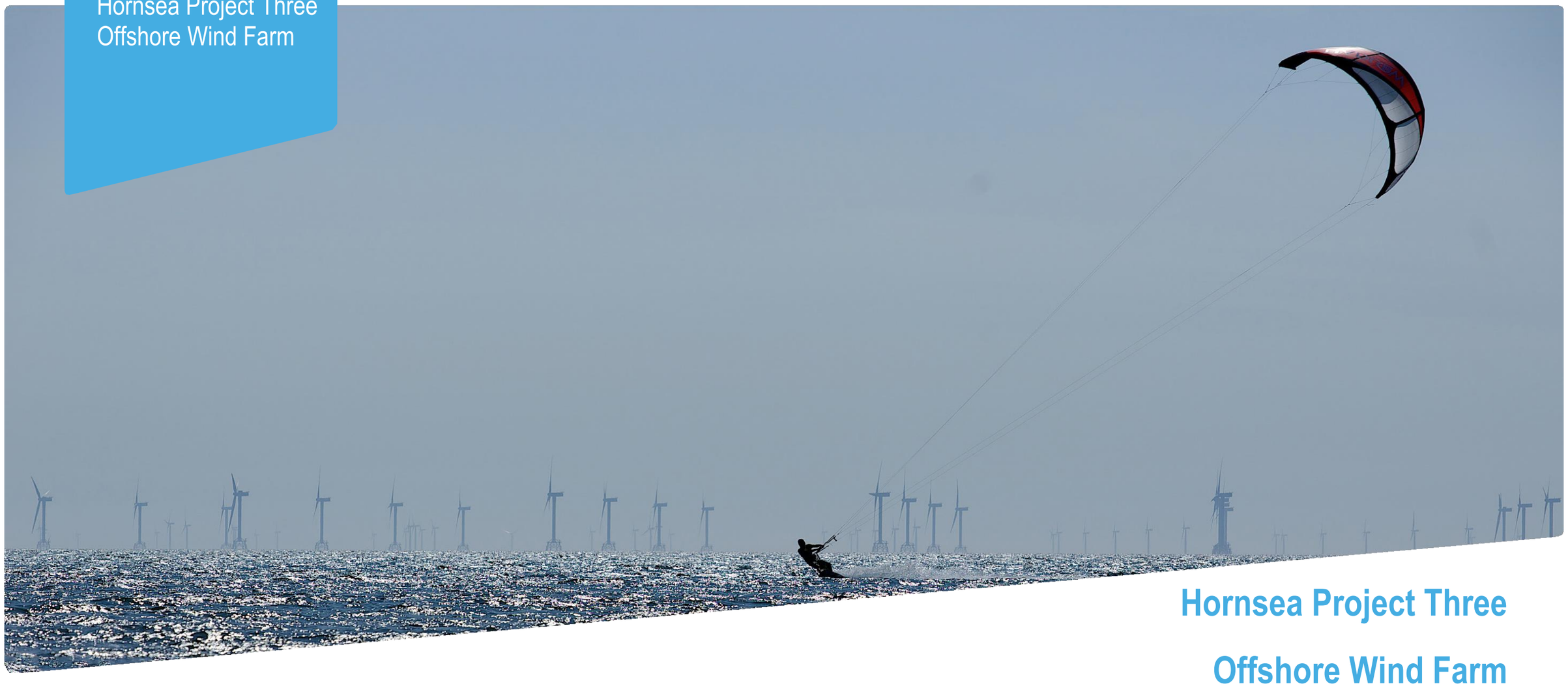
Hornsea Project Three
Offshore Wind Farm



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Offshore Wind Farm

Environmental Statement:
Volume 3, Chapter 1 – Geology and Ground Conditions

PINS Document Reference: A6.3.1
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Date: May 2018

Hornsea 3
Offshore Wind Farm

Ørsted

Environmental Impact Assessment

Environmental Statement

Volume 3

Chapter 1 – Geology and Ground Conditions

Liability

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Glossary

Term	Definition
Aquifer	A subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater.
Artificial ground	Artificial ground is a term used by the British Geological Survey (BGS) for those areas where the ground surface has been significantly modified by human activity. Whilst artificial ground is not part of the 'real geology' of bedrock and superficial deposits, it does affect them and needs recording because the near surface ground conditions are so important to human activities and economic development. Artificial ground includes: Made ground —such as embankments and spoil heaps on the natural ground surface. Worked ground — areas where the ground has been cut away such as quarries and road cuttings. Infilled ground — areas where the ground has been cut away then wholly or partially backfilled. Landscaped ground — areas where the surface has been reshaped. Disturbed ground — areas of ill-defined shallow or near surface mineral workings where it is impracticable to map made and worked ground separately.
Bedrock	Term used for the main mass of rocks forming the Earth and present everywhere, whether exposed at the surface in outcrops or concealed beneath superficial deposits or water. The bedrock has formed over vast lengths of geological time ranging from ancient and highly altered rocks of the Proterozoic, some 2,500 million years ago or older, up to the relatively young Pliocene, 2.6 million years ago.
Chalk	The Chalk Group (often just called 'Chalk') is the lithostratigraphic unit (a certain number of rock strata) which contain the late Cretaceous limestone succession in southern and eastern England. The same or similar rock sequences occur across the wider northwest European chalk province. It is characterised by thick deposits of chalk, a soft porous white limestone, deposited in a marine environment.
Confined aquifer	Permeable rock units containing groundwater that are confined above or beneath lower permeability rock or superficial deposits such as clay, which limit groundwater movement into and out of the confined aquifer.
Compressible ground hazard	Weak ground that compresses under load from overlying structures.
Cycle 1 data	Cycle 1 is the results of the monitoring and assessment carried out under the initial Water Framework Directive and reflects the aims for the improvements to 2015. Following the updates to the Water Framework Directive in 2017 all data and assessment undertaken by the Environment Agency from 2016 is cycle 2.
Designated sites	The UK's approach to conservation employs a range of different types of site and extensive area designations for landscape and nature conservation purposes. Statutory designated sites or areas relevant to geological and geomorphological conservation administered by Natural England (an Executive Non-departmental Public Body responsible to the Secretary of State for Environment, Food and Rural Affairs) are: National Parks; Areas of Outstanding Natural Beauty; and Sites of Special Scientific Interest. Non-statutory designated sites administered by county or unitary local authorities comprise: Local Geological Sites (LWS) formerly known as Regionally Important Geological Sites (RIGS).
Frac-out	During directional drilling operations the drill head is lubricated with either water or bentonite clay and is injected under high pressure. When drilling occurs too close to the surface and the ground is not stable the pressure of the lubricant and the vibration of the drill head cause week point to form resulting in a "frac-out".
Geology	The scientific study of the origin, history and structure of the Earth.
Geomorphology	The scientific study of landforms and their evolution over different timescales.
Glaciagenic	Materials deposited as a result of glaciation or deglaciation.
Glaciofluvial	Glacial river deposits, or glaciofluvial deposits, consist of material that has been transported by rivers originating from glaciers.
Ground conditions	The chemical and physical characteristics of the soil at a particular location and how it has been affected by historical land uses.
Groundwater	All water which is below the surface of the ground in the saturated zone and in direct contact with the ground or subsoil.
Groundwater Directive	Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration.
Hydrogeology	The branch of geology dealing with water below the Earth's surface and the geological aspects of surface waters.
Mineral Safeguarding Area	An area designated by a Mineral Planning Authority which covers known deposits of minerals which are desired to be kept safeguarded from unnecessary sterilisation by non-mineral development.
Mineral Planning Authority	A local authority with responsibility for mineral planning, including deciding planning applications.
Natural ground subsidence	Lowering or collapse of natural landform due to change in drainage patterns, groundwater abstraction largely associated with coal mining areas and karst landscapes. Can also occur in compressible soils such as peats.
Norfolk Geodiversity Partnership	Organisation comprising representatives from local authorities in Norfolk as well as statutory consultees, conservation organisations and Earth science specialists. One of their key roles is to develop the Norfolk Geodiversity Action Plan, which sets out a management framework for conserving Norfolk's Earth heritage.
Onshore elements of Hornsea Three	Hornsea Three landfall area, onshore cable corridor, the onshore HVAC booster station, the onshore HVDC converter/HVAC substation and the interconnection with the Norwich Main National Grid substation,
Permeability	A measure of the ability of a porous material such as a soil or rock to transmit fluids (liquids or gases).
Principal aquifer	Layers of rock or superficial deposits that have high inter-granular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as major aquifers.
Secondary A aquifer	Permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers.
Secondary B aquifer	Predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. These are generally the water-bearing parts of the former non-aquifers.
Secondary undifferentiated aquifer	This term has been assigned in cases where it has not been possible to attribute either category A or B to a rock type. In most cases, this means that the layer in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type.
Shrink-Swell hazard	As a result of changes in moisture content in clay rich ground, shrinkage leading to differential settlement and swelling can lead to ground heave.

Term	Definition
Soil	Soil is a natural body consisting of layers (soil horizons) that are primarily composed of minerals which differ from their parent materials in their texture, structure, consistency, and colour, chemical, biological and other characteristics. Soil is the unconsolidated or loose covering of fine rock particles that covers the surface of the Earth and is the end product of the influence of the climate (temperature, precipitation), relief (slope), organisms (flora and fauna), parent materials (original minerals) and time.
Source Protection Zone	Source Protection Zones are defined by the Environment Agency (for England) for groundwater sources such as wells, boreholes and springs that are used for public drinking water supply. Source Protection Zones show the level of risk of contamination from activities on or in the ground that have the potential to cause groundwater pollution in the area and affect water quality at an abstraction.
Superficial deposits	The youngest geological deposits formed during the most recent period of geological time (the Quaternary) which extends back about 2.6 million years from the present. They rest on older deposits or rocks referred to as bedrock.
Till	A glacial deposit consisting mainly of unstratified clay with embedded boulders.
Unconfined aquifer	Permeable groundwater aquifer rock unit that is in direct contact with the atmosphere through open pore spaces of the overlying soil or rock. The groundwater surface in an unconfined aquifer is called the water table.
Undifferentiated sediments	Rocks or sediments for which it is not possible to specify a finer age division.
Unproductive aquifer	Superficial deposits or bedrock strata which are generally unable to support abstractions greater than 10 $m^3.d^{-1}$ and are unlikely to provide significant base flow. Formerly classified as non- aquifers.
Water Framework Directive	Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy.
Zone of Impact	The Zone of Impact is the area considered to be at risk of impacts from each element of the development. The extent of this zone will depend on the differing impacts, ground conditions etc. and therefore is not a set distance.

Acronyms

Acronym	Description
BGS	British Geological Survey
bgl	Below ground level
CEA	Cumulative Effect Assessment
CFD	Contract for Difference
CoCP	Code of Construction Practice
DCLG	Department for Communities and Local Government
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
EIA	Environment Impact Assessment
HDD	Horizontal Directional Drilling
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IPC	Infrastructure Planning Committee
MHWS	Mean High Water Springs
NGP	Norfolk Geodiversity Partnership
NPPF	National Planning Policy Framework
NPS	National Policy Statement
NSIP	Nationally Significant Infrastructure Project
PEIR	Preliminary Environmental Information Report
PINS	Planning Inspectorate
PPG	Planning Practice Guidance
SPZ	Source Protection Zone
SSSI	Site of Special Scientific Interest
UXO	Unexploded Ordnance
WFD	Water Framework Directive
ZOI	Zone of Impact

Units

Unit	Description
g	Gram (weight)
GW	Gigawatt (power)
km	Kilometre (distance)
kV	Kilovolt (electrical potential)
kg	Kilogram (weight)
kW	Kilowatt (power)
m	Metre (distance)
$m^3.d^{-1}$	Cubic metres per day (volume)

Unit	Description
MW	Megawatt (power)
mg/l	Milligram per litre (concentration)
Ma	Million years (time)
$w.m^{-1}$	Watts per linear metre (power consumed over distance)

1. Geology and Ground Conditions

1.1 Introduction

1.1.1.1 This chapter of the Environmental Statement presents the results of the Environmental Impact Assessment (EIA) for the potential impacts of the Hornsea Project Three offshore wind farm (hereafter referred to as 'Hornsea Three') on geology and ground conditions. Specifically, this chapter considers the potential impact of Hornsea Three landward of Mean High Water Springs (MHWS) during its construction, operation and maintenance, and decommissioning phases.

1.1.1.2 Those impacts of Hornsea Three on hydrology and flood risk (including surface water resources) are assessed in volume 3, chapter 2: Hydrology and Flood Risk; those impacts on soil quality are assessed in volume 3, chapter 6: Land Use and Recreation.

1.1.1.3 This chapter summarises information from technical reports and information, which are included in volume 6, annex 1.1: Borehole Logs, annex 1.2: Abstraction Licences and Source Protection Zones, annex 1.3: Discharge Consents and Permits and annex 1.4: Water Framework Directive Groundwater Assessment.

1.2 Purpose of this chapter

1.2.1.1 The primary purpose of the Environmental Statement is to support the Development Consent Order (DCO) application for Hornsea Three under the Planning Act 2008 (the 2008 Act) and accompanies the application to the Secretary of State for Development Consent.

1.2.1.2 It is intended that the Environmental Statement will provide statutory and non-statutory consultees with sufficient information to complete the examination of Hornsea Three and will form the basis of agreement on the content of the DCO.

1.2.1.3 In particular, this Environmental Statement chapter:

- Presents the existing environmental baseline established from desk studies and consultation;
- Presents the potential environmental effects on geology and ground conditions arising from Hornsea Three, based on the information gathered and the analysis and assessments undertaken;
- Identifies any assumptions and limitations encountered in compiling the environmental information; and
- Highlights any necessary monitoring and/or mitigation measures which could prevent, minimise, reduce or offset the possible environmental effects identified in the EIA process.

1.3 Study area

1.3.1.1 The Hornsea Three geology and ground conditions study area comprises a 1 km buffer around the onshore elements of Hornsea Three (namely the Hornsea Three landfall, the onshore cable corridor, the onshore HVAC booster station, the onshore HVDC converter/HVAC substation and the interconnection with the Norwich Main National Grid substation), and the storage areas and compounds. The 1 km buffer was chosen to identify any existing assets or infrastructure (including landfills) that might not be directly within the footprint of Hornsea Three but have the potential to be affected by it or its activities or which may pose constraints on the development.

1.3.1.2 The accesses fall within the Hornsea Three geology and ground conditions study area and any impacts from the modifications and use of these accesses have been assessed. No modifications or construction works are proposed at the main compound, however its use has been considered within the geology and ground conditions assessment and the mitigation measures in Table 1.15 will be applied (as appropriate).

1.3.1.3 The Hornsea Three geology and ground conditions study area is shown on Figure 1.1 and the following features were identified in this area:

- Principle and secondary aquifers (either secondary A, secondary B or secondary undifferentiated);
- Groundwater abstraction licences (including potable water abstractions);
- Source Protection Zones (SPZ);
- Landfills (historic and active) and other waste management sites; and
- Mineral extraction sites and Mineral Safeguarding Areas.

1.3.1.4 For some geological/ground conditions features a narrower buffer of 500 m was used as impacts are most likely to occur within this distance. These features are identified below:

- Geology (comprising artificial ground, superficial deposits and bedrock geology);
- Environmental permits, incidents and registers;
- Current and historical land use;
- Designated sites of geological conservation importance; and
- Natural hazards (natural ground subsidence, shrink-swell hazard, compressible ground hazard).

1.3.1.5 Due to the variable nature in the shallow geology, borehole log records within a 100 m buffer around the onshore elements of Hornsea Three, storage areas and compounds were considered as these are most likely to reflect the ground conditions within the footprint of Hornsea Three.

1.3.1.6 Mining (and the associated risk of subsidence) and natural hazards (natural ground subsidence, shrink-swell hazard, compressible ground) are potential concerns when designing foundations. The only onshore elements of Hornsea Three where this is likely to be relevant is at the onshore HVAC booster station and the onshore HVDC converter/HVAC substation. Therefore, a buffer of 100 m around these locations has been applied to identify records of mining and natural hazards.

1.4 Planning policy context

1.4.1 National Policy Statements

1.4.1.1 Planning policy on offshore renewable energy Nationally Significant Infrastructure Projects (NSIPs), specifically in relation to geology and ground conditions, is contained in the Overarching National Policy Statement (NPS) for Energy (EN-1) (DECC, 2011a) and the NPS for Electricity Networks Infrastructure (EN-5) (DECC, 2011b).

1.4.1.2 NPS EN- 1 and NPS EN-5 include guidance on what matters are to be considered in the assessment. These are summarised in Table 1.1.

Table 1.1: Summary of NPS EN-1 and EN-5 provisions relevant to geology and ground conditions.

Summary of NPS EN-1 and NPS EN-5 provision	How and where considered in the Environmental Statement
Geology	
Where the development is subject to EIA the applicant should ensure that the Environmental Statement clearly sets out the effects on internationally, nationally and locally designated sites of ecological or geological conservation importance (paragraph 5.3.3 of NPS EN-1).	The Environmental Statement identifies internationally, nationally and locally designated sites of geological conservation importance within the Hornsea Three geology and ground conditions study area. Figure 1.2 shows that no designated geological sites would be directly affected. The distance to the designated sites are given in Table 1.6.
The applicant should show how the project has taken advantage of opportunities to conserve and enhance biodiversity and geological conservation interests (paragraph 5.3.4 of NPS EN-1).	The Hornsea Three onshore cable corridor has been refined in order to conserve geological interests within the geology and ground conditions study area.
Ground Conditions	
For developments on previously developed land, applicants should ensure that they have considered the risk posed by land contamination (Paragraph 5.10.8 of NPS EN-1).	The Environmental Statement considers the risk posed by land contamination in paragraphs 1.11.1.1 to 1.11.3.4.
Infrastructure development can have adverse effects resulting in groundwater or protected areas failing to meet environmental objectives established under the Water Framework Directive (WFD) 146 (Paragraph 5.15.1 of NPS EN-1).	Assessment of ground disturbance is undertaken specifically on secondary A and B aquifers and on the principal aquifer in paragraphs 1.11.1.1 to 1.11.3.4.
Where the project is likely to have effects on the water environment, the applicant should undertake an assessment of the existing status of, and the impacts of the proposed project on water quality, water resources and physical characteristics of the water environment. In particular the Environmental Statement should describe, any impacts of the proposed project on water bodies or protected areas under the WFD and SPZs around potable groundwater abstractions (paragraphs 5.15.2 and 5.15.3 of NPS EN-1).	Impacts on SPZs and water bodies protected under the WFD are assessed in paragraphs 1.11.1.8 to 1.11.1.20. A WFD groundwater assessment is provided as Annex 1.4.
NPS EN-5 Section 2.8: Landscape and Visual identifies the greater environmental consequences of undergrounding of power lines in comparison with overhead cabling where disturbance of ground may have an impact on soils and geology (paragraph 2.8.9 of EN-5).	Assessment of ground disturbance is undertaken specifically on secondary A and B aquifers and on the principal aquifer in paragraphs 1.11.1.8 to 1.11.1.28.
Applicants should safeguard any mineral resources on the proposed site as far as possible, taking into account the long-term potential of the land use after any future decommissioning has taken place (paragraph 5.10.9 of NPS EN-1).	The Hornsea Three onshore cable corridor has been refined to 80 m wide which reduces the area of Hornsea Three that falls within a Mineral Safeguarding Area (see Figure 1.3) An assessment of the potential impacts is undertaken in paragraphs 1.11.1.3 to 1.11.1.7.

1.4.1.3 NPS EN-1 and NPS EN5 also highlight a number of points relating to the determination of an application and in relation to mitigation. These are summarised in Table 1.2.

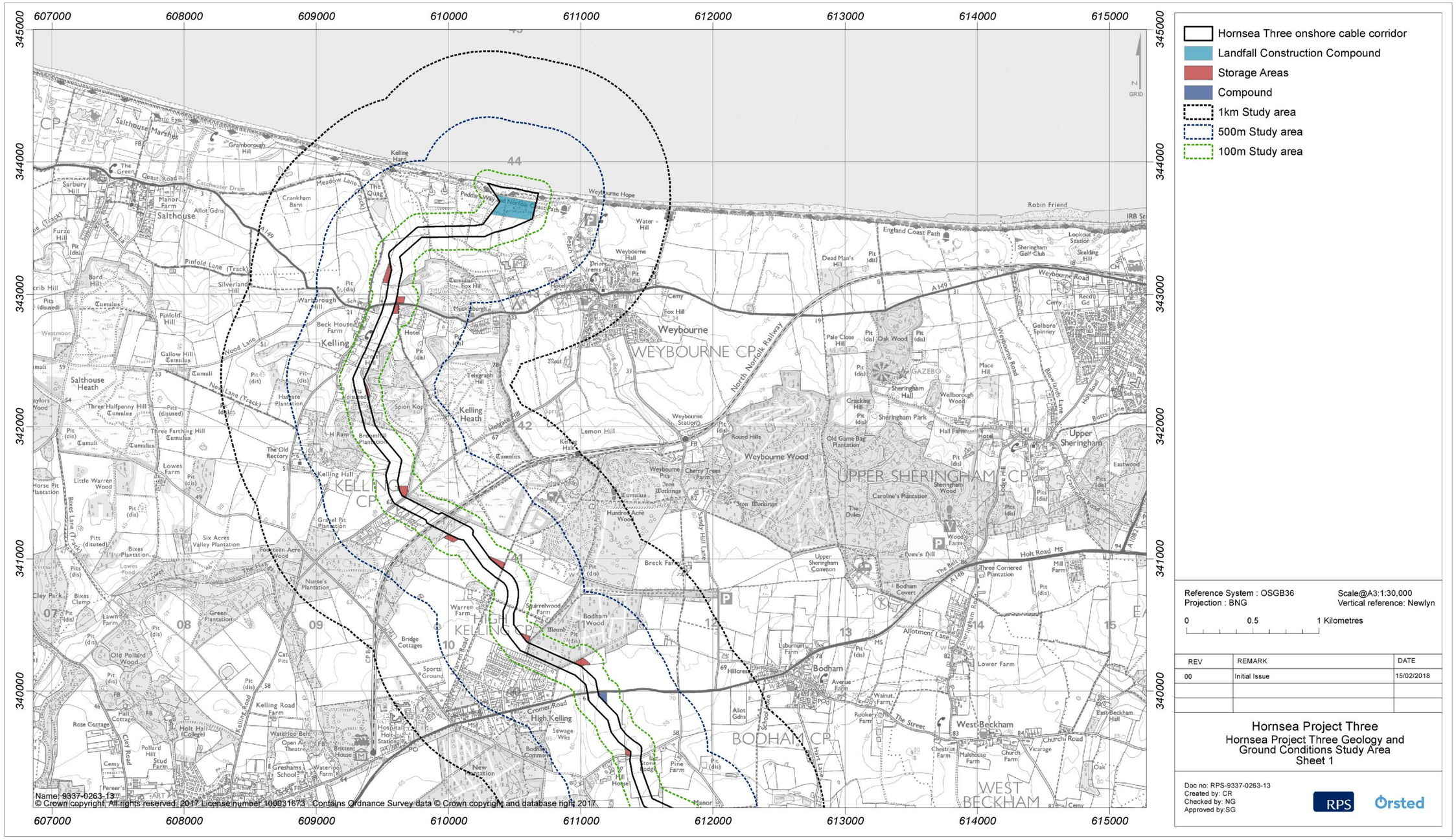
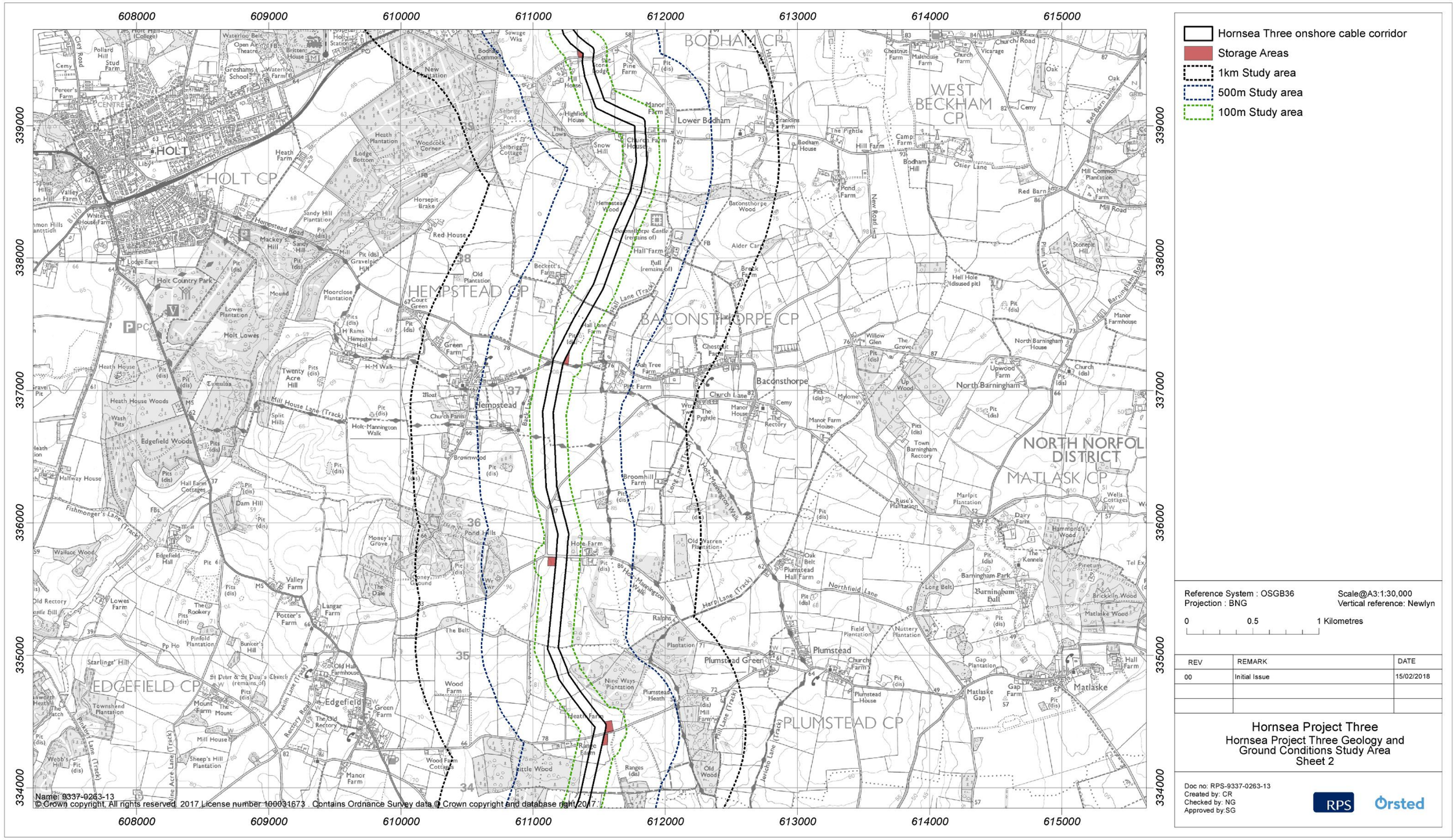


Figure 1.1: Hornsea Project Three geology and ground conditions study area.



