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The Kassandra Project Vindolanda Pilot Study

A Report from the Hadrian's Wall Climate Change & UNESCO Heritage Project

Hadrian's Wall Partnership Board
Atha Heritage Services (AHS)
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Cover Image: Aerial View of Roman Vindolanda Fort at Hadrian's Wall in Northumberland. Credit: Uwe

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1. Introduction

During the UKNC-DCMS £1.8 million funded Climate Change and UNESCO Heritage (CCUH) project (UNESCO 2025), the Newcastle University Hadrian's Wall Pilot team interviewed staff with responsibilities for climate change monitoring and response from all key partner organisations involved in the management of cultural and natural heritage across the corridor of the WHS. Although climate change threats and the need for impact mitigation strategies were widely acknowledged by partners in these interviews, the Vindolanda Trust was unusual in having installed continuous monitoring stations to better understand the challenges they faced.

At the World Heritage UK Spring Workshop (WHUK 2025) in London, the writer described how weather and environmental data gathered at Vindolanda Roman Fort were revealing a climate change regime of longer-term drought and more frequent extreme rainfall events. That combination, it was explained, is progressively impacting buried archaeological deposits by destabilising the anaerobic conditions responsible for the exceptional preservation of organic remains for which the site is best known[1].

Importantly, the findings at Vindolanda are challenging deeply held archaeological beliefs in such fundamental concepts as 'preservation in situ' and 'buried equals safe'. Should such climate change impacts be more widely evidenced, it would herald a seismic paradigm shift for the discipline in terms of the management of the buried archaeological resource.

Attending the WHUK gathering was Mark Cannata, co-founder and co-CEO of Kassandra Srl, the creators of a unique Integrated Decision Support System (IDSS) powered by generative AI, which is designed to improve climate change decision-making for managers of heritage sites. Central to the approach is the application of a series of 12 multi-disciplinary parameters to a digital twin model of the study site, which produces current resilience scores for the various elements comprising the site, and facilitates modelling of scenarios exploring how future climate change might impact resilience but be mitigated and managed by the use of 'Dynamic Adaptive Policy Pathways'.

The Kassandra methodology had already been successfully used at several major heritage sites (Kassandra Srl, nd), such UNESCO WHSs at Ironbridge Gorge in England and Modica in Sicily, and the National Trust's Mount Stewart house and gardens in Northern Ireland.

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[1] Vindolanda is most famous for its collection of Roman writing tablets but has also yielded the largest collection of leather shoes in the Roman world, as well as textiles, and artefacts of wood and bone.

While Hadrian's Wall is epitomised by the famous linear boundary, within the WHS buffer zone there are also many important military sites and associated settlements, such as the well-preserved, but increasingly threatened, archaeological site of Vindolanda. The Vindolanda Trust had also recently installed sub-surface environmental monitoring sensors, providing millions of datapoints underpinning potential below-ground analysis. As such, Vindolanda seemed an ideal candidate for the application of the Kassandra methodology, and the Kassandra team agreed with colleagues at the UNESCO UK National Commission and Vindolanda Trust to collaborate on an archaeological pilot focused on the site. The writer was invited on behalf of Newcastle University (NU) to facilitate liaison between Kassandra, the Vindolanda Trust (henceforward "the Trust"), and other partners involved in the management of Hadrian's Wall.

This report provides a reflective account of the Vindolanda Pilot undertaken by Kassandra in collaboration with the Trust. It begins with an overview of the work involved in supporting Kassandra's analyses and the datasets and other contributions their work required. It then reflects on the experience of collaborating with Kassandra in terms of the ease of communication and liaison, and how efficient and effective the process was in bringing the Vindolanda Pilot to a satisfactory conclusion. Most importantly, the utility of the modelling produced is evaluated, not only in terms of its implications for the future management of Vindolanda, but also of Hadrian's Wall and other UNESCO designations in the care of the UK National Commission.

2. Climate change context at Vindolanda

Given its history of sustained archaeological investigation and scientific research, exceptional preservation of organic remains, and ongoing environmental monitoring, Vindolanda was ideally suited to the piloting of Kassandra's IDSS modelling. Prior to the pilot, the work of the Trust was already demonstrating how a climate change regime of longer-term drought, punctuated by a more regular occurrence of what were once considered 'extreme' rainfall events, was resulting in the destabilisation of anaerobic deposits and rapid deterioration of the precious organic materials, such as leather shoes (see Figs.1 & 2), they contain (Guiney et al. 2021; Birley & O'Meara 2022; Taylor et al. 2025).

