Environmental Capacity for Industrial Clusters

Phase 2

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Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH

www.gov.uk/environment-agency

Contents

1. Executive summary

The UK government has set a target for two low carbon industrial clusters deploying hydrogen production and carbon capture and storage by the mid-2020s, and a minimum of four by 2030. This offers both an opportunity to decouple economic growth from greenhouse gas emissions in industrial heartlands by decarbonising carbon-intensive industry and generating cleaner energy. The challenge will be doing this at pace and scale, without causing environmental harm.

Government has sponsored the Environment Agency (EA) to investigate and report on the environmental capacity for deploying carbon capture and hydrogen production technology. This includes understanding industry plans at a cluster level alongside a review of water availability, the risk of flooding, and the impacts that deployment may have on the receiving environment (including water quality, air quality and habitats). It also considers how these factors will be influenced by a changing climate. This work focused on the Humber and Teesside industrial clusters due to their sizeable contribution of 12.4Mt and 3.9Mt respectively to the UK's 33.2Mt total annual industrial carbon dioxide emissions (BEIS, 2021).

Phase 1 (2021-22) considered water availability in the Humber. This report covers Phase 2 of the work (2022-23) which took a deeper look at in the environmental capacity for the Humber including water quality, air quality and flood risk and expanded to consider water capacity for the East Coast cluster by considering water availability and water quality in Teesside. This report does not consider any implications from Government announcements contained in the Net Zero Growth Plan (March 2023), although future phases of the project will consider this.

The work repeats and extends the collaborative approaches used in Phase 1 to explore the state of the environment, and industry needs to deliver carbon capture and hydrogen production technology in these clusters. Phase 2 has built on the learning of the stakeholder engagement in Phase 1 by expanding our engagement with place-makers (local authorities) and utility companies, engaging through workshops and interviews rather than questionnaires alone. The project worked with local and national EA specialists and leading industrial and place-maker stakeholders. The results will be incorporated into advice for all industrial clusters at the end of the project.

Water is crucial to the deployment of carbon capture and storage and hydrogen production for process and cooling. In the short and medium term, we expect to see an increasing supply-demand deficit for water due to population growth, climate change and demand from industry. Despite a current surplus of water in the Tees, it is likely that this surplus will be allocated before low and zero carbon technology is deployed. The Phase 1 report for the Humber has already identified water availability as an issue.

Water quality in both the Humber and Tees is already affected by multiple factors, including diffuse pollution from agriculture, storm and treated sewer discharges, industrial emissions, and land uses that affect air and water. As a result, some water bodies in both areas need improvement, having only ‘moderate’ ecological status, indicating that human activity has caused a change from natural conditions.

Looking to the future, the latest UK climate change and sea level rise projections from the Met Office (UKCP 2018) indicate warmer, wetter winters and hotter, drier summers in the years to come. Summer rainfall in the east of England is set to reduce (EA, 2019), increasing the frequency of drought conditions and low flows in rivers by 2050. This will affect the water available and the quality of water in the Humber and Tees for all users.

Our review of environmental capacity for Phase 1 indicated:

1. **The Humber environment is already seeing challenges from climate change impacts.**
   Climate change impact modelling indicates that average summer rainfall totals have dropped since 2010, creating lower river flows and a reduced groundwater recharge season. Rivers are warming, the ambient temperature of the Humber has increased by 2°C since the mid-20th century, increasing pressure on the aquatic environment.
2. **Water is a limiting factor – Current plans for low and zero carbon technology are not consistent with current and future challenges to water in the Humber.**
   Climate change impacts and heavy abstraction mean there is no water available for new abstractions on the South Humber bank, finding an extra 181Ml/day for industry will be a significant challenge between now and 2050.
3. **Water demand must be reduced if the assumptions about water use and impacts on water quality from the technology proposed are correct.**

   Water use will be the primary limiting factor for water intensive technologies on the South Humber bank. Water efficiency must be prioritised for process and cooling water at the concept development stage. Technologies must be flexible and incorporate multiple water sources and resilience options into their design. Government should consider the role of research and innovation programmes to drive the development of technologies that capture carbon, while minimising water use. Water quality must be considered alongside water use.
4. **Collaboration is crucial – There needs to be an effective local forum to explore environmental impacts and limits of low and zero carbon industrial clusters.**

   Collective deployment of low and zero carbon technologies requires early engagement and exchange of information with industry. Without this, regulators will make individual site-based decisions on water resources and quality through planning and permitting too late to make strategic, cohesive cluster-scale decisions. There needs to be more explicit, early collaboration at local level to explore environmental impacts and limits of low carbon industrial clusters. In Phase 1, 94% of industry stakeholders (75% of whom are intensive water users), didn’t respond to questionnaires, limiting our assessment of collective water needs and impacts on water quality. Without early insight into project development, we are unable to understand the full impact of environmental challenges until a permit is determined.

