MONITORING IMPACTS of CLIMATE CHANGE
on
BUILT HERITAGE

Report of the ICOMOS Ireland Climate Change Sub-Committee

January 2010

International Council on Monuments and Sites
Conseil International des Monuments et des Sites

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Abbreviations

DoEHLG	Department of the Environment Heritage and Local Government
EPA	Environmental Protection Agency
EU	European Union
ICOMOS	International Council on Monuments and Sites
IPCC	Irish Peatland Conservation Council
ME	Met Eireann
NBDC	National Biodiversity Data Centre
NUI	National University of Ireland Maynooth
OPW	Office of Public Works

1. BACKGROUND

International research relating to the measurement and monitoring of the effects of climate change on the built heritage is in its infancy and mainly deals with theoretical rather than practical perspectives. The ICOMOS Ireland climate change sub-committee was convened in the summer of 2008, its stated aim was to *research the effects of Climate Change on the Built Heritage and in particular our World Heritage Sites*. Following discussions with the Department of Environment Heritage and Local Government (DoEHLG) on the terms of reference and scoping of the research the DoEHLG requested ICOMOS to provide recommendations on monitoring solutions for impacts of climate change on built cultural heritage. The department provided ICOMOS Ireland with financial assistance to enable research on two specific sites of World Heritage/proposed World Heritage standard; Brú na Bóinne and Clonmacnoise. The following is a report of the findings of the ICOMOS sub-committee, focusing on its recommendations for monitoring possible climate change affects on the two sites.

The ICOMOS Ireland sub-committee on climate change is convened by Peter Cox and its members are Cathy Daly, Ann Cuffe Fitzgerald, Brandy Dubs and Dr. Tracy Pickerill.

The author of this report is Cathy Daly.

1.1 Introduction

Climate change predictions for Ireland over the coming century suggest we will experience warmer, wetter winters and warmer, drier summers.[1] There will be some regional variations however, and these will be observable at the case study sites (Table1).

Modeling the impacts of global climate change on Europe's built heritage has been conducted by the EU funded Noah's Ark project. The resultant publication of a vulnerability atlas for built heritage in Europe theoretically maps how climate change effects will develop over the next century.[2] Research on climate change in Ireland has not dealt specifically with built heritage to date but much of the work has nonetheless proved useful in assessing possible impacts on cultural landscapes.[3]

[1] Sweeney 2003
[2] Sabbioni et al 2010
[3] In particular a series of reports produced for the EPA by Prof. Sweeney at NUI Maynooth.

Table 1. Summary of climatic changes predicted by 2099 using ICARUS ensemble data for Dublin Airport & Birr (A2 emissions scenario)[4]

	Average Temperature	Average Summer Rainfall (July)	Average Winter Rainfall (December)	Intensity of Rainfall	Wind Gusts (frequency and intensity)
Clonmacnoise	↑ 2ºC	↓ 24% (12mm)	↑ 19% (15mm)	↑ 23% (days >5mm)	↑ (not modelled)
Brú na Bóinne	↑ 2ºC	↓ 30% (14mm)	↑ 24% (19.5mm)	↑ 15% (days >5mm)	↑ (not modelled)

The impacts of predicted climate change will be both direct, such as flooding and erosion, and indirect, such as changes in agricultural practices. The interactions involved are complex and often depend on more than one climatic parameter (figure 1). The monitoring scheme being proposed by ICOMOS will form a legacy for the future, producing quantifiable data over the coming century, which is vital in the assessment of climate change impacts on cultural heritage. In turn this will facilitate the development of appropriate and sustainable management practices for climate change impact mitigation and adaptation at these and other heritage sites in Ireland. The establishment of a pilot monitoring scheme will also be a substantial contribution to knowledge, placing Ireland at the fore-front of research in this area.

2. SITE EVALUATIONS

2.1 Brú na Bóinne

2.1.1 Description

Brú na Bóinne is one of two World Heritage sites in the Republic of Ireland. It is located in the north-east, 9km from the coast at Drogheda. The core and buffer zone cover approximately 3,300 hectares encompassing 93 recorded monuments protected under national heritage legislation. Characterised by the bend in the River Boyne where it encounters a hard shale ridge the area also includes several wetland habitats and rare

[4] Fealy 2007

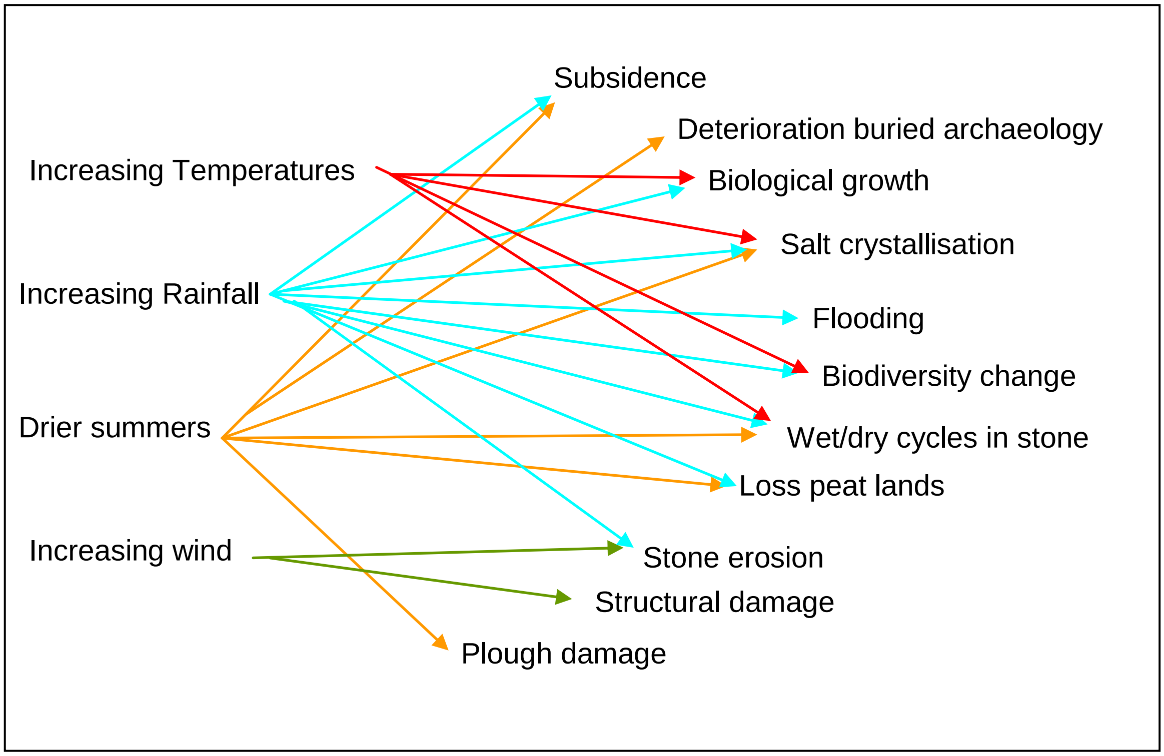
Plate 1: Location of Brú na Bóinne and Clonmacnoise

