Volume 6

A303 Amesbury to Berwick Down

TR010025

6.3 Environmental Statement Appendices

Appendix 8.25: Habitat Regulations Assessment (HRA): Statement to Inform Appropriate Assessment

APFP Regulation 5(2)(a)

Planning Act 2008

Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

October 2018

Table of contents

Foreword

The A303 Amesbury to Berwick Down scheme (“the Scheme”) forms part of a programme of improvements for upgrading the A303/A358 corridor, improving this vital connection between the South West and London and the South East and including the upgrade of remaining single carriageway sections on the route to dual carriageway. This investment is stated as a priority project in the National Infrastructure Plan and Government’s commitment is confirmed in the Road Investment Strategy (2015-2020). Subject to achieving an approved Development Consent Order (“DCO”), preliminary works are planned to start in 2020 with the main construction works following in 2021, and the Scheme is due to open to traffic in 2026.

Objectives for the Scheme have been formulated both to address identified problems and to take advantage of the opportunities that new infrastructure would provide. The objectives are defined by the Department for Transport (“DfT”):

- **Transport** - To create a high quality reliable route between the South East and the South West that meets the future needs of traffic;
- **Economic Growth** - to enable growth in jobs and housing by providing a free flowing and reliable connection between the South East and the South West.
- **Cultural Heritage** - To help conserve and enhance the World Heritage Site and to make it easier to reach and explore; and
- **Environment and Community** - To improve biodiversity and provide a positive legacy for nearby communities.

The objectives would be achieved by providing a high quality, two-lane dual carriageway on the A303 trunk road between Amesbury and Berwick Down in Wiltshire. The Scheme would resolve traffic problems and, at the same time, protect and enhance the Stonehenge, Avebury and Associated Sites World Heritage Site (“WHS”). The Scheme would be approximately 8 miles (13km) long and comprise the following key components:

a) A northern bypass of Winterbourne Stoke with a viaduct over the River Till valley;
b) A new junction between the A303 and A360 to the west of and outside the WHS, replacing the existing Longbarrow roundabout;
c) A twin-bore tunnel approximately 2 miles (3.3km) long, past Stonehenge; and
d) A new junction between the A303 and A345 at the existing Countess roundabout.

1 Introduction

1.1 Background

1.1.1 AmW has been appointed by Highways England to undertake the various assessments comprising the Habitats Regulations Assessment of the A303 Amesbury to Berwick Down scheme (hereafter called the Scheme). A separate document sets out the assessments of Likely Significant Effects for the scheme. This report contains the Statement to Inform Appropriate Assessment for those European sites for which likely significant effects could not be dismissed.

1.1.2 The Likely Significant Effects Report (Appendix 8.24 of the Environmental Statement) and this document (Appendix 8.25 of the Environmental Statement) provide information to enable the Secretary of State for Transport (and the Planning Inspectorate, acting on its behalf) to determine whether an appropriate assessment is required and to undertake the assessment pursuant to Regulation 63(2) of the Conservation of Habitats and Species Regulations 2017. The A303 is a trunk road in Southern England, connecting the M3 and the A30. It is one of the main routes from London to South West England, and on the most direct strategic route from the South East to the South West for business and tourists. However, the existing A303 has a number of traffic bottle-necks limiting accessibility to the South West with consequential impact on the region's economy and growth.

1.1.3 The Scheme would be approximately 8 miles (nearly 13 kilometres) long and would comprise the construction of a new dual two-lane carriageway between Amesbury and Berwick Down with the following key features:

- a bypass to the north of Winterbourne Stoke with a viaduct over the River Till valley;
- grassland habitat creation that would complement the adjacent Parsonage Down NNR;
- a new Longbarrow junction with the A360 to the west of and outside the WHS, with the A303 passing under the junction;
- a section through the WHS with a twin-bore tunnel past Stonehenge about 2 miles (approximately 3.3km) long;
- an upgraded junction with the A345 at Countess Roundabout to the north of Amesbury, with the A303 passing over the junction;
- the conversion of the existing A303 through the WHS into a route for walking, cycling and horse riding; and
- new 'green bridges' at various points along the length of the scheme to connect existing habitats and allow the movement of wildlife, maintain existing agricultural access and provide crossings for existing and new Public Rights of Way.

1.1.4 The UK is bound by the terms of the Habitats Directive (92/43/EEC). Under Article 6(3) of the Habitats Directive, an appropriate assessment is required, where a plan or project is likely to have a significant effect upon a European Site, either individually or in combination with other projects. The Directive is implemented in the UK by the Conservation of Habitats and Species Regulations 2017 (the "Habitats Regulations").

1.1.5 The objective of this Report is to discuss those aspects of the Scheme that would be likely to lead to adverse effects upon the integrity of sites afforded protection under the Habitats Regulations. Crucially, the report also discusses what mitigation or avoidance measures are needed to remove such effects.

1.1.6 In the UK, this comprises Special Areas of Conservation (SACs), candidate Special Areas of Conservation, and Special Protection Areas (SPAs). In accordance with Government policy, assessment is applied to sites designated under the Ramsar Convention as Wetlands of International Importance (Ramsar sites) and potential SPAs (pSPAs). These sites are referred to collectively in this Report as "European Sites".

1.1.7 The Scheme requires a crossing of the River Till, north of Winterbourne Stoke. This River is a component of the European designated River Avon Special Area of Conservation (SAC). The Scheme also involves working adjacent to a second part of the River Avon SAC: the River Avon System SSSI, east of Amesbury. Salisbury Plain SAC is located immediately adjacent to the Scheme boundary near Bulford camp in the eastern part of the Scheme and is adjacent to the Scheme boundary at two locations: (i) at the Diversion Route to the north of the Scheme and (ii) at Parsonage Down near the western end of the Scheme. Salisbury Plain SPA is located adjacent to the Scheme boundary along the Diversion Route to the north of the Scheme.

1.2 Legislative Context

1.2.1 The need for HRA is set out within Article 6 of the Habitats Directive, and transposed into UK law by the Conservation of Habitats and Species Regulations 2017. The ultimate aim of the Habitats Directive is to "*maintain or restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest*" (Article 2(2)). This aim relates to habitats and species, not the European Sites themselves, although the European Sites have a significant role in delivering favourable conservation status.

1.2.2 Under the Habitats Directive consent should only be granted for plans and projects once the relevant competent authority has ascertained that there will either be no likelihood of significant effects, or no adverse effect on the integrity of the European Site(s) in question. Where an Appropriate Assessment has been carried out and does not result in a finding that there is no such adverse effect, consent will only be granted if there are no alternative solutions and there are Imperative Reasons of Over-riding Public Interest (IROPI) for the development and compensatory measures have been secured.

1.2.3 In order to ascertain whether or not site integrity will be affected, an Appropriate Assessment should be undertaken of the plan or project in question. The competent authority is entitled to request the applicant to produce such information as the competent authority may reasonably require for the purposes of the assessment, or to enable it to determine whether an appropriate assessment is required. Plate 1 provides the legislative basis for an Appropriate Assessment.

Habitats Directive 1992

Article 6 (3) states that:

"*Any plan of project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives."*

Conservation of Habitats and Species Regulations 2017

Regulation 63 states that:

"*A competent authority, before deciding to … give any consent … for, a plan or project which – (a) is likely to have a significant effect on a European site … must make an appropriate assessment of the implications for the plan or project in view of that site's conservation objectives…*

In light of the conclusions of the assessment, and subject to regulation 64 [IROPI where negative assessment], the competent authority may agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the European site."

Plate 1. The legislative basis for Appropriate Assessment

1.2.4 Over the years, 'Habitats Regulations Assessment' has come into wide currency to describe the overall process set out in the Habitats Regulations, from screening through to identification of IROPI. This has arisen in order to distinguish the overall process from the individual stage of "Appropriate Assessment". Throughout this Report the term HRA is used for the overall process and restricts the use of Appropriate Assessment to the specific stage of that name.

1.2.5 In relation to Nationally Significant Infrastructure Projects, the Secretary of State acts as the competent authority with a duty to conduct an HRA.

1.3 Quality Assurance

1.3.1 All ecologists working on this project are members of (at the appropriate level) the Chartered Institute of Ecology and Environmental Management (CIEEM) and follow its code of professional conduct (CIEEM, 2017) when undertaking ecological work.

2 Protected Sites Potentially Affected by the Proposals

2.1.1 The assessment of Likely Significant Effects could not determine that effects were unlikely on the following European sites:

- River Avon SAC
- Salisbury Plain SAC
- Salisbury Plain SPA

2.1.2 The key characteristics of the three European sites are summarised in the tables that form sections 2.2 to 2.4 below. In all cases baseline data collection was undertaken through a combination of desk study, consultation and meetings with local Natural England and RSPB officers and bespoke field survey as reported in the Environmental Impact Assessment for the scheme.

2.2 River Avon SAC

Physical area of the European site	1) 416.57 ha
The qualifying interests of the European site	2) Annex I habitats that are a primary reason for selection: i. Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation 3) Annex II species that are a primary reason for selection: i. Desmoulin`s whorl snail *Vertigo moulinsiana* ii. Sea lamprey *Petromyzon marinus* iii. Brook lamprey *Lampetra planeri* iv. Atlantic salmon *Salmo salar* v. Bullhead *Cottus gobio*
European Site conservation objectives	4) The Conservation Objectives for the SAC state: *Ensure that the integrity of the site is maintained or restored as appropriate, and ensure that the site contributes to achieving the Favourable Conservation Status of its Qualifying Features, by maintaining or restoring:* *The extent and distribution of qualifying natural habitats and habitats of the qualifying species;* *The structure and function (including typical species) of qualifying natural habitats;* *The structure and function of the habitats of qualifying species;* *The supporting processes on which qualifying natural habitats and the habitats of qualifying species rely;* *The populations of qualifying species; and* *The distribution of qualifying species within the site.*
Details of the existing baseline	5) The River Avon and River Till were surveyed for

conditions of the site including details of data collection methodologies and consultations undertaken	macrophytes and fish in 2017 in six 500m reaches on each river and for Desmoulin's whorl snail. Survey methods and results are presented in detail in ES Appendices 8.7A and B for macrophytes, ES Appendices 8.12A and B for fish and ES Appendix 8.8 for Desmoulin's whorl snail. Two macrophyte survey methods were applied: (i) the Holmes method for surveying macrophytes and determining river community type, as described in Life in UK Rivers [1], applied at a 500m reach scale; and (ii) the LEAFPACS method as described in the UK TAG guidance for Water Framework Directive monitoring[2], applied at a 100m reach scale. Survey broadly followed the 'level 1' survey techniques detailed in Killeen and Moorkens[3] (2003) targeting areas of suitable habitat along the River Avon and River Till. Fish surveys were undertaken using a combination of methods depending on the depth, profile and width of the water course. All electric fishing surveys followed standard practice for operators and equipment[4]. Lamprey ammocoete (larvae) surveys followed the LIFE method[5], which uses electric fishing within a standard 1m square quadrat. River Habitat Survey was also carried out in the same stretches by the standard method[6]. 6) Desmoulin's whorl snail is absent from the section of the River Till within the Scheme boundary due to lack of suitable habitat in the 2km stretch around the proposed crossing. There were no Desmoulin's whorl snail recorded when the stretch was surveyed in 2001 or in 2017[7]. 7) The stretch of the River Till crossed by the Scheme does not have suitable habitat for spawning of Atlantic salmon, which were not recorded in the survey. The habitat is poor for spawning of brown trout and bullhead. Whilst there is gravel substrate present, much of the channel is seasonally overgrown by emergent vegetation such as fool's watercress. Baseline survey in late May 2017 showed that, even when there was flow present, fish were present at only very low density ($1.3/100m^2$). 8) The section of the River Till to be crossed by the new viaduct is a winterbourne. Parts of the channel are silted and both the banks and channel are grazed as part of the adjacent improved pasture. Aquatic plants present

[1] Life in UK Rivers (2003) *Monitoring Watercourses Characterised by Ranunculion fluitantis and Callitricho-Batrachion Vegetation Communities.* Conserving Natura 2000 Rivers Monitoring Series No. 11, English Nature, Peterborough.
[2] UKTAG (2014) Guide to Macrophytes in Rivers River LEAFPACS2. Available at: http://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/River%20Macrophytes%20UKTAG%20Method%20Statement.pdf [Accessed 21st August 2018].
[3] Killeen, I.J. and Moorkens, E.A. (2003) *Monitoring Desmoulin's whorl snail, Vertigo moulinsiana.* Conserving Natura 2000 Rivers Monitoring Series No. 6. English Nature, Peterborough
[4] Environment Agency (2001) Electric Fishing Code of Practice. Reference No. EAS/6100/4/02
CEN (2003) Water quality – sampling of fish with electricity. European standard –EN 14011:2003. Brussels: European Committee for Standardization, 18 pp.
[5] Harvey, J.P. and Cowx, I.G. (2003). *Monitoring the River, Brook and Sea Lamprey*. Conserving Natura 2000 Rivers Monitoring Series No. 5, English Nature, Peterborough, pp. 35
[6] Environment Agency (2003) *River Habitat Survey in Britain and Ireland*. Field Survey Guidance Manual: 2003. Bristol.
[7] Willing MJ. June 2017, amended August 2017. River Avon and River Till Desmoulin's Whorl Snail Surveys. Highway England report HE551506-AA-SGN-SWI-SU-YE-000001 P02

	included fools watercress but no water crowfoot, although this species is present in relative abundance further downstream on the River Till. 9) Natural England was consulted throughout the baseline data collection and scheme design phases and was provided with all of the baseline reports in February 2018.
The value of the site and qualifying interests therein to the Natura 2000 network	10) According to the JNCC page for the SAC, the Avon in southern England is a large, lowland river system that includes sections running through chalk and clay, with transitions between the two. Five aquatic *Ranunculus* species occur in the river system, but stream water-crowfoot *Ranunculus penicillatus* ssp. *pseudofluitans* and river water-crowfoot *R. fluitans* are the main dominants. Some winterbourne reaches, where *R. peltatus* is the dominant water-crowfoot species, are included in the SAC. 11) The SAC is also one of two sites representing Desmoulin's whorl snail in the south-western part of its range, in chalk stream habitat. 12) There are also excellent examples of the features that sea lamprey and brook lamprey needs for survival, including extensive areas of sand and gravel in the middle to lower reaches of the River Avon where they are known to spawn. 13) The salmon populations are typical of a high-quality chalk stream, unaffected by the introduction of genetic stock of non-native origin. The Avon has an excellent mosaic of aquatic habitats, which include extensive areas of gravels essential for spawning and growth of juvenile fry of both salmon and bulhead. There has been limited modification of the river course by comparison with many other southern lowland rivers in England. 14) The site is considered to be one of the best areas in the United Kingdom for all these interest features and is therefore integral to the Natura 2000 network.
Likely future changes in baseline conditions at the site in the absence of the project	15) In the absence of the project baseline conditions in terms of water quality, winter flooding of the River Till, and habitat connectivity, are expected to persist.
Details of the key species, habitat dynamics and functional relationships that maintain the site integrity	16) The fish and vegetation features of the River Avon SAC occur within the river itself and are therefore particularly dependent on appropriate hydrology (water levels and flows) and good water quality. The fish are also dependent on the presence of adequate fish spawning habitat (such as well-aerated, un-silted gravel substrate for salmon and clean loose cobble for bullhead, while lamprey species require gravel for spawning plus areas of organic silt for the ammocoetes). The fish interest features also require an absence of barriers to movement through the river system. In winterbourne rivers, such as the River Till, seasonal drying in the upper reaches is a natural characteristic of such rivers. The winterbourne sections can be utilised by fish for feeding seasonally but they have to disperse to

	perennial sections downstream when the rivers stop flowing, which can happen rapidly in spring or early summer. Desmoulin's whorl snail is a species of spring-fed wetland habitat rather rivers. The species requires a suitable stable hydrological regime with a high water table maintained close to the surface, in dense swamp vegetation and under a management regime that avoids excessive trampling and erosion by livestock, but prevents colonisation by scrub and loss of the swamp vegetation due to shading. It also requires an absence of barriers to dispersal.[8] Very localised populations have been found in groundwater-supported wetland adjacent to the River Avon south of the A303, but have not been recorded in the River Till. 17) Within the vicinity of the scheme the River Till component of the SAC is a winterbourne supported by water flowing from the aquifer in winter and early spring. As aquifer levels falls below the level of the river bed in summer, the winterbourne section dries and the river flows from a perennial head in the mid-section of the Till (downstream of the scheme)[9]. The ecological function of the River Till is therefore dependent on its ability to continue to flow and flood during periods of high flow and high water table.

2.3 Salisbury Plain SAC

Physical area of the European site	1) 21465.94 ha
The qualifying interests of the European site	2) Annex I habitats that are a primary reason for designation: i. Juniper *Juniperus communis* formations on heaths or calcareous grasslands ii. Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (*important orchid sites) 3) Annex II species that are a primary reason for site selection: vi. Marsh fritillary butterfly *Euphydryas (Eurodryas, Hypodryas) aurinia*
European Site conservation objectives	4) The Conservation Objectives for the SAC state: *Ensure that the integrity of the site is maintained or restored as appropriate, and ensure that the site contributes to achieving the Favourable Conservation Status of its Qualifying Features, by maintaining or restoring:* • *The extent and distribution of qualifying natural habitats and habitats of qualifying species;* • *The structure and function (including typical species) of qualifying natural habitats;*

[8] Killeen IJ (2003). Ecology of Desmoulin's Whorl Snail. Conserving Natura 2000 Rivers Ecology Series No. 6. English Nature, Peterborough.
[9] River Till SSSI citation

	• *The structure and function of the habitats of qualifying species;* • *The supporting processes on which qualifying natural habitats and the habitats of qualifying species rely;* • *The population of qualifying species; and* • *The distribution of qualifying species within the site.*
Details of the existing baseline conditions of the site including details of data collection methodologies and consultations undertaken	5) Botanical surveys were undertaken of the SAC at Parsonage Down within 200m of the scheme. In June 2017 three sets of 100 m long linear transects approximately parallel to the A303 were set up across Parsonage Bank at the bottom, middle and top of the bank over a linear distance of 75m in approximately the same places as in 2002 (NPA 2003)[10]. Twenty quadrats were randomly placed along each transect, each comprising nested sub-quadrats of 10 x 10, 25 x 25, 50 x 50 and 100 x 100 cm. For each size class of sub-quadrat, presence of all vascular plants and bryophytes was recorded. In addition, for the largest size class (100 x 100 cm), percentage cover of each species was also estimated. Details are included in ES Appendix 8.4. 6) Calcareous grassland of NVC type CG2 is present the transects surveyed in the SAC within 200m of the scheme. 7) There are no stands of juniper scrub in those parts of the SAC within 200m of the scheme; the highest density of bushes occurs at the SAC on the steep escarpment of Beacon Hill and at the Bulford Ranges. 8) The south-east part of Parsonage Down was surveyed for terrestrial invertebrates on three dates in late June and late July 2017, with 29th July focused on a survey for marsh fritillary larval webs at a time when webs were evident on other Wiltshire NNR. None were found in 2017, but evidence provided by Natural England[11] confirms that marsh fritillary butterfly has been recorded within Parsonage Down in 2018 and therefore could be found within 200m of the scheme. 9) Natural England was consulted throughout the baseline data collection and scheme design phases and was provided with the botanical survey report (ES Appendix 8.4) and terrestrial invertebrate report (ES Appendix 8.11) in February 2018.
The value of the site and qualifying interests therein to the Natura 2000 network	10) According to the JNCC website Salisbury Plain is the best remaining example in the UK of lowland juniper scrub on chalk. It is also the largest surviving semi-natural dry grassland within the EU and is therefore the most important site for this habitat in the UK. The site also supports marsh fritillary butterfly in calcareous grassland. This species has declined dramatically in Europe and is regarded as endangered or vulnerable in most of its European range. On the basis of existing knowledge, the UK and Spain constitute the European strongholds for this species.

[10] NPA. 2003. A303 Stonehenge Improvement: Environmental Statement Volume 2 Part 3 Nature Conservation and Biodiversity. Unpublished report for Mott MacDonald/Highways Agency. Nicholas Pearson Associates Ltd, Bath.
[11] Stuart Hales, Natural England Senior Reserves Manager, Wiltshire National Nature Reserves, personal communication

	11) The site is considered to be one of the best areas in the United Kingdom for all these interest features and is therefore integral to the Natura 2000 network.
Likely future changes in baseline conditions at the site in the absence of the project	12) In the absence of the project baseline conditions are expected to persist provided management continues as currently. Air quality is likely to improve as improved vehicle emissions technology leads to a reduction of NOx concentration and oxidised nitrogen deposition rates.
Details of the key species, habitat dynamics and functional relationships that maintain the site integrity	13) The calcareous grassland interest feature of the SAC is particularly dependent on an appropriate grazing regime (preventing over-grazing but also avoiding succession to rank grassland and dense scrub) and on the persistence of a calcareous substrate with low soil nitrogen and phosphate concentrations and good drainage. The area of the SAC in Parsonage Down SSSI/NNR is currently a closed sward, grazed by longhorn cattle plus sheep, although there are areas of short open sward and patches of bare ground on Parsonage Bank in the south-east part of the site nearest the Scheme. 14) The marsh fritillary is dependent upon the calcareous grassland (and therefore also relies on appropriate grazing, low fertility substrate and good drainage). It particularly requires suitably short open areas of grassland with an abundance of its larval food plant devil's-bit scabious *Succisa pratensis*. 15) The juniper scrub on the SAC is adapted to colonising open ground on nutrient poor, well-drained, soils. It is very susceptible to high grazing pressure in the seedling establishment phase. Grazing can create the open ground conditions suitable for colonisation by juniper seedlings. However, regular grazing prevents the subsequent establishment of seedlings and their growth into mature plants.[12]

2.4 Salisbury Plain SPA

Physical area of the European site	1) 19688.88 ha
The qualifying interests of the European site	2) This site qualifies under Article 4.1 of the Directive (79/409/EEC) on the Conservation of Wild Birds by supporting populations of European importance of the following species listed on Annex I of the Directive: 3) During the breeding season: i. Stone curlew *Burhinus oedicnemus* ii. Eurasian hobby[13] *Falco subbuteo*

[12] Salisbury Plain LIFE Project juniper factsheet http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=JuniperFactsheet.pdf

[13] A review of the UK network of SPAs was undertaken (by JNCC and other country agencies) and a report published by Stroud *et. al* in 2001 (http://jncc.defra.gov.uk/page-1412). It is understood that it is taking some time to revise all the relevant SPA citations in light of the review. As part of our desk study, we have noticed that quail and hobby are included in the latest Natura 2000 Standard Data Form for Salisbury Plain SPA (http://jncc.defra.gov.uk/pdf/SPA/UK9011102.pdf), but are not currently listed in the SPA citation (http://jncc.defra.gov.uk/page-2040-theme=default). However, Natural England has confirmed that these species should be regarded as interest features of the SPA.

	iii. Common quail *Coturnix coturnix* 4) Over winter: vii. Hen harrier *Circus cyaneus*
European Site conservation objectives	5) The Conservation Objectives for the SPA state: *Ensure that the integrity of the site is maintained or restored as appropriate, and ensure that the site contributes to achieving the aims of the Wild Birds Directive, by maintaining or restoring:* • *The extent and distribution of the habitats of the qualifying features;* • *The structure and function of the habitats of the qualifying features;* • *The supporting processes on which the habitats of the qualifying features rely;* • *The population of each of the qualifying features; and* • *The distribution of the qualifying features within the site.*
Details of the existing baseline conditions of the site including details of data collection methodologies and consultations undertaken	6) Data were collected through a combination of breeding bird surveys in 2016 and 2017 (detailed in ES Appendix 8.15) and data supplied by RSPB Wiltshire Ornithological Society and Wiltshire & Swindon Biological Records Centre. The breeding bird survey included three targeted for quail habitat in 2016 and seven walked transects 4-6km long in 2017 carried out in line with standard survey methods[14]. 7) Data on stone curlew nesting records dating back to 2006 were obtained from RSPB for an area up to 4km from the A303. There are records of stone curlew nesting on five plots within 1.5km of the current or realigned A303. All of these are located outside the SPA boundary itself. Following examination of these data and discussion with RSPB it was agreed that one successful stone curlew breeding plot outside the SPA (south-east of Parsonage Down) is expected to be rendered unusable as a direct result of the Scheme due to land-take for the Winterbourne Stoke by-pass. 8) Quail was not identified during the 2016 and 2017 surveys, but there have been sightings in 2018. Suitable nesting grassland and arable edge habitat are considered abundant throughout the study area and the Scheme is within the normal breeding distribution for this species. As the number of quail that arrive in the UK on spring migration varies considerably between years, it is possible that quail could breed in suitable habitats within the Scheme boundary. However, a conclusion of no likely significant effect could be made regarding this species, as set out in the likely significant effect report. 9) A known historically active hobby breeding site is located approximately 200m south of the Scheme

[14] Gilbert, G. Gibbons, D.W. and Evans, J.(1998). Bird Monitoring Methods: A Manual of Techniques for Key UK Species. RSPB, Bedfordshire, UK

	boundary. No further possible breeding sites were identified during the 2016 and 2017 surveys. Therefore, a conclusion of no likely significant effect could be made regarding this species, as set out in the likely significant effect report. 10) Hen harrier does not breed on the SPA. Its overwintering roosting locations on the SPA are well known and are more than 10km from the Scheme. 11) Natural England was consulted throughout the baseline data collection and scheme design phases. RSPB advised on survey methods and on assessment and mitigation for stone curlew during scheme design.
The value of the site and qualifying interests therein to the Natura 2000 network	12) According to the Natura 2000 Data Form, at the time of designation the SPA regularly supported: i. 22 pairs of stone curlew representing at least 11.6% of the breeding population in Great Britain (count as at 1998) ii. 1% of the British breeding population of Eurasian hobby iii. 20% of the British breeding population of common quail iv. 14 individual hen harrier, representing at least 1.9% of the wintering population in Great Britain 13) The site is considered to be one of the best areas in the United Kingdom for all these interest features and is therefore integral to the Natura 2000 network.
Likely future changes in baseline conditions at the site in the absence of the project	14) In the absence of the project baseline conditions at the SPA are likely to persist, notwithstanding an increase in disturbance from recreational pressure due to future housing development around Amesbury provided existing management (both habitat and recreational pressure) continues, particularly with regard to the net number of stone curlew nest plots available.
Details of the key species, habitat dynamics and functional relationships that maintain the site integrity	15) In the Salisbury Plain area stone curlew prefer areas of short, sparse vegetation on sandy, stony soils. Increased breeding success has been achieved by the establishment of stone-curlew plots, which are 1-2 ha areas of cultivated land within arable crops, or in some cases within pastures, which are kept free of crops and other vegetation before the arrival of the stone-curlew in March. Arable areas with autumn-sown crops become too tall and dense for breeding in spring so breeding is largely limited to these created breeding plots. Individual breeding territories are set up in April to May. The birds need open areas away from trees or other perches that can be used by avian predators of eggs and chicks. The stone curlews feed mainly at night, largely on grassland near the breeding sites. Communal roosting occurs after breeding, with a roost outside the SPA boundary attracting birds from the surrounding area. Stone curlews are present in the area until September, when they migrate to wintering areas. In order to successfully breed stone curlew require low levels of disturbance

	particularly by predators, people and dogs. Human disturbance can cause stone curlews to leave their nests, which increases the risk of nests being predated by crows or foxes. 16) Non-breeding hen harriers require suitable foraging and roosting habitat within the SPA. They roost communally in wetlands such as carr woodland, marshes and reedbeds, although they sometimes occur on heather moorland, lowland heath and conifer plantations.[15] 17) Breeding hobby requires suitable nesting locations and an adequate supply of insects and small birds. Quail require farmland and grassland with an adequate supply of seeds and insects.

2.4.1 Citations for the SACs and SPAs discussed in this report are included in Appendix A.

3 Assessment Methodologies

3.1 Introduction

3.1.1 The entire HRA (including this Statement to Inform Appropriate Assessment) has been carried out with reference to the general EC guidance on HRA[16] and PINS Advice Note 10. This report has also been prepared in accordance with Highways England guidance on HRA as set out in Design Manual for Roads & Bridges, Volume 11 Section 4 Part 1 (HD44/09). Annex E of HD44/09 sets out a Mitigation Measures Report that should be completed for all Highways England schemes where mitigation is required. That report constitutes Appendix B of this statement to inform appropriate assessment and summarises the mitigation measures identified in this document as well as providing information regarding how the mitigation will be implemented and monitored. Annex F of HD44/09 provides an example outline contents for a statement to inform an appropriate assessment, which has informed this analysis.

3.1.2 PINS Advice Note Ten requires an evaluation of the potential for the scheme to require other consents which could also require Habitats Regulations Assessment by different competent authorities, and a statement as to whether the Scheme boundary overlaps with devolved administrations or other European Economic Area (EEA) States. It is confirmed that the Scheme boundary does not overlap with areas of devolved administrations or with those of other EEA States.

3.1.3 Plate 2 below outlines the stages of HRA according to the Design Manual for Roads and Bridges. This corresponds with that in PINS Advice Note 10.

[15] http://jncc.defra.gov.uk/pdf/UKSPA/UKSPA-A6-47B.pdf
[16] European Commission (2001): Assessment of plans and projects significantly affecting Natura 2000 Sites: Methodological Guidance on the Provisions of Article 6(3) and 6(4) of the Habitats Directive.

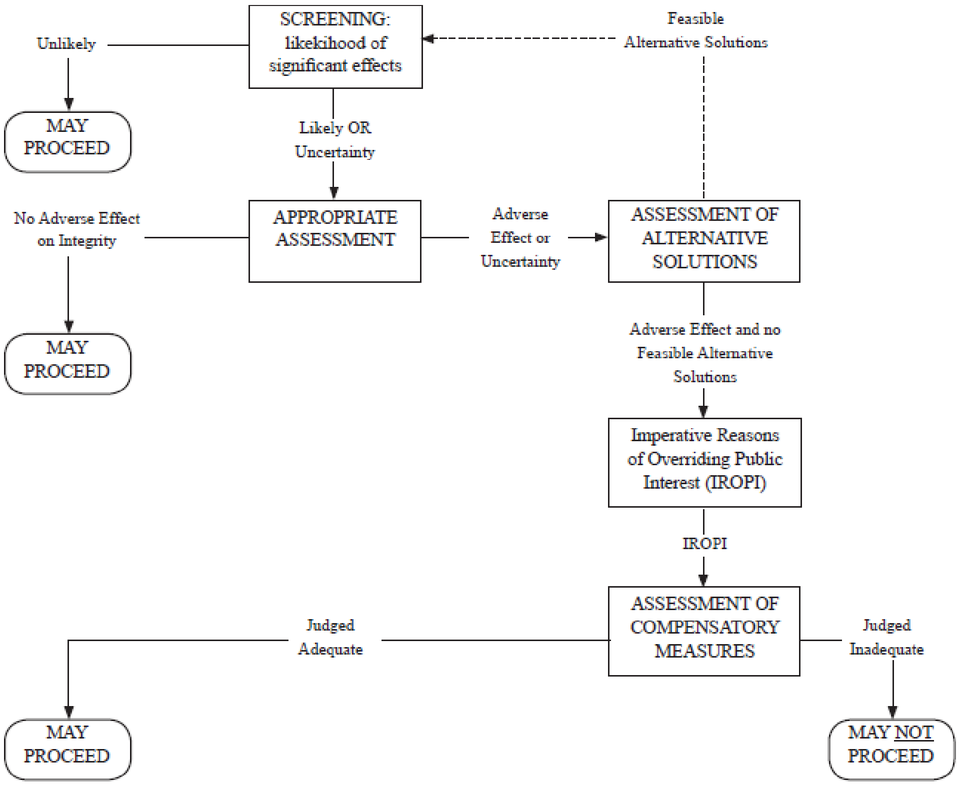


Plate 2. Generic Screening Process for Assessment of the Implications on European Sites. Source DMRB Vol 11, 2009[17].

3.1.4 The HRA covers the construction and operation phases of the scheme. The scheme is not considered to have a decommissioning stage as it is expected to be in place in perpetuity. Therefore no decommissioning impacts are discussed in this report.

3.2 HRA Task 2: Appropriate Assessment

3.2.1 As established by case law, 'appropriate assessment' is not a technical term; it simply means whatever further assessment is necessary to confirm whether there would be adverse effects on the integrity of any European sites that have not been dismissed at screening. Since it is not a technical term, and levels of analysis are likely to vary from site to site and impact pathway to impact pathway, it has no specific methodology except that it essentially involves repeating the analysis for the likely significant effects stage, but to a greater level of detail where practicable and necessary.

3.2.2 A given appropriate assessment may be very technically detailed or it may contain little additional technical analysis beyond that undertaken at screening. However, one of the key considerations during appropriate assessment is whether there is available mitigation (i.e. measures that are not part of standard design but which are included specifically to protect the European sites in question) that would entirely address the potential effect on integrity (in other words, disruption of the coherent structure and function of the European site(s)).

[17] Design Manual for Roads and Bridges, Volume 11 Section 4 Part 1, HD 44/09. Assessment of Implications (of Highways and/or Roads Projects) on European Sites (including Appropriate Assessment)

3.2.3 Recently, the 'People over Wind' European Court of Justice ruling[18] has confirmed that 'mitigation' (i.e. measures that are specifically introduced to avoid or reduce the harmful effects of the project on European sites) should not be taken into account when forming a view on likely significant effects during Task 1 screening.

3.2.4 In evaluating effects on site integrity, we have relied on the professional judgement of, as well as the results of previous stakeholder consultation regarding development impacts on the European sites. For shading at River Till from the new viaduct AECOM has used a considerable body of evidence:

- a literature review of published research;
- a field study into the effects of shading produced by bridges or varying designs and sizes which sampled 31 single-deck bridges and three twin-deck bridges with public access in southern England; and
- a shading modelling study examining the degree of shading that would be cast by the chosen viaduct design.

3.2.5 These are presented in Appendices D and E.

3.3 Impact pathways investigated in the Statement to Inform Appropriate Assessment

3.3.1 For River Avon SAC a single pathway exists for which likely significant effects could not be dismissed:

- Loss of vegetation (and thus potential soil erosion) due to shading from the construction of the River Till viaduct. This would exacerbate the following pressures identified on the Site Improvement Plan: siltation, water pollution, changes in species distributions and habitat fragmentation.

3.3.2 For Salisbury Plain SAC, a single pathway exists for which likely significant effects cannot be dismissed:

- Dust deposition during construction – the Winterborne Stoke bypass will bring the A303 within 60m of the Parsonage Down component of Salisbury Plain SAC. Dust deposition can have adverse effects on the calcareous grassland vegetation if uncontrolled. This would exacerbate the following pressures identified on the Site Improvement Plan: changes in species distributions. No areas of juniper scrub are adjacent to the works such that this interest feature would not be affected.