The main findings of Phase 2 are:

1. **Water quality is likely to challenge deployment in the Humber and Tees due to climate change, with stricter limits on pollutants in future discharges likely.**
   There are existing water quality concerns, so permitting additional discharges is likely to be challenging. The complexity of assessing water quality impacts could extend the time needed for permit determination. In the Tees, this will likely include stricter nitrogen nutrient loading limits that will require installation of additional treatment. In the Humber, conservation designations may limit what is permissible. Wastewater treatment and sewer capacity may also be a limiting factor, without improvements in infrastructure and treatment. Climate change will also present a challenge to the discharge of water in a warming environment.

2. **Development and operation of low and zero carbon technology could help improve the water environment.**
   In the Humber and Tees there is an opportunity to reduce river pollution during development and operation of low and zero carbon technology. Addressing historic contamination through land remediation can protect and improve surface water and groundwater quality as well as wastewater treatment and robust pollution prevention infrastructure. These should be considered during the early design phase of projects.

3. **Teesside is currently well placed to provide water for anticipated future demand but climate change means there is no room for complacency.**
   There is a current surplus to supply for planned deployments in Teesside. The Tees has reliable consumptive abstraction 50 to 70% of the time, although supply for future deployments is uncertain. Future availability of groundwater may be affected in a changing climate due to saline intrusion and groundwater recharge rates. Industry must share realistic estimates of their water needs and commit to this in the water resources management plan (WRMP) consultation process. There will be a need for reinvestment in transfer infrastructure, consistent with the Kielder Operating Agreement, to meet the demand of expected future deployments for non-household supply via water companies without impacting ecology.

4. **Deployments in the Humber are at risk of flooding, and industry should ensure its projects are resilient to current and future flood risk.**
   Successful development of a decarbonised industrial cluster relies on resilience to flood risk, now and in the future. A significant proportion of the Humber is already at risk of flooding. That risk will only increase with climate change and the impacts will be more severe unless appropriate action is taken. This includes industry planning for how they will operate safely and effectively during flood events, both now and in the future, for their site and beyond. Projects should work in partnership to develop co-ordinated and strategic adaptation action to manage the scale of future risk across the Humber cluster. Flood risk in Teesside has not been considered in this project phase.

5. **Air quality in the Humber is already affected. Deployment of low and zero carbon technology risk worsening local impacts including further habitat degradation.**
   Carbon capture and hydrogen production is expected to increase the combustion of hydrogen, the release of residual emissions and nitrogen/nutrient deposition in the region. Without robust abatement the risk of impacting already affected habitats is high. There is a lack of data on expected emissions from planned deployments and ambient levels of specific pollutants. Work is needed to further understand ambient levels, proprietary solvents, their by-products (such as nitramines and nitrosamines) and cumulative impacts of new pollutants. Early disclosure of emissions profiles from industry is crucial.

This project demonstrates that there are gaps in current knowledge that need to be addressed now before rapid deployment of low and zero carbon technology. For example, industry needs to improve their collective understanding and response to residual emissions from carbon capture and the impact on air and water. There is a need to understand the impact of increasing nitrogen dioxide emissions from hydrogen production and use on human health and habitats. Also, the extent to which heat discharges from cooling processes can affect river ecology should also be determined. Industry must also develop design standards to take account of the future climate. As recommended in Phase 1, there is a crucial role for industry to work in collaboration and to exchange information with the aim of developing combined plans and processes and to understand environmental capacity for industrial clusters. National and local Government have a strong leadership role to enable this. Information exchange with industry should include Government agencies, local authorities, and utilities.

2. Background

Low and zero carbon technology are a vital part of our aspiration to achieve net zero and limit the effects of climate change. However, they may also pose new risks to the environment and public health, particularly emerging technologies such as carbon capture and hydrogen production. These risks pose a potential challenge to government's intended target of deploying low and zero carbon technology this decade.

Carbon capture and hydrogen production in industrial clusters are the focus of this report. Each industrial cluster contains a diverse range of existing and proposed industries such as traditional heavy industries, varied types of power generation, petrochemicals, and chemical manufacture. There are large-scale plans for new low and zero carbon technology such as carbon capture and hydrogen production and use. These aim to decarbonise existing industry and encourage development of new ones. Facilities proposed by various projects will need to apply for and gain the appropriate authorisations to develop and operate. Permit applications will need to demonstrate that potential environmental impacts have been considered and suitably addressed. Policy makers and regulators need to understand the extent to which these impacts will pose a challenge that cannot be mitigated through the statutory processes. They will need to appreciate how industry and leading stakeholders are preparing to address them.

Water is an essential raw material for carbon capture and hydrogen production. It is used in a variety of ways that can affect the environment and its scale of use can be potentially limited. For power generation involving carbon capture, water can be used for cooling purposes where much of the water is returned to the environment, albeit at a higher temperature. Water is also needed for steam generation and as the basis of the solvents used in carbon capture.

For hydrogen production, water use varies according to production method. Manufacture of hydrogen from methane has the lowest demand, with some water needed to produce hydrogen and some required for carbon capture technologies to remove CO_2 generated from methane reformation. The most water intensive method for hydrogen generation is using electrolysis. Water is 11% hydrogen, so around 9 litres are needed to make 1kg of hydrogen. As very pure water is needed, most available water supplies will first need to be purified to generate the water that can be then split to make hydrogen. This means >20 litres per kg of hydrogen will be needed, the majority of which will become an effluent that needs to be disposed of.