Brú na Bóinne ▲

Clonmacnoise ▲

species protected under both EU and national legislation.[5]

Figure 1. Multiple Interactions: Climate change factors and impacts



There are 31 known Megalithic passage graves at Brú na Bóinne, dating to the time around 3,000 BCE. Many of the large stones used to construct the passage, chamber, and placed around the exterior of the mound are carved with designs. The majority of the stone used by Neolithic builders is greywacke or green grit, a Palaeozoic sandstone. There are 400 known pieces of rock art from Brú na Bóinne and when this is compared to only 200 from all similar sites in Western France the importance of the site for Megalithic art is clear.[6] The cultural landscape of the site spans the history of human habitation of Ireland, from Neolithic flint scatters to World War II defenses[7]. Some of the most significant elements include the Battle of the Boyne site and Ireland's earliest inland canal system.

[5] Protected sites include Natural Heritage Areas under Wildlife Amendment Act 2000 and Special Areas of Conservation under Annex I (habitats) & Annex II (species) of the EU Habitats Directive 1992.

[6] Eogan 1986.

[7] Dúchas The Heritage Service 2002

2.1.2 Values

In 1993 ICOMOS recommended the Archaeological ensemble of the Bend of the Boyne for World Heritage listing under three of UNESCO's criteria for Outstanding Universal Value (OUV):[8]

Criteria i: As a *masterpiece of human creative genius* for the **Megalithic rock art** collection.

Criteria ii: Because it *exhibits an important interchange of human values over a span of time.* In particular the archaeological and extant remains that indicate continuity of settlement from the Neolithic to Late Medieval period, in modern terms the **Cultural Landscape**.

Criteria iv: As an *outstanding example…which illustrates a significant stage in human history* for the **Megalithic passage grave assemblage**.

2.1.3 Vulnerability Modeling

The Vulnerability model (Table 2) will produce values for each heritage value to those impacts hypothesised to be most pertinent.

Table 2. Vulnerability Model

Climatic Factor	Sector or W. H. Value	Impact	Indicator	Sensitivity	Exposure	Adaptive Capacity	Measure of Vulnerability
Increased rainfall (winter)	Cultural Landscape	Flooding	XY[9]	1 - 3	1 - 3	1 - 3	Calculated as per below equation

Source: Daly 2009

The data inputted into the table is based on information gathered from research and stakeholder interviews. Values are assigned for sensitivity, exposure and adaptive capacity on a sliding scale of 1-3.[10] This is done in the case of each heritage value to every predicted climate change impact that may be relevant. The measure of vulnerability can then be calculated using the formula:

[8] ICOMOS 1993

[9] XY represents any indicator i.e. any quantifiable variable that can be used as proxy for assessing sensitivity, exposure or adaptive capacity, Schroter et al 2005.

[10] Based on Vulnerability Assessment methodology developed by Schroter et al 2005

Vulnerability = (Sensitivity + Exposure) – Adaptive Capacity

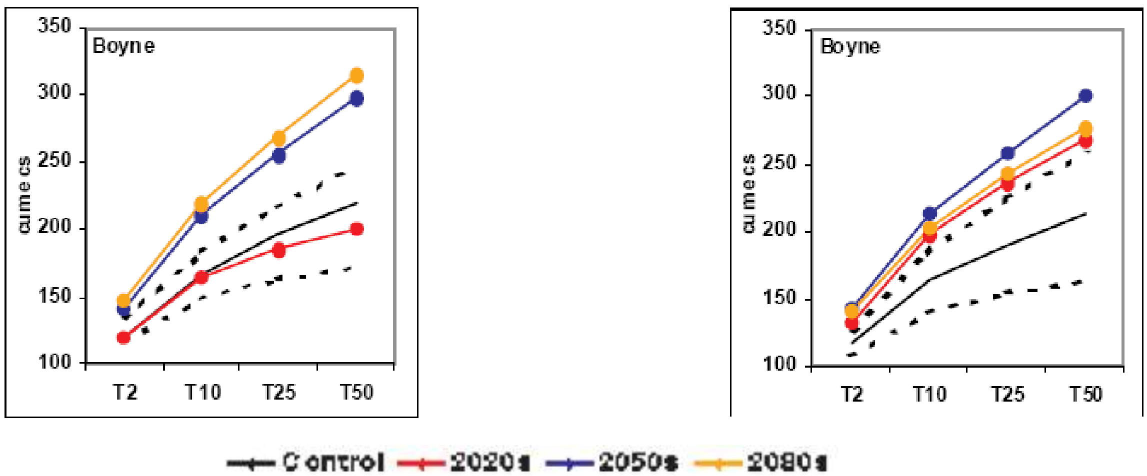
Where quantifiable indicators are available these help to establish values. In many cases suitable indicators are not available and stakeholder feedback is used as a means to verify results produced by the model.[11] The preliminary vulnerability assessment for Brú na Bóinne (Appendix 1) identifies areas which are expected to be most affected by climate change and are a priority for monitoring (Table 3). The time scale adopted is the one used by the ICARUS climate change model i.e. to the end of this century.

Plate 2. View of cultural landscape at Brú na Bóinne (photo C. Daly 2008)

[11] Daly 2009

Figure 2. Changes in the magnitude of selected Boyne flood events for each future time period under the A2/B2 emissions scenarios = doubling by end century

A1 scenario B2 scenario



Source: Sweeney et al 2008

Table 3. Key Impacts Brú na Bóinne to 2099.