Figure 1 (above): Exceptional anaerobic preservation of organic materials in lower strata at Vindolanda.

Figure 2 (left): Decline in condition of leather shoes found in 2017 (left) and 2023 (right) in a Roman horizon dating to AD 105-118.

Both images © Vindolanda Trust, used with permission.

The ‘new normal’ of repeated torrential rainfall events and increasing storminess was also a major concern in terms of a growing risk of structural damage, flooding, erosion and landslips for the archaeological site, visitor infrastructure, the museum and collections, café, and other buildings used as meeting spaces and offices by the Trust. Other climate change effects were envisaged such as

the impact on visitors and the Trust's facilities of a warming climate punctuated by more frequent heatwave events.

3. Facilitating Kassandra's Vindolanda Pilot Study

Following their introduction by the UNESCO UK National Commission's Head of Policy, Research and Communications, the Kassandra and Newcastle University Hadrian's Wall teams met online and agreed that a Kassandra pilot study at a site on Hadrian's Wall would be of interest. Vindolanda was identified as an ideal choice for the case study due to the amount of digital-born data available, and the Trust's operational scale, providing the organisational flexibility to work within the time constraints of all the partner organisations. During an initial online meeting between the Kassandra, NU and Vindolanda teams, the Kassandra team introduced their methodology, and the Trust outlined its primary concerns and priorities for the archaeological site. The meeting resulted in a commitment by all parties present to move forward with the Kassandra-Vindolanda Pilot.

In consultation with the Trust, representatives of many of the organisations involved in the management of Hadrian's Wall via the Partnership Board were invited to join the Pilot Team, as well as several members of the Vindolanda Board of Trustees.

The Pilot Team held a launch meeting at Vindolanda in August 2025, which was attended by the two Co-CEOs of Kassandra, who explained their IDSS and methodology, and ran an online survey to capture some baseline data from all Hadrian's Wall attendees in response to a series of questions on perceptions of climate change risks and priorities for the WHS. On the second day of the Kassandra team's visit, they explored Vindolanda and gathered additional geospatial data for the digital twin using a UAV to survey the site.

Over the following month, the Kassandra team identified and collated data suitable for their modelling, including various site-specific deposit and environmental datasets provided by the Vindolanda team (see Table 1 below for a selection of data used).

Table 1: Selected data types used in the Kassandra-Vindolanda modelling.

Data Type	Provider / Data Source	Comments
LiDAR Digital Terrain Model	Environment Agency	1m Resolution; UKGov. Open Source
Hydrology Flooding	Environment Agency	Risk of Flooding from Surface & Ground Water & Rivers; UKGov. Open Source
Weather	Weatherspark.com	Temp.; Humidity; Wind Speed; Rainfall; Cloud Cover; Snowfall; Open Source
UK Climate Projections	Met Office	UK Climate Projections User Interface; RCP 8.5 / UKCP18; Open Source

General Ground Conditions	British Geological Survey	Soil Heave & Landslip; BGS GeoClimate UKCP18 Open; Open Source
Site Burial Env. Monitoring	Vindolanda Trust Fixed On-site Sensors	Continuous Data Logging: Soil Moisture, pH, Temperature, Oxygen, Groundwater Levels.
Visitor Nos.	Vindolanda Trust	Monthly & Annual Data Via Paid Entries.

4. Creating the Digital Twin & Modelling Climate Change Scenarios

At the second Pilot Team meeting in September 2025, the Kassandra team presented the draft digital twin model of the Vindolanda site within a 1km^2 core study area, together with a larger 5km^2 block of landscape for lower resolution modelling of the site's hinterland, which extended northwards up to the watershed along the Whin Sill and Hadrian's Wall. An overview of the use of climate change scenarios in the IDSS was also presented to the Pilot Team.

During the month preceding the third meeting in October 2025, further data were supplied to Kassandra by the Trust, including geophysical survey results and site 3D models, which were then incorporated within more detailed analyses.

At the third Pilot Team meeting, the Kassandra team gave a more in-depth presentation focused on resilience modelling, using a site resilience score under present conditions as the baseline for analyses. A detailed assessment of the impacts on resilience of seven different climate change scenarios was then presented for the Vindolanda site.