Extreme weather and flooding can damage industrial assets and disrupt business operations. The level of disruption will depend, in part, on the resilience of sites and local infrastructure, including energy, transportation and telecoms. Planning policy requires decision-makers to apply strict tests that ensure people and property are safe from flooding, and that new development does not increase flood risk elsewhere. Emergency flood planning at sites at risk of flooding will help minimise the risk of pollution resulting from a flood event. will help industrial sites comply with their environmental permits

The work communicated in this Phase 2 report extends and builds on the preceding EA pathfinder project, now termed 'Phase 1: Environmental capacity for industrial clusters Humber - pathfinder project' sponsored by Department for Business, Energy & Industrial Strategy BEIS between Dec 2021, and March 2022. The pathfinder project developed and trialled an approach to identify environmental capacity (focusing on water availability and water quality) of deploying carbon capture and hydrogen production in the Humber industrial cluster early before environmental permit applications are submitted. It concluded that water supply and water quality are already under pressure in the Humber. Current plans for low and zero carbon technology are extremely challenging with current and future challenges to water, especially in the South Humber. Finding an extra 181ML/day in the South Humber will be a significant challenge between now and 2050. Under the current assumptions about water use and impacts on water quality from the technologies proposed, industry must work together to find ways to reduce water demand.

By extending the pathfinder project approach in the Humber and beyond the EA can further identify limits that the current and future environment will present, explore opportunities for working differently to mitigate environmental impacts, and avoid costly delays in technology deployment. With this proactive view of environmental capacity, the project can help government understand and minimise deployment delays and risks to industrial growth, communities, and the environment.

Together, the Humber and Teesside industrial clusters form the East Coast cluster and contribute to the wider decarbonisation project that will eventually cover over 50% of UK industrial emissions (Zero Carbon Humber 2021). Humber and Teesside are likely to be a cornerstone of the wider government aspirations detailed in its 'Ten Point Plan for a Green Industrial Revolution' (2020) that will help accelerate our path to net zero. The East Coast cluster has been confirmed as one of the Track-1 clusters selected to be taken forward into Track-1 negotiations for development by the mid-2020s. Additionally, the government recently announced the local projects that have met the eligibility criteria for Phase-2 sequencing. As such, the Humber and Teesside industrial clusters are already locations that must understand and plan for environmental capacity.

2.1. Role of the Environment Agency

Tackling the climate emergency is central to the work of the EA. The EA Climate Ambition is to create a net zero nation that is also resilient to climate change. Externally the EA is tackling climate change through regulation of key industrial sectors, and by administrating the UK Emissions Trading Scheme. The EA also play a critical role by helping communities to be better protected against climate impacts including rising sea levels and extreme

weather events. We work with government, policy makers and developers to manage environmental risks at the earliest opportunity. As the main environmental regulator in England, the EA regulate industry in industrial clusters and help industries prepare for necessary regulation. The EA regulate water, energy, waste and manufacturing sectors under the Environmental Permitting Regulations (England and Wales) 2016 (EPR), and carbon markets under the Greenhouse Gas Emissions Trading Scheme 2020.

Crucially, and with reference to this Phase 2 project, the EA is responsible for managing water resources in England, and the risk of flooding from main rivers, reservoirs, estuaries and the sea. The EA safeguard water resources and ensure abstraction from surface and groundwaters do not damage the environment. By licensing water, the EA control the amount of abstraction to protect both water supplies and the environment under the Water Resources (Abstraction and Impounding) Regulations 2006, soon to be brought under EPR in 2023. The EA regulate emissions to air, land and water under EPR, ensuring no deterioration in current water quality as a minimum. Alongside the Health and Safety Executive, the EA is the competent authority under the Control of Materials, Accidents and Hazards Regulations 2015 (COMAH) that covers the storage of hydrogen, as well as other industrial processes.

The EA play an important role in enabling society to meet emissions targets through our regulation and advice in leading sectors, including industry, water, waste and agriculture. The EA work with others to share thinking about how low and zero carbon technology and approaches may need to be regulated and the evidence needed to do this.

2.2. Project objectives

This work aims to support Government's Net Zero Strategy and help to enable successful development of low carbon industrial clusters that are environmentally sustainable. By extending the pathfinder project in the Humber and beyond the EA can further identify limits that the current and future environment will present, to inform working differently to mitigate environmental impacts and avoid costly delays in technology deployment.

Our vision is that all industrial clusters explore their environmental impacts, challenges and opportunities before deploying low and zero carbon technologies. This will benefit applications for planning and regulation, and the design and financing of the overall scheme, including associated infrastructure needs.