OUV:	*Rock Art*	*Megalithic Monuments*	*Cultural Landscape*
Impacts for which Vulnerability is High	• Wet-dry cycles • Salt crystallisation	• Flooding	• Flooding • Changes to biodiversity • Plough damage
Impacts for which Vulnerability is Medium	• Biological growth	• Collapse (saturation)	• Reduction in water levels

Source Daly 2009

2.2 Clonmacnoise

2.2.1 Description

The Monastic City of Clonmacnoise Co. Offaly and its Cultural Landscape is a candidate World Heritage Site. The proposed World Heritage property has a core zone of 2,903 hectares and a further 7,443 hectares in the buffer zone. The site is located in the centre of Ireland at an ancient crossroads. This was the meeting of the North-South routeway of the Shannon and the East-West tracks that follow raised glacial eskers (still used today for roads) through the bogland. The bogs and fens of this semi-natural landscape are important habitats for many rare and endangered species of flora and fauna and several areas are protected under EU and National legislation.[12]

Plate 3. View of Monastic enclosure at Clonmacnoise (photo C Daly 2009)

The relict monastic city of Clonmacnoise is a well preserved example of a medieval monastic civitas including several important early building types. The structures are built from a combination of limestone, sourced locally at the Rocks of Clorhane, and sandstone. The site declined after the twelfth century and the archaeological remains are therefore largely undisturbed and offer important evidence for pre-Viking proto-urban settlement in Ireland. The collection of cross slabs, which is the largest in Europe, and the carved stone crosses demonstrate that Clonmacnoise was an artistic centre during the period of Europe's Dark Age.

[12] Similarly to Brú na Bóinne the site contains protected Natural Heritage Areas and Special Areas of Conservation in addition to Special Protection Areas (EU Habitats Directive 1992).

2.2.2 Values

The 2009 DoEHLG draft Management Plan proposes the site for World Heritage listing under two of UNESCO's criteria for Outstanding Universal Value (OUV):

Criteria iv: As an *outstanding example…which illustrates a significant stage in human history* i.e. Early Medieval monastic city, for the **architectural ensemble**.

Criteria v: As an *outstanding example of traditional human settlement, land use…representative of…human interaction with the environment* for the **cultural landscape.**

2.2.3 Vulnerability Modeling

The Vulnerability model (Appendix 2), produced in the same manner as that for Brú na Bóinne, calculated vulnerability for each heritage value to those impacts hypothesised to be most pertinent. The preliminary assessment identified areas which are expected to be most affected by climate change and are a priority for monitoring (Table 4).

Table 4. Key Impacts Clonmacnoise to 2099.

OUV:	***Architectural ensemble***	***Cultural Landscape***
Impacts for which Vulnerability is High	• Flooding • Biological growth • Mechanical weathering • Wet/dry cycling	• Flooding • Changes to biodiversity • Decomposition of peatlands
Impacts for which Vulnerability is Medium	• Salt crystallisation • Clean rain dissolution	• Subsidence • Erosion

Source: Daly 2009

3. RECOMMENDATIONS

Two types of monitors required:

1. Climate Monitoring – recording detailed information on the local climate

2. Impact Monitoring – recording the effects of climate as manifested at each site

Relating the two sets of data will enable quantification of climate change effects. A standard set of climate monitors should be installed at both sites (see below). Recommendations for *site specific impact monitors* based on the results of the vulnerability analyses have been made in Table 5. These vary slightly between the two sites due to variations in their identified vulnerabilities. All monitoring solutions must be capable of continued operation until 2099. The final selection of monitors, their placement on site and the protocols for data management all require Office of Public Works (OPW) and Department of the Environment, Heritage and Local Government (DoEHLG) staff involvement. (Note installation of the equipment and any associated cabling may require Ministerial Consent under the National Monuments Acts)

3.1 Climate Monitoring

On site climate recording is recommended to include rainfall, relative humidity, temperature, wind (speed & direction) and solar radiation. When climate sensors are chosen, it is vital that the standards of accuracy and format set out by Met Éireann (see below) are observed. These standards are internationally recognised and will allow comparison with other data sets making the results of the study of wider scientific value.[13] In addition it was agreed with Met Éireann that climatic data that meets these standards could be sent to them for quality control and archiving, ensuring it is widely available over the long term.[14]

Met Éireann have expressed their interest in the possibility of establishing a synoptic[15] station at Brú na Bóinne if the DoEHLG could fund the initial cost (€ 25,000) and if

[13] For more see World Meteorology Organisation measuring standards 2008.

[14] David Fitzgerald & Seamus Walsh Met Éireann personal communication

[15] Synoptic stations *record meteorological elements on an hourly basis, such as air temperature, rainfall, humidity, vapour pressure, wind speed, wind direction and atmospheric pressure. Some have extra elements such as soil temperatures, weather, cloud, visibility and sunshine.*

permanent planning permission were secured. The running costs and data management would subsequently be covered by Met Éireann. For Clonmacnoise it was felt by Met Éireann[16] that the nearby station of Gurteen served to cover the region and it would therefore not be sustainable for them to place a station on site. Commercial alternatives are available in the form of automatic weather stations; Campbell Scientific and Vaisala are two reputable companies which supply in Ireland.[17]

3.1.1 Met Éireann Sensors for Brú na Bóinne[18]

The possible installation of a Met Éireann Tucson synoptic station at Brú na Bóinne is dependent on planning permission. Synoptic stations include a wind mast (measures speed and direction) two rain gauges, relative humidity and temperature sensors, global radiation sensors and earth and soil temperature sensors. The wind mast is 10m high and requires 20:1 ratio between height of mast and surrounding area (i.e. nothing within 200m that can obscure wind) and a 1m^3 approx. reinforced concrete foundation plinth. The station requires a 10x10m fenced area and power cables.

The following list details specifications for Met Éireann sensors:[19]

Wind Measurements

Type: Vector A100L Low Power anemometer. (+/- 2 knots)
Vector W200P Potentiometer windvane. (Degrees +/- 5)

Sampling interval every 0.25 seconds, wind direction discontinuity calculated using tan^-1 of vector co-ordinates.

Temperature measurements

Type: 8 mm PRT (DIN 1/10) (+/- 0.1 º C) with a time constant of approximately 35 seconds

Sampling interval every 15 seconds.

Averaging a one minute average of a running average of 12 raw values.

Humidity Measurements:

Estimated daily evaporation, potential evapotranspiration and soil moisture deficits are also available (www.met.ie).

16 David Fitzgerald & Seamus Walsh Met Éireann personal communication.
17 As above
18 David Fitzgerald Met Éireann personal communication.
19 As above

Type: Vaisala HMP45D capacitive sensor. (+/-2 %)

Vaisala HPM234 Heated dew point sensor. (+/-2 %)

Sampling interval : 15 seconds.

Averaging a one minute average of 4 raw values

Rain measurement

Type: Castella tipping rain gauge, 0.1 mm and 0.2 mm (+/- 0.1 mm) **Sampling Interval**: As the gauge tips during a 0.25 second interval

Solar Radiation:

Type: 2 x Kipp&Zonen CM6 (J/M^2) sensors are calibrated against a standard. **Sampling interval:** 5 second

3.1.2 Commercial Alternatives

The purchase of a commercial weather station is required for Clonmacnoise and may also be considered as a more cost effective solution for Brú na Bóinne. There are readily available automatic climate stations, ICOMOS has obtained quotes from Campbell Scientific and has also made contact with the Vaisala representative in Ireland. Met Éireann have offered to provide advice prior to any purchase to ensure the sensors are appropriate. Quality commercial automatic stations include all the parameters outlined and can also achieve the accuracy levels required.

