Norwich Western Link

Environmental Statement

Chapter 10: Biodiversity

Appendix 10.37: Solar Exposure Analysis

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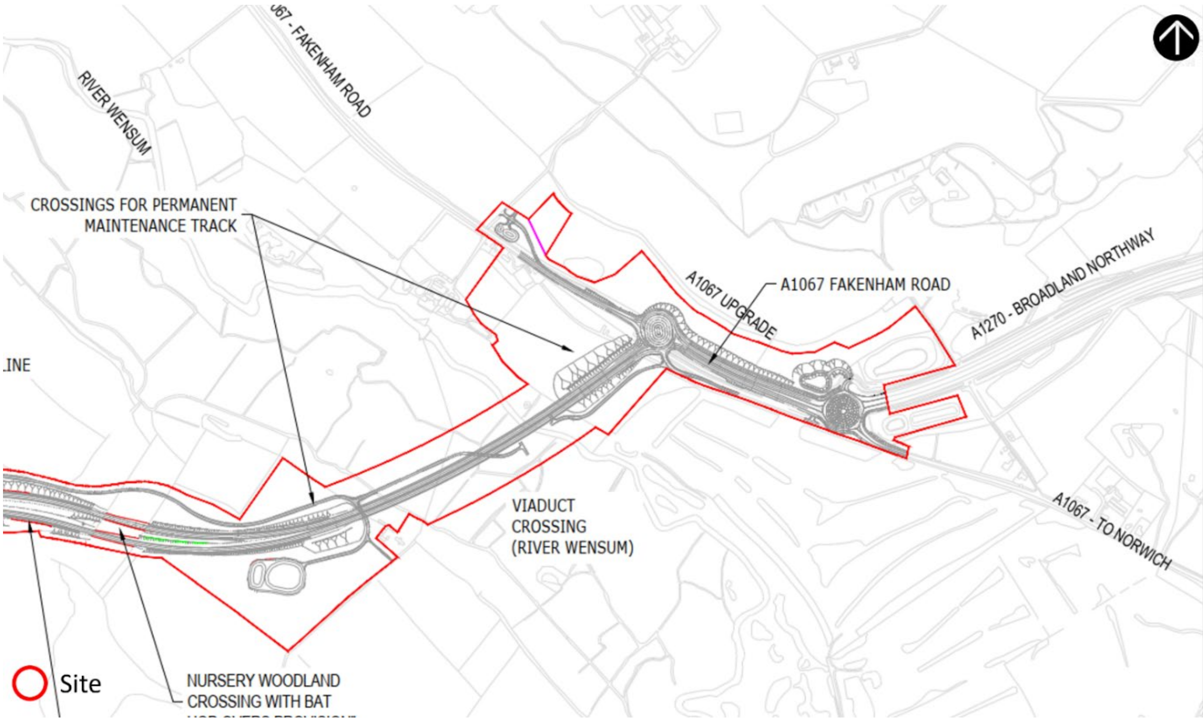
1 Introduction

1.1.1 We have included a summary of key information shown in this document in an accessible format. However, some users may not be able to access all technical details. If you require this document in a more accessible format please contact norwichwesternlink@norfolk.gov.uk

1.1.2 The aim of the assessment is to investigate the potential effect of the permanent viaduct structure and associated temporary works on the level of solar exposure on the areas under and adjacent to the structure, both on the ground and on the River Wensum where it intersects with the bridge.

1.1.3 **Figure 1.1** shows the location of the viaduct above the River Wensum and the general arrangements of the design, as shown on the **General Arrangement Plans** (Document Reference: 2.03.00).

Figure 1-1 'Site' location



2 Legislation and guidance

2.1.1 The River Wensum is a calcareous lowland river designated as a Special Protection Area (SAC) (**Ref. 1**). Therefore, there is a need to understand any potential impacts on the integrity of this designated site, and the impacts generally (given its status also as a Site of Specifical Scientific Interest (SSSI) which may result from the construction, operation, and maintenance of the NWL.

2.1.2 There is no specific legislative framework relating to new developments and their potential effect on their surrounding natural terrain in terms of the amount of daylight and sunlight it receives. However, guidance and regulations regarding the conservational areas are listed within **Chapter 10: Biodiversity** (Document Reference: 3.10.00).

3 Methodology and criteria

3.1 Site and study area

3.1.1 A 3D model, both of the permanent viaduct and the temporary structures was constructed for the study including the surrounding terrain and the River Wensum (**Figures 3.1** and **3.2**).

3.1.2 The model has been based on '**Structures Design Plans**' (Document reference: 2.06.01), and as can be seen in Temporary works platform general arrangement (Document 03.12.02k, **Figure 8**). The existing terrain elevations are negligible for the purpose of solar exposure and therefore, the terrain and river underneath the viaduct have been modelled as a one level flat surface 9.5m below the underside of steel for the lowest longitudinal plate girder. This height represents the average headroom above the riverbanks, which is the key area for the study.

Figure 3-1 Extent of the study area

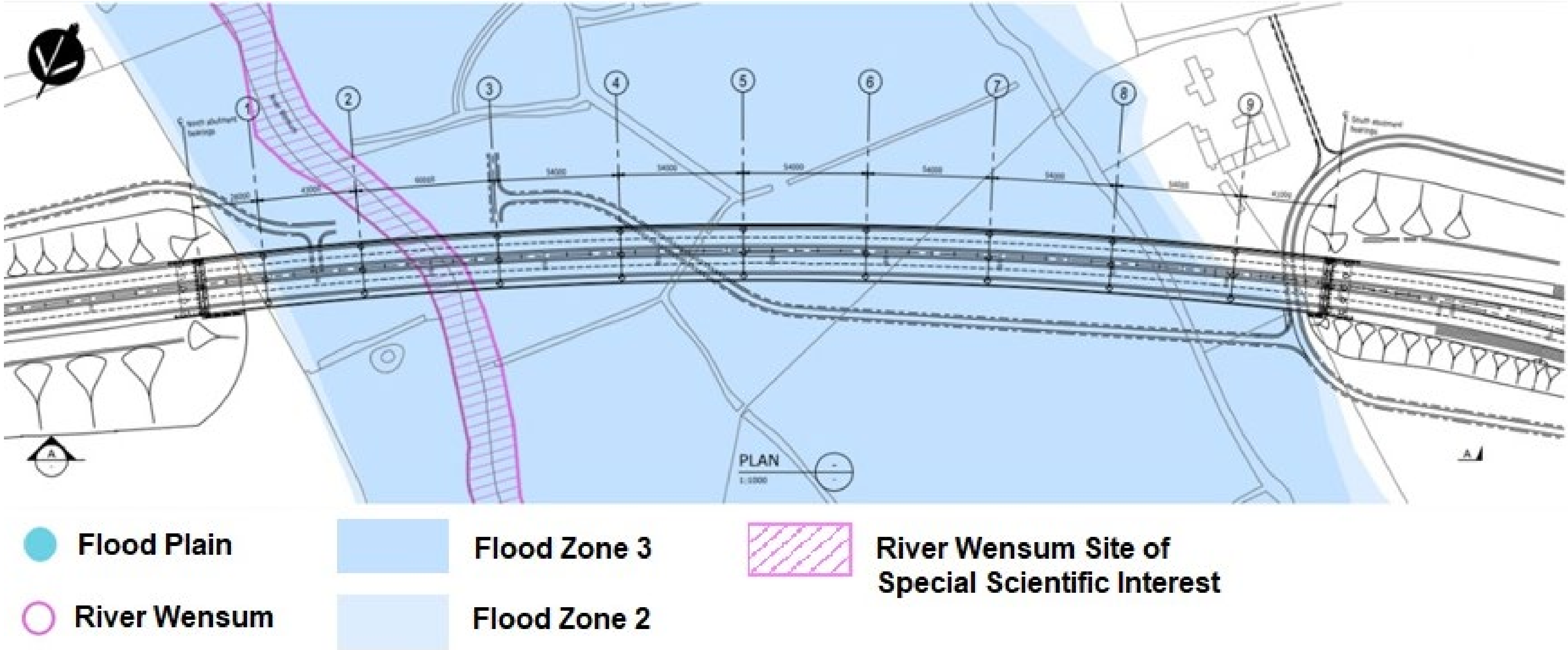


Figure 3-2 3D Model for the study – Southeast perspective

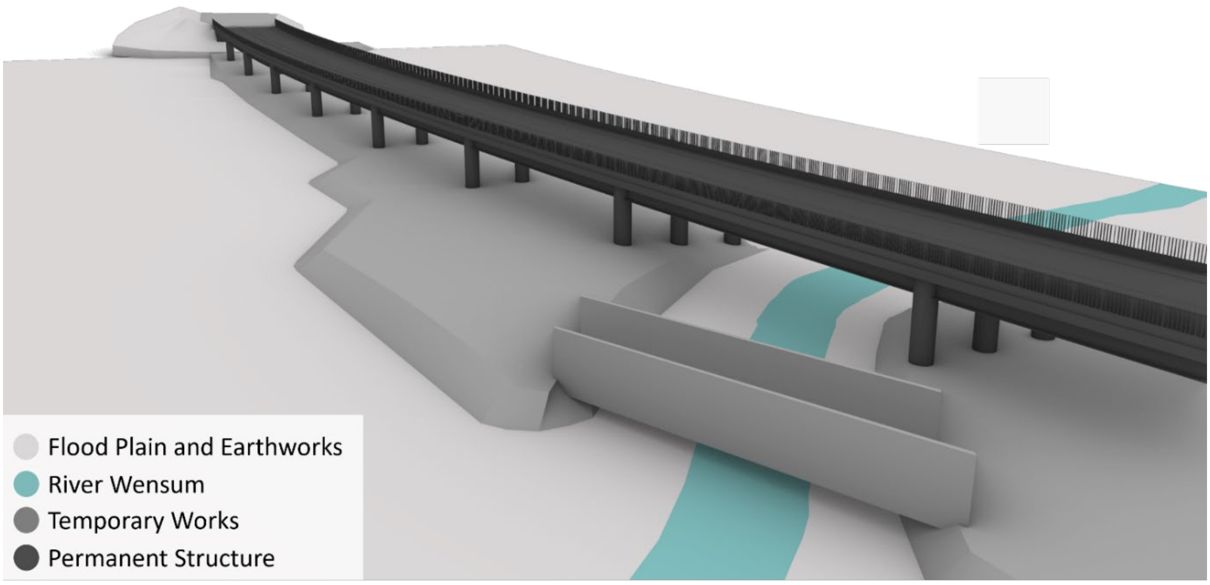


Table 3.1 Drawings and model used for the proposed viaduct structure and temporary works models

Used to Construct:	File name
Proposed Viaduct Design	'Structures Design Plans' (Document reference: 2.06.01).

3.2 Permanent viaduct structure

3.2.1 The permanent structure design includes an environmental barrier with solid and transparent elements, the height of which is yet to be determined. For the purpose of the solar assessment a height of 3m has been assumed as a worst-case scenario. Reducing the height of the barrier could lead to an improvement of the results, however, it is most likely that this would represent a negligible change. This is due to both the angle of sunlight (as the sun is broadly above the viaduct structure), and that the barrier is transparent.