The main work objectives for Phase 2 of this project were to:

a. Apply the stakeholder engagement and evidence investigation approaches developed in the Humber in Phase 1 to two industrial clusters: Humber and Teesside
b. In Humber, to revisit the environmental capacity of water quality and expand the scope of technical challenges considered to investigate emissions to air, flood risk and resilience from proposed deployment of hydrogen production and carbon capture technology
c. In Teesside, to investigate the environmental capacity of water quantity and quality with industry and local authorities to proposed deployment of hydrogen production and carbon capture
d. In both areas, to expand stakeholder engagement areas to include local place-makers, water and power utility companies
e. Incorporate these factors and results into signpost advice for all industrial clusters that include carbon capture and storage and hydrogen production

3. Project methodology

3.1. Overview

The Phase 2 project team comprised a cross-Environment Agency team of national and local operations staff with experience in climate change adaptation and mitigation, communications and engagement, and regulated industry. Working in consultation with additional internal experts for water, air quality and flood risk the team worked to draw the evidence together and create a literature review, manage the project, and develop and run the communications and engagement exercise. This helped us to understand from stakeholder groups the anticipated needs and environmental capacity of deploying low and zero carbon technologies directly. These 2 streams of evidence are brought together in this report.

3.2. Literature review

The project team carried out a review of publicly available material to understand relevant environmental capacity for low and zero carbon technologies planned for use across the Humber and Teesside. This includes information published by the EA and organisations such as United Kingdom Research and Innovation (UKRI), the Carbon Capture and Storage Association (CCSA), the United Kingdom Carbon Capture Storage Research Centre (UKCCSRC), Energy UK, Water Resource Regional Groups, Imperial College London and the University of Sheffield and also, where appropriate, from European or UK government funded projects for decarbonisation and hydrogen supply.

The literature review provided part of the evidence baseline. This can be found in the technical review annexes. It evaluates knowledge and assesses the collective evidence around environmental capacity.

The project also appealed for evidence from internal sources via our stakeholder engagement exercise. This helped to establish an evidence base of current pressures. It advanced our knowledge of water resource in the Tees, and the likely impacts to water quality from low and zero carbon technology. It also provided valuable information on air and water quality, water resource and flood risk for the Humber. This process informed the development of the engagement exercise. It focused on potential limitations of a future environment. In response, local and national teams provided published reports on water requirements for low and zero carbon technology; data on groundwater and surface water resource; and water quality data nationally and for the Humber region.

3.3. Stakeholder engagement

Phase 2 involved parallel communications and engagement exercises. Communication and engagement plans were created to guide our engagement for the project using the Environment Agency's 'Working with Others' approach. This step-by-step approach enabled teams in the Humber and Tees regions to determine what the project wanted to achieve; why the project needed to engage with stakeholders; who to approach, both externally and internally; what engagement techniques should be used; and to evaluate what went well and what could be improved. For the Humber, this built on work started in Phase 1. For the Tees, this plan has been created for this phase and can be adapted for the next phase of work in Tees ('Phase 3' for the overall project). For the Tees, that will, if funded by the Department for Energy Security and Net Zero DESNZ consider air quality and flood risk.

Two stakeholder analysis exercises were run for the Humber and the Tees to identify and prioritise those to engage. In our initial analysis, the project identified over 120 stakeholders in the Humber, and over 76 stakeholders in the Tees. The numbers increased as engagement commenced. The project needed to prioritise this extensive stakeholder list due to the tight project timescales for this work. However, it is anticipated that further stakeholders will be identified during the next project phase.

For Phase 2 of the project, the project focused on engaging with 4 stakeholder groups:

- internal (EA)
- industry (existing and new)
- local place-makers (Humber: East Riding of Yorkshire Council; Hull City Council; Northeast Lincolnshire Council; North Lincolnshire Council; North Yorkshire Council and Selby District Council; Tees: Tees Valley Combined Authority)
- water companies (Anglian Water, Hartlepool Water and Northumbrian Water Ltd)

Following a review of the engagement methods used in Phase 1, the project altered the external engagement approach to include running interactive workshops and one-to-one meetings with industry, local authorities, and water companies in the Humber industrial cluster. These engaged on what they considered local environmental capacity. With local authorities, this included validating strategic growth assumptions against their own net zero strategies and opportunities for collaboration. Energy UK, the trade association for the energy industry, also acted on our behalf, using its existing links with industry to encourage attendance at our external workshop.

In the Humber, the project did not engage with Yorkshire Water Services as Phase 1 of this project indicated that the water resources of Anglian Water were at the highest risk due to known capacity and the concentration of industry on the South Humber bank. This would, however, be a future aspiration of any further work in this area.

In Teesside, engagement methods included face-to-face meetings with existing industry the EA regulate, to introduce our project and understand low and zero carbon proposals. The project also used questionnaires to collect evidence from new industry making low or zero carbon proposals. The project held meetings with the Tees Valley Combined Authority to introduce the project and to validate the strategic growth assumptions against the authority's own net zero strategy. The project also held meetings with Hartlepool (Anglian) Water and Northumbrian Water Limited to understand their view on water availability and water quality demands of low or zero carbon proposals.

In both the Humber and the Tees, the project held meetings with local interest groups to raise awareness of the project.

Internally, the project also developed and presented communications to raise awareness of the project and identify any potential links to similar projects. In addition, the project ran several internal workshops for national and area water, air quality and flood risk experts to explore and advise on local environmental capacity.