Rainfall: In addition to standard volume measurements there are commercially available monitors which measure duration and intensity. While this is felt to be a desirable parameter the cost of such a monitor (starting at € 3,400) may be prohibitive at this point.[20]

Wind: Historic Scotland at Smailholm Tower used a Vaisala WXT 510 sensor to monitor wind speed and direction. When it was fixed to the top of a gable they found it to be relatively insignificant visually.[21] This type of wind measurement may provide locally

[20] OTT Hydrometry Ltd.

[21] Peter Ranson Historic Scotland personal communication

significant data but would not be considered reliable by Met Éireann due to interference or 'surface roughness' variables (they require a 10m mast).[22]

Plate 4. Weather station, archaeological site, Malta (photo K. Blackwood 2009)

3.2 Impact Monitoring

In order to study how climatic change is impacting on the stated World Heritage values at both sites, it is necessary to create a suite of tailored impact monitoring solutions (Table 5). Slight variations between each sites' vulnerabilities are reflected in the choice of tools. Wherever possible existing data collection schemes (e.g. OPW hydrometric gauges), or partnership opportunities, have been recommended in preference to establishing new systems on site. The aim is to create a sustainable network of monitors that minimises ongoing maintenance and staffing demands at the two sites.

Table 5. Impact Specific Monitors Recommended

[22] Discussed at ICOMOS & Met Éireann meeting November 2009

Specialist ‘buy in’ Monitoring	Frequency	Impact at Brú na Bóinne	Impact at Clonmacnoise
Field survey / Lidar mapping	5-10 year intervals	Plough damage, subsidence, erosion.	Subsidence, erosion.
Laser scan	As above	Wet/dry, salts, biological growth, mechanical erosion.	Salts, biological growth, mechanical erosion.
Structural survey	As above	Subsidence, collapse.	Subsidence, collapse, wind damage.
Species survey	As above	Biodiversity, biological growth.	Biodiversity, biological growth & sphagnum moss.
Stone testing	Once	Salts, wet/dry, chemical & mechanical erosion.	Salts, wet/dry, chemical & mechanical erosion.
Embedded Monitoring			
Condition reporting & photo survey	Annual	All observable changes	All observable changes
Soil moisture	Daily (automatic) or monthly (manual)	Archaeological preservation.	Peat lands, archaeological preservation.
Moisture in stone & walls	Annual	Salts & wet/dry cycles.	Salts & wind driven rain.
Water table	Monthly	Flooding, subsidence.	Peat lands, flooding, subsidence.
Flood level markers	Event led	River flood	River flood
Moth traps	Daily (manual)	Biodiversity	Biodiversity

3.2.1 Biodiversity

<u>Moths and Butterflies:</u>

Lepidoptera are recommended as indicators of climate change as they are relatively easy to identify and contain a large number of species which are indicators of various habitat types. A study of the first dates of appearance of the adults, and the number of generations per year would also provide useful comparative data.[23] ICOMOS strongly recommends partnering with the National Biodiversity Centre to locate Rothamsted moth traps at the visitor centres on both sites.[24] These traps require an electricity supply and one staff member approximately 5-10 minutes to empty every day. The samples are analysed in England free of charge (an annual donation would be appreciated to sustain the project) and results interpreted by the Biodiversity Centre. Ken Bond of UCC worked on a survey of Moths & Butterflies of Clonmacnoise in 1987 and periodic re-running of the survey would also demonstrate how species may have changed.[25] In addition, the Biodiversity Centre run the Irish Butterfly Monitoring Scheme which could be developed in conjunction with local volunteers and promoted through both the visitor centres.[26]

<u>Flagship Species:</u>

- Atlantic salmon in the Boyne are near their southern limits and any rise in water temperature could greatly affect their spawning. Increased soil run-off due to erosion following dry summers and heavy rainfall causes sedimentation of the river bed that also inhibits spawning. In addition to being a protected species for biodiversity, salmon in the Boyne have a high cultural value. In the Fianna mythological cycle the salmon of knowledge was caught in the Boyne and the High Kings traditionally ate Boyne salmon at the feast of Lughnasa. Today angling continues to be an important activity for the local area. The salmon population is already monitored by the Standing Scientific Committee of the National Salmon Commission and there is a fish counter on the River Boyne at Blackcastle Weir that provides information on the adult run.[27]
- Corn-crakes are a globally endangered migratory species which breed in the Shannon Callows. Their numbers are already thought to have been affected by unseasonable flooding of the nest sites.[28] The key issue to monitor in future is arrival and departure dates. There is data on departure dates for corncrakes from the Shannon Callows region for 2001-3. In addition the dates calling males

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[23] Mary Tubridy and Associates personal communication
[24] Eugenie Regan National Biodiversity Centre personal communication
[25] Bulletin of the Irish Biogeographical Society
[26] http://irishbutterflymonitoringscheme.biodiversityireland.ie/
[27] www.dcenr.gov.ie
[28] Draft Management Plan Clonmacnoise p. 107

were first reported to Bird Watch Ireland by the general public are kept by the office in Banagher, though this is subjective data.[29]

3.2.2 Peatland Deterioration

Bogs are extremely vulnerable to climate change, Jones has predicted that in Ireland we will lose 31% of raised bogs by 2055 due to climate change.[30] An Taisce advised ICOMOS that water levels in the bog would be the most relevant parameter to examine, and the annual cycle of drying and wetting of the peat. Ideally they recommend both physical and biological monitoring.[31] The Irish Peatland Conservation Council monitor water levels to ensure they are within 30cm of the surface for most of the year as this is the threshold depth required for sphagnum mosses to survive. They suggest a combination of monitoring hydrology on a monthly basis and monitoring vegetation (% sphagnum cover) by surveying the site every 6-10 years.[32] Simple wells can be made using plastic pipes inserted in the peat and levels checked by hand with a dip stick or ‘plopper’ (weighted string).[33]

3.2.3 Stone -Surface Erosion

Erosion of stone surfaces may be mechanical (e.g. salt crystallisation) or chemical (e.g. rain water dissolution of limestone). Accurately monitoring the incremental loss of surface is problematic but advances in laser scanning technology are currently providing the best results. ICOMOS recommends that surface loss of micro-detail on selected stones be periodically quantified using laser scanning. [34] This must be accompanied by more comprehensive photography and condition reporting conducted on an annual basis across the sites by OPW or DoEHLG staff. Photographic recording should be by rectified photography (photogrammetry) and supplemented by measured drawings to archive conservation standards. Photographic surveys must be archived consistently for deterioration monitoring. It is vital that all the survey methods may be accurately re-

[29] Anita Donaghy, Birdwatch Ireland personal contact
[30] Jones et al 2006
[31] Anja Murray An Taisce personal communication
[32] Richella Duggan IPCC personal communication
[33] http://www.ipcc.ie/diymanmonitoring.html
[34] http://www.qub.ac.uk/greening/laser.html (29.09.09)

produced at different times and by different staff members; therefore clear protocols are extremely important from the start.