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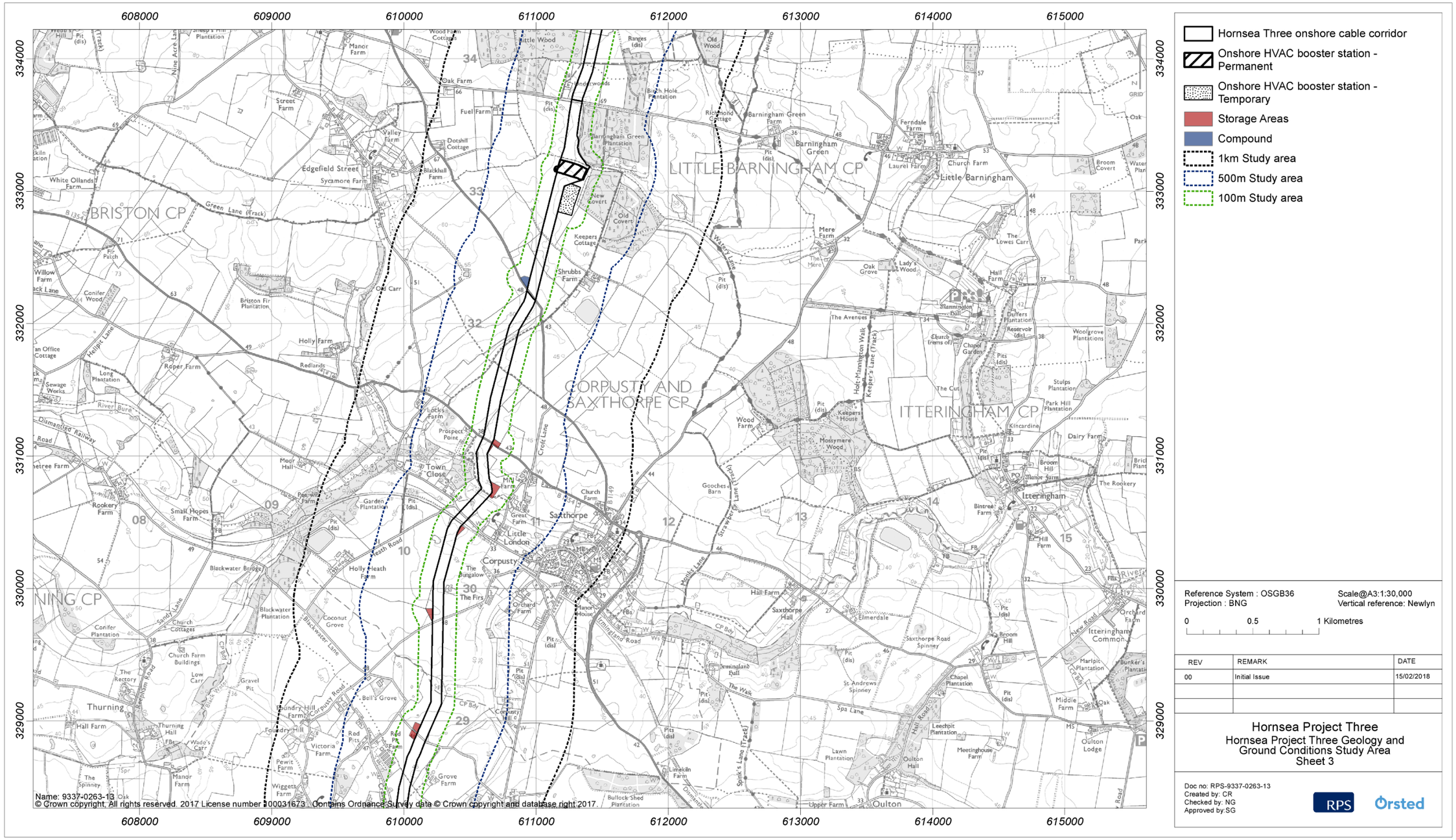

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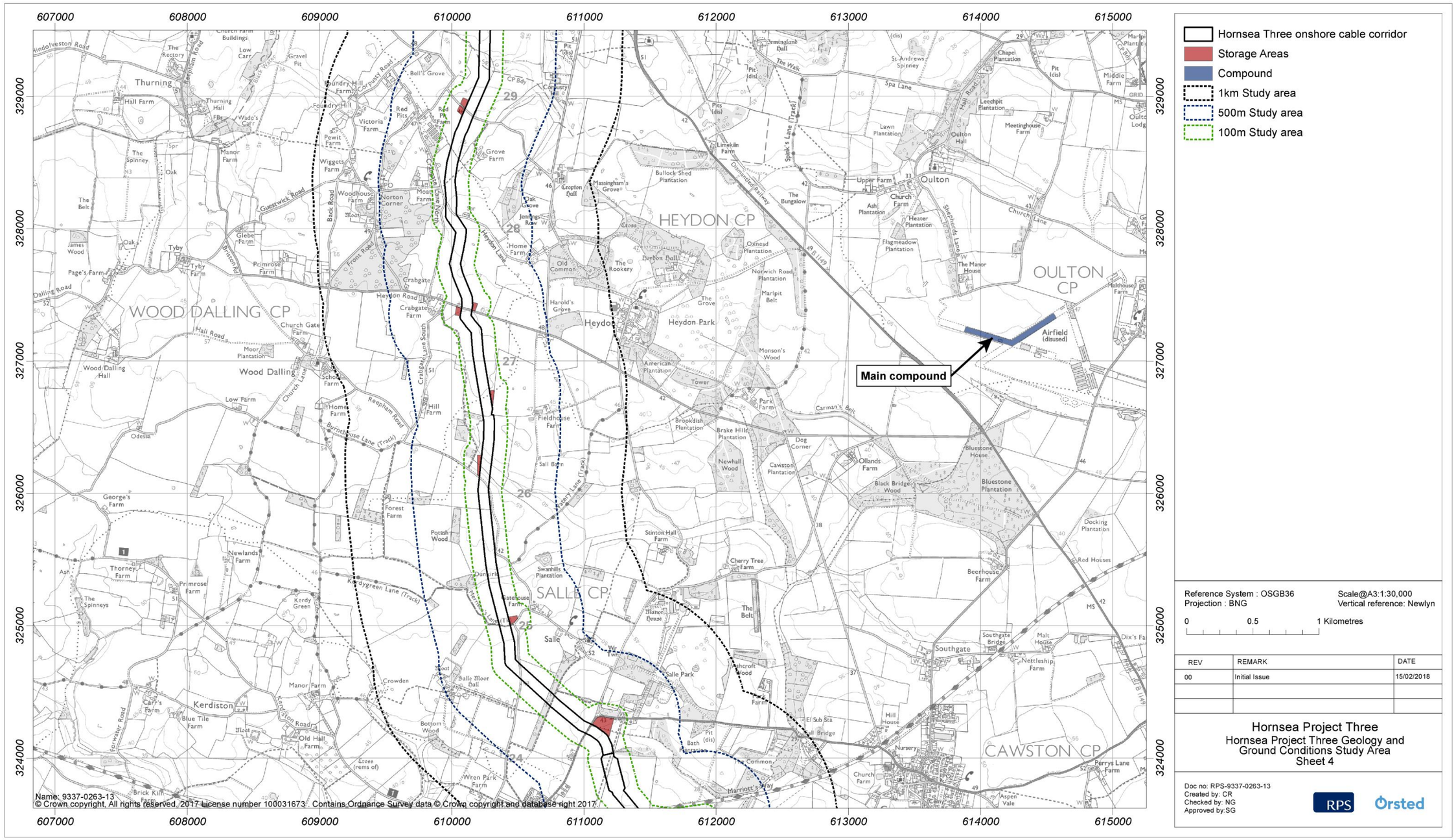

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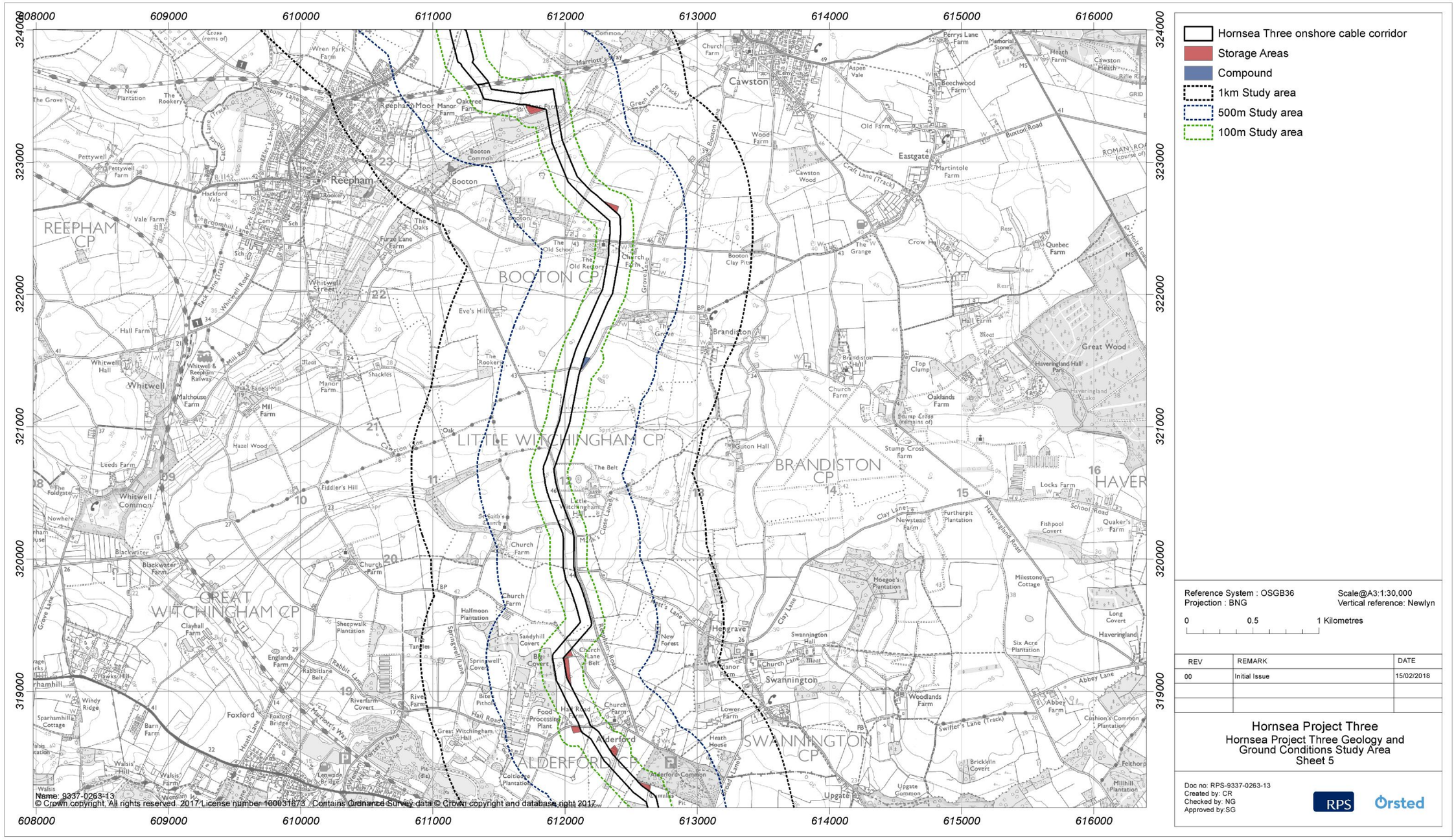

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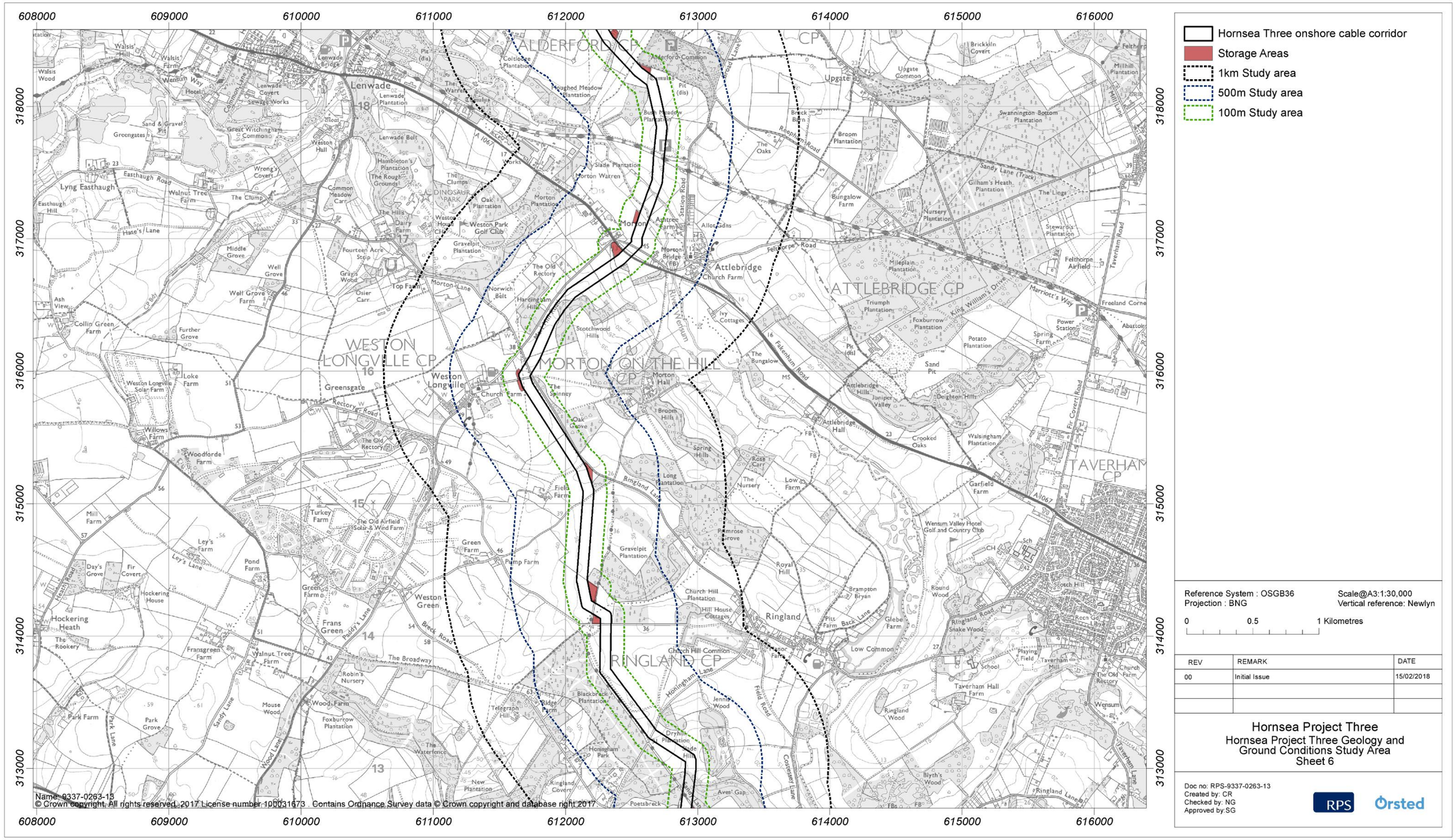

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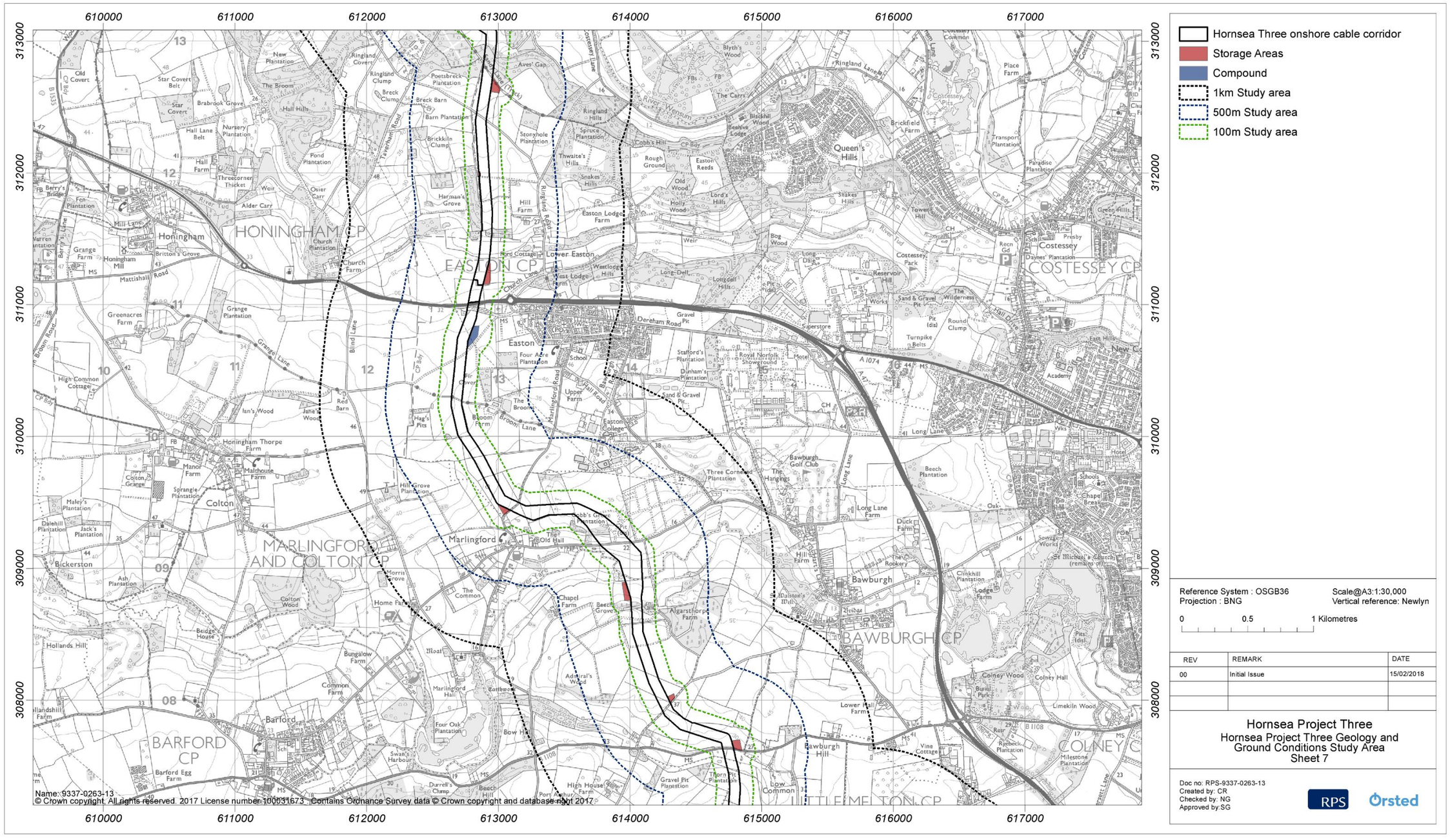

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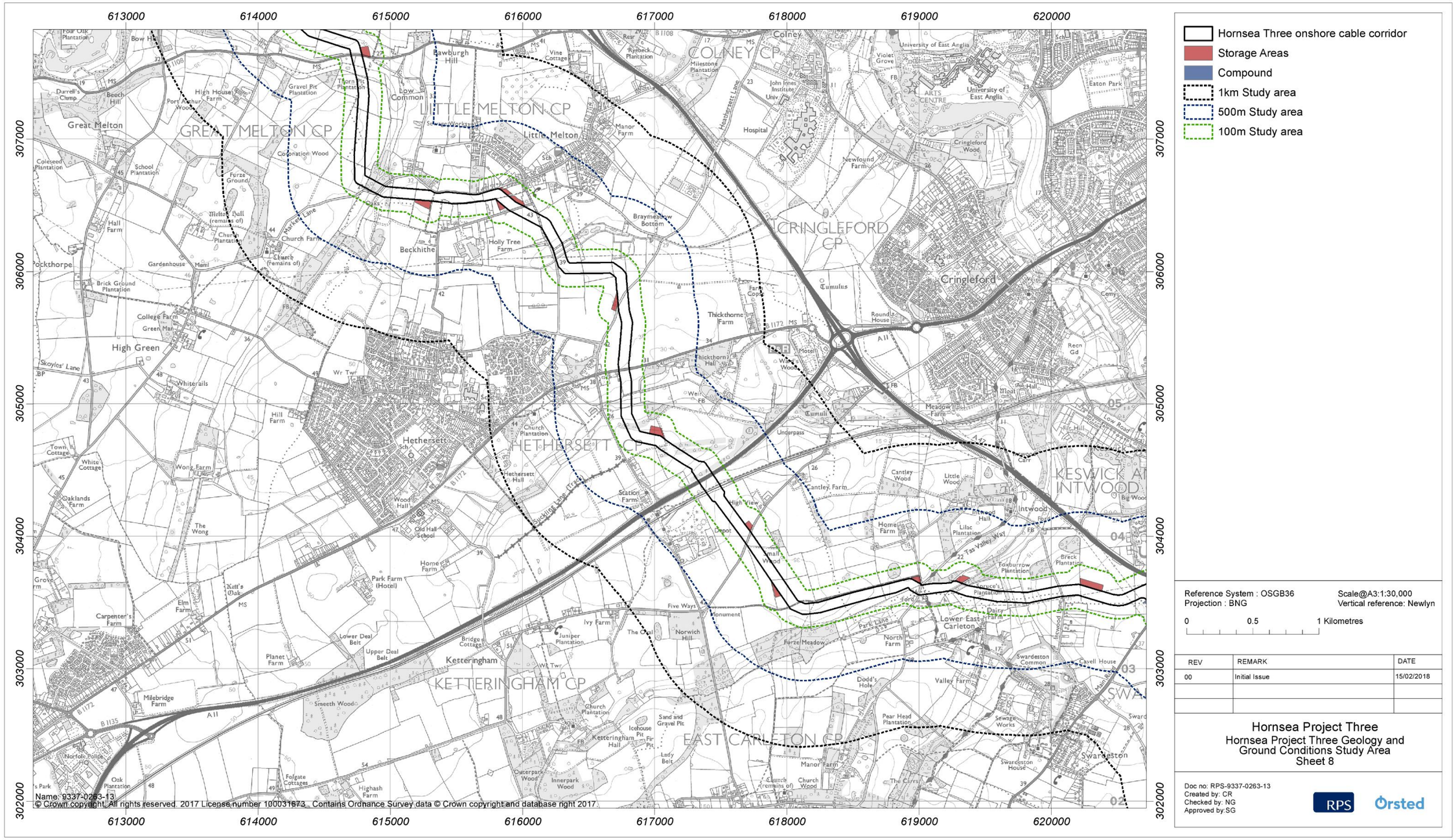

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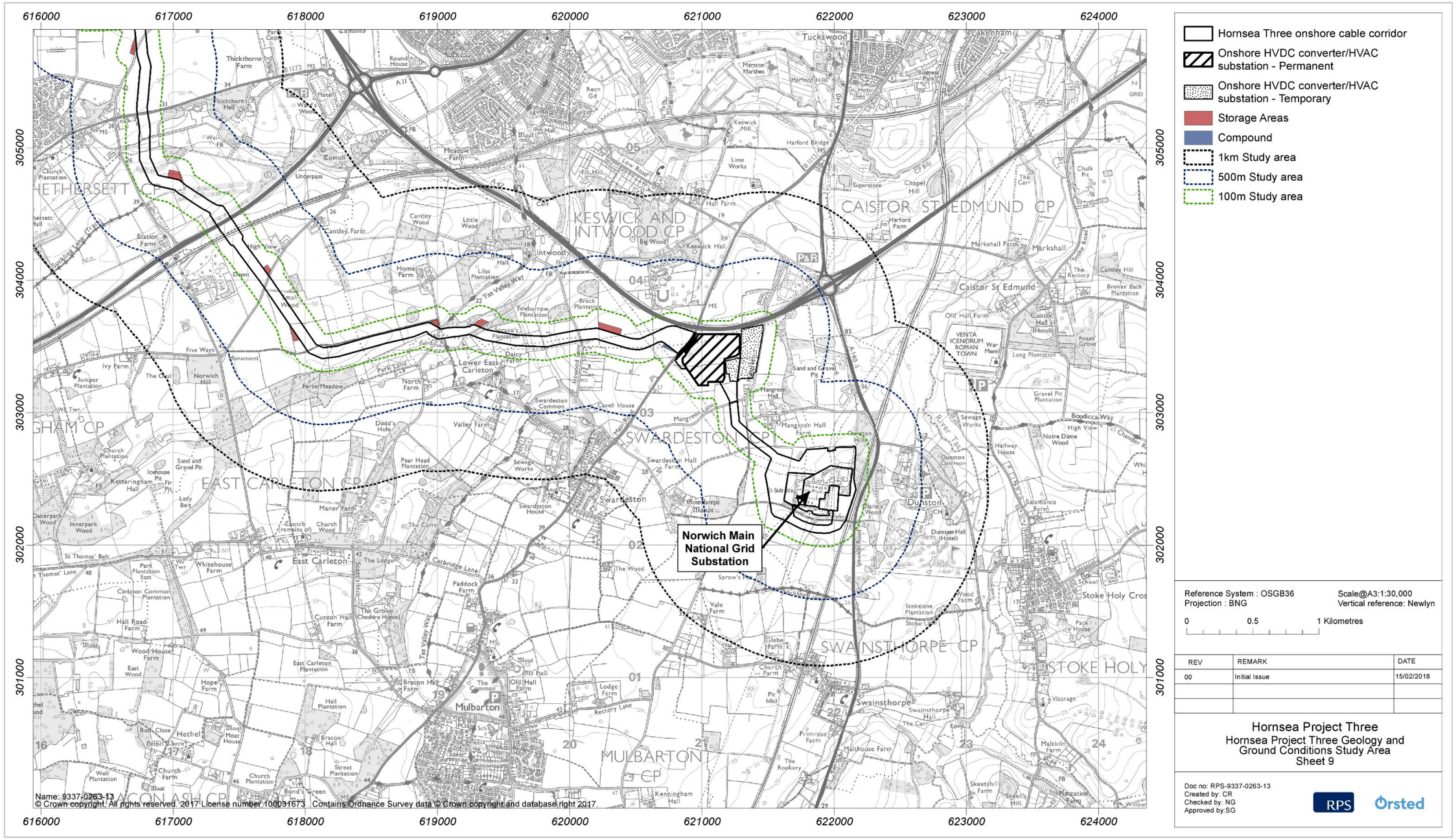

Figure 1.1: Hornsea Project Three geology and ground conditions study area.

Table 1.2: Summary of NPS EN-1 and NPS EN-5 policy on decision making relevant to geology and ground conditions.

Summary of NPS EN-1 and NPS EN-5 policy on decision making (and mitigation)	How and where considered in the Environmental Statement
Geology	
Decision making should ensure that appropriate weight is attached to designated sites of international, national and local importance and to geological interests within the wider environment (paragraph 5.3.8 of NPS EN-1). Sites of Special Scientific Interest (SSSIs) including all National Nature Reserves should be given a high degree of protection (paragraph 5.3.10 of NPS-EN1).	Two geological SSSIs are located within the Hornsea Three geology and ground conditions study area (see Table 1.6 and section 1.7.1), however, there will be no land take within the designated sites and as such there is no impact on designated SSSIs.
Development consent will not normally be granted where development within or outside an SSSI is likely to have an adverse effect on an SSSI, except where the benefits (including need) clearly outweigh the impacts on the features for which the SSSI is designated or the broader impacts on the national network of SSSIs. Decision makers should use requirements and/or planning obligations to mitigate the harmful aspects of the development and where possible to ensure the conservation and enhancement of the site's geological interest (paragraph 5.3.11 of NPS EN-1).	
Decision making should give due consideration to regional or local designations for sites of regional and local biodiversity and geological interest, which include Regionally Important Geological Sites, Local Nature Reserves and Local Geological Sites (paragraph 5.3.13 of NPS EN-1).	No county or local geological sites have been identified in the Hornsea Three geology and ground conditions study area.
Ground Conditions	
The applicant should demonstrate that during construction they will seek to ensure that activities will be confined to the minimum areas required for the works (paragraph 5.3.18 of NPS EN-1).	The design takes into account that construction activities will be confined to the minimum areas required for work (see volume 1, chapter 3: Project Description and chapter 4: Site Selection and Consideration of Alternatives). Appropriate mitigation measures in relation to geology and ground conditions are set out in Table 1.14.
Where a proposed development has an impact upon a Mineral Safeguarding Area, the Infrastructure Planning Committee (IPC) should ensure that appropriate mitigation measures have been put in place to safeguard mineral resources (paragraph 5.10.22 of NPS EN-1).	During the site selection and route refinement process (see volume 1, chapter 4: Site Selection and Consideration of Alternatives), the width of Hornsea Three onshore cable corridor has been refined. This has in turn reduced the area of Hornsea Three which has direct impacts on the Mineral Safeguarding Areas (see Figure 1.3 and discussion in section 1.7.2).
The environmental and archaeological consequences of undergrounding, for example undergrounding a 400kV line may mean disturbing a swathe of ground up to 40 metres across, which can disturb sensitive habitats, have an impact on soils and geology, and damage heritage assets, in many cases more than an overhead line would (paragraphs 2.8.8-2.8.9 of NPS EN-5)	No recommended mitigation in relation to geology in NPS EN-5. This chapter assesses the potential effects of cable undergrounding on geology and ground conditions (see section 1.11). Impacts on habitats, soils and heritage assets are assessed in chapter 3: Ecology and Nature Conservation, chapter 6: Land Use and Recreation and chapter 5: Historic Environment respectively.