As well as extensive engagement work, the project engaged with the Department for Energy Security and Net Zero (DESNZ) on communications planning and developed reactive lines to cover potential media interest.

Image 2 – Photograph of Saltend Cogeneration site adjacent to the Humber Special Area of Conservation (SAC)

Image 3 – Water quality workshop in Tees

In carrying out these methods of engagement, the project made some assumptions and identified several assumptions and barriers:

Assumptions:

- Stakeholders will want to participate.
- Stakeholders hold the knowledge/information and would be willing to share with us.

Barriers:

- The tight timescales to gather the information.
- The timescales given to stakeholders to digest what the project is asking for and to provide a response.
- Whether stakeholder projects have progressed sufficiently to provide a response.
- Questionnaires often have a low response rate.
- Potential concerns about data protection and commercially sensitive information (3 companies expressed a wish not to release their information for commercial reasons).

4. Humber Industrial Cluster

This section explores potential environmental capacity for new low and zero carbon developments relating to water quality (impacts of industrial discharges), air quality (industrial emissions) and flood risk (resilience of new developments).

4.1. Humber

This section explores potential environmental capacity within the area around the Humber Estuary. Water use for low and zero carbon technology was covered in Phase 1 though reference to water use has been made in this report.

The Humber industrial cluster takes in existing and proposed industry associated with decarbonising a range of activities either adjacent to the Humber estuary or closely linked with sites that are. They are located over a wide area due to the size of the estuary and include power generation at Drax, power and steel around Scunthorpe, industries near Immingham (such as oil refining and power generation) and the diverse range of chemical and energy sites at Saltend. Many are part of one or more consortiums such as Zero Carbon Humber or Humber Zero, that comprise of industry-initiated collaborations.

4.1.1. Water quality – State of the environment

Water quality objectives and impacts can only be fully quantified by understanding how the intended technologies operate and any related discharges that may affect water quality. Factors that will influence this include the type of technology, where it is deployed, at what scale and when, as the pace and intensity of development will be crucial factors. Given the nature of an industrial cluster, the cumulative impacts of multiple, often interdependent projects will be an important issue to consider. This emphasises the need for early dialogue and may inform the ultimate viability and sustainability of low and zero carbon projects deployed at scale.

Our ‘no deterioration’ policy aims to prevent increases in concentration and load of pollutants within a catchment that might affect standards and target species. It also seeks to prevent deterioration in the existing classification and status. There are existing challenges to water quality in the Humber. These include regular low dissolved oxygen levels during the summer in the lower reaches of the River Ouse and in the upper reaches of the Humber Estuary. These also include failed Water Framework Directive (WFD) standards for angiosperms, invertebrates, dissolved inorganic nitrogen (DIN) and a range of chemicals. There is a risk of abstraction-driven saline intrusion where deeper groundwater is pulled in from the coast because of climate change, increasing sea level and impacting water quality of the wider groundwater body. Maintaining and achieving good ecological status for some parameters is expected to be more challenging with a changing climate.

The Humber is heavily protected for ecology and water quality, including under the WFD and Habitats and Birds Directives. The Humber Estuary is designated as a Special Area of

Conservation (SAC), a Special Protection Area (SPA) and a Site of Special Scientific Interest (SSSI) under the Habitats Regulations and Ramsar Convention.

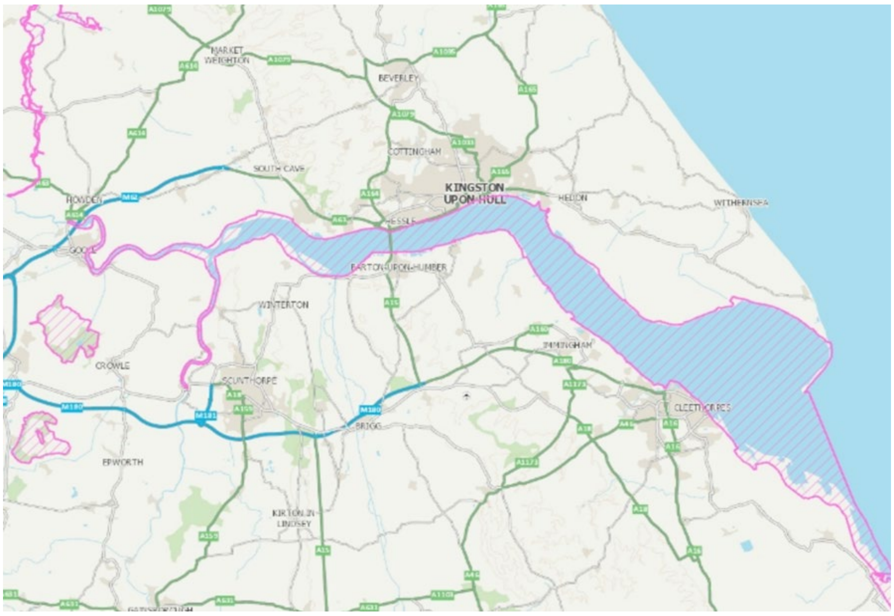

Image 4 - Map showing location of Humber SAC (other SAC sites also included)

The project carried out a review of current habitat/species designations for the Humber Estuary as part of this project. A list of the designated sites are:

- Humber Estuary Special Area of Conservation (UK0030170)
- Humber Estuary Special Protection Area (UK9006111)
- Humber Estuary Site of Special Scientific Interest
- Humber Estuary Ramsar (wetland designation)

Note: Ramsar criterion were considered as part of the assessment of relevant SAC and SPA qualifying features.