3.3.3 For Salisbury Plain SPA the three pathways for which likely significant effects could not be dismissed were:

- Direct loss of a successful stone curlew breeding plot immediately south of Parsonage Down which will lie within the scheme boundary in the area for the Winterbourne Stoke bypass and will therefore be lost during construction. Although this plot is outside the SPA it is used by the same population of stone curlew that nest within the SPA and a net reduction in the number of successful stone curlew plots will result in a net reduction in breeding

[18] People Over Wind and Sweetman v Coillte Teoranta (C-323/17)

opportunities for the species, which could affect the ability of Salisbury Plain SPA to achieve its conservation objectives.
- Construction activity/personnel disturbance of breeding stone curlew using the breeding plot at Parsonage Down prior to its removal.
- The operation of the A303 may facilitate recreational disturbance of stone curlew at Normanton Down. The placement of the A303 in tunnel at this location will open up the area to recreational activity, potentially resulting in recreational users on the footpath through Normanton Down crossing the fence-line and disturbing the stone curlew plots.

3.3.4 For all three European sites the need to take impacts forward to appropriate assessment was less to do with the need for further technical impact assessment to understand the adverse effects, and more because of the need to take mitigation into account in forming a conclusion regarding effects on integrity. The scale and nature of the effects and the necessary mitigation measures could be identified at the time the assessment of Likely Significant Effects was undertaken but the People over Wind ruling confirms that they can only be taken into account in an 'appropriate assessment'.

3.4 Principal Other Plans and Projects that May Act 'In Combination'

3.4.1 PINS Advice Note Ten: Habitat Regulations Assessment relevant to Nationally Significant Infrastructure Projects states that in assessing in-combination effects the following projects should be considered:

- Projects that are under construction;
- Permitted application(s) not yet implemented;
- Submitted application(s) not yet determined;
- All refusals subject to appeal procedures not yet determined;
- Projects on the National Infrastructure's programme of projects; and
- Projects identified in emerging development plans (e.g. Wiltshire Core Strategy) recognising that much information on relevant proposals will be limited and the degree of uncertainty which may be present.

3.4.2 In order to inform fully the appropriate assessment process, a number of surrounding plans and projects have been consulted to determine likely significant effects that could arise from the Scheme in combination with these other plans and projects. These were selected because they were the main land use plans and projects that are located within, or surrounding the Scheme, and may interact with the European sites discussed in this report. They are:

- Wiltshire Core Strategy (Adopted 2015);
- Local Transport Plan 3: Joint Strategy for South Hampshire (to 2031);
- Wiltshire Local Transport Plan (2011 – 2026);
- Draft Devizes Neighbourhood plan (2014);
- Winchester District Local Plan Part 1 (Adopted 2013);
- Winchester District Joint Core Strategy DPD (Adopted 2013);
- Southampton Adopted Core Strategy (amended 2015);
- Warminster Neighbourhood Plan (2015 – 2026);
- New Forest District Local Plan (2016 – 2036);
- Test Valley Borough Revised Local Plan (Adopted 2016); and

- Army Basing Programme (announced 2015).

3.5 Assumptions

3.5.1 Assumptions made in this appropriate assessment are:

- It is not possible to accurately quantify the depth or duration of dust soiling that would occur without mitigation. Therefore it has been assumed that any major dust generating activities that will take place within 200m of the SAC could be significant.
- It has been assumed that the net loss of any stone curlew plots in the Salisbury Plain area, even if outside the SPA boundary, could result in an adverse effect on the integrity of the SPA by reducing nesting opportunities for stone curlew.
- It has been assumed that clearance of a stone curlew nesting plot during the nesting season (March to September) could result in a level of disturbance that would adversely affect nesting success but that clearance outside the nesting season would not do so.
- It has been assumed that disturbance could arise from increased recreational usage of Public Rights of Way that lie within 500m of stone curlew plots and are physically connected to the old A303 and thus the large public assemblages that occur at the Stonehenge Monument.
- It is not possible to accurately predict the scale of increased use of such PRoW or the frequency of resulting disturbance events. Therefore, a precautionary assumption has been made that any increase in use of such PRoW could result in an increased incidence of disturbance.

3.6 Determining magnitude and significance

3.6.1 The approach to determining magnitude and significance during the appropriate assessment is tailored to each impact pathway and European site.

3.6.2 With regard to the magnitude and significance criteria for dust soiling impacts on Salisbury Plain SAC account has been taken of the sensitivity of the vegetation, the physical extent of potential soiling (within 200m), the extent of potential dust-generating activities and topography and the prevailing wind direction. It is not possible to accurately quantify the depth or duration of dust soiling that would occur without mitigation. Therefore it has been assumed that any major dust generating activities that will take place within 200m of the SAC could be significant.

3.6.3 With regard to the magnitude and significance criteria for net loss of stone curlew plots or construction disturbance of stone curlew plots during the breeding season, account has been taken of the relatively small breeding population associated with the Salisbury Plain SPA (and thus the high importance of any given plot to the population), the extent to which the population within the SPA is linked to the breeding population outside the SPA, the regularity with which plots have been successfully used for nesting and the number of pairs each relevant plot is known to support. This has resulted in the development of an assessment threshold which defines a significant adverse effect as the permanent loss of one stone curlew plot that is regularly-used by at least one pair.

3.6.4 With regard to the magnitude and significance criteria for recreational disturbance of stone curlew plots, account has been taken of the presence of Public Rights of Way which connect the old A303 to the wider landscape, the proximity of those PRoW to stone curlew nest plots (specifically whether they are located within 500m) and the likely risk of disturbance incidents arising from increased recreational use of those PRoW. However, since it is not possible to accurately predict the scale of increased use of those PRoW or the frequency of resulting disturbance events a precautionary assumption has been made that any increase in use of those PRoW could result in an increased incidence of disturbance which would be significant and thus result on an adverse effect on the integrity of the SPA.

3.6.5 With regard to the magnitude and significance criteria for shading of the River Till from the new crossing, account has been taken of the size of the structure, whether the structure consists of a single bridge deck or two (twin) decks with an intervening gap for daylight penetration, the permanence of the structure and the scale of vegetation loss that may arise. As a result a target height-width ratio of 0.6 to 0.8 has been developed for the permanent viaduct. A height-width ratio below 0.6 could result in an adverse effect on the integrity of the SAC.

3.7 Mitigation

3.7.1 The appropriate assessment makes use of mitigation that is plainly established and uncontroversial for the mitigation of dust emissions. These are long-standing tried and tested measures, which are explicitly recommended in guidance produced by the Institute of Air Quality Management as being measures that will normally reduce dust effects to an insignificant level. Hence the residual effect will normally be ‘not significant’. The assessment also contains mitigation that is plainly established and uncontroversial regarding construction disturbance of stone curlew, requiring clearance of the stone curlew nesting plot at Parsonage Down to take place outside the stone curlew nesting season. The assessment also makes use of more bespoke mitigation measures with regard to recreational disturbance of stone curlew at Normanton Down RSPB reserve, the net loss of stone curlew nesting opportunities at Parsonage Down and avoidance of significant shading of the River Till by the new viaduct.

4 Statement to Inform Appropriate Assessment for Salisbury Plain SAC

4.1 Impact Pathway: Dust Deposition during construction

4.1.1 Part of the SAC is directly adjacent to the Scheme boundary on both sides of the A303 near Bulford Camp; works in this location would be within the highway boundary. The Scheme will also involve construction works within 60m of Parsonage Downs SSSI, which is part of the SAC.

4.1.2 In the absence of mitigation, the Scheme would have an adverse effect on the integrity of the SAC through dust soiling, for the following reasons:

- The Scheme will be constructed within 60m of Parsonage Bank, which the most botanically rich part of Parsonage Down SSSI (within Salisbury Plain SAC) and the most sensitive area to deposition of dust.

- It is downslope of construction and downwind relative to the prevailing south-westerly wind such that dust would readily blow onto the SAC.
- The greatest impact would arise during the main topsoil strip, expected in the first year of construction. At this time agricultural soils blowing onto the vegetation would be expected to cause a blanketing effect on leaf surfaces. After removal of soil deposition of dust would be from dry dug chalk. As the cutting was deepened, more of the dust would potentially be trapped in the cutting, but this would depend on wind speed and direction.
- The subsequent deposition of excavated material would be much less likely to generate dust since it is likely to be damp during spreading and the area for deposition is downhill and predominantly downwind of the SSSI.

4.1.3 Dust emissions during construction could therefore affect the calcareous grassland interest feature within those parts of the SAC that lie relatively close to the works (i.e. within 200m), by coating vegetation and thus affecting evapotranspiration and photosynthesis. It is impossible to quantify the amount of dust soiling that would occur at any given time in the absence of mitigation. Plant communities near short-term works are likely to recover within a year of the dust soiling stress ceasing[19]. Moreover, the thin chalk soils of the general area mean that chalk dust can be generally found in the atmosphere in small quantities. Therefore the scale of any adverse effect even in an unmitigated situation would be small. Nonetheless, in the absence of controlling measures, heavy coating of chalk dust on vegetation close to the works area would potentially result in an adverse effect that could affect the integrity of the SAC.

4.2 Mitigation

4.2.1 Due to the sensitivity of the vegetation, the proximity of the works and the potential scale of dust generating activities, specific mitigation measures will be required. Considerable effort has been devoted over the years by various bodies to developing measures to control dust generation and dissemination. There is high confidence in the effectiveness of these measures based upon many years of practice. The measures that will be deployed on this scheme are being incorporated into an Outline Environment Management Plan (OEMP) which will be submitted as part of the DCO application and finalised at the end of the DCO Examination period. The measures in the OEMP will then be applied in practice by the appointed contractors wherever dust generation is a concern. The contractor will need flexibility to determine which measures are most effective in a given situation but the measures are listed in Institute of Air Quality Management guidance on assessment of dust from demolition and construction[20] and include:

- Undertake daily on-site and off-site inspection, where receptors (including roads) are nearby and can therefore be observed from within the red line boundary/works footprint or public footpaths/byways, to monitor dust and record inspection results
- When activities with a high potential to produce dust are being carried out and during prolonged dry or windy conditions increase the frequency of inspections.

[19] Guderian R. 1986. Terrestrial ecosystems: particulate deposition. In: Air Pollutants and Their Effects on the Terrestrial Ecosystem (Legge AH, Krupa SV, eds). Advances in Environmental Science and Technology, Vol. 18. 339-363, Wiley, New York, USA.

[20] Institute of Air Quality Management. 2014. Guidance on the Assessment of Dust from Demolition and Construction. Accessed at http://www.iaqm.co.uk/text/guidance/construction-dust-2014.pdf on 25/04/18

- Carry out regular dust soiling checks of vegetation surfaces within 100m of site boundary at Parsonage Down through access agreement with Natural England
- dust causing activities are located away from receptors, as far as is possible.
- Use intelligent screening where practicable – e.g. locating site offices between potentially dusty activities and the receptors.
- Erect solid screens or barriers around the site boundary if necessary.
- Remove materials that have a potential to produce dust from site as soon as possible, unless being re-used on site.
- Depending on the duration that stockpiles will be present and their size - cover, seed, fence or water to prevent wind whipping.
- Sheeting of vehicles carrying dusty substrates;
- Ensure all vehicles switch off engines when stationary – no idling vehicles;
- Impose and signpost a maximum-speed-limit of 15 mph on surfaced and 10 mph on un-surfaced haul roads and work areas
- Only use cutting, grinding or sawing equipment fitted or in conjunction with suitable dust suppression techniques such as water sprays or local extraction.
- Ensure an adequate water supply on the site for effective dust/particulate matter suppression/mitigation, using non-potable water where practicable.
- Use enclosed chutes, conveyors and covered skips, where practicable.
- Minimise drop heights from conveyors, loading shovels, hoppers and other loading or handling equipment and use fine water sprays on such equipment wherever appropriate.
- Ensure equipment is readily available on site to clean any dry spillages, and clean up spillages as soon as reasonably practicable after the event using wet cleaning methods.
- Wetting of dust generating activities). These are usually incorporated into a Dust Management Plan (where necessary) produced by the contractor.

4.2.2 These are long-standing tried and tested measures, which are explicitly recommended in guidance produced by the Institute of Air Quality Management as being measures that will normally reduce dust effects to an insignificant level. Hence the residual effect will normally be 'not significant'. Given this, a high level of confidence can be placed in a conclusion of no adverse effect on integrity with their deployment.

4.3 In Combination Effects

4.3.1 No in combination effects have been identified for this impact pathway on this European site.

5 Statement to Inform Appropriate Assessment for Salisbury Plain SPA

5.1 Impact Pathway: Loss of Stone Curlew Nesting Plots during construction

5.1.1 Stone curlews are ground nesting birds which breed on downland, heathland and arable farmland in the south and east of England. Within the Wessex area, the birds prefer areas of short, sparse vegetation on light, stony soils. Within and around the Salisbury Plain SPA this has been achieved by the establishment of stone-curlew plots, which are 1-2 ha areas of cultivated land within arable crops, or in some cases within pastures, which are kept free of crops and other vegetation before the arrival of the stone-curlew in March.

5.1.2 Data on stone curlew nesting records dating back to 2006 were obtained for an area up to 4km from the A303. Following examination of these data and discussion with RSPB it was agreed that one regularly used stone curlew breeding plot outside the SPA (south-east of Parsonage Down) and supporting c. 0.5% of the British breeding population of the species, is expected to be rendered unusable as a direct result of the scheme due to land-take for the Winterbourne Stoke by-pass. There are also records of stone curlew nesting close to the A303 further west of the affected plot but the A303 alignment will not be altered in that location. Although this plot is outside the SPA it is used by the same population of stone curlew that nest within the SPA and the net loss of any successful stone curlew plots will result in a net reduction in breeding opportunities for the species which could affect the ability of Salisbury Plain SPA to achieve its conservation objectives.

5.1.3 Research undertaken for the dualling of the A11 in the vicinity of Breckland SPA identified that average stone curlew nest density (per km^2) on arable land increased with increasing distance from the A11, up to 2km from the road[21]. It is important to note that the pattern of habitat use by stone curlews that breed around Breckland and those which breed around Salisbury Plain is notably different. In Breckland stone curlew generally nest on fields planted with late sown spring crops such as sugar beet and vegetables. In contrast, the arable farming around Salisbury Plain is predominantly autumn-sown cereals, which are not suitable for nesting stone curlew since the crop is too tall and dense during the nesting season. As such, stone curlews in the farmland around Salisbury Plain are dependent on man-made nesting plots, several of which are within 100-200m of the A303 but have nonetheless been regularly used for nesting since 2006. The distribution and density of stone curlew nesting around the A303 is therefore expected to be influenced primarily by the location and number of suitable nesting plots, in contrast to the A11.

5.1.4 Other than the plot to be lost under the bypass, there are records of stone curlew nesting at fourteen other locations within 2km of the A303 between Yarnbury Castle and Countess Junction since 2006. All but four of these historic records are more than 1km distant from the road. All four records within 1km of the A303 are in locations where the A303 will either become more distant due to the

[21] Clarke, R.T., Sharp, J., Liley, D. (2009). The impacts for stone curlews of increased traffic on the A11. Model and predictions. Footprint Ecology.

bypass, or (in the vicinity of Normanton Down) will be removed entirely by the A303 being placed in tunnel. Normanton Down is a focus of stone curlew nesting activity outside the SPA. The scheme would be beneficial to the stone curlew population of the SPA by removing the influence of the A303 from these locations. However, it would not represent a net positive impact when the in combination effects of recreational disturbance are considered (section 5.3 below). The only mitigation required for the loss of the plot which at Winterbourne Stoke bypass is the creation of a replacement nest plot on suitable soils at a suitable location close to the existing plot and with a commitment to manage the plot appropriately.

Mitigation

5.1.5 Discussions with Natural England and RSPB in preparing this appropriate assessment have identified that the mitigation objective should be to ensure no net loss of breeding plots in the Salisbury Plain area by delivering a replacement plot before the existing plot is lost to the Winterbourne Stoke bypass. The replacement plot should be as close to the location of the existing plot as possible (male stone curlew usually return to within 9 miles of their hatching site[22]). Since the plot to be lost is outside the SPA boundary itself the provision of a replacement plot does not class as 'compensation' *sensu* the Habitats Directive. Natural England has agreed that the location of the replacement breeding plot will be in an area of calcareous grassland at Parsonage Down approximately 500m from the current plot and further than that from construction of the Scheme. This location has also been agreed with RSPB. The breeding plot will be 1.2ha in area to allow for a surrounding fence and a long grass margin. The fence will be fitted with predator-resistant electric wire in addition to spikes to stop crows and other corvid predators using the posts as perches. It is intended to provide the new plot in advance of the loss of the existing plot.

5.1.6 Although the breeding plot will be located within the Salisbury Plain SAC boundary and will be located in an area of calcareous grassland (an SAC feature), it will not itself result in an adverse effect on the integrity (the coherence of the structure and function) of the SAC for the following reasons:

- the total area of grassland to be cultivated to create the breeding plot amounts to only 0.005% of the total area of the SAC (which is 21465.94ha);
- The plot creation will not constitute 'loss' of SAC habitat but rather a change to the overall grassland structure at Parsonage Down for both botany and potentially for marsh fritillary butterfly. Much ofhe grassland at the SSSI is currently uniformly tall and dense, whereas a greater botanical and invertebrate diversity on the SAC can be achieved by balancing tall dense areas with shorter, more open turf. The marsh fritillary butterfly in particular is an SAC interest feature that has only recently been recorded at Parsonage Down after an interval of many years[23] and thrives in areas of short disturbed turf on the SAC, such as shell holes on the MOD ranges; and finally,
- This approach to provision of stone curlew plots fits with the existing approach to provision of stone curlew plots within the SAC. Since the physical area of the SPA and SAC overlap it is normal practice for a balance between the

[22] https://www.rspb.org.uk/birds-and-wildlife/wildlife-guides/bird-a-z/stone-curlew/breeding-nesting-and-migration/
[23] Stuart Hales, Natural England Senior Reserves Manager, Wiltshire National Nature Reserves, personal communication

needs of the interest features to be struck through variations in sward management.

5.1.7 There is a high degree of confidence that this stone curlew plot will be utilised as it is to be provided in a suitable area on suitable soil close to an existing plot that has been regularly used by stone curlew, and the plot is being designed and delivered in conjunction with RSPB and Natural England in an manner that has been successful with the other plots around the Salisbury Plain area. Natural England has agreed to maintain this plot. The provision of this plot will ensure no net loss of breeding plots within the Salisbury Plain area. Coupled with the fact that (as already discussed) the A303 and Winterbourne Stoke bypass will be moved further away from at least 4 other stone curlew plots within 1km of the current A303 alignment it is considered that the scheme will result in no adverse effect on the integrity of the SPA through this pathway.

5.2 Impact Pathway: Construction disturbance of nesting stone curlew

5.2.1 Stone curlews breed outside the SPA in proximity to the scheme at Normanton Down RSPB reserve and at other locations known to historically support breeding stone curlew. These populations of stone curlew would have the potential to be disturbed by increased vehicular movements and human disturbance during construction. Disturbance impacts would have the potential to cause stress, which may result in a reduction in their resilience and breeding success. In extreme cases disturbance impacts may result in the abandonment of breeding plots.

5.2.2 It is considered that this pathway could arise from any construction works within 500m[24] of nesting plots that are undertaken during the breeding season and which represent a level of activity that exceeds the current levels to which those plots are exposed. Using this criterion, the only location where such disturbance is expected to occur in the absence of mitigation is when the existing plot north of the A303 at Parsonage Down is to be removed. If this occurred during the nesting season it would have an adverse effect on the integrity of the SPA by causing any nesting stone curlew pair to abandon their nest. As stated above it is planned to create the new plot in advance of construction. The existing plot would be made unsuitable to discourage any attempt at breeding that would subsequently expose stone curlew to disturbance during construction.

5.2.3 The stone curlew plots at Normanton Down RSPB reserve are more than 500m from the old A303 (the closest being 630m distant) and further than this from the tunnel portals. There is a stone curlew plot within 500m of the A303 south-west of Winterbourne Stoke, but it is partly screened by the landform and by existing hedge and trees along the A303. Moreover, in this area the A303 will be routed further away from the nest plot due to the Winterbourne Stoke bypass and construction work will therefore take place on the opposite side of the old A303. The old A303 will remain open and operational until the new route is complete, continuing to provide the existing background of activity. The reduction of the width of the highway when the old A303 is converted to a private means of access and Public Right of Way will involve activity by vehicles and some workers but this will be of short duration and in a location already subject to a high level of existing vehicle traffic on the A303 itself.

Mitigation

5.2.4 The primary effective mitigation measures will consist of ensuring that the clearance of the existing stone curlew plot to be lost to the scheme takes place outside the stone curlew breeding season of March to August and that the replacement plot is ready for use by stone curlew by the breeding season at the start of construction. All construction staff working within 500m of the plot will also be given a toolbox talk regarding the sensitivity of stone curlew.

5.2.5 This measure is included in the OEMP submitted with the DCO application and will be finalised at the end of the Examination. With these measures in place it is considered that no construction-related disturbance of nesting stone curlew would occur since they will not be present at the most sensitive plot when the most potentially disturbing works take place. As such, no adverse effect on the integrity of the SPA would arise through this pathway.

5.3 In-Combination Effect: Recreational Disturbance

5.3.1 Stone curlews are highly vulnerable to disturbance by walkers and dogs. They show an active response to a disturbance agent, even at large distances. For stone curlews this can be up to 500m for a person with a dog[25]. In contrast they are generally much less affected by individual vehicles in proximity to their nest sites. A disturbance event is a light, noise or visual cue that disrupts the bird’s activities. This could be flushing them from a nest or flushing from feeding, causing them to expend extra energy flying away from this disturbance. The effects this can have on birds include; disrupting birds from incubating eggs on a nest which can lead to abandonment and spoiling of the eggs and or leaves the nest more vulnerable to egg predation, therefore decreasing breeding success.

5.3.2 The Public Right of Way (PRoW) that runs north-south on the west side of the RSPB reserve is approximately 150m-220m from the active stone-curlew plots. At present the A303 separates the public visiting the Stonehenge monument and the RSPB reserve at Normanton Down; therefore the foot traffic passing the reserve is limited by the road and the vegetation along the existing fence line separating the footpath from the reserve provides some screening. However, at completion of the Scheme the highway near Normanton Down reserve will be within a tunnel and the old road will be converted to a restricted byway for non-motorised users. The removal of the A303 as a barrier to foot traffic will allow visitors from the focal point of Stonehenge monument to use the PRoW to the south of the A303. The scheme would not provide unrestricted access to farmland south of the A303 and public access is expected to continue to be on the existing byways. However, this increased tourism could operate in combination with an increase in the local population due to housing growth (such as that set out in the Wiltshire Core Strategy) and its associated increase in local recreational use of PRoW to increase the risk of disturbance of some stone curlew plots in the area. Visitors with dogs are likely to be the most disturbing to stone curlew. If the number of disturbing events increases above the threshold of tolerance of individual pairs of

[25] Taylor, E.C., Green, R.E., Perrins, J., 2007. *Stone-curlews Burhinus oedicnemus and recreational disturbance: developing a management tool for access.* RSPB. Ibis (2007), 149 (Suppl. 1), 37–44. http://www.avibirds.com/pdf/G/Griel2.pdf

stone curlews, then in combination, this may result in greater long-term disturbance on breeding stone curlew and an indirect adverse permanent effect on nesting success locally.

5.3.3 The boundaries of the RSPB reserve are currently fenced, with signs to discourage people from entering the reserve in periods when there is potential to disturb nesting birds. It is understood that the majority of existing users remain on the PRoW and do not climb fences or gates to enter the reserve. Nonetheless RSPB and the local landowner have reported cases of unauthorised camping on the PRoW from motor vehicles and some of those individuals entering the fields beyond the PRoW. The owner has also reported incidents of illegal hare coursing activity, with repeated damage to fencing and gates.

5.3.4 In 2018 Wiltshire Council carried out a test on the two PRoW adjacent to the reserve by closing those routes to motorised traffic, making them restricted byways, only open to pedestrians, cyclists and horse riders. This is a measure proposed as part of the management of the World Heritage Site, to protect the Outstanding Universal Value of the WHS. This is because parking of vehicles on the PRoW is considered to have an adverse effect on the setting of Stonehenge and other monuments within the WHS. If the measure that has been introduced by Wiltshire Council is applied permanently, the likelihood of trespass associated with camping and hare-coursing disturbing stone curlew nesting is likely to decrease.

5.3.5 This means that although the number of people using the PRoW may increase after opening of the Scheme, there may not be any direct link between the number of people and the frequency of disturbing events. Although Wiltshire Council is taking measures to address recreational pressure at Normanton Down, it is clear that there is uncertainty as to their efficacy and it would therefore not be robust to draw a conclusion of no adverse effect on integrity based on those measures.

Mitigation

5.3.6 Due to the possibility that the measures already being taken to address recreational use of the PRoW at Normanton Down RSPB reserve will not remove the risk of an effect entirely, a precautionary approach is being taken to mitigation for this scheme, in order to increase confidence that recreational disturbance in combination would not result in a net loss of nesting opportunities for stone curlew associated with the SPA. Provision of an additional stone curlew plot has been agreed in principle with RSPB on its reserve at Winterbourne Down. It is considered that an improvement in the nesting opportunities available there would ensure no adverse effect on the integrity (structure and function) of the SPA, even if there was some disturbance post-construction at Normanton Down.

5.3.7 As with the plot at Parsonage Down, the breeding plot will be 1.2ha in area to allow for a surrounding fence and a long grass margin. The fence will be fitted with predator-resistant electric wire in addition to spikes to stop crows and other corvid predators using the posts as perches. It is intended to provide the new plot prior to closure to traffic of the existing A303 route at Normanton Down..

5.3.8 There is a high degree of confidence that this stone curlew plot will be utilised as it is to be provided in a suitable area on suitable soil close to an existing plot that has been regularly used by stone curlew, and the plot will be designed and delivered in conjunction with RSPB in an manner that has been successful with the other plots around the Salisbury Plain area. RSPB has agreed to maintain this plot.

6 Statement to Inform Appropriate Assessment for River Avon SAC

6.1 Impact Pathway: Shading of the River Till as a result of viaduct construction

6.1.1 The Scheme will involve a new permanent viaduct crossing of the River Till, north of Winterbourne Stoke, as well as a temporary (2 year duration) crossing for construction traffic. The River Till is a component SSSI of the River Avon SAC designated for supporting 'Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation' listed on Annex I of the Habitats Directive. Depending on the details of design, the bridges could result in some level of shading which could in turn affect vegetative growth at this point of the River Till. This is particularly the case for the permanent viaduct. If shading was sufficient in scale and duration to cause loss of vegetation, this could result in soil erosion from denuded banks during periods of high flow, which could then lead to water quality effects downstream by siltation. Investigation of published literature on the subject reveals the following:

- Shading has the potential to impact on above ground biomass. In field trials, Heger (2016) established plots of grass and legume species and found that compared to the control, community biomass production decreased under shading (-56%)[26].
- Shading also has the potential to impact on the composition of plant communities. Edelkraut & Gusewell (2006) investigated how the composition of wetland communities changed over time in response to altered light regimes[27]. Over three years, these were subjected to artificial shading (continuous or seasonal) in a field experiment. Communities were initially dominated by three grass species in all treatments, but subsequently sedges (*Carex* species) increased and reached dominance in the control plots, whereas grasses remained dominant in the shaded plots.
- In the late 1970s, Dawson and Kern-Hansen (1979) showed that light is nearly always one of the main limiting factors to plant growth, and that there is a linear relationship between the light available at the stream surface and the submerged plant standing crop for species such as water crowfoot *Ranunculus* sp[28]. This finding led to a study into the control of rooted macrophytes in flowing waters using polypropylene material to shade the aquatic plants. Dawson & Hallows (1983) reported a direct correlation between shading and reduced biomass of submerged *Ranunculus* species and also emergent plant species[29]. Although some chalk stream macrophyte species are shade-tolerant, most are not strongly so. Ham et al. (1982) found

[26] Heger, T. 2016. *Light availability experienced in the field affects ability of following generations to respond to shading in an annual grassland plant.* Journal of Ecology, 104, pp. 1432-1440

[27] Edelkraut, K.A. and Gusewell, S. 2006. Progressive effects of shading on experimental wetland communities over three years. Plant Ecology. Volume 183, Issue 2, pp. 315–327

[28] Dawson, F.H. and Kern-Hansen, U. 1979. The Effect of Natural and Artificial Shade on the Macrophytes of Lowland Streams and the Use of Shade as a Management Technique. Int. Rev. Ges. Hydrobiol., 64: 437-255

[29] Dawson, F.H. and Hallows, H.B. 1983. Practical Applications of a shading material for macrophytes control in watercourses. Aquatic Botany, 17, 301 - 308

that the growth of *Ranunculus* was restricted by shading, and the morphological changes recorded included reduced leaf size[30].

- Within a temperate eutrophic lowland river, Kohler et al. (2010) observed a significant reduction in macrophyte biomass at shading levels greater than 55%[31]. Similarly, Garbey et al. (2006) found reduced biomass of *Ranunculus peltatus* with 50% shading compared to unshaded conditions[32]. Garbey et al. (2004) reported differences between sites with *R. peltatus* related to flow, nutrient status, disturbance and shading[33]. *R. peltatus* flowered in sunny sections (less than 5% shade) and had lower production in shaded sites. In addition, Garbey et al. (2006) identified that regeneration of *R. peltatus* from current-dispersed fragments depended strongly on light availability, with regeneration from plant fragments occurring in open conditions and 50% shading, but not under 100% shading.
- Few studies have considered the shading effects of bridges on vegetation. The only relevant one identified was a study conducted in North Carolina, in which Broome et al. (2005) reported a correlation between the ratio of bridge height (H) and bridge width (W) and effects of shading on saltmarsh habitat at seven permanent bridges 3m-15m high[34]. Broome et al. (2005) found that bridges with height to width (H:W) ratios less than 0.5 affected marsh productivity and function under the bridges. At H:W ratios between 0.5 and 0.68, bridge effects were detected but were greatly diminished. Above H:W ratios of 0.70 the effects from shading by bridges were no longer measurable. Broome et al. (2005) therefore concluded that shading by bridges with H:W ratios >0.7 do not adversely impact the productivity or function of the underlying marsh. There do not appear to be any similar studies of shading by bridges carried out for terrestrial or aquatic habitats in England or other parts of Europe prior to the shading study in Appendix D.

6.1.2 The proposed permanent viaduct over the River Till SSSI has the potential to result in impacts on the SAC due to the permanent shading associated with the River Till viaduct. If not mitigated, the shading would be expected to result in an area of reduced terrestrial and aquatic vegetation coverage within the SSSI and adjacent river valley. If bare ground persisted under the bridge it would be susceptible to erosion, leading to potential siltation downstream and hence indirect impacts on aquatic vegetation within the SAC/ SSSI downstream and on spawning sites for fish. The erosion would be expected to continue as long as there was soil or other fine substrate that could be eroded.

6.1.3 A study into the effects of shading produced by permanent bridges of varying designs and sizes has been undertaken to inform the design of the proposed River Till viaduct. This study sampled 31 permanent single-deck bridges and three twin-deck bridges with public access beneath them in southern England. A variety of measurements were taken from these bridges, including their width,

[30] Ham, S. F., Cooling, D. A., Hiley, P. D., McLeish, P. R., Scorgie, H. R. A. & Berrie, A. D. 1982. Growth and recession of aquatic macrophytes on a shaded section of the River Lambourn, England, from 1971 to 1976. Freshw. Biol. 12: 1–15.

[31] Kohler, J., Hachol, J. and Hilt, S. 2010. Regulation of submersed macrophyte biomass in a temperate lowland river: Interactions between shading by bank vegetation, epiphyton and water turbidity. Aquatic Botany 92 129–136

[32] Garbey, C., Thiébaut G. and Muller, S. 2006. An experimental study of the plastic responses of Ranunculus peltatus S. Hydrobiologica, 570 41-46

[33] Garbey, C., Thiébaut G. and Muller, S. 2004. Morphological plasticity of a spreading aquatic macrophyte, Ranunculus peltatus, in response to environmental variables. Plant Ecology 173: 125–137.

[34] Broome, S.W., Craft, C.B., Struck, S.D. and M. SanClements. 2005. Effects of Shading from Bridges on Estuarine Wetlands. [pdf] Available at: https://connect.ncdot.gov/projects/planning/RNAProjDocs/2001-12FinalReport.pdf

height, aspect, vegetation cover and the light levels beneath the bridge relative to an unshaded control. Sketches and qualitative observations were also made. Analysis of these data was undertaken to determine any significant relationships between the variables, and any effect of the bridge's height-width (H:W) ratio and aspect on vegetation beneath. The study is presented in Appendix D. It concluded that there is an increased likelihood of significant adverse effects on vegetation if the height to width ratio of the permanent structure is 0.6 or less. Therefore, the minimum recommended height-width ratio for a permanent bridge is in the range of 0.6 to 0.8.

6.1.4 The results from this study were used to inform the design of the permanent viaduct, to minimise the likely shading on the River Till section of the SAC and allow sufficient light beneath the viaduct to maintain vegetation and in conjunction with other factors, led to the selection of a twin deck design rather than a single deck. The chosen design is a twin deck bridge structure, with each deck of width 13.4 m, approximately 7.0 m gap between the decks, parapets, a noise barrier on the southern edge of the westbound bridge deck, the decks at a height of 10.0 m above average ground level with each deck supported by four piers, and with an east-west orientation. The design has been developed taking into account a range of factors, including: highway design requirements; the horizontal and vertical alignment of the whole bypass necessary to avoid impact on the Outstanding Universal Value of the World Heritage Site; reduction of visual and noise impacts for residents at Winterbourne Stoke, and the experience of users of the PRoW along the Till valley; the balance of cut and fill, as well as the intended avoidance or reduction of harmful effects on the SAC.

6.1.5 This bridge design was then subject to a shading modelling study, presented in Appendix E, to provide quantitative data on the shading by the viaduct. For the purposes of comparison a range of designs were modelled. The following metrics have been applied in this study:

- Spatial distribution of solar exposure throughout the growing season - The solar exposure provides information on the number of hours when sunlight is available during a specified period i.e. in this case the growing season.
- Area-based solar radiation attenuation factor throughout the growing season (ASRAF) – This compares total incident solar insolation at ground level with a bridge present to the total available global solar radiation at ground level without a bridge present throughout the growing season from March to September inclusive, as a ratio.
- Daylight attenuation factor throughout the growing season – This compares total daylight received at ground level with the bridge in place to the total available unobstructed daylight for the growing season at the site at ground level without a bridge present. Modelling was done with two approaches 'Overcast sky', which models diffuse light only, and 'Intermediate Sky with Sun' which models a combination of direct sunlight under the bridge and diffuse light, taking into account the angle of the sun seasonally and throughout the day.

6.1.6 For all three metrics the chosen bridge design (Option 2.1 in Appendix E) would mean that even for the most affected 20-40m stretch of the River Till (i.e. beneath the bridge deck) the vegetation would still receive c. 40-60% of the daylight that it would receive with no bridge at all. For the viaduct as designed, the zone of influence is limited mainly to the area under the bridge decks (Bridge Zone). Shading occurs beyond the bridge close to sunrise and sunset but in the zone up to 35m from the bridge the cumulative reduction of solar radiation would be less than 3% of the total in a growing season. The area-based solar radiation attenuation factor (ASRAF) for the growing season for the chosen structure was an average of 0.56 (i.e. 56% of the wholly unshaded areas north and south of the bridge). Using the CIE 'Intermediate Sky with Sun' model, which is considered to be most representative of typical conditions during a growing season in England, the daylight attenuation factor for the a series of modelled points beneath the bridge and in the gap between decks varied from 0.4 (under the northern bridge deck) to 0.5 (under the southern bridge deck). In all instances considerably more daylight would penetrate with the twin deck than if a similar total width of single bridge deck, was used, with no central gap. The modelling enabled the effects of shading to be calculated for transects across the bridge zone, across the middle of the viaduct, representing the River Till, and in peripheral areas of the bridge nearer the abutments (range 0.37 to 0.75).

