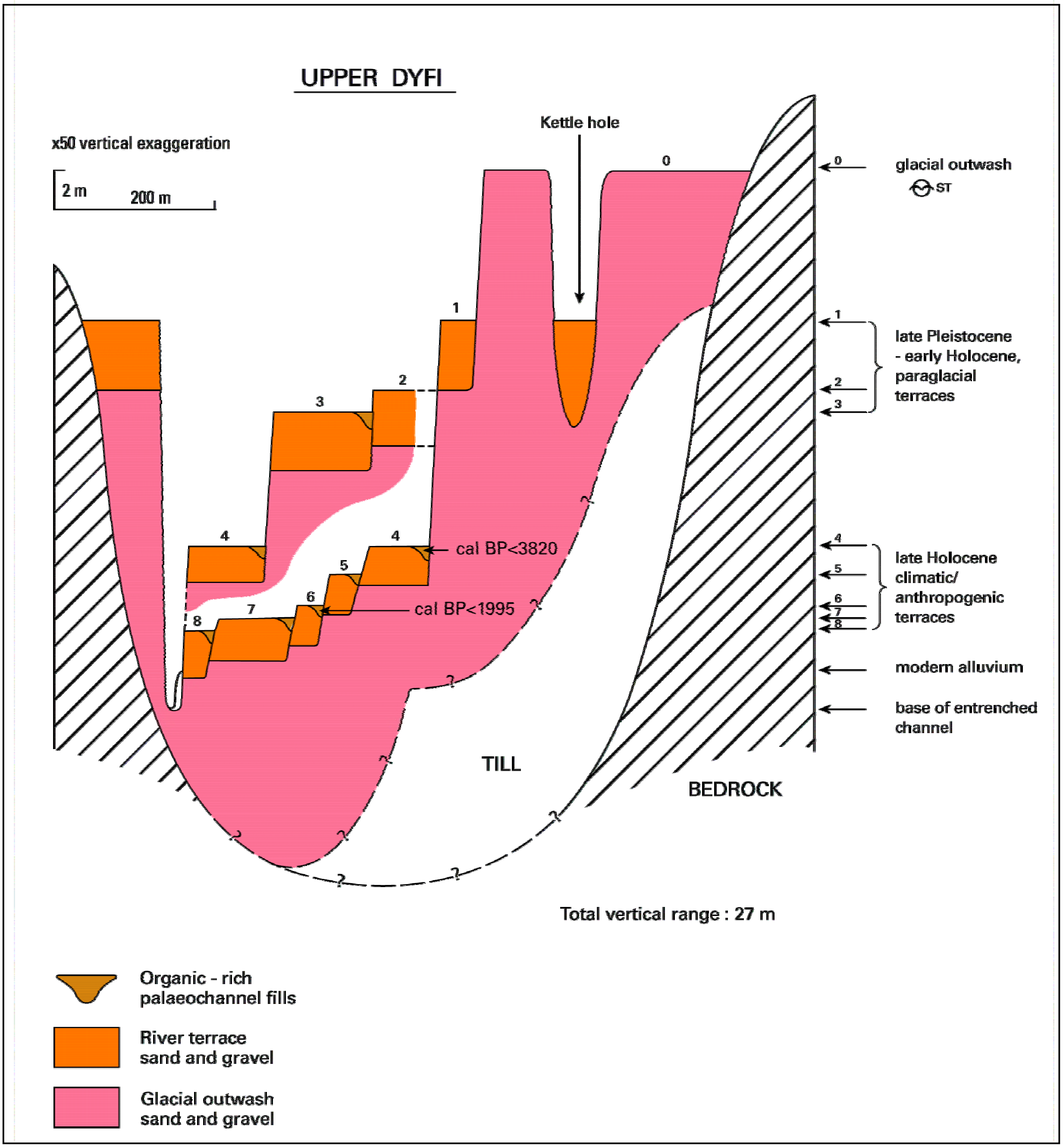

Figure 3. Cross-section through alluvial deposits of the upper Dyfi

In contrast, the clay and silt-rich terrace deposits of the lower Dyfi are the product of more recent alluvial deposition and erosion and might be viewed as geologicaly ephemeral features created by the normal process of lateral migration (Figure 4). Though they are thought to cap an aggradational sequence of late Pleistocene and earlier Holocene paraglacial deposits which represent the products of incision in the upland reaches, the surface landforms relate to exclusively late Holocene climatic and anthopogenic events.

Thus, the Dyfi's upland and lowland terrace systems are of very different origin and composition, yet BGS would depict them all as river terrace deposits. Moreover, if the lithostratigaphic approach currently being considered by the BGS Quaternary Stratigraphic Framework Committtee were applied, these terraces would each be assigned member status (i.e. 8 members) within a catchment formation.