The sensitivity of these will vary according to the location of the sites in relation to potential new discharges and the nature of the designation. There is a range of protected areas, but of particular importance to the estuary are those that are within or adjacent to the estuary itself.

Image 5 – Saltmarsh in the lower Humber

Image 6 - Saltmarsh features (lower Humber)

The risk from direct water emissions will be confined to those areas of the estuary that are always wet and those within the tidal range. Sensitivity and impact will be affected by the nature of the emissions. Gross contamination/long-term effects will potentially affect water quality during all tidal conditions, while lower levels of contamination may only affect certain habitats during low tide conditions such as concentrated effluents, having localised impacts due to lower levels of dilution.

Good surface water and groundwater quality is driven by requirements in WFD. WFD aims for ‘good status’ for all groundwater and surface waters (rivers, lakes, transitional waters, and coastal waters). One purpose of WFD is the introduction of spatial planning at river basin district scales.

Each river basin district has a river basin management plan (RBMP). These plans set out the environmental objectives and a summary programme of measures to achieve those objectives. The Humber river basin district has 18 management catchments including the Humber management catchment and 3 operational catchments including the Humber Estuary operational catchment, with 6 individual water bodies.

Table 1 - WFD water bodies of the Humber Estuary

Water body	WFD ecological status	WFD chemical status	WFD target status	WFD target (by 2063)
Upper Humber	Moderate	Good	Moderate	Good
Middle Humber	Moderate	Fail	Moderate	Good
Lower Humber	Moderate	Fail	Moderate	Good

The area of potential peak impact is likely to be the lower reaches of the estuary due to the combination of the sensitive habitats combined with the main concentration of cluster developments near Immingham on the South Humber bank and developments around the Saltend chemical plant, east of Kingston upon Hull. This area is subject to existing discharges from a range of industrial processes and would likely be used for new or altered discharges resulting from the adoption of low and zero carbon technology. Other notable areas of current effluent/cooling water discharges can be found on the River Ouse and the lower stretches of the River Trent near Scunthorpe. These are summarised in Table 2.

Table 2 - Source: Environment Agency (taken from EPR permit discharge limits)

Site name	Permitted volume	Destination
Saltend Chemicals Park	15,000m^3 per day (mixed industrial effluents)	Fleet Drain
Immingham Combined Heat and Power (CHP) Power Plant (VPI)	10,000m^3 per day (process and surface water)	South Killingholme Drain

Humber Refinery (Phillips 66 Ltd)	16,000m^3 per day (process water)	South Killingholme Drain
Prax Lindsey Oil Refinery	12,000m^3 per day (process water)	South Killingholme Drain
Drax Power Ltd	302,400m^3 per day (predominantly cooling water)	River Ouse
Saltend Cogeneration Plant	1,000,000m^3 per 24-hour period (cooling water)	Queen Elizabeth Dock
Keadby Power Station 1&2 (combined)	985,670m^3 per 24-hour period (predominantly cooling water)	River Trent
Keadby Power Station 2 (cooling water only)	8,640m^3 per 24-hour period (cooling water)	River Trent (via Keadby 1 outfall)
British Steel (Scunthorpe Integrated Iron and Steelworks)	Process effluents (various sources) 5,000m^3 per day	River Trent (outfall is downstream of Keadby)
	18,800m^3 per day	Brumby Beck (to River Trent via Bottesford Beck and upstream of Keadby)

For context on the scale of these effluents, Hull Waste Water Treatment Works operated by Yorkshire Water Services (YWS), which receives domestic, commercial and industrial effluents from Kingston upon Hull and surrounding villages has a dry weather daily flow discharge limit of 91,620m^3 per day. The industrial effluents listed above are therefore significant especially when the lower Humber could receive >50,000m^3 per day from the sites listed at Saltend and Immingham.

Impacts on the SAC relate to potential damage or uncertain effects on either sensitive habitats or habitats that support annex II species (river/sea lamprey and grey seal). The area of the estuary selected corresponds to Middle and Lower Humber water bodies within the larger EA Humber Estuary operational catchment.

Potential impacts on the SPA are not likely to include direct and immediate impact on bird species (toxic effects) but are more likely to relate to damage to habitats such as feeding grounds that support some of these species. The potential impacts of effluents on sensitive habitats are based on Natural England's advice for developers and discussed further in Annex 1 for Humber.

Advice to industry from Natural England shows that sensitive habitats are at risk from a range of impacts resulting from both new and existing effluents. Given the location of sensitive habitats and discharge locations, the main habitats to be affected by water pollution appear to be "Salicornia and other annuals colonising mud and sand" and "Atlantic salt meadows" (Natural England 2022).