6.1.7 Shading of course occurs naturally, rather than purely due to structures. To put this percentage reduction into a natural context, Kohler et al (2010) [35] observed that within a temperate eutrophic lowland river, bank vegetation at a shaded site can decrease the light supply to the water surface by 79%. As has already been reported, Kohler et al. (2010) recorded a statistically significant 20% reduction in macrophyte biomass at shading levels greater than 55% (i.e. daylight penetration reduced to less than 45% of an unshaded situation), although the species persisted even at this level of shading. Similarly, Garbey et al. (2006) found reduced biomass of *Ranunculus peltatus* with 50% shading compared to unshaded conditions but the species persisted[36]. They identified that regeneration of *R. peltatus* from current-dispersed fragments did still occur in 50% shading albeit at a lower scale than in unshaded conditions.

6.1.8 The River Till in the area of the viaduct does not currently support *Ranunculus* but is instead bordered by pasture. Natural England have confirmed that they would require this grassland to continue beneath the viaduct and that any conversion to bare ground via shading would be deemed an adverse effect on the integrity of the SAC. The data regarding the continued persistence of *Ranunculus* at shading levels greater than those to which the River Till will be subject strongly indicates that due to the attention paid to bridge design the stretch of the River Till beneath the viaduct will continue to be vegetated. The shading cast by the viaduct will be less than the level of shading that could be cast in a natural situation by dense bankside tree cover, as already occurs along the River Till immediately south of the A303.

6.1.9 During the construction period the retained vegetation within the SSSI would be mowed rather than grazed. Areas of the adjacent floodplain affected by construction will be re-seeded as grassland. It would be possible to restore grazing throughout once the pasture has re-established. However, the area beneath the viaduct is likely to be attractive to livestock for shelter and shade and if not controlled this could lead to excessive trampling and risk of erosion and

[35] Kohler, J., Hachol, J. and Hilt, S. 2010. Regulation of submersed macrophyte biomass in a temperate lowland river: Interactions between shading by bank vegetation, epiphyton and water turbidity. Aquatic Botany 92 129–136

[36] Garbey, C., Thiébaut G. and Muller, S. 2006. An experimental study of the plastic responses of *Ranunculus peltatus* S. Hydrobiologica, 570 41-46

siltation. Hence in the post-construction period management will be by mowing initially. After establishment of the sward, a trial will be carried out under the viaduct outside the SSSI to assess whether grazing can be resumed without adverse effects. An area around the central span of the viaduct including the SSSI will be fenced to exclude livestock in order to control poaching[37]. The fenced zone including the SSSI and adjacent grassland will remain in place for at least 5 years after completion of the viaduct and the area will be permanently fenced if this is necessary to avoid adverse effects of grazing and trampling under the viaduct.

6.1.10 The temporary construction crossing will be a bailey-bridge type structure and will be in place for a relatively short period of 2 years. The risk of any shading causing loss of vegetation (and therefore erosion of bare ground) is therefore considerably less than for the permanent viaduct. Nonetheless, in order to render this risk negligible the construction crossing has been designed to be as narrow as possible, consisting of a single lane structure approximately 4-5m wide. With the mitigation of a single lane width, vegetation beneath the temporary bridge is expected to survive the shading and to fully recover from any reduction in growth after removal of the bridge.

6.1.11 With these measures in place it is considered that there would be no adverse effects on the integrity of the River Avon SAC from temporary bridge or the permanent viaduct.

6.2 In-Combination Effects

6.2.1 No in-combination effects associated with the scheme and other plans or projects have been identified for River Avon SAC.

7 Proposals for Monitoring and Reporting

7.1 Monitoring

Salisbury Plain SAC

7.1.1 Dust control measures include a commitment to check for dust deposition on vegetation within the SAC on a daily basis when there is construction activity that may cause dust going on within 200m of the SAC (determinable by visual inspection from within the Scheme boundary/works footprint, public footpaths/byways or by agreement with Natural England). In the event that a significant dust deposition event does occur it will be washed off by normal weather but dust control measures will be updated to ensure it does not recur.

Salisbury Plain SPA

7.1.2 Natural England will observe use of the replacement stone curlew plots at Parsonage Down National Nature Reserve, while RSPB will do so for the replacement plot at Winterbourne Down. This monitoring may also be incorporated into the existing contract for monitoring stone curlew breeding plots elsewhere in the Salisbury Plain area. In the event that the fencing protection of the plots proves inadequate it will be strengthened.

River Avon SAC

7.1.3 With regard to shading by the River Till viaduct, avoidance of this is an inherent design feature. Botanical condition monitoring will be carried out during the construction period to check the cover of vegetation beneath the temporary bridge. Monitoring will also be carried out to check the cover and composition of existing retained vegetation within the SSSI/SAC beneath and adjacent to the viaduct and similarly the cover and composition of retained and re-seeded vegetation post-construction for five years. The stock-proof fencing beneath the viaduct will be monitored annually to ensure it remains intact. Fencing will be retained until and unless monitoring indicates that grazing can be resumed without increasing the risk of siltation in the River Till.

7.2 Reporting

7.2.1 The monitoring undertaken by the construction contractor will be documented in their construction logs.

8 Consultations

8.1.1 Natural England and RSPB have been consulted throughout the EIA process with regard to the loss of stone curlew nest plots, including devising mitigation. Natural England has been consulted on the HRA screening exercises (Likely Significant Effects). Natural England will be consulted on this statement to inform an appropriate assessment during Pre-Examination.

9 Conclusions

9.1.1 The following measures identified in this appropriate assessment would need to be implemented during construction in order to ensure no adverse effects on integrity:

- An OEMP (Appendix 2.2) containing mitigation measures for construction dust on Salisbury Plain SAC within 200m of Parsonage Down and construction disturbance at Salisbury Plain SPA and its implementation;
- The delivery of a replacement breeding plot for stone curlew at Parsonage Down and a new breeding plot at Winterbourne Down.

9.1.2 The other mitigation measures (to minimise shading of the River Till from the construction crossing and the new permanent viaduct) is already integrated into the design of both features.

9.1.3 Following the implementation of the mitigation noted above it is concluded that the scheme would have no adverse effect on the integrity of any European sites alone or in combination with other projects and plans.

9.1.4 There are no residual effects that would constitute an adverse effect on the integrity of European sites either alone or in combination with other plans or projects.

10 References

Broome, S.W., Craft, C.B., Struck, S.D. and M. SanClements. 2005. Effects of Shading from Bridges on Estuarine Wetlands. [pdf] Available at: https://connect.ncdot.gov/projects/planning/RNAProjDocs/2001-12FinalReport.pdf

Clarke, R.T., Sharp, J., Liley, D. 2009. The impacts for stone curlews of increased traffic on the A11. Model and predictions. Footprint Ecology.

Dawson, F.H. and Kern-Hansen, U. 1979. The Effect of Natural and Artificial Shade on the Macrophytes of Lowland Streams and the Use of Shade as a Managemert Technique. Int. Rev. Ges. Hydrobiol., 64: 437-255

Dawson, F.H. and Hallows, H.B. 1983. Practical Applications of a shading material for macrophytes control in watercourses. Aquatic Botany, 17, 301 - 308

Edelkraut, K.A. and Gusewell, S. 2006. Progressive effects of shading on experimental wetland communities over three years. Plant Ecology. Volume 183, Issue 2, pp. 315–327

European Commission (2001): Assessment of plans and projects significantly affecting Natura 2000 Sites: Methodological Guidance on the Provisions of Article 6(3) and 6(4) of the Habitats Directive.

Garbey, C., Thiébaut G. and Muller, S. 2004. Morphological plasticity of a spreading aquatic macrophyte, Ranunculus peltatus, in response to environmental variables. Plant Ecology 173: 125–137.

Garbey, C., Thiébaut G. and Muller, S. 2006. An experimental study of the plastic responses of Ranunculus peltatus S. Hydrobiologica, 570 41-46

Ham, S. F., Cooling, D. A., Hiley, P. D., McLeish, P. R., Scorgie, H. R. A. & Berrie, A. D. 1982. Growth and recession of aquatic macrophytes on a shaded section of the River Lambourn, England, from 1971 to 1976. Freshw. Biol. 12: 1–15.

Heger, T. 2016. Light availability experienced in the field affects ability of following generations to respond to shading in an annual grassland plant. Journal of Ecology, 104, pp. 1432-1440

Institute of Air Quality Management. 2014. Guidance on the Assessment of Dust from Demolition and Construction. Accessed at http://www.iaqm.co.uk/text/guidance/construction-dust-2014.pdf on 25/04/18

JNCC. 2001. Porton Down SPA description. Joint Nature Conservation Committee [Accessed 18/07/18] from http://jncc.defra.gov.uk/page-2040-theme=default

JNCC. 2001. Salisbury Plain SPA description. Joint Nature Conservation Committee [Accessed 18/07/18] from http://jncc.defra.gov.uk/page-2039-theme=default

JNCC 2015. Salisbury Plain: Natura 2000 – Standard Data Form. Joint Nature Conservation Committee [Accessed 18/07/18] from http://jncc.defra.gov.uk/pdf/SPA/UK9011102.pdf.

Kohler, J., Hachol, J. and Hilt, S. 2010. Regulation of submersed macrophyte biomass in a temperate lowland river: Interactions between shading by bank vegetation, epiphyton and water turbidity. Aquatic Botany 92 129–136

Natural England. 2014. European Site Conservation Objectives for River Avon SAC (UK0013016) [Accessed 18/07/18] from http://publications.naturalengland.org.uk/publication/6048472272732160

Natural England. 2014. European Site Conservation Objectives for Salisbury Plain SAC (UK0012683) [Accessed 18/07/18] from http://publications.naturalengland.org.uk/publication/4786217489006592

Natural England. 2014. European Site Conservation Objectives for Salisbury Plain SPA (UK9011102) [Accessed 18/07/18] from http://publications.naturalengland.org.uk/publication/5745803545018368

Natural England. 2014. Site Improvement Plan Avon River and Valley [Accessed 18/07/18] from http://publications.naturalengland.org.uk/file/6247102287970304

People Over Wind and Sweetman v Coillte Teoranta (C-323/17)

RSPB. Breeding, nesting and migration. Royal Society for the Protection of Birds [Accessed 18/07/18] from https://www.rspb.org.uk/birds-and-wildlife/wildlife-guides/bird-a-z/stone-curlew/breeding-nesting-and-migration/

Stroud, DA, Chambers, D, Cook, S, Buxton, N, Fraser, B, Clement, P, Lewis, P, McLean, I, Baker, H & Whitehead, S (eds). 2001. The UK SPA network: its scope and content. JNCC, Peterborough [Accessed 18/07/18] from http://jncc.defra.gov.uk/page-1412

Taylor, E.C., Green, R.E., Perrins, J., 2007. Stone-curlews Burhinus oedicnemus and recreational disturbance: developing a management tool for access. RSPB. Ibis (2007), 149 (Suppl. 1), 37–44. http://www.avibirds.com/pdf/G/Griel2.pdf

UNESCO. 2005. The Precautionary Principle. United Nations Educational, Scientific and Cultural Organization [Accessed 18/07/2018] from http://unesdoc.unesco.org/images/0013/001395/139578e.pdf

Appendices

Appendix A European Designated Sites Background

A.1 Salisbury Plain SAC

A.1.1 Introduction

A.1.1.1 Largest remaining area of chalk grassland in north-west Europe that supports several important habitats and associated species, including calcareous grasslands and juniper scrub on these grasslands or heaths. The ancient grasslands and scrubland support important assemblages of invertebrates, particularly butterflies, moths, flies and bees.

A.1.1.2 The SAC encompasses Salisbury Plain SPA along with their respective SSSIs. Salisbury Plain SAC also includes Parsonage Down SSSI.

A.1.2 Reasons for Designation

A.1.2.1 Salisbury Plain SAC qualifies as a SAC through its habitats and species. The SAC contains the Habitats Directive Annex I habitats:

- *Juniperus communis* formations on heaths and calcareous grasslands
- Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia) (*important orchid sites)

A.1.2.2 The SAC also supports the following Habitats Directive Annex II qualifying species:

- Marsh fritillary butterfly (*Euphydryas aurinia*)

A.1.3 Current Pressures and Threats[38]

- Changes in species distributions
- Air pollution: risk of atmospheric nitrogen deposition

A.1.4 Conservation Objectives[39]

A.1.4.1 With regard to the SAC and the individual species and/or assemblage of species for which the site has been classified (the ‘Qualifying Features’), and subject to natural change;

A.1.4.2 Ensure that the integrity of the site is maintained or restored as appropriate, and ensure that the site contributes to achieving the Favourable Conservation Status of its Qualifying Features, by maintaining or restoring;

- The extent and distribution of qualifying natural habitats an habitats of qualifying species
- The structure and function (including typical species) of the qualifying natural habitats
- The structure and function of the habitats of qualifying species
- The supporting processes on which qualifying habitats and the habitats of the qualifying species rely

[38] http://publications.naturalengland.org.uk/publication/5745803545018368 [accessed 29/03/2018]
[39] http://publications.naturalengland.org.uk/publication/4786217489006592 [accessed 29/03/2018]

- The population of each of the qualifying species, and,
- The distribution of the qualifying species within the site.

A.2 Salisbury Plain SPA

A.2.1 Introduction

A.2.1.1 Largest remaining area of chalk grassland in north-west Europe that supports rare plants such as tuberous thistle (*Cirsium tuberosum*) and meadow clary (*Salvia pratensis*). The site also supports important scrub communities which include juniper (*Juniperus communis*), buckthorn (*Rhamnus cathartica*), hawthorn (*Crataegus monogyna*), yew (*Taxus bacatta*) and wayfaring-tree (*Viburnum lantana*). Breeding stone curlew and other birds are dependent upon the extensive areas of short grassland and scrubland, and wintering birds forage across these habitats.

A.2.1.2 Salisbury Plain is a composite site comprised of three large sections. Although the A303 is between 2.5km and 3.6km away from the sites north-west of Amesbury, the east section of the SPA is traversed by the road just south of Bulford Camp. Salisbury Plain SSSI is encompassed within the SPA area.

A.2.2 Reasons for Designation

A.2.2.1 The site qualifies under Article 4.1 of the Directive (79/409/EEC) supporting populations of European importance of the following species listed on Annex I of the Directive, during the breeding season:

- Stone curlew (*Burhinus oedicnemus*) – 20 breeding pairs (approximately 10.5% of the population in Great Britain)[40]

A.2.2.2 The site also qualifies as it supports the following over wintering populations:

- Hen harrier (*Circus cyaneus*) – 14 individuals (approximately 1.9% of Great Britain's wintering population)[41]

A.2.2.3 Qualifying species not listed in Annex I of the Wild Birds Directive (Article 4.2) include the following species during the breeding season:

- Eurasian hobby (*Falco subbuteo*)
- Common quail (*Coturnix coturnix*)

A.2.3 Current Pressures and Threats[42]

- Changes in species distributions
- Air pollution: risk of atmospheric nitrogen deposition

A.2.4 Conservation Objectives[43]

A.2.4.1 With regard to the SPA and the individual species and/or assemblage of species for which the site has been classified (the 'Qualifying Features'), and subject to natural change;

40 http://jncc.defra.gov.uk/page-2039-theme=default [accessed 28/03/2018]
41 http://jncc.defra.gov.uk/page-2040-theme=default [accessed 29/03/2018]
42 http://publications.naturalengland.org.uk/publication/5745803545018368 [accessed 29/03/2018]
43 http://publications.naturalengland.org.uk/file/5230260905836544 [accessed 28/03/2018]

A.2.4.2 Ensure that the integrity of the site is maintained or restored as appropriate, and ensure that the site contributes to achieving the aims of the Wild Birds Directive, by maintaining or restoring;

- The extent and distribution of the habitats of the qualifying features
- The structure and function of the habitats of the qualifying features
- The supporting processes on which the habitats of the qualifying features rely
- The population of each of the qualifying species, and,
- The distribution of the qualifying species within the site.

A.3 River Avon SAC

A.3.1 Introduction

A.3.1.1 The River Avon begins in Wiltshire as two separate rivers, rising east of Devizes and east of Pewsey adjacent to the Avon and Kennet Canal. The confluence of occurs at Upavon, with the river flowing south through Salisbury Plain, through Amesbury and Salisbury, continuing through the New Forest until it enters the sea at Christchurch.

A.3.1.2 The River Avon runs through several areas of chalk and clay, which supports five aquatic *Ranunculus* species. Stream water-crowfoot (*Ranunculus penicillatus* ssp. *pseudofluitans*) and river water-crowfoot (*R. fluitans*) are the main dominants; however, some winterbourne reaches where pond water-crowfoot (*R. peltatus*) are also present.

A.3.1.3 The River Avon SAC consists of three Sites of Special Scientific Interest, River Avon System SSSI, Lower Woodford Water Meadows SSSI and River Till SSSI.

A.3.2 Reasons for Designation

A.3.2.1 River Avon SAC qualifies as a SAC through its habitats and species. The SAC contains the Habitats Directive Annex I habitat:

- Water courses of plain to montane levels with Ranunculion fluitantis and *Callitricho-Batrachion* vegetation communities.

A.3.2.2 The SAC also supports the following Habitats Directive Annex II qualifying species:

- Desmoulin’s whorl snail (*Vertigo moulinsiana*)
- sea lamprey (*Petromyzon marinus*)
- brook lamprey (*Lampetra planeri*)
- Atlantic salmon (*Salmo salar*) and
- bullhead (*Cottus gobio*)

A.3.3 Current Pressures and Threats[44]

- Physical modification
- Siltation
- Water pollution

[44] http://publications.naturalengland.org.uk/file/6247102287970304 [accessed 28/03/2018]

- Water abstraction
- Changes in species distributions
- Invasive species
- Public access/disturbance
- Hydrological changes
- Inappropriate weed control
- Change in land management
- Habitat fragmentation

A.3.4 Conservation Objectives[45]

A.3.4.1 With regard to the SAC and the individual species and/or assemblage of species for which the site has been classified (the 'Qualifying Features'), and subject to natural change;

A.3.4.2 Ensure that the integrity of the site is maintained or restored as appropriate, and ensure that the site contributes to achieving the Favourable Conservation Status of its Qualifying Features, by maintaining or restoring;

- The extent and distribution of qualifying natural habitats an habitats of qualifying species
- The structure and function (including typical species) of the qualifying natural habitats
- The structure and function of the habitats of qualifying species
- The supporting processes on which qualifying habitats and the habitats of the qualifying species rely
- The population of each of the qualifying species, and,
- The distribution of the qualifying species within the site.

[45] http://publications.naturalengland.org.uk/publication/6048472272732160 [accessed 28/03/2018]

Appendix B DMRB Mitigation Measures Report for the Appropriate Assessment (Annex E of DMRB Vol. 11, Section 4, part 1 HD 44/09)

Project Name	**A303 Amesbury to Berwick Down**	**Date**	**Author (Name/Organisation)**	**Verified (Name/Organisation)**
Natura 2000 Site under Consideration	**Salisbury Plain SAC**	**16/07/18**	**James Riley**	
Ref:	*Measures to be introduced*	*Explanation of how these measures will avoid adverse effects*	*Explanation of how these measures will reduce adverse effects*	*Evidence of how they will be implemented and by whom*
1	Dust control measures during construction within 200m of Parsonage Down	N/A	Dust control measures will ensure that no significant dust coating of vegetation within Salisbury Plain SAC will arise	Dust control measures are expressed in OEMP covered by the DCO. They will then be implemented by the construction contractors.
Ref	*Measures to be introduced*	*Evidence of degree of confidence of success*	*Timescale for implementation*	*Proposals for monitoring and for rectification of failure*
1	Dust control measures during construction within 200m of	Long-standing tried and tested measures which are explicitly recommended in	During construction	Dust control measures include a commitment to check for dust deposition on vegetation

	Parsonage Down	guidance produced by the Institute of Air Quality Management as being measures that will normally reduce dust effects to an insignificant level.		within the SAC on a daily basis when there is construction activity that may cause dust going on within 200m of the SAC (determinable by visual inspection from within the Scheme boundary/works footprint, public footpaths/byways or by agreement with Natural England). In the event that a significant dust deposition event does occur it will be washed off by normal weather but dust control measures will be updated to ensure it does not recur.

Project Name	**A303 Amesbury to Berwick Down**	**Date**	**Author (Name/Organisation)**	**Verified (Name/Organisation)**
Natura 2000 Site under Consideration	**Salisbury Plain SPA**	**16/07/18**	**James Riley**	
Ref:	*Measures to be introduced*	*Explanation of how these measures will avoid adverse effects*	*Explanation of how these measures will reduce adverse effects*	*Evidence of how they will be implemented and by whom*

1	Delivery of a replacement stone curlew nesting plot at Parsonage Down	Adverse effects will be avoided by ensuring no net loss of stone curlew nesting plots.	N/A	Will be implemented by Highways England with permission from Natural England at Parsonage Down National Nature Reserve prior to loss of existing nesting plot to Winterbourne Stoke bypass.
2	Avoidance of works within 500m of the stone curlew plot at Parsonage Down during March to September, until the plot is cleared.	Avoidance of the stone curlew nesting period will ensure that no significant disturbance of nesting stone curlew at Parsonage Down will arise during clearance of the plot		Disturbance management measures are expressed in OEMP covered by the DCO. They will be implemented by the construction contractors.
3	Delivery of a new stone curlew nesting plot at Winterbourne Down	N/A	Will ensure no net loss of nesting opportunities for stone curlew in the Salisbury Plain area in the event that disturbance instances of the plots at Normanton Down increase following removal of the old A303	Will be implemented by RSPB with support from Highways England. Will be installed prior to closure to traffic of the existing A303 route at Normanton Down.
Ref	*Measures to be introduced*	*Evidence of degree of confidence of success*	*Timescale for implementation*	*Proposals for monitoring and for rectification of failure*

1	Delivery of a replacement stone curlew nesting plot at Parsonage Down	High degree of confidence based on RSPB and Natural England expertise creating successful nest plots for stone curlew in this area. High degree of confidence also based on close proximity of new plot to existing plot, suitable substrate, suitable predator protection and commitment to appropriate management overseen by a suitable organisation (Natural England).	Prior to construction (and prior to loss of the existing nest plot)	Natural England will observe use of the replacement stone curlew plot at Parsonage Down National Nature Reserve. This monitoring may also be incorporated into the existing contract for monitoring stone curlew breeding plots elsewhere in the Salisbury Plain area. In the event that the fencing protection of the plot proves inadequate it will be strengthened.
2	Avoidance of works within 500m of the stone curlew plot at Parsonage Down during March to September, until the plot is cleared.	Measures are based upon the known behaviour of stone curlew such as their nesting season and common-sense methods to avoid disturbance such as avoiding that season	Prior to construction of the Winterbourne Stoke bypass (in terms of clearing the stone curlew plot at Parsonage Down outside the nesting season).	Will be monitored by Natural England and RSPB.
3	Delivery of a new stone curlew nesting plot at	High degree of confidence based on RSPB expertise creating	Prior to closure to traffic of the existing A303 route at Normanton	RSPB will observe recreational pressure within Normanton Down.

	Winterbourne Down	successful nest plots for stone curlew in this area. High degree of confidence also based on suitable substrate, suitable predator protection and commitment to appropriate management overseen by a suitable organisation (RSPB).	Down.	They will also observe use of the replacement stone curlew plot at Winterbourne Down. This monitoring may also be incorporated into the existing contract for monitoring stone curlew breeding plots elsewhere in the Salisbury Plain area. In the event that the fencing protection of the plot proves inadequate it will be strengthened.

<table>
<tr><td>Project Name</td><td>A303 Amesbury to Berwick Down</td><td>Date</td><td colspan="2">Author (Name/Organisation)</td><td>Verified (Name/Organisation)</td></tr>
<tr><td>Natura 2000 Site under Consideration</td><td>River Avon SAC</td><td>16/07/18</td><td colspan="2">James Riley</td><td></td></tr>
<tr><td>Ref:</td><td>Measures to be introduced</td><td colspan="2">Explanation of how these measures will avoid adverse effects</td><td>Explanation of how these measures will reduce adverse effects</td><td>Evidence of how they will be implemented and by whom</td></tr>
<tr><td>1</td><td>Bridge design to minimise shading of River Till</td><td colspan="2">N/A</td><td>The modelling undertaken demonstrates that the bridge design will ensure that even the</td><td>During construction of the River Till viaduct by the construction contractors</td></tr>
</table>

			most shaded area under the bridge will receive 40-60% of the daylight hours/radiation that the unshaded areas will receive and this is sufficient to ensure that vegetation will persist under the viaduct.	
Ref	*Measures to be introduced*	*Evidence of degree of confidence of success*	*Timescale for implementation*	*Proposals for monitoring and for rectification of failure*
1	Bridge design to minimise shading of River Till	High degree of confidence based on literature review, comparative survey of bridges that do not have a comparable height:width ratio and numerical shade modelling of the viaduct structure.	During construction	This is an inherent design feature such that monitoring will be undertaken to ensure bridge construction complies with the agreed design. Failure is not anticipated. However, the stock-proof fencing beneath the viaduct will be monitored annually to ensure it remains intact. The cover of vegetation will be monitored during the period when the temporary bridge is in place. In the event that

				monitoring shows there is an increase in bare ground and in the risk of subsequent erosion and siltation, bank stabilisation measures such as geotextile, would be used temporarily in any affected areas until vegetation recovered.

Appendix C PINS Appropriate Assessment Matrices

10.1.1 Likely Significant Effects have been identified for the following sites:

- Salisbury Plain SAC
- Salisbury Plain SPA
- River Avon SAC

10.1.2 These sites have been subject to further assessment in order to establish if the NSIP could have an adverse effect on their integrity, taking account of mitigation. Evidence for the conclusions reached on integrity is detailed within the footnotes to the matrices below.

Matrix Key

✓ **=** Adverse effect on integrity **cannot** be excluded
✕ **=** Adverse effect on integrity **can** be excluded

C = construction
O = operation
D = decommissioning

HRA Integrity Matrix 1: Salisbury Plain SAC

Name of European site and designation: Salisbury Plain SAC						
EU Code: UK0012683						
Distance to NSIP: 0m						
European site features	**Adverse effect on integrity**					
Effect	Atmospheric pollution (dust deposition)			In combination effects		
Stage of Development	C	O	D	C	O	D
Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia) (*important orchid sites)	X a		X a			
Marsh fritillary	X a		X a			
Juniperus communis formations on heaths and calcareous grasslands	X b		X b			

a. Calcareous grassland and marsh fritillary could both be affected by dust deposition during construction of the Winterbourne Stoke bypass within 200m of Parsonage Down (particularly the initial topsoil strip) if it is unmanaged. However, the dust control measures that will be deployed on this scheme are long-standing tried and tested nature of these measures, which are explicitly recommended in guidance produced by the Institute of Air Quality Management as being measures that will normally reduce dust effects to an insignificant level (Paragraph 4.2.1-4.2.2, pages 19-20).

b. No areas of juniper scrub are adjacent to the works such that this interest feature would not be affected (Paragraph 3.3.2 bullet one, page 15).

HRA Integrity Matrix 2: Salisbury Plain SPA

Name of European site and designation: Salisbury Plain SPA									
EU Code: UK9011102									
Distance to NSIP: 2.8km									
European site features	**Adverse effect on integrity**								
Effect	Clearance of stone curlew nesting plot			Disturbance of nesting stone curlew through clearance of nesting plot			In combination effects (recreational disturbance)		
Stage of Development	C	O	D	C	O	D	C	O	D
Stone curlew	X c			X d				X e	

c. The loss of a known effective nesting plot for stone curlew due to the footprint of the Winterbourne Stoke bypass would have an adverse effect on the integrity of the SPA (even though it is outside the SPA boundary) as it would reduce nesting opportunities for the SPA population. Discussions with Natural England and RSPB in preparing this appropriate assessment have identified that the mitigation objective should be to ensure no net loss of breeding plots in the Salisbury Plain area by delivering a replacement plot before the existing plot is lost to the Winterbourne Stoke bypass. The replacement plot should be as close to the location of the existing plot as possible (male stone curlew usually return to within 9 miles of their hatching site[46]). Since the plot to be lost is outside the SPA boundary itself the provision of a replacement plot does not class as 'compensation' *sensu* the Habitats Directive. Natural England has agreed that the location of the replacement breeding plot will be in an area of calcareous grassland at Parsonage Down approximately 500m from the current plot. This has also been agreed with RSPB. The breeding plot will be 1.2ha in area to allow for a surrounding fence and a long grass margin. The fence will be fitted with predator-resistant electric wire in addition to spikes to stop crows and other corvid predators using the posts as perches (pages 22-23).

d. The clearance of the existing stone curlew plot to be lost to the scheme would have an adverse effect if it took place during the nesting season. However, it will take place outside the stone curlew breeding season of March to August. All construction staff working within 500m

[46] https://www.rspb.org.uk/birds-and-wildlife/wildlife-guides/bird-a-z/stone-curlew/breeding-nesting-and-migration/

of the plot would also be given a toolbox talk regarding the sensitivity of stone curlew. With these measures in place it is considered that no construction-related disturbance of nesting stone curlew would occur and thus no adverse effect on the integrity of the SPA would arise through this pathway (Paragraph 5.2.4 - 5.2.5, page 24).

e. Recreational disturbance of Normanton Down RSPB reserve and its nesting stone curlew could increase once the old A303 is removed in combination with population and tourism growth in the local area. To address this it has been agreed with RSPB that the most appropriate measure will be to create a new stone curlew plot on the RSPB reserve at Winterbourne Down, thus ensuring no net loss of stone curlew nesting opportunities in the Salisbury Plain area even if disturbance incidents at Normanton Down do increase (Paragraph 5.3.6 to 5.3.8, pages 25-26).

HRA Integrity Matrix 3: River Avon SAC

Name of European site and designation: River Avon SAC						
EU Code: UK9011102						
Distance to NSIP: 0km (Scheme crosses river)						
European site features	**Adverse effect on integrity**					
Effect	Shading of the River Till			In combination effects		
Stage of development	C	O	D	C	O	D
Water courses of plain to montane levels with Ranunculion fluitantis and Callitricho-Batrachion vegetation	X f	X f	X f			
Desmoulin's whorl snail	X f	X f	X f			
Sea lamprey	X f	X f	X f			

Brook lamprey	X f	X f	X f			
Atlantic salmon	X f	X f	X f			
Bullhead	X f	X f	X f			

f. Excessive shading of the River Till from the new viaduct could lead to vegetation loss and thus erosion causing sedimentation downstream and affecting the fish and snail interest features of the SAC that are found downstream. However, the data strongly indicate that the stretch of the River Till beneath the viaduct will continue to be vegetated, provided suitable livestock management is introduced to control poaching[47]. The shading cast by the viaduct will be less than the level of shading that could be likely cast in a natural situation by dense bankside tree cover, as already occurs along the River Till immediately south of the A303. The modelling undertaken demonstrates that the bridge design will ensure that even the most shaded area under the bridge will receive 40-60% of the daylight hours/radiation that the unshaded areas will receive and this is sufficient to ensure that vegetation will persist (Paragraph 6.1.1 - 6.1.9, pages 27-30). The temporary construction crossing will be a bailey-bridge type structure and will be in place for a relatively short period of 2 years. The risk of any shading causing loss of vegetation (and therefore erosion of bare ground) is therefore considerably less than for the permanent viaduct. Nonetheless, in order to render this risk negligible the construction crossing has been designed to be as narrow as possible, consisting of a single lane structure approximately 4-5m wide (paragraph 6.1.10, page 31).

[47] Livestock will cluster beneath bridges, which can lead to poaching (denuding of the vegetation and exposure of bare mud through excessive trampling)

Appendix D Bridge Shading Study (December 2017)

EXECUTIVE SUMMARY

1. The main aim of the study was to determine the impact that bridge design has on habitats, with a particular emphasis on the effects of shading on vegetation cover. Several factors that have the potential to limit vegetation cover were accounted for e.g. height-width (H:W) ratio, aspect, single or twin deck bridges, management beneath the bridge, water availability and different types of disturbance.

2. A review of available scientific literature was undertaken. In summary, shading has the potential to significantly affect plant growth and can alter the vegetation community over time. Generally, species richness decreases with shading. Different species respond to changes in light levels in different ways, depending on their tolerance to shading and are able to adapt their growth to changes in conditions, within limits. Although some chalk stream macrophyte species are shade-tolerant, most are not strongly so. Studies on *Ranunculus peltatus*, found reduced biomass with 50% shading compared to unshaded conditions and regeneration depended strongly on light availability. Few studies have considered the shading effects of bridges on vegetation, but one study reported a correlation between the ratio of bridge height and width and cover of vegetation, observing no adverse impacts on the growth of the underlying saltmarsh when the height to width ratio of the bridge was more than 0.7.

3. The study described in this report sampled 31 single-deck bridges and three twin-deck bridges in southern England with public access beneath them. A variety of measurements were taken from these bridges, including their width, height, aspect, vegetation cover and the light levels beneath the bridge relative to an unshaded control. Sketches and qualitative observations were also made. Analysis of this data was undertaken to determine any significant relationships between the variables, and any effect of the bridge’s H:W ratio and aspect on vegetation beneath it.

4. The vegetation cover found at the centre of bridges with a H:W ratio of 0.6 or more was greater than those with a H:W ratio of less than 0.6. The findings of this study also suggest that an east-west bridge aspect has less shading effect than a north-south orientation. Beneath the edges of bridges shading was much greater under those bridges with a low H:W ratio.

5. Based on this study the minimum H:W ratio required to maintain vegetation cover across the width of a bridge is in the range 0.6-0.8.

1 Introduction

1.1 Shading from bridges has the potential to greatly affect the vegetation growing beneath it. This study aims to investigate shading and the extent of vegetation under bridges in Southern England. The main aim of the study was to determine the impact that bridge design has on habitats, with a particular emphasis on the effects of shading on vegetation cover. Several factors that have the potential to limit vegetation cover have been accounted for including height-width (H:W) ratio, aspect, bridge design, management beneath the bridge, water availability and different types of disturbance. Previous studies have found that shading can cause changes in biomass, growth form and plant communities.

1.2 Shading has the potential to impact on above ground biomass. In a glasshouse experiment, Heger (2016) found that across shading treatments, plants from low-light environments produced more above-ground biomass. Heger's study indicates that there is a close linkage between the light availability experienced in the field and the ability of following generations to respond to shading. This therefore suggests that shading has the potential to alter the vegetation community over time. Siebenkas *et al.* (2016) studied aboveground biomass production in experimental monocultures, each representing two functional groups (grasses and herbs) and two growth statures (small, tall). This vegetation was exposed to different combinations of light and nutrient availability. On average, shade led to a decrease in aboveground biomass production of 24%. In field trials, Roscher *et al.* (2016) established plots of grass and legume species and found that compared to the control, community biomass production decreased under shading (-56%).