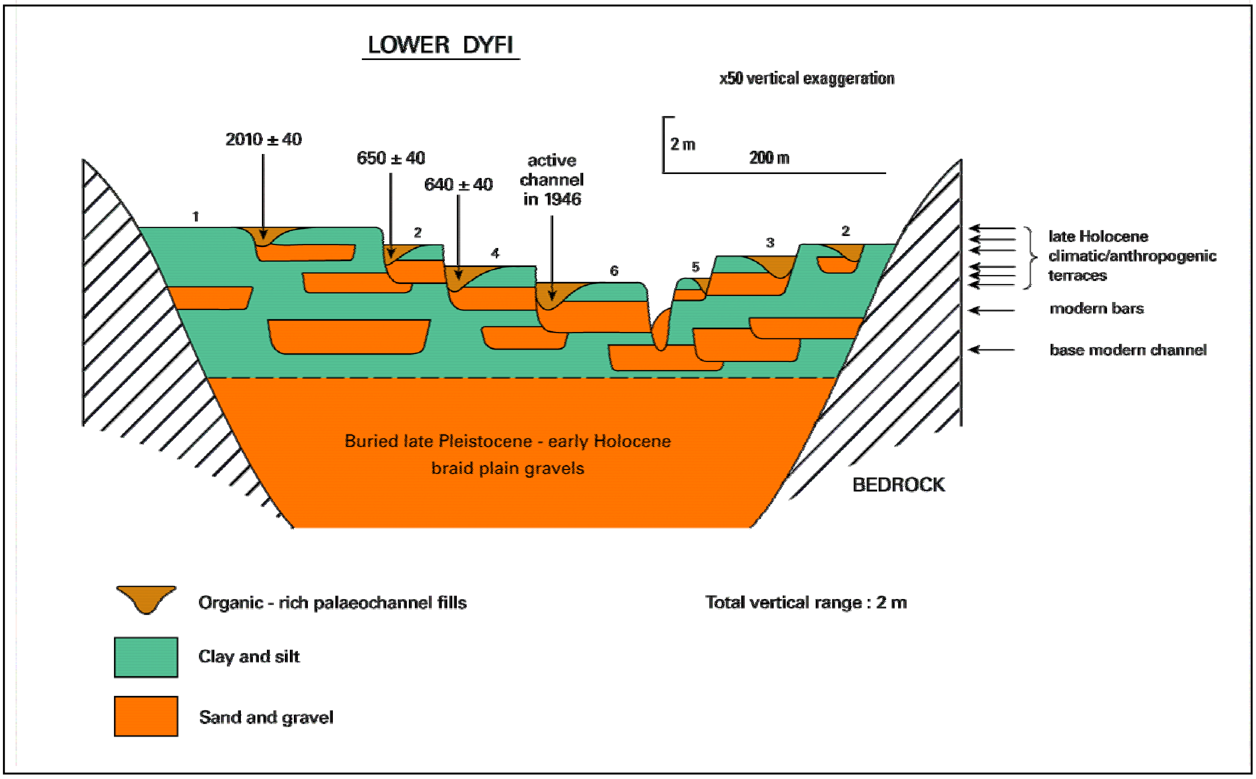

Figure 4. Cross-section through the alluvial deposits of the lower Dyfi

This illustrates the problem with the 'one size fits all' approach currently employed by BGS. However, many of these difficulties would disappear if we depicted geomorphological features separately from deposits. Thus, the upland terraces of the Dyfi could be shown as terrace features, but mapped as paraglacial fluvial deposits (sand and gravel). In contrast, the lowland terraces could be depicted as topographic features cut in recent alluvium. Of course this approach would carry serious implications for the application of a lithostratigraphical classification to these alluvial sequences.

8 Preliminary assessment of CAESAR modelling

RBDHRG's flood risk modelling and assessment methodology is effectively a pyramid structure (Figure 1). The methodology involves the generation of a high-resolution geomorphological map and a high resolution terrain model (either LIDAR data or a manual topographic survey with a GPS system). The terrain model is then 'tweaked' to fit the geomorphological model (ensuring that breaks of slope co-incide with terrace fronts etc). This is then modelled with CAESAR.

CAESAR is a cellular automation model, that is, it requires a cellular raster (grid) input (a DTM) and calculates the change in elevation of each cell in the DTM grid as a consequence of erosion and deposition. It does this by modelling fluid flow (derived from precipitation and river gauge data) as affected by erosion, deposition, vegetation, mass movement etc, and therefore can also provide flood modelling. Its principal strength is its ability to model catchment evolution and thus predict future flooding by running repeated iterations each building on the outputted predictions from the previous iteration.

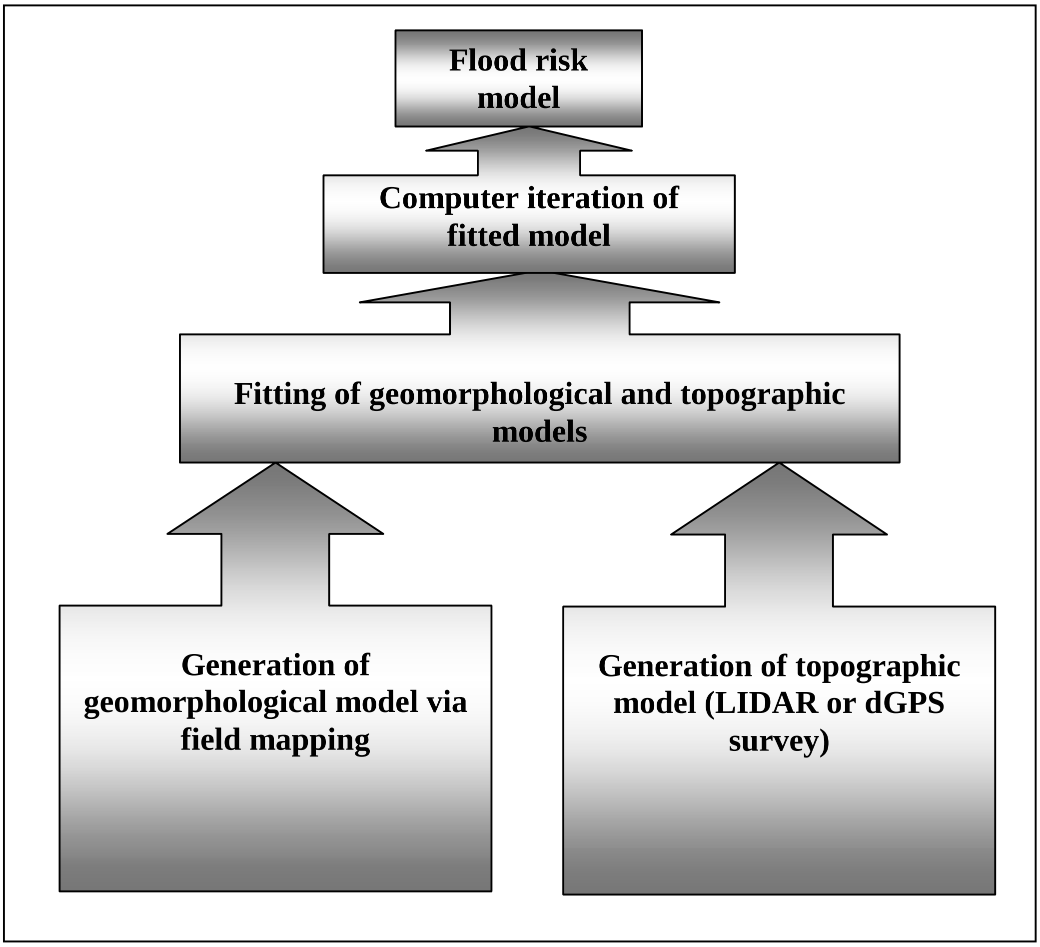

Figure 5. Representation of RBDHRG modelling methodology

CAESAR is a very powerful and impressive tool with a large number of potential applications for BGS. The recent release (December 2003) of an MS Windows Graphical User Interface (GUI) for CAESAR has gone a significant way towards allaying previous concerns over the usability of the software and reproducibility of results outside RBDHRG. However, the GUI is as yet untested in BGS.