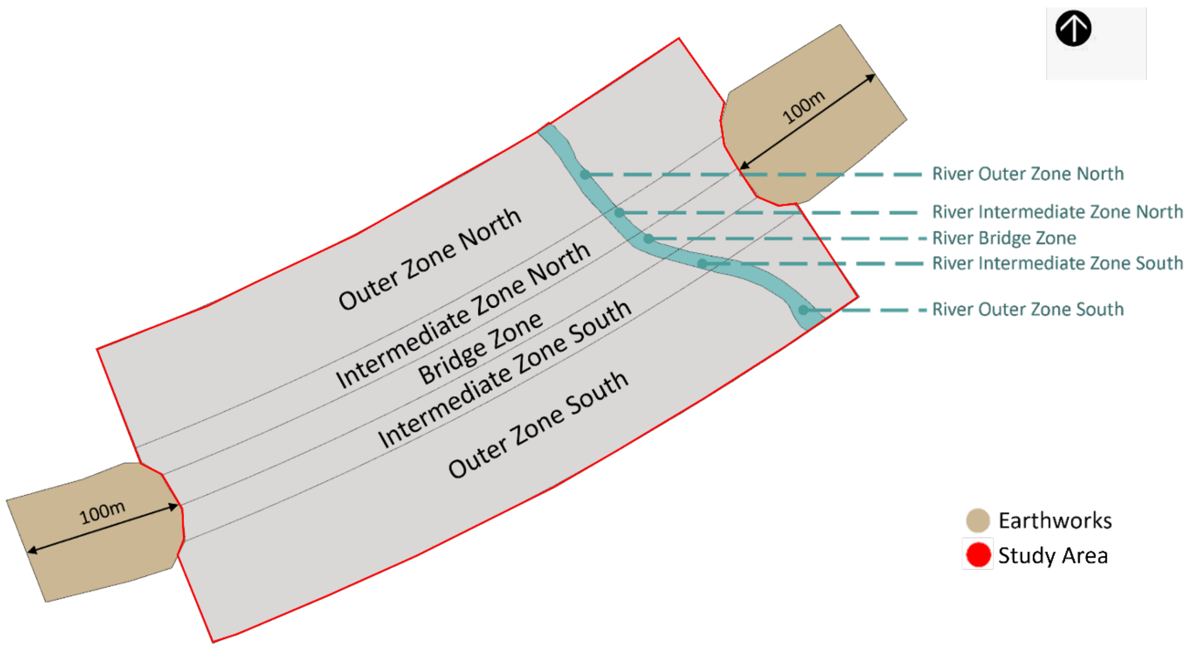
3.2.2 The assessment excludes the permanent access tracks since given their distance to the River Wensum and their potential minimal shading effect on the flood plain, it is most likely that they will have a negligible impact on the assessment results.

3.2.3 The solar assessment model includes a 100m offset on either side, which represents the earthworks (**Figure 3.3**).

3.3 Analysis receptors

3.3.1 The receptors for the assessment were selected based on the natural terrain and River Wensum zones. The area of assessment was divided into 5 zones to provide a clear understanding of the shading. The first zone (Bridge Zone) comprises the actual projected area of the viaduct on the terrain. This zone is then offset on each side by equal widths, the same as the width of the Bridge Zone (approximately 25m). These two zones are identified as Intermediate Zone North and Intermediate Zone South. Lastly, there is a larger offset on each side (3 times the width of the intermediate zones), that forms the Outer Zone North and Outer Zone South. **Figure 3.3** below shows the division of these zones.

Figure 3-3 Study zones division



3.4 Assessment methodology and metrics

3.4.1 The assessment comprises the following configurations:

- Baseline Scenario: assessment of the existing conditions of sunlight, solar radiation, and daylight on the analysis surfaces of the River Wensum and surrounding flood plain.
- Proposed Scenarios:
  - Temporary Works: assessment of the levels of sunlight, solar radiation, and daylight on the analysis surfaces of the River Wensum and surrounding flood plain with the temporary works platform and Bailey Bridge in place.
  - Temporary Works and Permanent Structure: assessment of the levels of sunlight, solar radiation, and daylight on the analysis surfaces of the River Wensum and surrounding flood plain with the temporary works platform, Bailey Bridge, and permanent viaduct structure in place.
  - Permanent Structure: assessment of the levels of daylight, solar radiation, and sunlight on the analysis surfaces of the River Wensum and surrounding flood plain with the viaduct in place.

3.4.2 The solar study estimates the potential levels of solar exposure on the site to identify the likely effects of shading on the identified zones adjacent to the viaduct as described in the previous section. The assessment therefore focuses on the comparison between the existing conditions on the site (baseline scenario) and the temporary and operational phase of the Proposed Scheme.

3.4.3 The assessment uses three metrics to assess the impacts: the sunlight hours attenuation factor, the area-based solar radiation attenuation factor, and the daylight attenuation factor throughout the year and during the growing season. These indicate the available sunlight hours, solar radiation, and illuminance levels within the site both with and without the viaduct and/or temporary works.

3.4.4 An assessment grid subdivided in 10m x 10m cells was created within the software (see paragraph 3.4.13) for each of the 5 zones.

Sunlight hours

3.4.5 Sunlight hours measure the number of hours when direct sunlight reaches the analysis zones. The level of sunlight availability a surface can receive is dependent on its orientation as well as on the external obstructions. The location and orientation of the assessed surface have been carefully considered to calculate the sunlight availability as the sun's path throughout the day moves from east to west on the south part of the sky. The shadowing due to the permanent structure is most likely to occur on areas positioned immediate north of the viaduct and beneath it.

3.4.6 The Sunlight Hours Attenuation Factor was calculated as the ratio of the total sunlight hours at ground level (h) with the proposed structures in place (temporary works and permanent structure) to (h) without the proposed structures (baseline scenario) for the growing season at the site. The annual ratio is also calculated as an extension of the assessment for comparison.

3.4.7 The solar exposure calculations use the sun vectors generated from the hourly solar data of the weather file, to produce results expressed in total sunlit hours over the specified period for each cell.

Solar radiation

3.4.8 The global solar radiation (diffused and direct solar radiation) data within the weather file were used for the solar radiation calculations. Solar radiation is defined as the power per unit area received from the sun in the form of electromagnetic radiation during the assessed period; it is expressed in kWh/m^2.

3.4.9 The Area-based Solar Radiation Attenuation Factor (ASRAF) was calculated as a ratio of the total global solar radiation (kWh/m^2) at ground level with the proposed structures in place (temporary works and permanent structure) to the total available global solar radiation (kW/m^2) at ground level without the proposed structures (baseline scenario) for the growing season at the site. The annual ratio was also calculated as an extension of the assessment for comparison.

Illuminance (Lux)

3.4.10 This metric has been used to assess the impacts on daylight. Illuminance measures the amount of luminous flux spread over a given area. It is measured in per sunlight hour (lux/h) and quantifies the level of incident light on a surface over a period of time. Per sunlight hour is defined in section 3.4.5 to 3.4.7 above. The calculation uses the sky conditions of the selected weather file's historical data.

3.4.11 The Daylight Attenuation Factor compares the total daylight (lux) received at ground level with the proposed structures in place (temporary works and permanent structure) to the total daylight (lux) available at ground level without the proposed structures (baseline scenario) for the growing season at the site. The annual ratio is also calculated as an extension of the assessment for comparison.

Criteria and Targets

3.4.12 The target assumed for the study was an attenuation factor of 0.50. Software and tools

3.4.13 The sunlight and daylight calculations were carried out using a 3D model of the structure and the specialist software Radiance and associated plug-ins within Grasshopper software. The ray-tracing tool Radiance was developed by the Building Technologies Department of the Environmental Energy Technologies Division at the Lawrence Berkeley National Laboratory, University of California. The software is widely used in the lighting and daylighting industry for a number of applications in the built environment. Radiance calculates the distribution of visible light in daylight illuminated spaces based on pre-defined sky and solar radiance models.

Weather Data

3.4.14 The annual weather data for Norwich International Airport in Norfolk adopted for this assessment represent 15 years of recorded data, between 2004 and 2018 and was obtained from Climate.OneBuilding.Org.

Assessment Period

3.4.15 The selected period to undertake the assessment was the growing season which has been assumed to be from March to September inclusive. Furthermore, an annual analysis was conducted to provide a holistic study and a comparison against the growing season. The calculations were carried out with the date, time, and site location (longitude and latitude) taken into account.

Materials and Reflectance

3.4.16 The level of luminance at each assessed surface depends on three key factors: reflectance, specularity and roughness of its material. Based on information provided by the design team and materials properties derived from Jaloxa, an online library suggested by Ladybug Tools (**Ref. 7**), the assessment used the parameters and values indicated in **Table 3.2** and **Figure 3.4**.

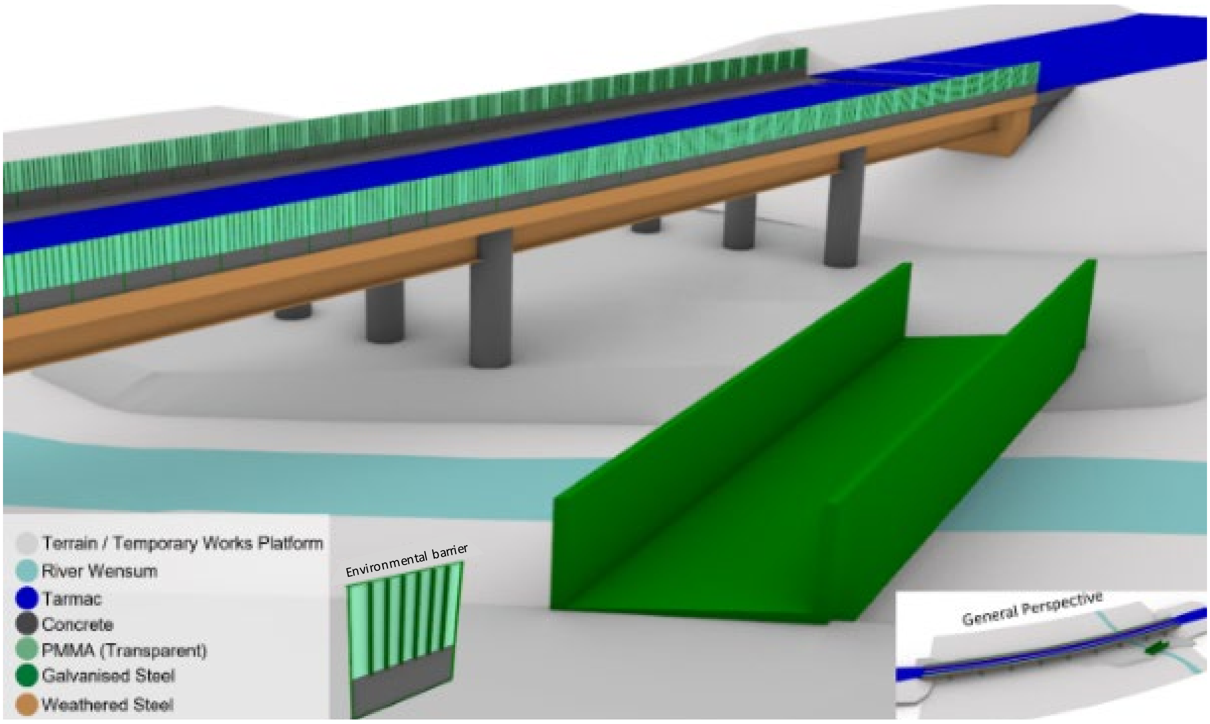
3.4.17 An average reflectance of 0.2 has been assumed for all surfaces of the terrain, river, and temporary works.