1.3 Semchenko *et al.* (2012) examined interspecific variation in growth responses to shade using 46 temperate grassland species grown at different levels of shading. Moderate shade (50% daylight) had, on average, a net facilitative effect on plant biomass. Plant growth in the 25% daylight treatment was not significantly different from that in full daylight, and it was only when 90% of natural light was made unavailable that shaded plants attained a significantly lower dry mass than plants in full daylight. Hence, in this experiment the response of the plants to shading was to divert more resources into tall growth to improve their exposure to light and by growing taller than competing plants in the surrounding vegetation.

1.4 In an experiment that provided additional illumination (using mirrors) rather than shading, Lepik *et al.* 2003 identified a significant increase in the biomass in species with narrow, grass-like leaves (graminoids). Zobel and Eek (2002) concluded that the ability of plant species to react to variation in seasonal and local direct light availability appears to be a trait more characteristic of species with graminoid growth form. Devkota *et al.* (1998) reported different responses to shading in experimental plots sown with different grass species. Similarly, Mika *et al.* (1998) found that grasses in the shade grew slower and gave lower yield when compared with a stand of grasses in direct light. Lepik & Zobel (2015) report that plasticity to light directly enhances the small-scale co-existence of species. Hence different species have been found to respond to reduced light in different ways, but they are capable of adapting their growth to the conditions, within limits.

1.5 Roscher *et al.* (2011) found a close correlation between leaf mass per area with changes in light availability, which suggested that small-statured herbs are capable of adjusting to exploit seasonal niches, maintaining their carbon metabolism and thus enabling their survival within the shaded conditions created by multi-species assemblages at different times of the year.

1.6 Seidlova *et al.* (2009) found that net photosynthetic rate at growth Photon Flux Density (P (net)) may be used as a means of characterizing potentially shade-tolerant species that are likely to establish in dense vegetation in the field. Several previous studies have investigated how light levels influence plant communities in a variety of habitats.

1.7 On chalk grassland soil, Grubb *et al.* (1996) observed differences between tall-shrub and shade tolerant tree species grown under a shade gradient, finding appreciably different responses. Similarly, Zobel *et al.* (1996) identified that competition for light is the main interaction determining the community change during succession to a relatively species-poor deciduous forest (overgrown former grassland) from species-rich grassland.

1.8 Working in wooded meadows and pastures in Southern Sweden, Einarsson and Milberg (1999) found that composition of herbaceous species in square-metre plots along 60 light gradients varied significantly with light availability. Species typical for open areas tended to be confined to them, but species characteristic of shaded areas also grew in unshaded plots. Species richness increased with light availability, but was not related to grass sward density. Also, working in wooded meadow habitat, Skornik *et al.* (2008) investigated the species richness and species composition in relation to light and management regime within riparian forests in Slovenia. The number of species within riparian wooded meadows still under management was found to be negatively correlated with light intensity.

1.9 Edelkraut & Gusewell (2006) investigated how the composition of wetland communities changed over time in response to altered light regimes. Over three years, these were subjected to artificial shading (continuous or seasonal) in a field experiment. Communities were initially dominated by three grass species in all treatments, but subsequently sedges (*Carex* species) increased and reached dominance in the control plots, whereas grasses remained dominant in the shaded plots.

1.10 Staley *et al.* (2013) found that in unmanaged hedgerow communities, the species composition shifted towards species associated with greater shade tolerance. This change was related to changes in management (specifically the move from traditional forms of management such as coppicing and hedge-laying towards either no management or frequent cutting with a mechanical flail) and eutrophication.

1.11 In the late 1970s, Dawson and Kern-Hansen (1979) showed that light is nearly always one of the main limiting factors to plant growth, and that there is a linear relationship between the light available at the stream surface and the submerged plant standing crop for species such as water crowfoot *Ranunculus* sp. This finding led to a study into the control of rooted macrophytes in flowing waters using polypropylene material to shade the aquatic plants. Dawson & Hallows (1983) reported a direct correlation between shading and reduced biomass of submerged *Ranunculus* species and also emergent plant species. Although some chalk stream macrophyte species are shade-tolerant, most are not strongly so. Ham *et al.* (1982) found that the growth of *Ranunculus* was restricted by shading, and the morphological changes recorded included reduced leaf size.

1.12 Within a temperate eutrophic lowland river, Kohler *et al.* (2010) observed a significant reduction in macrophyte biomass at shading levels greater than 55%. Similarly, Garbey *et al.* (2006) found reduced biomass of *Ranunculus peltatus* with 50% shading compared to unshaded conditions. Garbey *et al.* (2004) reported differences between sites with *R. peltatus* related to flow, nutrient status, disturbance and shading. *R. peltatus* flowered in sunny sections (less than 5% shade) and had lower production in shaded sites. In addition, Garbey *et al.* (2006) identified that regeneration of *R. peltatus* from current-dispersed fragments depended strongly on light availability, with regeneration from plant fragments occurring in open conditions and 50% shading, but not under 100% shading.

1.13 The potential effect of built structures on semi-natural vegetation is of particular relevance to the current study. The influence of solar photovoltaic arrays on microclimate and ecosystem processes was studied by Armstrong *et al*. (2016) over the course of a year at a UK solar park sited on species-rich grassland. The array rows were at an angle of 30°, less than 1 m from the ground at the low side, in rows 4.4 m wide, 11.2 m apart. Areas under the photovoltaic arrays were shaded: not only was 92% less photosynthetically active radiation recorded than in the gaps between rows but there was also more diffuse radiation (90% compared to 79%). Armstrong *et al.* (2016) found conditions under the arrays were cooler during the growing season, but less cool in autumn and winter. Significantly, under the arrays there was less above-ground biomass. Plant diversity in sown mixes of grasses and wildflowers was also reduced as grasses grew taller and out-competed less shade-tolerant herbs of hay meadows.

1.14 Few studies have considered the shading effects of bridges on vegetation. Only one study identified was relevant this was conducted in North Carolina, in which Broome *et al.* (2005) reported a correlation between the ratio of bridge height (H) and bridge width (W) and effects of shading on saltmarsh habitat at seven bridges 3m-15m high. Broome *et al.* (2005) found that bridges with H:W ratios less than 0.5 affected marsh productivity and function under the bridges. At H:W ratios between 0.5 and 0.68, bridge effects were detected but were greatly diminished. Above H:W ratios of 0.7 the effects from shading by bridges were no longer measurable. Broome *et al.* (2005) therefore concluded that shading by bridges with H:W ratios >0.7 do not adversely impact the productivity or function of the underlying marsh. There do not appear to be any similar studies of shading by bridges carried out for terrestrial or aquatic habitats in England or other parts of Europe.

2 Field Survey Method

2.1 An initial search area was selected approximately east of Bristol, west of London and south of Birmingham. Ordnance Survey maps and aerial photographs were used to identify potentially suitable bridges, mainly road bridges. Any confirmed in the desk study to have solely hard surfacing beneath them were excluded from the sample. The desk study identified 31 single deck bridges and 3 twin deck bridges potentially suitable for survey. Locations are shown in the figure in Appendix A.

2.2 Each bridge met the following criteria to be included in the study: the bridge can be viewed from below from a publicly accessible road, bridleway or footpath; and the bridge crosses grassland and/or other valley habitat with a watercourse. Each bridge was then visited by a team of two surveyors in September to October 2017, and the following information was recorded:

1. cross-section and plan sketch;
2. measurements to calculate the height of the bridge;
3. width of the bridge;
4. aspect of the bridge;
5. quadrats along a transect recording the vegetation (including cover and species) and light levels;
6. light levels at locations beneath the bridge where vegetation cover reduced to 50% and 0%; and,
7. photographs of the bridge, quadrats, vegetation and any other relevant features.

<u>Cross Section</u>

2.3 A cross section sketch of each bridge was drawn, with supporting photographs from both sides of the bridge (see Figure 1 for an example sketch). The sketch included (where applicable):

1\. The design of the bridge including piers and embankments;
1\. Locations of watercourse, vegetation, hardstanding, paths and transect route;
2\. Estimates of appropriate distances;
3\. Features that may affect the vegetation through shading;
4\. Features that may have other effects on the vegetation; and
5\. Any other applicable features.

2.4 To support this cross section sketch, measurements were taken (using a combination of clinometer, distance to the bridge and height to eye level of surveyor) to enable the calculation of the height of the bridge to the deck and underside (clearance).

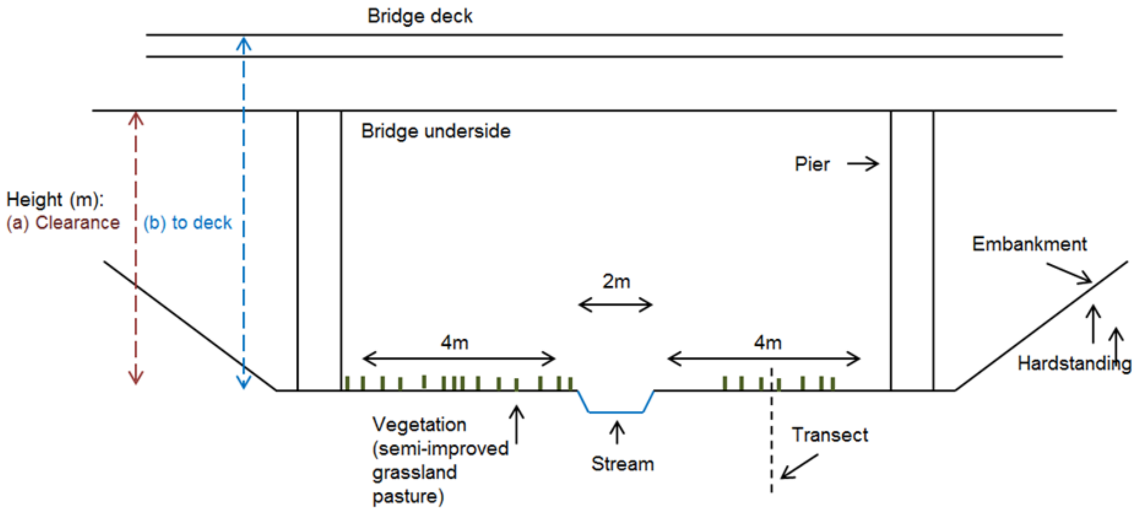


Figure 1 - Example of a cross section sketch

Plan sketch

2.5 A plan view of the transect was sketched (see Figure 2 for an example) and included:

1. the bridge edges include sides A and B labelled;
2. the location of the transect including the location of the quadrats;
3. any prominent features under the bridge, e.g. vegetation, watercourses, path;
4. features that may affect the vegetation through shading;
5. features that may have other effects of the vegetation; and,
6. compass bearings in alignment with the bridge edges (to indicate the aspect of the bridge).

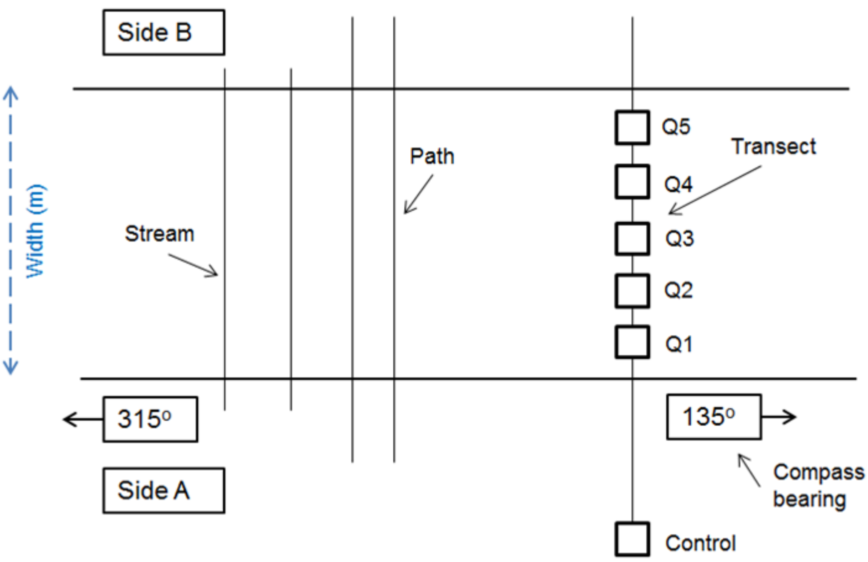


Figure 2 - Example of a plan sketch

Control

2.6 A scientific control location was used for comparison when taking the quadrat samples and lux (light level) readings. Where possible, this control quadrat was located in an area which had a clear view of the sky and no influence of shading from the bridge (or other features). In most cases this was a minimum of one bridge height away from the bridge (allowing for the shadow the bridge may cast across different times of the day and seasons). These control measurements were used as a reference for the vegetation and light levels present without the influence of the shading by the bridge.

Transect Data

2.7 Samples were taken using a systematic sampling approach, with 0.5 x 0.5m quadrats used along a transect under each bridge (see Figure 2). The number of quadrat samples taken depended partially on the width of the bridge. At wide bridges five quadrats were sampled. One in the middle of the bridge, two 1m from each edge of the bridge (Sides A and B) and two mid-way between the central and outer quadrats. For bridges with an approximate deck width of 20m or less, three quadrats were taken (one 1m from Side A, one 1m from Side B and a central quadrat). This was also the case for bridges that had an observably abrupt decrease in vegetation cover (typically to 0%) near to the edge of each bridge deck i.e. predominantly comprising bare ground. Within each quadrat the following was recorded:

1. the distance from Side A of the bridge to the quadrat;
2. a photograph of the quadrat from directly above;
3. an estimate of the percentage of bare ground and vegetation within the quadrat;
4. the average sward height (mm);
5. broad habitat type as classified within the JNCC Handbook for Phase 1 habitat survey (JNCC, 2010);
6. notes on the location of the quadrat to any features which may have an effect on shading e.g. bridge structures, buildings, fences;
7. dominant/characteristic plant species; and,
8. any factors which may have an effect on the vegetation other than shading e.g. dryness, flooding, trampling, grazing etc.

2.8 Where twin-deck bridges were surveyed, each deck was surveyed separately and an additional quadrat was recorded in the gap between the decks to provide data on changes in vegetation between the bridge decks.

Light levels

2.9 Readings of the light levels were taken for each quadrat recorded, using a lux meter. Control readings were taken outside of any effects of shading from the bridge and were recorded by another surveyor at the same time as the surveyor taking the measurements underneath the bridge. Five measurements were recorded at each location so an average could be taken (to reduce the variability within the measurements from the lux meter).

2.10 In addition, average light level measurements (including control measurements) were recorded at approximate locations along the transect where the vegetation cover reduced to 50% and 0%. The distance in metres from each of these locations to Side A, or Side B of the bridge (depending on which was closer) was recorded.

2.11 In order to quantify the extent of shading created by the bridge an inverse percentage of the amount of light at each location compared to the control was calculated, using the following formula:

((average lux (quadrat) / average lux (control)) x 100) – 100

For example: a reduction in light of 99.9% would be rounded to 1.0, a reduction of 50% compared to the control location would be represented as 0.5, no change from the control would be 0 and an increase in light levels by 20% from the control would be -0.2.

Summary description

2.12 To further support the data recorded, a description was recorded of the conditions on site. That summary paragraph included any change in vegetation, influence of disturbance and limitations that may not have been recorded within the other methods of data collection. Photographs were taken to support these summary descriptions.

Limitations

2.13 Several limitations were encountered during sampling. The bridges selected in the initial desk search were limited to those with public access beneath. Some bridges were excluded at this desk search stage where on-line photography indicated that there was no vegetation present beneath the bridge. Not all bridges could be checked in this way. Some bridges encountered whilst on site were not suitable as no vegetation was present, so had to be excluded from the study. Other bridges were significantly influenced by disturbance by livestock as seen under Bridge 1A (Appendix C Plate 14 & 15) or by the public as seen under bridge B4A (Plate 10) or a change in management such as storage of farm equipment as seen under bridge B4E (Appendix C Plate 16). The data collected is therefore indicative of a response of vegetation to shading in conditions with varying degrees of disturbance. All observed limitations due to disturbance and management on site were recorded.

2.14 The bridge not only limits light availability but also causes further changes in the microclimate including reducing water availability, reducing relative temperatures in the warmer months and increasing them in the colder months. In addition scouring of the land may be caused by run-off from areas of hard standing. This was seen in bridges B3B (Appendix C Plate 17) and B4A (Appendix C Plate 18)

2.15 Since not all the bridges could be sampled during the same weather conditions at the same time of day the light levels and direction of shade cast by the bridge varied between bridges. The shade cast by a bridge in the morning is very different to the shade cast in the evening. This hour by hour change in shade would not have affected the data collected for vegetation, but would have affected the associated light levels recorded at the time. The small changes in light levels caused by the changes in weather were mitigated for by the control readings; however, it was not possible to mitigate the change in the shade cast by the bridge. The time of day and weather conditions were therefore recorded, so that this limitation could be taken into account during analysis of the data if required.

2.16 Generally, there was no public access to the banks of watercourses crossed by the bridges surveyed so, although observations were made wherever possible using the three to five quadrats already mentioned, there are no quadrat samples of aquatic or riparian vegetation. Nonetheless, most of the bridges had vegetation present beneath them, albeit some had more shade-tolerant communities in which grasses did not predominate.

2.17 Furthermore, the study was limited by the timeframe in which the field surveys were required to be carried out within. The study had a timeframe of one month in which to conduct all of the field surveys. This therefore limited the number of bridges that could be surveyed. The surveys were also carried out in September to October, where the length of day is shortened and the sun is lower in the sky in comparison to mid-summer. These factors may have had an effect of the level and direction of shade cast by the bridges.

Analyses

2.18 Correlation analyses were undertaken for single-deck and twin-deck bridges using the Pearson's correlation coefficient. These analyses were undertaken between combinations of H:W ratio, bridge height, width, percentage shade and percentage vegetation cover. There were not enough twin bridges for comparison with equivalent single deck bridges.

2.19 A Mann-Whitney U test was undertaken to analyse the effect that H:W ratio has on vegetation cover at the central point beneath bridges.

2.20 Fisher's Exact test was used to analyse three data sets. This includes a test related to bridge H:W ratio, aspect and the effect they each have on whether vegetation cover reduced to 50% cover before or after the first quarter of the bridge width.

2.21 A reference level of 50% cover was selected as representing a degree of impact on vegetation but without loss of continuity. The H:W ratio to the bridge underside was used for the purposes of analysis (i.e. clearance height), rather than height to road surface (deck height), because bridges with the same deck height might have different clearance height depending on the design. Where possible, qualitative observations on the amount of aquatic vegetation were made across all bridges where a river or other watercourse ran beneath. The observed vegetation was categorised into two categories relating to the reduction in cover. These categories were: 1) no visible difference or slight reduction, and 2) substantial reduction or complete loss of vegetation. Fisher's exact test was used to analyse these categories; their relation to H:W ratios above and below 0.6 and the level of vegetation reduction impacted.

2.22 The data for light levels at all quadrats beneath all bridges were tested for statistical normality. A Kruskal-Wallis and a post hoc test were performed to analyse the light levels found at varying points beneath bridges. The post hoc test follows the procedures set out by Seigel and Castellan (1988).

2.23 For the aspect analysis, all bridges with evident disturbance were omitted e.g. previous excavation of vegetation, excessive trampling, canalisation or hard surfacing. Some bridges exhibited a percentage cover of vegetation greater than 50% throughout the width. To allow for this, all distances were converted into a proportion of half the bridge's width using the following equation: distance to 50% shading/half the bridges width. In the instance of vegetation not decreasing to 50% beneath a bridge, the code DR ('did not reduce') was given.

2.24 Qualitative observations on the amount of aquatic vegetation were made across all bridges. These were based on the aquatic or marginal vegetation present relative to the biomass and floral community observed away from the bridge. No quadrat samples of aquatic vegetation were taken during the survey, and in most cases no direct access to the banks of watercourses crossed by the bridges was possible. Therefore, only qualitative assessment of the effects on vegetation was undertaken. Where little to no change occurred, the sample was categorised as 'low reduction' (slight or no reduction). 'High reduction' was used where there was substantial or complete loss of vegetation. The data were then analysed for possible correlations with H:W ratio and aspect

3 Results

Height-width ratio

3.1 Field data from 31single-deck and three twin-deck bridges were analysed. Four of the bridges identified for survey were excluded from analysis due to hard-standing preventing vegetation growth. A further three bridges only contained qualitative observations of aquatic vegetation. The full data set is presented in Appendix B. The full set of field record sheets and photographs is not included here, but can be made available on request.

3.2 Table 1, below, groups each bridge (each deck of the twin-deck bridges were assessed separately) into classes dependent on their H:W ratio. The table shows the max, median and minimum percentage of vegetation cover observed at the mid-point of each bridge deck in relation to their H:W ratio class. In general, the higher the H:W ratio the greater the percentage of vegetation cover at the mid-point of the bridge. The maximum percentage cover at the mid-point of bridge decks with a H:W ratio between 0 and 0.2 was 1% cover, whereas for bridges with a H:W ratio >0.6 vegetation cover at the mid-point ranged between 30% and 100%.

Table 1 – Summary of percentage of vegetation cover at the mid-point of each bridge deck relative to its H:W ratio class.

H:W ratio class	Number of bridges			Percentage of vegetation cover at mid-point of bridge deck		
	Single-deck	Twin-deck*	Total	Maximum	Median	Minimum
0 - 0.10	8	0	9	15	0	0
0.11 - 0.20	10	0	11	1	0	0
0.21 - 0.40	5	2	7	<5	0	0
0.41 - 0.60	3	2	5	90	30	0
0.61 - 0.80	3	0	3	100	50	30
0.81 - 1.25	2	0	2	90	n/a	80
* Each deck of the twin-deck bridges were assessed separately						

3.3 For both the single and twin-deck bridges a strong negative correlation was observed between the bridge H:W ratio and the percentage of increased shading at the bridge mid-point. In other words, as the H:W ratio increases shading decreases (single-deck n=29 Pearson's correlation coefficient: r=-0.89; twin-deck n=6 Pearson's correlation coefficient: r=-0.95). A positive correlation was observed between H:W ratio and vegetation cover. In other words, as the H:W ratio increases vegetation cover also increases (single-deck: n=29 Pearson's correlation coefficient: r=0.76; twin-deck: n=6 Pearson's correlation coefficient: r=0.58). There was only a weak negative correlation between increasing shade and vegetation cover (single-deck: n=29 Pearson's correlation coefficient: r=-0.63; twin-deck: n=6 Pearson's correlation coefficient: r=-0.79), suggesting other factors may be operating. Appendix E, Table E1 summarises the correlations calculated between combinations of bridge height, width, percentage shade and percentage vegetation cover.

3.4 Figure 3 ranks all of the bridges assessed from highest to lowest H:W ratio, with bars showing the H:W ratio for each bridge. The proportion of shading, in comparison to the control, is plotted for three locations beneath each bridge (near side, centre and far side). As can be seen from Figure 3 there appears to be a slight negative trend between increased H:W ratio and shading within the central location. There is a threshold apparent at H:W ratio c.0.4 where the shading at the centre of the bridge drops below 0.90 in bridges with a H:W ratio ≥0.4. However, this isn't a clear trend, as the shading at the majority of the bridges (B3E, B3Z, B3A and B6E) is still relatively high (between 0.76 and 0.89). There doesn't appear to be any trend within the near side and far side locations, but this has not been assessed in detail.

3.5 Figure 4 also ranks the bridges by H:W ratio, from the highest to lowest, and includes the percentage of vegetation cover within the near side, central and far side locations for each bridge. There is a positive trend between H:W ratio and vegetation cover at the centre of the bridge, with limited or no vegetation at the centre of the bridge below a H:W ratio of 0.4. On the other hand, aside from bridges with very low H:W ratios (B7A, B3D and B69) and a few anomalies (which may be as a result of other influences such as disturbance), there does not seem to be much variation in the vegetation cover at the near side and far side locations of the bridges, with the vegetation cover generally being high (between 80 and 100%).

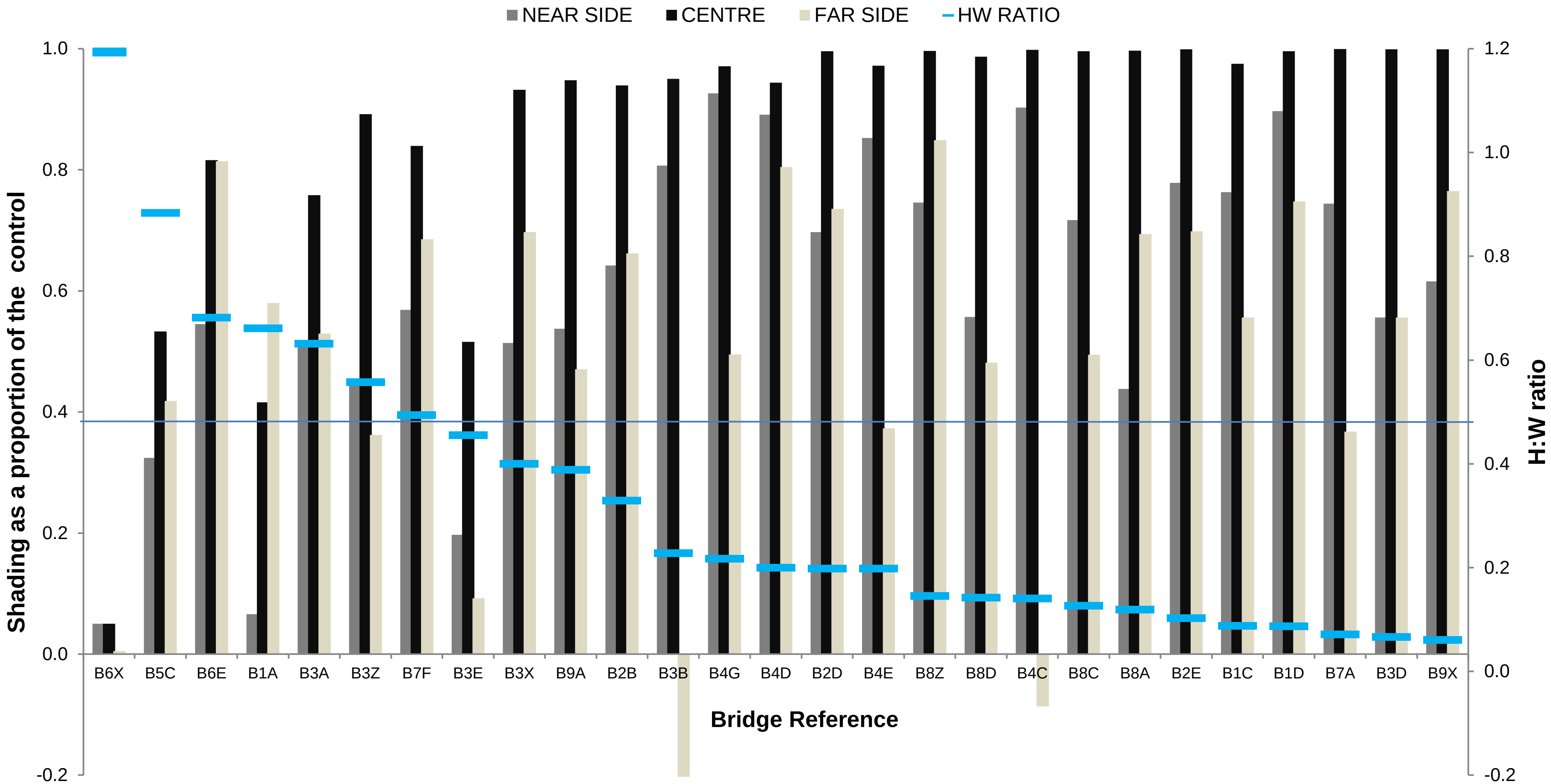


Figure 3 Proportion of increased shading compared to the control (the higher the proportion the greater the level of shading) for three locations beneath single-deck bridges (near side, centre and far side). Bridges are plotted in order of decreasing H:W ratios (shown by horizontal bars).

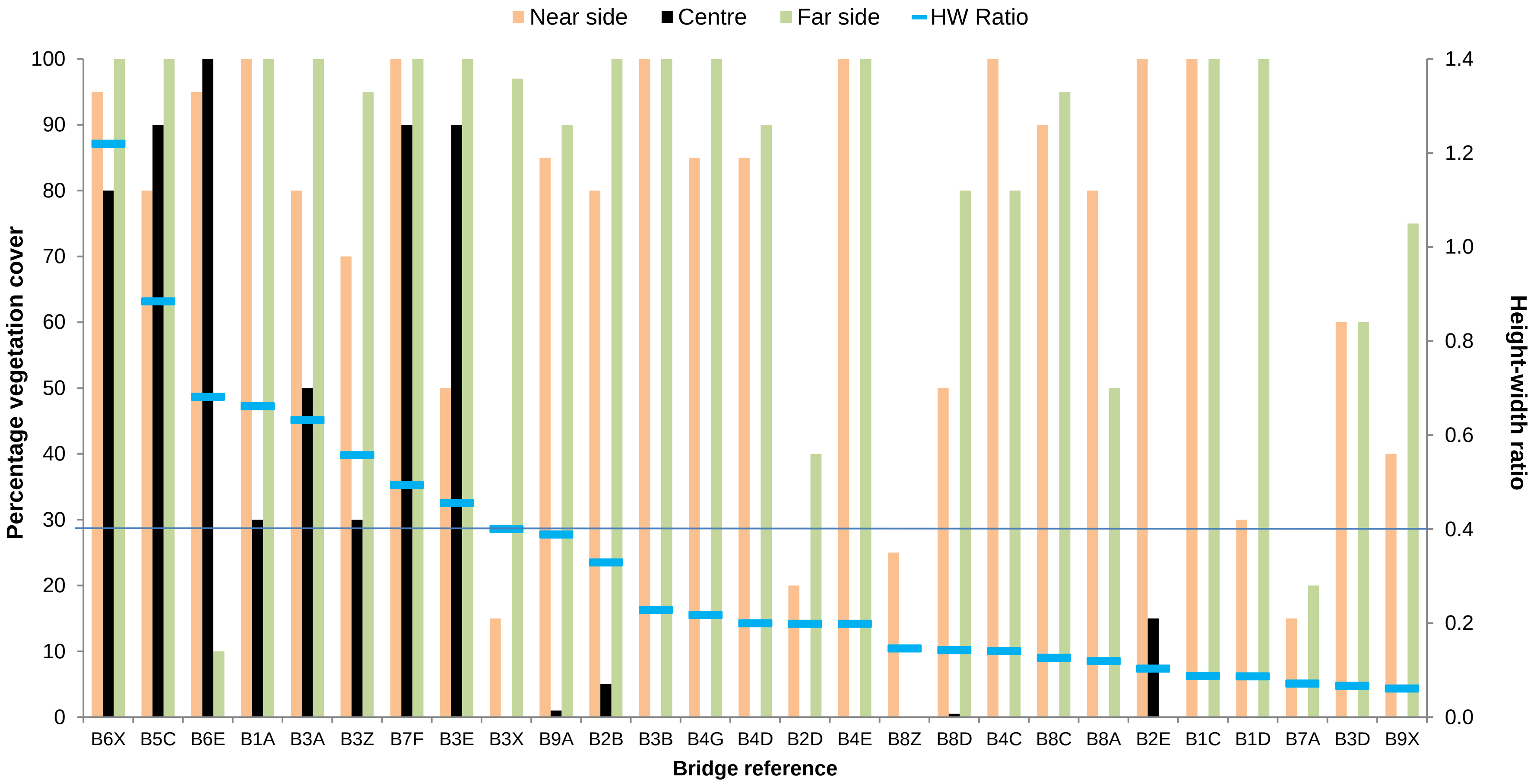


Figure 4 Percentage of vegetation cover for three locations beneath single-deck bridges (near side, centre and far side). Bridges are plotted in order of decreasing H:W ratios (shown by horizontal bars). A threshold at a H:W ratio of 0.4 has been included where bridges below this threshold have limited of no vegetation cover at the centre of the bridge.

3.6 There was a statistically significant difference in the percentage vegetation cover observed at the centre point beneath bridges for bridges with a H:W ratio <0.6 (n=27) compared to those with a H:W ratio ≥0.6 (n=5) (Mann-Whitney test: $U_{27,5}$ = 9.5, P<0.01).

3.7 A statistically significant difference was observed in the distance at which vegetation cover reduced to 50% (before or after the first quarter of the bridge width) between bridges with a H:W ratio ≥0.6 (n=3) versus those <0.6 (n=25) (Fisher's exact test: P=0.037). Bridges with a H:W ratio >0.6 were more likely to provide the conditions for vegetation cover to grow further beneath the bridge i.e. if a 50% reduction in vegetation cover occurred, it did so beyond the first quarter of the total width of the bridge.

3.8 When observing the H:W ratio of bridges in relation to the average vegetation cover beneath them, the following results were found. All bridges with a H:W ratio ≥0.6 were found to have vegetation growing throughout, with an average of 70% cover. Both of the bridges with a H:W ratio ≥0.8, had on average greater than 90% vegetation cover throughout. Bridges with a H:W ratio of <0.6, had on average 12% vegetation cover. Some examples of bridges are given below, which illustrate some of the effects seen.

3.9 Bridge B3X had a H:W ratio of 0.4 (Plate 1). This bridge had no vegetation cover within the central quadrat, which is consistent with most of the bridges with this ratio or less. However, the river bank besides the sampled land comprised an inaccessible area dominated by tall ruderal herbs, which grew along the whole width of the bridge (Plate 2). The tall ruderal species such as nettle (*Urtica dioica*) thus showed greater tolerance of shading and/or benefited from closer proximity to the watercourse.

Plate 1 - Bare ground within amenity area of B3X (H:W ratio 0.4)

Plate 2 - Tall ruderal dominate throughout the deck of bridge B3X (H:W 0.4)

3.10 Bridge B2B (Plate 3) had a H:W ratio of 0.33. Directly beneath the bridge, a high degree of shading effect was observed, with vegetation cover reduced to 50% at 3m and 8m respectively from the edge of the bridge and with no vegetation in the middle zone (<5% in Q3 and 0% in Q4). B3B (Plate 4).was similarly wide (at 23m) but was also lower (5.2m clearance, H:W ratio 0.23). The reduction of vegetation to 50% thus occurred over a shorter distance, with 50% cover recorded at 1.5m and 6m from the edges respectively and 0% cover recorded at 3.4m and 8.4m. This asymmetry of response is likely to be due to the aspect in this north-south bridge

Plate 3 – Bridge B2B showing reduction of vegetation on towpath (H:W ratio 0.33)

Plate 4 – Bridge B3B showing transition to no vegetation (H:W ratio 0.23)

3.11 Bridge B4E shows the loss of marginal vegetation from a bridge with relatively high clearance (8m), but a low H:W ratio of 0.2 due to its considerable width (40.6m) (Plates 5 and 6).