The components of UWA's flood modelling methodology are all sound in principle and appear capable of providing an effective modelling approach to river dynamics and flood risk. However it has to be stressed that no single component of the RBDHRG pyramid provides effective or meaningful flood-risk data unless it is integrated with all other components, including those not traditionally gathered by BGS, and modelled with (and only with) the CAESAR software. This means that predicting flood risk requires an all-or-nothing approach to data acquisition and compilation because anything short of a complete model is insufficient. For instance: the three principal elements required for simple flood risk modelling are morphology, elevation and flow data. Geomorphological maps contain no absolute elevation information and not enough flow information, terrain models do not contain any flow and not enough geomorphological information, and flow data contains no geomorphological or elevation information at all. In order to produce a reliable flood risk model then all three components must be obtained as two alone simply will not provide adequate information. Flood risk modelling in CAESAR requires many more datasets such as vegetation cover, sediment grain size etc, and the same principle applies.

To date, initial DTM and GPS data input to CAESAR has been undertaken for the Teifi and Severn catchments.

9 Summary

The project represents an innovative multipartner project designed to develop and test software for use in predicting future flood risk in Welsh river catchments. The software requires the input of digital data relating to topography, geology, hydrology, hydrogeology, land use and vegetation cover, as well as climate and models for future climate change. Each of the partner organisations has provided different datasets. As part of its contribution, BGS has provided digital geological data (drift and solid) for the study catchments and collaborated in the ongoing selection and identification of 14C sampling sites. The costs of processing of the 14C samples used to date alluvial surfaces are covered by a BGS university collaboration grant to Aberystwyth University.

The project affords an opportunity for BGS to assess different surveying techniques and datasets used in the mapping of alluvial deposits and landforms, and to assess different systems of classification. The dating of terrace sequences is revealing how Welsh river catchments have evolved since the last Ice Age, and their responses to post glacial erosion, changes in climate and rising sea level. The importance of changes wrought by man, notably deforestation and improved land drainage, are emerging as factors which have had a significant impact on sedimentation and flooding over the last 4000 years.

The implications of the project for BGS in the context of mapping, shallow subsurface investigation and classification of alluvial systems will be assessed more fully in a subsequent end of project report.

Appendix 1 Project details

SELECTION OF STUDY CATCHMENTS

The selection of study catchments is influenced by the different requirements of the agencies involved. These can be summarised as follows.

There is an urgency to produce flood predictions at key developed sites that are at risk from flooding, so that appropriate and defensible long-term flood mitigation measures and planning polices can be put in place (for example, the Dee near Wrexham and the lower Dyfi at Machynlleth). Several of the rivers (Dee, Teifi) to be studied will form the basis for pilot CFMPs. A number of the rivers have habitats and species associated with them that are of international importance, these include floodplain grasslands, flooded woodlands, and salmon. Two of the reaches to be examined (Caersws and Roundabout, upper Severn) are being considered as a landscape Geological Conservation Review (GCR) site/Site of Special Scientific Interest (SSSI).

However, there is also a need for the catchments to be selected on the basis of objective hydrological criteria and to base the modelling on catchments for which there exists high quality research data. Furthermore, they should be representative of the different types of rivers within Wales. Based on these criteria, candidate catchments include:

a. The upper Severn, a semi-regulated river, where existing work has been carried out on the Caersws SSSI (Figure 1), and there is ongoing NERC sponsored research.

b. The Dyfi, an unregulated river where there is ongoing RBDHRG project evaluating the effects of environmental change on river activity and annual flooding problems at Machynlleth.

c. The Dee – regulated river (Llyn Tegid) with a history of flooding.

d. The Teifi – an unregulated river

In addition to their other interests in this project, CCW also require detailed information on the River Severn Roundabout GCR site to underpin the development of a site management plan (see Appendix III for project specification).

Parts of the following catchments are scheduled for survey as part of the NAW co-funded, BGS mapping programme in mid Wales: Upper Wye, Upper Tywi, Teifi and Aeron.

Given these considerations, it is proposed to select study reaches on each of the rivers Dee (2 reaches), Severn (2 reaches), Teifi (2 reaches) and Dyfi (1 reach) (7 reaches in total). The lower Usk near Newport is clearly also an important reach. However, the tidal nature of the river here presents an additional challenge to the modelling technique. It is suggested that the modelling methodology and application is developed and tested on the inland rivers proposed and if seen to be successful, a separately funded 6 month study of the Usk could be undertaken as an extension to the current proposal.

PROGRAMME OF WORK

The project has four clear phases of activity which can be broken down into a series of separate tasks as set out below. The schedule of work is detailed in Table 5.

Phase	Task	Year 1												Year 2												Year 3											
Phase 1 Site selection and data collection		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
A	**Establish study reaches**	■	■																																		
B	**Collate gauged & historical flood records**	■	■	■	■	■	■	■	■	■	■	■	■																								
C	**Collect land use & climate data**			■	■	■	■	■	■	■	■	■	■	■	■																						
Phase 2 Mapping and fieldwork																																					
D	**Purchase APs, maps & aquire LiDAR**	■	■	■											■																						
E	**Process LiDAR data**			■	■											■	■																				
F	**High resolution mapping of study reaches**					■	■	■	■	■	■	■						■	■	■	■	■	■	■													
G	**Sediment sampling for contaminant metals**							■	■											■	■																
H	**Collection & processing of ^{14}C dates**							■	■											■	■																
I	**Interpretation**												■	■	■										■	■	■	■	■								
Phase3 Modelling and assessment of results																																					
J	**Generate present day topography**					■												■																			
K	**Run 1d model on present day topography**						■	■											■	■																	
L	**CAESAR runs to simulate future topography**							■	■	■	■	■	■	■						■	■	■	■	■	■	■											
M	**Evaluation**												■	■	■										■	■	■										
N	**Re-run 1d models on future topography**															■	■											■	■								
O	**Generate flood risk maps**																													■	■	■	■	■			
P	**Compare results to Section 105 maps**																■	■											■	■							
Phase 4 Dissemination of results																																					
Q	**Project final reports**																															■	■	■	■	■	■
R	**Seminar 'roadshow' and training courses**																																			■	■
S	**Web site**																									■	■	■	■	■	■	■	■	■	■	■	■
T	**Data integration**															■	■	■																	■	■	■
U	**Further publication**																															■	■	■	■	■	■

