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Assessing riverine threats to heritage assets posed by future climate change through a geomorphological approach and predictive modelling in the Derwent Valley Mills WHS, UK



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ABSTRACT

Future climate change is likely to pose significant challenges for heritage management, especially in landscape settings, such as river valleys as the magnitude, intensity and nature of geomorphological processes alter in response to changing threshold conditions. Industrial landscapes afford particular challenges for the heritage community, not only because the location of these historic remains is often intimately linked to the physical environment, but also because these landscapes can be heavily polluted by former (industrial) processes and, if released, the legacy of contaminants trapped in floodplain soils and sediments can exacerbate erosion and denudation. Responding to these challenges requires the development of methodologies that consider landscape change beyond individual sites and monuments and this paper reports the development of such an approach based on investigation of the Derwent Valley Mills World Heritage Site, Derbyshire, UK. Information on geomorphological evolution of the Derwent Valley over the last 1000 years, a time period encompassing the last two periods of major climatic deterioration, the Medieval Warm Period and Little Ice Age, has been dovetailed with archaeological and geochemical records to assess how the landscape has evolved to past landscape change. However, in addition to assessing past evolution, this methodology uses national climate change scenarios to predict future river change using the CAESAR-Lisflood model. Comparison of the results of this model to the spatial distribution of World Heritage Site assets highlights zones on the valley floor where pro-active mitigation might be required. The geomorphological and environmental science communities have long used predictive computer modelling to help understand and manage landscapes and this paper highlights an approach and area of research cross-over that would be beneficial for future heritage management.

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1. Introduction

It is now widely acknowledged by the global scientific community that greenhouse gas emissions are causing irrevocable changes to our climate system. Whilst the precise impact of these emissions upon climate remains uncertain, it seems likely that both the frequency and intensity of severe weather events will increase, with

extremes of both temperature and rainfall commonplace. These predictions of the nature of change, based upon a combination of empirical data analysis and computer simulation, appear to be confirmed by major news reports from around the globe.

In the UK, the focus of this paper, climate change scenarios [1], provide an insightful backdrop to the major river flood events recorded at Boscastle (Devon) in summer 2004 [2], nationwide in summer 2007 [3], at Cockermouth (Cumbria) in autumn of 2009 [4] and nationwide in the autumn and winter of 2013–2014 [5–8]. Of course, weather conditions alone cannot be held responsible for the severity of these events, with physiography, antecedent conditions, landscape and current flood mitigation measures, all affecting response to individual storms. These exacerbating factors have been termed ‘risk multipliers’ [9].

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Economically, the cost of floods in the UK is substantial; for example, the summer floods of 2007 resulted in a bill of around £3 billion (<http://www.floodfreehomes.org.uk>). However, the social, environmental and political impact of flooding is equally as significant [3]. Within our communities, the Historic Environment plays a unique role in economic generation (e.g. sustainable tourism), social/cultural cohesion and well-being, and over the last decade there has been a growing awareness of the potential impact of climate change upon these assets, both in the UK [10–15,9] and globally [16–21].

Within the Northern and Western parts of the UK, some of the landscapes and heritage assets most vulnerable to climate change are those associated with the 'Industrial Revolution' (considered for the purposes of this paper, the 18th and 19th centuries). During this period of rapid industrial and economic growth, industry exploited natural resources, including coal, limestone and metal ores and used water for power; however, paradoxically, many of these advantageous physiographic and geological characteristics essential to industrial development are also environments where geomorphological processes are most sensitive to climatic change. Furthermore, many of these regions, particularly those specifically associated with historic metal mining, have a legacy of pollution now trapped in floodplain soils and sediments [22–25]. Empirical evidence has shown that the release of large volumes of fine-grained sediment and toxic contaminants during periods of increased flood frequency and magnitude caused a significant number of rivers in the Northern Pennines (North Yorkshire, County Durham and Northumberland) to transform from single to multi-channelled braided systems during the Little Ice Age [26], the last period of major climatic deterioration.

Given the scenario developed above, there is clearly a need to mitigate against the impacts of future climate change over large areas of industrialized historic landscape, but a major challenge is the development of strategies and methodological approaches that look beyond (single) heritage sites and provide an integrated approach to land management.