3.4.18 The visible light transmittance of the poly (methyl methacrylate) (PMMA) of the environmental barrier has been assumed to be 92% with a maintenance factor of 0.92. These values were assumed following the information found online from PLEXIGLAS® Soundstop, which is an example of one of the potential materials to be specified during detailed design of the viaduct.

Table 3.2 Material properties and assumptions

Material	Reflectance	Roughness	Specularity
Tarmac	0.26	0.05	0.00
Concrete	0.40	0.05	0.00
Galvanised Steel	0.50	0.20	0.30
Weathered Steel	0.11	0.20	0.30

Figure 3-4 Construction materials of the temporary works and permanent structure



3.5 Sensitive Receptors

3.5.1 The receptors for the assessment were selected based on the natural terrain and River Wensum zones. **Figure 3.5** summarise the receptors selected for the sunlight hours, solar radiation, and illuminance assessments.

Figure 3-5 Sensitive receptors surrounding the proposed viaduct structure

4 Baseline scenario

4.1.1 An assessment of the baseline conditions has been carried out as described in section 3. The baseline conditions include the existing site and existing surroundings around the site, which include only the surrounding open fields (**Figure 4.1**).

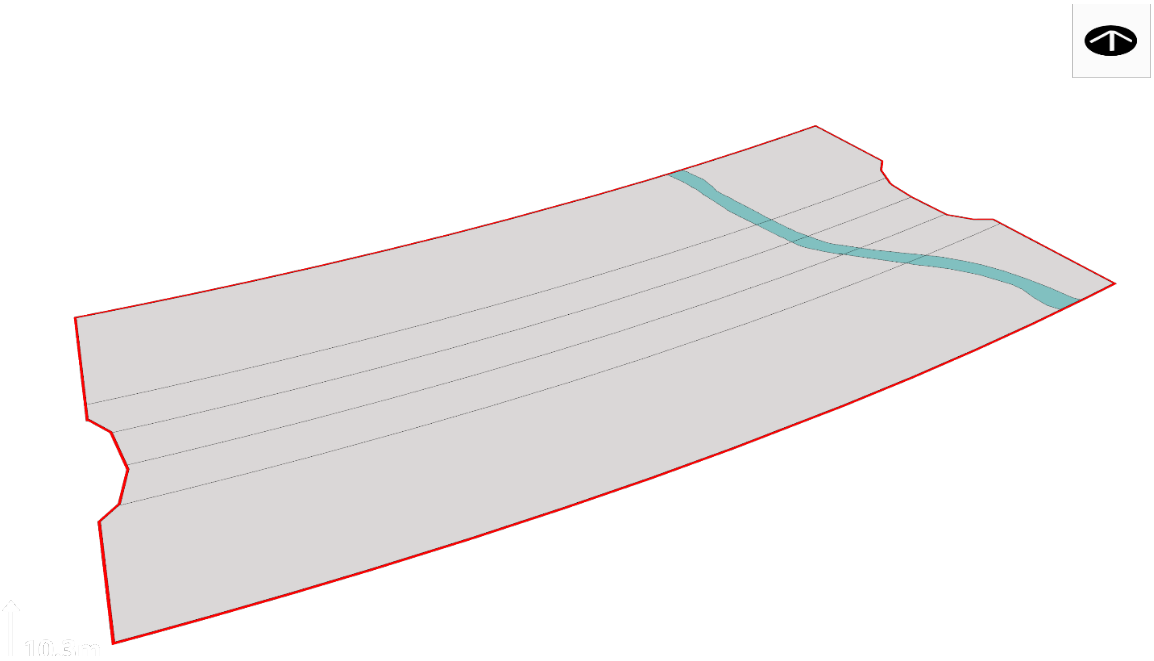
4.1.2 The 3D model of the baseline scenario has been used to determine the baseline conditions in terms of sunlight hours, solar radiation, and illuminance levels of the zones of study.

4.1.3 The detailed sunlight hours, solar radiation and illuminance baseline levels for each zone is given in Appendices A-C.

4.1.4 The results indicate that every 10m x 10m cell of the analysis plane receives 3095 h of sunlight hours; around 1,060 kWh/m^2 of solar radiation and around 114,000 kilolux of illuminance during the growing season.

4.1.5 In summary, the results indicate that in the baseline scenario, the maximum levels of sunlight hours, solar radiation and daylight are achieved for all the zones due to the absence of obstructions.

Figure 4-1 3D model of the baseline scenario – Southwest perspective



5 Proposed scenario

5.1.1 The impact of the temporary works and permanent structure has been assessed by assessing first the temporary works, followed by the temporary works together with the permanent structure, and lastly, the permanent structure alone. The 3 sets of analysis for each zone were assessed keeping all the materials' assumptions the same, for a direct comparison.

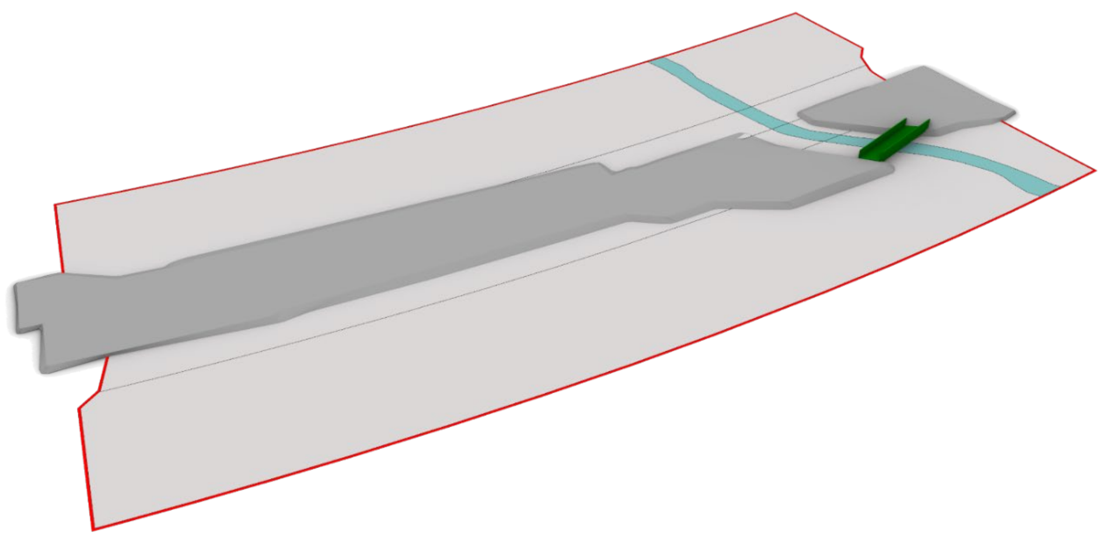
5.1.2 All 10 zones identified for the study have been included in the assessment. As discussed in section 3.5, there are five sensitive zones which cover the entire surface of the river within the site and five sensitive receptors for the open fields surrounding the site (flood plain). Seasonal and annual results for each assessment are presented fully in Appendices A-C. A comparison between annual and seasonal attenuation factors can be found in **section 5.5**, while tabulated and graphical results are included in Appendix D.

5.2 Temporary works

5.2.1 The full extent of the temporary works (temporary works platform and Bailey Bridge) has been used as the basis for the assessment of the effects of sunlight hours, solar radiation, and daylight in this assessment. **Figure 5.1** shows the southwest perspective of the model of the 'Temporary Works' scenario.

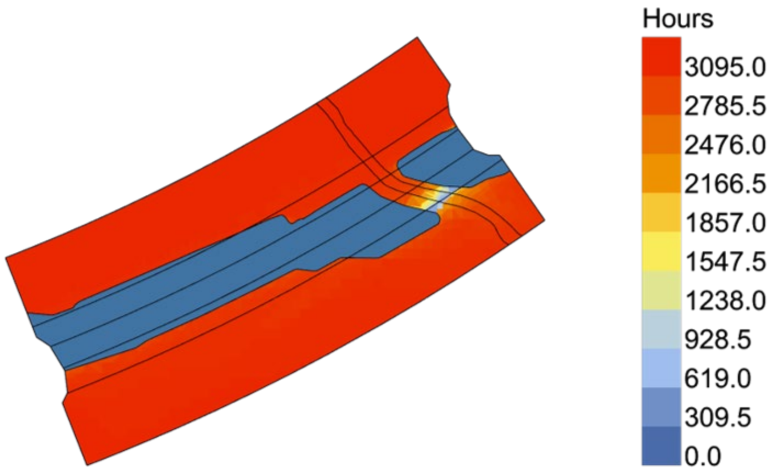
This scenario accounts for the impact of the temporary works platform located within the middle zones of the flood plain. This platform sits directly on top of the terrain of the flood plain blocking the solar and daylight access to the areas directly underneath it, which leads to a significant reduction of the total levels of sunlight, solar radiation and illuminance of the entire assessment zones partially covered by the platform. However, this impact is temporary and, given the relatively low height of the platform, it is only observed in the area directly covered by the platform with no significant change in the remaining area of the zones.

Figure 5-1 3D model of the temporary works – southwest perspective



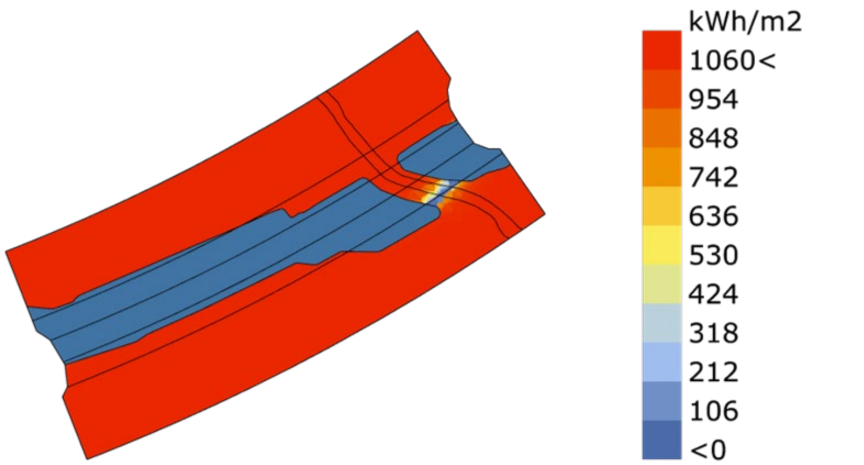
5.2.2 The results of the sunlight hours assessment, illustrated in **Figure 5.2**, indicated that in addition to the areas of the flood plain overshadowed by the temporary works platform sitting mostly on top of the middle zones, the areas that showed the most impact are the ones of the river under and to the north of the Bailey Bridge (receptors D and E: River Intermediate Zone South and River Outer Zone South, respectively). In the case of receptor D, the area receives an average of approximately 1,794 hours of sunlight, a 42% reduction compared to the baseline condition, and for receptor E, an average of 2,454 hours and a reduction of 21% from the baseline.