PGRA 1 in post	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PGRA 2 in post	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 5. Project Schedule

Phase 1: Study reach selection and data collection

a. All the rivers listed above form part of the ongoing CCW/EAW/UWA funded Exposed Riverine Sediment (ERS) project. This project has created a channel change database for nearly 50 rivers in Wales. This national database will be interrogated to delineate study reaches within catchments each of between 5-10 km in length. These will include a full range of river-floodplain systems found in Wales (laterally mobile, stable, and divided channels; incising and aggrading channels; presence or absence of ERS, silt / clay and sandy floodplains; tree and grass covered floodplains).

b. Collect gauged & historical flood records for study catchments. These will be used to establish whether there has been a change in flooding regime, identify its probable cause and to provide discharge data for the modelling phase.

c. Collect other climate and land cover histories for catchments (e.g afforestation/deforestation/vegetation cover/land drainage/mining records) that can be used to determine whether past changes in river activity is related to climate or land-cover change. Land cover data will be provided by Phase 1 Habitat maps which map 17 types of vegetative cover for all catchments proposed. The hydrological data associated with all 17 types will be collected in a short study to be undertaken prior to the main mapping exercise.

PHASE 1 PRIMARY DELIVERABLES

i. Identification of the full range of channel and floodplain types in Wales.

ii. Establish whether there has been a change in flooding and identify its probable cause.

Phase 2: Mapping and fieldwork

High-resolution topographic, geomorphic and geological drift maps of each study reach will be produced, to identify the major alluvial units (surfaces) present, including palaeochannel positions. An exemplar of this is the Caersws SSSI upper Severn (Figure 2).

There are several stages required to generate these maps which are outlined below.

d. Purchase base maps (paper and digital), colour air photographs and acquire LiDAR data from EAW.

e. Processing of LiDAR data to generate high resolution topographic maps.

f. High resolution (1:2,500-1:5,000) reach scale mapping of the study reaches which will be used to enhance the detail of the LiDAR data. These data will also be used to drive the CAESAR modelling runs.

g. Sediment sampling for floodplain contamination assessment. Two of the proposed study rivers (Dyfi and upper Severn) have been affected by historical metal mining, which have left metal-contaminated sediment within the river system. These include contaminant metals such as Pb, Cu, Cd and Zn.

h. Collection of organic material preserved within floodplain and river terrace sediments for ^{14}C dating. These dates will allow us to establish a chronology of alluvial units, that is to understand when and where the river has changed in the past.

i. Geological and geomorphological interpretation of new field maps. The data generated by the mapping and fieldwork phase will generate detailed maps of the valley floor calibrated both topographically and in terms of age. This will allow us to understand the processes and events which lead to episodes of channel and floodplain change and establish which technique(s) for valley floor zoning provides the most robust and cost-effective means of identifying the flood risk.

PHASE 2 PRIMARY DELIVERABLES

i. Establish which technique(s) for valley floor zoning provides the most robust and cost-effective means of identifying the floodplain for a given flood magnitude.

ii. Valley floor maps showing heavy metal contamination levels and remobilisation potential.

Phase 3: Modelling and assessment of results

This phase will involve populating the CAESAR model with the catchment characteristics, testing the model, simulating future climate change and land-use/vegetation cover scenarios, and finally interpreting the results to predict future flood risk. This will include:

j. Utilising LiDAR data and high resolution topographic maps from phase 2 to establish present day topography.

k. Running a 1d hydraulic model (e.g. ISIS) over present day topography to determine current flood risk.

l. Using CAESAR to first model past changes in the reaches (retro-validation), and then to simulate future changes in topography on the study rivers (using a range of climate and land-use change scenarios).

m. Evaluating results and modify modelling, if necessary.

n. Re-running 1d hydraulic models on simulated future channel-floodplain topographies and vegetation cover changes.

o. Generating a range of future flood risk maps, including a flood likelihood factor based on the ensemble of future change maps. These future changes will be based on a range of climate change and land-use change scenarios.

p. Comparison of model and field mapping results with existing Environment Agency Wales Section 105 maps.

PHASE 3 PRIMARY DELIVERABLES

iii. Forecast the effects of climate and land-use change on flooding.

iv. Produce maps showing zoned assessment of flood risk.

Phase 4: Dissemination of results

q. Produce end of project reports with a detailed evaluation of the methodology and recommendations for its future application, including a separate report for CCW on the Severn Roundabout GCR site.

r. A ‘Roadshow’ of seminars and training courses to inform end users.

s. Production of a project web site.

t. Data integration. The final project maps will be produced in a digital, GIS compatible format. The geomorphological maps produced as part of the project will be either integrated with the products of the BGS mapping programme in Wales, or used to revise existing BGS maps currently in a digital format.

u. Flood risk maps will be produced as a joint BGS/CCW/EA/NAW/UWA publication, and subsequent to its completion, papers describing the project methodology, and both its applied and scientific findings will be published. There will also be a discussion of the policy implications for this work, focussed particularly on the potential implications for changes to land use, land cover and developments.

Appendix 2 Use of BGS DigMap data

The BGS geology data will be used by collaborators at the University of Wales Aberystwyth three distinct ways:

a) The nature of the solid and drift geology at any site within the catchments, together with information on topography, climate, land use and vegetation, will be factored into the modelling software developed by the University. Populated with this data, the modelling programme can then provide data on rates of run-off, and on sediment and ground water budgets within the selected river catchments.

b) The nature of the geology will also be used to factor in information on the erodability of a river's bed and banks along its length. Along reaches where a river flows between banks of solid rock its course will be fixed, but its course will be less stable where the banks are formed of more easily eroded drift materials.

c) The BGS alluvium and river terrace data will be used as an initial indicator of the form and position of active river floodplains and higher terraces. However, this geomorphological data will be calibrated and refined by comparison with detailed LiDAR derived topographic data. Selected reaches will be surveyed by University geomorphologists and these more detailed floodplain maps will be used for more targeted modelling procedures.

