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6.4 Environmental Statement
Appendix 14.1 Greenhouse Gas Assessment Assumptions, Methodology and Emissions Factors

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1 Greenhouse gas assessment assumptions, methodology and emissions factors

1.1 Carbon assessment supporting information

1.1.1 This appendix presents all assumptions made in the quantification of the capital carbon assessment, presented in ES Chapter 14 Climate of the Environmental Statement (ES) (Document Reference 6.2).

Table 1-1 Greenhouse gas assessment assumptions

Item Category	Location	Description	Units	Quantity	Assumptions
Pavements	Mainline	Pavements - Sub-base type 1 unbound mixture: in carriageway, hardshoulder and hardstrip	m^2	134,025	1. Assume the subbase type 1 is equivalent to natural aggregate, 2. Assume the density of subbase type 1 is 2000 Kg/m^3 3. 330mm thickness. = 88,456.50 tonnes
Pavements	Mainline	Pavements - Base - Dense bitumen macadam (DBM50): In carriageway hardshoulder and hardstrip	m^2	134,025	1. Assume the density of dense bitumen macadam is 2300 Kg/m^3 2. Assume the dense bitumen macadam has the same carbon factor as Asphalt, 6% binder content 3. 220mm thickness. = 67,816.65 tonnes
Pavements	Mainline	Pavements - Binder course - Dense bitumen macadam (DBM50) in carriageway hardshoulder and hardstrip	m^2	134,025	1. Assume the density of dense bitumen macadam is 2300 Kg/m^3 2. Assume the dense bitumen macadam has the same carbon factor as Asphalt, 6% binder content 3. 60mm thickness. = 18,495.45 tonnes
Pavements	Mainline	Pavements - Surface course - Close graded macadam - Thin - in carriageway, hardshoulder and hardstrip 10mm agg. 60PSV	m^2	134,025	1. Assume the density of close bitumen macadam is 2300 Kg/m^3 2. Assume that close graded macadam has the same carbon factor as Asphalt, 7% binder content 3. 40mm thickness. =12,330.30 tonnes
Pavements	Side roads	Pavements - Sub-base type 1 unbound mixture: in carriageway, hardshoulder and hardstrip	m^2	68,272	1. Assume the subbase type 1 is equivalent to natural aggregate, 2. Assume the density of subbase type 1 is 2000 Kg/m^3 3. 420mm thickness. = 57,348.48 tonnes
Pavements	Side roads	Pavements - Base - Dense bitumen macadam (DBM50): In carriageway hardshoulder and hardstrip	m^2	68,272	1. Assume the density of dense bitumen macadam is 2300 Kg/m^3 2. Assume the dense bitumen macadam has the same carbon factor as Asphalt, 6% binder content. 3. 160mm thickness. = 25,124.10 tonnes
Pavements	Side roads	Pavements - Binder course - Dense bitumen macadam (DBM50) in carriageway hardshoulder and hardstrip	m^2	68,272	1. Assume the density of dense bitumen macadam is 2300 Kg/m^3 2. Assume the dense bitumen macadam has the same carbon factor as Asphalt, 6% binder content. 3. 60mm thickness. =9,421.54 tonnes
Pavements	Side roads	Pavements - Surface course - Close graded macadam - Thin - in carriageway, hardshoulder and hardstrip 10mm agg. 60PSV	m^2	68,272	1. Assume the density of close bitumen macadam is 2300 Kg/m^3 2. Assume that close graded macadam has the same carbon factor as Asphalt, 7% binder content. 3. 40mm thickness. = 6,281.02 tonnes