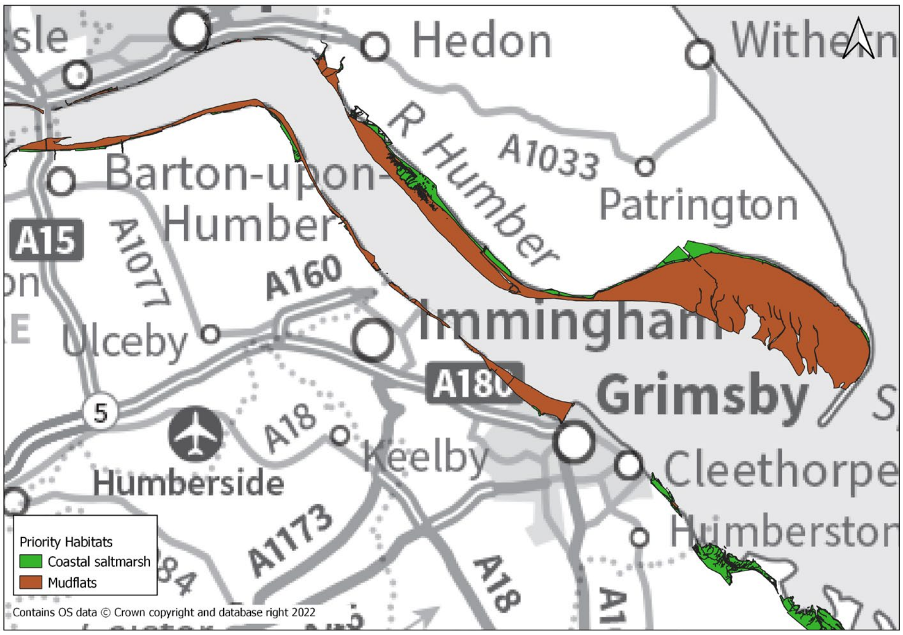

Image 7 - Map showing location of 2 important habitats in the lower Humber data.gov.uk (2022)

Given the known or suspected effects of effluent from low and zero carbon projects, these habitats are likely to be at most risk from temperature changes and physical impacts from effluent flow resulting from smothering by disturbed sediments or suspended solids within the effluent. Toxic contamination from direct air deposition is not considered in this section but is considered a risk to sensitive sites.

While these two habitats seem less sensitive to nutrient enrichment, there is a potential for a combined impact of air and water deposition of nitrogen compounds. Some saltmarsh sites are approaching the critical loads for nutrient nitrogen around the estuary using latest Air Pollution Information System (APIS) data (2017 to 2019). Although the figures quoted from APIS are for surface deposition, the saltmarsh communities could be subjected to a mixture of air and water deposition, making them susceptible to future increases in nutrients. Therefore, further nitrogen additions to saltmarsh communities from new or changes to existing effluents pose a risk to these communities.

There is some uncertainty around the potential impact from effluents on saltmarsh and seagrass beds. To increase understanding of potential risks, Natural England has commissioned literature reviews considering these potential impacts and sensitivities. These are due to be completed in spring 2023 so were not available for this project.

While currently a small part of the habitats found in the estuary, seagrass has been identified as a target habitat to expand for biodiversity reasons. Seagrass is sensitive to nutrient enrichment and toxic contamination, so any changes to effluents that could affect these could reduce the spread of seagrass beds. These would seem particularly sensitive given Spurn's proximity to Immingham and Saltend industrial areas.

Spurn Point, at the tip of the Humber Estuary, was once covered in seagrass beds. The UK has lost 92% of its seagrass meadows, with almost half of this loss occurring since the 1980s. However, Yorkshire Wildlife Trust has been working to restore the meadow at Spurn Point to restore lost habitats which could be cut by future surface water emissions.

The estuary acts as a migratory route for several fish species, allowing access to upstream water bodies. These include:

- Atlantic salmon
- Sea lamprey
- River lamprey

- European eel

Due to the lifecycle differences, eel larvae are likely to be the most at risk from entrainment of fish and eels. However, to comply with the Eels Regulations, any new water abstraction must include a screen at an abstraction point to keep eels out, so they are, in fact, likely to be low risk.

A general concern about fish migration is the impact of water discharges on river temperatures (likely compounded by climate change) where thermal hot spots could impede migration in certain circumstances. This is because the water bodies are tidal and can experience concentrations of effects during higher tide conditions. Periodic lower dissolved oxygen conditions seen on the Lower Ouse could also be a barrier to migration. While these issues are not new, any negative impacts resulting from low and zero carbon development would need to be considered when planning projects.