Using all these data, the University software can be used to predict and map-out which parts of a river catchment are at greatest risk of flooding in the future. The Welsh Assembly Government (WAG) hope to use this predictive mapping to underpin future planning policy for development on river floodplains in Wales.

The BGS data will be used purely to enable the essential geological information to be factored into the modelling equations. No BGS data will be reproduced in any of the final products of the project, though its use will be fully acknowledged and the necessary caveats appended.

All the other partners are providing data to the project free of charge. The data on landuse and vegetation coverage is to be supplied to the University by CCW. The LiDAR data is to be provided by the WAG and EA Wales. The EA will also freely provide their indicative floodplain mapping data. Existing University mapping of the Dyfi and upper Severn catchments is to be utilised by the project.

The detailed floodplain mapping undertaken by the University will be made freely available to BGS to upgrade our alluvial and terrace linework for the catchments studied. Dating and correlation of terrace landforms undertaken as part of the project will improve our understanding of the evolution of Welsh river catchments and of their alluvial architecture. The results of the project may have profound implications for the mapping methods and nomenclature BGS uses for alluvial landforms and deposits, both in Wales and throughout the UK.

Appendix 3 Using the NEXTMap Britain Terrain Model for floodplain mapping: an interim assessment

1. SPECIFICATION

NEXTMap Britain is a seamless digital terrain model (DTM) for the UK land area produced by Intermap Technologies. Originally produced by Intermap as a flood-risk model for the insurers Norwich Union, it comprises three products: a Digital Surface Model (DSM), a Digital Terrain Model (DTM) and Orthorectified Radar Imagery (ORI). All models are generated exclusively from airborne IFSAR (Interoferometric Synthetic Aperture Radar) measurements.

The Digital Surface Model (Figure 1) product is a 'raw' terrain model, representing 'first surface' elevation measurements. Consequently the DSM product records buildings, forestry plantations and individual trees as height measurements. Such data is useful for terrain modelling applications such as the initial flood-risk purpose (e.g. large, anthropogenic hydrological barriers, such as dams, will be imaged on the DSM) but for geological purposes these measurements represent artefacts. However, the DSM has the greatest vertical accuracy of the NEXTMap product range (Table 1).

The Digital Terrain Model (Figure 2) represents a second-pass interpretation of the DSM wherein an algorithm has been applied to strip the anthropogenic artefacts and produce a 'bare-earth' model. This algorithm is not altogether successful; in particular, anthropogenic elements with sharp or abrupt edges (such as forestry plantations) often remain. However, over 90% of the artefacts are removed producing a satisfactory 'bare earth' model. Application of the algorithm causes some loss of vertical accuracy in the resultant DTM (Table 1).

The Orthorectified Radar Imagery (Figure 3) is analogous to monochrome aerial photography. Its pixel size of 1.25m/pixel is analogous to that of photographs at 25K.

2. USES IN FLOODPLAIN MAPPING

Figures 4, 5 and 6 present a BGS 1:10 000 scale map of the BGS/UWA carbon-dating coring site at Penddol Farm near Llanfair Clydogau in the Teifi Valley, Central Wales. At this site, a wide floodplain (valley floor) is enclosed by steeply banked and thus abrupt late-Pleistocene glaciogenic terraces. The valley floor is differentiated into a wide strip of active alluvium and a terrace on the eastern side of the Afon Teifi (Figure 4). The map of the coring site was produced by walkover survey and represents an hour or two of mapping.

It can be seen from Figures 1, 2 and 3 that the limits of the Holocene valley floor are easily picked using both the DSM and DTM products. It is not easy to pick these lines using the ORI imagery alone. This data's strength is that it can be used as an orthorectified backdrop for the DSM/DTM products or alternatively used as a lit land-surface image for anaglyph production and stereo image manipulation. However, these mapping techniques are outside the scope of this interim report.

It is also easy to trace the limit of the Holocene deposits in Figure 4. However, the DSM NEXTMap data also records the elevation differences between the terraced area where core samples have been taken (purple-blue) and the currently active alluvium (purple-white).

Figure 5 illustrates the same site but uses the 'bare-earth' DTM model. Again, the Holocene-Pleistocene limit is easily picked, and the terrace unit is also seen, but the artefact removal algorithm has resulted in a loss of definition.

Figure 6 illustrates the Penddol site using ORI imagery. Although the difference between the terrace unit and alluvium may still be seen as the drier terrace is imaged as a paler area of ground, it is difficult to pick clear lines using the ORI imagery.

3. INTERIM CONCLUSIONS

NEXTMap terrain models are useful tools for mapping fluvial deposits. Delimiting the Holocene limit/valley floor is straightforward at any reasonable scale with both the DSM and DTM products. However, it is possible to recognise intra-Holocene features such as terracing, provided small segments of the valley floor are processed individually in order to focus the colour spectrum of the terrain model and highlight subtle changes. This can be done with both the DSM and DTM models, although best results have provisionally been obtained with the DSM. The ORI imagery is too coarse to be of use in floodplain mapping as a stand-alone product, although its' applications as a backdrop for stereo imagery and potential combination with the DSM and DTM models has not been explored in this evaluation.