Plate 5– Bridge B4E seen from afar (H:W ratio 0.2)

Plate 6– Dense shading and decrease in marginal vegetation beneath bridge B4E (H:W ratio 0.2)

3.12 Bridges with a H:W ratio of 0.1 of less were found to contain extensive bare earth beneath the bridge (discounting those that had been deliberately hard-surfaced). In many of these examples, a marked transitional decrease in vegetation was observed from outside to just beneath the bridge. Bridge B3D was a wide bridge (36m) that also had a relatively low clearance height (2.4m). In this example, complete bare soil was observed beneath the bridge, with sparse vegetation growing to a maximum distance of 8m from the side of the bridge (Plate 7). This was also noticeable in other examples, such as bridge B1C (Plate 8 & 9) in which the great bridge width and low bridge height combined to create un-colonisable conditions.

Plate 7 – Bare earth conditions created beneath the low, wide bridge B3D (H:W ratio <0.1)

Plate 8 – Bare earth conditions created beneath the bridge B1C (H:W ratio <0.1)

Plate 9 – Effect of shading created by bridge B1C on a small stream (H:W ratio <0.1)

3.13 Bridge B4A indicates that vegetation is able to grow beneath a bridge under partially shaded conditions. B4A traverses the River Frome in an approximate east-west orientation. It is on a twin-deck bridge with a H:W ratio of 0.57. Beneath B4A, areas of bare ground with no colonising vegetation are present (Plate 10). However, this is likely a result of footpath disturbance. Despite the evident lack of vegetation on the steep slopes to the bridge abutments and the trampled path, vegetation was observed growing within the 7m gap between the bridges and along the whole length of river bank, under both bridges (Plate 11). Although growth was not as extensive beneath each bridge compared to adjacent habitat, this does highlight tolerance of this habitat of scrub woodland and herbs to partial shading, even with a moderately high level of disturbance.

Plate 10 - Bare ground and associated lack of vegetation due to trampling and clearance at twin-deck bridge B4A (H:W ratio 0.57)

Plate 11- Extent of vegetation growing beneath and most notably within the 7m gap of twin-deck bridge B4A (H:W ratio 0.57)

3.14 Bridge B6E, an east-west running bridge with a H:W ratio of 0.68, had 100% vegetation cover in the central quadrat but one of the outer quadrats only had 10% vegetation cover (Q3). However, the affected area was naturally shaded by adjacent hedging and tree cover. This natural shading appeared to be the reason for the localised reduction in vegetation. Bridge B6E traverses a stretch of the River Itchen, a shallow chalk stream habitat. The habitat surveyed was not typical of the Itchen, comprising a disturbed roadside verge. However, the private land adjacent comprised a chalk stream and associated habitat. Although not directly accessed, this habitat was visible from the road. The vegetation beneath the bridge was seemingly unaffected by the partial shade cast by the bridge: watercress (*Nasturtium officinale*) and submerged aquatic macrophytes were visibly growing beneath the bridge

(Plate 12 & 13). Also of note is the intact grazed pasture beneath the bridge, albeit with cover slightly more sparse in the immediate vicinity of the bridge supports.

Plate 12 - Chalk stream and pasture beneath B6E (H:W ratio 0.68)

Plate 13 - Watercress growing within chalk stream beneath B6E (H:W ratio 0.68)

Effects of bridge aspect

3.15 A 50% reduction in vegetation occurred beyond the first quarter of the bridge in most east-west facing bridges (n=7), whereas, this occurred before the first quarter in all but one occurrence in north-south bridges (n=8). This difference is shown in Table 2 and was statistically significant (Fisher's exact test: P=0.041). It indicates that the effect of shading occurred closer to the edge of bridges with a north-south orientation.

Table 2 - Frequency table of bridges with 50% vegetation cover occurring before or after a proportionate distance of 0.25 (one quarter of the total width) for bridges with an east-west or north-south orientation.

	Number of bridges		
Bridge orientation	**Before 0.25**	**After 0.25**	**Sub-total**
East-West	2	5	7
North-South	7	1	8
Sub-total	9	6	15

3.16 It was observed that bridges with a north-south orientation had a greater effect on the reduction of vegetation beneath in comparison to bridges with an east-west orientation (Figure 5). It was found that bridges with a north-south aspect tended to have a more abrupt effect on the reduction of vegetation cover close to the edge of the bridge.

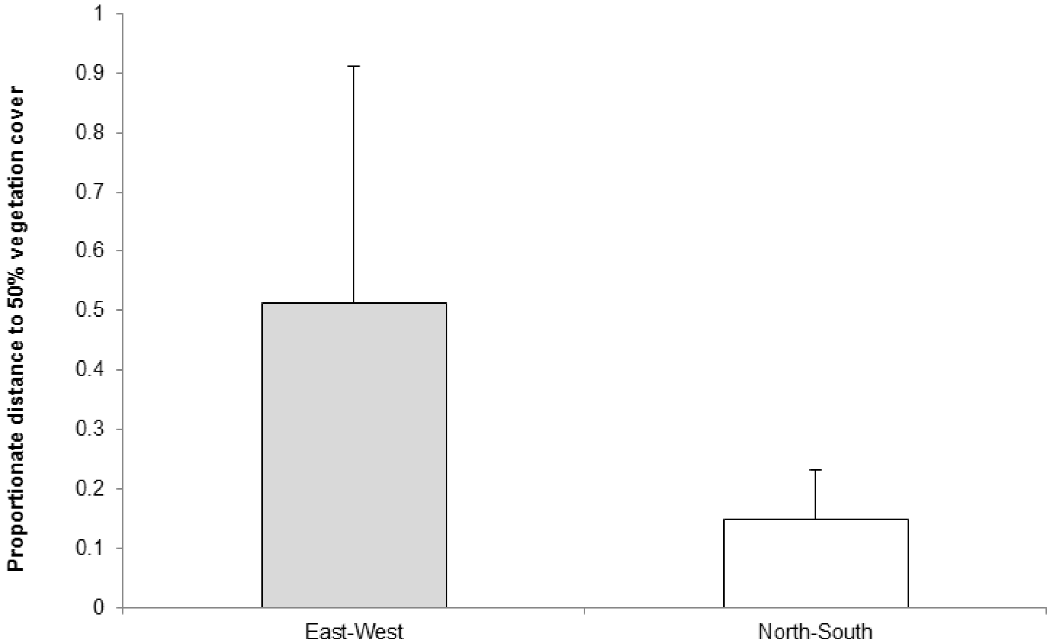


Figure 5 - Mean proportionate distance from the edge of the bridge deck in which a 50% reduction in vegetation was observed for bridges in an east-west (n=7) orientation versus north-south (n=8).

Aquatic vegetation

<u>Correlation between aquatic vegetation cover and H:W ratio</u>

3.17 Table 3 shows that there was no statistically significant difference in the reduction of aquatic vegetation between bridges with a H:W ratio above 0.6 and those below 0.6 (n=7 for both 'low' and 'high', Fisher's exact test: P=0.1). However, the sample size was small in the category with H:W ratio $\geq$0.6.

Table 3 – H:W ratio of bridges with varying reductions in aquatic vegetation.

Bridge H:W ratio	Number of bridges with low reduction in aquatic vegetation	Number of bridges with high reduction in aquatic vegetation
< 0.6	6	6
≥ 0.6	1	1

3.18 Of the bridges sampled, most watercourses had been canalised, or had experienced disturbance (e.g. trampling), which was observed to limit the biomass of aquatic or marginal vegetation. Comparison of the lack of shading impact in B6E (H:W ratio 0.68, Plate 13) and the loss of emergent vegetation in B4E (H:W ratio 0.2, Plate 6) are indicative of the effect of a low H:W ratio, but there are not enough samples of this kind to be conclusive.

Correlation between aquatic vegetation cover and aspect

3.19 There was no significant difference in the reduction of aquatic vegetation observed beneath bridges with an east-west or north-south orientation (n=7 for both 'low' and 'high', Fisher's exact test: P=0.659) (Table 4).

Table 4 - Bridge aspect with varying reductions in aquatic vegetation.

Bridge aspect	Number of bridges with low reduction in aquatic vegetation under the bridge	Number of bridges with high reduction in aquatic vegetation
East-West	4	2
North-South	7	7

3.20 The same potential limiting factors as described in paragraph 5.16 are appropriate for this test.

4 Discussion

General Interpretation

Role of height-width ratio in vegetation cover

4.1 The results show that although bridge H:W ratio is well correlated with shade, there is a weaker correlation between shade and vegetation cover, which is likely to be related to disturbance observed during this study and other factors discussed below.

4.2 It is important to note that shade did not appear to affect the vegetation directly underneath the bridge for especially tall bridges. In several sampled bridges (e.g. B1A and B6X), shade was observed to one side of the bridge covering another area, as expected in autumn afternoons, when the sun is lower in the sky than would be the case at the same time of day in summer. Therefore, it is possible that this cast shade may have an effect beyond the extent of the bridge, something which has not been assessed within this study. Nonetheless, the continuous movement of shadow during the day and the lack of cover overhead i.e. continuous diffuse light, suggest that effects are likely to be much less than under bridges.

4.3 A clear difference in the cover of vegetation within the central region of the bridge was observed for bridges with a H:W ratio greater than 0.6, compared to those lower than 0.6. The study by Broome *et al.* (2005) discovered that a H:W ratio >0.7 had no measurable effect on the habitat beneath, that ratios of 0.5-0.7 had detectable but diminished effects and that ratios ≤0.3 caused partial or complete loss of vegetation in the saltmarsh vegetation studied. The results from the current study indicate a threshold for significant effects, with vegetation at or below 50% cover under bridges, with an H:W ratio range of 0.4 to 0.6. There is an increasing risk of areas of bare ground as the H:W ratio decreases below 0.4 (as shown in Figure 4).

4.4 Due to the limited number of bridges within our study that had a H:W ratio >0.7, it is difficult to conclude a definite H:W ratio for which there is no detectable effect on vegetation cover for pasture and riverine habitats. A notably small effect is still visible within the ≥0.6 dataset when compared to the control values. H:W ratios in the range 0-6-0.8 or above are thus the minimum recommended to sustain vegetation. The recommended H:W ratio for bridge design is an estimate derived from the study but is similar to the 0.7 value given by Broome *et al.* (2005).

4.5 Only two bridges with a H:W ratio over 0.7 were sampled (B5C & B6X). Both of these showed an average difference from the control of only 8% and 10% less vegetation cover respectively. In addition, within the >0.6 dataset, two outliers were noted, B1A and B3A. The vegetation cover observed beneath these bridges was highly disturbed; bridge B1A (Appendix C Plate 14 & 15) was subject to heavy trampling by sheep, whereas, B3A had been hard-surfaced with a gravel substrate during construction. These may have inflated the reduction in vegetation cover for bridges above 0.6.

4.6 Example B3A does highlight the resilience of plants to recolonise a disturbed environment when the H:W ratio allows sufficient light under the bridge. However, the composition of species predominantly comprised shade-tolerant ruderal herbs, such as Himalayan balsam (*Impatiens glandulifera*) and common nettle (*Urtica dioica*), or scrub such as bramble (*Rubus fruticosus* agg.). This is, in part, due to the fact that all were publicly accessible, with some level of footpath disturbance being encountered. Furthermore, some disturbance (e.g. roadside verges, grazing and trampling) was apparent beneath most bridges. It is likely that disturbance associated with the creation of the bridge (e.g. excavation of habitat), subsequent use of the land and the effect of shading collectively create conditions enabling these opportunistic species to dominate. In certain habitats, these plants are common components of the floral community.

4.7 All bridges with very low H:W ratios (i.e. ≤0.4), were typically partly or wholly hard-surfaced. However, in the few cases in which they were not surfaced, bare earth with little to no vegetation was recorded. It is assumed that due to the densely shaded conditions created by bridges with a low H:W ratio complete hard-surfacing was preferred in order to prevent dusty bridge underpasses, with associated risk of runoff of soil to the adjacent watercourse, forming as a by-product of construction.

Factors other than shading that may cause bare ground

4.8 Most of the bridges surveyed were estimated to have been constructed several decades ago. The underside of most surveyed bridges had either been concreted, or had been laid with an artificial substrate. As such, the percentage vegetation cover data largely reflects the post-construction colonisation of vegetation beneath a bridge rather than any pre-existing habitat altering under the impact of shading (e.g. B8A).

4.9 Other factors likely to result in reduced vegetation beneath bridges relate to management. Bridge B1A (Appendix C Plate 14 & 15) was a tall bridge which had no direct shading beneath. However, sheep were grazing on site and had excessively trampled the area directly beneath the bridge, resulting in a sparsely vegetated habitat in which bare ground was predominant. The attraction of the bridge to sheltering livestock led to a highly disturbed habitat, despite the lack of shading. In addition, most habitats under the bridges surveyed included footpaths. As such, trampling of vegetation and erosion of paths is also likely to have influenced the dataset. Hence, the study may have over-estimated the impact of shading, at least in combination with other factors.

4.10 Dryness under the bridges may have been a contributing factor in some cases, especially at bridges where the ground level along the survey transect was markedly higher than the water level in the adjacent watercourse, often 1-2m or more. This may explain why vegetation along the margins of watercourses showed less effect of shading than the survey transects.

Role of Aspect

4.11 A significant difference in vegetation beneath bridges with different orientations was observed. The point at which 50% vegetation cover occurred beneath east-west orientated bridges was largely beyond the first quarter of the bridge, suggesting that light was able to penetrate further beneath the bridge. North-south bridges, however, were observed to elicit the opposite effect, with the point at which 50% vegetation cover was observed occurring before the first quarter, suggesting that light couldn't penetrate as far. This concurs with the notion that the underpass of an east-west orientated bridge would receive a higher proportion of sunlight compared with north-south orientations.

Effect of H:W ratio on Aquatic vegetation

4.12 Analysis carried out for both H:W ratio and aspect produced non-significant outputs, this is most probably due to the small sample size. Despite the non-significant outputs, the P-value ($P=0.1$) for the H:W ratio test was not far from being significant. The data thus provide an indication that bridges with a H:W ratio ≥0.6 are likely to result in slight or no reduction in aquatic vegetation, with those <0.6 producing an opposite result. It is therefore likely that the low number of samples is the underlying factor in the non-significant outcome, rather than the absence of a relationship. A more robust sampling procedure with better matching of habitat types may show an effect of bridge aspect on aquatic vegetation cover.

5 Conclusion

5.1 Overall, this study of bridges in southern England shows that there is a negative relationship between vegetation and extent of shading under bridges, although the response is not differentiated by habitat type. Results showed that vegetation cover was greater under tall, relatively narrow bridges compared to low wide bridges. Indeed, many low bridges were excluded from the study at the desk study stage because they had been treated with hard surfacing, which would limit the erosion of bare ground produced by the expected shading.

5.2 H:W ratio is a key factor in determining the shading and the response of vegetation. On the basis of the study, the minimum H:W to maintain continuous vegetation with at least 50% cover is approximately 0.6 to 0.8. Other related factors influence the vegetation under bridges, notably the impacts of trampling by people or livestock and water availability.

6 References

Armstrong, A. Ostle, N.J. and Whitaker, J. 2016. Solar park microclimate and vegetation management effects on grassland carbon cycling. Environmental Research Letters.

Broome, S.W., Craft, C.B., Struck, S.D. and M. SanClements. 2005. Effects of Shading from Bridges on Estuarine Wetlands. [pdf] Available at: https://connect.ncdot.gov/projects/planning/RNAProjDocs/2001-12FinalReport.pdf [Accessed 20th Oct 2017]

Dawson, F.H. and Hallows, H.B. 1983. Practical Applications of a shading material for macrophytes control in watercourses. Aquatic Botany, 17, 301 - 308

Dawson, F.H. and Kern-Hansen, U. 1979. The Effect of Natural and Artificial Shade on the Macrophytes of Lowland Streams and the Use of Shade as a Managemert Technique. Int. Rev. Ges. Hydrobiol., 64: 437-255

Devkota, N.R, Kemp, P,D., Valentine, I. and Hodgson, J. 1998. Performance of perennial ryegrass and cocksfoot cultivars under tree shade. Proceedings Of The Agronomy Society Of New Zealand 28th Annual Conference of the Agronomy-Society-of-New-Zealand.

Edelkraut, K.A. and Gusewell, S. 2006. Progressive effects of shading on experimental wetland communities over three years Plant Ecology. Volume 183, Issue 2, pp. 315–327

Einarsson, A. and Milberg, P. 1999. Species richness and distribution in relation to light in wooded meadows and pastures in southern Sweden. Annales Botanici Fennici. Vol. 36, No. 2, pp. 99-107

Garbey, C., Thiébaut G. and Muller, S. 2004. Morphological plasticity of a spreading aquatic macrophyte, Ranunculus peltatus, in response to environmental variables. Plant Ecology 173: 125–137.

Garbey, C., Thiébaut G. and Muller, S. 2006. An experimental study of the plastic responses of Ranunculus peltatus S

Grubb, P.J., Lee, W.G., Kollmann, J. and Wilson, J.B. 1996 (Rev 2nd Ed). Interaction of irradiance and soil nutrient supply on growth of seedlings of ten European tall-shrub species and Fagus sylvatica. Journal of Ecology. Vol. 84, No. 6, pp. 827-840

Heger, T. 2016. Light availability experienced in the field affects ability of following generations to respond to shading in an annual grassland plant Journal of Ecology, 104, pp. 1432-1440

Joint Nature Conservancy Council (JNCC), 2010. Handbook for Phase 1 Habitat Survey: A Technique for Environmental Audit. Joint Nature Conservancy Council, Peterborough.

Kohler, J., Hachol, J. and Hilt, S. 2010. Regulation of submersed macrophyte biomass in a temperate lowland river: Interactions between shading by bank vegetation, epiphyton and water turbidity. Aquatic Botany 92 129–136

Lepik, M. & Zobel, K. 2015. Is the positive relationship between species richness and shoot morphological plasticity mediated by ramet density or is there a direct link? Oecologia, Volume 178, Issue 3, pp. 867–873. Mika, V., Kohoutek, A. and Beran, S. 1998. Grass quality at shading of the stand ROSTLINNA VYROBA

Lepik, M; Liira, J; Zobel, K. 2003. The space-use strategy of plants with different growth forms, in a field experiment with manipulated nutrients and light. Folia Geobotanica. Volume 39, Issue 2, pp. 113–127

Roscher C, Schmid B, Kolle O, Schulze E-D. 2016. Complementarity among four highly productive grassland species depends on resource availability. Oecologia; 181: 571–582. pmid:26932467.

Roscher, C., Kutsch, W.L., Kolle, O., Ziegler, W. and Schulze, E.D. 2011. Adjustment to the light environment in small-statured forbs as a strategy for complementary resource use in mixtures of grassland species. Annals Of Botany, 107, pp. 965–979,

Seidlova, L., Verlinden, M., Gloser, J., Milbau, A. and Nijs, I. 2009. Which plant traits promote growth in the low-light regimes of vegetation gaps? Plant Ecology. 200, Issue 2, pp. 303–318.

Semchenko, M., Lepik, M., Gotzenberger, L. and Zobel, K. 2012. Positive effect of shade on plant growth: amelioration of stress or active regulation of growth rate? Journal of Ecology, 100, 2, pp. 459 – 466.

Siebenkas, A., Schumacher, J. & Roscher, C. 2016. Resource Availability Alters Biodiversity Effects in Experimental Grass-Forb Mixtures. PLOS ONE. vol. 11, issue 6, p. e0158110

Skornik, S., Sajna, N., Kramberger, B., Kaligaric, S. and Kaligaric, M. 2008. Last Remnants of Riparian Wooded Meadows along the Middle Drava River (Slovenia): Species Composition Is a Response to Light Conditions and Management. Folia Geobotanica. Volume 43, Issue 4, pp. 431–445

Staley, J.T., Bullock, J.M., Baldock, K.C.R., Redhead, J.W., Hooftman, D.A.P., Button, N. and Pywell, R.F. (2013). Changes in hedgerow floral diversity over 70 years in an English rural landscape, and the impacts of management. Biological Conservation. Volume 167, November 2013, pp. 97-105.

Zobel, K. and Eek, L. 2002. Seasonal direct light availability affects mean leaf orientation in a herbaceous multi-species canopy. Plant Biology. Volume 4, Issue 4. Pages 503–507

Zobel, M., Suurkask, M., Rosen, E. and Partel, M. 1996. The dynamics of species richness in an experimentally restored calcareous grassland Journal of Vegetation Science. Vol. 7, No. 2 , pp. 203-210

AmW Approvals

Role	Name	Signature	Date
Authors	**Hannah Mitchell**	[redacted]	28/02/2018
	Ashley Welch	[redacted]	13/11/2017
Checker	**Stephanie Peay**	[redacted]	12/12/2017

Appendix A Figure 1: Map of southern England showing the location of bridge sampling sites

Appendix B Shading study data

Table B1 – Raw data table

Bridge ref.	Width (m)	Aspect (°)	Height to underside	Height-width ratio underside	Estimate of vegetation cover (%)					Estimate of point where vegetation cover reduced to 50%				Estimate of point where vegetation cover reduced to 0%				Percentage of shading proportionate to control					Comments
										Distance (m)		Proportionate distance to half of bridge		Distance (m)		Proportionate distance to half of bridge							
					Q1	Q2	Q3	Q4	Q5	Side A	Side B	Side A	Side B	Side A	Side B	Side A	Side B	Q1	Q2	Q3	Q4	Q5	
Single-deck bridges																							
B9X	43.2	224-44	2.6	0.06	40	0	75	NA	NA	NR	NR	NR	NR	1.5	4.0	0.07	0.19	62	100	77	NA	NA	
B6A	41.5	120-300	2.6	0.06	NA	NA	NA	NA	NA	0.0	0.0	0.00	0.00	-1.0*	1.0	-0.05	0.05	99	100	54	NA	NA	Canal - hardstanding
B6F	38	200-10	2.4	0.06	NA	NA	NA	NA	NA	0.0	0.0	0.00	0.00	0.8	0.0	0.04	0.00	93	100	100	NA	NA	Hardstanding
B3D	36	235-58	2.4	0.07	60	0	60	NA	NA	7.7	5.5	0.43	0.31	12.5	8.0	0.69	0.44	56	100	56	NA	NA	
B7A	28.2	109-289	2.0	0.07	15	0	20	NA	NA	3.3	NR	0.23	0.0	NR	NR	0.00	0.00	74	100	37	NA	NA	
B1D	37.6	60-220	2.0	0.09	30	0	100	NA	NA	2.2	3.5	0.12	0.19	7.5	6.5	0.40	0.35	90	100	75	NA	NA	Excavation beneath
B1C	22.9	0-180	2.0	0.09	100	0	100	NA	NA	4.0	3.0	0.35	0.26	5.5	6.5	0.48	0.57	76	98	56	NA	NA	Excavation beneath
B2E	32.5	350-175	3.3	0.10	100	15	0	NA	NA	2.6	2.6	0.16	0.16	6.0	4.7	0.37	0.29	78	100	70	NA	NA	Excavation beneath, inability to recolonise
B8A	60	90-270	7.1	0.12	80	0	50	NA	NA	NR	NR	NR	NR	NR	NR	NR	NR	44	100	69	NA	NA	Hardstanding
B8C	31	240-70	3.9	0.13	90	100	0	0	95	9.0	6.0	0.58	0.39	10.5	9.0	0.68	0.58	72	97	100	97	49	

Bridge ref.	Width (m)	Aspect (°)	Height to underside	Height-width ratio underside	Estimate of vegetation cover (%)					Estimate of point where vegetation cover reduced to 50%				Estimate of point where vegetation cover reduced to 0%				Percentage of shading proportionate to control					Comments
										Distance (m)		Proportionate distance to half of bridge		Distance (m)		Proportionate distance to half of bridge							
					Q1	Q2	Q3	Q4	Q5	Side A	Side B	Side A	Side B	Side A	Side B	Side A	Side B	Q1	Q2	Q3	Q4	Q5	
B2A	20.8	180-0	2.7	0.13	0	0	0	NA	NA	0.9	3.5	0.09	0.34	3.0	5.5	0.29	0.53	35	100	80	NA	NA	Canal - hardstanding
B4C	34.6	347-167	4.8	0.14	100	0	80	NA	NA	6.0	4.0	0.35	0.23	12.8	9.0	0.74	0.52	90	100	-9	NA	NA	
B8D	31	130-270	4.4	0.14	50	95	1	25	80	8.0	7.5	0.52	0.48	14.0	15.0	0.90	0.97	56	92	99	95	48	Canal - hardstanding
B8Z	28.5	150-330	4.2	0.15	25	0	0	NA	NA	NR	NR	NR	NR	1.0	0.0	0.07	0.00	75	100	85	NA	NA	Canal - hardstanding
B9Y	35	154-338	5.5	0.16	NA	NA	NA	NA	NA	8.2	5.0	0.47	0.29	15.0	10.0	0.86	0.57	57	1	33	NA	NA	
B4E	40.6	43-217	8.0	0.20	100	0	100	NA	NA	4.0	2.6	0.20	0.13	5.7	7.6	0.28	0.37	85	97	37	NA	NA	Canal - hardstanding
B2D	29	10-190	5.8	0.20	20	0	40	NA	NA	-1.0*	0.6	-0.07*	0.04	3.2	2.5	0.22	0.17	70	100	74	NA	NA	
B4D	35	218-40	7.0	0.20	85	70	0	65	90	8.8	10.0	0.50	0.57	14.0	16.0	0.80	0.91	89	95	94	95	80	Excavation beneath – inability to recolonise
B4G	36.1	40-230	7.8	0.22	85	10	0	20	100	5.0	5.5	0.28	0.30	12.0	15.1	0.66	0.84	93	97	97	95	50	Immature tree growing beneath
B3B	23	30-210	5.2	0.23	100	0	100	NA	NA	1.5	6.0	0.13	0.52	3.4	8.4	0.30	0.73	81	95	-28	NA	NA	
B2B	26	10-190	8.6	0.33	80	25	<5	0	100	3.0	8.0	0.23	0.62	13.6	13.0	DR	DR	64	87	94	92	66	Canal - hardstanding
B9A	9.8	2-71	3.8	0.39	85	1	90	NA	NA	2.5	2.6	0.51	0.53	4.6	5.4	0.94	DR	54	95	47	NA	NA	Canal - hardstanding
B3X	10.4	282-105	4.2	0.40	15	0	97	NA	NA	0.8	0.5	0.15	0.10	3.8	2.1	0.73	0.40	51	93	70	NA	NA	Only tree coverage deterred
B3E	13.5	273-95	6.1	0.45	50	90	100	NA	NA	6.8	6.8	DR	DR	6.8	1.0	6.80	DR	20	52	9	NA	NA	Scrub coverage throughout

Bridge ref.	Width (m)	Aspect (°)	Height to underside	Height-width ratio underside	Estimate of vegetation cover (%)					Estimate of point where vegetation cover reduced to 50%				Estimate of point where vegetation cover reduced to 0%				Percentage of shading proportionate to control					Comments
										Distance (m)		Proportionate distance to half of bridge		Distance (m)		Proportionate distance to half of bridge							
					Q1	Q2	Q3	Q4	Q5	Side A	Side B	Side A	Side B	Side A	Side B	Side A	Side B	Q1	Q2	Q3	Q4	Q5	
B7F	22.7	45-220	11.2	0.49	100	45	90	95	100	5.2	11.4	0.46	DR	11.4	11.4	DR	DR	57	79	84	66	69	
B3Z	10	318-138	5.6	0.56	70	30	95	NA	NA	1.5	2.6	0.30	0.52	5.0	5.0	DR	DR	45	89	36	NA	NA	Bare ground either side to 2m outside of bridge
B3A	40	175-351	25.3	0.63	80	75	50	100	100	NR	NR	NR	NR	20.0	20.0	DR	DR	51	72	76	70	53	
B1A	22.7	280-100	15.0	0.66	100	80	30	90	100	10.4	11.4	0.92	DR	22.7	11.4	DR	DR	7	-4	42	51	58	Excessive sheep trampling
B6E	14.2	105-240	9.7	0.68	95	100	10	NA	NA	7.1	NR	DR	NR	7.1	7.1	DR	DR	55	82	81	NA	NA	Disturbance (pasture)
B5C	11.5	80-260	10.2	0.88	80	90	100	NA	NA	4.5	2.5	0.78	0.43	6.7	5.8	1.17	DR	32	53	42	NA	NA	Canal - hardstanding
B6X	13.7	240-60	16.7	1.22	95	80	100	NA	NA	6.9	6.9	DR	DR	6.9	6.9	DR	DR	5	5	1	NA	NA	
Twin-deck bridges																							
B6H (A)	14.2	330-165	2.3	0.16	NR	NR	NR	NR	NR	NA	NA	NA	NA	2.0	2.0	0.28	NR	99	100	100	NA	NA	
B6H (B)	31	330-165	2.3	0.07	NR	NR	NR	NR	NR	NA	NA	NA	NA	1.1	2.0	0.07	-2.00	100	100	100	NA	NA	
B7D (A)	10.5	189-4	3.0	0.29	50	0	0	NA	NA	0.8	NR	0.15	NR	1.7	0.0	0.32	0.00	81	95	87	NA	NA	
B7D (Gap)	0.25	NA	NA	NA	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	83	1	60	NA	NA	
B7D (B)	10.5	189-4	3.0	0.29	9	1	60	NA	NA	NR	0.6	NR	0.11	2.2	3.3	0.42	0.62	90	1	60	NA	NA	
B4A (A)	20	115-340	11.5	0.57	40	30	95	NA	NA	5.1	8.8	0.51	0.88	6.7	9.8	0.67	0.98	77	86	92	NA	NA	Excavation beneath

Bridge ref.	Width (m)	Aspect (°)	Height to underside	Height-width ratio underside	Estimate of vegetation cover (%)					Estimate of point where vegetation cover reduced to 50%				Estimate of point where vegetation cover reduced to 0%				Percentage of shading proportionate to control					Comments
										Distance (m)		Proportionate distance to half of bridge		Distance (m)		Proportionate distance to half of bridge							
					Q1	Q2	Q3	Q4	Q5	Side A	Side B	Side A	Side B	Side A	Side B	Side A	Side B	Q1	Q2	Q3	Q4	Q5	
B4A (Gap)	7	NA	NA	NA	95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	92	NA	NA	NA	NA	
B4A (B)	20	115-340	11.5	0.57	40	0	60	NA	NA	0.5	2.2	0.05	0.22	0.9	6.0	0.09	0.60	90	91	91	NA	NA	Excavation beneath

Red highlighted values indicate the central point of the bridge

* Negative numbers are used where the vegetation cover reduces before the edge of the bridge (e.g. -1 is used if the vegetation cover reduced to 0% 1 m away from the bridge edge)

NA – Not applicable i.e. completely hard-surfaced beneath bridge

NR – Not recorded because % cover did not reach reduce to the applicable value

DR – Vegetation did not reduce to the associated percentage

Appendix C Photographs

Plate 14 – Bridge B1A with extreme disturbance caused by trampling by grazing sheep

Plate 15 – Bridge B1A, a view away from the heavily trampled underpass

Plate 16 – Bridge B4E showing the storage of farm equipment under the bridge

Plate 17 – Bridge B3B displaying severe scouring of the river bank

Plate 18 – Bridge B4A showing scouring of the embankments beneath the bridge

Plate 19 – Bridge B1C. A typical example of the conditions created by low height bridges

Plate 20 – Bridge B2B. A typical example of the hard-standing amenity use of the underpass of bridges.

Plate 21 – Bridge B7C. A typical example of the hard-standing canalised stretch of river beneath a bridge.

Appendix D Shading in other habitats

6.1 The focus of the study is the effect of shading beneath bridges, but in order to help put this in context, comparative light levels were also recorded under tree canopy and in open areas to indicate the degree of shading by natural vegetation. Note that these levels were recorded with a light meter (see *Light Levels*), rather than recording the photosynthetically available radiation (PAR) beneath the canopy. The shading by the woodland canopy was compared with the bridge study using data from the point at which vegetation cover reduces to 50% and 0% respectively, beneath a bridge (Figure C1), and across near edge, intermediate and centrally placed quadrats (Figure C2). The shading coefficient was calculated as an inverse percentage value of the amount of light compared to a control.

6.2 There was a significant difference in the percentage increase of shading (shading coefficient) of woodlands and, areas of 0% and 50% vegetation cover beneath bridges (Kruskal-Wallis test: H_2 = 22.696, P<0.01). The post-hoc test indicates a significant difference in the percentage increase of shading of areas of 0% and 50% vegetation cover beneath bridges, however, the mean rank for woodland was not significant to 0% or 50% cover areas (Figure C1). This suggests that 0% vegetation cover occurs within greater shade cover compared to areas of 50% cover. However, the shading created by woodland is comparable to data collected for 50% and 0% cover areas.

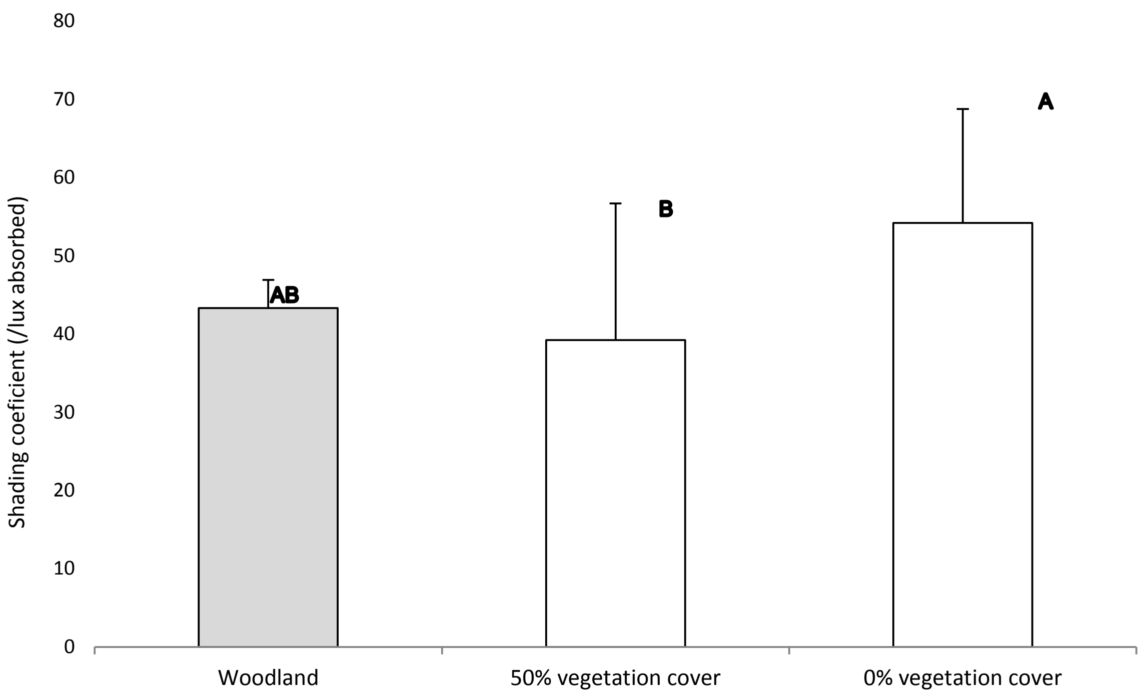


Figure D1 - Comparison of mean rank shading levels on woodland floor (n=6) and beneath bridges (n=23). Letters A and B indicate *post hoc* groupings.