Figure 5-2 Sunlight hours – temporary works



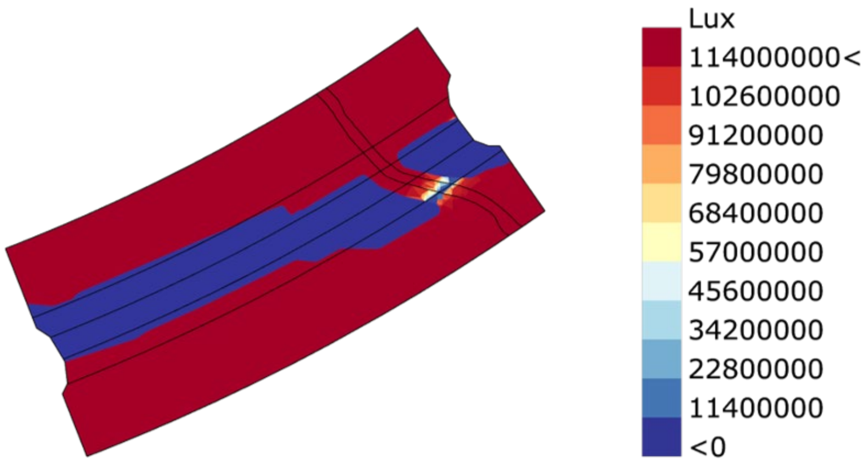
5.2.3 Concerning the assessment of solar radiation, the most affected areas are consequently also located below and to the north of the Bailey Bridge. Receptor D receives on average 648 kwh/m2, around 39% less solar radiation compared to the baseline scenario. In the case of receptor E, the area receives on average 878 kwh/m2, maintaining 83% of the cumulative solar radiation from the existing condition. **Figure 5.3** shows the maximum and minimum incident solar radiation during the growing season.

Figure 5-3 Solar radiation – temporary works



5.2.4 The illuminance results followed the pattern of the previous assessments (**Figure 5.4**). Receptors D and E maintain around 65% and 85% of the daylight received in the baseline scenario, respectively. Receptor D receives an average of around 73,755 kilolux per grid cell and in the case of receptor E, each cell receives an average of 96,415 kilolux.

Figure 5-4 Illuminance – temporary works

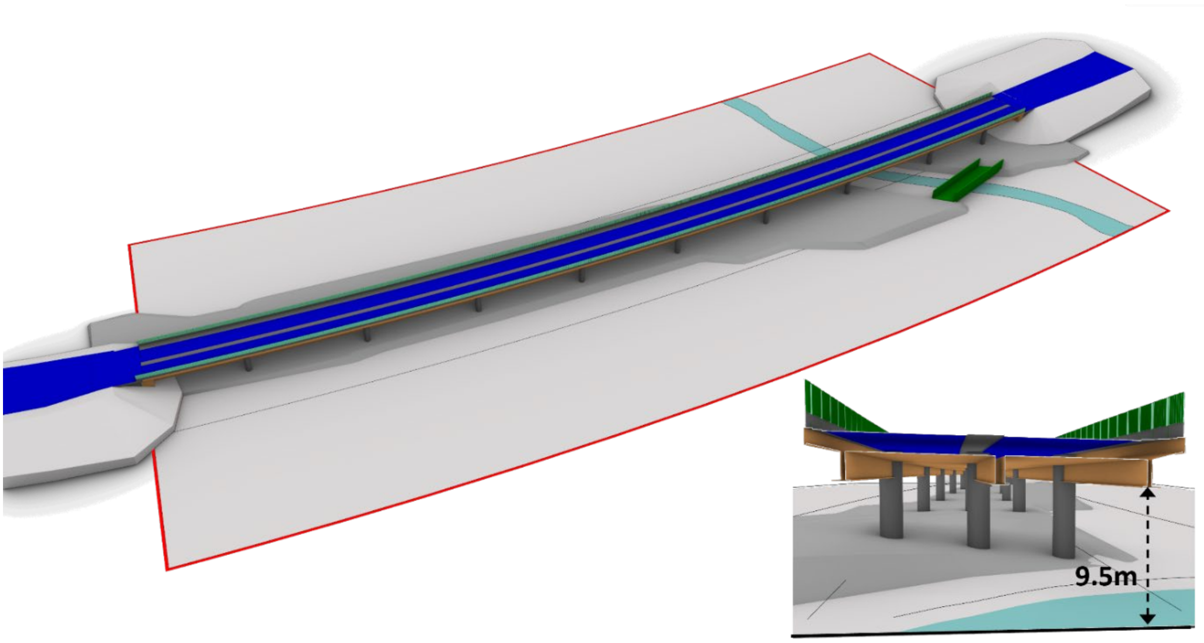


5.3 Temporary works and permanent structure

5.3.1 To account for the cumulative effect of both the temporary works and permanent structure on the levels of sunlight and daylight within the flood plain and river surfaces, the permanent structure was introduced in the model together with the temporary works platform and Bailey Bridge. **Figure 5.5** shows in perspective and section views of the model of the 'Temporary Works and Permanent Structure' scenario.

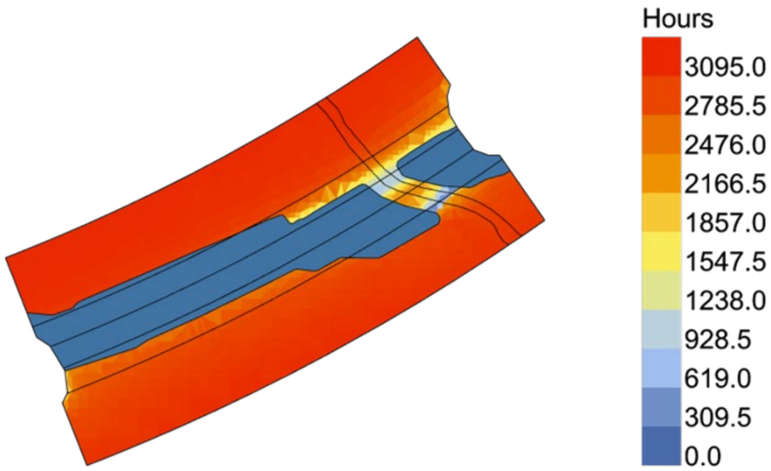
5.3.2 As in the 'Temporary Works' configuration, this scenario accounts for the impact of the temporary works platform located within the middle zones of the flood plain. This platform sits directly on top of the terrain of the flood plain blocking the solar and daylight access to the areas directly underneath it, which leads to a significant reduction of the total levels of sunlight, solar radiation and illuminance of the entire assessment zones partially covered by the platform. However, this impact is temporary and, given the relatively low height of the platform, it is only observed in the area directly covered by the platform with no significant change in the remaining area of the zones.

Figure 5-5 3D model of the temporary works and permanent structure – Southwest perspective and section



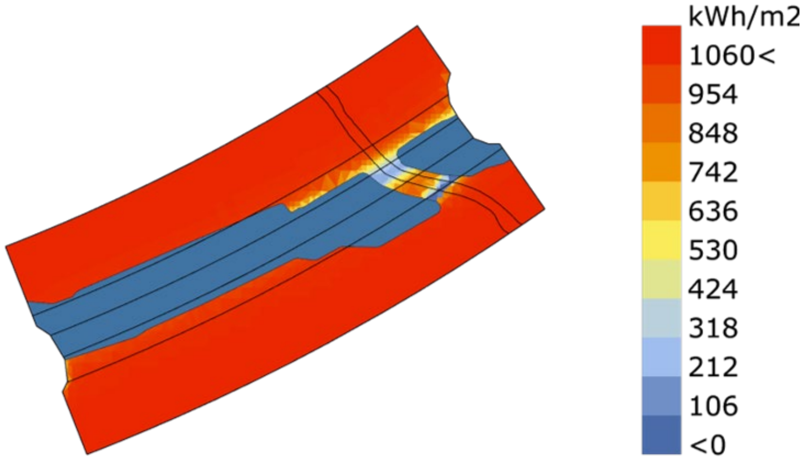
5.3.3 The results of the sunlight hours assessment (**Figure 5.6**) indicated that when both the temporary works and permanent structure are considered, the areas under and between the two bridges (receptors B, C and D) receive the least amount of sunlight besides the area covered by the platform in the flood plain zones, with an average of around 1,930 hours for receptor C, 1,526 hours for receptor D and 1,412 hours for receptor D. This represents a loss of 38%, 51% and 54% of sunlight hours in comparison to the existing conditions, respectively. The permanent structure also showed an impact to the zone immediately to the north of the viaduct (receptor 2).

Figure 5-6 Sunlight hours – temporary works and permanent structure



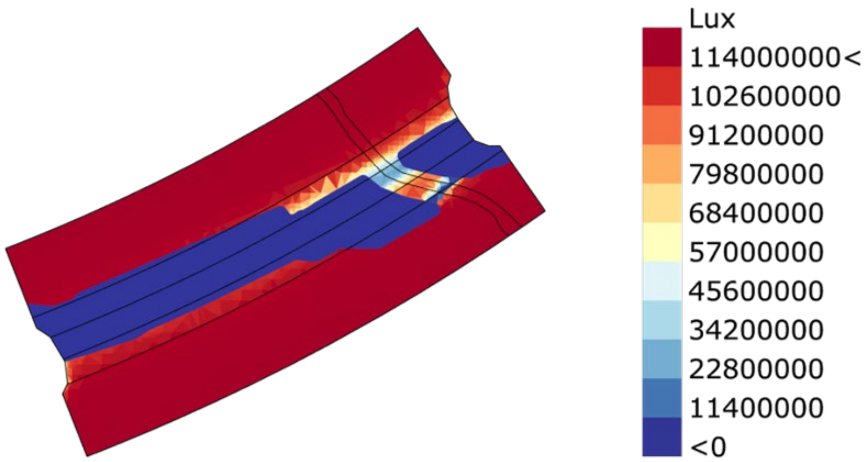
5.3.4 Regarding the assessment of solar radiation, the most affected areas of the river, namely receptors B, C and D, receive on average 753 kwh/m^2, 432 kwh/m^2 and 542 kwh/m^2, respectively. This represents a reduction in solar radiation of 29% for receptor B, 59% for receptor C and 49% for receptor D compared to the baseline scenario. **Figure 5.7** shows the maximum and minimum incident solar radiation during the growing season.

Figure 5-7 Solar radiation – temporary works and permanent structure



5.3.5 The illuminance results (**Figure 5.8**) showed that receptors B, C and D maintain around 70%, 40% and 53% of the daylight received in the baseline scenario, respectively. Receptor B receives an average of around 79,507 kilolux per grid cell, receptor C indicated an average of 45,872 kilolux per cell, and in the case of receptor D, each cell receives an average of 60,807 kilolux.