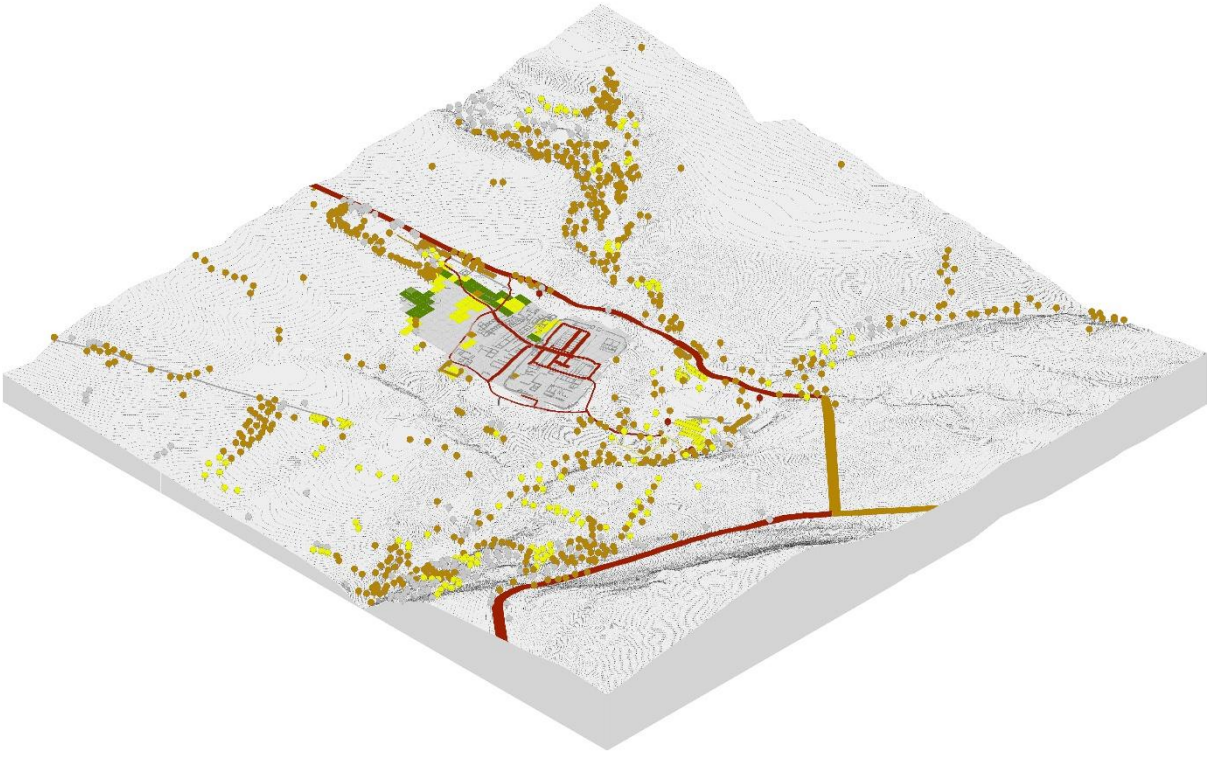

Figure 3: Kassandra's digital twin model of the Vindolanda site in its landscape setting, showing climate resilience grid (darker grey 2m grid over fort and civilian settlement site) and resilience scores for archaeological deposits, site infrastructure, facilities and natural resources (e.g. trees). Resilience Index scores from 0-100 (low-high): 0-25 (red), 25-50 (orange), 50-75 (yellow) and 75-100 (green). (Image © Kassandra Srl, used with permission).

Thereafter, with the goal of strengthening the basis for Kassandra's analyses, a range of supplementary datasets were supplied, some by the Trust and others, such as the Environment Agency flood data, via the writer.

The fourth and final Pilot Team meeting, at which Kassandra presented their more fully developed models of climate change scenarios and adaptive responses to maintain site resilience, took place in late January 2026. Also presented at the meeting was the newly created Kassandra for Archaeology (KfA) platform, which was shared with delegates in beta form for their testing. The Kassandra team requested feedback on both the detailed scenarios presented and the KfA platform.

In mid-February 2026, the Draft Kassandra-Vindolanda Pilot Report was circulated for review, and comments were provided to Kassandra by the NU team and colleagues at the Trust. The report was then finalised and published (Kassandra 2026), and the Pilot's results were presented in person by the Kassandra team to the members of the Hadrian's Wall Partnership Board at the meeting in Hexham on Friday 20th March 2026.

5. Reflections on the Pilot Experience

Overall, the positive experience of developing the Pilot generated significant confidence in Kassandra as a highly professional and competent organisation, easy to work with and thorough in the application of their methods.

The sequence of events comprising the collection of the necessary data, building the digital twin, developing the scenarios, and adaptive policy pathway plans was very clearly explained and presented at each stage by the Kassandra team, making the entire process logical and understandable for all members of the Pilot Team.