3.2.4 Stone - Internal Stresses

Moisture enables 80% of all decay mechanisms in stone and any increase in moisture levels will have a detrimental effect on masonry. Masonry is porous by nature and this tends to increase with age. Predictions for longer wetting periods, increasing cycles of wetting/drying and increased wind driven rain will cause greater loss of surface material.

Plate 5. Shattered kerb stone, Knowth (photo C Daly 2009)

Internal stresses caused by salt crystallization, wet/dry cycling and thermal expansions are difficult to monitor until the damage is manifested by a change in the surface condition – such as efflorescence, granulation and/or spalling. Changes in moisture content in walls is a key indicator of these impacts yet there is currently no satisfactory monitoring solution. At Smailholm Tower Dr Paul Baker of Glasgow Caledonian University inserted sensors beneath turf capping on walls to detect moisture based upon capacitance. This system is not suitable for the body of a wall or for monoliths however. While new systems are being developed and tested, the best Historic Scotland could recommend is wooden dowels set into the walls that change weight according to moisture levels.[35] These only give comparative readings and not absolutes, they are also destructive to install. Measuring moisture levels in masonry non-destructively is difficult, the three options are:

- Thermo Imaging
- Rilem Tube Test
- Laser Scanning

All the above would require a bench mark record to re-measure on an annual basis, these would need to be at predetermined locations and fully accessible.

3.2.5 Stone Characterisation

Stone deterioration has many potential causes as outlined above. In order to diagnose the most likely source of any damage it is necessary to understand the sensitivities of the stone in question. In the case of salt crystallisation for example, the porosity and the soluble salt content of the stone are key indicators of vulnerability to this impact. ICOMOS therefore recommends that laboratory testing of the greywhacke from Brú na Bóinne and the sandstone and limestone from Clonmacnoise be carried out with this specific purpose in mind. Characteristics of interest include; soluble salt content, porosity, abrasion resistance, clay content, pore size, laminar structure.

3.2.6 Flooding

The OPW are in the process of undertaking the Catchment Flood Risk Assessment and Management scheme for areas at potential risk from flooding (including cultural assets). The flood risk maps are due to be completed by 2013.[36] Historic data for daily measurements of water flow and levels on the Boyne and Shannon are available on the OPW website.[37] In the future it is intended that real-time data will also be available on this website and this would allow access to current flow and level information, providing an indication of the risk of flooding.[38] For Clonmacnoise the relevant stations are Athlone (upstream) and Shannonbridge (downstream). For Brú na Bóinne the nearest gauge is at Slane Castle (upstream). The EPA has an automated water level gauge on

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[35] Rob Thomson Historic Scotland personal communication
[36] Mark Adamson OPW personal communication
[37] http//.opw.ie/hydro
[38] Peter Newport OPW personal communication

the pedestrian bridge at the Brú na Bóinne visitor centre. The data is downloaded periodically although if funding was made available it could be live streamed.[39] The OPW and EPA gauges provide an indication of flood risk but it is vital that there is also on-site monitoring of the reach of flood waters, providing information on the actual impact. Monitoring should include installation of level gauges (at Clonmacnoise only) from which maximum water levels can be read. In addition the flood extent at both sites should be mapped & recorded. Photographic and documentary records could be strengthened by the implementation of a simple set of spaced markers from which the flood extent can be quickly assessed (e.g. 10 markers 5m apart perpendicular to river bank). Condition reporting in the aftermath of a flood would be seen as part of flood monitoring, factors such as pollution and erosion would need to be assessed when the waters recede.

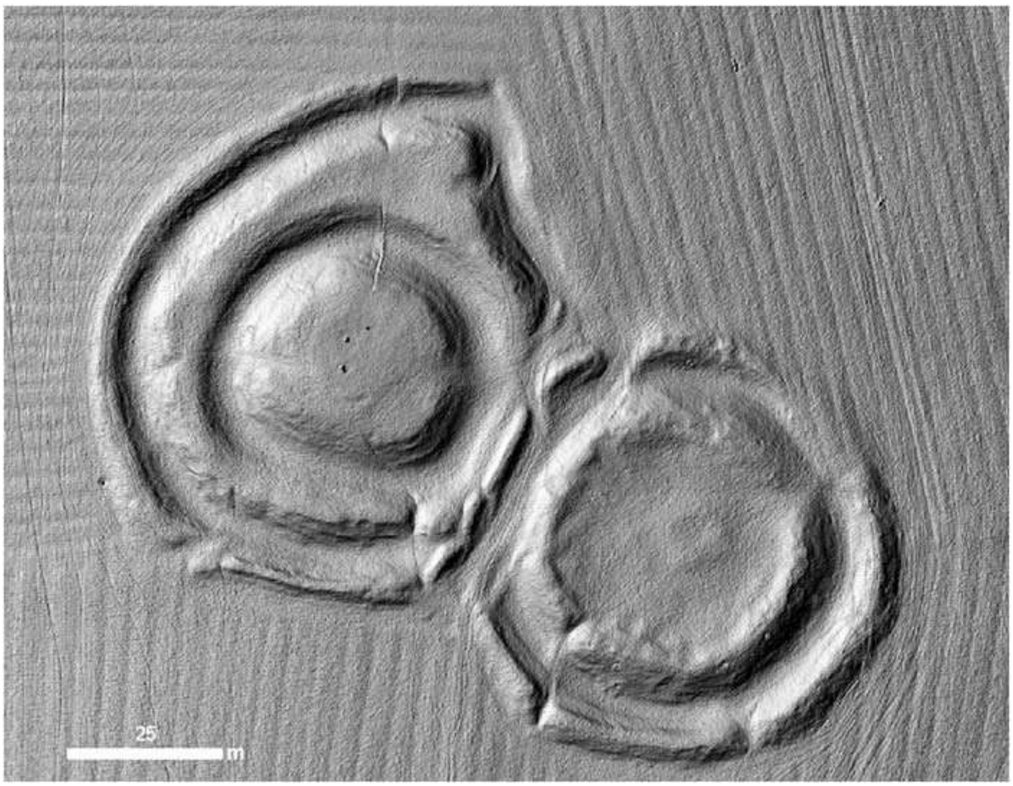
Plate 6. Knowth and the flooding Boyne (image by DoEHLG)

[39] Micheal MacCarthaigh EPA personal communication

3.2.7 Groundwater

The EPA currently has a groundwater monitoring programme in operation around the country but none in the area of the two sites. The GSI also have a number of historical borehole water level records but none of these are located near Clonmacnoise or Brú na Bóinne either. In order to monitor the water table, wells in the area could be selected, ideally in partnership with the EPA, and dipped regularly using one of the available tools.[40] Alternatively a permanent monitor can be installed in a bore hole to produce automatic readings. Groundwater readings will relate to flooding, subsidence, peat-land deterioration and impacts on buried archaeology.