Figure 5-8 Illuminance – temporary works and permanent structure

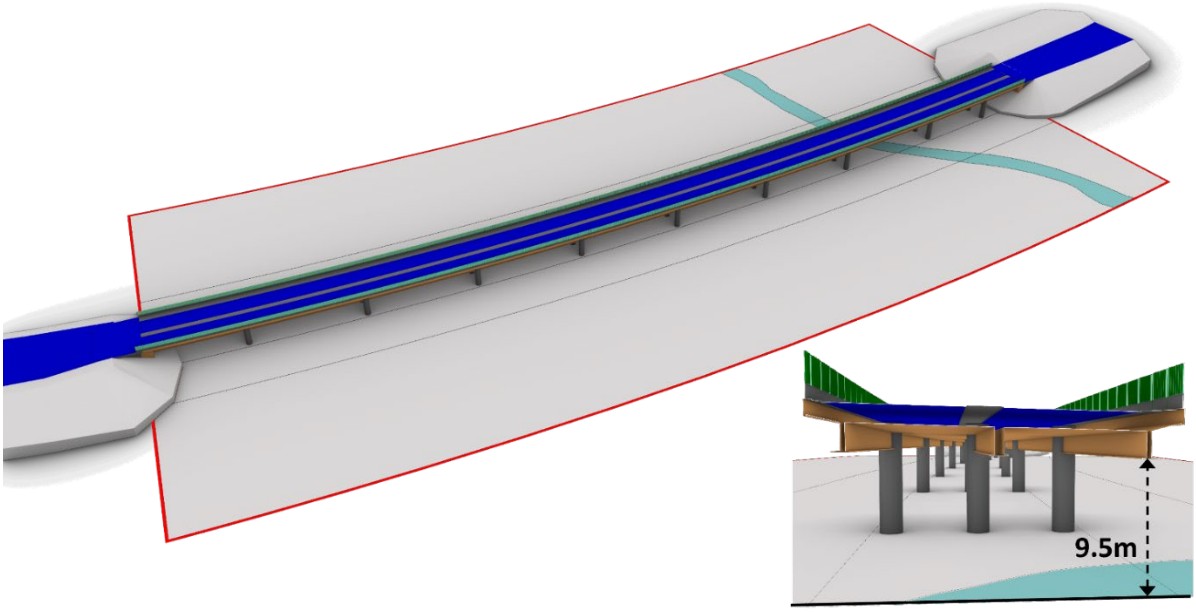


5.4 Permanent Structure

5.4.1 The full extent of the viaduct structure has been used as the basis for the assessment of the effects of sunlight hours, solar radiation, and daylight in this assessment. **Figure 5.9** shows in perspective and section views the model of the 'Permanent Structure' scenario.

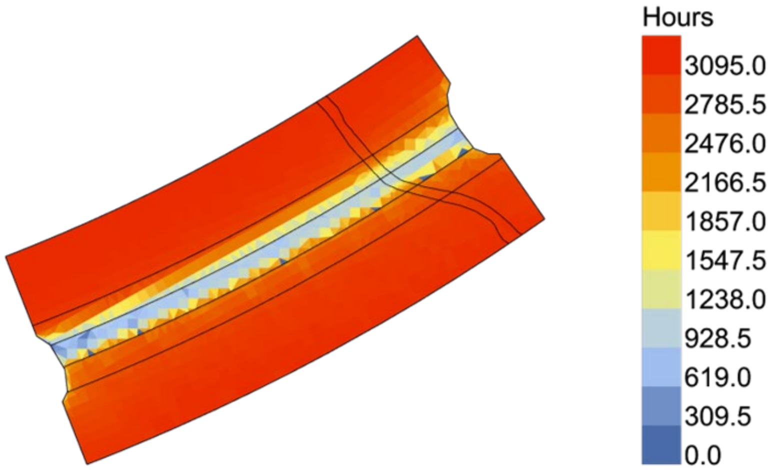
5.4.2 This configuration only accounts for the impact of the proposed viaduct and environmental barrier.

Figure 5-9 3D model of the Permanent structure – southwest perspective



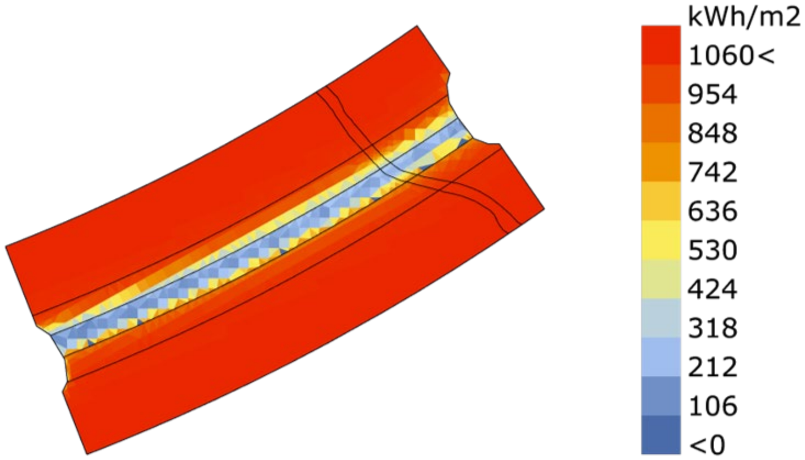
5.4.3 The results of the sunlight hours assessment (**Figure 5.10**) indicated that for the analysis period of 1st March to 30th September, the areas under the viaduct (receptors 3 and C) receive the least amount of sunlight, with an average of around 1,295 hours for receptor 3 and of 1,645 hours for receptor C, which means 58% and 47% less than the average hours in the baseline scenario, respectively. In addition, it is noticed that the northern intermediate zones are the second most affected areas with a reduction of approximately 38% compared to the existing conditions and receive between 20% to 23% fewer hours than the southern intermediate zones.

Figure 5-10 Sunlight hours – permanent structure



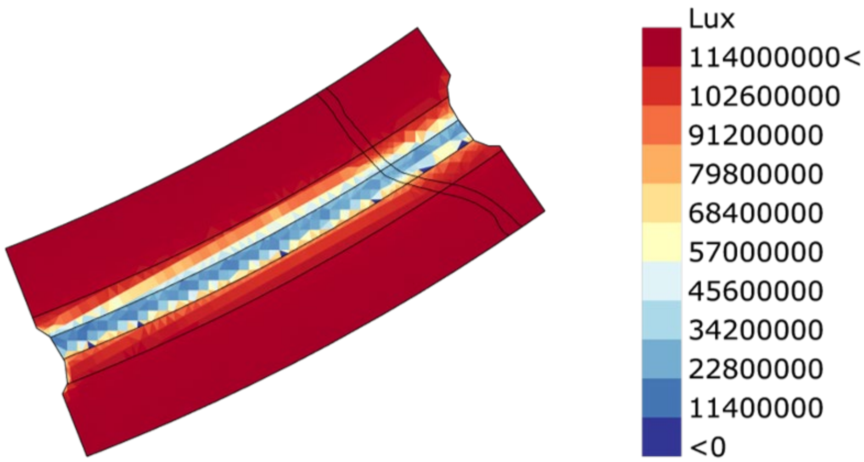
5.4.4 Regarding the assessment of solar radiation, it is also noticed that the longer the distance of the receptors from the viaduct, the lower the impact is observed, and the more solar radiation values remain similar to the baseline. The most affected areas are located below the viaduct, both for the floodplain, receptor 3, and the river, receptor C. Receptor C receives on average 349 kwh/m^2 or around 67% less solar radiation than in the baseline scenario, and receptor C receives on average 442 kwh/m^2 or around 58% less solar radiation compared to the existing conditions. **Figure 5.11** shows the maximum and minimum incident solar radiation during the growing season. In this case, the northern intermediate zones indicated a reduction of up to 32% compared to the existing conditions and receive around 20% fewer hours than the southern intermediate zones.

Figure 5-11 Solar radiation – permanent structure



5.4.5 The illuminance results followed the pattern of the previous assessments (**Figure 5.12**). Receptors 3 and C maintain around 33% and 41% of the daylight received in the baseline scenario, respectively. Furthermore, the same receptors receive between 35% and 39% less daylight compared to the adjacent zones in the north (Intermediate Zone North and River Intermediate Zone North) and between 55% and 48% less daylight compared to the south (Intermediate Zone South and River Intermediate Zone South). Receptors 2 and B (Intermediate Zone North and River Intermediate Zone North) showed a reduction of around 31% in comparison to the baseline and of around 20% compared to the intermediate southern zones (receptors 4 and D).

Figure 5-12 Illuminance – permanent structure



5.5 Annual and seasonal attenuation factors for all configurations

5.5.1 The seasonal and annual results for each assessment are presented in Appendices A-C, while the graphs and tables of Sunlight Hours Attenuation Factor, Area-based Solar Radiation Attenuation Factor and Daylight Attenuation Factor are shown in Appendix D.

5.5.2 Overall, results of the seasonal sunlight hours assessment showed that the current viaduct design indicated an improvement of 5% in relation to sunlight access to the area of the River Wensum below the viaduct compared to the previous 2020 design (from an attenuation factor of 0.48 to 0.53, reaching the 0.5 threshold). The results of the seasonal radiation assessment showed the River Bridge Zone with an improvement of 3% (from an attenuation factor of 0.39 in 2020 to 0.42 in 2022). The seasonal daylight attenuation factor reported no change for this zone.

Sunlight Hours Attenuation Factor

5.5.3 The sunlight hours attenuation factor has been calculated for each of the ten receptors, for both growing season and entire year, as seen in **Figure 5.13**.

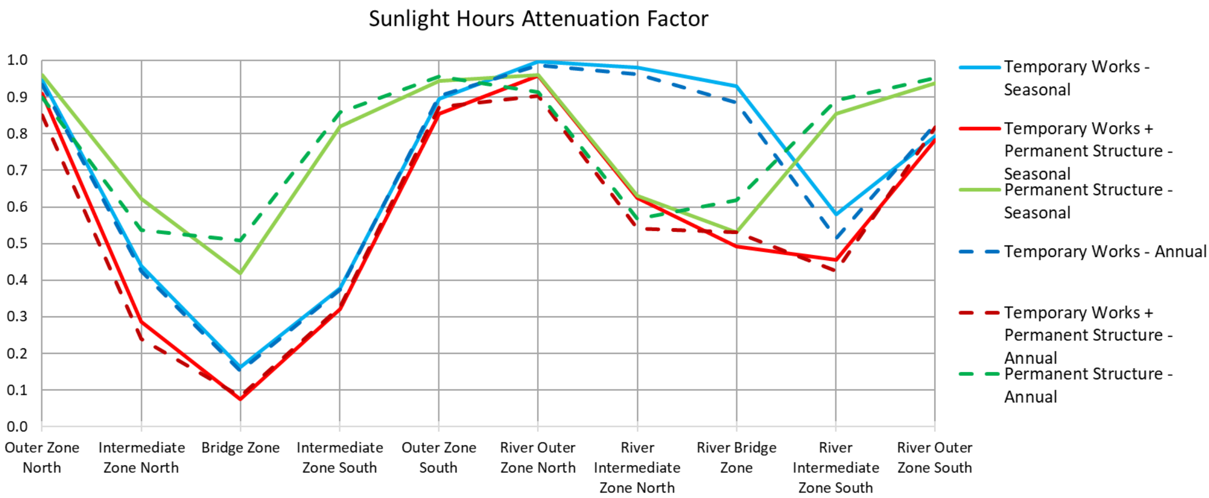
5.5.4 The outcome demonstrates that for the ‘Permanent Structure’ configuration in green in **Figure 5.13**, only the Bridge Zone ratio is lower than 0.50 in the seasonal assessment, which means there is a sunlight loss of at least 50% compared to the baseline scenario. The attenuation factor of the river area under the bridge (River Bridge Zone) in this scenario is in both seasonal and annual assessments above the 0.50 threshold.

5.5.5 In the ‘Temporary Works’ and ‘Temporary Works and Permanent Structure’ scenarios, given the location of the temporary works platform which blocks solar access to the area directly underneath it, a greater impact is observed in the intermediate zones and in the Bridge Zone of the flood plain. In the ‘Temporary and Permanent Structure’ scenario, the River Bridge Zone indicated an attenuation factor below 0.50 in the seasonal assessment and the River Intermediate Zone South showed more than a 50% impact in both annual and seasonal assessments.

5.5.6 Overall, the attenuation factors in all configurations rise gradually towards the outer zones, maintaining more hours of sunlight compared to the baseline conditions, where the proposed structure showed less impact.