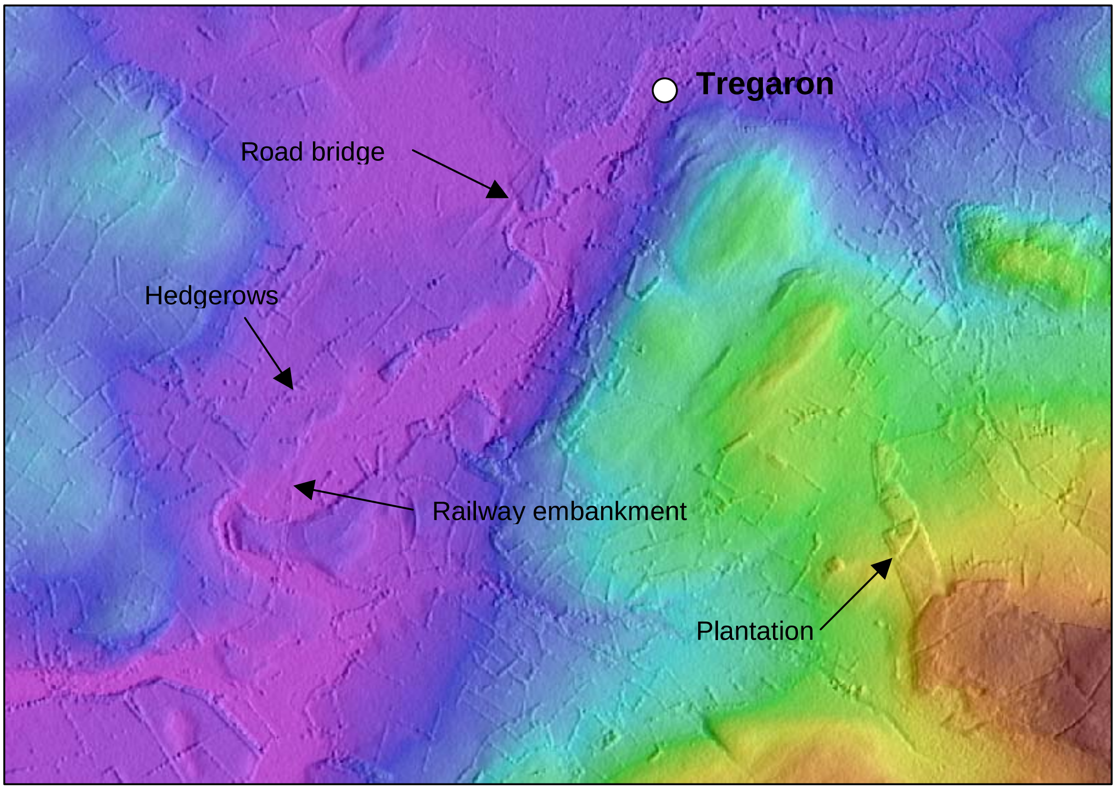

Figure 1. NEXTMap DSM model of the area around Tregaron.

Specification: DSM model coloured at 2 standard deviations using standard ArcGIS palette; overlain with stretched minimum-maximum grayscale hillshade model, vertical exaggeration of x1.0 and a cell spacing of 5.0m, lit with a sun azimuth of 90º and a sun elevation of 40º, modelled shadow and a 50% transparency. Anthropogenic elements recorded as measurements by the DSM are labelled.

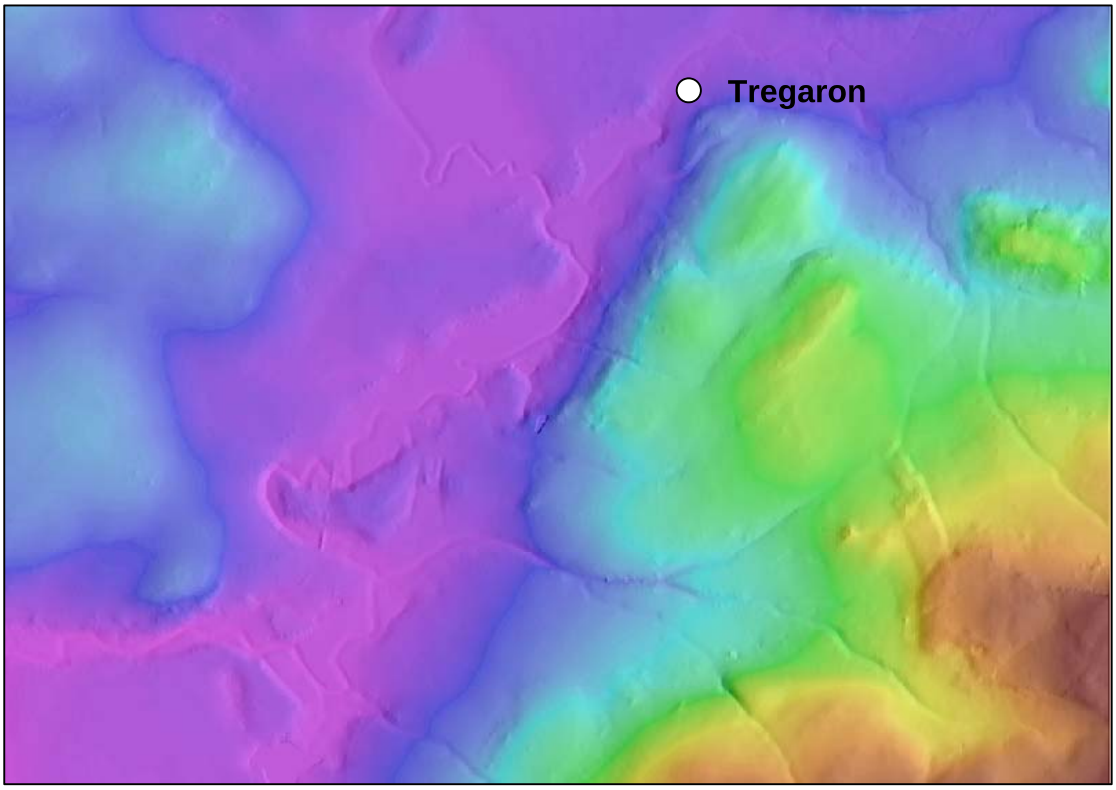

Figure 2. NEXTMap DTM model of the area around Tregaron.

Specifications as for Fig.1. Although some artefacts remain (notably those with abrupt edges, such as forestry plantations and parts of the railway embankment), much of the anthropogenic layer has been removed leaving a 'bare-earth' terrain model.