Plate 7. Lidar scan of the Hill of Tara (Image by The Discovery Programme)



3.2.8 Plough Damage

Predicted climatic change over the next century may lead to arable farming becoming the dominant form of agriculture in the east of Ireland.[41] This will expose buried archaeological remains to a greatly increased risk from plough damage. In Brú na Bóinne where the majority of the archaeological resource is on private farmland, close to

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[40] Personal communications Dr. Caoimhe Hickey GSI & Tom O'Reilly EPA
[41] Sweeney et al 2003

the surface and susceptible to such damage (earth works, paleo-environmental evidence) this is of major concern. Archaeological field survey conducted in selected 'at risk' areas at regular intervals would provide comparative data on any such damage. This type of survey is limited by its detailed nature to small sections of the large landscape protected at both sites. For this reason it is suggested the ground work be supplemented by an aerial survey such as Lidar (light detection and ranging) mapping. Lidar mapping of parts of Meath including the Boyne valley were carried out in 2007-8.[42] Repetition of Lidar at regular intervals would yield valuable detail about the general condition of the whole site in addition to monitoring plough damage.

3.2.9 Dehydration Damage

Dehydration of the soil during hotter drier summers will place ongoing preservation of buried archaeological remains in question. Organic preservation, both of artefacts and environmental evidence, relies on waterlogged soils. In addition there is some concern that drying of soils may cause destabilisation of some monuments e.g. loosening of standing Megaliths/orthostats. It is therefore proposed that soil-moisture should be monitored on a permanent basis at a few key areas where such impacts are of most concern to site management/archaeologists. Soil moisture can be calculated by automatic sensors at the climate stations or by using manual soil moisture monitors. The latter have the advantage that they can be used in several locations, independent of the climate station.

3.2.10 Collapse & Subsidence

ICOMOS suggests that regular structural surveys of the monuments be carried out to monitor physical effects related to climate change including wind and rain, namely subsidence and collapse. This would be complemented by other monitoring such as the Photogrammetric survey, Lidar survey and the water table levels, to provide an accurate picture of threats to the structures under protection.

3.2.11 Biological Action

Biological action includes the surface damage (mechanical, chemical and aesthetic) of stone by micro-biological fungi and algae as well as damage by larger plants and animals. Climate change is likely to cause a variation in the species present and in the

[42] Heritage Council & Meath County Council.

growth patterns of existing species. Conducting a species survey at regular intervals (e.g. 5-10 years) would provide information on how this biological profile is changing. This information, in conjunction with regular condition assessments (laser scans, photography etc.) will provide a picture of the threats from biological action.

Plate 8. Biological growth on wall, Clonmacnoise (Photo C Daly 2009)

4. DISSEMINATION OF RESULTS

The information that will be gathered by the on-site monitors is a valuable resource and provides a unique opportunity to enhance the visitor experience at both sites while also raising public awareness about climate change. The sub-committee therefore suggest that the project be allocated a dedicated web address and that results be published online (in real time where feasible). It also proposes that screens should be installed in the interpretive centres at both sites to display the climate data as a live stream. Providing live information will create an interaction between the visitor and the site, engaging and hopefully stimulating them to think about heritage and climate change in new ways. Creation of an online resource would subsequently allow visitors to return to the site 'virtually' and would also ensure a much higher awareness of the project. The wider messages of climate change (impacts, adaptation and mitigation) can all be delivered through the novel medium of cultural heritage conservation. In November 2009 the members of the sub-committee submitted a funding application to the Heritage Council for this aspect of the project.

5. COSTS & REQUIREMENTS

5.1 Summary

The summary of costs for each site is presented in Table 6 and a detailed breakdown of the individual requirements along with the cost of possible options are given in Table 7. Accurate figures are only possible in respect to capital outlay on equipment. In the case of specialist services, such as the structural or species surveys, individual quotations will have to be sought. Estimates have been made for the number of man hours involved and it is important to note that this includes a substantial amount that could be undertaken by committed volunteers (where they are available).

Table 6. Cost Summary Table

	Climate Station	**Impact Monitors**[43]	**Specialist Services**	**Man hours**[44]
BRÚ NA BÓINNE				
Option A	€5,000	€1,500	To be negotiated	3.5 days/month
Option B	€25,000 ME Tucson station	€1,300 (static soil moisture calculated at synoptic station)	As above	3 days/month (Climate station managed by Met Éireann)
CLONMACNOISE				
Option A	€5,000	€2,300 (additional costs of river gauge & peat water level)	As above	4 days/month (additional time req. for peat water levels)

[43] Voluntary annual donation towards the Rothamsted moth traps project is not included in this figure.
[44] No differentiation is made here between paid staff and volunteer hours.

Table 7. Climate and Impact Monitoring Specifications

Monitor	Specifications	Data management	Cost/site
CLIMATE			
Met Éireann Tucson climatological and synoptic station (Brú na Bóinne only)	High spec. station to WMO standards	Station management by Met Éireann	€25,000
Rainfall	0.1-0.2mm accuracy required by Met Éireann (ME). Intensity and duration desirable	Downloaded by local staff. Archived by ME. Published online & at interpretive centres	€454 (Campbell Scientific ARG100 & base plate) €3,407 (OTT Pluvio 2; duration & intensity gauge)
Temperature	+/- 0.1 º C accuracy by Met Éireann	As above.	€344 (Campbell Scientific CS215 & shield) but accuracy +/- 0.3 º C €580 (Vaisala HMP45C & shield) accuracy +/- 0.2 º C
Relative humidity (RH)	+/-2% accuracy by Met Éireann	As above	RH measurement of +/-2% accuracy included in above sensors; best range with HMP45C