Item Category	Location	Description	Units	Quantity	Assumptions
Pavements	Central reserve	Pavements - Sub-base type 1 unbound mixture: in carriageway, hardshoulder and hardstrip	m^2	30,710	1. Assume the subbase type 1 is equivalent to natural aggregate, 2. Assume the density of subbase type 1 is 2000 Kg/m^3, 3. 400mm thickness. = 24,568 tonnes
Pavements	Central reserve	Pavements - Binder course - Dense bitumen macadam (DBM50) in carriageway hardshoulder and hardstrip	m^2	30,710	1. Assume the density of dense bitumen macadam is 2300 Kg/m^3 2. Assume the dense bitumen macadam has the same carbon factor as Asphalt, 6% binder content, 3. 60mm thickness. = 4,237.98 tonnes
Pavements	Central reserve	Pavements - Surface course - Close graded macadam - Thin - in carriageway, hardshoulder and hardstrip 10mm agg. 60PSV	m^2	30,710	1. Assume the density of close bitumen macadam is 2300 Kg/m^3 2. Assume that close graded macadam has the same carbon factor as Asphalt, 7% binder content, 3. 40mm thickness. =2,852.32 tonnes
Barriers	Central reserve	Pre-cast concrete step barrier	m	6,300	Data provided via email 29/10/2019. Carbon factor taken from the ICE V3: Concrete> Precast concrete beams and columns - steel reinforced with 100kg world average steel per m^3. Volume of concrete step barrier taken to be 0.5m^3 per metre with density of 2.4tonnes per m^3. = 7,560tonnes
Barriers	Non-central reserve	Road restraint system/safety barrier	m	8,700	1. Assume Steel RRS barrier, single sided - data provided via email 29/10/19. Carbon factor taken from Highways England carbon tool. = 193.2 tonnes
Barriers		Fencing - Environmental barriers (absorptive and reflective) - Environmental/ Noise barriers; all types - including foundations 2.0m high	m	17,844.00	Assume fencing is a type of Timber noise barrier Highways England Carbon tool: Fencing> Noise barrier> Timber barrier 2m. Weight taken to be 33kg/m^2 (density 0.09) = 1,177.70tonnes
Fencing			m	20,063.00	Assume a type of steel/wire/chain fence (includes posts) Highways England Carbon tool: Steel/wire/chain fence. Weight of steel per metre estimate from supplier for a 1.8m high chain link fence and steel post to be 3.8kg. = 76.24tonnes
Culvert	Tributary of Norman's Brook	Extension/replacement of existing culvert under widened A417, 600mm diam, 70m long	m	70.00	Assume the carbon factor for precast concrete culvert is equivalent to Precast concrete circular pipework, with 600mm diam. Factor from Highways England Carbon tool: Drainage>Precast concrete circular pipework>600mm diameter. = 34.16tonnes

Item Category	Location	Description	Units	Quantity	Assumptions
Culvert	Tributary of Norman's Brook	Culvert headwall	m^3	11.44	Assume volume of concrete in each headwall is 5.72m^3 (see drawings tab), Assume 1.5% of the concrete volume is steel reinforcement. Assume density of concrete is 2400kg/m^3. Assume the density of reinforcement is 7850kg/m^3. Concrete factor - Concrete>C32/40>0% (Using CEM1) Steel factor - Steel>bar & rod = 1.35t Steel & 27.04t Concrete
Culvert	Tributary of Norman's Brook	Culvert backfill	m^3	6.40	Factor from Highways England Carbon tool: Bulk materials>fil, aggregate and sand>general mixture. Assume density of 2000kg/m^3
Culvert	Dry valley under A417	New culvert 900mm diam, 90 m long	m	90.00	Assume the carbon factor for precast concrete culvert is equivalent to Precast concrete circular pipework, with 900mm diam. Factor from Highways England Carbon tool: Drainage>Precast concrete circular pipework>900mm diameter
Culvert	Dry valley under A417	Culvert Headwall	m^3	11.44	Assume volume of concrete in each headwall is 5.72m^3 (see drawings tab), Assume 1.5% of the concrete volume is steel reinforcement. Assume density of concrete is 2400kg/m^3. Assume the density of reinforcement is 7850kg/m^3. Concrete factor - Concrete>C32/40>0% (Using CEM1) Steel factor - Steel>bar & rod = 1.35t Steel & 27.04t Concrete
Culvert	Dry valley under A417	Culvert backfill	m^3	6.40	Factor from Highways England Carbon tool: Bulk materials>fil, aggregate and sand>general mixture. Assume density of 2000kg/m^3
Culvert	Dry valley under Shab Hill slip road	New culvert 900mm diam, 85 m long	m	85.00	Assume the carbon factor for precast concrete culvert is equivalent to Precast concrete circular pipework, with 900mm diam. Factor from Highways England Carbon tool: Drainage>Precast concrete circular pipework>900mm diameter
Culvert	Dry valley under Shab Hill slip road	Culvert Headwall	m^3	11.44	Assume volume of concrete in each headwall is 5.72m^3 (see drawings tab), Assume 1.5% of the concrete volume is steel reinforcement. Assume density of concrete is 2400kg/m^3. Assume the density of reinforcement is 7850kg/m^3. Concrete factor - Concrete>C32/40>0% (Using