5.5.7 The annual results of most zones are higher than the seasonal results, except from the northern zones which are always lower. This is because during the colder seasons, the sun altitude is lower and therefore, less available sunlight to the north of the proposed viaduct. **Figure 5.13** displays in dashed lines the annual results.

Figure 5-13 Sunlight hours attenuation factor



Area-based Solar Radiation Attenuation Factor

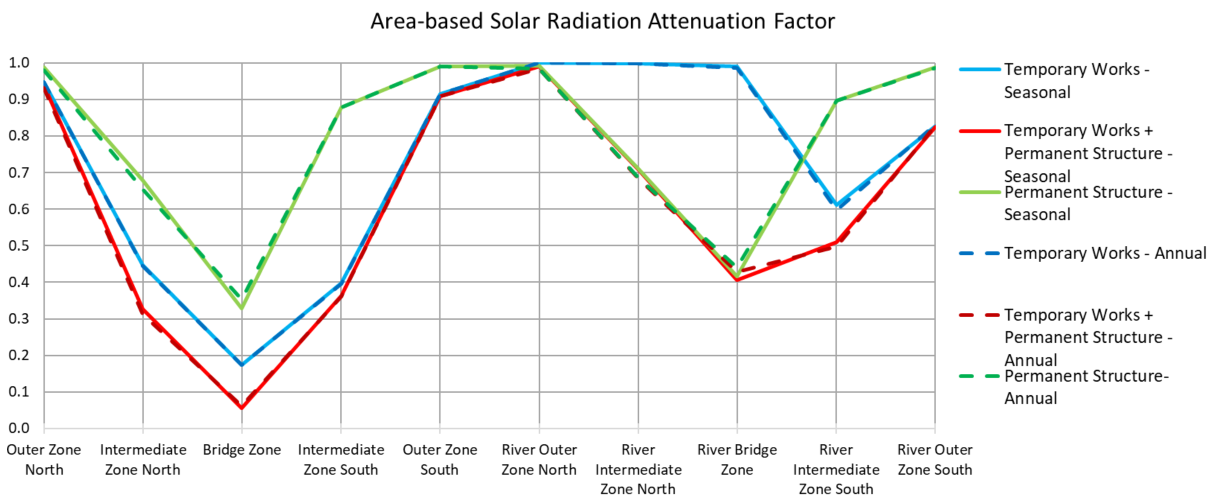
5.5.8 **Figure 5.14** illustrates a continuity between the results of the area-based solar radiation attenuation factors in all scenarios during the year and 6-month season.

5.5.9 As observed in the sunlight hours case, in the 'Temporary Works' and 'Temporary Works and Permanent Structure' scenarios in both annual and seasonal assessments, the intermediate zones (north and south) and the area below the viaduct of the flood plain reported a ratio below 0.50 due to the temporary works platform blocking solar radiation to most of their area. In the 'Permanent Structure' scenario, only the Bridge Zone among the flood plain zones indicated an attenuation factor below 0.50 in the annual and seasonal assessments.

5.5.10 The results showed that the annual and seasonal assessments of all scenarios except from the 'Temporary Works' configuration indicated a reduction of more than 50% in global horizontal radiation in the River Bridge Zone.

5.5.11 In the case of area-based solar radiation, there is a negligible difference between annual and seasonal results in all configurations.

Figure 5-14 Area-based solar radiation attenuation factor

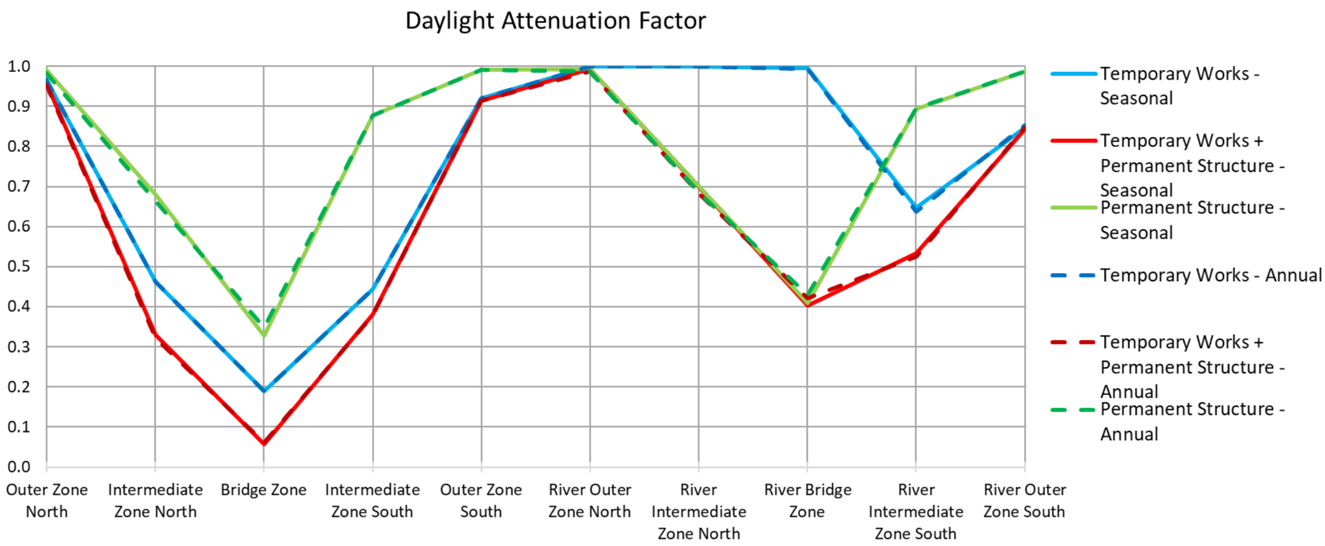


Daylight Attenuation Factor

5.5.12 The daylight attenuation factors (**Figure 5.15**) indicated very similar patterns to the area-based solar radiation ones, with the lower ratios occurring for the flood plain areas in the Bridge Zone and among the river areas, in the River Bridge Zone.

5.5.13 In the 'Temporary Works' and the 'Temporary Works and Permanent Structure' scenarios, the Intermediate Zone North, the Bridge Zone, the Intermediate Zone South, and River Bridge Zone reported an attenuation factor below 0.50 (for the latter, except from the 'Temporary Works' scenario) for both annual and seasonal assessments. In the case of the 'Permanent Structure' scenario, only the Bridge Zone and the River Bridge Zone showed a reduction of more than 50% in relation to daylight compared to the baseline conditions.

Figure 5-15 Daylight attenuation factor



6 Ecological response

6.1 Effects of viaduct shading on aquatic flora

6.1.1 A total of 24 macrophyte taxa were recorded in the macrophyte survey conducted on 16 August 2022, 12 of which are LEAFPACS2 scoring taxa. The majority of the Survey Area was dominated by macrophytes with an Ellenberg light indicator value of 7 (plants that grow generally in well-lit places but also occur in partial shade) (Ellenberg *et al*., 1991).

6.1.2 Clasping-leaved pondweed *Potamogeton perfoliatus* was the most dominant species, accounting for an estimated 60% of the Survey Area's total macrophyte cover. Stream water-crowfoot *Ranunculus penicillatus* subsp.

pseudofluitans, a species characteristic of the River Wensum SAC, was the only species of water-crowfoot observed, accounting for an estimated 15% of the Survey Area's total macrophyte cover.

6.1.3 In addition to stream water-crowfoot and clasping-leaved pondweed, a further four macrophyte species listed as characterising habitat type 3260 vegetation 'watercourses of plain to montane levels with *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation' were recorded in the survey.

6.1.4 The macrophyte community within the Survey Area was found to be diverse and indicative of 'High' ecological status as defined by the WFD.

6.1.5 For detailed survey methodology and survey results (including the Survey Area definition) see Norwich Western Link - Aquatic Ecology Report (WSP, 2022).

6.1.6 It is noted that the river within the Survey Area is uncharacteristic of a typical chalk river as described by Natural England (then English Nature, 1999), who state that chalk rivers are typified by the following features:

- Low longitudinal frequency of riffles and pools;
- Infrequent gravel shoals and exposed riverine substrates;
- Shallow cross section (average width to depth ratios of 33); and
- Sinuous channel form.

6.1.7 The River Wensum within the Survey Area has been artificially widened and deepened, as evidenced by a mean width of approximately 8m and a mean depth of greater than 1m throughout the Survey Area. This has resulted in a relatively low flow velocity compared to shallower/narrower sections of the River Wensum.

6.1.8 Garbey *et al*. (2006) demonstrated that a 50% reduction in light intensity leads to a reduction in biomass of pond water-crowfoot *Ranunculus peltatus*. Therefore, it is considered that the viaduct will result in levels of shading that could reduce water-crowfoot abundance directly underneath the structure, albeit at present their density is low. However, it should be noted that *Ranunculus* spp. are still able to regenerate under such conditions and other species, also characteristic of HT 3260, are able to grow under such levels of shading.

6.1.9 Stream water-crowfoot and clasping-leaved pondweed, like pond water-crowfoot, have Ellenberg light indicator values of 7. As such, it is likely that these species will respond similarly to pond water-crowfoot and will still be able to regenerate and adapt to a reduction in light intensity. Clasping-leaved pondweed, and other submerged macrophyte species, are known to alter their physiology and morphology as an adaptation in response to low light conditions (Twilley and Barko, 1990; Asaeda *et al*., 2004; Sultana *et al*., 2009).

6.1.10 For the above reasons, there will be a potential change in the composition of the plant community in areas affected by shading, but it is unlikely to significantly impact the HT 3260 vegetation community within the River Wensum SAC as a whole.

6.1.11 There is unlikely to be a significant impact as some of the plants within the designated community which are more shade tolerant could still grow, while others which are less tolerant of shade may be eventually replaced. Additionally, the plasticity observed in the morphology of many macrophyte species in response to lower light conditions will enable plants to adapt.

6.1.12 Therefore, it is unlikely that the proposed viaduct will result in an overall loss of macrophytes.

6.2 Effects of Viaduct shading on Aquatic Fauna

6.2.1 The direct effects of shading on aquatic fauna will be negligible due to their tolerance of shade and the ability of fish and invertebrates to change their individual spatial distribution (i.e. move in and out of shade freely).

6.2.2 Indirect effects from shading on aquatic fauna are possible through the loss of shelter, food items and breeding habitat. However, as it is unlikely that there will be an overall loss of macrophytes, the indirect effects on aquatic fauna are also unlikely.

6.3 Effects of Temporary Crossing Shading on Aquatic Flora

6.3.1 As detailed above in **section 5.2**, the installation of the Bailey Bridge will result in a reduction in sunlight hours, solar radiation, and illuminance. This will likely result in localised shading and temporary loss of the macrophyte community within the immediate vicinity of the Bailey Bridge. The Bailey bridge will be in place temporarily for approximately four years.

6.3.2 As the temporary crossing is transient in nature, no long-term vegetation loss or reduction to roughness is foreseen.

6.3.3 Following removal of the Bailey Bridge it is expected that the macrophyte community will recolonise areas that had been affected by shading, and therefore no long-term impacts on the macrophyte community are anticipated.

6.4 Effects of Temporary Crossing Shading on Aquatic Fauna

6.4.1 The temporary loss of macrophytes will result in a temporary loss of shelter, food items, and breeding habitat for aquatic fauna within the immediate vicinity of the Bailey Bridge. However, the bridge itself will provide some shelter.