Monitor	Specifications	Data management	Cost/site
Wind	Direction & speed. ME specifications (detailed previously) are unlikely to be met by commercial sensor	As above for Tucson station. For non-standarised anemometer downloading on site and archiving by OPW. Publish as above	€730 (Campbell RS232 anemometer & mount)
Accessories	Data logger, enclosures, power supply, software and communications devices are all priced separately with commercial stations (all included in Tucson station)		€3,039 (Campbell Scientific)
Additional costs			Annual calibration Campbell Scientific €200 Staffing approx. 2 hour/week (unless use Met Éireann)
IMPACTS			
Aerial survey	Repeated every 10 years. Covering extent of protected area. High resolution recording. Lidar preferably	Published on-line. Archived by OPW, copies at each site	Site specific cost to be determined with consultant

Monitor	Specifications	Data management	Cost/site
Field survey	Repeated every 3-5 years, select representative areas with DoEHLG	As above	Site specific cost to be determined with consultant
Structural survey	Repeated every 3-5 years, key monuments identified with OPW	As above	Site specific cost to be determined with consultant
Species surveys	Repeated at regular intervals – dependant on expert advice. Butterflies & biological growth on stones most NB. Corn-crakes secondary	As above, depending on partners agreement; National Biodiversity Centre, Birdwatch Ireland, Botanic Gardens etc.	Suggested donation for Rothamsted moth traps is €5000/year (service currently free) + 15 minutes/day staff/volunteer time. Specialist survey - specific cost to be determined with consultant
Stone characterisation	Once only laboratory testing of stone properties	Archived by OPW, copies at each site	Cost to be determined with consultant
Laser scan	Repeat every 3-5 years, key stone details identified with OPW/DoEHLG	Published on-line Archived by OPW, copies at each site depending on partner/consultant agreement	Site specific cost to be determined with consultant

Monitor	Specifications	Data management	Cost/site
Photographic record	Repeat every year; write clear methodology to enable accurate repetition under similar conditions.	Published on-line Archived by OPW, copies at each site	2-4 staff days/year. Camera equipment made available
Peat water content (Clonmacnoise only)	Monthly manual dipping acc. To IPCC guidelines	As above	€150 equipment + 6 days/year staff/volunteer.
Soil moisture	Permanent, automatic soil moisture measurement at climate station and/or manual monthly measurement across site (NB at Brú na Bóinne)	As above	€ 149 & €2.65 /m cable (Campbell CS616 requires direct connection to data logger) + 1 day/year staff. €700 (CD620 Portable field unit) + half day/month staff/volunteer
Moisture in walls & stone	Annual scan using Rilem test/thermo imaging/laser scan	As above, depending on partner/consultant agreement	Site specific cost to be determined with consultant

Monitor	Specifications	Data management	Cost/site
Flooding	Water level at Clonmacnoise: Manual readings from on site flood level gauge benchmarked against OPW hydrometric readings or Automatic water level sensor. Both sites: Flood extent determination using markers or survey.	Published on-line Archived by OPW, copies at each site	Flood level gauge €650 OTT Or Automatic water level sensor €2,500 OTT (Clonmacnoise only) + Flood extent markers Or Topographic survey (site specific cost to be determined with consultant) + Staff time
Water table	Bore hole or well monthly dipping or permanent sensor preferably in partnership with EPA or GSI	As above, depending on partner agreement.	Manual dipping (electronic well sounder) portable & can be used at multiple spots e.g. OTT (600 Euro) + half day/month staff/volunteer time Or Automatic water level sensor e.g Campell Scientific (560 Euro) installed at one point.

6. CHALLENGES

- Uncertainties inherent in future climate change scenarios mean that predictions for the impacts on heritage can only be approximated. It may be the case that as climate change evolves new threats may emerge, and the monitoring scheme will have to be flexible to meet this challenge.
- Planning permission, ministerial consent and possible OUV issues for a Met Éireann Tucson station at Brú na Bóinne may be problematic given the requirement for a permanent 10m mast (see 3.1.1).
- The availability of human resources at each site for maintenance, calibration, data collection and processing is a key issue. Staff and volunteer continuity is vital to ensuring the long term viability of this study.
- Data management, including collection, downloading and backup, will be done at each site. However, a centralised system of archiving would also need to be devised. Met Éireann have agreed to archive the climatological results (see 3.1) which is an ideal solution for this particular data.
- Funding of the project needs to be secured over the long-term in order to ensure that the initial investment in capital outlay returns a benefit.
- The final selection and location of sensors must be done in conjunction with local staff and relevant experts to ensure the most pragmatic and effective decisions are made.
- Opportunities for inter-departmental co-operations & partnerships have been flagged at several points in the recommendations and it is felt that if pursued from within the DoEHLG these could be very fruitful.
- The dissemination of results to the public at large requires some additional resources but could bring substantial added value to the project (see 4)

7. BENEFITS

Although climate change science is constantly improving, predictions for the future will always contain a degree of uncertainty. It is clear however that climate change is occurring, and that it will come to affect the conservation of our heritage in the future. Establishing a monitoring scheme at Brú na Bóinne and Clonmacnoise will therefore provide much needed quantifiable data on climate change impacts. Although we cannot confidently attribute results to climate change until around 30 years of data has been collected, conservation and management responses can be implemented immediately. Results from the scheme can feed into sustainable management systems for mitigation and adaptation. Therefore although this project is envisaged as a legacy for the future it is also an aid to current conservation and management at the sites and could potentially inform Government policy on climate change.

Research into climate change impacts on cultural heritage is in its infancy internationally and no similar scheme has yet been implemented. This project thus represents a significant contribution to knowledge. It will see Ireland at the forefront of international research in this area and Irish World Heritage potentially becoming a best practice model for UNESCO. In time it would be desirable to extend the monitoring scheme to include other geographical and typological sites in Ireland and internationally, in co-operation with the World Heritage network of sites.

The global network of the World Heritage Sites is ideally suited to build public and political support through improved information dissemination and effective communication on the subject [of climate change], given the high profile nature of these sites.

UNESCO Director General Koichiro Matsuura, Nairobi 2006

APPENDIX 1. Causal model of vulnerability of Brú na Bóinne to predicted climate change to 2099.