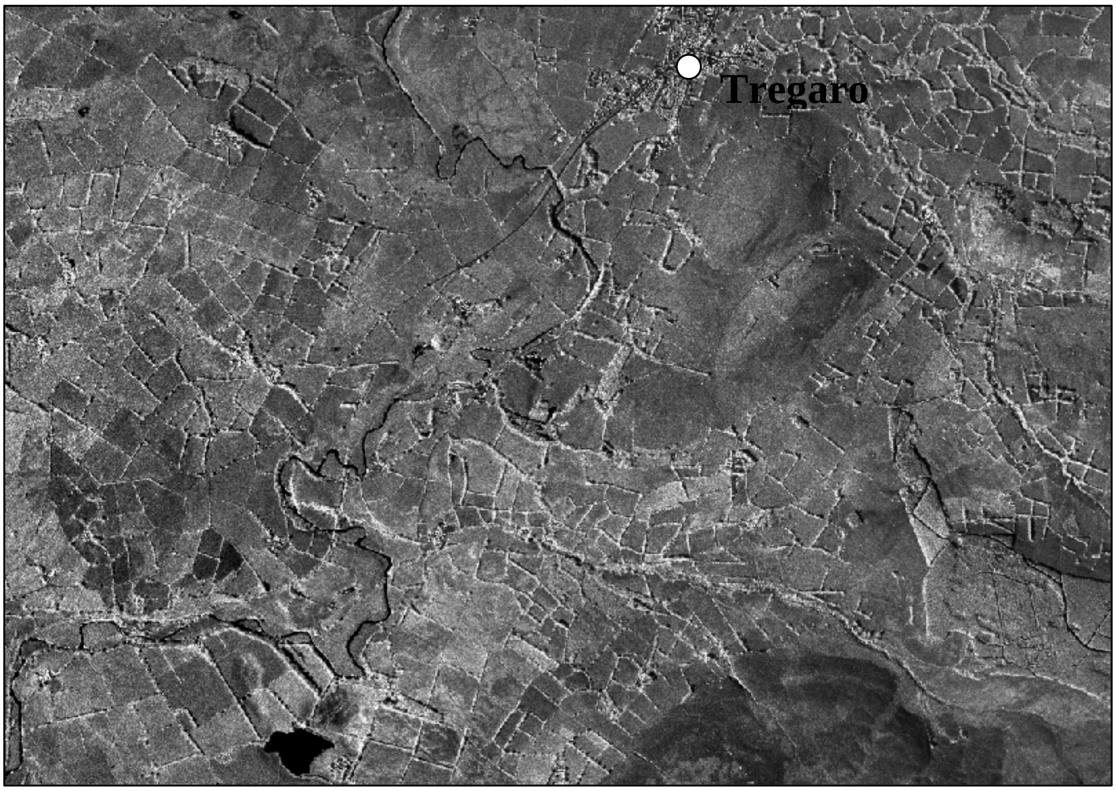

Figure 3. ORI image of the area around Tregaron.

No post-processing is applied to the image. Resolution is analogous to a 25K monochrome air photograph.

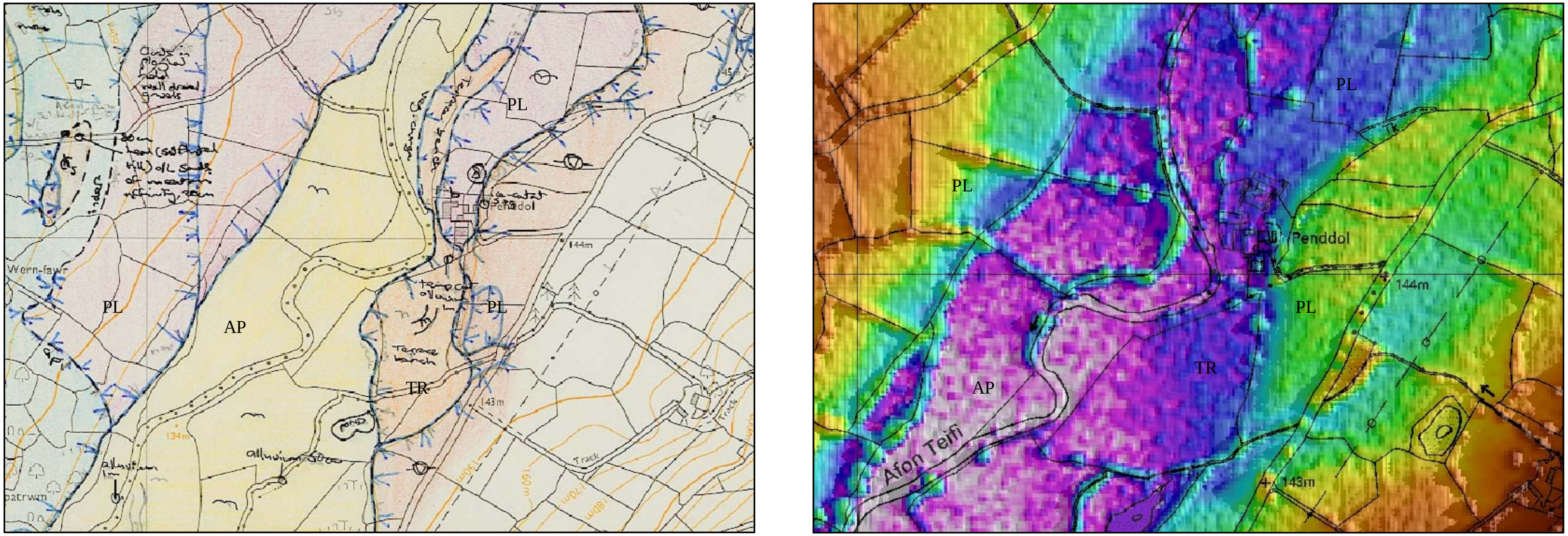

Figure 4. BGS 1:10 000 fieldslip and NEXTMap DSM coverage of the UWA coring site at Penddol Farm in the Teifi Valley.

The fieldslip represents a walkover survey. Floodplain features recorded include the wide present alluvial plain of the Afon Teifi (AP, yellow), abandoned terrace levels (TR, orange) and Pleistocene terraces confining the Holocene deposits (PL, all other units). The NEXTMap DSM image is clipped from a 25K tile in order to apply the full colour scale to a small area. The DSM model uses a histogram-equalised standard ArcGIS palette, and is overlain by a stretched grayscale hillshade with sun azimuth of 75º and sun altitude at 25º, using a x2 exaggeration, a 2m cell size wih modelled shadows and 60% transparency. An Ordnance Survey 10K topographic overlay is applied for reference. All features mapped by walkover survey can be recognised from the DSM (labelled).