Item Category	Location	Description	Units	Quantity	Assumptions
					CEM1) Steel factor - Steel>bar & rod = 1.35t Steel & 27.04t Concrete
Culvert	Dry valley under Shab Hill slip road	Culvert backfill		6.40	Factor from Highways England Carbon tool: Bulk materials>fil, aggregate and sand>general mixture. Assume density of 2000kg/m^3
Culvert	Dry valley under A417	New culvert 750mm diam, 40m long	m	40.00	Assume the carbon factor for precast concrete culvert is equivalent to Precast concrete circular pipework, with 750mm diam. Factor from HIGHWAYS ENGLAND Carbon tool: Drainage>Precast concrete circular pipework>900mm diameter (rounded up to nearest available factor)
Culvert	Dry valley under A417	Culvert Headwall	m^3	11.44	Assume volume of concrete in each headwall is 5.72m^3 (see drawings tab), Assume 1.5% of the concrete volume is steel reinforcement. Assume density of concrete is 2400kg/m^3. Assume the density of reinforcement is 7850kg/m^3. Concrete factor - Concrete>C32/40>0% (Using CEM1) Steel factor - Steel>bar & rod = 1.35t Steel & 27.04t Concrete
Culvert	Dry valley under A417	Culvert backfill	m^3	6.40	Factor from Highways England Carbon tool: Bulk materials>fil, aggregate and sand>general mixture. Assume density of 2000kg/m^3
Culvert	Chambers	1000mm diameter, 1.2m - 3m depth	No.	8.00	As per call with Water engineer (29/10/19) assume two chambers per culvert (=8) Factor from Highways England Carbon tool: Drainage>Precast concrete inspection chambers>1000mm diameter, 1.2m-3m depth
Attenuation ponds	Culverts	Assume average of 4 culverts above	No.	24.00	As per call with Water engineer (29/10/19) assume culvert design is same as drawing in "drawings" tab. 2 per pond = 24.
Attenuation ponds	Chambers	1000mm diameter, 1.2m - 3m depth	No.	48.00	As per call with Water engineer (29/10/19) assume two chambers per culvert (=48) Factor from Highways England Carbon tool: Drainage>Precast concrete inspection chambers>1000mm diameter, 1.2m-3m depth
Attenuation ponds	Geotextile membrane		m^2	4,469.20	As per call with Water engineer (29/10/19) assume 20% of attenuation ponds (by m^2 area) will require Geotextile membrane - 4,469.2m^2 Factor from Highways England

Item Category	Location	Description	Units	Quantity	Assumptions
					Carbon tool: Earthworks>Geotextiles>Polypropylene geotextile/matting
Attenuation ponds	HDPE impermeable layer		m^2	4,469.20	As above - HDPE density = $0.097t/m^3$ Assume 2mm thickness = $89.38m^3$
Attenuation ponds	Sand		m^3	670.35	As per call with Water engineer (29/10/19) assume 20% of attenuation ponds (by m^2 area) require sand. 150mm depth.
Attenuation ponds	Compacted clay				Assume Site won soil - 0tOo2e
Line painting	Traffic sings and road markings - laying - continuous lines	Thermoplastic road marking	m	28,071	1. Assume road marking paint is thermoplastic 2. Assume the width of continuous road marking is 150mm (as per Traffic signs manual>Chapter 5 road marking> table 4-5 edge of carriageway markings: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/773421/traffic-signs-manual-chapter-05.pdf) 3. Assume the thickness of thermoplastic marking is 2mm (as per http://www.alharamain.com/prod01.htm) 4. Assume the density of thermoplastic road marking is 2150 kg/m^3 (as per Highways England carbon tool: Road pavement>road marking>thermoplastic road marking)
Line painting	Traffic sings and road markings - laying - intermittent lines	Thermoplastic road marking	m	26,056	1. Assume the road marking paint is thermoplastic 2. assume the length of road marking lines excludes blank spaces between lines 3. Assume the width of intermittent marking is 200mm 4. Assume the thickness of thermoplastic marking is 2mm 5. Assume the density of thermoplastic road marking is 2,150kg/m^3
Bridge	Shab Hill Junction underbridge	Steel-concrete composite - Average value for composite viaduct and girder bridges	m^2	2,883	Bridge and underpass factors taken from Collings.D, An environmental comparison of bridge forms. Proceedings of the Institution of Civil Engineers; Bridge engineering 159