This paper focuses on the development of such a methodology evaluated within the Derwent Valley Mills World Heritage Site (hereafter, DVMWHS), situated along a 24 km stretch of the River Derwent, Derbyshire, UK. This novel, interdisciplinary approach utilises information on past landscape history reconstructed using a variety of archaeological, geochemical and geomorphological records, coupled with computer modelling of future river development. These results are compared against the spatial distribution of assets of the World Heritage Site and used to flag key factors of concern for heritage and environmental managers.

2. The character of the Derwent Valley Mills World Heritage Site

The River Derwent has a catchment area of around 1200 km². It originates some 9 km east of Glossop at an elevation of 590 m OD on the high moorland of the Peak District National Park and flows south, encountering the northern boundary of the DVMWHS at the downstream limit of the dramatic incised gorge at Matlock Bath (Fig. 1). The DVMWHS was inscribed in 2001 and encompasses a series of 18th and 19th century cotton mills recording the birth of the modern factory system, together with its associated infrastructure including workers housing, schools, churches and model farms [27].

For most of the length of the World Heritage Site, the River Derwent cuts through complexly folded and faulted mudstones, shales, siltstones and sandstones of Carboniferous age, although at its southern end, it cuts through mudstones, siltstones and sandstones of Permo-Triassic age. Despite being a sizeable river, it

is constrained within a relatively narrow valley floor (maximum width of 500 m), which has prevented the preservation of laterally extensive river terraces along its valley sides; instead, fragmentary remnants have been preserved.

The mills themselves required water for power and are therefore situated on the contemporary floodplain, immediately adjacent to the channel and associated with elaborate systems of weirs and sluices, which maintained a head of water (Fig. 2). In contrast, the infrastructure associated with milling (e.g. housing, schools) was situated on the higher terrace fragments, enlarging hamlets and villages to create small towns, such as Belper. As well as activity directly associated with milling, much of the surrounding landscape was owned by the industrialists and became the focus of agricultural innovation, particularly through the development of 'Model Farms' [28,29], creating an even richer supplementary legacy of post-medieval archaeological remains.

Whilst the World Heritage Site designation is associated with the textile industry, the limestone bedrock that crops out in the far north of the study area is host to a rich base-metal mining industry, principally lead and zinc in the Derwent catchment, with peak production in the 18th and early 19th centuries. An indirect consequence of mining has been the release of metal-contaminated sediments into the environment, which have been deposited across the valley floor and is stored within the alluvium [30]. The release of contaminants initially commenced during mining, but importantly, is on-going through the erosion of spoil heaps and former processing areas; these deposits are akin to the agro-industrial alluvium reported in the northern Pennines [31].

3. Methodology

To provide a tight research focus, the project area was restricted to the established boundaries of the DVMWHS core zone (1229 ha) and buffer zone (4363 ha), as defined in the site designation and inscription (<http://whc.unesco.org/en/list/1030>) (see Fig. 1). Inclusion of the buffer zone was deemed crucial to methodological development since much of this area includes abandoned mine workings and areas of slope instability, which may be influential in supplying contaminated sediments to the valley floor.

Geoarchaeological evolution of the valley floor over the last 1000 years was selected as the timescale of study, since this period includes the major climatic anomalies of the Medieval Warm Period and Little Ice Age. To elucidate geomorphological development of the valley floor, landform assemblages (river terraces, palaeochannels, ridge and swale topography) were identified and mapped from aerial photographs and lidar with additional information provided by historic maps and published literature. Information on the geochemical and contamination history of the region was collated from mine records, published literature, unpublished doctoral theses and the holdings of the British Geological Survey. Historic Environment Records (HER) for the medieval, post-medieval and modern periods provided information on the location and interpretation of heritage assets, although the analysis of lidar mapping identified a number of additional archaeological features unrecorded by the HER. Further information on each data source is provided in Table 1 as well as in the full project report [32]. The capture of all of these data within the project GIS (QGIS version 2.6 Brighton) allowed landscape evolution to be compared with the location of heritage assets to assess the hazards posed to these remains based on historic natural processes.

However, as well as understanding the past and contemporary landscape, a key aim of the methodological approach was to assess how the River Derwent might respond to future climate change and how these changes might impact on historic assets of the World Heritage Site. In geomorphology, the application of computer

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