The two images are for comparative purposes only and are not identically scaled.

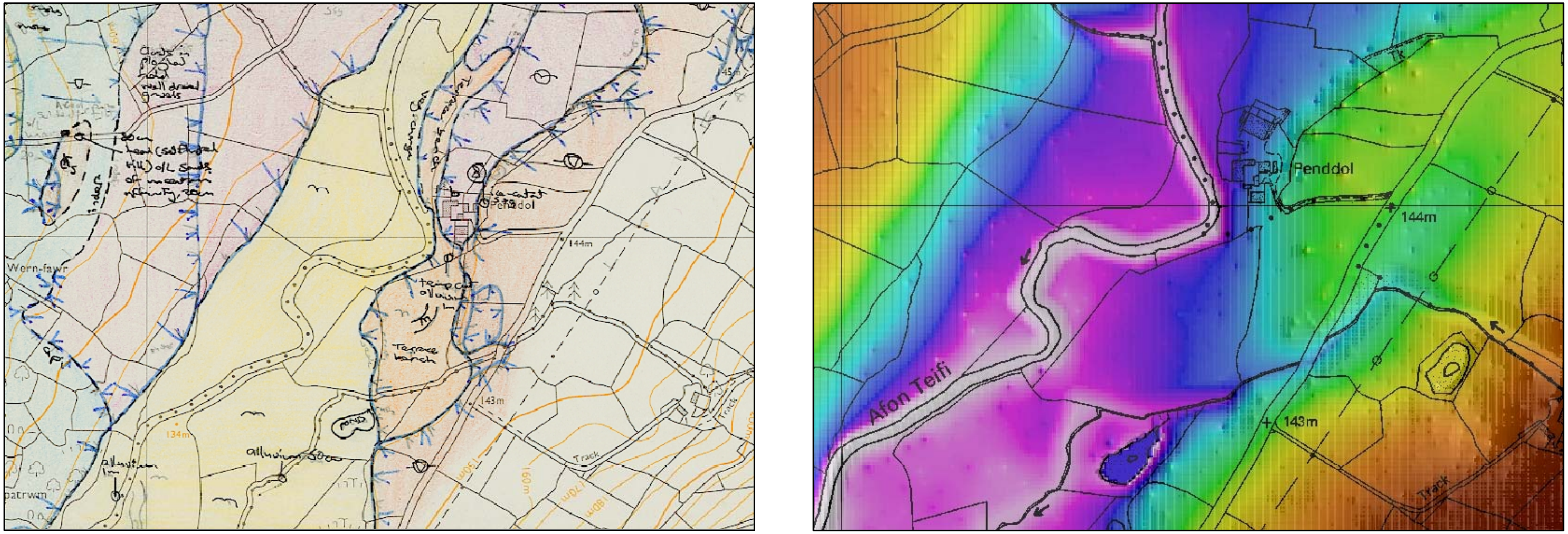

Figure 5. The Penddol site imaged using the NEXTMap 'bare-earth' DTM model.

The DTM image is prepared as for Figure 4. Although the floodplain features imaged by the DSM in Figure 4 are still recognisable, considerable definition has been lost by the algorithm-based terrain stripping used to generate the DTM.

The two images are for comparative purposes only and are not identically scaled.

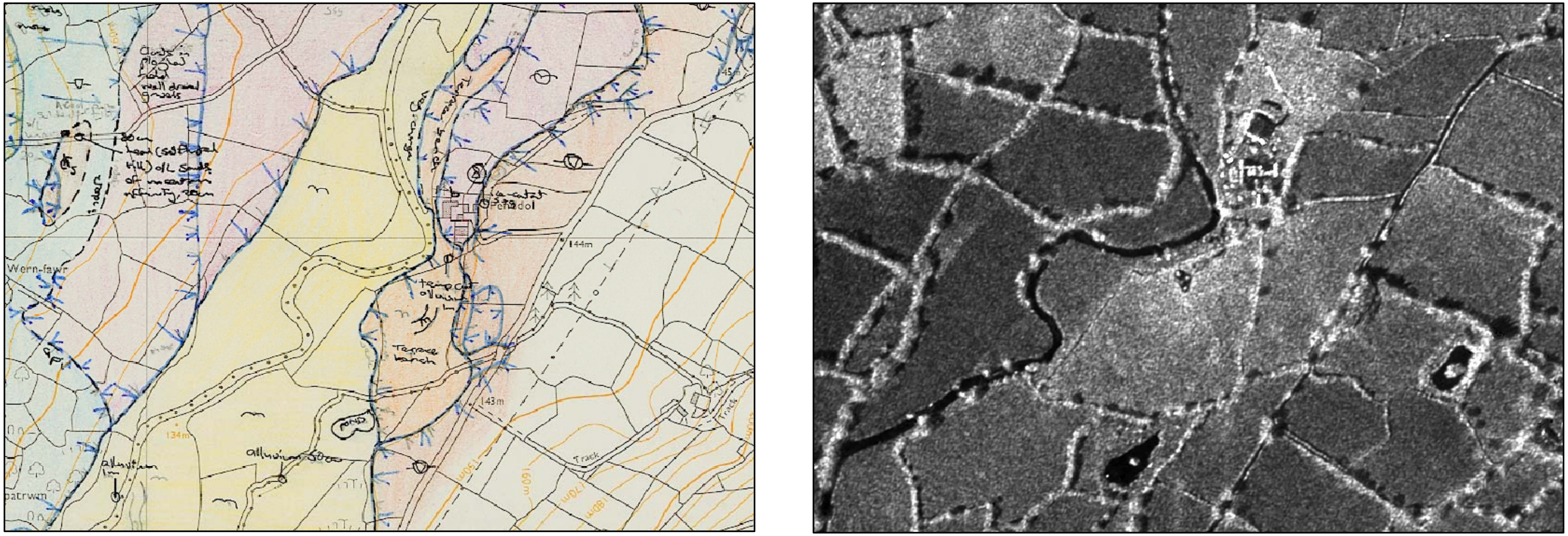

Figure 6. The Penddol site imaged using NEXTMap ORI imagery.

The ORI imagery picks out the terraced units as paler (drier) ground in the valley floor.

The two images are for comparative purposes only and are not identically scaled.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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