1.4.2 Other relevant policies

1.4.2.1 A number of other policies are relevant to geology and ground conditions. These include including:

- National Planning Policy Framework (NPPF) (2012);
- Web based planning practice guidance is provided by the Department for Communities and Local Government (DCLG). Guidance on the Natural Environment (updated in January 2016), and Land Affected by Contamination (updated in March 2014);
- Norfolk Minerals and Waste Local Development Framework (2011); and
- Norfolk Geodiversity Action Plan (2011).

1.4.2.2 Key provisions of these policies are set out in Table 1.3.

Table 1.3: Summary of other policies relevant to geology and ground conditions.

Summary of provision	How and where considered in the Environmental Statement
National Planning Policy Framework	
Paragraph 121 of section 11 states that planning policies and decisions should ensure that sites are suitable for any proposed new use and that account is taken of ground conditions and land stability including natural hazards, former activities and appropriate mitigation including remediation. After remediation, land must not be capable of being determined as contaminated land under Part IIA of the Environmental Protection Act 1990 and adequate site investigation information prepared by a competent person must be presented	Baseline geology and ground conditions have been used to inform the site selection process (see volume 1, chapter 4: Site Selection and Consideration of Alternatives) and route refinement. The detailed design process will ensure that ground conditions are suitable for the intended use (see Table 1.14).
Paragraph 143 of the NPPF states that local planning authorities should define Mineral Safeguarding Areas and that local plans should "*set out policies to encourage the prior extraction of minerals, where practicable and environmentally feasible, if it is necessary for non-mineral development to take place*".	Mineral Safeguarding Areas within the Hornsea Three geology and ground conditions study area are identified in Figure 1.3 and discussed in section 1.7.2.

Summary of provision	How and where considered in the Environmental Statement
National Planning Practice Guidance	
Land Affected by Contamination (updated March 2014) considers where contamination is most likely to occur and the role of planning in addressing contamination issues.	The potential for land to be classified as contaminated based on current and historic land uses is discussed in paragraphs 1.7.4.34 to 1.7.4.39.
Guidance on the Natural Environment (updated in January 2016) includes the need to protect geodiversity.	Hornsea Three will not have a direct impact on designated or non-statutory geological sites (see Figure 1.3 and section 1.7.1).
Local Planning Policy	
Norfolk Minerals and Waste Local Development Framework - Core Strategy and Minerals and Waste Development Management Policies Development Plan Document 2010 – 2026 (September 2011) Policy CS16 - Safeguarding mineral and waste sites and mineral resources "*The County Council will safeguard existing, permitted and allocated mineral extraction and associated development and waste management facilities, within the following categories…all mineral extraction sites that are active, and sites with planning permission and allocated sites….*"	Mineral Safeguarding Areas and Consultation Areas within the Hornsea Three geology and ground conditions study area are identified in Table 1.3 and discussed in section 1.7.2.
Geodiversity in Planning – Supplementary Planning Guidance (Norfolk Geodiversity Partnership, 2014) The document provides guidance on conserving and enhancing Norfolk's geodiversity through the planning system. It recommends that developers consider the impact of their proposals on geodiversity features, include geology within the scope of EIA and establish effective mitigation measures as part of planning consents (e.g. designing development to avoid damage to geological features).	Designated geological sites within the Hornsea Three geology and ground conditions study area are identified in Table 1.6 and on Figure 1.2. The design of the Hornsea Three landfall area and Hornsea Three onshore cable corridor have been refined to avoid designated geological sites (see volume 1, chapter 4: Site Selection and Consideration of Alternatives). Other aspects of geodiversity (i.e. soil quality) are considered in volume 3, chapter 6: Land Use and Recreation.

1.5 Consultation

1.5.1.1 Table 1.4 below summarises the issues raised relevant to geology and ground conditions, which have been identified duting consultation activities to date. Table 1.4 also indicates either how these issues have been addressed within this Environmental Statement or how the Applicant has had regard to them. Further information on the consultation activities undertaken for Hornsea Three can be found in the Consultation Report (document reference number A5.1) that accompanies the application for Development Consent.

1.5.1.2 It is noted that no comments on geology and ground conditions were made by North Norfolk District Council, Broadland District Council or South Norfolk District Council.

Table 1.4: Summary of key consultation issues raised during consultation activities undertaken for Hornsea Three relevant to geology and ground conditions.

Date	Consultee and type of response	Issues raised	Response to issue raised and/or where considered in this chapter
September 2016	Norfolk County Council – consultation meeting	Identification of existing minerals extraction sites and safeguarded areas in the vicinity of the projects onshore scoping area.	Mineral Safeguarded Areas are identified in paragraphs 1.7.2.1 and 1.7.2.2. Where relevant planned mineral extractions have been considered in the cumulative impacts assessment section 1.13.
November 2016	Environment Agency – Scoping Response	The Environment Agency was pleased with the impacts being scoped into the Assessment. If an area of land contamination is identified within the cable corridor which may affect principal and secondary aquifers a Preliminary Risk Assessment will need to be undertaken.	A review of current and historical land use within the Hornsea Three geology and ground conditions study area has been undertaken and is described in paragraphs 1.7.4.34 to 1.7.4.42 and Table 1.15. Procedures to deal with contamination (including Preliminary Risk Assessments where appropriate) would be prepared before development commenced (see Table 1.15).
		The Environment Agency recommends that the cable corridor does not pass through areas designated as Source Protection Zone 1.	Source Protection Zones within the Hornsea Three geology and ground conditions study area are described in paragraphs 1.7.4.23 to 1.7.4.26.
		Horizontal Directional Drilling (HDD) should be used where sensitive habitats cannot be avoided. Further information will be required detailing the sensitive locations where it is proposed to carry out HDD. However, ground investigation is required to inform the suitability of HDD and there may be locations where this technique would not work due to the geology. Appropriate pollution prevention measures will need to be in place to prevent the release of drilling fluid into the water environment and to prevent the release of silt downstream together with appropriate incident plans in case of any pollution incidents.	Site investigations will be undertaken (during detailed design) at each proposed HDD location to confirm suitability of geology (see Table 1.15). Measures for trenchless techniques under watercourses and pollution prevention measures are outlined in Table 1.15.
November 2016	Norfolk County Council – Scoping Response	Additional data sources should be added to the list. • Safeguarded Mineral resource mapping, as defined within the Norfolk Minerals and Waste Local development Framework; and • Safeguarded Mineral and Waste sites, as defined within the adopted Norfolk Minerals and Waste Local development Framework.	These data sources were obtained from Norfolk County Council following the meeting in September 2016. Mineral safeguarding areas are described in paragraphs 1.7.2.1 and 1.7.2.2 and shown on Figure 1.3. Where relevant planned mineral extractions have been considered in the cumulative impacts assessment section 1.13 and Mineral Safeguarded Areas are considered in section 1.11.
		An additional paragraph is required to explain that Mineral Safeguarding Areas/Mineral Consultation Areas are recognised in national policy.	This is set out within Table 1.3.
		Table 10.2 of volume 4, annex 5.5: Scoping Report and PINS Scoping Opinion should be amended to take into account the potential for impacts to safeguard mineral resources and safeguarded mineral and waste sites.	Assessment of the impacts to mineral safeguarding areas is discussed in paragraphs 1.11.1.3 to 1.11.1.7.
December 2016	PINS – Scoping Opinion	Careful consideration should be given to the potential for overlapping cable corridors with the Norfolk Vanguard offshore wind farm and any resultant cumulative impacts.	Cumulative impacts are discussed in section 1.13.
November 2016	Public Health England – Scoping Response	We would expect the promoter to provide details of any hazardous contamination present on site (including ground gas) as part of the site condition report. Emissions to and from the site should be considered in terms of previous history of the site and the potential of the site, once operational, to give rise to issues.	Potential contamination is identified in paragraphs 1.7.4.34 to 1.7.4.40. An approach to deal with potentially contaminated land is set out in Table 1.15.
September 2017	Environment Agency – Section 42 Response	Whilst the proposal to provide a written scheme for dealing with unexpected contaminated land and groundwater will be required, the Environment Agency expect that the Preliminary Risk Assessment should look to identify potential contamination within the search area prior to work being undertaken. This should include the presence of historical landfills as well as permitted sites.	Historic and active landfills have been identified within the Hornsea Three geology and ground conditions study area (see Figure 1.4). The potential for contamination to have occurred as a result of other historic and current land uses within the Hornsea Three geology and ground conditions study area has also been considered. The mitigation measures include a commitment to undertake Preliminary Risk Assessment where appropriate before construction commences. The risk assessment will identify areas of contaminated land and where this has impacted on groundwater/surface water.

Date	Consultee and type of response	Issues raised	Response to issue raised and/or where considered in this chapter
		The Environment Agency request that further assessment in line with the water framework directive is carried out. In particular the assessment needs to make a clear link between activities and WFD receptors, quantifying the likely impacts and assessing the risk of deterioration	A WFD Groundwater Assessment has been carried out and is provided in volume 6, annex 1.4: Water Framework Directive Groundwater Assessment. It contains WFD specific details, in particular it makes a clear link between the construction activities of Hornsea Three and the WFD receptors. According to the Groundsure reports, there are no sites recorded as contaminated land under Part IIA of the Environmental Protection Act 1990 within the Hornsea Three geology and ground conditions study area. In respect to white-clawed crayfish populations, results of the Hornsea Three surveys are provided in volume 6, annex 3.4: White Clawed Crayfish Survey. Potential impacts on white clawed crayfish are assessed in chapter 3: Ecology and Nature Conservation, which concludes no siognficant effects. In terms of the WFD they are considered in volume 6, annex 2.5. Water Framework Directive Surface Water Assessment.
		The Environment Agency advises that the SPZ boundaries are under review and that there are additional boreholes at Mace Hill and near Bodham. The Environment Agency is concerned that the assessment does not consider how groundwater supplies from the three chalk abstractions within or adjacent to the cable corridor presented in Preliminary Environmental Information Report (PEIR) or groundwater flow around the monitoring borehole at Weston Longville would be secured. Consideration should be given to groundwater flow and the impact on local abstractors in terms of achieving groundwater yield and quality. The Environment Agency would like to be consulted on the methodologies for any site investigations at watercourse crossing points along with those for HDD work.	The Environment Agency has provided details of the revised SPZ boundaries and these are shown in volume 6, annex 1.2: Abstraction Licences and Source Protection Zones. The potential impacts of Hornsea Three in terms of disruption of groundwater flow and the yields and quality of groundwater abstractions have been included in the assessment, section 1.11. The Environment Agency will be consulted on the methodologies of the site investigations at watercourse crossing points (particularly where HDD is used) and secured through the Outline Code of Construction Practice (CoCP) (document reference A8.5). The purpose of the investigations will be to characterise the ground conditions and to provide information for the hydrogeological risk assessment.
September 2017	Natural England – Section 42 Response	Without details of the pollution prevention measures in terms of run-off from the cable route activities, it is not possible to comment on the assessment of magnitude and significance of its effect.	An Outline CoCP (document reference A8.5) forms part of the DCO application which contains management measures to minimise pollution including a commitment to prepare Pollution Prevention and Emergency Response Plans.
		The cable trenches and lines may act as preferential flow paths for groundwater and effects of this needs consideration and mitigation.	The potential impacts of Hornsea Three in terms of creating preferential pathways have been included in the assessment, section 1.11. Mitigation measures are set out in Table 1.15.
September 2017	Norfolk County Council – Section 42 Response	The further mitigation suggested in the PEIR is considered to be effective. Therefore, the County Council in its capacity as the Mineral Planning Authority does not object to this proposal provided that the applicant continues to work with the County Council regarding the mitigation of impacts on the Mineral Safeguarding Areas as the final scheme design continues.	The refinement of the onshore cable corridor, has resulted in a reduction in the area of Mineral Safeguarding Area that would be occupied by Hornsea Three.
September 2017	South Norfolk District Council – Section 42 Response	There are a number of private drinking supplies in the vicinity of the land in South Norfolk that will be impacted by this proposal. These represent the only source of drinking water for the premises they serve. The PEIR outlines mewasures that will be taken to address this issue which are considered acceptable but the detail will need to be agreed at the appropriate time.	A number of private water supplies have been identified in the Hornsea Three hydrology and flood risk study area. They are primarily from groundwater resources and are identified in volume 6, annex 1.2: Abstraction Licences and Source Protection Zones.
November 2017	Environment Agency – Meeting and follow up	The purpose of the meeting was to discuss the comments raised during Section 42 and to propose an approach to address the Environment Agency's comments. Following the meeting the Environment Agency sent details of the update to the SPZ boundary associated with the abstraction at Bernard Matthews, Great Witchingham. The updated boundary showed that the Hornsea Three onshore cable corridor was still located within SPZ2 and SPZ3. The SPZ1 for the Anglian Water abstraction at Easton College is also being updated but no plan of the proposed changes is available.	The updated SPZ boundary has been incorporated into the assessment at paragraph 1.7.4.26 and volume 6, annex 1.2: Abstracting Licences and Source Protection Zones.

Date	Consultee and type of response	Issues raised	Response to issue raised and/or where considered in this chapter
December 2017	Environment Agency – Second Section 42 Response	From an initial review of historic maps, the Environment Agency identified potentially contaminating land uses which are close to or cross the application corridor (including railway lines, former depot and historic landfill). Sufficient information should be provided with the application to provide assurance that the risks to the water environment are fully understood and can be addressed through appropriate measures including the need for site investigation, risk assessment and remediation. The Environment Agency have reviewed the updated boundary of the SPZ1 at Easton College and stated that "*the application corridor appears to skirt around the edge of the source protection zone 1*". A plan of the updated boundary is not available at this time.	A review of historic maps has been undertaken and did not identify any land uses that are likely to result in widespread significant contamination. There is the potential for localised contamination to exist as a number of land uses identified in paragraphs 1.7.4.34 to 1.7.4.40. Mitigation measures include a written scheme dealing with contamination are set out in Table 1.15. For the purpose of this assessment the original SPZ1 boundary has been used as this represents the maximum design scenario. The SPZ1 is discussed in paragraph 1.7.4.27 and shown in volume 6, annex 1.2: Abstraction Licences and Source Protection Zones.
December 2017	Norfolk County Council – Second Section 42 Response	The Council confirmed that the disused airfield at Oulton Street is underlain by a Minerals Safeguarding Area for sand and gravel. If permanent development is intended in this area, an assessment will be required.	No permanent development associated with Hornsea Three is proposed at the Oulton airfield.

1.6 Methodology to inform the baseline

1.6.1 Desktop study

1.6.1.1 The baseline conditions were identified by a desktop review of existing studies and datasets. These are summarised at Table 1.5.

Table 1.5: Summary of key desktop sources.

Title	Source	Year	Author
Hydrogeology	Hydrogeological Map of Northern East Anglia	1976	BGS (published by predecessor body the Institute of Geological Sciences - IGS)
Norfolk's Earth Heritage- valuing our geodiversity	Norfolk Geodiversity Partnership	2010	Norfolk Geodiversity Partnership
BGS 1:50,000 and 1:10,000 digital geological mapping	BGS via Groundsure GeoInsight Report	2017	BGS
Borehole records for locations in the vicinity	BGS Website http://mapapps2.bgs.ac.uk/geoindex/home.html	2016	BGS
SPZs/Aquifer Designations	Environment Agency via Groundsure EnviroInsight Report Correspondence with the Environment Agency.	2017	Environment Agency
Private Water Supplies	BGS Well data set and Local Authority Environmental Health data sets	2017	N/A
Natural Hazards data set	BGS via Groundsure GeoInsights Report	2017	BGS
Geological descriptions	BGS Website http://mapapps2.bgs.ac.uk/geoindex/home.html	2016	BGS
County Geodiversity Sites	Norfolk County Council (www.norfolk.gov.uk)	2017	Norfolk County Council
Waterbodies designated under WFD	http://environment.data.gov.uk/catchment-planning/	2017	Environment Agency
Designated geological sites	www.magic.gov.uk.	2017	Department for Environment, Food & Rural Affairs (Defra)
Environmental Permits	Environment Agency and Local Authority via Groundsure EnviroInsight Report	2017	N/A
Landfill sites	Environment Agency and Local Authority via Groundsure EnviroInsight Report	2017	N/A

Identification of designated geological sites

1.6.1.2 All designated geological sites within the Hornsea Three geology and ground conditions study area that have the potential to be impacted/affected by the construction, operation and maintenance, and decommissioning of Hornsea Three for geology and ground conditions, were identified using the three step process described below:

- Step 1: All designated sites of international, national and local importance within the Hornsea Three geology and ground conditions study area were identified using a number of sources including MAGIC and Norfolk County Council Website.
- Step 2: Information was compiled on the relevant geological features for each of these sites as follows; name, location and details of relevant features.
- Step 3: Using the above information and expert judgement, sites were included for further consideration if, for example:
  - A designated site directly overlapped with Hornsea Three; and/or
  - Sites and associated features were located within the potential Zone of Impact (ZoI) for impacts associated with Hornsea Three.

1.6.2 Site specific surveys

1.6.2.1 The baseline characterisation provided by the desktop survey is considered sufficient to inform the assessment and therefore no site specific surveys have been undertaken to inform the EIA for geology and ground conditions.

1.6.2.2 In this regard, it is noted that no requirements to undertake investigations were requested by the Environment Agency or the Environmental Health Officers of North Norfolk District Council, Broadland District Council, South Norfolk District Council or Norfolk County Council during the consultation process as part of their response to S42 consultation or in the follow up meetings.

1.6.2.3 Site specific surveys, such as intrusive investigations would be undertaken, if required, during the detailed design stage and in consultation with the relevant authorities.

1.6.2.4 However, it is noted that where information pertinent to the baseline conditions was identified through landowner consultation, this is acknowledged in this chapter.

1.7 Baseline environment

1.7.1 Designated geological sites

1.7.1.1 Designated geological sites within the Hornsea Three geology and ground conditions study area are described in Table 1.6 and shown on Figure 1.2. Only those areas of the Hornsea Three geology and ground conditions study area containing designated sites are shown on Figure 1.2. Distances are provided to the Hornsea Three onshore cable corridor, as the closest onshore element.

Table 1.6: Geologcial SSSIs.

Designated Geological Site	Distance to Hornsea Three onshore cable corridor (m)	Features
Kelling Heath SSSI	18	Kelling Heath SSSI provides perhaps the best example of glacial outwash plain in England It has steep slopes and is dissected by deep dry valleys and is a geomorphological site of national importance.
Weybourne Cliffs SSSI	369	Cliffs east of Weybourne afford the best Pleistocene sections showing the pre-Cromerian deposits of the Cromer Forest bed. The type locality for the Pastonian Weybourne Crag.
Description from Natural England website via www.natureonthemap.naturalengland.org.uk (Defra, 2017).		

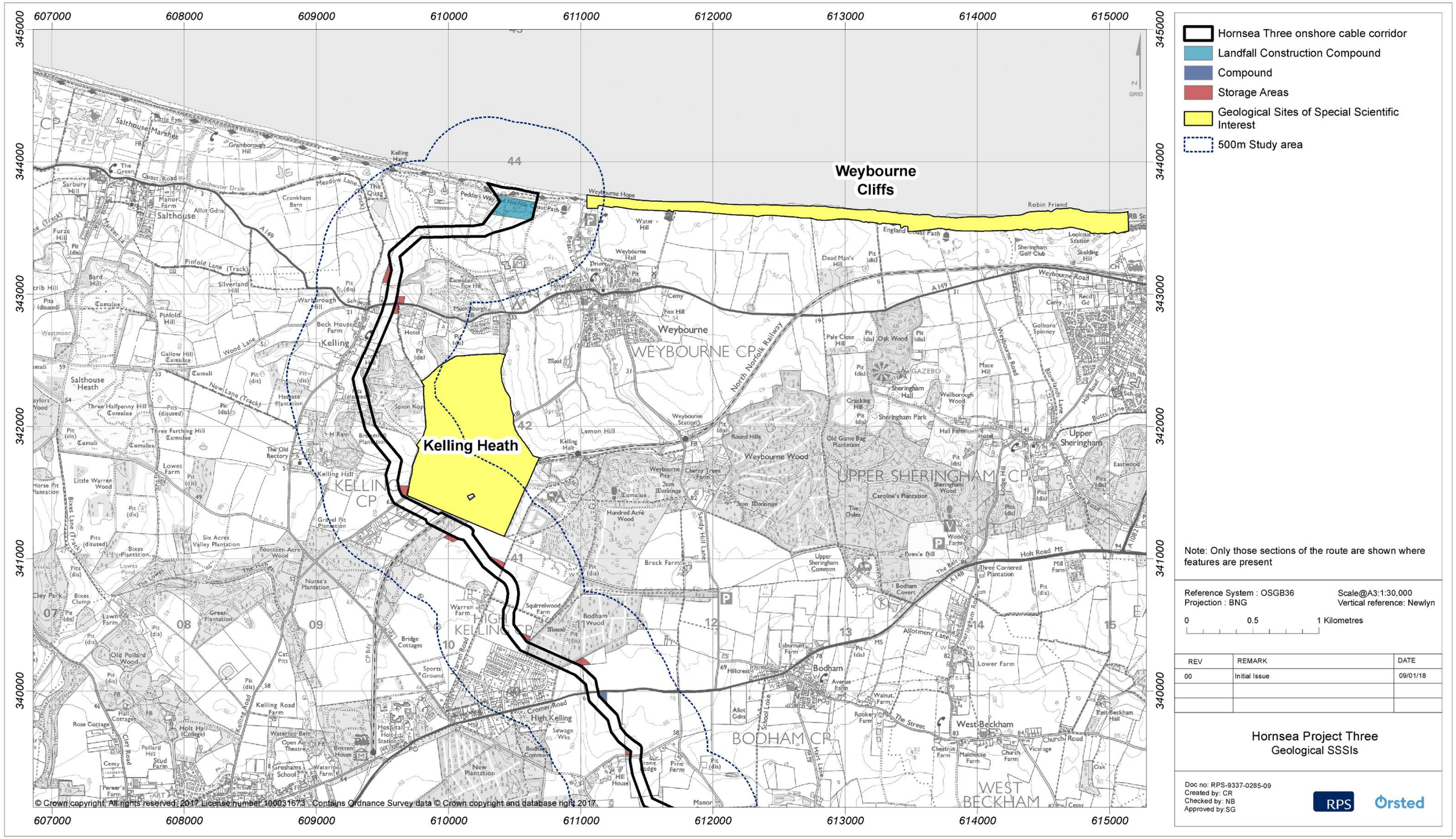

Figure 1.2: Hornsea Project Three geological SSSIs

1.7.2 Mineral Extraction Sites and Safeguarding Areas

1.7.2.1 Sand and gravel resources are abundant and located throughout large areas of Norfolk (Norfolk County Council, 2011). The closest quarry to the onshore elements of Hornsea Three is at Mangreen, which is immediately to the east of the onshore HVDC converter/HVAC substation area (see Figure 1.3). The quarry has been extended to the immediate south of the original quarry. Both the quarry and its extension are operational with restoration required before the end of 2023. Two site allocations for further southern extensions to Mangreen quarry have been put forward through the Minerals Site Specific Allocations Development Plan Document (Norfolk County Council, 2011).

1.7.2.2 The Minerals and Waste Development Framework (prepared by the Norfolk County Council in, 2011), identifies several Mineral Safeguarding Areas (sand and gravel), which are located within the Hornsea Three geology and ground conditions study area (in particular, sections of the Hornsea Three onshore cable corridor and the onshore HVAC booster station area). Areas which are partially or wholly within the Hornsea Three geology and ground conditions study area are shown on Figure 1.3. Guidance from Norfolk County Council on the mineral safeguarding process for aggregates (Norfolk County Council, 2014) defines Mineral Safeguarding Areas as "*those areas where there is an underlying mineral resources which may be of economic interest, which should be protected from unnecessary sterilisation by non-mineral development*". The guidance also states that mineral deposits found in Norfolk are highly variable and the data used to define the Mineral Safeguarding Areas is general in nature (e.g. BGS Mineral and resources map (Harrison *et al.*, 2014). The guidance goes on to state that planning applications for non-mineral uses in Mineral Safeguarding Areas should consult Norfolk County Council Mineral Planning Authority on the assessment of the mineral resources to identify the quality of any mineral and the depth of any overburden present.