Climatic Factor	Sector or W. H. Value	Impact	Indicator	Sensitivity	Exposure	Adaptive Capacity	Measure of Vulnerability
Increased Temperature	Rock Art	Accelerated chemical weathering	SO_2 conc. = 2µg/m^3 & decreasing	Low (1)	Low (1)	Low (-1)	Low (1)
Increased Temperature	Rock Art	Increased biological action	Nitrates conc. = 4µg/m^3 & increasing	Low (1)	Medium (2)	Low (-1)	Medium (2)
Increased Temperature	Rock Art	Cryoclastic weathering	T < 0^{o}C = reduced 80%(2080)	High (3)	Low (1)	High (-3)	Low (1)
Increased Temperature	Rock Art	Thermoclastic weathering		Low (1)	Low (1)	Low (-1)	Low (1)
Increased Wind & extr. rainfall	Rock Art	Mechanical weathering	Abrasion resistance = 88.3%	Low (1)	Medium (2)	Medium (-2)	Low (1)
Increased Temperature & Rainfall	Rock Art	Wet dry cycles		Medium (2)	High (3)	Medium (-2)	High (3)
Increased Temperature & Rainfall	Rock Art	Salt crystallisation	Information resources 07-08	Low (1) or Medium (2)	High (3)	Low (-1)	High (3+)
Increased Wind	Megalithic Tombs	Structural damage		Low (1)	Medium (2)	Medium (-2)	Low (1)
Increased Rainfall	Megalithic Tombs	Flooding		Medium (2)	Medium (2)	Low (-1)	High (3)
Increased Rainfall	Megalithic Tombs	Collapse (landslide)		Medium (2)	Medium (2)	Medium (-2)	Medium (2)
Decreased Rainfall (summer)	Megalithic Tombs	Subsidence (drought)		Low (1)	Low (1)	Low (-1)	Low (1)
Decreased Rainfall (summer)	Cultural Landscape (archaeology)	Reduction in water table	Population pressure +18%	High (3)	Low (1)	Medium (-2)	Medium (2)
Increased Temperature (summer)	Cultural Landscape (natural her.)	Change to Biodiversity		Medium ? (2)	Medium (2)	Low (-1)	High (3)
Increased Temperature (summer)	Cultural Landscape (agriculture)	Increased plough damage	Tilled farmland 2000 = 16.2%	High (3)	High (3)	Medium (-2)	High (3+)

Climatic Factor	Sector or W. H. Value	Impact	Indicator	Sensitivity	Exposure	Adaptive Capacity	Measure of Vulnerability
Increased Rainfall	Cultural Landscape	Landslide	Caine's threshold	Low (1)	Low (1)	Low (-1)	Low (1)
Incr Rain /Sea level	Cultural Landscape	Flooding	% M/FL 20m=10%	Medium (2)	High (2) Expected x2 flood magnitude on Boyne (Sweeney et al 08)	Low (-1)	High (3+)

Source: Daly 2009

APPENDIX 2. Causal model of vulnerability of Clonmacnoise to predicted climate change to 2099.

Climatic Factor	Sector or W. H. Value	Impact	Indicator	Sensitivity	Exposure	Adaptive Capacity	Measure of Vulnerability
Increased Temperature	Architectural ensemble	Increased biological action	Red growth on SW gables of houses (Tom Moore)	Limestone = 2.5 Sandstone = 1.5	Carved crosses and slabs protected indoors. Rest of stonework exposed = 2	Lack of research & no response plan = -1	Limestone = 3+ Sandstone = 2.5
Increased Temperature	Architectural ensemble	Cryoclastic weathering	T < 0^oC = 93% reduction by 2099	Limestone = 1.5 Sandstone = 2	Expected to decrease rapidly = 1	No steps to manage risk = -1	Limestone = 1.5 Sandstone = 2
Increased Wind & extr. rainfall	Architectural ensemble	Mechanical weathering (wind driven rain)	Abrasion resistance = ??	Limestone = 2 Sandstone = 2.5	Prevailing wind S/SW. Most exposed on W/NW side = 2	Ongoing conservation works, research on consolidation = -2	Limestone = 2 Sandstone = 3
Increased Temperature & Rainfall	Architectural ensemble	Wet dry cycles	Clay content of stone	Limestone = 2 Sandstone = 2.5	Carved crosses and slabs protected indoors. Rest of stonework exposed = 2	Ongoing conservation works, research on consolidation = -2	Limestone = 2 Sandstone = 3
Increased Temperature & Rainfall	Architectural ensemble	Salt crystallisa-tion	Soluble salt content of stone	Limestone = 1 Sandstone = 2	Carved crosses and slabs protected indoors. Rest of stonework exposed = 2	Ongoing conservation works, research on consolidation = -2	Limestone = 1 Sandstone = 2
Increased Rainfall	Architectural ensemble	Clean rain dissolution		Limestone = 2 Sandstone = 1	Carved crosses and slabs protected indoors. Rest of stonework exposed = 2	Ongoing conservation works, research on consolidation = -2	Limestone = 2 Sandstone = 1
Increased	Architectural	Structural		Unknown –	Prevailing	Ongoing	2

Climatic Factor	Sector or W. H. Value	Impact	Indicator	Sensitivity	Exposure	Adaptive Capacity	Measure of Vulnerability
Wind	ensemble	damage		shape, height, integrity = 2?	wind S/SW. Most exposed on W/NW side = 2	conservation & maintenance = -2	
Increased Rainfall	Architectural ensemble	Flooding		Varies dep on structure = 2	Location on river = 3	Current protection = -1	3
Increased Rainfall	Architectural ensemble	Collapse (landslide)		Well drained soil = 1	Steep multi-level gradient of site = 2	Lack of data = -1	2
Decreased Rainfall (summer)	Architectural ensemble	Subsidence (drought)		Sandy well drained soil = 1	Proximity to river = 1	Lack of data = -1	1
Decreased Rainfall (summer)	Cultural Landscape	Deterioration of peatland	Water levels	Growth of peat forming mosses = 3	By 2055 32% raised bogs pred. loss = 3	Science is done, no plans in place = -2	3+
Increased Temperature (summer)	Cultural Landscape (natural her.)	Change to Biodiversity	Butterfly lifecycle	Varies dep on species & habitat, generally high = 3	Varies between migrating and native = 2	Protected areas of WH site offers some buffer = -2	3
Increased Temperature (summer)	Cultural Landscape	Change in agricultural practices	% land under tillage	Landscape of eskers, archaeological remains = 3	Current practices also dep on social and economic issues = 1	Protective legislation would limit impact of any shift to arable = -3	1
Increased Rainfall	Cultural Landscape	Landslide	Caine's threshold	Well drained sandy soils = 1	Rainfall predictions do not meet Caine's threshold = 1	No data on risk = -1	1
Increased Rainfall	Cultural Landscape	Flooding	OPW hydrometric levels on Shannon	Combination of well draining eskers, floodplains and peatland = 1	Location on Shannon = 3	Ability of peatland to absorb water and slowly release it = 3	1

Source: Daly 2009

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