6.4.2 The direct effects of this temporary structure on aquatic fauna will be negligible due to their tolerance of shade and their ability to change their individual spatial distribution (i.e. move in and out of shade freely).

6.4.3 Following removal of the Bailey Bridge it is expected that the macrophyte community will recolonise areas that had been affected by shading, and therefore no long-term indirect effects are anticipated for aquatic fauna.

7 Geomorphic response

7.1 Assumptions

7.1.1 The ecological response to the solar exposure reduction caused by the Proposed Scheme is expected to neutralise roughness changes because of vegetation replacement in the long term when a new ecological equilibrium is achieved (Section 6). Similarly, the reduction of solar exposure during the construction phase is not expected to have sufficient time to change in-channel vegetation significantly. Hence, impacts upon fluid dynamics and river morphology are expected to be negligible in the long term (during the operational phase) and the construction phase.

7.1.2 However, although the construction phase is not expected to impact hydraulics (therefore, it is not simulated in the hydraulic model), short-term variations may still occur due to different vegetation growth paces during the operational phase. To simulate possible short-term effects of vegetation loss due to shading, a 2D hydraulic modelling analysis was conducted for the operation phase of the Proposed Scheme.

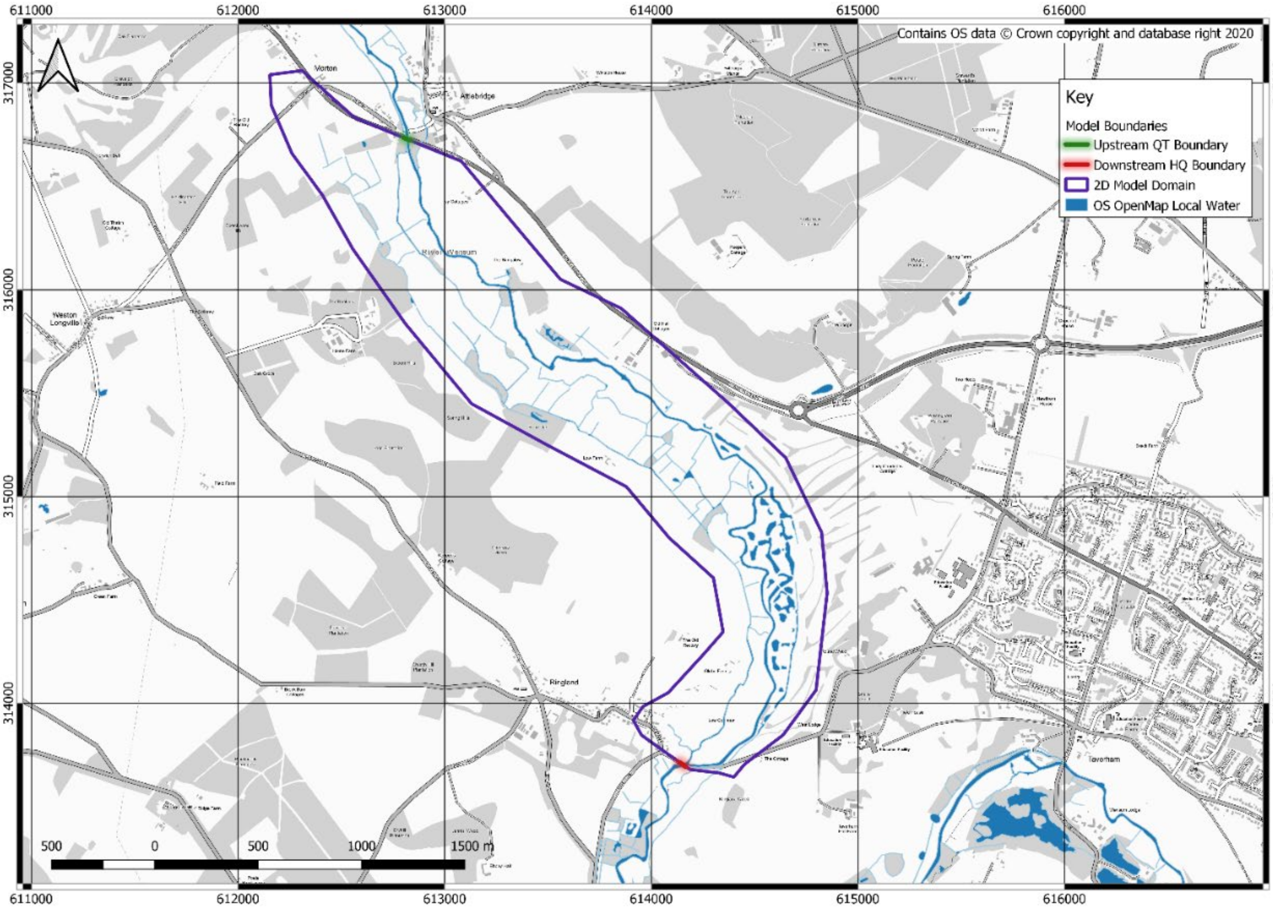
7.1.3 In the simulations, rather than using average roughness for each land use type, as is usually implemented for baseline conditions, a minimum value approach is adopted for simulating vegetation loss. In the modelled scenarios, the landscape area affected by the viaduct shading is represented in the model domain with the lowest roughness coefficient of the landcover type defined by an OS MasterMap data in the vegetation loss scenarios. These simulations are assumed to accurately represent a reduction in roughness triggered by solar exposure.

7.1.4 The hydraulic modelling of the Proposed Scheme is available as part of the planning application. It simulates maximum velocity, maximum depth, bed shear stress, Froude number, and stream power for five peak flows (2-years, 5-years, 20-years, 100-years, 100-years +20% climate change). The sections below show only water depth and velocity for a 2-year flood event as a summary of the key findings. The complete hydraulic modelling results are available in the ES **Appendix 12.4: River Wensum Geomorphology Assessment** (Document Reference 3.12.04).

7.2 Hydraulic modelling set-up

7.2.1 A fully two-dimensional (2D) hydraulic model was developed in TUFLOW using a combination of Environment Agency aerial LiDAR (2m resolution) and topographic survey data. The hydraulic model has been produced to assess the impacts of the Proposed Scheme on maximum velocity (m/s), maximum depth (m), bed shear stress (N/m^2) Froude number (dimensionless), and stream power (W/m) for a range of return period peak flows (2-years, 5-years, 20-years, 100-years, 100-years +20% climate change). The hydraulic model is of a relatively simple set-up and is shown in **Figure 7.1**.

Figure 7-1 2D hydraulic model set up



7.3 Hydraulic modelling results

7.3.1 The simulations of vegetation loss due to shading demonstrate that the impact upon fluid, sediment dynamics and river morphology is negligible. Simulations with minimum roughness coefficient (i.e., simulating vegetation loss) remain spatially similar to those with average roughness (i.e., simulating baseline vegetation). The similarity remains for all investigated parameters (maximum velocity, maximum depth, bed shear stress, Froude number, and stream power), and for all return period peak flows (2-years, 5-years, 20-years, 100-years, 100-years +20% climate change). In summary, the hydraulic modelling results show that a potential reduction of roughness along the Proposed Scheme would not cause a noticeable change in hydraulics and river morphology during the operational phase compared to the current situation.

7.3.2 The figures below provide an overview of predicted water depth and velocity in a 2-year flood event for the operation phase. A comprehensive set of maps portraying all parameters and return period peak flows is given in ES **Appendix 12.4: River Wensum Geomorphology Assessment** (Document Reference 3.12.04).

Figure 7-2 Hydraulic modelling results showing water depth in a 2 year flood event being simulated using average roughness

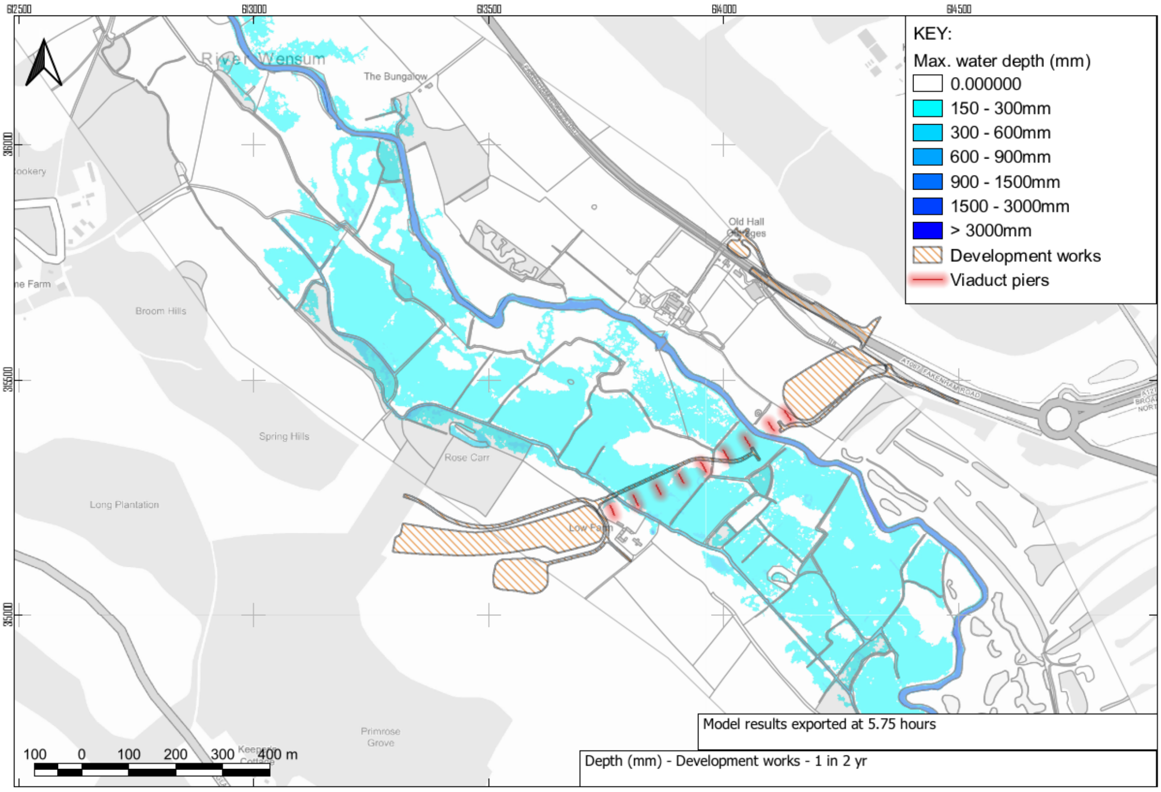


Figure 7-3 Hydraulic modelling results showing water depth in a 2 year flood event being simulated using minimum roughness