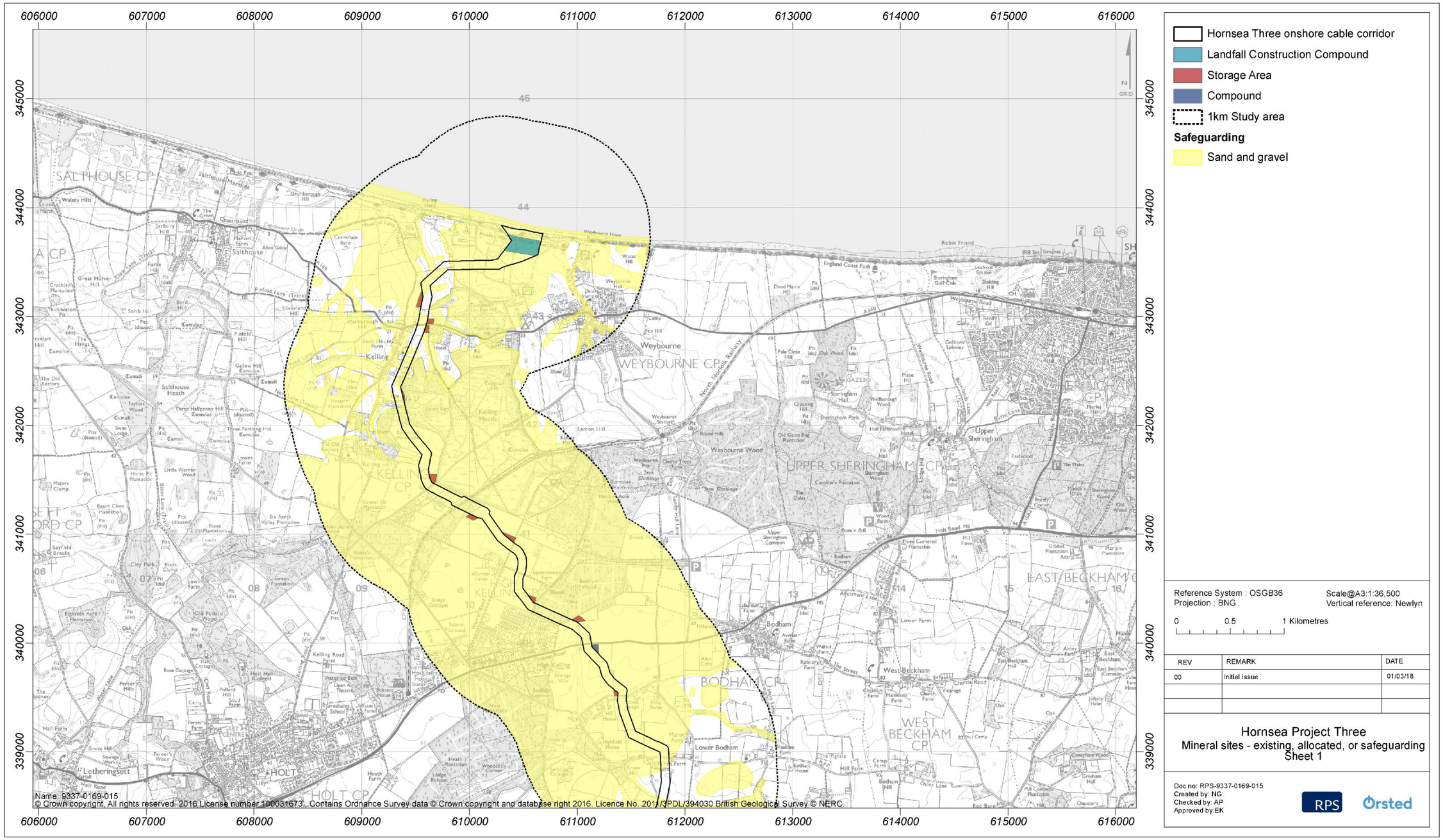

Figure 1.3: Mineral sites – existing, allocated or safeguarding

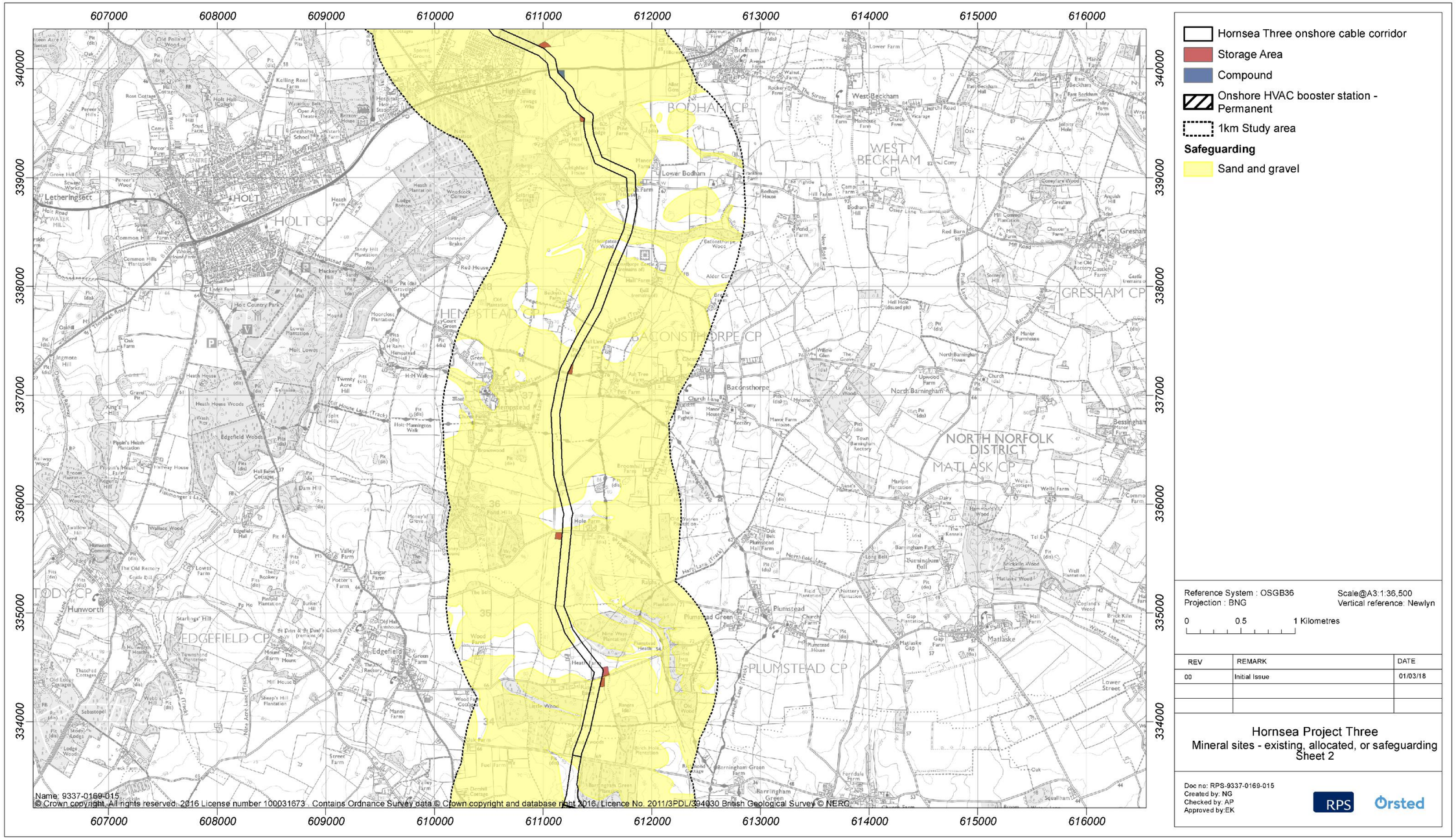

Figure 1.3: Mineral sites – existing, allocated or safeguarding.

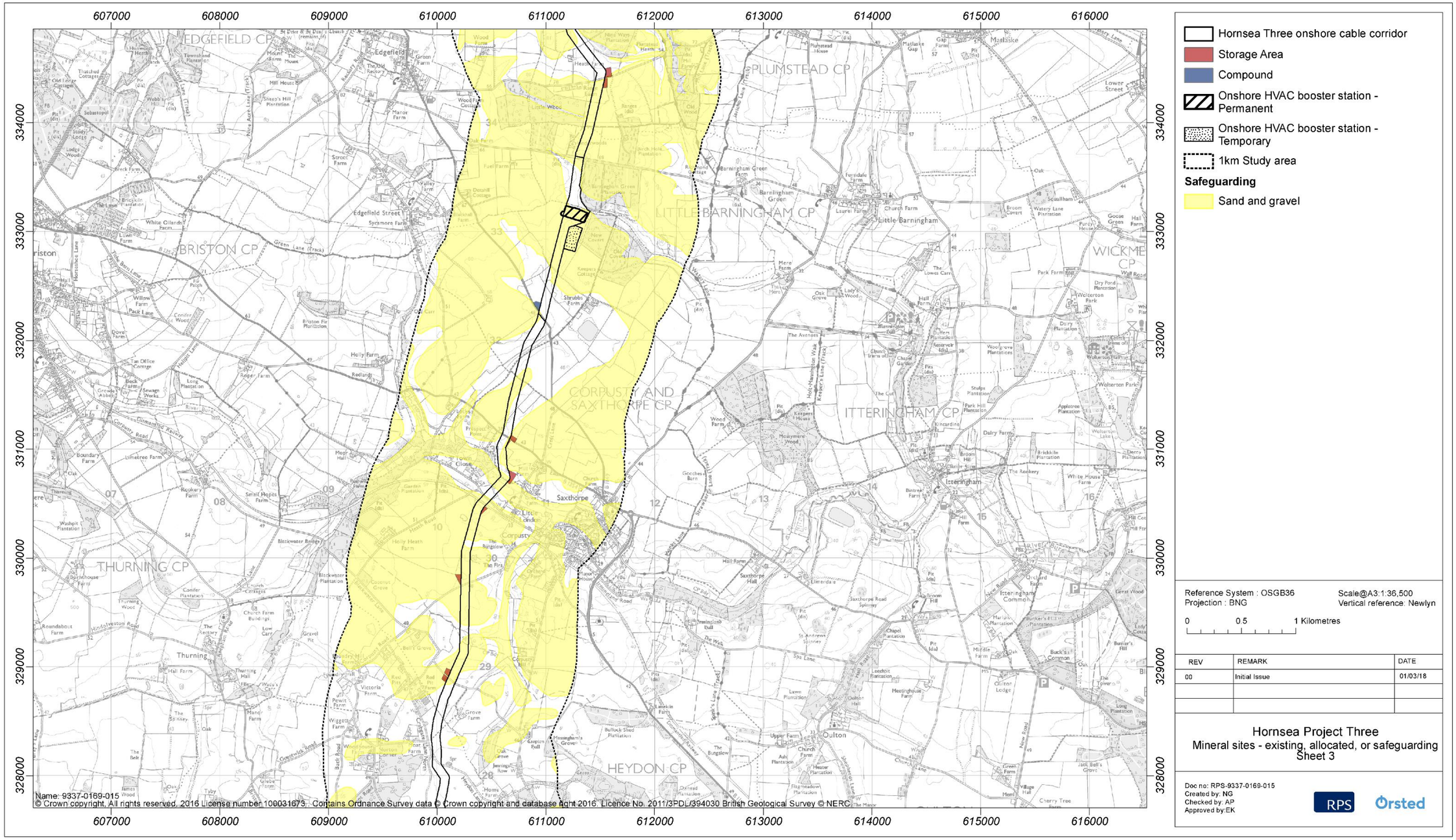

Figure 1.3: Mineral sites – existing, allocated or safeguarding.

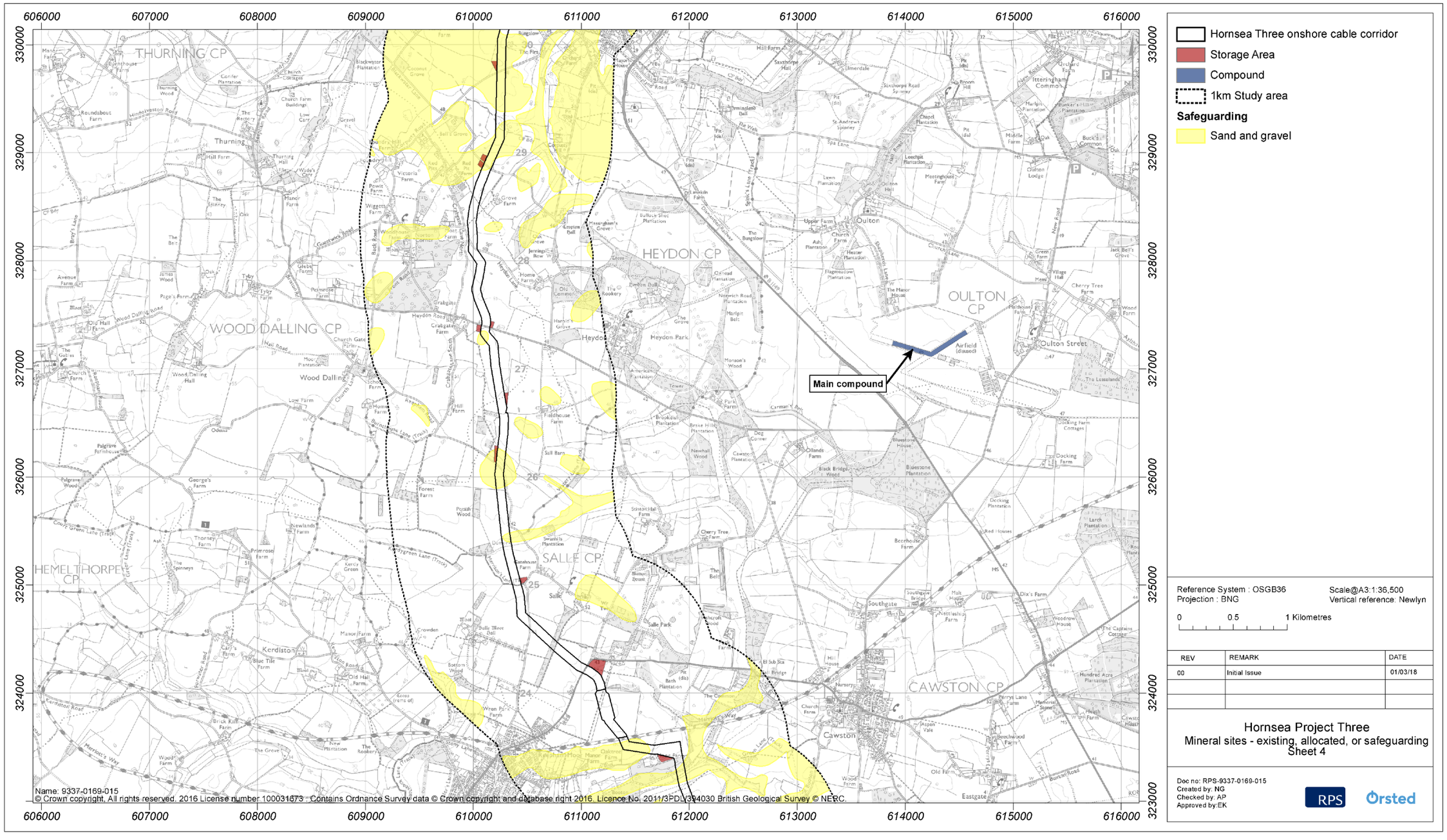

Figure 1.3: Mineral sites – existing, allocated or safeguarding

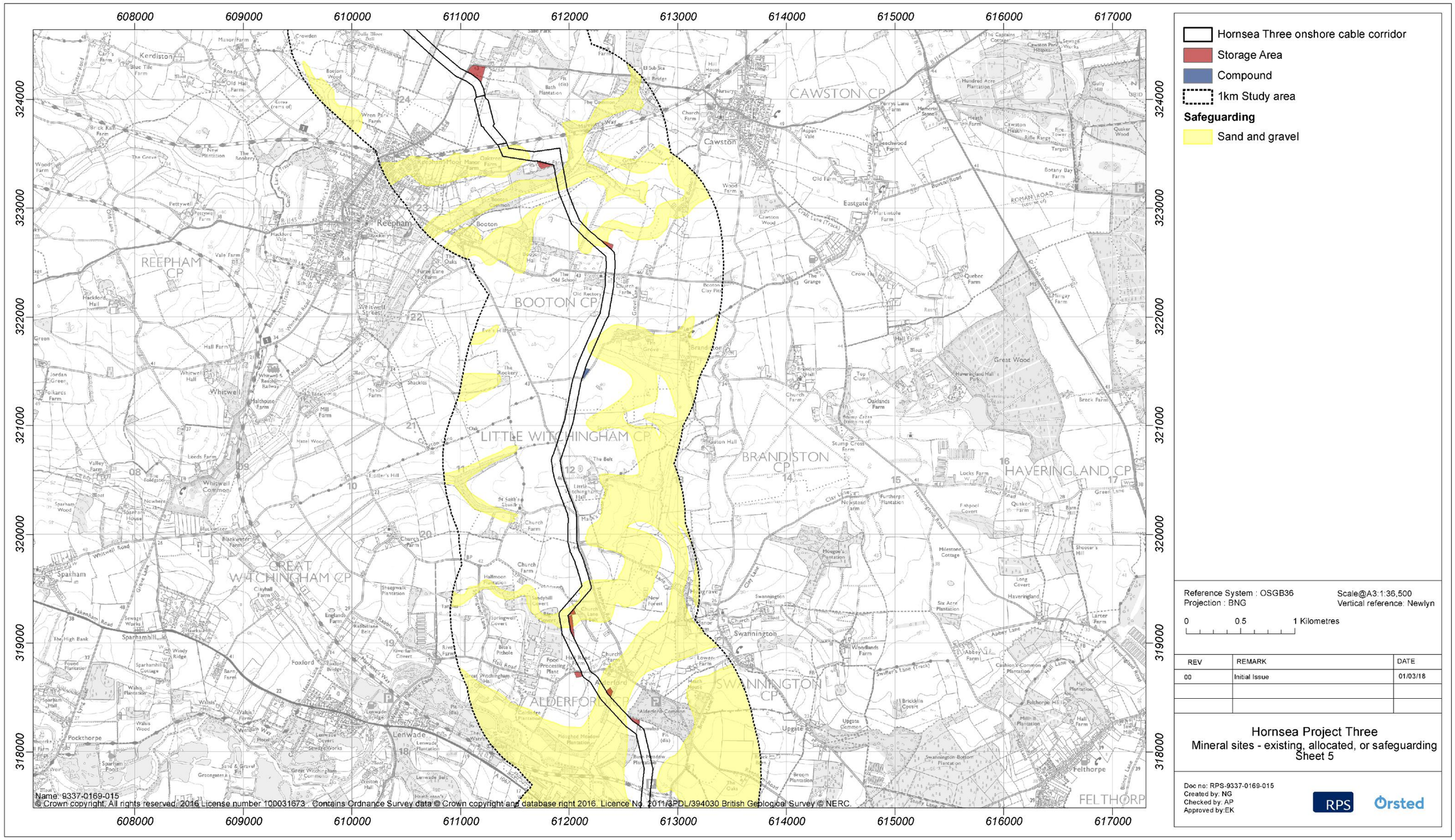

Figure 1.3: Mineral sites – existing, allocated or safeguarding.

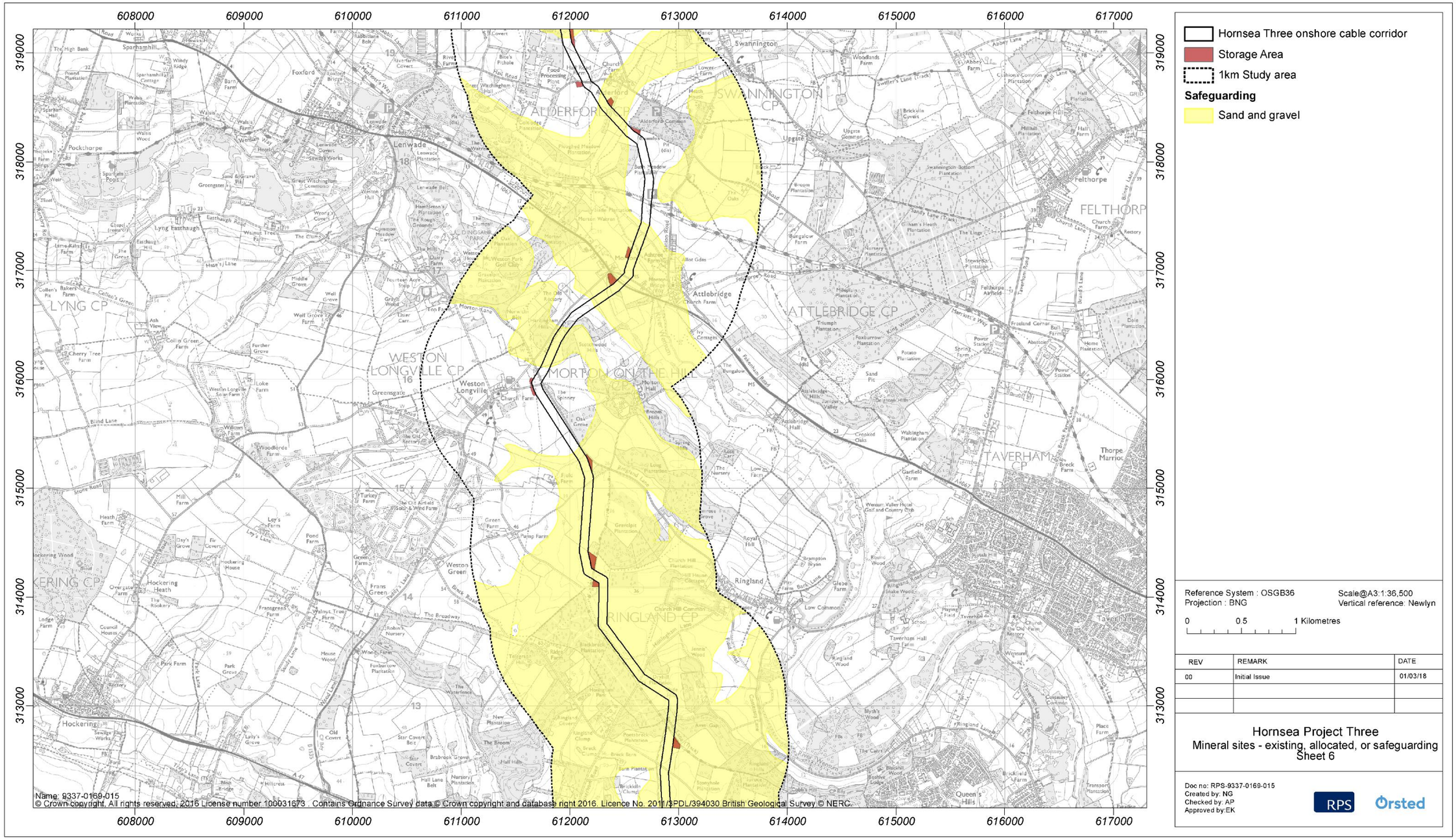

Figure 1.3: Mineral sites – existing, allocated or safeguarding.

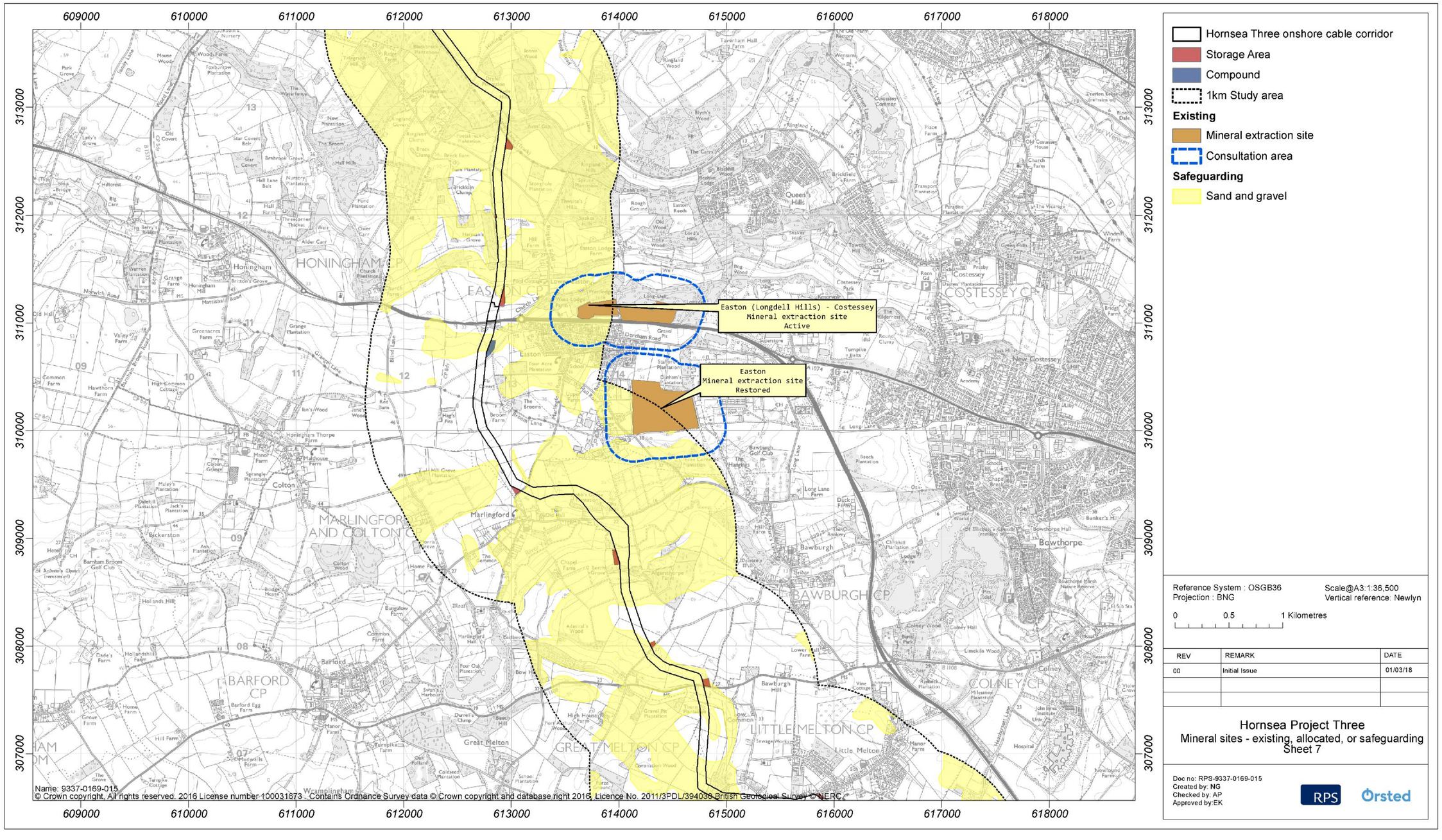

Figure 1.3: Mineral sites – existing, allocated or safeguarding.

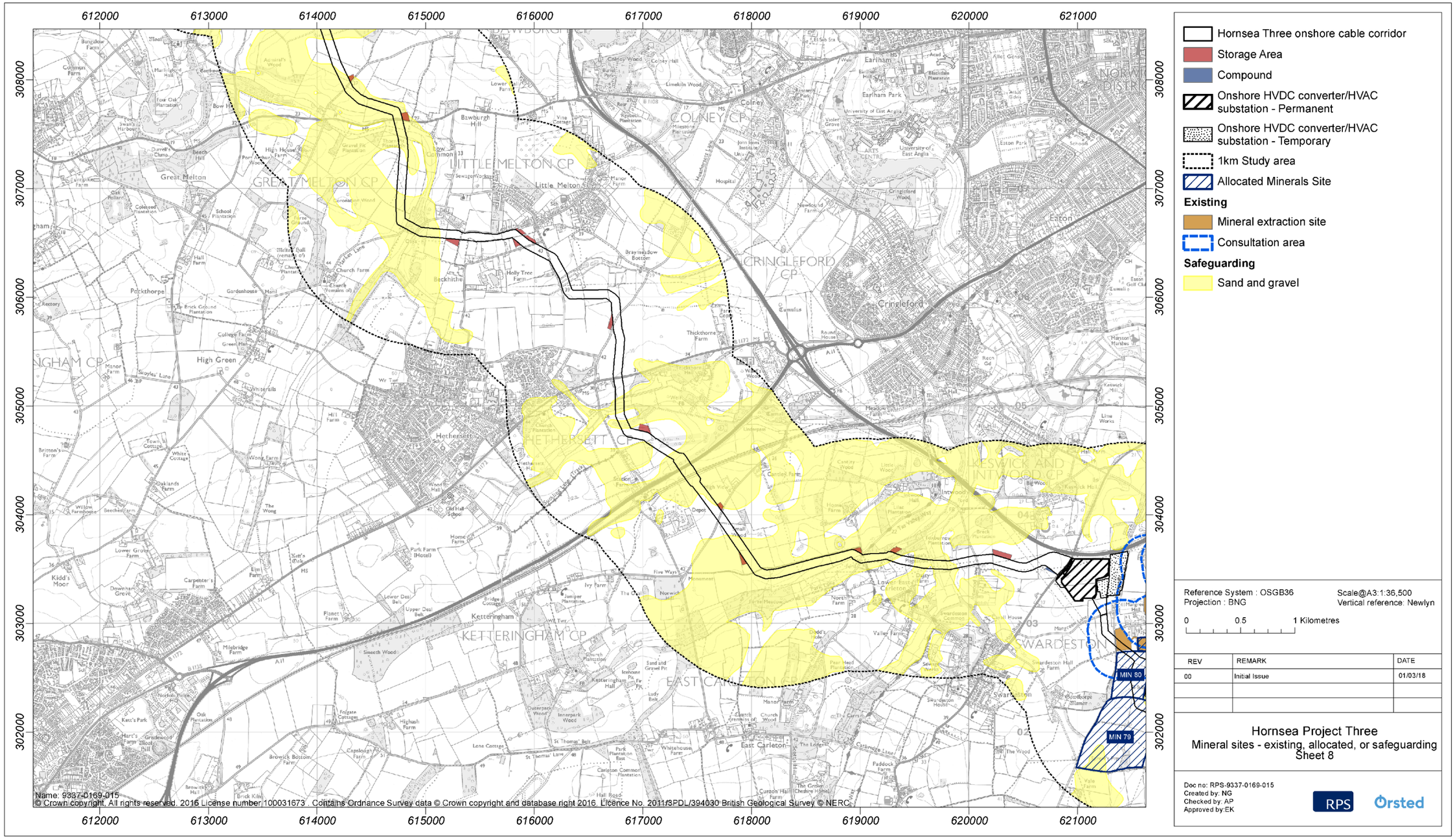

Figure 1.3: Mineral sites – existing, allocated or safeguarding.