6.3 There was a significant difference in the percentage increase of shading (shading coefficient) between all sections of bridges (Kruskal-Wallis test: H_2 = 34.76, P<0.01). The post-hoc test indicates a significant difference in the percentage increase of shading of central sections compared with near edge sections and woodland; woodland shading is also significantly different to intermediate bridge sections. This provides evidence that shading is darkest at the centre of the bridge, followed by intermediate and then near edge sections. The shading created by woodland is comparable to that found at the near edge of bridges sampled.

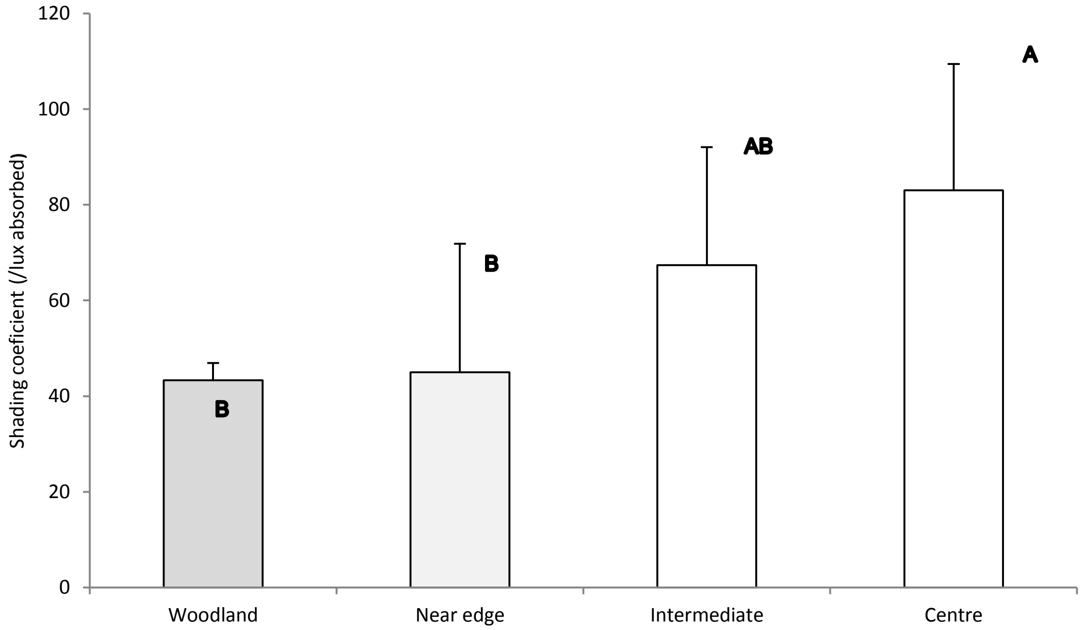


Figure D2 - Mean rank shading levels at different sections beneath bridges. Letters A and B indicate *post hoc* groupings.

Appendix E Correlation analysis

Table E1 - Summary of Pearson's correlation coefficient analysis carried out between combinations of bridge height, width, percentage shade and percentage vegetation cover

Variables correlation analysis undertaken between		Correlation value*	
Variable 1	**Variable 2**	**Single-deck bridges (N=29)**	**Twin-deck bridges** (N=6)**
H:W ratio underside	Percentage of increased shading at bridge mid-point	-0.89	-0.95
H:W ratio underside	Percentage of vegetation cover at bridge mid-point	0.76	0.58
H:W ratio deck	Percentage of increased shading at bridge mid-point	-0.83	-0.92
H:W ratio deck	Percentage of vegetation cover at bridge mid-point	0.79	0.62
Height to underside	Percentage of increased shading at bridge mid-point	-0.60	-0.90
Height to underside	Percentage of vegetation cover at bridge mid-point	0.49	0.63
Height to deck	Percentage of increased shading at bridge mid-point	-0.65	-0.92
Height to deck	Percentage of vegetation cover at bridge mid-point	0.47	0.62
Percentage of increased shading at bridge mid-point	Percentage of vegetation cover at bridge mid-point	-0.63	-0.79
Width of bridge deck	Percentage of increased shading at bridge mid-point	0.46	0.07
Width of bridge deck	Percentage of vegetation cover at bridge mid-point	-0.59	0.13

* Negative values indicate a negative correlation, positive values indicate a positive correlation, the closer the number is to 1 or -1, the stronger the correlation.

** Each deck of the twin-deck bridges were assessed separately

Appendix E River Till Viaduct Shade Modelling Calculations

Project:	A303 Stonehenge				
Title:	River Till Viaduct Shading study				
Doc ID:	-				
Date:	July 2018	**Version:**	P01	**Status:**	S0

1 Introduction

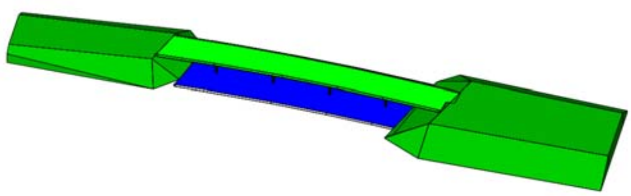
1.1 The purpose of this technical note is to propose metrics to assess levels of shading beneath bridges and viaducts, and then using these metrics to present the results from a shading modelling study considering options for the design for the proposed River Till Viaduct, part of the planned major A303 Stonehenge realignment scheme. This shading study has been carried out to support design development for the proposed viaduct with the ultimate intent of helping to avoid habitat loss beneath it. The starting point for the study is the current scheme design, i.e. a twin deck bridge structure on piers, with each deck of width 13.4 m, a 7.0 m gap between the decks, parapets, a noise barrier on the southern edge of the westbound bridge deck, the underside of the decks at a height of 10.0 m above average ground level, and with an east-west orientation.

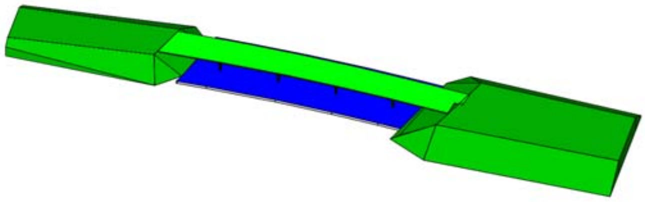
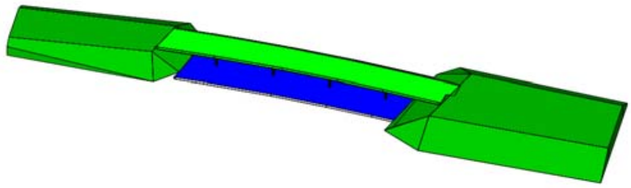
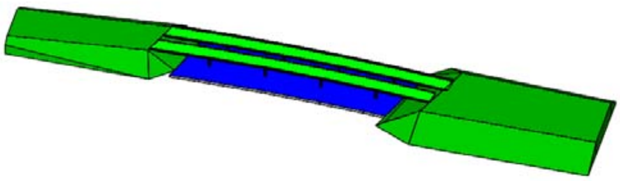
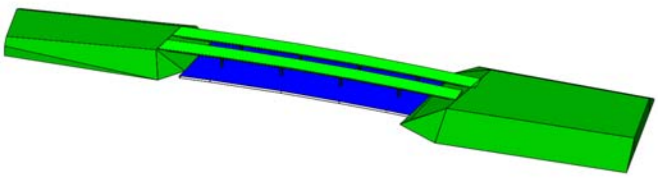
1.2 The Conservation of Habitats and Species Regulations (2010) neither specify that a particular methodology should be followed for carrying out such shading assessments, nor do they refer to other guidance. Therefore, in the absence of specific guidance, the following metrics have been applied in this study:

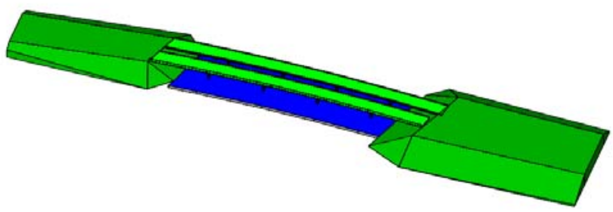
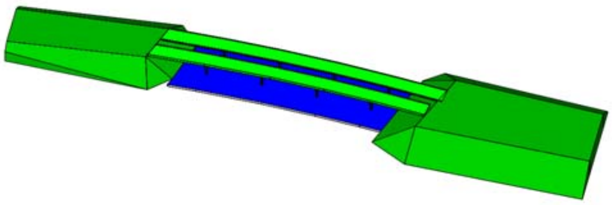
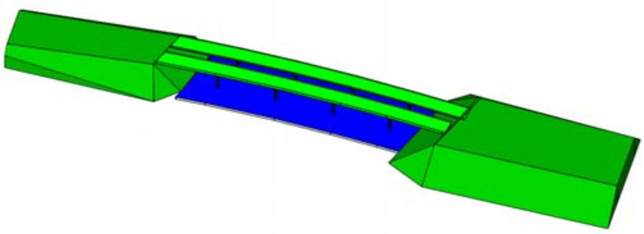
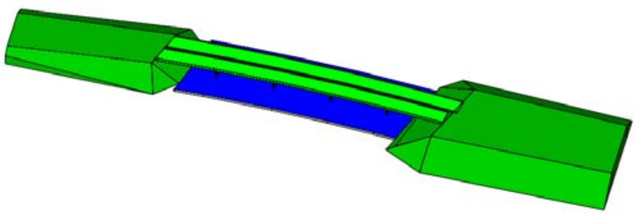
- Spatial distribution of solar exposure (expressed in number of hours)
- Area-based solar radiation attenuation factor (dimensionless)
- Daylight attenuation factor (dimensionless)

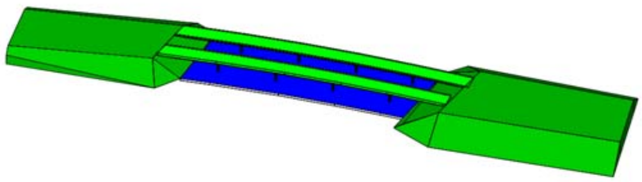
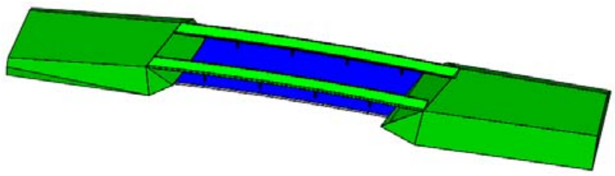
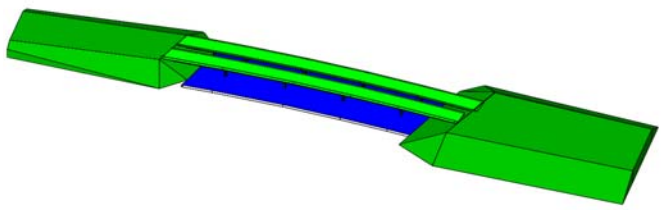
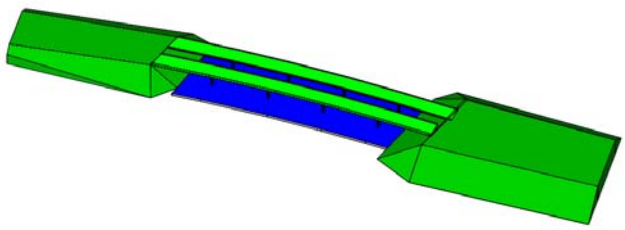
1.3 As avoiding habitat loss is a key concern for this scheme, the possible impacts of further design options on levels of shading beneath the bridge has been assessed in this study. An overview of the current design (Option 2.1) and possible further design options are included in Table 1.

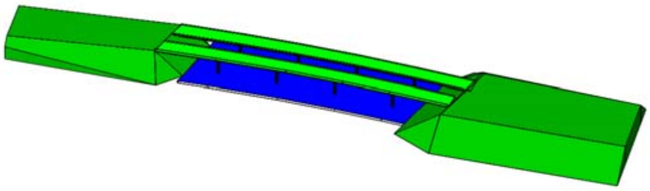
Table 1.The design options investigated in the shading assessments.

Option number	Base model	Description	Screenshots of the IES VE model geometry
1.1	Base-1	Orientation east-west; single deck; 1 m high infilled parapets; 2 m high noise barrier; deck height 10.0 m above average ground height	

Option number	Base model	Description	Screenshots of the IES VE model geometry
			Similar to current scheme design, but with a single deck (29.1 m wide)
1.2	Base-1	Orientation east-west; single deck; deck height 10.0 m above average ground height	 Similar to current scheme design, but with a single deck (29.1 m wide) and no parapets or noise barrier
1.3	Base-1	Orientation north-south; single deck; 1 m high infilled parapets; 2 m high noise barrier; deck height 10.0 m above average ground height	 Similar to current scheme design, but with a single deck (29.1 m wide) and alternative orientation
2.1	Base-2	Orientation east-west; twin deck with 7.0 m gap between decks; 1 m high mesh infilled parapets; 2 m high noise barrier; deck height 10.0 m above average ground height	 Based on current scheme design
2.2	Base-2	Orientation east-west; twin deck with 7.0 m gap between decks; deck height 10.0 m above average ground height	 Based on current scheme design, but no

Option number	Base model	Description	Screenshots of the IES VE model geometry
			parapets or noise barrier
2.3	Base-2	Orientation east-west; twin deck with 7.0 m gap between decks; 1 m high infilled parapets; 2 m high noise barrier; deck height 8.0 m above average ground height	 Based on current scheme design, but decreased deck height
2.4	Base-2	Orientation east-west; twin deck with 7.0 m gap between decks; 1 m high infilled parapets; 2 m high noise barrier; deck height 13.0 m above average ground height	 Based on current scheme design, but increased deck height
2.5	Base-2	Orientation east-west; twin deck with 7.0 m gap between decks; 1 m high infilled parapets; 2 m high noise barrier; deck height 16.0 m above average ground height	 Based on current scheme design, but increased deck height
2.6	Base-2	Orientation east-west; twin deck with 2.0 m gap between decks; 1 m high infilled parapets; 2 m high noise barrier; deck height 10.0 m above average ground height	 Based on current scheme design, but decreased gap width

Option number	Base model	Description	Screenshots of the IES VE model geometry
2.7	Base-2	Orientation east-west; twin deck with 15.0 m gap between decks; 1 m high infilled parapets; 2 m high noise barrier; deck height 10.0 m above average ground height	 Based on current scheme design, but increased gap width
2.8	Base-2	Orientation east-west; twin deck with 35.0 m gap between decks; 1 m high parapets; 2 m high noise barrier; ; deck height 10.0 m above average ground height	 Based on current scheme design, but increased gap width
2.9	Base-2	Orientation east-west; twin deck with 6.0 m gap between decks; 1 m high infilled parapets; 2 m high noise barrier; deck height 8.0 m above average ground height	 Based on current scheme design, but decreased both gap width and deck height
2.10	Base-2	Orientation east-west; twin deck with 9.0 m gap between decks; 1 m high infilled parapets; 2 m high noise barrier; deck height 12.0 m above average ground height	 Based on current scheme design, but increased both gap width and deck height

Option number	Base model	Description	Screenshots of the IES VE model geometry
2.11	Base-2	Orientation east-west; twin deck with 11.0 m gap between decks; 1 m high infilled parapets; 2 m high noise barrier; deck height 14.0 m above average ground height	 Based on current scheme design, but increased both gap width and deck height

2 Shading metrics

2.1 The following metrics have been used for assessing the design option:

1. Spatial distribution of solar exposure throughout the growing season [1] – The solar exposure provides information on the number of hours when sunlight is available during a specified period i.e. in this case the growing season. The number of hours is displayed visually on the surfaces below the bridge using a grid resolution of 10 m x 10 m. Five adjacent assessment surfaces have been defined as below:

- - Outer Zone South (approx. 27,400 m2): the flat surface located south of the bridge at the ground level that is three times wider than the widest bridge span investigated, i.e. Option 2.8.
- - Intermediate Zone South (approx. 11,300 m2): the flat surface located south of the bridge at the ground level, with the same width as the widest bridge span investigated, i.e. Option 2.8.
- - Bridge Zone (approx. 11,200 m2): the flat surface directly below the bridge, at the ground level, with the same width as the widest bridge span investigated, i.e. Option 2.8.
- - Intermediate Zone North (approx. 11,300 m2): the flat surface located north of the bridge at the ground level, with the same width as the widest bridge span investigated, i.e. Option 2.8.
- - Outer Zone North (approx. 23,600 m2): the flat surface located north of the bridge at the ground level that is three times wider than the widest bridge investigated, i.e. Option 2.8.

2. Area-based solar radiation attenuation factor throughout the growing season (ASRAF) – This compares total incident solar insolation at ground level with a bridge present to the total available global solar radiation at ground level without a bridge present throughout the growing season from March to September inclusive. The solar radiation attenuation factor for each design option has been calculated as:

1 The 'growing season' is defined in this study as the period from March to September inclusive.

$$a_i = \frac{\sum_{n=1}^{5136} I_n}{\sum_{n=1}^{5136} G_n},$$

where:

a_i - is the growing season solar radiation attenuation factor for design option i,

I_n - is the average incident solar radiation flux at hour n, over an assessment surface, W/m^2

2.2 G_n - is the average global solar radiation flux at ground level at hour n, W/m^2.

Reflection and re-radiation of solar radiation by the ground, the bridge or the earthworks are excluded from the calculation of this attenuation factor. The solar radiation attenuation factor has been calculated for five assessment surfaces as defined as below:

- - Outer Zone South (approx. 27,400 m2): the flat surface located south of the bridge at the ground level that is three times wider than the widest bridge span investigated, i.e. Option 2.8.
- - Intermediate Zone South (approx. 11,300 m2): the flat surface located south of the bridge at the ground level, with the same width as the widest bridge span investigated, i.e. Option 2.8.
- - Bridge Zone (approx. 11,200 m2): the flat surface directly below the bridge, at the ground level, with the same width as the widest bridge span investigated, i.e. Option 2.8.
- - Intermediate Zone North (approx. 11,300 m2): the flat surface located north of the bridge at the ground level, with the same width as the widest bridge span investigated, i.e. Option 2.8.
- - Outer Zone North (approx. 23,600 m2): the flat surface located north of the bridge at the ground level that is three times wider than the widest bridge span investigated, i.e. Option 2.8.

3. Daylight attenuation factor throughout the growing season – This compares total daylight received at ground level for each of 11 'virtual sensor points' underneath the bridge with landscape present to the total available unobstructed daylight for the growing season at the site at ground level. The sensor points have been distributed at ground level below the bridge along three transects lines as shown in Figure 3. Seven sensor points have been located on the transect line under the centre of the bridge, and two sensor points placed under both ends of the bridge.

2.3 Certain sensitivity analyses have been carried out for all three metrics to investigate the impact on extending the assessment period to a whole year. In addition, the impact of applying two different sky models ('CIE Standard Overcast' and 'Intermediate Sky with Sun') for assessing daylight attenuation factor has been investigated. The results from the sensitivity analyses are presented and discussed in Appendix B.

3 Calculation methodologies

3.1 The shading analysis was carried out using the modules 'SunCast' (solar shading analysis module), 'ApacheSim' and 'IES Radiance' integrated within Integrated Environmental Solutions ‘Virtual Environment’ modelling suite – IES v2017.

- - SunCast calculates surface shading and external solar insolation from any sun position defined by date, time, orientation, site latitude and longitude.
- - ApacheSim calculates external surface incident solar flux based on annual hourly weather data files.
- - Radiance calculates the distribution of visible light in daylight illuminated spaces based on pre-defined sky and solar radiance models.

3.2 Three distinct calculation methodologies have been used to assess the shading metrics:

- - The solar exposure calculations use hourly solar shading data generated with SunCast to produce results expressed in total sunlit hours over the specified period for each 10 m x 10 m grid cell. The calculations were carried out for monthly design days (on the 15th day of each month), with the date and time and site location (longitude and latitude) taken into account.
- - For the solar radiation attenuation factor calculations, the surface incident solar fluxes underneath and adjacent to the bridge have been calculated using ApacheSim. These calculations are based on an hourly weather data file for Southampton ('Southamption_TRY.epw') as the closest available location, which includes global solar radiation data.
- - The calculations for daylight illuminance under the bridge used IES Radiance. The illuminance levels are determined at specified points ('sensors'). The calculation are carried out for monthly design days (on the 15th day of each month) using standardised sky models 'CIE Standard Overcast' and 'Intermediate Sky with Sun', with the date and time and site location (longitude and latitude) taken into account. The CIE Overcast Sky includes no direct daylight and is a representation of dull sky conditions2. 'Intermediate Sky with Sun' assumes thin to moderate cloud cover with hazy atmospheric conditions that may be more likely to occur in England than totally overcast skies during the growing season. The sun is not as bright as with a clear sky model and the brightness changes are not as drastic.

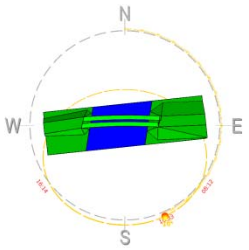
4 General assumptions

4.1 The following general assumptions have been made for the design option studied (Option 2.1).

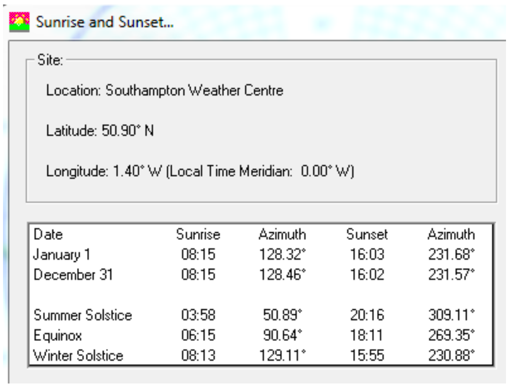
LOCATION AND ORIENTATION

Latitude (deg): 50.90° Orientation:
N
Longitude (deg): 1.40° W

2 https://www.radiance-online.org/community/workshops/2003-berkeley/presentations/Mardaljevic/rwr_ch6.pdf



Summary of Site Solar Data



Sunrise and Sunset...

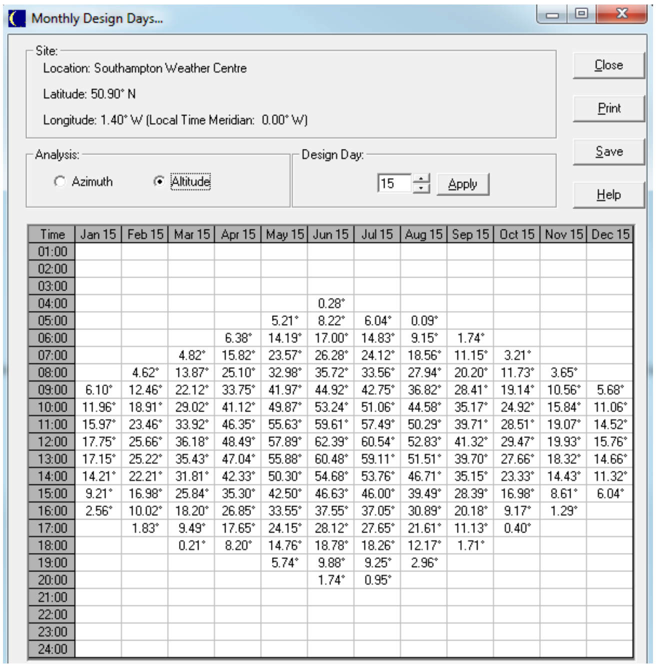
Site:

Location: Southampton Weather Centre

Latitude: 50.90° N

Longitude: 1.40° W (Local Time Meridian: 0.00° W)

Date	Sunrise	Azimuth	Sunset	Azimuth
January 1	08:15	128.32°	16:03	231.68°
December 31	08:15	128.46°	16:02	231.57°
Summer Solstice	03:58	50.89°	20:16	309.11°
Equinox	06:15	90.64°	18:11	269.35°
Winter Solstice	08:13	129.11°	15:55	230.88°



Monthly Design Days...

Site:

Location: Southampton Weather Centre

Latitude: 50.90° N

Longitude: 1.40° W (Local Time Meridian: 0.00° W)

Analysis: Azimuth / Altitude (selected)

Design Day: 15 Apply

Close Print Save Help

Time	Jan 15	Feb 15	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 15	Oct 15	Nov 15	Dec 15
01:00												
02:00												
03:00												
04:00						0.28°						
05:00					5.21°	8.22°	6.04°	0.09°				
06:00				6.38°	14.19°	17.00°	14.83°	9.15°	1.74°			
07:00			4.82°	15.82°	23.57°	26.28°	24.12°	18.56°	11.15°	3.21°		
08:00		4.62°	13.87°	25.10°	32.98°	35.72°	33.56°	27.94°	20.20°	11.73°	3.65°	
09:00	6.10°	12.46°	22.12°	33.75°	41.97°	44.92°	42.75°	36.82°	28.41°	19.14°	10.56°	5.68°
10:00	11.96°	18.91°	29.02°	41.12°	49.87°	53.24°	51.06°	44.58°	35.17°	24.92°	15.84°	11.06°
11:00	15.97°	23.46°	33.92°	46.35°	55.63°	59.61°	57.49°	50.29°	39.71°	28.51°	19.07°	14.52°
12:00	17.75°	25.66°	36.18°	48.49°	57.89°	62.39°	60.54°	52.83°	41.32°	29.47°	19.93°	15.76°
13:00	17.15°	25.22°	35.43°	47.04°	55.88°	60.48°	59.11°	51.51°	39.70°	27.66°	18.32°	14.66°
14:00	14.21°	22.21°	31.81°	42.33°	50.30°	54.68°	53.76°	46.71°	35.15°	23.33°	14.43°	11.32°
15:00	9.21°	16.98°	25.84°	35.30°	42.50°	46.63°	46.00°	39.49°	28.39°	16.98°	8.61°	6.04°
16:00	2.56°	10.02°	18.20°	26.85°	33.55°	37.55°	37.05°	30.89°	20.18°	9.17°	1.29°	
17:00		1.83°	9.49°	17.65°	24.15°	28.12°	27.65°	21.61°	11.13°	0.40°		
18:00			0.21°	8.20°	14.76°	18.78°	18.26°	12.17°	1.71°			
19:00					5.74°	9.88°	9.25°	2.96°				
20:00						1.74°	0.95°					
21:00												
22:00												
23:00												
24:00												

CONSTRUCTION GEOMETRY

4.2 The model geometry is based on layouts received from the AECOM Structural Engineering team. The details of the drawings supplied are as follows:

Drawing Name	Sheet Title	Revision	Date
HE551506-AMW-SBR-Z1_BR_T00_Z-DR-CB-1301	River Till Viaduct Option 1-5 Span PT Concrete Box Grider GA Sheet 1 of 2	P02	03/04/2018
HE551506-AMW-SBR-Z1_BR_T00_Z-DR-CB-1301	River Till Viaduct Option 1-5 Span PT Concrete Box Grider GA Sheet 2 of 2	P02	03/04/2018
HE551506-AMW-SBR-Z1_BR_T00_Z-DR-CB-1304	River Till Viaduct Option 2-5 Span Steel Composite GA Sheet 2 of 2	P02	03/04/2018
HE551506-AMW-SBR-Z1_BR_T00_Z-DR-CB-1320	River Till Viaduct PT Concrete Option General Arrangement GA Sheet 1 of 2	P01.1	20/06/2018
HE551506-AMW-SBR-	River Till Viaduct PT Concrete Option General Arrangement GA Sheet 2 of	P01.1	20/06/20

Drawing Name	Sheet Title	Revision	Date
Z1_BR_T00_Z-DR-CB-1321	2		18

4.3 The actual ground surface underneath the bridge has been modelled as a level flat surface at the average ground height adjacent to the bridge.

SURFACE VISIBLE LIGHT REFLECTANCES (ONLY USED WITHIN IES RADIANCE)

4.4 An average reflectance of 0.4 has been assumed for all surfaces of the bridge construction.

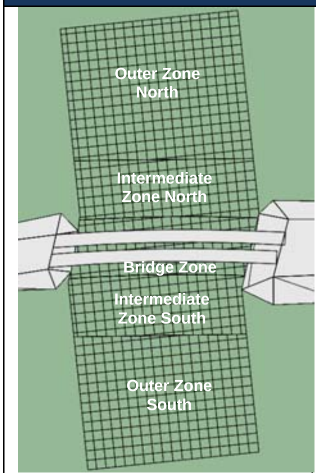
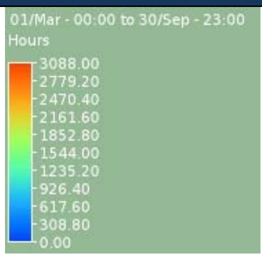
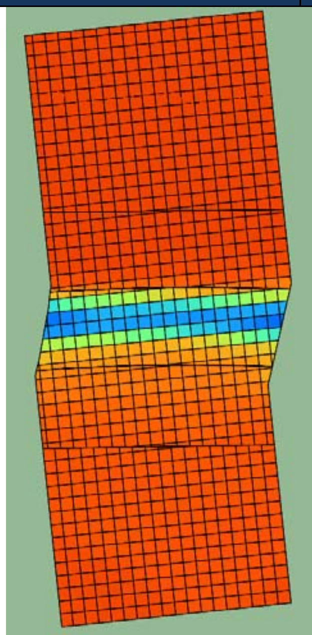
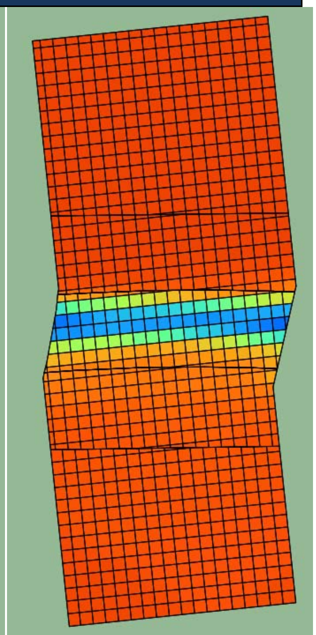
4.5 An average reflectance of 0.2 has been assumed for all surfaces of the landscape.

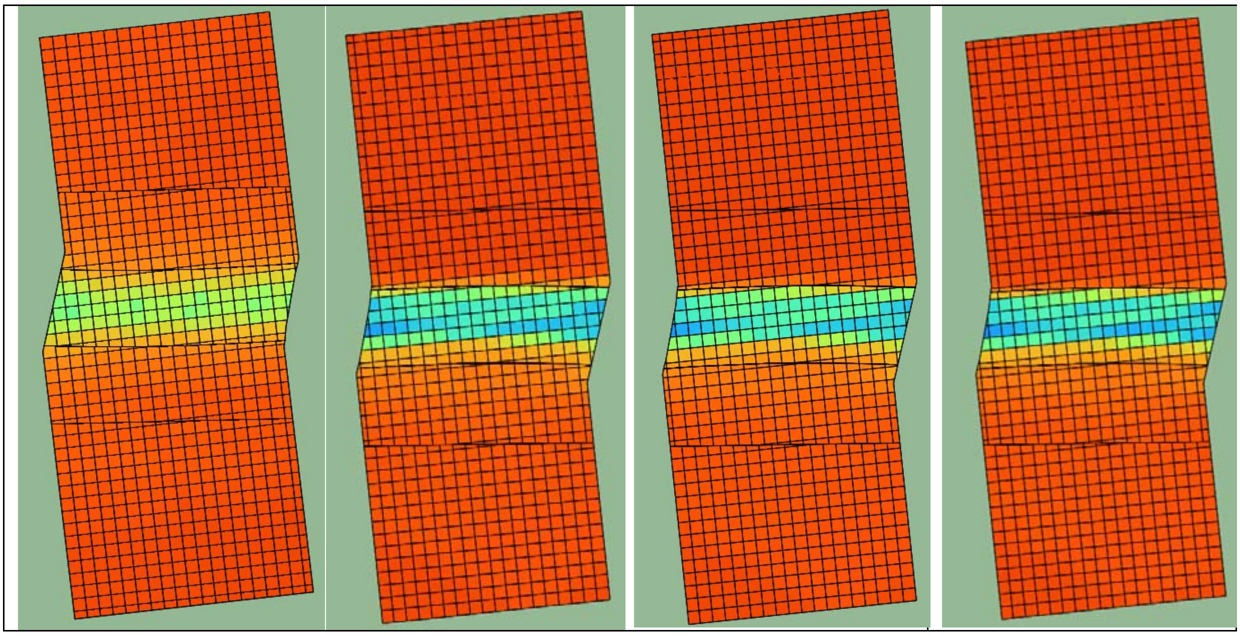
5 Results

SPATIAL DISTRIBUTION OF SOLAR EXPOSURE THROUGHOUT GROWING SEASON

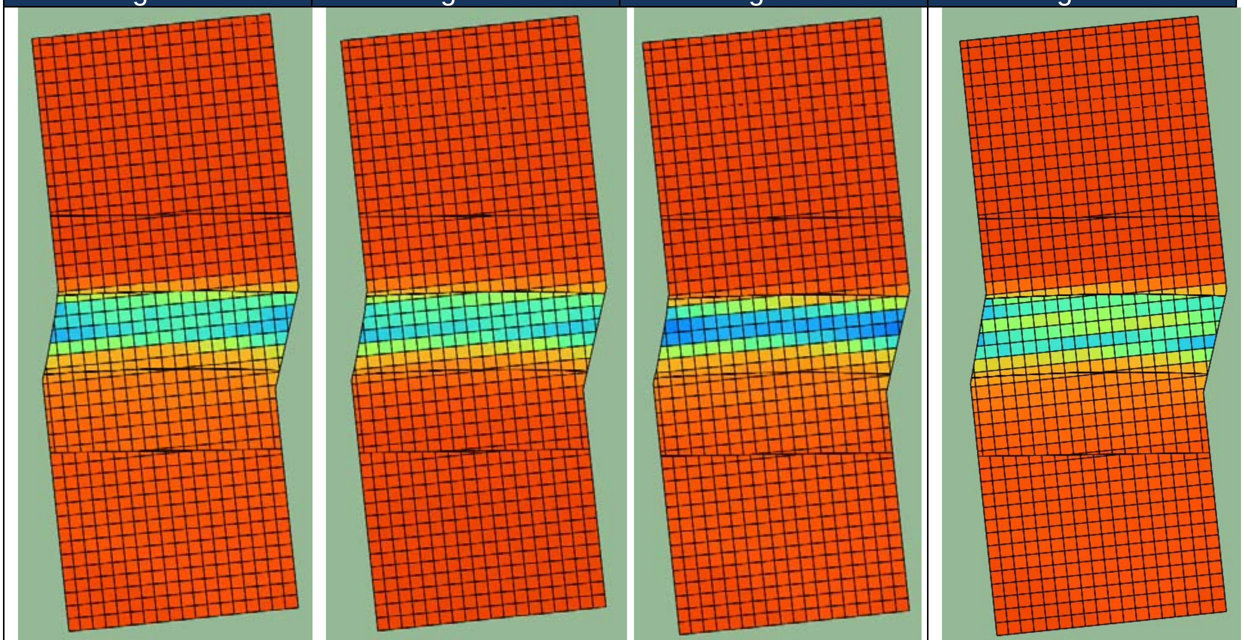
5.1 Table 2 shows the number of hours displayed visually using a grid resolution of 10 m x 10 m when daylight is available for the growing season from March to September inclusive.

5.2 For Option 2.1 (with bridge width 35 m), the influence is limited mainly to the Bridge Zone, of which a width of approximately 40 m is strongly affected by the bridge (i.e. number of hours is reduced to approx. 1500 hours, shown with grid cells coloured green or blue).