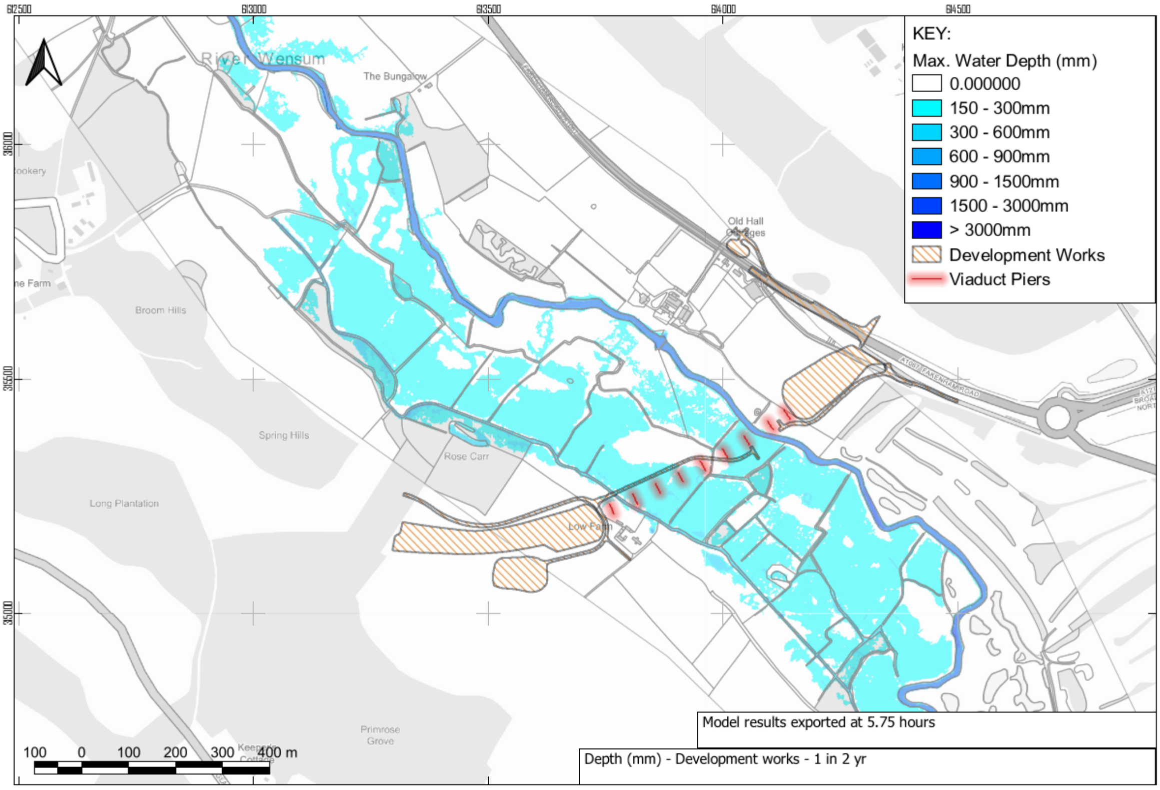


Figure 7-4 Hydraulic modelling results showing maximum velocity in a 2 year flood event being simulated using average roughness

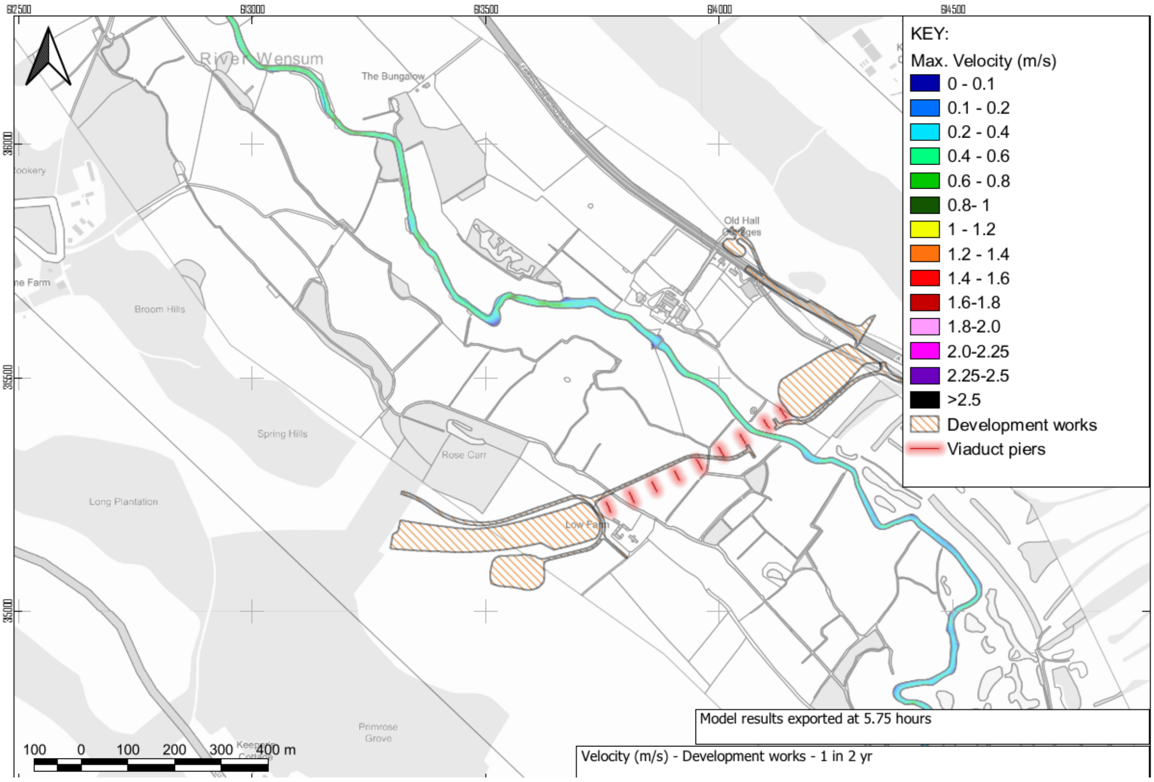
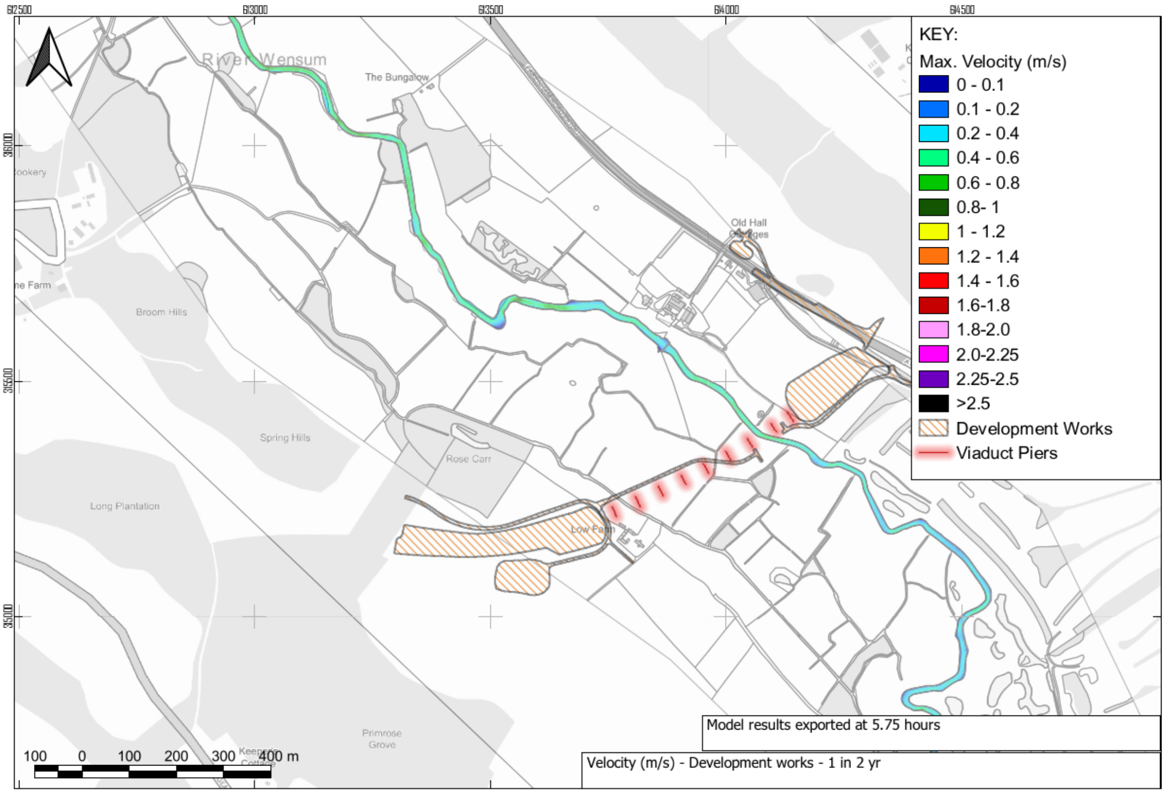


Figure 7-5 Hydraulic modelling results showing maximum velocity in a 2 year flood event being simulated using minimum roughness



8 Conclusions

8.1.1 A solar exposure analysis has been undertaken in relation to the proposed viaduct structure of the Proposed Scheme. The aim of the assessment was to investigate the potential levels of solar exposure on the area of the site and identify any likely effects of shading due to the proposed viaduct structure on the vegetation and species for which the River Wensum is designated.

8.1.2 The sunlight hours, area-based solar radiation and daylight attenuation factors calculations have been conducted for the growing season, assumed to be from March to September, and also for the entire year, as an extension of the assessment for completion and comparison purposes.

8.1.3 Overall, the results of the assessment indicated that the zones with the lowest attenuation factors are the ones which are partially covered by the temporary works platform. This is because the platform sits directly on top of the terrain of the flood plain, blocking the solar and daylight access to the areas directly underneath it which leads to a significant reduction of the total levels of sunlight, solar radiation, and illuminance of these entire assessment zones. However, this impact is temporary and, given the relatively low height of the platform, it is only observed in the area directly covered by the platform with no significant change in the remaining area of these zones.

8.1.4 The results showed that when only the proposed viaduct is considered, the areas that receive the least amount of sunlight, daylight and solar radiation are located under the bridge, identified as Bridge Zone and River Bridge Zone. The second lowest amount of solar, radiation and daylight exposure in this scenario was observed in the northern intermediate zones followed by the southern intermediate zones which are the least impacted areas.

8.1.5 For the River Wensum zones in particular, the results of the showed that the seasonal sunlight hours attenuation factor is only lower than 0.50 in the ‘Temporary Works and Permanent Structure’ scenario, in the River Bridge Zone and River Intermediate Zone South.

8.1.6 In the case of the seasonal area-based radiation and daylight attenuation factors of the river zones, the River Bridge Zone reported a ratio lower than 0.50 in the ‘Temporary Works and Permanent Structure’ and ‘Permanent Structure’ scenarios.

8.1.7 In relation to the aquatic environment of the River Wensum, the solar exposure changes as a result of the viaduct and temporary crossing are unlikely to affect the macrophyte community as a whole. It is unlikely that the proposed viaduct will result in an overall loss of macrophytes as shade tolerant species are likely to still grow, with species less tolerant to shade eventually replaced. The installation of the temporary crossing is likely to result in a localised, temporary loss of the macrophyte community within the immediate vicinity of the Bailey Bridge. However, as the temporary crossing is transient in nature, no long-term vegetation loss is anticipated, and it is expected that the macrophyte community will recolonise areas affected by shading, following the removal of the Bailey Bridge.

8.1.8 In terms of geomorphic responses to the solar exposure changes, they are expected to be negligible for both the construction and operational phases. Therefore, as bed roughness remains constant in the long-term, no adverse impacts on geomorphic processes are foreseen because of the proposed viaduct structure.

9 References

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10 Limitations and assumptions

10.1.1 All calculations have been based on best practice guidance and on drawings and models of the temporary works and permanent structure.. Where required, estimations have been made with regards to the height and massing of the terrain, based on available satellite photographs and mapping and with regards to the environmental barrier, based on available information online.