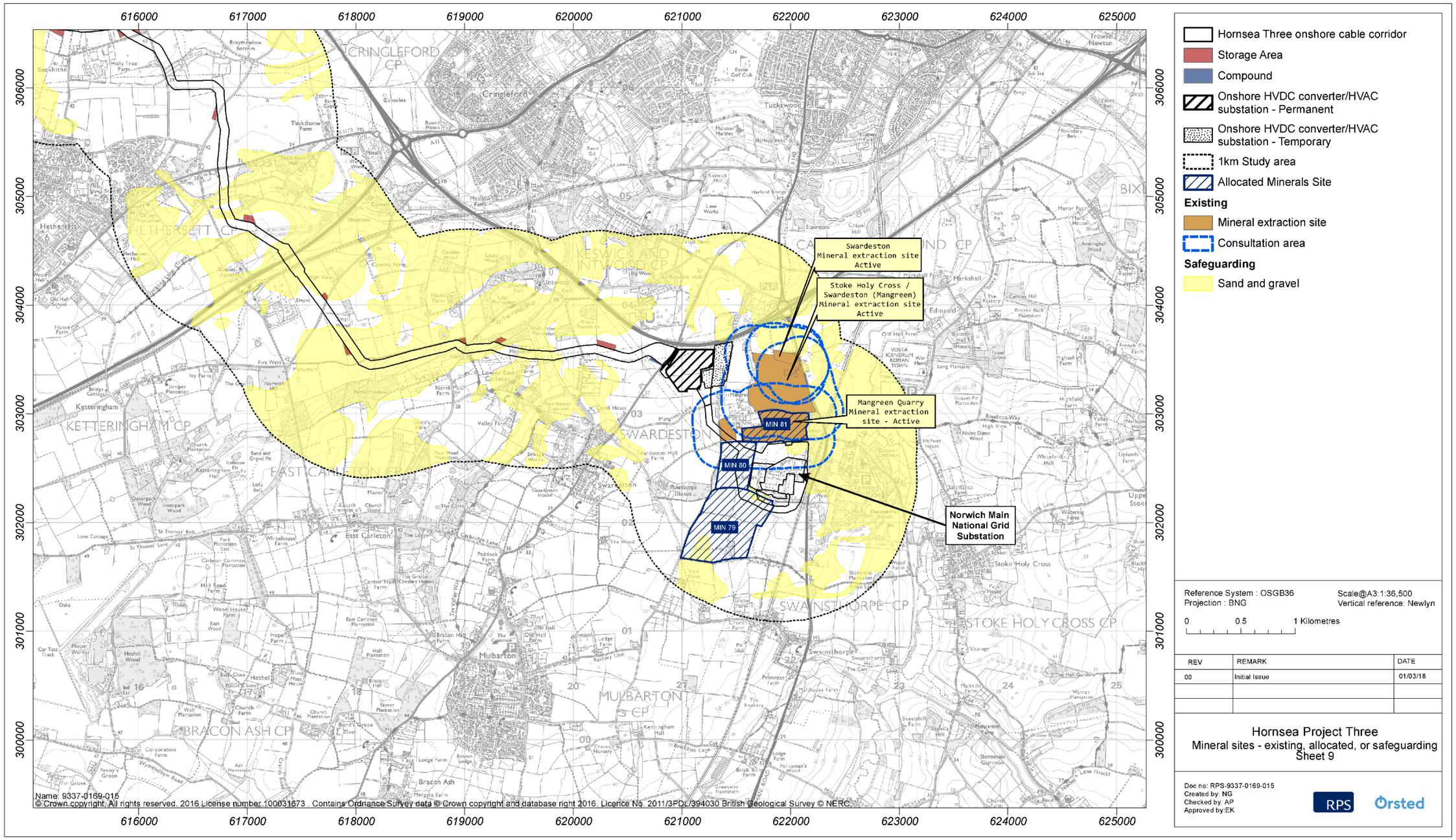

Figure 1.3: Mineral sites – existing, allocated or safeguarding.

1.7.3 Geology: bedrock, superficial deposits and artificial ground, superficial deposits and bedrock

1.7.3.1 The superficial deposits and bedrock within the Hornsea Three geology and ground conditions study area have been identified using the Groundsure Geo Insight report (Groundsure, 2017b), BGS geology maps and borehole logs. In addition, areas of artificial ground have been mapped by the BGS in several locations within the Hornsea Three geology and ground conditions study area.

Bedrock

1.7.3.2 The bedrock underlying the northern and central part of the Hornsea Three geology and ground conditions study area is split between the Lewes Nodular Chalk of the White Chalk Subgroup (in the west) and the Wroxham Crag Formation (in the east). The rest of the Hornsea Three geology and ground conditions study area is underlain by Lewes Nodular Chalk of the White Chalk Subgroup.

1.7.3.3 The White Chalk Subgroup is described by the BGS as "*Chalk with flints, with discrete marl seams, nodular chalk, sponge-rich and flint seams throughout*" (BGS, n.d.). There are a number of localised chalk exposures on the valley sides in the following locations: Aldeford, Aldeford Common, Scotchwood Hills (southwest of Attlebridge) and Algarsthorpe Farm (southeast of Marlingford).

1.7.3.4 The BGS describe the Wroxham Crag Formation as comprising "*a sheet of interbedded gravels, sands, silts and clays. The gravels are dominated by flint (up to c.80%) and by quartz and quartzite (up to c.60%), with far-travelled minor lithogies including Carboniferous chert, Rhaxella chert, Greensand chert, Spilsby Sandstone and felsic volcanic rocks from North Wales. The deposits are interpreted as estuarine and near-shore marine*" (BGS, n.d.).

Superficial deposits

1.7.3.5 The majority of the Hornsea Three geology and ground conditions study area is underlain by superficial deposits predominantly made up of glacial deposits. In the northern part of the Hornsea Three geology and ground conditions study area, the valley floors are dominated by Alluvium and Head. Peat is also present near Beach Lane at the Hornsea Three landfall area. The higher ground is underlain by Head deposits, Britons Lane Sand and Gravel Member and Weybourne Town Till. From Bodham to Corpusty the deposits are more varied but are still dominated by glacial deposits. These deposits include: Briton Lane Sand and Gravel Member, Head deposits, Weybourne Town Till, Sheringham Cliff Formation, Glacio-fluvial deposits, Alluvium and Till.

1.7.3.6 Moving south, the superficial deposits are similar to the above but with areas of River Terrace Deposits in the valley floors. Other mapped strata include Brickearth, the Lowestoft Formation and the Leet Hills Sand and Gravels Formation. The Leet Hills deposits are limited in their extent to the area of the existing substation at Dunston and its immediate surrounds.

1.7.3.7 The onshore HVAC booster station area is underlain by Briton Lane Sand and Gravel Member with Head deposits potential along the north boundary. The onshore HVDC converter/HVAC substation area is underlain by the Lowestoft Formation.

1.7.3.8 BGS (n.d.) provide the following descriptions for each of the superficial deposits encountered within the Hornsea Three geology and ground conditions study area:

- Alluvium: Normally soft to firm consolidated, compressible silty clay, but can contain layers of silt, sand, peat and basal gravel. A stronger, desiccated surface zone may be present.
- River Terrace Gravels comprise sand and gravel, locally with lenses of silt, clay or peat.
- Head deposits are located in valley bases/sides and are described by the BGS as "*Polymict deposit: comprises gravel, sand and clay depending on upslope source and distance from source. Poorly sorted and poorly stratified deposits formed mostly by solifluction and/or hillwash and soil creep. Essentially comprises sand and gravel, locally with lenses of silt, clay or peat and organic material*" (BGS, n.d.).
- Brickearth varies from silt to clay, and is usually yellow-brown.
- The Briton's Land Sand and Gravel Member consists of horizontal, massive and low angle planar cross-bedded gravels and cobble gravels with thin seams of horizontal and rippled sand. The lithology has a distinctive high flint content (c.85-89%) of which the majority is of non-chatter marked variety (c.78-85%). The gravels also contain a wide range of far-travelled crystalline erratics including rocks of British and Scandinavian provenance.
- Till – Diamicton. The Weybourne Town Till Member consists of a highly calcareous silt and chalk-rich matrix supported diamicton. It is generally massive in structure, but locally, (such as at the unit's stratotype locality), the diamicton is highly stratified, consisting of highly attenuated and deformed inclusions of pre-existing till (Bacton Green Till Member).
- Sheringham Cliffs Formation is described by the BGS as "*consisting of a thick glacigenic sequence that contains several distinctive features such as the Mundesley Sand Member, which consists of stratified fine-grained sands; this is overlain by the laminated silts and clays of the Ivy Farm Laminated Silt Member. Overlying these waterlain sediments are the Runton Till and Bacton Green Till members; these are matrix-supported diamictons, which in turn, are overlain by thin units of clay (Trimingham Clay Member) and sand (Trimingham Sand Member). These deposits are truncated by the chalky Weybourne Town Till Member, a highly consolidated matrix-supported diamicton, and finally by the Runton Cliffs Sand and Gravel Member which forms the highest stratigraphical unit within the Formation*" (BGS, n.d.).
- Lowestoft Formation (also Happisburgh Glaciagenic) forms an extensive sheet of chalky till, together with outwash sands and gravels, silts and clays. The till is characterised by its chalk and flint content. The carbonate content of the till matrix is about 30%, and tills within the underlying Happisburgh Formation have less than 20%.
- Leet Hill Sand and Gravel Formations are "*stratified and channelled proximal glaciofluvial outwash deposits. Lithologically, the gravels are rich in flint and quartzose clasts, and contain gravel sourced from different geological strata in northern areas*" (BGS, n.d.).

1.7.3.9 The BGS mapping indicates a thrust fault within the superficial deposits near to Little Wood (NGR 611486E, 334062N). The fault is evident within the Briton Sand and Gravel Member.

1.7.3.10 BGS geological logs have been obtained for the Hornsea Three geology and ground conditions study area. The location of the boreholes and a summary of the borehole logs and are included in volume 6, annex 1.1: Borehole Logs.

Artificial Ground

1.7.3.11 The majority of the Hornsea Three geology and ground conditions study area is not shown to be underlain by artificial ground. However, it should be noted that localised made ground is likely to be present along the Hornsea Three onshore cable corridor as a result of current and historic development, which is not shown on the BGS geology map.

1.7.3.12 Small pockets of artificial ground classified as "*worked ground (undivided) – voids*" are mapped by the BGS within the Hornsea Three geology and ground condition study area. These are typically associated with historical ponds, quarries and pits. The majority of which will have been historically backfilled.

1.7.3.13 In the north of the Hornsea Three geology and ground condition study area, where the cable makes landfall there is an area of artificial ground mapped which has been classified as "*disturbed ground (undivided)*", with localised pockets of "*infilled ground*" and "*made ground (undivided)*". The BGS describes these deposits as a man-made superficial deposit of variable composition, with the infilled ground related to backfilling activities of a former quarry, pit or pond. The nature and provenance of these materials is unknown. However, based on the historical land uses in this area and the potential age of the backfill strata it is considered unlikely that significant and widespread contamination will be present.

1.7.4 Hydrogeology and groundwater: bedrock, superficial deposits and artificial ground

1.7.4.1 The hydrogeology and groundwater conditions within the Hornsea Three geology and ground conditions study area have been identified characterised using the Groundsure Geo Insight and Enviro Insight reports (Groundsure, 2017b), hydrogeological maps, BGS geology maps and aquifer maps.

Bedrock

1.7.4.2 In North Norfolk, the Chalk aquifer is dominated by groundwater flow via fissures and bedding planes, which tend to be more prevalent in the top 30 to 60 m of the chalk leading to a high flow potential at these depths. Depth to groundwater and groundwater flow direction is heavily influenced by the overlying topography. Seasonal fluctuations in groundwater levels are likely to occur based on the low storage capacity of the chalk with such variation being more prevalent towards the higher topographic areas. Inter-seasonal variation in groundwater levels are also likely to occur based on the preceding weather conditions (i.e. higher groundwater levels following wetter than typical periods and vice versa). The chalk is a well utilised groundwater source as detailed below in the description of licensed abstraction boreholes and SPZs.

1.7.4.3 Chalk is generally located at approximately 10 m Above Ordnance Datum along the Hornsea Three geology and ground conditions study area, indicating a significant depth of superficial deposits along much of the corridor with zones of thicker superficial deposits along former glacial channels. The presence of overlying superficial deposits, including lower permeability clays means that the chalk will locally be a confined aquifer.

1.7.4.4 Groundwater flow in the upper part of the Hornsea Three geology and ground conditions study area is towards the north. Groundwater levels are high at Hempstead due to a divide between groundwater catchments. To the north of the divide groundwater forms the North Norfolk Chalk Catchment and flow will be to the north. Whereas to the south of the divide groundwater form the Broadlands Rivers Chalk and Crag Catchment and flow will be in a southerly direction.

1.7.4.5 Towards the central area of the Hornsea Three geology and ground conditions study area, groundwater flow direction is determined by the river valleys which form the dominant topographic features. A groundwater divide is located at Heydon (E 610642 N 327003); to the north of this divide flow is generally to the north. South of the divide, groundwater flow is to the south and southeast.

1.7.4.6 The direction of groundwater flow in the southern end of the Hornsea Three geology and ground conditions study area also follows the dominant topographic features of the river valleys with corresponding groundwater flows to the east.

1.7.4.7 The chalk is designated as a principal aquifer, which is defined by the BGS as "*layers of rock or superficial deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as major aquifers*" (BGS, n.d.).

1.7.4.8 Chalk is highly transmissive but can store relatively little groundwater as the majority of flow and storage is attributable to fractures. These characteristics mean that it is susceptible to drought with rapid flow and discharge occurring after it recharges in winter (i.e. most recharges passes rapidly through the aquifer system).

1.7.4.9 The Wroxham Crag Formation is also a principal aquifer but is less utilised as a source groundwater due to its unconsolidated nature (i.e. loose material making construction and use of abstraction wells more problematic than the underlying chalk).

1.7.4.10 The Environment Agency undertake groundwater level monitoring in the area and they use the data to calculate the quantity of groundwater that can be abstracted each year through the abstraction licensing system. A key borehole in their monitoring network is located at Weston Longville, the monitoring data from which is used to assess if cessation conditions should be imposed on numerous abstractions within the Wensum catchment. The location of the Environment Agency monitoring boreholes is shown in volume 6, annex 1.4: Water Framework Directive Groundwater Assessment.

1.7.4.11 The Environment Agency has provided groundwater level monitoring data, which indicates two distinct groundwater bodies, with shallow groundwater at depths of between 0.0 and 4.9 m below ground level (bgl) and a deeper groundwater body at depths of 11.5 to 25.97 m bgl.

Superficial deposits

1.7.4.12 The hydrogeology of the superficial deposits will be dominated by localised perched groundwater generally present in the more permeable strata such as sand and gravels or more localised permeable lenses with more clay dominated strata such as Till. Groundwater flow within the superficial deposits will be more linked to local topography with potential for seepages when more permeable layers overlie less permeable layers.

1.7.4.13 All the superficial deposits underlying the Hornsea Three geology and ground conditions study area, with the exception of localised peat and Brickearth, are all classified as either secondary A aquifer or secondary undifferentiated. The peat is considered to be unproductive strata defined as having negligible significance for water supply or river base flow. Brickearth deposits are classified as secondary B aquifers.

1.7.4.14 Secondary a aquifers are defined by the Environment Agency (n.d.) as "*permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers*".

1.7.4.15 The category of secondary undifferentiated has been assigned in cases where it has not been possible to attribute either category A or B to a rock type. In most cases, this means that the layer in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type.

1.7.4.16 The Environment Agency (n.d.) define secondary B aquifers as "*predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. These are generally the water-bearing parts of the former non-aquifers*".

Artificial Ground

1.7.4.17 Artificial ground is generally classified as unproductive strata and is not anticipated to contain significant quantities of water. Artificial ground, which is granular in nature can contained localised perched pockets of groundwater, especially after periods of heavy and prolonged rainfall. Any groundwater within these deposits would not be considered under the local and regional water framework. However, where present they provide preferential pathways for any potential localised contamination.

Water Framework Directive

1.7.4.18 In relation to groundwater, the WFD is designed to:

- Promote the sustainable use of water;
- Reduce pollution of water, especially by 'priority' and 'priority hazardous' substances; and
- Ensure progressive reduction of groundwater pollution.

1.7.4.19 The Hornsea Three geology and ground conditions study area is located within the Anglian River Basin District. Each river basin district is required to prepare a river basin management plan which provides a framework for protecting and enhancing the benefits provided by the water environment based on the following information:

- Baseline classification of water bodies;
- Statutory objectives for protected areas – areas of land and water bodies that have specific use that require special protection (e.g. waters used for drinking water or those supporting important ecological habitats and species). The legally binding objectives protect those uses from potentially harmful activities and new developments;
- Statutory objectives for water bodies – these are legally binding objectives. The default objective is "good" status, however less stringent objectives have been set in some cases where natural conditions or technical feasibility make improvement impractical. The default deadline for achieving objectives is 2021, however in some cases extended deadlines of 2027 have been set; and
- Summary programme of measures to achieve statutory objectives.

1.7.4.20 River basin management plans are updated every six years and the current plan for the Anglian River Basin District was prepared in 2016 (Department of Food and Rural Affairs, 2016).

1.7.4.21 The groundwater bodies within the Hornsea Three geology and ground conditions study area are the North Norfolk Chalk Unit (reference GB40501, G400100) and the Broadland Rivers Chalk and Crag Unit (GB40501, G400300). The current status of these groundwater bodies (cycle 1 data) is set out Table 1.7 and Table 1.8. Cycle 1 data is the data collected under the initial WFD with cycle 2 data relating to the updated WFD 2017.

Table 1.7: WFD data for North Norfolk Chalk Unit.

Criteria	Classification
Waterbody ID	GB40501, G400100
Current quantitative quality	Good
Groundwater dependent terrestrial ecosystems (quantitative impacts)	Good
Impact on surface waters	Good
Saline or other intrusions	Good
Resource balance	Good

Criteria	Classification
Current chemical quality	Poor
Upward chemical trend	Yes

Table 1.8: WFD data for Broadland Rivers Chalk and Crag Unit.

Criteria	Classification
Waterbody ID	GB40501, G400300
Current quantitative quality	Poor
Groundwater dependent terrestrial ecosystems (quantitative impacts)	Poor
Impact on surface waters	Good
Saline or other intrusions	Good
Resource balance	Good
Current chemical quality	Poor
Upward chemical trend	Yes

1.7.4.22 A detailed assessment of the anticipated risk to groundwater bodies has been carried out in line with the Water Framework Directive and is included as volume 6, annex 1.4: Water Framework Directive Groundwater Assessment.

Source Protection Zones

1.7.4.23 The Environment Agency defines SPZs for groundwater sources such as wells, boreholes and springs used for public drinking water supply. Table 1.9 outlines the different types of groundwater SPZs. The different SPZs (see Table 1.9) show the sensitivity to contamination from any activities that might cause pollution in the area and are based on the travel time through the aquifer to the abstraction point. The closer the activity is to the abstraction source, the shorter the travel time and hence greater the source sensitivity. SPZ mapping comprises three main zones (inner, outer and total catchment) and a fourth zone of special interest, which may be occasionally applied to a groundwater source but is not present in this locality.

1.7.4.24 The groundwater vulnerability within an SPZ1 is considered by the Environment Agency to be very high.

1.7.4.25 The SPZ mapping shown in volume 6, annex 1.2: Abstraction Licences and Source Protection Zones shows the location of SPZs within the Hornsea Three geology and ground conditions study area. The SPZs, within the study area, relate to existing major public water supply abstractions from the principal aquifer.

Table 1.9: Definitions of Groundwater Source Protection Zones.

Zone	Definition
SPZ1	Inner protection zone defined as the 50 day travel time from any point below the water table to the source. This zone has a minimum radius of 50 m.
SPZ2	Outer protection zone defined by a 400 day travel time from a point below the water table. The previous methodology gave an option to define SPZ2 as the minimum recharge area required to support 25% of the protected yield. This option is no longer available in defining new SPZs and instead this zone has a minimum radius of 250 m or 500 m around the source, depending on the size of the abstraction.
SPZ3	Source catchment protection zone defined as the area around a source within which all groundwater recharge is presumed to be discharged at the source. In confined aquifers, the source catchment may be displaced some distance from the source. For heavily exploited aquifers, the final Zone Definition.
Zone of Special Interest	For some groundwater sources an additional Zone of Special Interest may be defined. These zones highlight areas where known local conditions mean that potentially polluting activities could impact on a groundwater source even though the area is outside the normal catchment of that source.

1.7.4.26 There are six SPZs within the Hornsea Three geology and ground conditions study area; these comprise.

- Norfolk Agricultural College Source – SPZ1;
- Dunston Common Source – SPZ1, SPZ2 and SPZ3;
- Bernard Matthews Source – SPZ1, SPZ2 and SPZ3;
- Costessey Source – SPZ2 and SPZ3;
- Colney Source – SPZ2 and SPZ3; and
- Mactintosh and Sons Source – SPZ3.

1.7.4.27 Of the list of SPZs listed above, there is one SPZ1 which is partially within the footprint of the onshore elements of Hornsea Three. This is associated with the boreholes at Norfolk Agricultural College Source.

1.7.4.28 During the pre-application phase, the Environment Agency has indicated that the location of the SPZ boundaries is currently under review and will be published in 2018. The Environment Agency have advised how these updates will affect the SPZs in the Hornsea Three geology and ground conditions study area and this has been taken into account (see Table 1.4).

Groundwater abstractions

1.7.4.29 Records held by Groundsure (2017a) and the Local Authorities identify 77 licensed and de-regulated groundwater abstractions located within the Hornsea Three geology and ground conditions study area. Of these, two abstractions are for public water supply both of which are located at Easton College. There are three licensed abstractions and one private groundwater abstraction located within or immediately adjacent to the Hornsea Three onshore cable corridor, which are used for general farming/domestic and spray irrigation purposes. The source of these abstractions, as well as the majority of the abstractions within the Hornsea Three onshore cable corridor, is likely to be the underlying chalk bedrock. In a few cases, the abstractions are sourced from the superficial glacial sands/gravel deposits.

1.7.4.30 The groundwater abstractions within the Hornsea Three geology and ground conditions study area are identified in volume 6, annex 1.2: Abstraction Licences and Source Protection Zones.

Discharge consents and permit

1.7.4.31 Records held by Groundsure (2017a) identify 51 consented discharges to land, either directly, via a borehole or via a soakaway, which are located within the Hornsea Three geology and ground conditions study area. The discharges are regulated using discharge consents and environmental permits issued by the Environment Agency.

1.7.4.32 The majority of discharge consents within the Hornsea Three geology and ground conditions study area relate to final/treated effluent from domestic properties which are discharged into land. The remaining discharge consents relate to water company sewage discharge and storm water discharge, agricultural discharges including emergency discharges, unspecified discharges and cooling water discharges.

1.7.4.33 Consented discharges within the Hornsea Three geology and ground conditions study area are identified in volume 6, annex 1.3: Environment Agency Discharge Consents and Permits.

Current and historic land uses

1.7.4.34 Land within the Hornsea Three geology and ground conditions study area is predominantly used for agriculture and open land. The study area also crosses roads, ditches/drains and larger watercourses.

1.7.4.35 A former military camp was located to the east of the Hornsea Three onshore cable corridor close to the Hornsea Three landfall area. An internet search has identified this site as the former Muckleburgh camp which was in use during the First and Second World Wars as an anti-aircraft artillery station (Britains Finest, n.d.).

1.7.4.36 A disused Ministry of Defence pipeline is located within the Hornsea Three geology and ground conditions study area near to Hethersett, which was identified during consultation with the landowner. The pipeline was used to transport oil to Royal Air Force Coltishall and it is understood that this pipeline has been decommissioned. Land above the pipeline has been farmed and there is no evidence visible within the vegetation of any significant fuel spills along the section of the pipeline within the Hornsea Three geology and ground conditions study area. The exact location of the pipeline will be determined as part of the detailed design stage.

1.7.4.37 Whilst the review of historic maps has not identified any land uses within the Hornsea Three geology and ground conditions study area that are likely to result in significant widespread contamination, there are a number of uses which may have potentially caused localised ground and groundwater contamination. These include: infilled ponds; disused pits; infilled pits; former factories and warehouses of unknown use; cemeteries; substations; sewage treatment works and former military land. The risks associated with these localised areas will be confirmed and addressed as part of preliminary risk assessments and/or site investigations during the detailed design stage.

1.7.4.38 Reference to Groundsure (2017a) data identifies that there are no active petrol stations within the Hornsea Three geology and ground conditions study area.

1.7.4.39 According to the Groundsure (2017a) records, there are no sites recorded as contaminated land under Part IIA of the Environmental Protection Act 1990 within the Hornsea Three geology and ground conditions study area.

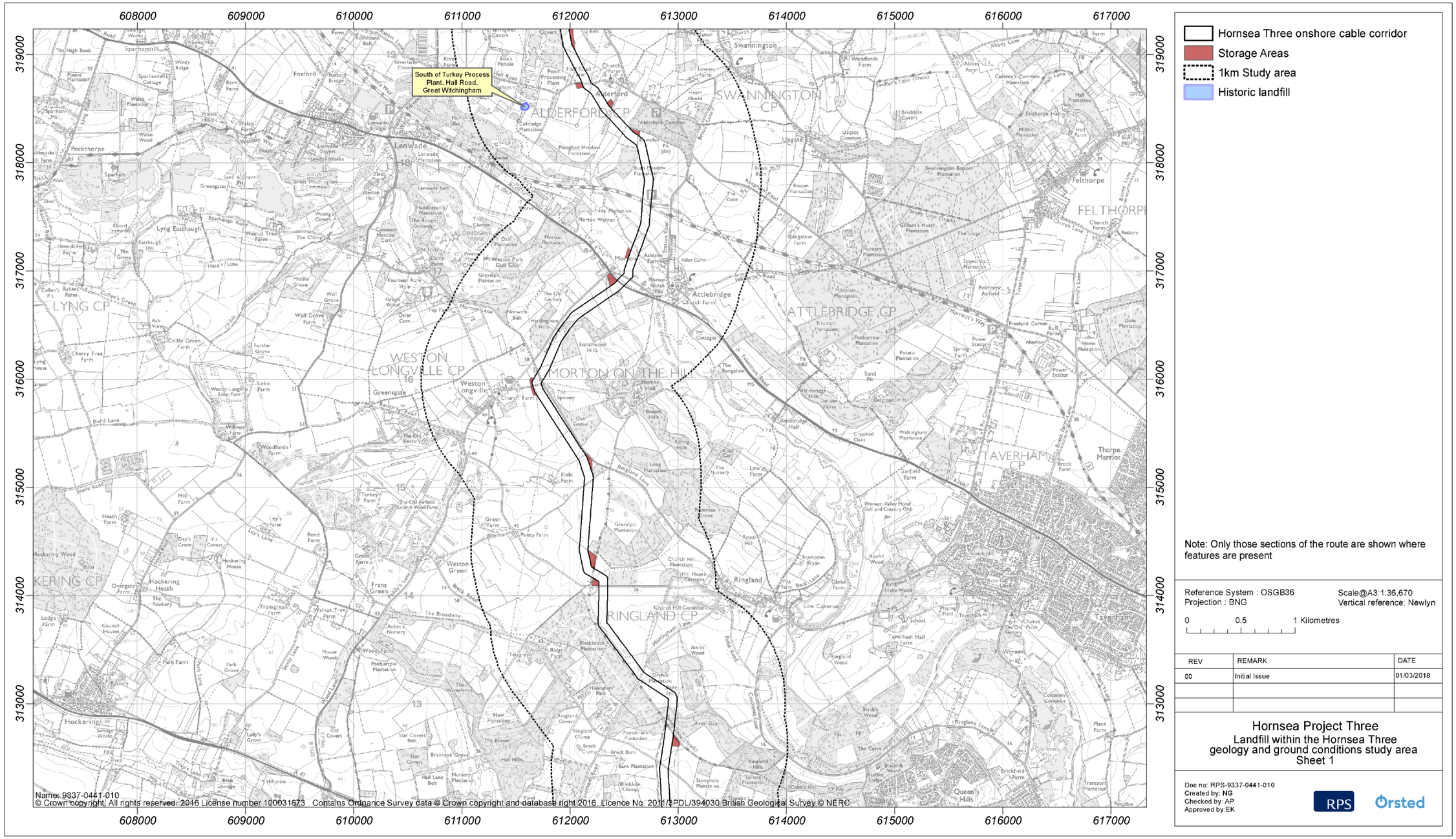

Figure 1.4: Landfills within the Hornsea Three geology and ground conditions study area.