Location of the bridge, landscape and assessment zones		Option 1.1 Deck height: 10.0 m Orientation: east-west	Option 1.2 Deck height: 10.0 m Orientation: east-west
			
Option 1.3 Deck height: 10.0 m Orientation: north-south	Option 2.1 Gap between decks: 7.0 m Deck height: 10.0 m	Option 2.2 Gap between decks: 7.0 m Deck height: 10.0 m	Option 2.3 Gap between decks: 7.0 m Deck height: 8.0 m



Option 2.4 Gap between decks: 7m Deck height: 13.0 m	Option 2.5 Gap between decks: 7m Deck height: 16.0 m	Option 2.6 Gap between decks: 2m Deck height: 10.0 m	Option 2.7 Gap between decks: 15m Deck height: 10.0 m



Option 2.8 Gap between decks: 35.0 m Deck height: 10.0 m	Option 2.9 Gap between decks: 6.0 m Deck height: 8.0 m	Option 2.10 Gap between decks: 9.0 m Deck height: 12.0 m	Option 2.11 Gap between decks: 11.0 m Deck height: 14.0 m

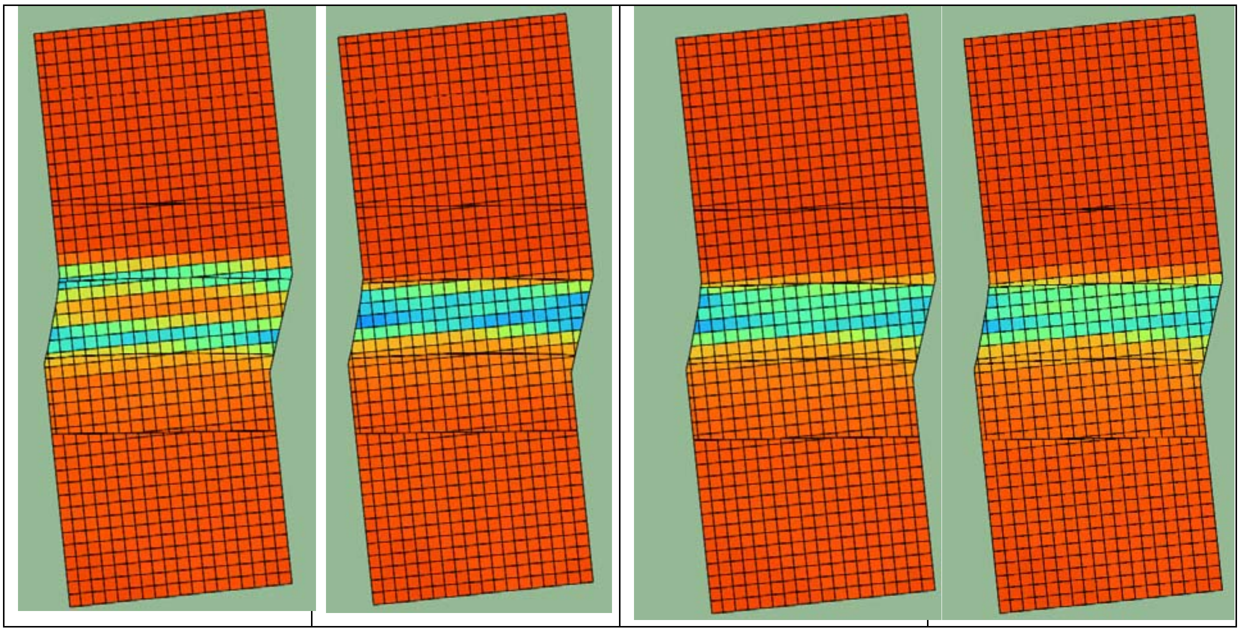


Figure 1. Zones of bridge influence - solar exposure through the growing season (from March to September inclusive).

AREA-BASED SOLAR RADIATION ATTENUATION FACTOR (ASRAF) FOR THE GROWING SEASON

5.4 Table 2 shows the results for the five assessment surfaces.

Table 2. Solar radiation attenuation factor results.

	Area-based solar radiation attenuation factors for the growing season				
	Outer Zone North	Intermediate Zone North	Bridge Zone	Intermediate Zone South	Outer Zone South
Option 1.1	1.00	0.98	0.56	0.98	1.00
Option 1.2	1.00	0.98	0.57	0.98	1.00
Option 1.3 Note 1	1.00	0.97	0.58	0.96	0.99
Option 2.1	1.00	0.98	0.56	0.97	1.00
Option 2.2	1.00	0.98	0.58	0.98	1.00
Option 2.3	1.00	0.98	0.56	0.98	1.00
Option 2.4	1.00	0.97	0.57	0.97	0.99
Option 2.5	0.99	0.95	0.59	0.96	0.99
Option 2.6	1.00	0.98	0.56	0.98	1.00
Option 2.7	1.00	0.97	0.57	0.97	1.00
Option 2.8	1.00	0.89	0.67	0.95	0.99
Option 2.9	1.00	0.98	0.55	0.98	1.00
Option 2.10	1.00	0.97	0.57	0.97	0.99
Option 2.11	0.99	0.96	0.58	0.96	0.99

Note 1: The Outer and Intermediate Zones are West and East.

5.5 An example of the radiation flux over a single day is shown in Figure 2, and over a whole year in Figure 3 for Option 2.2 for the Bridge Zone. Figure 2 indicates that the incident solar flux on the ground surface during the example day has a similar but attenuated trend to global radiation. This is also shown in Figure 3, in which annual incident solar flux on the ground surface and global radiation are presented graphically.

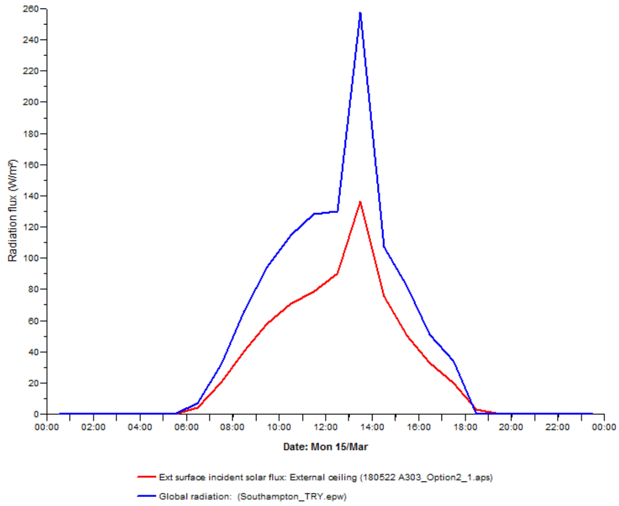


Figure 2. Example external surface incident solar flux and global radiation over a single day (15th March) for the Bridge Zone for Option 2.2

Figure 3. Example incident solar radiation and global radiation flux over a whole year for the Bridge Zone for Option 2.2

DAYLIGHT ATTENUATION FACTOR

5.6 The positions of the 'virtual sensors' under the bridge in Option 2.2 are as shown in Figure 4.

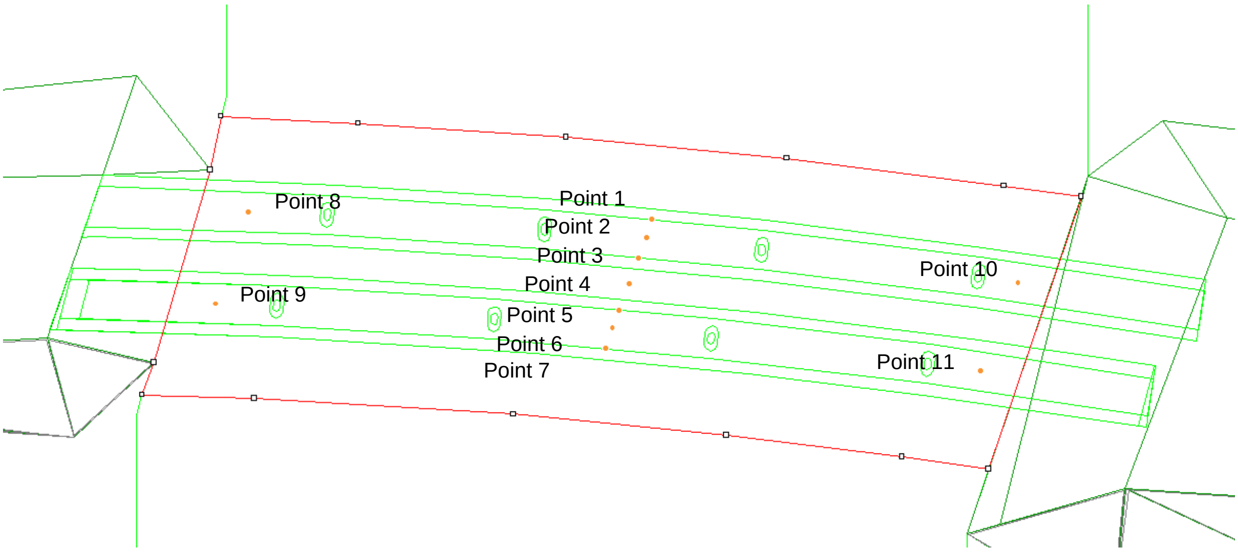


Figure 4. The virtual sensor locations under the bridge for Option 2.2

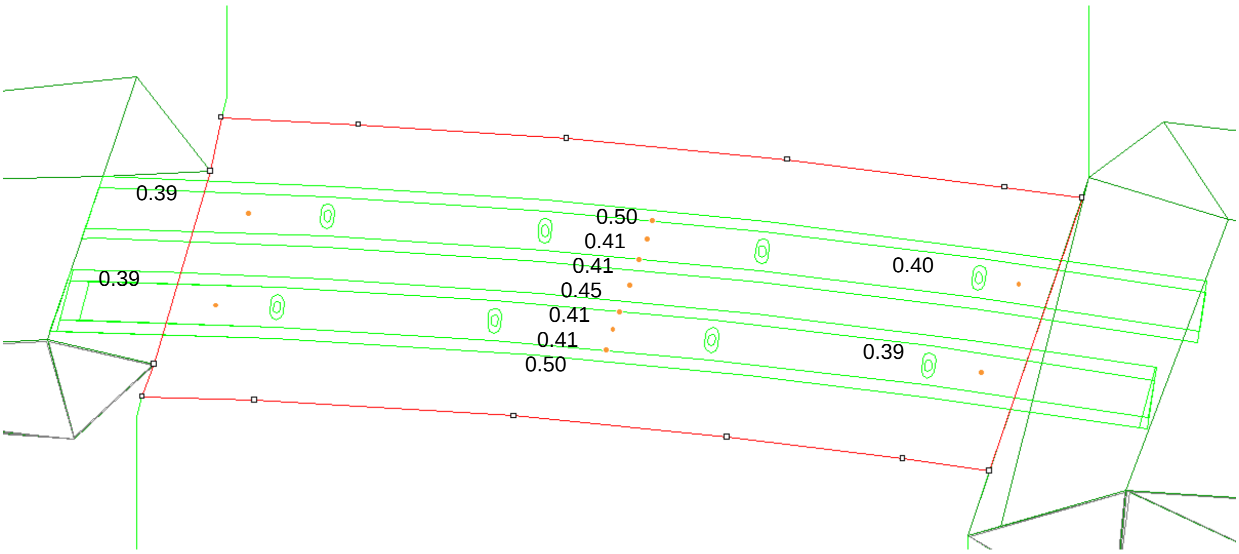


Figure 5. Example daylight attenuation factors for March to September inclusive with the CIE Overcast Sky model for Option 2.2

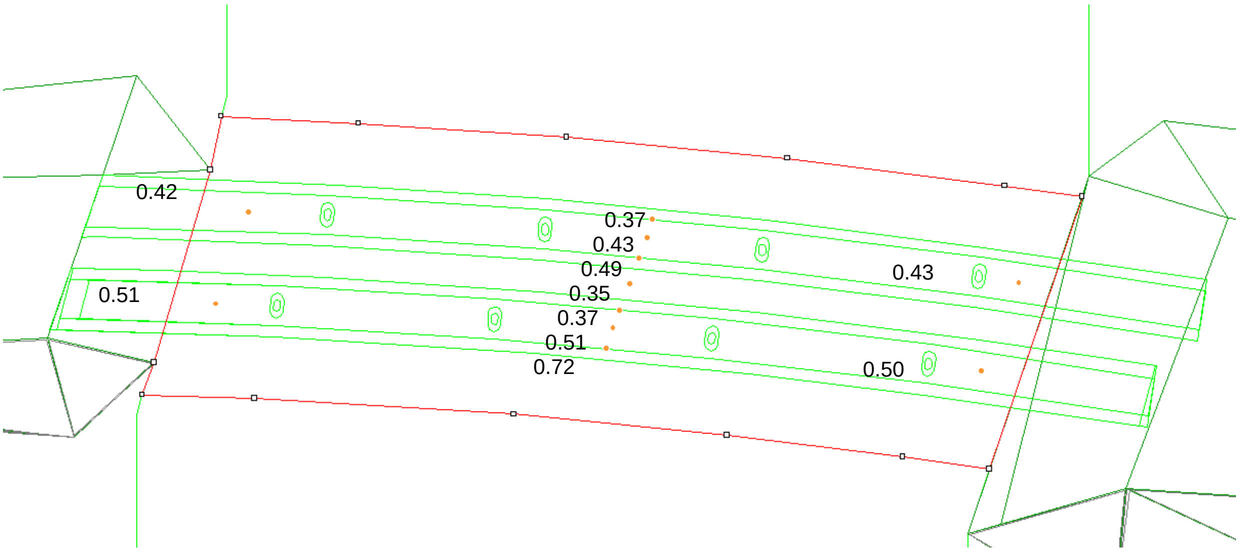


Figure 6. Example daylight attenuation factors for March to September inclusive with the Intermediate Sky with Sun model for Option 2.2

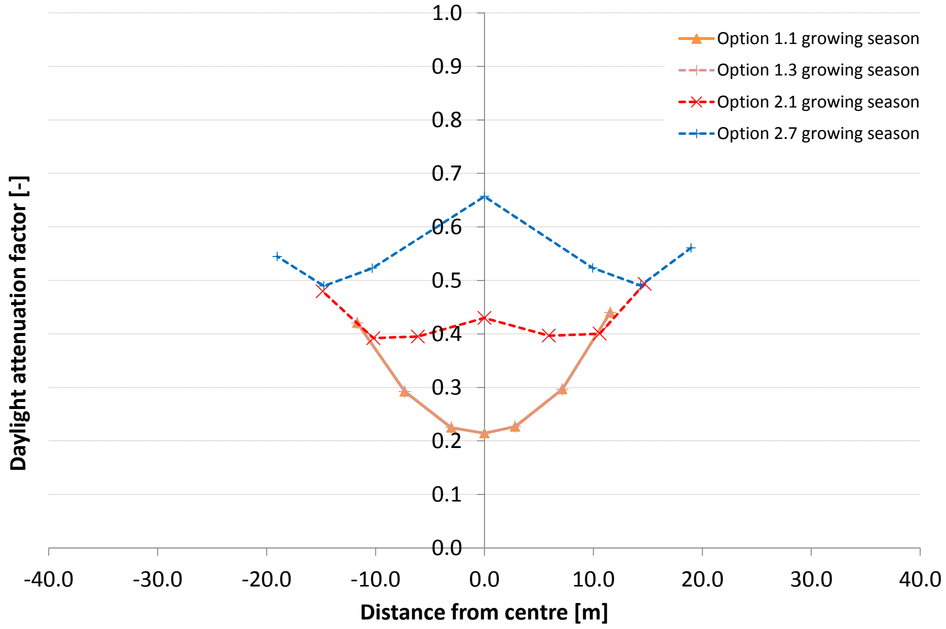


Figure 7. Daylight attenuation factors for March to September inclusive with the CIE Overcast Sky model for single deck (1.1 east-west; 1.3 north-south) and twin deck viaduct options (current design 2.1 east-west with 7.0 m gap width; 2.7 as 2.1 but 15.0 m gap width).

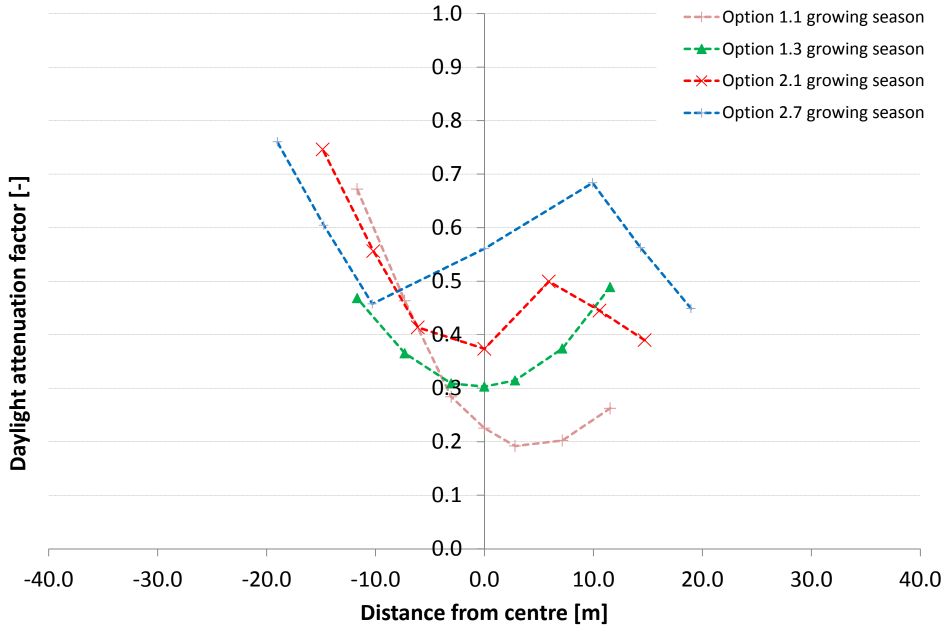


Figure 8. Daylight attenuation factors for March to September inclusive with the Intermediate Sky with Sun model for single deck (1.1 east-west, no gap; 1.3 north-south, no gap) and twin deck viaduct options (current design 2.1 east-west with 7.0 m gap width; 2.7 as 2.1 but with 15.0 m gap width).

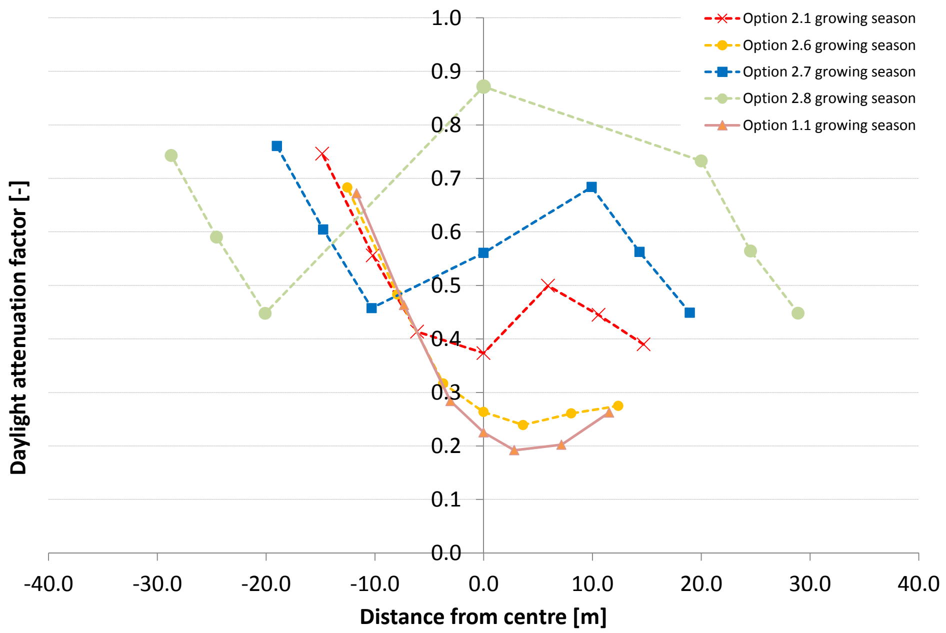


Figure 9. Daylight attenuation factors for March to September inclusive with the Intermediate Sky with Sun model for single deck (1.1, no gap) and twin deck viaduct options (current design 2.1 with 7.0 m gap width; 2.6 as 2.1 but with 2.0 m gap width; 2.7 as 2.1 but with 15.0 m gap width; 2.8 as 2.1 but with 35.0 m gap width).

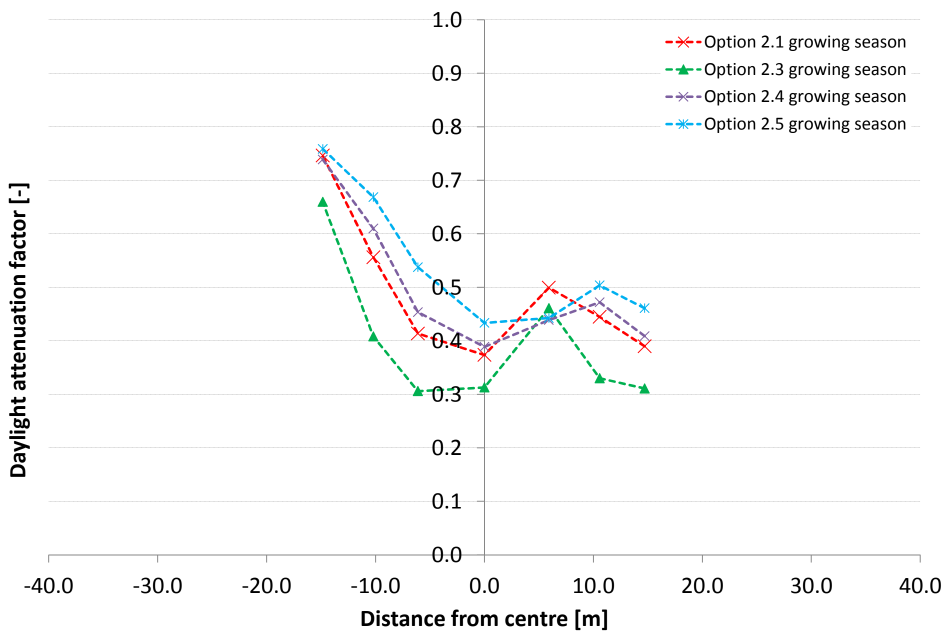


Figure 10. Daylight attenuation factors for March to September inclusive with the Intermediate Sky with Sun model for various twin deck viaduct options (current design 2.1 with 10.0 m deck height; 2.3 as 2.1 but with 8.0 m deck height;2.4 as 2.1 but with 13.0 m deck height; 2.5 as 2.1 but with 16.0 m deck height).

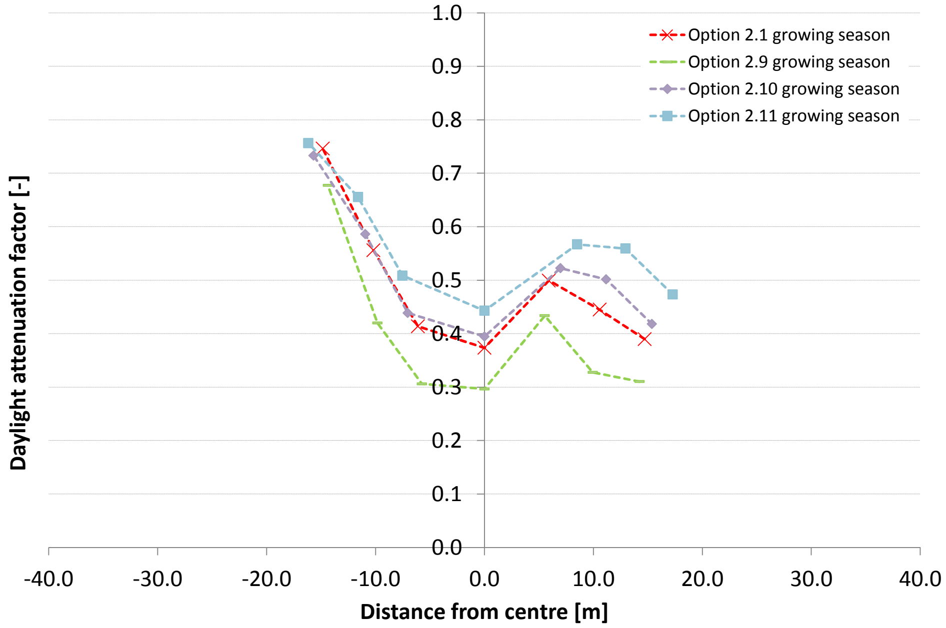


Figure 11. Daylight attenuation factors for March to September inclusive with the Intermediate Sky with Sun model for various twin deck viaduct options (current design 2.1 with 7.0 m gap width and 10.0 m deck height; 2.9 as 2.1 but with 6.0 m gap width and 8.0 m deck height; 2.10 as 2.1 but with 9.0 m gap width and 12.0 m deck height; 2.11 as 2.1 but with 11.0 m gap width and 14.0 m deck height).

Table 3. Daylight attenuation factors for CIE Overcast Sky model.

Sensor point name	Growing season daylight attenuation factor (-)						
	Option 1.1	Option 1.2	Option 1.3	Option 2.1	Option 2.2	Option 2.3	Option 2.4
Sensor point 1	0.44	0.44	0.44	0.49	0.50	0.46	0.54
Sensor point 2	0.30	0.30	0.30	0.40	0.41	0.35	0.46
Sensor point 3	0.23	0.23	0.23	0.40	0.41	0.36	0.44
Sensor point 4	0.21	0.21	0.21	0.43	0.45	0.43	0.45
Sensor point 5	0.22	0.23	0.23	0.40	0.41	0.36	0.44
Sensor point 6	0.29	0.29	0.29	0.39	0.40	0.34	0.45
Sensor point 7	0.42	0.43	0.42	0.48	0.50	0.44	0.53
Sensor point 8	0.30	0.30	0.30	0.38	0.40	0.33	0.44
Sensor point 9	0.30	0.31	0.30	0.38	0.39	0.33	0.44
Sensor point 10	0.30	0.30	0.30	0.39	0.40	0.34	0.45
Sensor point 11	0.28	0.28	0.28	0.38	0.39	0.33	0.44

Sensor point name	Growing season daylight attenuation factor (-)						
	Option 2.5	Option 2.6	Option 2.7	Option 2.8	Option 2.9	Option 2.10	Option 2.11
Sensor point 1	0.57	0.45	0.56	0.56	0.45	0.53	0.57
Sensor point 2	0.51	0.33	0.49	0.49	0.33	0.46	0.52
Sensor point 3	0.48	0.28	0.52	0.54	0.34	0.46	0.51
Sensor point 4	0.48	0.28	0.66	0.88	0.39	0.49	0.54
Sensor point 5	0.48	0.28	0.52	0.54	0.34	0.46	0.51
Sensor point 6	0.50	0.32	0.49	0.49	0.33	0.45	0.51
Sensor point 7	0.56	0.43	0.54	0.54	0.43	0.52	0.56
Sensor point 8	0.50	0.30	0.46	0.48	0.33	0.43	0.50
Sensor point 9	0.49	0.31	0.46	0.48	0.32	0.44	0.50
Sensor point 10	0.50	0.31	0.47	0.48	0.34	0.45	0.51
Sensor point 11	0.49	0.31	0.46	0.47	0.32	0.44	0.50

Table 4. Daylight attenuation factors for Intermediate Sky with Sun model.

Sensor point name	Growing season daylight attenuation factor (-)						
	Option 1.1	Option 1.2	Option 1.3	Option 2.1	Option 2.2	Option 2.3	Option 2.4
Sensor point 1	0.26	0.26	0.49	0.39	0.38	0.31	0.41
Sensor point 2	0.20	0.20	0.37	0.44	0.43	0.33	0.47
Sensor point 3	0.19	0.19	0.31	0.50	0.49	0.46	0.44
Sensor point 4	0.23	0.22	0.30	0.37	0.35	0.31	0.39
Sensor point 5	0.28	0.28	0.31	0.41	0.38	0.31	0.45
Sensor point 6	0.46	0.46	0.37	0.56	0.52	0.41	0.61
Sensor point 7	0.67	0.68	0.47	0.75	0.72	0.66	0.74
Sensor point 8	0.19	0.19	0.38	0.42	0.42	0.32	0.45
Sensor point 9	0.51	0.52	0.36	0.54	0.51	0.41	0.60
Sensor point 10	0.19	0.19	0.38	0.43	0.43	0.33	0.45
Sensor point 11	0.45	0.45	0.36	0.52	0.50	0.40	0.59

Sensor point name	Growing season daylight attenuation factor (-)						
	Option 2.5	Option 2.6	Option 2.7	Option 2.8	Option 2.9	Option 2.10	Option 2.11
Sensor point 1	0.46	0.27	0.45	0.45	0.31	0.42	0.42
Sensor point 2	0.50	0.26	0.56	0.56	0.33	0.50	0.50
Sensor point 3	0.44	0.24	0.68	0.73	0.43	0.52	0.52
Sensor point 4	0.43	0.26	0.56	0.87	0.30	0.39	0.39
Sensor point 5	0.54	0.32	0.46	0.45	0.31	0.44	0.44
Sensor point 6	0.67	0.48	0.60	0.59	0.42	0.59	0.59
Sensor point 7	0.76	0.68	0.76	0.74	0.68	0.73	0.73
Sensor point 8	0.48	0.24	0.54	0.58	0.30	0.48	0.48
Sensor point 9	0.66	0.50	0.58	0.58	0.45	0.59	0.59
Sensor point 10	0.48	0.24	0.54	0.58	0.31	0.49	0.49
Sensor point 11	0.65	0.50	0.56	0.59	0.43	0.59	0.59

6 Discussion and conclusions

6.1 The shading modelling study has been carried out to assist with decision making during the design process for the new A303 Stonehenge River Till Viaduct. The viaduct design would influence the shading beneath at ground level. The current scheme design consists of a twin deck viaduct with a 7.0 m gap between the decks, 1.0 m high mesh infilled parapets, a 2.0 m high noise barrier mounted at the southern edge, both deck heights at 10.0 m above average ground level, and with east-west orientation. The current scheme design and further design options that vary this design have been analysed to understand the impacts on levels of shading at ground level beneath the viaduct as follows:

- single deck viaduct;
- single deck viaduct without parapets or noise barrier;
- single deck viaduct with north-south orientation;
- twin deck as current scheme design;
- twin deck viaduct without parapets or noise barrier;
- twin deck viaduct with gap width of 2.0 m, 15.0 m, or 35.0 m between decks;
- twin deck viaduct at deck height 8.0 m, 13.0 m, or 16.0 m above average ground level;
- twin deck viaduct with 6.0 m gap between decks at 8.0 m above average ground level;
- twin deck viaduct with 9.0 m gap between decks at 12.0 m above average ground level;
- twin deck viaduct with 11.0 m gap between decks at 14.0 m above average ground level.

6.2 As defined in Section 2, the following three distinct metrics for the level of shading have been proposed to assess and compare the design options for the growing season, the results for which have been summarised in the sections below:

- spatial distribution of solar exposure,
- area-based solar radiation attenuation factor, and
- daylight attenuation factor.

SPATIAL DISTRIBUTION OF SOLAR EXPOSURE FOR THE GROWING SEASON

6.3 During the growing season, the number of hours when sunlight is available at ground level underneath the viaduct is influenced by the shadow that it casts. From the calculation results, it was observed that for all options, the width across the area shaded by the viaduct would be at least as wide as the total viaduct width. In general, the number of hours in the growing season when sunlight is available would be mainly affected by deck type (single or twin) and viaduct height. The number of sunlit hours would be more greatly decreased for a single deck than for a twin deck viaduct design, while the mesh-infilled parapets and noise barrier would have negligible effect on the spatial distribution of solar exposure results (omitted in Options 1.2 and 2.2).

6.4 It was further observed from the results that in the affected area for the Options with the viaduct height set at 10 m, including the current scheme design (Option 2.1), the solar exposure would be reduced to approximately 1500 hours during the growing season, i.e. to about half of the potential maximum hours available in an unobstructed area. Also, the viaduct at 8 m height (Option 2.3) would have fewer available sunlit hours than the higher viaduct designs.

6.5 With a 35 m gap between the decks (Option 2.8), the viaduct would not only overshade the Bridge Zone but also Intermediate Zone North, although the gap between the decks would still allow sunlight to reach directly under the north deck, resulting in the number of sunlit hours exceeding that for the other options. It was also found that the number of hours when sunlight is available at ground level would be greater for the viaduct oriented north-south (Option 1.3) than east-west (Option 1.1) i.e. with approximately two thirds of the potential maximum numbers of hours available in an unobstructed area, compared to one third of the maximum hours.

AREA-BASED SOLAR RADIATION ATTENUATION FACTOR FOR THE GROWING SEASON

6.6 For all Options, the area-based solar radiation attenuation factor results for the growing season show that the area directly below the viaduct (Bridge Zone) would have a significantly greater reduction in total incident solar insolation at ground level compared with the adjacent areas (Intermediate and Outer Zones). For example, for the Bridge Zone directly below the viaduct, the area-based solar radiation attenuation factor was calculated to be 56% for the current scheme design (Option 2.1). In this case, this means that the total incident solar insolation at ground level in the Bridge Zone area with a viaduct present would be 44% lower over the season than the total available global solar radiation at ground level without a viaduct present. The mesh infilled parapets and high noise barrier would have negligible effect on the area-based solar radiation attenuation factor results (omitted in Options 1.2 and 2.2).

6.7 The highest area-based solar radiation attenuation factor of 67% would be achieved for the viaduct design with a 35 m gap (Option 2.8). This means that in the Bridge Zone the total solar insolation over the season would be reduced by 33% in comparison with no viaduct present. However, in this case the Intermediate Zone North area would be affected more significantly than in the other Options, with a total solar insolation reduction at 11% over the season in comparison with reductions ranging from 2% to 5% for the other Options.

DAYLIGHT ATTENUATION FACTOR FOR THE GROWING SEASON

6.8 The total daylight received at ground level was estimated by computer modelling at 11 'virtual sensor points' underneath the viaduct and compared to the total available daylight throughout the growing season as if the site were unobstructed. Seven sensor points have been located on the transect line under the centre of the viaduct, and two further sensor points placed under each end of the viaduct.

6.9 The assessment was carried out using two separate sky models: 'CIE Overcast Sky' (Overcast) and 'Intermediate Sky with Sun' (ISwS). It should be noted that neither of these models fully represents conditions as they occur in reality throughout the year. The Overcast model represents a luminance distribution of the sky under heavily overcast conditions, i.e. without the Sun and where the daylight is only diffuse. The ISwS model represents a hazy sky, where the Sun is present but not bright, and brightness changes are not large. These sky models have been selected as generally representative for England in winter and summer respectively. Of these two models, ISwS may be considered to be most representative of the growing season.

6.10 For ISwS, The daylight attenuation factor would be 23% in the middle of the single deck viaduct (Option 1.1) and 37% for the twin deck current scheme design (Option 2.1). Increasing the height of the viaducts would also allow more daylight to reach ground level and the daylight attenuation factor would increase in the middle point (Sensor point 4) to 39% for a 13 m high (Option 2.4) and to 43% for a 16 m high twin deck viaduct (Option 2.5). Also, higher viaducts would have more daylight available under both ends.