For both technical and commercial reasons, one aspect of the Pilot that may have to remain an 'acceptable unknown' for the Trust and other Hadrian's Wall partners, is the process by which generative AI produces the resilience scores central to the IDSS. While the underlying code and algorithms cannot be shared, there is a very intuitive and easily accessible interface that allows users to drill down into the detail of the relational database to enter data and alter settings to test and adjust the models. The high resolution of this modelling became

apparent when examining the KfA platform, which potentially accommodates more detailed variation within models at scales finer than $1m^2$.

Perhaps the ultimate measure of success was the belief and confidence shown by the Trust's senior management team and trustees in the findings of the Kassandra Pilot, which offered them genuinely new insights and provided a greater basis for confidence in planning for change in the decades to come.

6. Assessing the Utility of Kassandra for Hadrian's Wall & UNESCO UK

Hadrian's Wall is a huge, geographically diverse, and complex WHS with many constituent parts, of which the site of Vindolanda Roman Fort is just one. Within the WHS boundary are around twenty major Roman sites located in a diversity of landscape settings, which can be broadly grouped into those located at the coast, in urban centres, in rural river valleys, and in the grazing land of the central uplands. Heritage assets in the WHS comprise not only the visible and buried archaeological remains pertaining to the Hadrian's Wall monument but also include multiple standing buildings that serve as museums and visitor centres, as well as archives and collections containing many thousands of artefacts and documents. The modelling can address direct and indirect impacts on these assets, including buildings where archives and collections are held.

Recent research conducted by the writer and NU colleagues during the Climate Change and UNESCO Heritage (CCUH) project, Hadrian's Wall Pilot, backed up by further insights gained during the recent Kassandra study, suggests that the threats identified at Vindolanda are likely to be affecting other sites across the Wall. Moreover, a range of *different* threats have also been identified at sites in contrasting landscape settings, including: marine flooding and erosion on the Cumbrian coast (e.g., Beckfoot & Bowness-on-Solway); fluvial flooding, erosion and landslips at river valley sites (e.g., Birdoswald & Chesters); and soil heave and erosion at sites in the drought-affected uplands (e.g., Carvoran).

Until recently, the identification of climate change threats and attempted management and mitigation of impacts have occurred largely as reactive, site-specific activities, as a facet of crisis management, rather than being addressed through a more coordinated, proactive and WHS-wide strategic approach. That said, although the ongoing environmental-weather monitoring and data gathering being done by the Trust at Vindolanda and Carvoran is atypical of the situation at archaeological sites across the Wall; English Heritage and the National Trust, for example, are both actively attempting to better understand and manage the climate related challenges they face. In the case of the National

Trust, adaptive pathway planning and the use of critical trigger points are now being widely used in the climate change management strategies for their properties.

In parallel with this reflective report, the NU team has also prepared a Business Case (Atha & Collins 2026) assessing the possibilities for rolling out the Kassandra modelling across the WHS, focused on a priority 'longlist' of 12 major sites spanning the breadth of the WHS. In parallel with the detailed modelling of a shortlist selected from the 12, we would argue that there is also a strong case for attempting a lower resolution Kassandra assessment of the entire corridor of the WHS. That broader study could use a combination of open-source climate and environmental data, together with Wall specific data accessible through the Hadrian's Wall Partnership Board and its Working Groups.

The CCUHP was a logical development of the preceding Sites for Sustainable Development study (UNESCO 2022) and further developed the notion of using UNESCO properties as laboratories for exploring the management of climate change impacts and developing adaptive strategies to support more resilient landscapes and communities. Kassandra's multi-parameter landscape scale analyses integrating, amongst other things, heritage, environmental, community and economic considerations in their resilience modelling, are arguably a logical extension of that earlier work.

Given its scale and complexity, Hadrian's Wall is uniquely well placed to serve as a 'landscape laboratory' within which Kassandra can be more thoroughly tested and evaluated. Kassandra's IDSS could be similarly beneficially deployed at other landscape-scale UNESCO properties, such as the other two CCUHP pilot sites of North Devon Biosphere Reserve and Fforest Fawr Global Geopark. Both would benefit from larger-scale lower resolution Kassandra modelling of the entire properties, coupled with detailed studies of smaller areas warranting finer resolution study and/or facing more specific climate-related threats. A similar approach might also be beneficial at other landscape-scale properties such as Blaenavon, Stonehenge and the Heart of Prehistoric Orkney WHSs.

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Online Sources

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