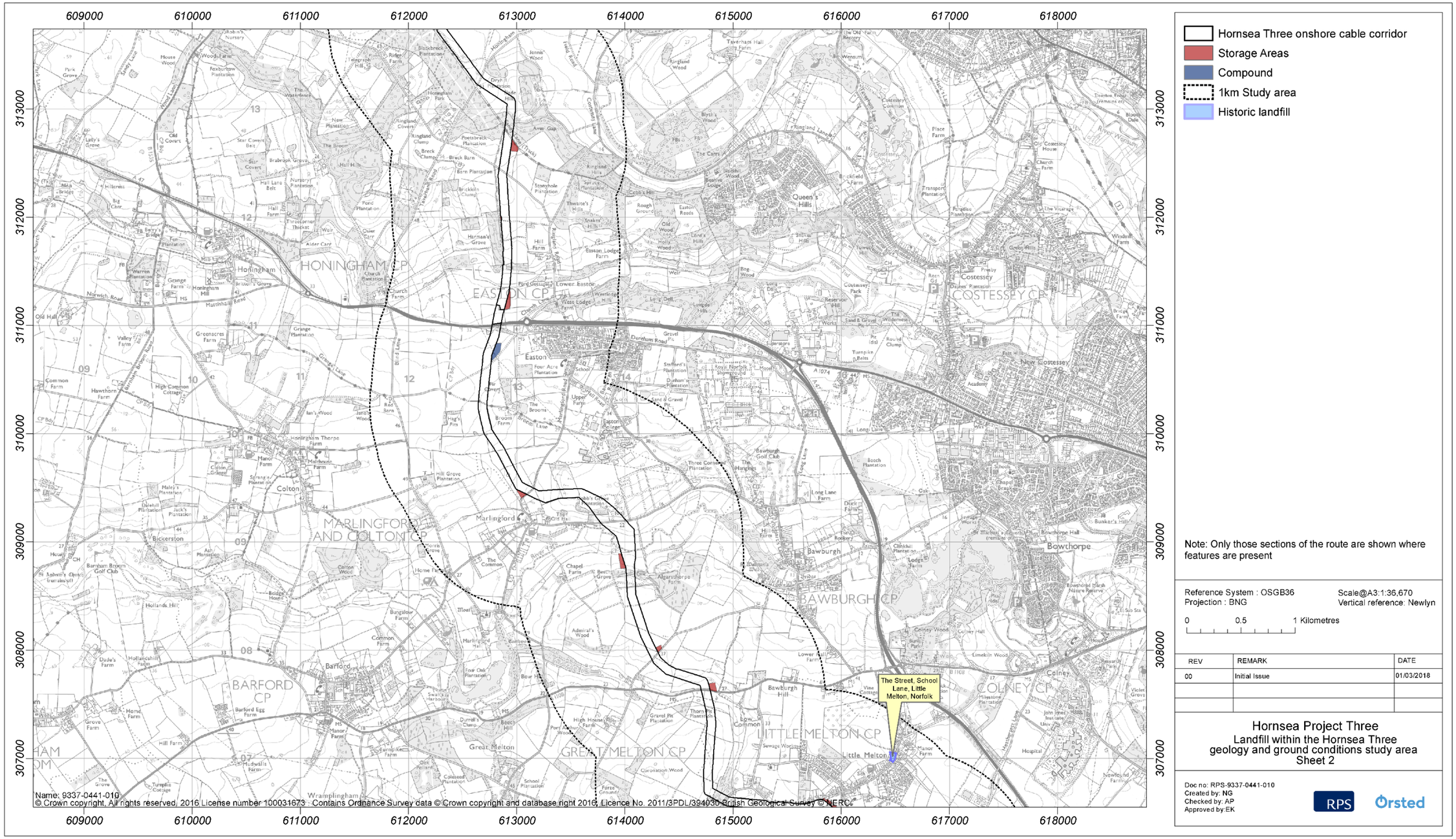

Figure 1.4: Landfills within the Hornsea Three geology and ground conditions study area.

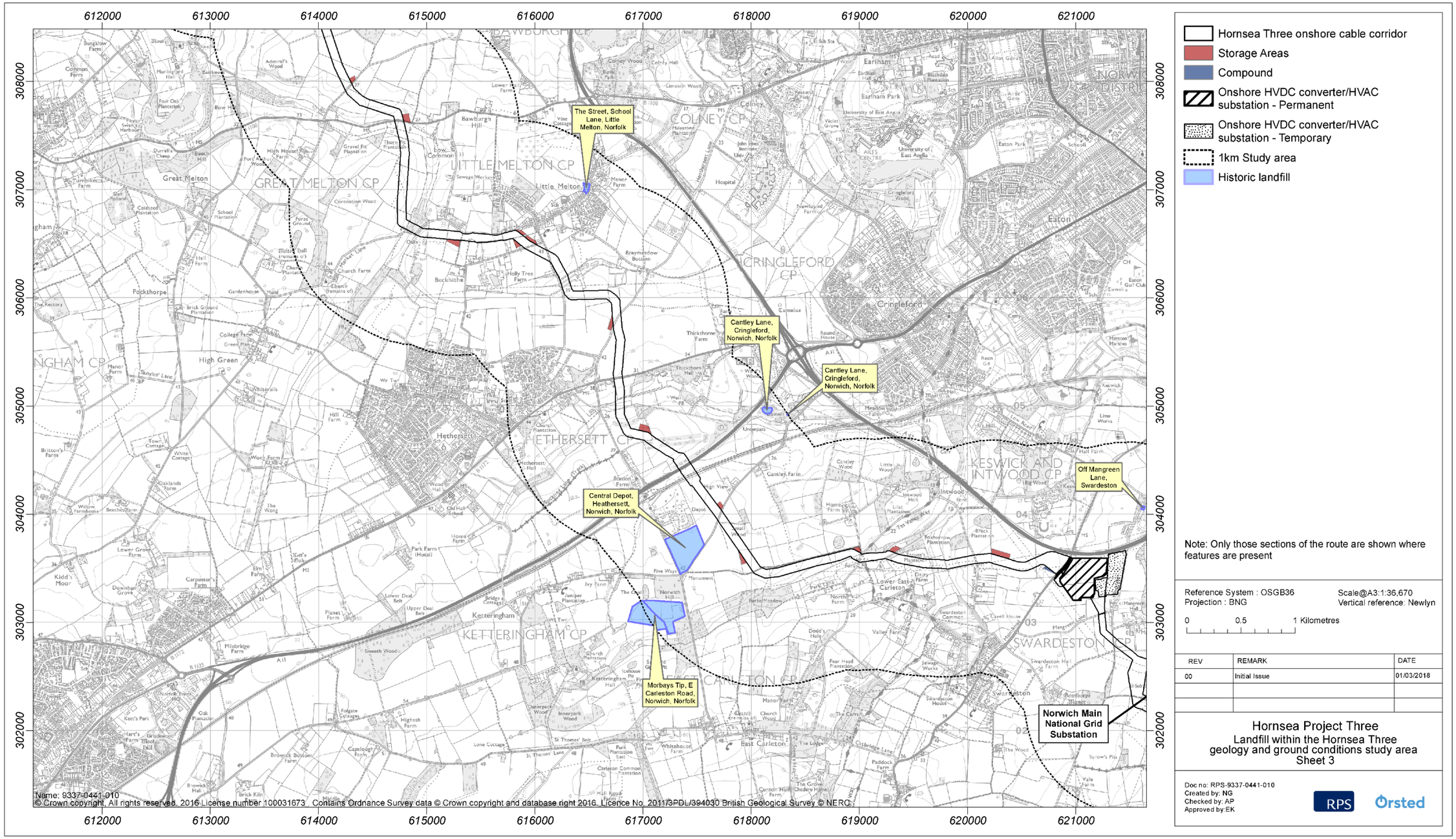

Figure 1.4: Landfills within the Hornsea Three geology and ground conditions study area.

Landfill and other waste sites

1.7.4.40 Waste management facilities within the Hornsea Three geology and ground conditions study area are shown on Figure 1.4.There are no current (i.e. active) landfill sites within the geology and ground conditions study area however there are a number of historic landfills and these are listed below:

- South of Turkey Process Plant, Great Witchingham;
- The Street, Little Melton;
- Cantley Lane, Cringleford;
- Central Depot, Heathersett;
- Morbays Tip, Norwich; and
- Off Mangreen Lane, Swardeston.

1.7.4.41 Only those areas of the Hornsea Three geology and ground conditions study area where waste management facilities were identified are shown on Figure 1.4.

Natural hazards and mining

1.7.4.42 The Hornsea Three geology and ground conditions study area is not in an area affected by coal mining. There is no evidence of mining or the associated risk of subsidence within 50 m of the onshore HVAC booster station and HVDC converter/HVAC substation. The potential hazards associated with running sands; landslides, compressible deposits and dissolution soluble rocks within the onshore HVAC booster station area or onshore HVDC converter/HVAC substation area are characterised as being low. However, these will be considered during detailed design phase.

1.7.5 Future baseline scenario

1.7.5.1 The Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 requires that "*an outline of the likely evolution thereof without implementation of the development as far as natural changes from the baseline scenario can be assessed with reasonable effort on the basis of the availability of environmental information and scientific knowledge*" is included within the Environmental Statement.

1.7.5.2 In the event that Hornsea Three does not come forward, an assessment of the future baseline conditions has been carried out and is described within this section.

1.7.5.3 The future baseline in relation to geology and ground conditions is unlikely to differ significantly from that which has been described above. It is assumed that in the absence of Hornsea Three, the majority of the Hornsea Three geology and ground conditions study area would remain as farmland and that there would be no significant change in geology, hydrogeology and ground conditions without any significant change in land use.

1.7.6 Data limitations

1.7.6.1 BGS geological mapping terminology classifications are inconsistent, due to different publication dates of the mapping. This also affects the aquifer classifications as these are based on the underlying geological mapping. Whilst potentially adding a degree of confusion it does not affect the certainty/predictability of assessment as the sensitivity is not fundamentally changed.

1.7.6.2 In addition, it should be noted that during discussions with the Environment Agency, it has been indicated that the SPZ are in the process of being updated. At the time of writing this newly updated information on existing SPZs was not available. Details of an additional SPZs were however provided (see 1.7.4.28). Although these updates may change the boundaries of the SPZs, it is not considered that any of the changes would significantly affect the groundwater assessment conclusions presented in this chapter.

1.8 Key parameters for assessment

1.8.1 Maximum design scenario

1.8.1.1 The maximum design scenarios identified in Table 1.10 have been selected as those having the potential to result in the greatest effect on an identified receptor or receptor group. These scenarios have been selected from the details provided in the project description (volume 1, chapter 3: Project Description). Effects of greater adverse significance are not predicted to arise should any other development scenario, based on details within the project Design Envelope, to that assessed here be taken forward in the final design scheme.

1.8.2 Impacts scoped out of the assessment

1.8.2.1 On the basis of the baseline environment and the project description outlined in volume 1, chapter 3: Project Description, a number of impacts are proposed to be scoped out of the assessment for geology and ground conditions. These impacts are outlined, together with a justification for scoping them out, in Table 1.11.

Table 1.10: Maximum design scenario considered for the assessment of potential impacts on geology and ground conditions.

Potential impact	Maximum design scenario	Justification
Construction phase		
Impacts of construction may result in the loss of mineral resources within Mineral Safeguarding Areas	<u>Hornsea Three landfall area</u> Open cut at the Hornsea Three landfall area including: • Up to 42,000 m^2 compound area including up to 1,500 m^2 from transition joint bays (based on 250 m^2 x 6); • Up to six cables; and • Corridor width up to 240 m wide (comprising six cables (with installation area up to 15 m) plus up to 20 m separation between each cable. The maximum duration over which works could occur at the landfall would be approximately 5.5 years (assuming a three year gap between the two phases). <u>Hornsea Three onshore cable corridor</u> • Up to 1,650,000 m^2 (5 m x 55,000 m x 6) from installation of up to six cable trenches; • On average 0.6 m stabilised backfill in each 2 m deep trench; • Up to 99,000 m^2 from jointing bays (based on 440 jointing bays (each jointing bay is 9 m x 25 m)); • Up to 3,960 m^2 from link boxes (based on 440 link boxes (each link box: is 3 m x 3 m)). Link boxes are permanent sub surface structures; • Up to 396,000 m^2 from installation of temporary haul road/accesses (6 m x 66,000 m per phase); • Up to 120 HDD locations per phase (up to 105 minor HDDs and 15 major HDDs per phase), up to 54,000 m^2 from major HDD compounds (based on 15 HDD compounds (each compound is 60 m x 60 m)); • Up to five secondary compounds; • Up to 55 storage areas; and • The haul road would be surfaced with aggregate on geotextile and would be removed at the end of each construction phase. The maximum duration over which construction could occur at the onshore cable corridor would be 5.5 years incorporating two phases (assuming a three-year gap between the two phases). The work in each phase is expected to progress along the Hornsea Three onshore cable corridor with a typical active construction works duration of three months at any particular location. <u>Onshore HVAC booster station</u> Up to 30,407 m^2 for permanent area of site plus a temporary works area up to 25,000 m^2. Maximum building footprint of 9,000 m^2 (based on single building scenario (120 m length and 75 m width) and height up to 12.5 m). Up to 30,000 m^3 excavated for basement (based on 5m deep and area of 6,000 m^2). The maximum duration over which construction could occur at the onshore HVAC booster station would be five years incorporating two phases assuming a three-year gap with no active construction activity between the two phases. <u>Construction programme</u> The maximum duration of construction for all onshore elements of Hornsea Three would be eight years, which assumes construction across two phases with a three-year gap in-between, as a result of staggered construction of the components (onshore HVAC booster station, onshore HVDC converter/HVAC substation and Hornsea Three onshore cable corridor) and each phase would be preceded by pre construction activities such as borehole investigations at HDD crossing points	The maximum design scenario for potential loss of mineral resources would be the HVAC transmission option due to the greater number of cable trenches required and the potential need to construct the onshore HVAC booster station as this may result in greater areas of sand and gravel being impacted. The onshore HVDC converter/HVAC substation is not located within a Mineral Safeguarded Area. Open cut methods at landfall represent the maximum design scenario for the potential loss of mineral resources due to the greatest footprint required.

Potential impact	Maximum design scenario	Justification
Impacts of construction may cause disturbance or contamination of secondary aquifers.	<u>Hornsea Three onshore cable corridor</u> • Up to 1,650,000 m^2 (5 m x 55,000 m x 6) from installation of up to six cable trenches; • On average 0.6 m stabilised backfill in each 2 m deep trench; • Up to 99,000 m^2 from jointing bays (based on 440 jointing bays (each jointing bay is 9 m x 25 m)); • Up to 3,960 m^2 from link boxes (based on 440 link boxes (each link box: is 3 m x 3 m)). Link boxes are permanent sub surface structures; • Up to 396,000 m^2 from installation of temporary haul road/accesses (6 m x 66,000 m per phase); • Up to 120 HDD locations per phase (up to 105 minor HDDs and 15 major HDDs per phase), up to 54,000 m^2 from major HDD compounds (based on 15 HDD compounds (each compound is 60 m x 60 m)); • Up to five secondary compounds; and • Up to 55 storage areas. • The haul road would be surfaced with aggregate on geotextile and would be removed at the end of each construction phase. The maximum duration over which construction could occur would be 5.5 years incorporating two phases (assuming a three-year gap between the two phases). The work in each phase is expected to progress along the Hornsea Three onshore cable corridor with a typical active construction works duration of three months at any particular location <u>Onshore HVAC booster station</u> Up to 30,407 m^2 for permanent area of site plus a temporary works area up to 25,000 m^2. Maximum building footprint of 9,000 m^2 (based on single building scenario (120 m length and 75 m width) and height up to 12.5 m). Up to 30,000 m^3 excavated for basement (based on 5m deep and area of 6,000 m^2). The maximum duration over which construction could occur at the onshore HVAC booster station would be five year incorporating two phases (assuming a three-year gap with no active construction activity between the two phases). <u>Onshore HVDC converter/HVAC substation</u> Up to 149,302 m^2 for permanent area of site (including an area which may be used for landscaping) plus a temporary works area of 91,000 m^2. Maximum building dimensions: up to 220 m length, 75 m width and 25 m height for main buildings. The maximum duration over which construction could occur at the onshore HVDC converter/HVAC substation would be six years incorporating two phases assuming a three-year gap with between the two phases. <u>Construction programme</u> The maximum duration of construction for all onshore elements of Hornsea Three would be eight years, which assumes construction across two phases with a three-year gap in-between, as a result of staggered construction of the components (onshore HVAC booster station, onshore HVDC converter/HVAC substation and Hornsea Three onshore cable corridor) and each phase would be preceded by pre construction activities such as borehole investigations at HDD crossing points.	The maximum design scenario for disturbance of secondary A and B aquifers would be the HVAC transmission option due to the greater number of cable trenches required and the potential need to construct the onshore HVAC booster station as this would result in the largest area of disturbance of the secondary aquifers. The dimensions of the main buildings at the onshore HVDC converter/HVAC substation represent the maximum design scenario as the largest area of disturbance to secondary aquifers from the construction of foundations. In terms of contamination to secondary aquifers, both crossing options may create pathways for contaminants, however HDD methods represent the maximum design scenario as they go deeper below the ground, increasing the likelihood of hydraulically connecting with groundwater in secondary aquifers.
Impacts of open cut trench construction may affect the groundwater quality and groundwater flow of the principal aquifer including at the SPZs.		The 2 m depth of the onshore export cable trench represents the maximum design scenario for affecting groundwater quality of principal aquifers by open cut trench construction as in some locations of the onshore export cable corridor superficial deposits may be locally thin and there is the potential for the cable trenches to intersect the principal aquifer and therefore, create a pathway. The HVAC transmission option requires a greater number of cable trenches, link boxes and junction bays and therefore the greater footprint increases the possibility of intersecting the principal aquifer.
Impacts of HDD and piling works (potentially required for the construction of the onshore HVAC booster station or onshore HVDC converter/HVAC substation) may affect the groundwater quality and groundwater flow of the principal aquifer, including conduit construction within any SPZs.		HDD methods represent the maximum design scenario for affecting groundwater quality and flow of the principal aquifer as these methods go deep below the ground (bypassing lower permeability superficial deposits) and may create a pathway for contaminants to the groundwater resource within the principal aquifer with minimal potential for attenuation. The dimensions of the main buildings at the onshore HVDC converter/HVAC substation represent the maximum design scenario as the largest area of disturbance to the principal aquifer from the construction of foundations. However, in terms of affecting groundwater quality and flow at depth, the onshore HVAC booster station represents the maximum design scenario as this requires the construction of a basement 5 m deep.
Impacts of construction may affect the quantity and quality of surface waters fed by groundwater.		The HVAC transmission option represents the maximum design scenario for affecting the quantity and quality of surface waters fed by groundwater as it requires the greatest number cable trenches and the potential need for the onshore HVAC booster station resulting in the greatest area of disturbance and a higher likelihood that temporary localised dewatering of the trenches may be required. Dewatering of secondary aquifers may impact on the quantity of surface waters where there is a hydraulic connection. In terms of crossing locations, HDD represents the maximum design scenario as they go deeper below the ground, increasing the likelihood of creating a pathway.

Potential impact	Maximum design scenario	Justification
Operation and maintenance phase		
Impacts of operations and maintenance may affect the water quality of secondary aquifers and any associated surface waters together with the principal aquifer.	Routine maintenance of the onshore HVDC converter/HVAC substation and HVAC booster station.	The maximum design scenario for water quality of secondary aquifers (any associated aquifers) and the principal aquifers during operation is that chemicals and oils would be used in the routine maintenance of the onshore HVDC converter/HVAC substation. An onshore HVAC booster station would also potentially be required for the HVAC transmission (in addition to a HVAC substation) which would also require maintenance and therefore, represents the maximum design scenario
Impacts of operation may affect groundwater quality from thermal effects of underground power cables.	***Hornsea Three onshore cable corridor*** On average 0.6 m depth of thermally stabilised material to surround the cables and back fill the trench.	The HVAC transmission option represents the maximum design scenario in terms of thermal pollution effects on principal aquifers from operation of cables.
Decommissioning phase		
Impacts of decommissioning may cause disturbance or contamination of secondary aquifers (and any associated surface waters) and principal aquifer.	Removal of the following (above and below ground): ***Onshore HVAC booster station*** Up to 30,407 m^2 for permanent area of site ***Onshore HVDC converter/HVAC substation*** Up to 149,302 m^2 for permanent area of site (including an area which may be used for landscaping). ***Hornsea Three onshore cable corridor*** Surface features of the link boxes may be removed and made safe.	The maximum design scenario for disturbance or contamination during decommissioning is the removal of the onshore HVDC converter/HVAC substation and onshore HVAC booster station as this presents the greatest disturbance and potential risk of contaminants being released. The removal of the link boxes surface features during decommissioning represents the maximum design scenario as this would result in disturbance of land along the onshore export cable corridor.

Table 1.11: Impacts scoped out of the assessment for geology and ground conditions

Potential impact	Justification
Construction phase	
Impacts of construction may lead to the direct loss or damage to nationally and regionally important geological sites.	Following the refinement of the onshore cable corridor, no direct land take would be required from nationally or regionally designated geological sites. On this basis, the impact on nationally and regionally important geological sites can be scoped out of the assessment.
Operation and maintenance phase	
Impacts of operations and maintenance (for the onshore cable corridor) may affect the water quality of secondary aquifers and any associated surface waters together with the principal aquifer	There are no proposed routine maintenance operations for the onshore cable corridor.

1.9 Impact assessment methodology

1.9.1 Overview

1.9.1.1 The geology and ground conditions EIA has followed the methodology set out in volume 1, chapter 5: Environmental Impact Assessment Methodology. Specific to the geology and ground conditions EIA, the following guidance documents have also been considered:

- Highways Agency (1993, amended August 1994) DMRB Volume 11, Section 3, Part 11 Geology and Soils;
- British Standards (2013) BS10175: Code of Practice for Investigation of Potentially Contaminated Sites;
- Environment Agency and Defra (2004) Model Procedures for the Management of Land Contamination (CLR11); and
- CIRIA (2001) Contaminated land risk assessment: A guide to good practice.

1.9.1.2 In addition, the geology and ground conditions EIA has considered the legislative framework as defined by:

- Part IIA Environmental Protection Act (1990);
- Environment Act (1995);
- Contaminated Land (England) Regulations (2006) and Amendment (2012);
- Groundwater Regulations (1998);
- Groundwater (England and Wales) Regulations (2009);
- Water Resources Act (1991);
- Water Act (2003);
- Groundwater Regulations (1998), which transport the EC Groundwater Directive (80/68/EC) into UK law;
- Water Environment (Water Framework Directive) (England and Wales) Regulations (2017), which transpose the Water Directive 200/60/EC into UK law; and
- Environmental Permitting (England and Wales) Regulations (2016).

1.9.2 Impact assessment criteria

1.9.2.1 The criteria for determining the significance of effects is a two stage process that involves defining the sensitivity of the receptors and the magnitude of the impacts. This section describes the criteria applied in this chapter to assign values to the sensitivity of receptors and the magnitude of potential impacts. The terms used to define sensitivity and magnitude are based on those used in the Design Manual for Roads and Bridges (Highways Agency, 2009) methodology, which is described in further detail in volume 1, chapter 5: Environmental Impact Assessment Methodology.

1.9.2.2 The criteria for defining sensitivity in this chapter are outlined in Table 1.12.

Table 1.12: Definition of terms relating to the sensitivity of the receptor.

Sensitivity	Definition used in this chapter
Very High	Receptor is very high value or critical importance to local, regional or national economy. Receptor is highly vulnerable to impacts that may arise from the project and recoverability is long term or not possible.
High	Receptor is of high value with reasonable contribution to local, regional or national economy. Receptor is generally vulnerable to impacts that may arise from the project and recoverability is slow and/or costly (e.g. remedial measures to groundwater may be required to prevent a wider impact).
Medium	Receptor is of medium value with small levels of contribution to local, regional or national economy. Receptor is somewhat vulnerable to impacts that may arise from the project and has moderate to high levels of recoverability (e.g. up to 5 years for groundwater to return to its current or an improved condition).
Low (or lower)	Receptor is of low value with little contribution to local, regional or national economy. Receptor is not generally vulnerable to impacts that may arise from the project and/or has high recoverability (e.g. up to 1 year before groundwater returns to its current or improved condition).
Negligible	Receptor is of negligible value with no contribution to local, regional or national economy. Receptor is not vulnerable to impacts that may arise from the project and/or has high recoverability.

1.9.2.3 The criteria for defining magnitude in this chapter are outlined in Table 1.13.

Table 1.13: Definition of terms relating to the magnitude of an impact.

Magnitude of impact	Definition used in this chapter
Major	Total loss of ability to carry on activities. Impact is of extended temporal or physical extent and of long term duration (i.e. up to 10 years duration).
Moderate	Loss or alteration to significant portions of key components of current activity. Loss of resource but not affecting integrity of resource. Impact is of moderate temporal or physical extent and of medium term duration (i.e. less than 5 years).
Minor	Some measurable change in attributes, quality or vulnerability. Minor shift away from baseline conditions, leading to a reduction in level of activity that may be undertaken. Impact is of limited temporal or physical extent and of short term duration (i.e. up to 2 years).
Negligible	Very slight change from baseline conditions. Physical extent of impact is negligible and of short term duration (i.e. up to 1 year).
No change	No change from baseline conditions.

1.9.2.4 The significance of the effect upon geology and ground conditions is determined by correlating the magnitude of the impact and the sensitivity of the receptor. The method employed for this assessment is presented in Table 1.14. Where a range of significance of effect is presented in Table 1.14 the final assessment for each effect is based upon expert judgement.

1.9.2.5 For the purposes of this assessment, any effects with a significance level of minor or less have been concluded to be not significant in terms of the EIA Regulations.

Table 1.14: Matrix used for the assessment of the significance of the effect.

		Magnitude of impact				
		No change	***Negligible***	***Minor***	***Moderate***	***Major***
Sensitivity of receptor	***Negligible***	Negligible	Negligible	Negligible or minor	Negligible or minor	Minor
	Low	Negligible	Negligible or minor	Negligible or minor	Minor	Minor or moderate
	Medium	Negligible	Negligible or minor	Minor	Moderate	Moderate or major
	High	Negligible	Minor	Minor or moderate	Moderate or major	Major or substantial
	Very high	Negligible	Minor	Moderate or major	Major or substantial	Substantial

1.10 Measures adopted as part of Hornsea Three

1.10.1.1 As part of the project design process, several designed-in measures have been proposed to reduce the potential for impacts on geology and ground conditions (see Table 1.15). As there is a commitment to implementing these measures, they are considered inherently part of the design of Hornsea Three and have therefore been considered in the assessment presented in section 1.10 (i.e. the determination of magnitude and therefore significance, assumes implementation of these measures). These measures are considered standard industry practice for this type of development. These measures will be implemented under the Outline CoCP (document reference A8.5).

Table 1.15: Designed-in measures adopted as part of Hornsea Three.