6.11 Also for ISwS, the lowest daylight level was found to be in the middle of the viaduct for all design options, apart from the wider viaduct design with a 35 m gap (Option 2.8), for which the daylight attenuation factor would be 87%. This means that the gap between the decks would allow more daylight to reach ground level under the north viaduct with only 13% of the daylight blocked. For both options for the twin deck viaduct with a wider gap than the current scheme design, (15 m in Option 2.7 and 35 m in Option 2.8), there would be similar levels of daylight available directly under the north deck to the south deck. The daylight level distribution available across the single deck viaduct (Option 1.1) would be similar to the twin deck viaduct with a 2 m gap (Option 2.6), i.e. higher daylight attenuation factors would be achieved under the south side of the viaduct and would be reduced under the north side. Increasing the gap width of the twin viaduct would also increase an amount of daylight available in the middle at ground level under the viaduct gap. The daylight attenuation factor would be 56% for a 15 m gap twin deck viaduct (Option 2.7). An increase of the gap width would improve the daylight attenuation factors more significantly then increasing the viaduct height for the ranges considered.

VIADUCT HEIGHT TO WIDTH RATIO AS A CHARACTERISATION OF IMPACT ON VEGETATION

6.12 The height to width ratio (HW ratio) takes into account two main viaduct characteristics that determine the degree of shading. Generally, low viaducts with HW ratios less than 0.7 typically have significant negative impacts on vegetation structure and function 3, 4. The 'single deck equivalent' HW ratio for the current scheme design is 0.47 (Option 2.1), which indicates that the vegetation under the viaduct may be affected by it to a certain extent. The HW ratio for a single deck viaduct (Option 1.1, 28 m wide and 10 m high) would be 0.37, significantly lower than for the current design - This is confirmed by the single point daylight attenuation factor that drops to 0.19 under the viaduct. Based on this study, a daylight attenuation factor above approximately 50% would be achieved by a twin deck viaduct with a 15 m gap and at 10 m height (Option 2.7), which is characterised by a single deck equivalent HW ratio of 0.6.

CONCLUSIONS

6.13 Shading by the viaduct after construction is dependent on viaduct orientation, number of decks, height and width.

3 Broome, S.W., Craft, C.B., Struck, S.D. and M. SanClements. 2005. Effects of Shading from Bridges on Estuarine Wetlands.

4 Broome, S.W., Craft, C.B., Struck, S.D., SanClements, M and Sacco, J.N. 2004. Effects of Bridge Shading on Estuarine Marsh Benthic Invertebrate Community Structure and Function

6.14 A viaduct with a twin deck may be expected to have greater overall width than one with a single deck due to the gap between the decks. For an east-west orientation a sufficiently wide gap between the decks can allow sunlight to reach under the north viaduct deck, and so increasing the number of sunlit hours at ground level compared with a design with a narrow gap or a single deck. The overall viaduct width also would have an impact on the extent of the overshaded area, i.e. the wider the viaduct, the greater is the overshaded area underneath and adjacent.

6.15 In addition, the height of the viaduct impacts on the level of sunlight available underneath at ground level. A higher viaduct decreases the level of shading that it produces compared to a lower viaduct.

6.16 Taking this into account, the scheme design for the viaduct consists of a twin deck viaduct with 7.0 m gap between decks, a deck height of 10.0 m above the average ground level and an east-west orientation.

Appendix A – Hourly illuminance (lux) results for Option 2.2 for Intermediate Sky with Sun model

Unshaded Reference Case

		01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
Jan		.	.	.	.	.	.	.	.	2591.4	5231.8	7770.2	8664.6	8277.1	6714.7	3712.7	1569.7	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	2150.3	5719.9	9324.9	11900	12974	12923	11214	8322	4211.5	1272.3	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	2218.2	6515.7	10876	14900	17092	17990	17859	15814	12754	8710.3	3916.6	866.9	.	.	.	.	.	.
Apr		.	.	.	.	.	2724.9	7514.7	12677	16886	20029	20875	21093	21085	20023	17636	13779	8583.1	3286.6	.	.	.	.	.	.
May		.	.	.	.	2295.7	6596.8	11837	16436	20060	21352	21729	21576	21651	21565	19939	16736	12190	6840.8	2426.4	.	.	.	.	.
Jun		.	.	.	855.7	3338.3	8196	13486	17807	20647	21541	21563	21090	21354	21713	20833	18590	14596	9178.9	4147.2	1204.6	.	.	.	.
Jul		.	.	.	.	2590.3	6846.1	12245	16746	20198	21489	21452	21310	21248	21700	20827	18482	14054	8877.9	3899.4	1055.3	.	.	.	.
Aug		.	.	.	.	894.7	3855.2	9116.7	14098	18322	20900	21590	21520	21605	21289	19200	16098	11357	5681.2	1691.9	.	.	.	.	.
Sep		.	.	.	.	.	1382.6	4918.1	10151	14620	17631	19469	19883	19958	17846	14837	10235	5112.9	1482.4	.	.	.	.	.	.
Oct		.	.	.	.	.	.	1807	5386.2	9704.2	12940	14893	15343	14868	12162	8539.5	4084.6	1089.9	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	1942.4	4736	7977.2	9547.4	9994	9223.4	6807.3	3563.5	1274.7	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	2539.7	4878.7	6837.5	7688.3	6703.1	4870.8	2506.7	.	.	.	.	.	.	.	.	.

		01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
	Grid	Statistics																							
	Units	=	Lux	(lumens/m2)																					
		Intermec	Sky	with	Sun:	BR000001:1																			
Jan		.	.	.	.	.	.	.	.	1386	2482	4275	4488	4372	3624	1934	824	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	1078	2452	3378	3764	4119	4056	3538	3420	1941	692	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	1058	3133	4593	6630	7383	7855	8125	7737	5933	4226	1901	378	.	.	.	.	.	.
Apr		.	.	.	.	.	1581	2972	4605	6359	8244	9268	9889	8261	7631	6184	4669	3331	1937	.	.	.	.	.	.
May		.	.	.	.	1418	4480	5125	5547	5814	5438	4891	4657	4874	5406	5821	5602	5437	4507	1523	.	.	.	.	.
Jun		.	.	.	593	2110	5794	6843	6019	5945	5320	4575	4179	4453	5158	5908	6080	6503	6474	2697	774	.	.	.	.
Jul		.	.	.	.	1602	4745	6436	5781	5956	5427	4758	4361	4550	5177	5848	5982	5300	6163	2485	681	.	.	.	.
Aug		.	.	.	.	578	2380	3613	4915	5737	5574	5853	5025	6230	5458	5661	5246	4115	3695	1068	.	.	.	.	.
Sep		.	.	.	.	.	658	2228	5222	8653	10896	11417	12266	11594	10346	8458	5184	2270	771	.	.	.	.	.	.
Oct		.	.	.	.	.	.	826	2483	3320	4094	4770	4886	4914	3871	3073	1858	492	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	1087	2419	3633	3926	4025	3828	3543	1847	658	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1318	2385	4067	4653	3964	2591	1345	.	.	.	.	.	.	.	.	.
		Total	=	645898																					
		Average	=	4424																					
		Intermec	Sky	with	Sun:	BR000001:2																			
Jan		.	.	.	.	.	.	.	.	1189	2789	4383	4808	4681	3856	1816	782	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	1042	2634	3352	4396	5047	4538	3804	3897	1839	624	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	920	2460	3443	4385	4872	5075	5379	4666	3984	2878	1706	334	.	.	.	.	.	.
Apr		.	.	.	.	.	1365	2643	6421	10193	12653	12154	13491	13692	12605	11052	7024	3278	1588	.	.	.	.	.	.
May		.	.	.	.	1213	4064	3845	4947	7171	11029	10200	12704	10132	9252	6625	4975	3977	3943	1311	.	.	.	.	.
Jun		.	.	.	470	1840	5272	4299	5205	5398	5835	6321	8931	6709	6107	5391	5286	4620	5592	2357	686	.	.	.	.
Jul		.	.	.	.	1378	4321	4017	5020	5672	7781	8282	10131	8706	6748	6017	5251	4476	5260	2187	607	.	.	.	.
Aug		.	.	.	.	486	2076	3079	5617	8880	12769	13751	13689	14162	12435	10319	5241	3588	2921	919	.	.	.	.	.
Sep		.	.	.	.	.	534	2306	4959	6490	7234	6517	7383	8618	7388	6623	5180	2408	640	.	.	.	.	.	.
Oct		.	.	.	.	.	.	719	2400	3336	4028	4348	4444	4304	3814	3167	1751	427	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	948	2168	4197	4535	5017	4532	3882	1770	604	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1152	2678	3930	4464	3913	2584	1233	.	.	.	.	.	.	.	.	.
		Total	=	721842																					
		Average	=	4944																					
		Intermec	Sky	with	Sun:	BR000001:3																			
Jan		.	.	.	.	.	.	.	.	1223	2892	4638	5276	5095	3897	1868	794	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	1048	2372	4673	6210	6516	5755	5595	4368	2069	637	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	878	2414	3497	4513	5249	5350	5255	4885	4190	2920	1543	308	.	.	.	.	.	.
Apr		.	.	.	.	.	1133	4001	6711	6407	6576	5947	6371	7016	6725	7349	7389	4365	1376	.	.	.	.	.	.
May		.	.	.	.	1153	2920	3676	9679	12868	13053	13519	13451	13718	14041	12957	9501	3767	2435	1260	.	.	.	.	.
Jun		.	.	.	439	1707	3826	4096	8194	13554	14732	15234	15136	15157	14679	13531	7604	4358	3188	2259	600	.	.	.	.
Jul		.	.	.	.	1322	3624	3813	8224	13125	14386	15075	15231	14889	14680	13512	9800	4568	3484	2076	539	.	.	.	.
Aug		.	.	.	.	487	1668	3556	8530	9980	11023	10533	9221	9270	11189	11080	10190	4723	2084	911	.	.	.	.	.
Sep		.	.	.	.	.	522	2052	3447	4433	5311	5697	5745	5662	5329	4558	3658	2315	574	.	.	.	.	.	.
Oct		.	.	.	.	.	.	738	2644	3401	4928	5105	5397	4727	5352	4104	1802	460	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	919	2571	4671	5940	6246	5747	4062	1813	605	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1237	2624	3940	4609	4068	2655	1266	.	.	.	.	.	.	.	.	.
		Total	=	827301																					
		Average	=	5666																					
		Intermec	Sky	with	Sun:	BR000001:4																			
Jan		.	.	.	.	.	.	.	.	1355	3058	4787	5479	5309	3982	1922	854	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	982	3406	5826	7499	8158	8311	7355	5177	2267	653	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	929	2749	5409	6841	7673	8067	7492	6578	6237	4157	1630	342	.	.	.	.	.	.
Apr		.	.	.	.	.	1116	3432	4028	5135	5676	5791	5749	5750	5728	5263	4315	3874	1443	.	.	.	.	.	.
May		.	.	.	.	1104	2321	6972	7118	5746	5836	5475	5383	5489	5789	5826	7357	6924	2464	1188	.	.	.	.	.
Jun		.	.	.	485	1686	2753	7670	10243	7345	5776	5288	5060	5248	5714	6254	11182	8412	3040	1892	648	.	.	.	.
Jul		.	.	.	.	1316	2534	6746	8803	7009	5851	5391	5191	5273	5707	6084	9265	8705	3070	1796	566	.	.	.	.
Aug		.	.	.	.	447	1567	5159	5067	5436	5858	5675	5600	5634	5773	5620	5432	6375	2054	923	.	.	.	.	.
Sep		.	.	.	.	.	600	1917	3502	4534	5353	6061	5738	5680	5372	4730	3547	1990	648	.	.	.	.	.	.
Oct		.	.	.	.	.	.	853	2493	6038	8043	9106	9199	8639	7412	5205	2133	506	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	1031	2673	5039	6065	6379	6003	4285	1875	725	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1309	2807	4064	4781	4174	2805	1310	.	.	.	.	.	.	.	.	.
		Total	=	670018																					
		Average	=	4589																					
		Intermec	Sky	with	Sun:	BR000001:5																			
Jan		.	.	.	.	.	.	.	.	1360	3070	5003	5491	5458	4123	1941	834	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	1083	3484	6117	7901	8692	8734	7348	5284	2342	740	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	896	3851	6738	9786	11344	12229	12028	10594	8371	5393	1917	335	.	.	.	.	.	.
Apr		.	.	.	.	.	1158	2491	4321	6374	8447	9938	10826	9276	8365	6339	4336	2818	1436	.	.	.	.	.	.
May		.	.	.	.	1088	2666	4149	4915	5580	5599	5253	5072	5220	5462	5535	4958	4597	2835	1191	.	.	.	.	.
Jun		.	.	.	469	1502	3200	5502	5172	5524	5243	4709	4437	4612	5104	5495	5301	5525	4172	1997	583	.	.	.	.
Jul		.	.	.	.	1175	2706	5141	4993	5522	5381	4944	4659	4796	5179	5524	5300	4433	4089	1829	524	.	.	.	.
Aug		.	.	.	.	442	1611	2942	4413	5541	5821	6335	5640	6877	5753	5546	4772	3478	2694	815	.	.	.	.	.
Sep		.	.	.	.	.	538	1874	5266	9129	11468	12780	13029	12627	11113	8905	5280	1975	599	.	.	.	.	.	.
Oct		.	.	.	.	.	.	828	3033	6182	8724	10218	10376	10009	7781	5420	2157	602	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	1021	2673	5131	6283	6745	5980	4346	1870	689	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1310	2827	4283	4820	4283	2870	1322	.	.	.	.	.	.	.	.	.
		Total	=	716514																					
		Average	=	4908																					
		Intermec	Sky	with	Sun:	BR000001:6																			
Jan		.	.	.	.	.	.	.	.	1455	3298	5279	5944	5859	4417	2123	853	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	1154	3595	6529	8460	9246	9290	8090	5483	2477	683	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	1033	4027	7344	10650	12198	13289	13025	11425	8812	5730	2123	344	.	.	.	.	.	.
Apr		.	.	.	.	.	1206	2683	6532	10846	13807	15052	15352	15431	14217	12222	7507	3320	1496	.	.	.	.	.	.
May		.	.	.	.	1057	3285	3803	5200	8030	11773	11248	13782	11243	10214	7154	5306	3879	3490	1154	.	.	.	.	.
Jun		.	.	.	398	1537	4284	4133	5384	5982	6648	7125	9719	7340	6963	6027	5516	4447	5177	1893	628	.	.	.	.
Jul		.	.	.	.	1203	3259	3862	5191	6285	8397	9052	10935	9365	7686	6621	5586	4397	4522	1718	562	.	.	.	.
Aug		.	.	.	.	425	1725	3066	5739	9318	13753	15185	15225	15564	13656	11089	5739	3614	2808	773	.	.	.	.	.
Sep		.	.	.	.	.	529	2621	6498	10057	12759	14065	14793	14435	12608	10226	6499	2702	567	.	.	.	.	.	.
Oct		.	.	.	.	.	.	902	3268	6533	9206	10910	11176	10585	8532	5650	2332	604	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	1099	2900	5448	6726	7058	6374	4499	2038	711	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1402	3021	4566	5061	4649	3062	1406	.	.	.	.	.	.	.	.	.
		Total	=	922114																					
		Average	=	6316																					
		Intermec	Sky	with	Sun:	BR000001:7																			
Jan		.	.	.	.	.	.	.	.	1683	3760	5942	6793	6627	4940	2453	1013	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	1351	4067	7106	9374	10315	10466	8739	6183	2769	817	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	1227	4425	8434	11945	13617	14711	14523	12763	9804	6327	2414	416	.	.	.	.	.	.
Apr		.	.	.	.	.	1262	4569	9027	12694	15883	16787	17657	17311	16146	13372	9917	5001	1561	.	.	.	.	.	.
May		.	.	.	.	1101	2873	4440	10801	14952	16843	17887	17751	17729	16882	15181	10866	4501	3081	1225	.	.	.	.	.
Jun		.	.	.	445	1616	3857	4805	9109	15453	16915	17625	17396	17655	17163	15655	9084	5144	3914	1896	656	.	.	.	.
Jul		.	.	.	.	1330	3420	4470	9271	15187	16796	17559	17640	17643	17095	15808	11435	5345	3943	1739	582	.	.	.	.
Aug		.	.	.	.	459	1730	4165	9853	13682	16322	17622	17869	17542	16858	14695	11669	5410	2450	856	.	.	.	.	.
Sep		.	.	.	.	.	620	3142	7201	11241	14100	16055	16527	16030	14047	11410	7348	3216	664	.	.	.	.	.	.
Oct		.	.	.	.	.	.	1075	3598	7109	10262	12132	12493	11826	9299	6329	2654	702	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	1266	3359	6051	7455	7711	7261	5182	2373	839	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1626	3432	5088	5868	5197	3482	1653	.	.	.	.	.	.	.	.	.
		Total	=	######																					
		Average	=	8411																					
		Intermec	Sky	with	Sun:	BR000001:8																			
Jan		.	.	.	.	.	.	.	.	1260	2893	3944	4756	4565	3675	1637	567	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	1070	2726	3775	3985	4973	4372	3696	3584	1503	473	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	898	2397	3358	4296	4787	4938	5103	4472	3828	2964	1441	300	.	.	.	.	.	.
Apr		.	.	.	.	.	1231	3148	7280	9693	11777	11812	12651	13368	12405	10572	5848	2681	1309	.	.	.	.	.	.
May		.	.	.	.	1204	3530	3761	5389	9218	12334	11463	13777	9908	8389	5487	4659	3729	2372	1029	.	.	.	.	.
Jun		.	.	.	533	1792	4815	4228	5112	5342	6855	7939	9836	6396	5534	5065	5006	4417	4599	1781	543	.	.	.	.
Jul		.	.	.	.	1365	3974	3932	4974	6797	8949	9898	11299	8390	6040	5271	4970	4194	3812	1664	465	.	.	.	.
Aug		.	.	.	.	510	1928	3043	6574	10235	13011	13824	14044	13953	11852	8801	4558	3349	1992	710	.	.	.	.	.
Sep		.	.	.	.	.	530	2252	4309	5469	6354	5707	7023	8279	7340	6884	5152	1784	549	.	.	.	.	.	.
Oct		.	.	.	.	.	.	785	2372	3386	4119	4248	4317	4116	3593	2913	1468	381	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	961	2539	3718	4683	4984	4448	3788	1415	443	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1209	2474	3912	4355	3904	2496	1015	.	.	.	.	.	.	.	.	.
		Total	=	706097																					
		Average	=	4836																					
		Intermec	Sky	with	Sun:	BR000001:9																			
Jan		.	.	.	.	.	.	.	.	1448	3364	5385	6027	5692	4372	2040	729	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	1202	3683	6470	8478	9243	9214	7801	5344	2127	508	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	1145	4056	7469	10732	12317	13199	12734	11238	8526	5029	1507	294	.	.	.	.	.	.
Apr		.	.	.	.	.	1116	3244	7796	11574	14058	15113	15419	14996	13974	11315	5966	2681	1238	.	.	.	.	.	.
May		.	.	.	.	1026	3184	3809	5766	9975	13721	12736	14655	11198	9420	6165	4828	3529	2117	897	.	.	.	.	.
Jun		.	.	.	459	1506	4246	4137	5433	6075	7930	8955	10530	7573	6246	5637	5073	4066	3563	1421	435	.	.	.	.
Jul		.	.	.	.	1246	3323	3868	5277	7484	10131	11047	11968	9872	6755	5951	5129	3975	3059	1359	373	.	.	.	.
Aug		.	.	.	.	469	1680	3156	7081	11278	14619	15573	15532	15237	13053	9631	4810	3308	1846	628	.	.	.	.	.
Sep		.	.	.	.	.	539	2877	6618	10200	12767	14144	14719	14457	12394	9747	5817	1808	528	.	.	.	.	.	.
Oct		.	.	.	.	.	.	1016	3235	6613	9242	11078	11090	10460	8260	5497	1794	395	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	1085	2942	5454	6640	7070	6310	4470	1936	502	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1391	3036	4687	5165	4548	2979	1363	.	.	.	.	.	.	.	.	.
		Total	=	919753																					
		Average	=	6300																					
		Intermec	Sky	with	Sun:	BR000001:10																			
Jan		.	.	.	.	.	.	.	.	971	2133	4149	4666	4489	3739	1686	804	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	811	1840	3234	4280	4962	4479	4046	3253	2046	600	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	848	2074	3362	4156	4692	4945	4948	4595	3874	2824	1589	344	.	.	.	.	.	.
Apr		.	.	.	.	.	1074	2400	5117	9158	11911	11906	12821	13453	12185	10883	7752	3677	1379	.	.	.	.	.	.
May		.	.	.	.	968	2721	3660	4616	6467	10380	10427	14124	12090	11133	8486	5339	3910	3259	1315	.	.	.	.	.
Jun		.	.	.	367	1456	4033	4110	4916	5104	5566	6695	10208	9140	7922	5907	5277	4591	4750	2294	703	.	.	.	.
Jul		.	.	.	.	1142	2980	3849	4743	5183	7286	8431	11525	11622	9091	7362	5306	4452	4396	2111	627	.	.	.	.
Aug		.	.	.	.	347	1558	2891	4484	7629	12101	13392	13895	13932	13195	11821	6596	3555	2312	922	.	.	.	.	.
Sep		.	.	.	.	.	510	1735	4921	6920	7370	6476	7000	7412	6617	5774	4606	2537	578	.	.	.	.	.	.
Oct		.	.	.	.	.	.	678	1785	2872	3746	4140	4317	4163	3898	3383	1892	484	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	726	1635	3840	4590	5009	4618	3981	1580	670	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	935	1961	3699	4287	3794	2559	1047	.	.	.	.	.	.	.	.	.
		Total	=	713918																					
		Average	=	4889.9																					
		Intermec	Sky	with	Sun:	BR000001:11																			
Jan		.	.	.	.	.	.	.	.	1119	2606	5196	5854	5724	4414	2069	872	.	.	.	.	.	.	.	.
Feb		.	.	.	.	.	.	.	876	2548	5980	8097	9037	9227	7901	5535	2436	663	.	.	.	.	.	.	.
Mar		.	.	.	.	.	.	853	2240	7176	10216	11808	12915	12765	11367	8719	5730	2135	427	.	.	.	.	.	.
Apr		.	.	.	.	.	1004	2370	5242	10463	13562	14614	15263	15083	13915	12006	8076	3634	1346	.	.	.	.	.	.
May		.	.	.	.	840	2390	3513	4734	6483	10284	10669	13872	11712	10930	8594	5552	3845	3356	1056	.	.	.	.	.
Jun		.	.	.	297	1224	3420	3829	4893	5451	5825	6393	9845	8189	7529	6077	5493	4421	4646	1703	617	.	.	.	.
Jul		.	.	.	.	965	2469	3606	4727	5449	7138	8097	11056	10311	8486	7357	5570	4333	4114	1525	545	.	.	.	.
Aug		.	.	.	.	298	1425	2790	4539	8116	12722	14763	15041	15287	13830	12364	6569	3611	2404	761	.	.	.	.	.
Sep		.	.	.	.	.	488	1745	5421	9526	12257	13804	14627	14306	12744	10410	6715	2811	559	.	.	.	.	.	.
Oct		.	.	.	.	.	.	711	2070	5891	8829	10624	10883	10441	8630	5656	2382	656	.	.	.	.	.	.	.
Nov		.	.	.	.	.	.	.	810	2153	5165	6615	6887	6523	4451	1976	701	.	.	.	.	.	.	.	.
Dec		.	.	.	.	.	.	.	.	1092	2489	4544	5067	4591	2914	1382	.	.	.	.	.	.	.	.	.

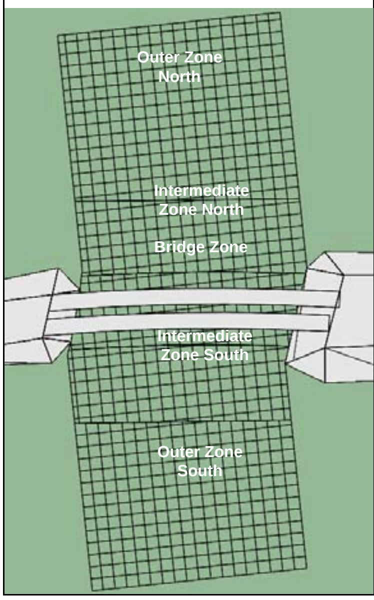
Appendix B – Sensitivity analyses

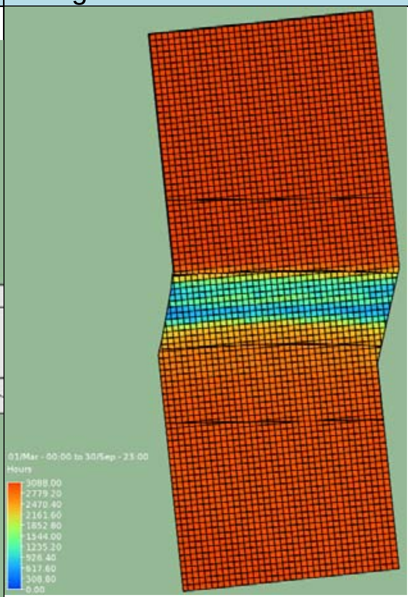
Spatial distribution of solar exposure with 5 m and 10 m grid size

6.18 Figure B1 shows the number of hours displayed visually using a grid resolution of 5 m x 5 m and 10 m x 10 m when daylight is available for the growing season from March to September inclusive for Option 2.2 (with bridge width 35 m).

6.19 As the purpose of this metric is showing graphically the zone of the bridge influence, a grid size of 10 m x 10 m is considered to be sufficient.

Location of the bridge, landscape and assessment zones	Solar exposure for the growing season for a grid size of 5 m x 5 m	Solar exposure for the growing season for a grid size of 10 m x 10 m
-		





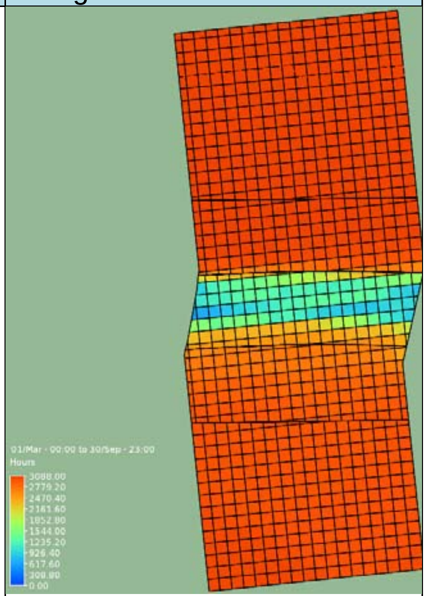


Figure B12. Zones of bridge influence on solar exposure using different grid size (Option 2.2). Note the colour scales are identical

SPATIAL DISTRIBUTION OF SOLAR EXPOSURE THROUGHOUT A WHOLE YEAR AND FOR THE GROWING SEASON ONLY

6.20 A sensitivity analysis was carried out for comparing the result generated for a whole year and the growing season only. The results show that the most affected area by the bridge construction is clearly the Bridge Zone for both annual and growing season assessments. The annual results also show that Intermediate Zone North is somewhat affected due to low sun angles in autumn, winter and spring. The number of daylight hours is reduced more significantly for the results for the growing season only. As the purpose of this study is assessing levels of shading beneath bridges with the ultimate intent of helping to avoid habitat loss, therefore the results for the growing season only were reported in this study.

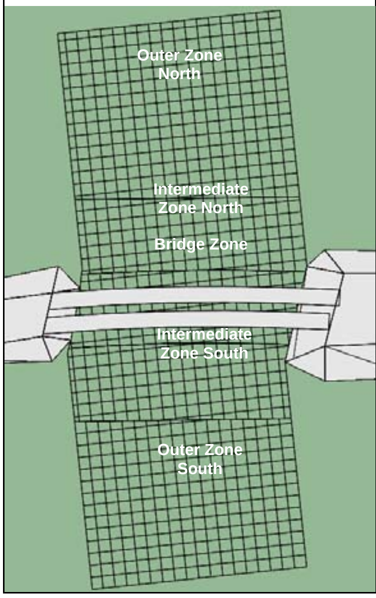
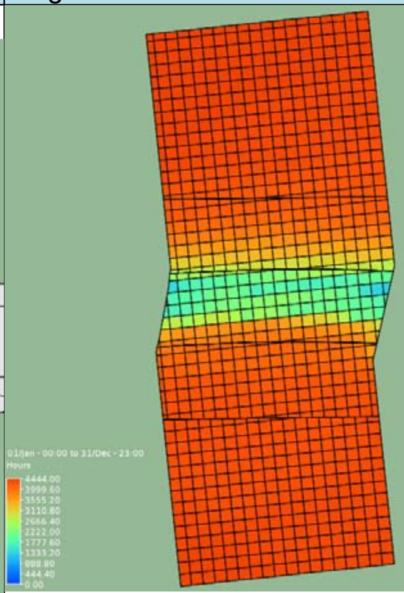
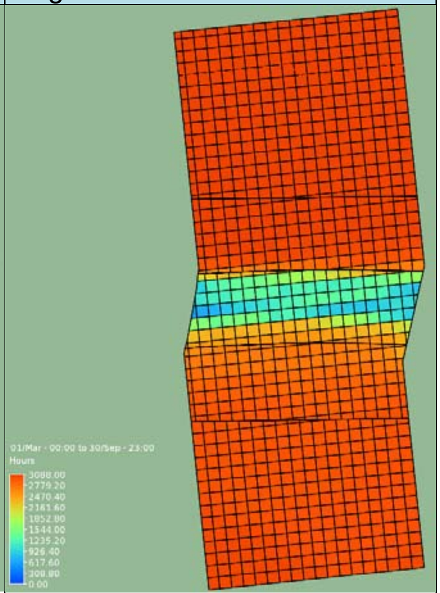
Location of the bridge, landscape and assessment zones	Annual solar exposure for grid size of 10 m x 10 m	Solar exposure through the growing season for grid size of 10 m x 10 m
-  		

Figure B2. Zones of bridge influence on solar exposure using different assessment periods (Option 2.2). Note the colour scales are not identical

AREA-BASED SOLAR RADIATION ATTENUATION FACTOR (ASRAF) THROUGHOUT A WHOLE YEAR AND FOR THE GROWING SEASON ONLY

6.22 A sensitivity analysis was carried out for comparing the result generated for a whole year and the growing season only. Table B1 shows the results for the five assessment surfaces. The results for Option 2.2 are very similar; therefore the results for the growing season only were reported in this study.

TableB1 Zones of bridge influence on solar radiation attenuation factors using different assessment periods (Option 2.2).

	Area-based solar radiation attenuation factors				
Assessment period	Outer Zone North	Intermediate Zone North	Bridge Zone	Intermediate Zone South	Outer Zone South
Annual	0.99	0.96	0.59	0.98	0.99
Growing season	1.00	0.98	0.58	0.98	1.00

DAYLIGHT ATTENUATION FACTOR

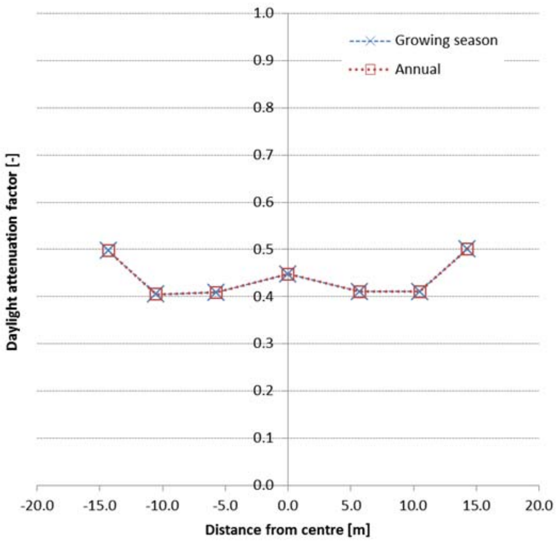
6.24 The total daylight received at ground level was estimated at 11 'virtual sensor points' underneath the bridge and compared to the total available daylight at ground level as if the site was unobstructed. The assessment was carried out using two sky models: CIE Overcast Sky and Intermediate Sky with Sun and for two assessment periods: over a whole year and for the growing season. The sky models represent two different sky luminance distributions, therefore the Daylight attenuation factor varies.

Table B2. Daylight attenuation factors (Option 2.2).

	CIE Overcast Sky model		Intermediate Sky with Sun model	
Virtual sensor point name	Annual daylight attenuation factor (-)	Daylight attenuation factor (-) March to September inclusive	Annual daylight attenuation factor (-)	Daylight attenuation factor (-) March to September inclusive
Sensor point 1	0.50	0.50	0.38	0.37
Sensor point 2	0.41	0.41	0.43	0.43
Sensor point 3	0.41	0.41	0.49	0.49
Sensor point 4	0.45	0.45	0.40	0.35
Sensor point 5	0.41	0.41	0.42	0.37
Sensor point 6	0.40	0.40	0.54	0.51
Sensor point 7	0.50	0.50	0.73	0.72
Sensor point 8	0.39	0.39	0.42	0.42
Sensor point 9	0.39	0.39	0.54	0.51
Sensor point 10	0.40	0.40	0.42	0.43
Sensor point 11	0.39	0.39	0.53	0.50

Daylight attenuation factors for March to September inclusive with the CIE Overcast Sky model

Daylight attenuation factors for March to September inclusive with the Intermediate Sky with Sun model



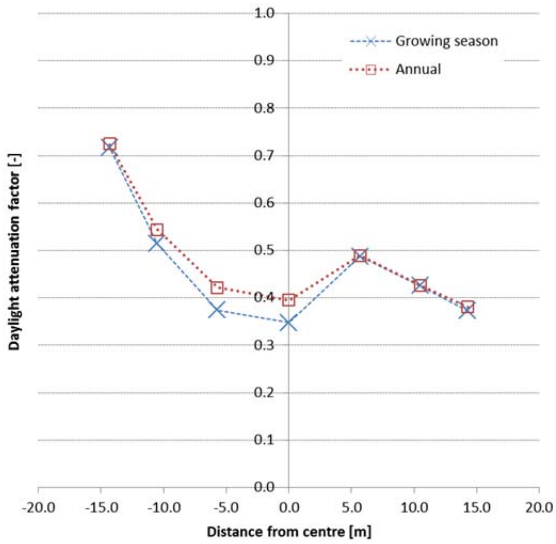


Figure B3. Example daylight attenuation factors distribution under the bridge for the sensor points from 1 to 7 for Option 2.2.

If you need help accessing this or any other Highways England information, please call **0300 123 5000** and we will help you.

This document is also available on our website at **www.gov.uk/highways**

If you have any enquiries about this document email **info@a303stonehenge.co.uk**
or call **0300 123 5000***.

*Calls to 03 numbers cost no more than a national rate call to an 01 or 02 number and must count towards any inclusive minutes in the same way as 01 and 02 calls.
These rules apply to calls from any type of line including mobile, BT, other fixed line or payphone. Calls may be recorded or monitored.

Registered office Bridge House, 1 Walnut Tree Close, Guildford GU1 4LZ
Highways England Company Limited registered in England and Wales number 09346363