Item Category	Location	Description	Units	Quantity	Assumptions
Bridge	Cowley overbridge	Steel-concrete composite - Average value for composite viaduct and girder bridges	m^2	544.5	(2006) Due to lack of design detail, a complexity factor was applied through engagement with bridge engineers.
Bridge	Stockwell overbridge	Steel-concrete composite - Average value for composite viaduct and girder bridges	m^2	544.5	
Underpass	Bridge - Bat underpass east of Flyup	Precast Reinforced Concrete Box (I suggest we use the minimum value for concrete viaduct bridges as this is a relatively simple structure – 1499kg/m^2)	m^2	210	
Underpass	Wingwalls - Bat underpass east of Flyup		m^3	48	Assume 3x8m reinforced concrete and 0.5m thickness per wing - 4 wings in total Assume 1.5% of volume is steel, Assume density of concrete is 2400kg/m^3. Assume the density of reinforcement is 7850kg/m^3. Concrete factor - Concrete>C32/40>0% (Using CEM1) Steel factor - Steel>bar & rod = 5.652t Steel & 113.47t Concrete
Underpass	Bridge - Grove Farm underpass	Precast Prestressed Concrete (I suggest we use the average value for concrete girder bridges – 2457 kg/m^2)	m^2	279	As above
Underpass	Wingwalls - Grove Farm underpass		m^3	960	Assume two lots of 20*30*0.75m and two lots of 10*4*0.75m. Reinforced concrete Assume 1.5% of volume is steel, Assume density of concrete is 2400kg/m^3. Assume the density of reinforcement is 7850kg/m^3. Concrete factor - Concrete>C32/40>0% (Using CEM1) Steel factor - Steel>bar & rod = 113.04t Steel & 2269.44t Concrete
Bridge	Bridge - Cotswold Way crossing	Steel Box Girder (I suggest we use the average value for steel girder bridges – 2810kg/m^2)	m^2	570	As above
Bridge	Bridge - Gloucestershi	Steel-Concrete Composite (I suggest we use the average	m^2	2,520	As above

Item Category	Location	Description	Units	Quantity	Assumptions
	re Way crossing	value for composite girder bridges – 2750kg/m^2)			
Maintenance			m^2	1,398,042.00	Assume surface course is replaced once every 10 years = 233,007*6 = 1,398,042m^2
Bridge	Transport of materials				Bridge-related emissions for A1-A3 equate to 46.35% of A1-A3 emissions. Transport emissions without bridges = 1,823.14 tCO_2e. To estimate transport emissions relating to bridges assume adding 46.35% (845.03 tCO_2e) onto transport total as an estimate of likely transport-related emissions.
A5 Earthworks excavation	scheme-wide		m^3	3,172,164.00	<u>Plant - Excavation Assumptions</u> Excavator Weight: 35 tonnes Excavator Bucket Size: 1.85 m^3 Mins worked/hour: 50 Output based on cycle time loading vehicles: 186m^3/hr Fuel consumption Excavator: 35.6l/hr CO_2 per litre of fuel: 3.782Kg
A5 Earthworks movement /transport on site	scheme-wide		m^3	3,106,219.00	<u>Plant - Dumper/on site movement Assumptions</u> Weight: 22.5 tonnes Dump capacity: 16.6m^3 Mins worked per hour: 50 Output based on cycle time moving earth: 186m^3/hr (assuming 2 dumpers) Fuel consumption: 22.5l/hr CO_2 per litre of fuel :2.97049kg If excavator does 186m^3/hr then it can fill a dumper 11X per hour One dumper filled every 5 mins 10 mins to transport each load, dump and return Can shift 5 loads per hour So assume 2 dumpers working 50 mins per hour each

Item Category	Location	Description	Units	Quantity	Assumptions
A5 Earthworks transport of excess offsite	scheme-wide		m^3	86,099.00	Transport off site Assumptions Wagon size: 17 m^3 Transport distance: 20 Km each way CO_2e per tkm 100% laden: 0.00011kg CO_2e/tkm CO_2e per tkm 0% laden: 0.00012kg CO_2e/tkm Density factor for Earth: 1t/m^3
Land use changes	scheme-wide		Ha	125.65	1. Pre and post construction habitat loss and gain provided by GIS on 05 March 2021 2. UK land cover data from CEH used at 20m resolution to get areas of land use/habitat types for Tewkesbury and Cotswold 3. Emissions data relating to different land uses per local authority was sourced from BEIS - UK local authority and regional carbon dioxide emissions national statistics: 2005-2018 4. land cover and emissions data were combined to give a tCO_2e/ha per year figure for each broad land use type (woodland, grassland, pasture) 5. These figures were applied to the pre and post construction habitat loss and gain data to get total annual changes for loss and gain, which were then multiplied by 60years to cover the design life
Land use changes	scheme-wide		Ha	111.70	
Treatment of waste	scheme-wide		m^3	614.44	Waste quantities taken from ES Chapter 10 Material assets and waste (Table 10-16 Estimated waste arisings)