Measures adopted as part of Hornsea Three	Justification
Construction Phase	
Ongoing consultation with Norfolk County Council Mineral Planning Authority regarding the Mineral Safeguarding Areas located along the Hornsea Three onshore cable corridor and the onshore HVAC booster station area.	To minimise the area of viable mineral resource affected by the project.
Implement measures to protect groundwater during construction, including good environmental practices based on legal responsibilities and guidance on good environmental management in: guidance in: CIRIA C532 Control of Water Pollution from Construction Sites – Guidance for Consultants and Contractors (2001); and CIRIA C648 Control of Water Pollution from Linear Construction Projects (2006).	To help avoid pollution incidents occurring.
A written scheme dealing with contamination of any land and groundwater will be submitted and approved by the Local Authority before any part of the development commences. The scheme will include preliminary risk assessment where appropriate.	To help to deal with potentially contaminated land or groundwater and reduce the risk of creating additional / preferential pathways.
Minimise where practicable production of silt and contaminated water by minimising for example: • Disturbance of river bed and bank; • Dewatering and pumping of excavations and subsequent disposal of water; • Runoff from exposed ground and stockpiles; • Plant and wheel washing; • Site roads and river crossings; • Fuel spillages; and • Waste storage and disposal. Mitigation in accordance with CIRIA C692 Environmental good practice on site guide (2010).	To reduce the potential for construction and maintenance activities in or near water to cause serious pollution or impact on the bed and banks of a watercourse and on the quality and quantity of the water.
Cable trenching across the SPZ1 areas requires measures to ensure that the principal aquifer is unaffected either directly or indirectly. The depth of superficial deposits would be confirmed via site investigation to ensure works are not undertaken within the chalk aquifer. The site investigation will allow an assessment of the relationship between the aquifer within the superficial deposits and the underlying principal aquifer, to ensure works will not directly impact the principal aquifer. Hydrogeological risk assessment, will be undertaken at each trenchless conduit crossing location within a SPZ. Direct Current cabling to be thermally insulated.	To prevent chemical or thermal pollution of principal aquifers and public water supply. To ensure that the construction of the cable does not adversely affect regional groundwater flows and any local changes in flow direction are minimal.
Cable trenching across areas with secondary A or B aquifers requires measures to ensure the groundwater quality is not adversely affected and that groundwater does not use the trenches as a conduit to convey groundwater elsewhere. Direct Current cabling to be thermally insulated.	To prevent chemical or thermal pollution of secondary aquifers. To ensure that the construction of the cable does not adversely affect regional groundwater flows and any local changes in flow direction are minimal.
Trenchless conduits for onshore watercourse cable crossing points to be a minimum 2 m below the hard bed of the watercourse subject to site investigation confirming a suitable standoff above the chalk principal aquifer. This is to minimise the risk of "frac-out" and avoid disruption of groundwater flows to surface watercourses. A minimum standoff of 2 m above the chalk aquifer is suggested. Hydrogeological risk assessment), will be undertaken at each trenchless conduit crossing location of a watercourse. A method statement will be prepared for the watercourse crossings in discussion with the Environment Agency. The method statement will include details of the proposed trenchless methods, any monitoring to be undertaken and any remedial measure to be put in place. For those crossings identified as highly sensitive (due to interactions with adjacent ecologically designated sites) site specific method statements will be prepared.	To minimise impacts to principal aquifers.
Site investigations will be undertaken at each proposed HDD location during the detailed design stage to confirm local geological conditions. The Environment Agency will be consulted on the methodology of the site investigations.	To confirm suitability of geology for HDD techniques. To determine the absence of localised impacted soils and groundwater.

Measures adopted as part of Hornsea Three	Justification
Deep trenchless excavations and deep excavations for pile foundations to be mitigated by casing off shallow groundwater units during construction works and sealing off once the casing is removed. Based on guidance in: Piling and Penetrative Ground Improvement Methods on land Affected by Contamination: Guidance on Pollution Prevention (Environment Agency, 2001).	To prevent contamination of groundwater and mixing of different groundwater units.
Implement measures to prevent and control spillage of oil, chemicals and other potentially harmful liquids. Ensure appropriate storage and handling of materials and products to include for example: • Avoidance of oil storage within 50 m of a spring, well or borehole; • Within 10 m of a watercourse • Where oil could run over hard ground into a watercourse; • Secondary containment system that can hold at least 110% of the oil volume stored; and • Avoidance of storage of oil in areas at risk of flooding. In accordance with The Control of Pollution (Oil Storage) (England) Regulations 2001. Refuelling of machinery would be undertaken within designated areas where spillages can be easily contained. Machinery would be routinely checked to ensure it is in good working condition; and any tanks and associated pipe work containing oils and fuels would be double skinned and be provided with intermediate leak detection equipment.	To minimise ground contamination and prevent contaminated runoff entering surface water or groundwater.
Used oils will be disposed of properly in accordance with Environmental Permitting (England and Wales) Regulations 2016.	To reduce the risk of soil, surface water and groundwater pollution.
Operation and Maintenance Phase	
Operational practices to incorporate measures to prevent pollution of ground, geology and groundwater, to include emergency spill response procedures, clean up and remediation of contaminated soils.	To reduce the risk of soil, surface water and groundwater pollution.
Decommissioning Phase	
Decommissioning practices to incorporate measures to prevent pollution of geology and ground conditions, to include emergency spill response procedures, and clean up and remediation of contaminated soils. The measures will follow a similar approach to those set out for the construction phase.	To reduce the risk of soil, surface water and groundwater pollution to protect ground and groundwater based on guidance that will be appropriate at the time of decommissioning.

1.11 Assessment of significance

1.11.1 Construction Phase

1.11.1.1 The impacts of the onshore construction of Hornsea Three have been assessed on geology and ground conditions. The potential impacts arising from the construction of Hornsea Three are listed in Table 1.10 along with the maximum design scenario against which each construction phase impact has been assessed.

1.11.1.2 A description of the potential effect on geology and ground conditions receptors caused by each identified impact is provided in the following sections.

Impacts of construction may result in the loss of mineral resources within Mineral Safeguarding Areas.

Magnitude of impact

1.11.1.3 A review of the Norfolk County Council Mineral Safeguarding Area for sand and gravel shows that approximately 245 hectares of the Mineral Safeguarding Area would be impacted by the onshore elements of Hornsea Three. This is considered to be a relatively small proportion of the total Mineral Safeguarding Area for sand and gravel in Norfolk (as shown in Figure 1.3). Furthermore, it is noted that the areas which would be impacted are spread along a relatively narrow linear route rather than a single large area. This, coupled with the variable quality of the resource underlying the Hornsea Three onshore cable corridor, is likely to make extraction unfeasible. In addition, it should be noted that some of the Mineral Safeguarding Areas along the geology and ground conditions study area are small in extent which would also reduce the viability of mineral extraction. Therefore, although Hornsea Three would lead to a reduction in the level of extraction activity that could be undertaken within the Hornsea Three onshore cable corridor, the impact is predicted to be of limited physical extent, with areas adjacent to the Hornsea Three onshore cable corridor still be available for extraction.

1.11.1.4 Furthermore the impact would be reversible as the mineral resource within the Hornsea Three onshore cable corridor would not be permanently sterilised. The operating life of Hornsea Three is 35 years after which time, the mineral resource could be extracted subject to economic viability. Where the mineral resource is extracted, the associated environmental impacts would be assessed as approipriate on a site by site basis.

1.11.1.5 The magnitude is predicted to be of local spatial extent, of long term duration, of continuous occurrence and high reversibility. Whilst long term duration impacts are normally associated with a higher magnitude of impact, the limited spatial extent of the mineral resource that would be affected by Hornsea Three in relation to the total mineral resource within Norfolk and that adjacent areas of mineral resource could still be extracted (subject to the viability of the resource) have been taken into account. Taking into consideration, the integration of measures adopted in Table 1.15, the magnitude is considered to be minor.

Sensitivity of receptor

1.11.1.6 Sand and gravel resources are relatively abundant throughout Norfolk, however the resource as a whole is deemed to be medium vulnerability, moderate recoverability (in that the resource is abundant in Norfolk and there are alternative sources of sand and gravel) and of regional value. Therefore the sensitivity of these Mineral Safeguarding Areas is considered to be medium.

Significance of the effect

1.11.1.7 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of **minor adverse** significance, which is not significant in EIA terms.

Impacts of construction may cause disturbance or contamination of secondary aquifers.

Magnitude of impact

1.11.1.8 Direct impacts may occur to the secondary aquifers underlying the Hornsea Three onshore cable corridor (and onshore HVAC booster station and onshore HVDC converter/HVAC substation) due to the intrusive nature of trenching and piling. The nature of the impact would include potential disruption to groundwater flow and reduction in groundwater quality. The magnitude of impact depends on the nature and depth of the superficial deposits (and aquifer unit) in relation to the proposed depth of excavation.

1.11.1.9 Secondary aquifers are likely to be present at relatively shallow depth (based on the BGS logs), however, given the highly variable nature of the superficial strata, both locally and regionally, lateral and vertical migration of water within the aquifers is potentially limited. Therefore, although the secondary aquifers may be in hydraulic connectivity with the underlying principal aquifer, movement between the two is likely to be limited. Therefore, the impact is predicted to be of local spatial extent, of short term duration, of intermittent occurrence and high reversibility. With the integration of the measures adopted in Table 1.15 and the Outline CoCP (document reference A8.5), the magnitude is therefore, considered to be negligible.

Sensitivity of receptor

1.11.1.10 The secondary aquifers, which comprise the groundwater within the superficial deposits, are deemed to be of medium vulnerability, but of moderate to high recoverability and medium value. The sensitivity of the receptor is therefore, considered to be medium.

Significance of the effect

1.11.1.11 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **negligible** significance, which is not significant in EIA terms.

Impacts of open cut trench construction may affect the groundwater quality and groundwater flow of the principal aquifer including at SPZs.

1.11.1.12 There are six SPZs located within the Hornsea Three geology and ground conditions study area, all of which relate to groundwater abstractions where water is abstracted from the chalk aquifer. The chalk aquifer beneath the Hornsea Three study area is generally covered by superficial deposits with the exception of a number of small chalk exposures. None of the chalk exposures correspond with the location of SPZs.

Magnitude of impact

1.11.1.13 Given the relatively shallow depth of the cable trench (i.e. up to 2 m deep), the open cut trench construction would generally occur within the superficial deposits and not within the bedrock strata. The variable nature of the superficial deposits will likely limit downward migration of shallow waters into the principal aquifer. However there remains the potential for impacts to occur from vertical hydraulic connections between groundwater within the secondary aquifers (within the superficial deposits) and principal aquifer groundwater during piling, or during open cut trench construction, particularly in locations where the superficial deposits are shallow.

1.11.1.14 The impacts from the construction of the cable trench on the groundwater within the SPZ1 are considered to be limited. This is due to the relatively shallow depth of the cable trench and the presence and depth of the superficial deposits overlying the principal aquifer in this location (as identified in BGS borehole TG10NW14 and presented in volume 6, annex 1.1: Borehole Logs) which would provide a degree of attenuation to the downward migration of contaminants.

1.11.1.15 The depth of the cable trench, located within the superficial deposits and potentially encroaching on the secondary aquifers, will minimise the effects of the cable on the local groundwater flow direction during construction. As no construction is anticipated within the principal aquifer, regional groundwater flow will remain unaltered.

1.11.1.16 The impacts are predicted to be of local spatial extent, of short term duration, of intermittent occurrence and high reversibility. It is predicted that the impact will affect the receptor indirectly. With the integration of the measures in Table 1.15 and the Outline CoCP (document reference A8.5), the magnitude of impact on the groundwater quality within the principal aquifer (including the SPZ1, SPZ2 and SPZ3) is therefore, considered to be negligible.

Sensitivity of receptor

1.11.1.17 The majority of the principal aquifer in the Hornsea Three geology and ground conditions study area is overlain by superficial deposit although BGS mapping indicates there are localised areas where the bedrock strata is encountered at much shallower depth and no superficial deposits are present. This would be confirmed at detailed design stage. The nature of the superficial deposits is variable and includes lower permeability glacial till clays and also more permeable deposits (alluvium, river terrace gravels and sand and gravels). The principal aquifer is considered to have a slow/costly recoverability and is of high value. The sensitivity of the receptor is therefore, considered to be high.

1.11.1.18 Where the principal aquifer is classified as SPZ2 and SPZ3 within the Hornsea Three geology and ground conditions study area, the sensitivity is considered to be high.

1.11.1.19 Where the principal aquifer is classified as SPZ1 within the Hornsea Three onshore cable corridor, the sensitivity is considered to be very high.

Significance of the effect

1.11.1.20 Overall, the sensitivity of the principal groundwater aquifer (SPZ2 and SPZ3) is considered to be high and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **minor adverse** significance, which is not significant in EIA terms.

1.11.1.21 Where the principal aquifer is classified as SPZ1 within the Hornsea Three onshore cable corridor, the sensitivity of the receptor is considered to be very high and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **minor adverse** significance which is not significant in EIA terms.

Impacts of HDD and piling works (potentially required for the construction of the onshore HVAC booster station or onshore HVDC converter/HVAC substation) may affect the groundwater quality and groundwater flow of the principal aquifer (including within SPZs).

Magnitude of impact

1.11.1.22 Direct impacts to the principal aquifer may occur from deeper ground workings related to HDD operations for cable installation beneath surface watercourses or infrastructure. The Environment Agency will be consulted on an appropriate standoff between the trenchless conduit and the chalk which will be confirmed following a site investigation and hydrogeological risk assessment (see Table 1.15). A similar approach will be followed where piling is required to provide foundation for the onshore HVAC booster station and onshore HVDC converter/HVAC substation.

1.11.1.23 The depth of HDD is likely to be contained within the superficial deposits. The variable nature of the superficial deposits comprising low permeability glacial till clays and more permeable deposits (alluvium, river terrace gravels and sand and gravels), will limit potential downward migration of any potential contamination present in shallow soils and groundwater. It will also minimise the effects during construction on the local groundwater flow direction.

1.11.1.24 The impacts during the construction from HDD operations on the groundwater within the SPZ1 is considered to be minor. This is due to the presence and depth of the superficial deposits overlying the principal aquifer in this location (as identified in BGS borehole TG10NW14 and presented in volume 6, annex 1.1: Borehole Logs) which would provide a degree of attenuation.

1.11.1.25 The impacts are predicted to be of local spatial extent, of short term duration, of intermittent occurrence and high reversibility. It is predicted that the impact will affect the receptor indirectly. With the implementation of the mitigation measures in Table 1.15 and the Outline CoCP (document reference A8.5), the magnitude of impact on the principal aquifer (including the SPZ1, SPZ2 and SPZ3) is therefore, considered to be negligible.

Sensitivity of receptor

1.11.1.26 The principal aquifer, which underlies the superficial deposits beneath the Hornsea Three onshore cable corridor, the onshore HVAC booster station and onshore HVDC converter/HVAC substation, is deemed to be of high vulnerability. The principal aquifer is considered to have a slow/costly recoverability and is of high value. The sensitivity of the receptor is therefore considered to be high.

1.11.1.27 Where the aquifer is also classified as within a SPZ1 within Hornsea Three onshore cable corridor search area, the aquifer sensitivity is considered to be very high.

Significance of the effect

1.11.1.28 Overall, the sensitivity of the principal groundwater aquifer (SPZ2 and SPZ3) is considered to be high and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **minor adverse** significance, which is not significant in EIA terms.

1.11.1.29 Where the principal aquifer is classified as SPZ1 within the Hornsea Three onshore cable corridor search area, the sensitivity of the receptor is considered to be very high and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **minor adverse** significance which is not significant in EIA terms.

Impacts of construction may affect the quantity and quality of surface waters fed by groundwater.

Magnitude of impact

1.11.1.30 Indirect impacts may occur where shallow groundwater is in hydraulic connectivity with the surface water features, in particular where groundwater acts as a feeder for surface water features. The potential for indirect impacts will be higher in areas affected by trenching, or piling construction, which may be required during the construction of foundations associated with the HVAC booster station and HVDC converter/HVAC substation

1.11.1.31 The impact is predicted to be of local spatial extent, of short term duration, of intermittent occurrence and high reversibility. It is predicted that the impact will have a minor effect on the receptors both directly and indirectly. With the integration of the measures in Table 1.15 and the Outline CoCP (document reference A8.5), the magnitude is therefore, considered to be minor.

Sensitivity of receptor

1.11.1.32 Surface water courses in hydraulic connection with secondary aquifer units, comprising groundwater within the superficial deposits beneath the onshore elements of Hornsea Three are deemed to be of moderate vulnerability, but of moderate to high recoverability and medium value. The sensitivity of the receptor is therefore, considered to be medium.

Significance of the effect

1.11.1.33 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of **minor adverse** significance which is not significant in EIA terms.

Future monitoring

1.11.1.34 No geology and ground conditions monitoring, to test the predictions made within the construction phase, is considered necessary.

1.11.2 Operation and maintenance phase

1.11.2.1 The impacts of the onshore operation and maintenance of Hornsea Three have been assessed on geology and ground conditions. The environmental potential impacts arising from the operation and maintenance of Hornsea Three are listed in Table 1.10 along with the maximum design scenario against which each operation and maintenance phase impact has been assessed.

1.11.2.2 A description of the potential effect on geology and ground conditions receptors caused by each identified impact is given below.

Impacts of operations and maintenance may affect the water quality of secondary aquifers and principal aquifer together with any associated surface waters.

Magnitude of impact

1.11.2.3 Indirect impacts may occur to the secondary aquifers and the principal aquifer together with any associated surface waters underlying the onshore HVAC booster station and onshore HVDC converter/HVAC substation from spilled chemicals (e.g. oils, greases, lubricants and other chemicals) used during the routine maintenance. The use of such materials will be managed under the management plans which will detail protocols for dealing with any spills. The magnitude of impact from any accidental spills is dependent on the depth of the aquifer unit.

1.11.2.4 The impact is predicted to be of local spatial extent, of short term duration, of intermittent occurrence and high reversibility. It is predicted that the impact will affect the receptor directly. With the implementation of the measures in Table 1.15 the magnitude is therefore, considered to be negligible.

Sensitivity of receptor

1.11.2.5 The secondary aquifers, which are located within the superficial deposits are deemed to be of medium vulnerability, but of moderate to high recoverability and medium value. The sensitivity of the receptor is therefore, considered to be medium.

1.11.2.6 Surface water courses in hydraulic connection with secondary aquifer units are deemed to be of medium vulnerability, but of high recoverability and medium value. The sensitivity of this receptor is therefore considered to be medium.

1.11.2.7 The groundwater associated with the principal aquifer underlying the onshore HVAC booster station and HVDC converter/HVAC substation is not within a SPZ. It is deemed to be of medium vulnerability beneath low permeability glacial till clays, and of high vulnerability beneath more permeable alluvium, river terrace gravels and sand and gravels; and of slow/costly recoverability and high value. The sensitivity of the receptor is therefore considered to be high.

Significance of the effect

1.11.2.8 Overall, the sensitivity of the secondary and principal aquifers is considered to be medium to high (respectively) and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **negligible** to **minor adverse** significance, which is not significant in EIA terms.

Impacts of operation may affect groundwater quality from thermal effects of underground power cables.

1.11.2.9 Soil thermal resistivity is important in dissipating the heat generated by electricity flow through the transmission cable (conductor). A resistance to heat flow between the cable and the ambient environment causes the cable temperature to rise. Catastrophic failure can occur when cable temperatures rise to beyond their operating limits. In the case of underground cables the soil is in the heat flow path between the cable and the ambient environment, and therefore forms part of the thermal resistance. Hence soil thermal properties are an important part of the overall design, and may account for over 50% of the total thermal resistance (Campbell and Bristow, 2014).

1.11.2.10 Clearly whilst it is important to keep the cables within safe operating temperatures there is an effect on the surrounding ambient environment caused by the heat transfer. Assuming no forced cooling, underground cable systems have to dissipate the heat associated with losses via the surrounding soil. A cross-linked polyethylene cable system operated at nominal capacity and with a conductor temperature close to 90°C dissipates about 50 $W.m^{-1}$ to 100 $W.m^{-1}$ (Watts per linear metre).

1.11.2.11 Even assuming stationary full load conditions, the impact on soil temperature has been found to be strictly local and very limited, with temperature rises at the surface directly above a cable not exceeding 1 to 2 degrees Kelvin (K) (Campbell and Bristow, 2014). Makhkamova (2011) investigated the effects of dynamic changes in the surrounding environmental conditions of conductors using Computational Fluid Dynamic Methods. The computer models specifically considered the effects of changes in soil moisture, seasonal (winter/summer) temperatures and wind speed on buried underground cables in various arrangements using a 1600 mm x 1600 mm computational domain for single cables and 2500 mm x 2500 mm domain for grouped cables – three single cables buried in flat formation and three cables buried in trefoil formation. The soil temperature increase in response to heat loss by electrical flow through the conductor temperature decreased rapidly with increasing distance from the cables and the heating effect was undetectable beyond 1,200 mm either side of the cables in both the horizontal and vertical planes.

1.11.2.12 Nevertheless, in a region of about 0.5 m around a highly loaded cable, soil can dry out due to the generated heat which results in a reduced heat transfer capability and is therefore undesired. For that reason cables are often backfilled with a thermally stabilised layer consisting of concrete or sand blends that guarantee a specific heat resistance of less than 1.0 $W.m^{-1}$. This approach would be adopted for Hornsea Three.

1.11.2.13 The thermal effects of properly installed cables in a thermally stabilised layer will be minimal more than 1,200 mm from the cables in both horizontal and vertical planes.

Magnitude of impact

1.11.2.14 As a result of the review of the thermal effects of underground cables above, the thermal impact is predicted to be of local spatial extent within the immediate vicinity of each cable within the ground and any shallow aquifer unit, but of long term duration, of continual occurrence and high reversibility. The potential impact will be minimised by the use of a thermal stabilising layer (i.e. stabilised backfill) which will limit heat transference to the surrounding soil and shallow groundwater (see volume 1, chapter 3: Project Description). Potential impacts on the use of the soil are set out in chapter 6: Land Use and Recreation. Installation using HDD techniques within 2 m of the chalk would have limited potential to cause changes on local superficial deposit temperatures and would be undetectable at rock head. It is predicted that the impact will affect the receptors indirectly, through heat transference. The magnitude is therefore, considered to be minor. Where water receptors are at a distance of greater than 1.2 m from the cable, heat transference is undetectable and the magnitude of impact will be negligible. The downstream impact on any groundwater dependent watercourses is considered to be minor.

Sensitivity of receptors

1.11.2.15 The secondary groundwater aquifers, within the superficial deposits, are deemed to be of medium vulnerability, but of moderate to high recoverability and medium value. The sensitivity of the receptor is therefore, considered to be medium.

1.11.2.16 Surface watercourses in hydraulic connection with affected secondary aquifer units are deemed to be of medium vulnerability, but of high recoverability and medium value. The sensitivity of the receptor is therefore, considered to be medium.

1.11.2.17 The principal aquifer which underlies the superficial deposits beneath the Hornsea Three onshore cable corridor, onshore HVAC booster station and onshore HVDC converter/HVAC substation is deemed to be of high to very high vulnerability and of slow/costly recoverability and high value. The sensitivity of the receptor is therefore, considered to be high.

Significance of effect

1.11.2.18 Overall, the sensitivity of the secondary aquifers and hydraulically connected surface watercourses is considered to be medium and the principal aquifer is considered to be highly sensitive, and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of **minor adverse** significance, which is not significant in EIA terms.

Future monitoring

1.11.2.19 No geology and ground conditions monitoring, to test the predictions made within the operation and maintenance phase impact assessment, is considered necessary.

1.11.3 Decommissioning phase

1.11.3.1 The impacts of the onshore decommissioning of Hornsea Three have been assessed on geology and ground conditions. The potential environmental effects arising from the decommissioning of Hornsea Three are listed in Table 1.10, along with the maximum design scenario against which each decommissioning phase impact has been assessed.

1.11.3.2 A description of the potential effect on geology and ground conditions receptors caused by each identified impact is given below.

Impacts of decommissioning may cause disturbance or contamination of secondary aquifers and principal aquifer together with associated surface waters.

1.11.3.3 The effects of decommissioning activities are expected to be similar to the effects from construction. The significance of effect is therefore of **negligible** to **minor adverse** significance, which is not significant in EIA terms (see section 1.11.1)

Future monitoring

1.11.3.4 No geology and ground conditions monitoring, to test the predictions made within the decommissioning phase is considered necessary.

1.12 Cumulative Effect Assessment Methodology

1.12.1 Screening of other projects and plans into the Cumulative Effect Assessment

1.12.1.1 The Cumulative Effect Assessment (CEA) takes into account the impacts associated with Hornsea Three together with other projects and plans. The projects and plans selected as relevant to the CEA presented within this chapter are based upon the results of a screening exercise undertaken as part of the 'CEA long list' of projects (see volume 4, annex 5.2: Cumulative Effects Screening Matrix and Location of Schemes). Each project on the CEA long list has been considered on a case by case basis for scoping in or out of this chapter's assessment based upon data confidence, effect-receptor pathways and the spatial/temporal scales involved.

1.12.1.2 In undertaking the CEA for Hornsea Three, it is important to bear in mind that other projects and plans under consideration will have differing potential for proceeding to an operational stage and hence a differing potential to ultimately contribute to a cumulative impact alongside Hornsea Three. For example, relevant projects and plans that are already under construction are likely to contribute to cumulative impact with Hornsea Three (providing effect or spatial pathways exist), whereas projects and plans not yet approved or not yet submitted are less certain to contribute to such an impact, as some may not achieve approval or may not ultimately be built due to other factors. For this reason, all relevant projects and plans considered cumulatively alongside Hornsea Three have been allocated into 'Tiers', reflecting their current stage within the planning and development process. This allows the CEA to present several future development scenarios, each with a differing potential for being ultimately built out. Appropriate weight may therefore be given to each Tier in the decision making process when considering the potential cumulative impact associated with Hornsea Three (e.g. it may be considered that greater weight can be placed on the Tier 1 assessment relative to Tier 2). An explanation of each tier is included below:

- Tier 1: Hornsea Three considered alongside:
    - Other project/plans1 currently under construction and/or;
    - Those with consent, and, where applicable (i.e. for low carbon electricity generation projects), that have been awarded a Contract for Difference (CFD) but have not been implemented; and/or
    - Those currently operational that were not operational when baseline data was collected, and/or those that are operational but have an on-going impact.
- Tier 2: All projects/plans considered in Tier 1, as well as:
    - Those project/plans that have consent but, where relevant (i.e. for low carbon electricity generation projects) have no CFD; and/or
    - Submitted but not yet determined.
- Tier 3: All projects/plans considered in Tier 2, as well as those on relevant plans and programmes likely to come forward but have not yet submitted an application for consent (the Planning Inspectorate (PINS) programme of projects and the adopted development plan including supplementary planning documents are the most relevant sources of information from the relevant planning authorities regarding planned major works being consulted upon, but not yet the subject of a consent application). Specifically, this Tier includes all projects where the developer has advised PINS in writing that they intend to submit an application in the future, those projects where a Scoping Report is available and/or those projects which have published a PEIR.

[1] 'Other projects/plans' are major developments as defined in the Town and Country Planning (Development Management Procedure) Order 2010, or as a Nationally Significant Infrastructure project under the Planning Act 2008.

1.12.1.3 It is noted that offshore wind farms seek consent for a maximum design scenario and the as built offshore wind farm will be selected from the range of consented scenarios. In addition, the maximum design scenario quoted in the application (and the associated Environmental Statement) are often refined during the determination period of the application. For example, it is noted that the Applicant for Hornsea Project One considered a maximum of 332 turbines within the Environmental Statement, but has gained consent for 240 turbines. Similarly, Hornsea Project Two has gained consent for an overall maximum number of turbines of 300, as opposed to 360 considered in the Environmental Statement and the as built number of turbines is likely to be less than this. A similar pattern of reduction in the project envelope from that assessed in the Environmental Statement, to the consented envelope and the 'as built' project is also seen across other offshore wind farms of relevance to this CEA. This process of refinement can result in a reduction to associated project parameters, for example, the number of cable trenches or the height of onshore substations. The CEA presented in this geology and ground conditions chapter has been undertaken on the basis of information presented in the Environmental Statements for the other projects, plans and activities. Given that this broadly represents a maximum design scenario, the level of impact on geology and ground conditions would likely be reduced from those presented here

1.12.1.4 The specific projects scoped into this CEA and the Tiers into which they have been allocated, are outlined in Table 1.16. The distance to Hornsea Three relates to the closest distance from the onshore elements of Hornsea Three (as defined in 1.1.1.1). The projects included as operational in this assessment have been commissioned since the baseline studies for this project were undertaken and as such were excluded from the baseline assessment.

1.12.1.5 No Tier 1 projects have been identified and therefore, only Tier 2 and 3 assessments have been undertaken.

Table 1.16: List of other projects and plans considered within the CEA.

Tier	Phase	Project/Plan	Distance from Hornsea Three	Details	Date of Construction (if applicable)	Overlap of construction phase with Hornsea Three construction phase	Overlap of operation phase with Hornsea Three operation phase
2	Construction/Operation and Maintenance/Decommissioning	C/7/2014/7030	0 m	(I) For a southern extension to Mangreen Quarry and ancillary works with progressive restoration to agriculture and nature conservation by the importation of inert restoration materials; (II) Retention of existing consented facilities at Mangreen Quarry; (III) Establishment of crossing point over Mangreen Lane; and (IV) Proposed variation to approved restoration scheme at Mangreen Quarry. Approved 2 October 2015	2017 to 2024	Yes	Yes
	Construction/Operation and Maintenance/Decommissioning.	2011/1804/O	0 m	Residential led mixed use development of 1196 dwellings and associated uses including Primary School, Local Services (up to 1,850 sq.mtrs (GIA) of A1, A2, A3, A4, A5, D1 & B1 uses) comprising shops, small business units, community facilities/ doctors' surgeries, sports pitches, recreational space, equipped areas of play and informal recreational spaces. Extension to Thickthorn Park and Ride including new dedicated slip road from A11. Approved 22 July 2013 Reserved matters (2015/1681) for appearance, layout, and scale and landscaping of the first phase of development for 126 dwellings in relation to outline permission 2011/1804. (Reserved matters approved 18 February 2016) Reserved matters (2017/0151)- proposed residential development (phase A1-B) comprising 91 dwellings including 20% affordable housing and associated open space and infrastructure. (Reserved matters approved 17 May 2017)	2017 to 2026	Yes	Yes
	Construction/Operation and Maintenance/Decommissioning	2013/0092	7 m	Outline application for up to 20 residential units and associated highways works with all matters reserved. Approved 20 March 2014	2020 to 2021	Yes	Yes
	Construction/Operation and Maintenance/Decommissioning	2014/2611	21 m	The erection of 890 dwellings; the creation of a village heart to feature an extended primary school, a new village hall, a retail store and areas of public open space; the relocation and increased capacity of the allotments; and associated infrastructure including public open space and highway works. Approved 2 October 2015	2018 to 2028	Yes	Yes
	Construction/Operation and Maintenance/Decommissioning	20170789	55 m	Erection of grain store (revised proposal) Approved 19 July 2017	2020	Yes	Yes

Tier	Phase	Project/Plan	Distance from Hornsea Three	Details	Date of Construction (if applicable)	Overlap of construction phase with Hornsea Three construction phase	Overlap of operation phase with Hornsea Three operation phase
	Construction/Operation and Maintenance/Decommissioning	2013/0086/O	72 m	Outline application including means of access for residential development and ancillary works. Approved 30 April 2014	2017 to 2018	No	Yes
	Construction/Operation and Maintenance/Decommissioning	20170052	303 m	Greater Norwich Food Enterprise Zone Approved 31 October 2017	Unknown	Yes	Yes
	Construction/Operation and Maintenance/Decommissioning	2015/1697	312 m	Erection of 27 dwellings, accesses, open space, parking areas and associated works"	2019 to 2021	Yes	Yes
	Construction/Operation and Maintenance/Decommissioning	2012/1836	313 m	Erection of 27 dwellings, accesses , open space, parking areas and associated works. Approved 27 June 2016	2018 to 2021	Yes	Yes
	Construction/Operation and Maintenance/Decommissioning	2012/1836	338 m	Outline application for residential development (20 dwellings) and associated infrastructure works, including highway improvement works at the Mill Road/School lane/Burnthouse Lane junction. Approved 29 April 2014	Unknown	Yes	Yes
3	Construction/Operation and Maintenance/Decommissioning	EN010079" Norfolk Vanguard	0 m	Norfolk Vanguard is a proposed offshore wind farm with an approximate capacity of 1800MW off the coast of Norfolk. Pre-application stage PEIR October 2017	2020 to 2024	Yes	Yes

1.12.2 Maximum design scenario

1.12.2.1 The maximum design scenarios identified in Table 1.17 have been selected as those having the potential to result in the greatest effect on an identified receptor or receptor group. The cumulative impact presented and assessed in this section have been selected from the details provided in the Hornsea Three project description (volume 1, chapter 3: Project Description), as well as the information available on other projects and plans, in order to inform a 'maximum design scenario'. Effects of greater adverse significance are not predicted to arise should any other development scenario, based on details within the project Design Envelope to that assessed here be taken forward in the final design scheme.

Table 1.17: Maximum design scenario considered for the assessment of potential cumulative impacts on geology and ground conditions.

Potential impact	Maximum design scenario	Justification
Construction phase		
Impacts of construction may result in the loss of mineral resources within Mineral Safeguarding Areas	Tier 2 – 2014/2611 Tier 2 – 2013/0092 Tier 2 – 20170052 Tier 2 – C/7/2014/7030 Tier 3 – EN010079	Outcome of the CEA will be the greatest when most development occurs within Mineral Safeguarding Areas.
Impacts of construction, including HDD, may cause disturbance or contamination of principal aquifers or surface waters fed by groundwater	Tier 2 – 2014/2611 Tier 2 – C/7/2014/7030 Tier 2 – 2011/1804/O Tier 2 – 2013/0092 Tier 3 – EN010079	The construction phase of these projects potentially overlap with the construction of Hornsea Three. When considering these projects in combination with Hornsea Three there may be a cumulative effect on groundwater quality and groundwater flow. The greatest potential for cumulative impacts to occur with those projects immediately adjacent to the onshore elements of Hornsea Three.
Operation and Maintenance phase		
Impacts of operations and maintenance may affect the water quality of the principal aquifer and any associated surface waters	Tier 2 – C/7/2014/7030	Outcome of the CEA will be greatest where the projects are immediately adjacent to Hornsea Three and require operation and maintenance measures.
Impacts of operation may affect groundwater quality from thermal effects of underground power cables	Tier 3 – EN010079	Outcome of the CEA will be greatest where other thermal effects may exist.
Decommissioning phase		
Impacts of decommissioning may cause disturbance or contamination of secondary aquifers, principal aquifer, and any associated surface waters	Tier 2 – C/7/2014/7030	Outcome of the CEA will be greatest when the decommissioning of the HVAC booster station or HVDC converter/HVAC substation overlaps with projects likely to cause disturbance to the ground.

1.13 Cumulative Effect Assessment

1.13.1.1 A description of the significance of cumulative effects upon geology and ground conditions receptors arising from each identified impact is given below.

1.13.2 Construction Phase

Impacts of construction may result in the loss of mineral resources within the Mineral Safeguarding Areas.

Tier 2

Magnitude of impact

1.13.2.1 Sand and gravel mineral resources are relatively abundant in Norfolk and many of the sites listed in Table 1.16 are located within the Mineral Safeguarding Areas. Five of the projects listed are predicted to overlap with the construction timeframe of Hornsea Three. Of these projects, C//2014/7320 has been discounted in terms of cumulative impacts as this project involves the extraction of the sand and gravel resources (i.e. the resources will not be 'lost').

1.13.2.2 The greatest potential for cumulative impacts occur where the projects comprise large sites and where the development is permanent as this would result in the mineral resources being sterilised (e.g. 2014/2611). However, as part of the planning application process, the applicants would be required to follow the guidance provided by Norfolk County Council Mineral Planning Authority (Norfolk County Council, 2014) to investigate the quality of the resource and the feasibility of extraction prior to development. Where viable sand and gravel resources exist on the project sites listed in Table 1.17, it is assumed that these resources would be extracted prior to development as part of the planning consent.

1.13.2.3 Application C/7/2014/7030 involves the extension to the existing Mangreen Quarry. The proposed connection of the Hornsea Three onshore HVDC converter/HVAC substation overlaps with part of this proposed extension, however the information supporting project C/7/2014/7030 shows that the area of overlap will be used for ancillary works to the quarry (i.e. a new compound area) rather than the quarry extension. Subject to when construction on the quarry extension begins (programmed for 2017) and the operational life of the quarry, the underlying mineral resource in the area of overlap will already have been sterilised by the establishment of the compound area.

1.13.2.4 The impact is predicted to be of local spatial extent, of long term duration of continuous occurrence and high reversibility. The magnitude of the impact is therefore, considered to be minor.

Sensitivity of receptor

1.13.2.5 The sensitivity of these Mineral Safeguarding Areas is considered to be medium as set out in paragraph 1.11.1.6.

Significance of the effect

1.13.2.6 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to the minor. The effect will, therefore, be of **minor adverse** significance, which is not significant in EIA terms.

Tier 3

Magnitude of impact

1.13.2.7 The proposed Norfolk Vanguard cable route is linear in nature and the combined area with Hornsea Three is considered to represent a small proportion of the Norfolk's sand and gravel resources. As with Hornsea Three, the Norfolk Vanguard cable route does not represent permanent development and the resource could be extracted, as part of any future mineral extraction activity, following decommissioning of the onshore cable corridor.

1.13.2.8 The impact is predicted to be of local spatial extent, of long term duration of continuous occurrence and high reversibility. The magnitude of the cumulative impact is therefore, considered to be minor.

Sensitivity of receptor

1.13.2.9 The sensitivity of the Mineral Safeguarding Areas is considered to be medium as set out in paragraph 1.11.1.6.

Significance of the effect

1.13.2.10 Overall, the sensitivity of the receptor is considered to be medium and the magnitude of the impact is deemed to the minor. The effect will, therefore, be of **minor adverse** significance, which is not significant in EIA terms.

Impacts of construction, including HDD, may cause disturbance or contamination of the principal aquifers or surface waters fed by groundwater.

Tier 2

Magnitude of impact

1.13.2.11 As part of this assessment it has been assumed that there will be some overlap in the construction phases of several projects (e.g. 2013/0092). The projects included all have a spatial overlap with the onshore elements of the Hornsea Three project, although there is no spatial overlap between the projects themselves. Where construction is carried out at the same time there is the potential for cumulative impacts which could cause disturbance and potentially lead to contamination of the secondary and principal aquifers or surface waters fed by groundwater.

1.13.2.12 The nature of the impacts would include the potential disruption to groundwater flow and a reduction of groundwater quality. The magnitude of these impacts will depend on the nature and depth of the superficial deposits in relation to the proposed excavation depth of Hornsea Three onshore cable corridor (see volume 1, chapter 3: Project Description) and the cumulative projects.

1.13.2.13 Superficial deposits are mapped as present across the majority of the Hornsea Three geology and ground conditions study area, which are variable in nature. Shallow groundwater within the secondary aquifer is likely to be present however, downward migration of groundwater and therefore mobile contaminants are likely to be limited by the variable nature of the superficial deposits.

1.13.2.14 Excavations associated with the construction of the Hornsea Three onshore cable corridor are considered to be shallow and placed within the superficial deposits, therefore reducing the risk of preferential pathways being created.

1.13.2.15 The impact is predicted to be of local spatial extent, of short term duration, or intermittent occurrence. The magnitude is therefore, considered to be minor.

Sensitivity of receptor

1.13.2.16 The sensitivity of the surface waters fed by groundwater are considered to be medium (see paragraph 1.11.1.32) and the principal aquifer is considered to be of high sensitivity (see paragraphs 1.11.1.17 and 1.11.1.18).

Significance of the effect

1.13.2.17 Overall, the sensitivity of the receptors is considered to be medium to high and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of **minor adverse** significance which is not significant in EIA terms.

Tier 3

Magnitude of impact

1.13.2.18 The spatial overlap between Hornsea Three and Norfolk Vanguard (EN010079), which occurs between Salle and Booton, is relatively small in comparison to the extent of each of the projects. Furthermore, at this spatial overlap, it is understood that there will be limited temporal overlap in construction phases of the two projects. However, where construction is carried out at the same time or consecutively there is the potential for cumulative impacts which could cause disturbance of the groundwater and potentially lead to contamination of the secondary and principal aquifers or surface waters fed by groundwater.

1.13.2.19 The nature of the impacts would include the potential disruption to groundwater flow and a reduction of groundwater quality. The magnitude of these impacts will depend on the nature and depth of the superficial deposits in relation to the proposed excavation depths in both developments.

1.13.2.20 At the intersection point of the two projects, the first project would be installed using HDD techniques and the second project would be installed using open cut techniques. Based on the borehole records in the vicinity of where the two projects would cross, the superficial deposits are relatively shallow such that there is the potential for cables from one of the projects to be situated within the chalk deposits.

1.13.2.21 Groundwater monitoring levels are monitored by the Environment Agency and the closest monitoring location to the crossing of Hornsea Three and Norfolk Vanguard is located to the south of Marriot's Way. Data from the Environment Agency shows that the groundwater levels within the area to be at a depth of approximately 5m bgl, however groundwater levels for the crossing location would be confirmed by site specific investigations during the detailed design stage. There is the potential that one set of cables from either Hornsea Three or Norfolk Vanguard may be constructed at depths of up to 12 m bgl to allow for adequate standoff between the cables of the two projects. Therefore, based on the Environment Agency's groundwater level data there is the potential that the deeper set of cables may be placed within the groundwater body. However, the standoff distance would be designed to minimise the impacts on groundwater flow and would be based on a hydrogeological risk assessment. Although localised changes in groundwater flow may occur during construction, these will be of moderate reversibility following completion of construction.

1.13.2.22 The impact is predicted to be of local spatial extent, of short term duration, of intermittent occurrence and high reversibility. It is predicted that the impact will affect the receptor indirectly. With the implementation of the mitigation measures in the Outline CoCP (document reference A8.5), the magnitude of impact on the principal aquifer is therefore, considered to be minor.

Sensitivity of receptor

1.13.2.23 The sensitivity of the surface waters fed by groundwater are considered to be medium (see paragraphs 1.11.1.32) and the principal aquifer is considered to be highly sensitive (see paragraphs 1.11.1.17 and 1.11.1.18).

Significance of the effect

1.13.2.24 Overall, the sensitivity of the receptor is considered to be medium to high and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of **minor adverse** significance which is not significant in EIA terms.

1.13.3 Operation and Maintenance Phase

Tier 2

Impacts of operations and maintenance may affect the water quality of the principal aquifer and any associated surface waters

Magnitude of impact

1.13.3.1 Indirect impacts may occur from accidental spills of chemical used during maintenance work at the onshore HVDC converter/HVAC substation and associated with processes at the Mangreen Quarry. The use of chemicals during maintenance at the onshore HVDC converter/HVAC substation will be managed according to industry guidance.

1.13.3.2 The impact is predicted to be of local spatial extent, of short duration and intermittent occurrence. The magnitude is therefore, considered to be negligible.

Sensitivity of receptor

1.13.3.3 The sensitivity of the surface waters fed by groundwater are considered to be medium and the principal aquifer is considered to be highly sensitive (see paragraphs 1.11.2.5 to 1.11.2.7).

Significance of the effect

1.13.3.4 Overall, the sensitivity of the receptor is considered to be medium to high and the magnitude of the impact is deemed to be negligible. The effect will, therefore, be of **minor adverse** significance which is not significant in EIA terms.

Impacts of operation may affect groundwater quality from thermal effects of underground power cables

Tier 3

Magnitude of impact

1.13.3.5 There is a potential for cumulative thermal effects on soils and groundwater in vicinity of where the Hornsea Three onshore cables intersect with the Norfolk Vanguard cable corridor. However, thermal stabilising layers are proposed in the construction of the Hornsea Three cable trenches. Where this material is used, thermal effects are minimal at distances greater than 1.2 m from each individual set of cables. It has been assumed that the construction of the Norfolk Vanguard cable trenches would also include using thermal stabilising material.

1.13.3.6 During detailed design at the proposed intersection location, a standoff between the Hornsea Three and Norfolk Vanguard schemes would be identified that would avoid creating a cumulative thermal impact. This standoff will be a minimum of 2 m.

1.13.3.7 The cumulative impact is predicted to be of local spatial extent, but of long duration and of continual occurrence. The magnitude is therefore, considered to be minor.

Sensitivity of receptor

1.13.3.8 The sensitivity of the secondary aquifer is considered to be medium and the principal aquifer is considered to be highly sensitive (see paragraphs 1.11.2.15 to 1.11.2.17).

Significance of the effect

1.13.3.9 Overall, the sensitivity of the receptor is considered to be medium to high and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of **minor adverse** significance which is not significant in EIA terms.

1.13.4 Decommissioning Phase

Tier 2

Impacts of decommissioning may cause disturbance or contamination of secondary aquifers, principal aquifers and any associated waters

Magnitude of impact

1.13.4.1 Direct and indirect impacts may occur to the secondary aquifers and principal aquifer underlying the onshore HVDC converter/HVAC substation due to the intrusive nature of works required to remove the above and below ground structures. This is located to the west of the Mangreen Quarry (C/7/2014/7030).

1.13.4.2 The impact of decommissioning and the ongoing restoration works at Mangreen Quarry is predicted to be of local spatial extent within each aquifer unit, of short term duration, of intermittent occurrence and high reversibility. It is predicted that the cumulative impact may affect the receptor directly. The magnitude is however considered to be minor.

Sensitivity of receptor

1.13.4.3 The sensitivity of the secondary aquifer and surface waters fed by groundwater are considered to be medium (see paragraphs 1.11.1.10 and 1.11.1.32) and the principal aquifer is considered to be highly sensitive (see paragraphs 1.11.1.17 and 1.11.1.18).

Significance of the effect

1.13.4.4 Overall, the sensitivity of the receptor is considered to be medium to high and the magnitude of the impact is deemed to be minor. The effect will, therefore, be of **minor adverse** significance which is not significant in EIA terms.

1.14 Transboundary effects

1.14.1.1 A screening of transboundary impacts has been carried out and is presented in volume 4, annex 5.4: Transboundary Impacts Screening Note. This screening exercise identified that there was no potential for significant transboundary effects with regard to geology and ground conditions from Hornsea Three upon the interests of other EEA States.

1.15 Inter-related effects

1.15.1.1 Inter-relationships are considered to be the impacts and associated effects of different aspects of the proposal on the same receptor. These are considered to be:

- Project lifetime effects: Assessment of the scope for effects that occur throughout more than one phase of the project (construction, operation and maintenance, and decommissioning), to interact to potentially create a more significant effect on a receptor than if just assessed in isolation in these three key project stages (e.g. construction noise, operational noise and noise during decommissioning and dismantling of the onshore HVDC converter/HVAC substation); and
- Receptor led effects: Assessment of the scope for all effects to interact, spatially and temporally, to create inter-related effects on a receptor. As an example, all effects on geology and ground conditions, such as disturbance or contamination of secondary aquifers, loss of mineral resources, may interact to produce a different, or greater effect on this receptor than when the effects are considered in isolation. Receptor-led effects might be short term, temporary or transient effects, or incorporate longer term effects.

1.15.1.2 A description of the likely inter-related effects arising from Hornsea Three on geology and ground conditions is provided in volume 3, chapter 11: Inter-Related Effects (Onshore).

1.16 Conclusion and summary

1.16.1.1 There are two designated geological sites (Kelling Heath SSSI and Weybourne Cliffs SSSI) within the Hornsea Three geology and ground conditions study area. No land take within the designated sites is required for the construction of Hornsea Three and design measures will be implemented to minimised potential impact during construction.

1.16.1.2 The Hornsea Three geology and ground conditions study area is predominantly underlain by chalk bedrock, which is classified as a principal aquifer. There are six SPZs within the Hornsea Three geology and ground conditions study area, including an SPZ1. The majority of the principal aquifer is overlain by superficial deposits. The deposits include glacial deposits, brickearth, alluvium, and sand and gravel. The superficial deposits are classified as secondary A and B aquifers. The variable nature of the superficial deposits (both locally and regionally) indicates that the groundwater within these deposits is likely to be localised and lateral and vertical movement maybe limited. However, the risk of pathways being created as a result of disturbance of the deposits during construction cannot be ruled out.

1.16.1.3 Given their sensitivity (high to very high), and the negligible magnitude of impact, the effect of Hornsea Three on SPZs and the principal aquifer are predicted to be of minor adverse significance during construction following the implementation of mitigation measures (see Table 1.15 and the Outline CoCP (document reference A8.5)). These measures would be discussed with the Environment Agency, following site investigation carried out as part of the detailed design stage. Effects on the secondary aquifers are also predicted to be of minor adverse significance.

1.16.1.4 Although the Hornsea Three geology and ground conditions study is partially located within a Mineral Safeguarding Area for sand and gravel, the mineral resources are of variable quality and some of the safeguarding areas are of small extent. Given this, the effect on Mineral Safeguarding Areas during construction is considered to be of minor adverse significance.

1.16.1.5 During the operation and maintenance phase, it has been assumed that oils and lubricants will be used in the maintenance of the onshore HVAC booster station and onshore HVDC converter/HVAC substation. The effect of spills and leaks occurring and affecting underlying groundwater resources is considered to be minor adverse, assuming appropriate mitigation measures are in place (see Table 1.15). The thermal effect of underground cables on groundwater during the operation and maintenance phase is considered to be minor adverse as stabilised backfill material will be used in the construction of the onshore cable trenches (see volume 1, chapter 3: Project Description).

1.16.1.6 During the decommissioning phase, above and below ground buildings and structures at the onshore HVAC booster station and HVDC converter/HVAC substation will be removed, the onshore cable corridor will be cut and sealed, and link boxes will be removed where feasible. Impacts on secondary and principal aquifers have been assessed to be negligible (of minor adverse significance) assuming that appropriate mitigation is in place (see Table 1.15).

1.16.1.7 Cumulative impacts from projects screened into the assessment have been assessed using a tiered approach. The impacts are predicted to result in effects of minor adverse significance on the groundwater quality of the principal aquifers, due to the high sensitivity of the groundwater resource. None of the projects assessed within the CEA are located within the SPZ1.

1.16.1.8 Screening of potential transboundary impacts (as presented in volume 4, annex 5.4: Transboundary Impacts Screening Note) has identified that there was no potential for significant transboundary effects with regard to geology and ground conditions.

1.16.1.9 A summary of the findings of the geology and ground conditions EIA are presented in Table 1.18.

Table 1.18: Summary of potential environment effects, mitigation and monitoring.

Description of impact	Measures adopted as part of Hornsea Three	Magnitude of impact	Sensitivity of receptor	Significance of effect	Additional measures	Residual effect	Proposed monitoring
Construction Phase							
Impacts of construction may result in the loss of mineral resources within the Mineral Safeguarding Areas.	Mineral assessment (see Table 1.15).	Minor	Medium	**Minor Adverse** (not significant in EIA terms)	None	N/A	None
Impacts of construction may cause disturbance or contamination of secondary aquifers.	Good environmental practice, storage and handling of materials and waste management (see Table 1.15).	Negligible	Medium	**Negligible** (not significant in EIA terms)	None	N/A	None
Impacts of open cut trench construction may affect the groundwater quality and groundwater flow of the principal aquifer including at SPZs.	Good environmental practice, storage and handling of materials and waste management (see Table 1.15).	Negligible	High Very high (SPZ1)	**Minor Adverse** (not significant in EIA terms).	None	N/A	None
Impacts of HDD and piling works (potentially required for the construction of the onshore HVAC booster station or onshore HVDC converter/HVAC substation) may affect the groundwater quality and groundwater flow of the principal aquifer (including within SPZs).	Good environmental practice (see Table 1.15).	Negligible	High Very high (SPZ1)	**Minor Adverse** (not significant in EIA terms).	None	N/A	None
Impacts of construction may affect the quantity and quality of surface waters fed by groundwater.	Good environmental practice (see Table 1.15).	Minor	Medium	**Minor Adverse** (not significant in EIA terms)	None	N/A	None
Operation and Maintenance Phase							
Impacts of operations and maintenance may affect the water quality of secondary aquifers, principal and any associated surface waters.	Operational measures (see Table 1.15).	Negligible	Medium (secondary aquifers and surface waters) High (principal aquifer)	**Negligible** to **Minor Adverse** (not significant in EIA terms)	None	N/A	None
Impacts of operation and maintenance may affect the groundwater quality from thermal effects of the power cables.	Operational measures (see Table 1.15).	Minor	Medium (secondary aquifers) High (principal aquifer)	**Minor Adverse** (not significant in EIA terms)	None	N/A	None
Decommissioning Phase							
Impacts of decommissioning may cause disturbance or contamination of secondary aquifers (and associated surface waters) together with principal aquifer.	Decommissioning measures (see Table 1.15).	Negligible to Minor	Medium (secondary aquifers and surface waters) High (principal aquifer)	**Negligible** to **Minor Adverse** (not significant in EIA terms)	None	N/A	None

1.17 References

Britains Finest (n.d.) The Muckleburgh Military Collection. [Online]. Available at: www.britainsfinest.co.uk/museums/museums.cfm/searchazref/80001240MUCA.

British Geological Society (n.d.) GEOINDEX ONSHORE. [Online]. Available at: http://mapapps2.bgs.ac.uk/geoindex/home.html.

Campbell G. S. and Bristow K.L. (2014) The Effect of Soil Thermal Resistivity (RHO) on Underground Power Cable Installations. Decagon Devices Application Note. USA, Decagon Devices.

CIRIA (2001) Control of water pollution from construction sites – Guidance for consultants and contractors (C532). London, CIRIA.

CIRIA (2006) Control of Water Pollution from linear construction projects (C648). London, CIRIA.

CIRIA. (2010) Environmental good practice on site (C650). London, CIRIA.

Department for Communities and Local Government (2012) National Planning Policy Framework. London, The Stationery Office.

Department of Energy and Climate Change (2011a) Overarching National Policy Statement for Energy (EN-1). London, The Stationery Office.

Department of Energy and Climate Change (2011b) National Policy Statement for Electricity Networks Infrastructure (EN-5). London, The Stationery Office.

Department of Food and Rural Affairs (2016). Part 1: Anglian river basin district river basin management plan.

Department of Food and Rural Affairs (2017) MAGIC. [Online]. Available at: http://magic.defra.gov.uk/MagicMap.aspx.

Environment Agency (2001) Piling into contaminated sites. Bristol, Environment Agency.

Environment Agency (2017) Catchment Data Search. [Online]. Available at: http://environment.data.gov.uk/catchment-planning/.

Environment Agency (n.d.) Aquifers. [Online]. Available at: http://apps.environment-agency.gov.uk/wiyby/117020.aspx.

Groundsure (2017a) Groundsure Enviro Insight. s.l., Groundsure.

Groundsure (2017b) Groundsure Geo Insight. s.l., Groundsure.

Harrison, D.J., Henney, P.J., Cameron, D.G., Hobbs, S., Steadman, E.J., Moorlock, B.S.P., Evans, D.J., Lott, G.K., Highley, D.E. (2004) Mineral Resources Information in Support of National, Regional and Local Planning: Norfolk. London, Office of the Deputy Prime Minister.

Highways Agency (2009) Design Manual for Roads and Bridges: Volume 11. London, The Stationary Office.

Institute of geological Sciences (1976) Hydrogeological Map of Northern East Anglia. [Online]. Available at: http://www.largeimages.bgs.ac.uk/iip/hydromaps.html?id=northern-east-anglia.jp2.

Makhkamova, I. (2011) Numerical Investigations of the Thermal State of Overhead Lines and Underground Cables in Distribution Networks. [Online]. Available at: http://etheses.dur.ac.uk/866/.

Masters-Williams, H. (2001) Control of water pollution from construction sites (C532). London, CIRIA.

Murnane, E., Heap, A. and Swain, A. (2006) Control of water pollution from linear construction (C648). London, CIRIA.

Norfolk County Council (2011) Norfolk Minerals and Waste Development Framework. Core Strategy and Minerals and Waste Development Management Policies Development Plan Document 2010 – 2026. Norwich, Norfolk County Council.

Norfolk County Council (2014) Guidance note on the mineral safeguarding process for aggregates – sand & gravel and Carstone. s.l., Norfolk County Council.

Norfolk Geodiversity Partnership (2011) The Norfolk Geodiversity Action Plan. s.l., Norfolk Geodiversity Partnership.

Norfolk Geodiversity Partnership (n.d.) County Geodiversity Sites. [Online]. Available at: https://sites.google.com/site/norfolkgeodiversity/action-ngap/3-protecting/protected/cgs