There is a potential scenario where several impacts combine to amplify the risks to the aquatic environment. Ammonia is more toxic at higher temperatures which are expected to occur through long-term warming and occasional extreme heat events associated with climate change. The discharge of cooling waters adds to this. Higher temperatures also increase the growth of algae which are stimulated by additional nutrient enrichment. Freshwater inputs and intensive rainfall to the estuary can also change river flows, with more nutrient wash out in the upper estuary. Diurnal algal activity and/or seasonal die off leads to dissolved oxygen sags. Low flow conditions due to reduced freshwater inputs or low tidal states reduce the overall dilution available. At certain times, estuarial tidal flows can act to trap and concentrate these impacts in the upper estuarine reaches to create a barrier to migratory fish as well as a zone of more concentrated impact. These cumulative risks are already happening.

Water Framework Directive sampling doesn’t currently cover all the pollutants expected from low and zero carbon technology, leaving a gap in our knowledge and understanding. For example, some chemicals or degradation products associated with amine scrubbers do not have environmental quality standards, so there is a limited understanding of risk and no current environmental quality standard (EQS) to use when designing an effluent treatment system and permitting a process to minimise impacts on the surface water environment.

Water resources

Water resource is closely linked to water quality, with abstractions from water bodies (surface and groundwater) potentially influencing water quality in a variety of ways, such as reduced flows (increasing the impact of water discharges) or saline intrusions. Since the Phase 1 pathfinder project that evaluated current and future water supply and demand within the industrial clusters, further detail is now available for the projects studied. More attention has been given to future demand versus available supply. There is a growing appreciation from industry water users and water companies that water is a significant challenge for low and zero carbon projects.

At the time of writing this report, draft resource plans were out for consultation before being submitted to Ofwat. The main issues for the water resource planning groups including Water Resources East (WRE) and Water Resources North (WReN) are:

Water Resources East (WRE)

Water use could increase in the longer term depending on how much high-quality water is needed for hydrogen production, and if carbon capture, usage, and storage (CCUS) technology is deployed at power and industrial sites in the region as part of the UK's Net Zero strategy.

- Predicted demand 2025: 4Ml/day
- Predicted demand 2050: 28 to 347Ml/day

In the WRE region, the South Humber Bank and the tidal Trent are expected to be the focus for hydrogen generation, although the potential exists for significant hydrogen production with CCUS in other areas of the region too.

Anglian Water Services (AWS) has recently shared with industry on the South Humber bank the observation that the earlier forecast of a small non-potable water surplus in the area has now been taken up by new enquires for supply and there is no longer a surplus. Where there is no available water, and the cost of sourcing new water resource is prohibitive, new applications for non-potable supply to industrial users are likely to be refused.

AWS intends to make a case under the Water Resource Management Plan (WRMP) consultation process to develop future supply for industry on the South Humber bank by canvassing for consultation responses from local place-makers (local authorities) and politicians. It also wants industry to detail realistic estimates of their water needs and to commit to this in writing as part of the WRMP consultation process. AWS hopes that this will help support the argument for new supply in the South Humber bank area.

Water Resources North (WReN):

- Needs an additional non-public water supply of 236Ml/day by 2050 for power sector
- Currently it is not clear if sufficient water will be available for power/hydrogen developments in the WReN region
- Currently no long-term solution to ensuring that the power sector has access to the water it is expected to need in the future to decarbonise and provide electricity system security

One solution that is being considered for both water resource areas is large-scale transfers of water within or between areas and water companies (this does already occur in certain areas). Transfer strategies can vary and include movement solely within water company distribution systems but could also include the use of rivers or canals for part of the transmission route.

Transferring water from one river to another may result in significant environmental effects, including damage to ecology because of different water quality and flow regimes. The transfer of fish diseases and alien species, as well as the significant carbon cost of water transfers are examples of unintended consequences. These effects could result in a risk of 'deterioration' or failure to meet 'good ecological status' or 'good ecological potential' under the WFD.

4.1.2. Water quality – Low and zero carbon technologies changes to the baseline

Low and zero carbon technologies are less understood than tried and tested technology such as combined cycle gas turbines (CCGTs) for electricity generation. For carbon capture, the environmental permitting decision-making processes are less developed, understanding of the cumulative impacts of rapidly deployed technology is more complex. Within the Humber there are existing water quality concerns, so permitting additional discharges could be problematic. The River Humber's conservation designations may limit what is permissible in the immediate vicinity. Waste management, sewage works and sewer capacity may also limit the extent of what is permissible without improvements in infrastructure and treatment, or available disposal capacity. There are likely to be other pressures to due to more general development and growth in addition to low and zero carbon technology.

There will likely be an increase in the amount of wastewater discharges to the environment from the deployment of low and zero carbon technology. Disposal options for these discharges will be to existing municipal sewage treatment or specialised waste facilities for sludge or solid wastes or discharged directly to the environment, dependent on the type of discharge.

Many industries within the Humber industrial cluster share several utilities, such as wastewater treatment and discharge points. Two of the industrial sites the project engaged with confirmed additional wastewater would be treated by existing treatment plants prior to an 'indirect' discharge. However, one of these, the Saltend Chemicals Park, can discharge to the public foul sewer system (indirect) or to the Humber Estuary (direct) depending on the quality of the wastewater.

Initial scoping by the EA suggests that potential water quality impacts of the processes intended in the Humber industrial cluster include thermal pollution, pollution from amines, nitrogen or ammonia in wastewater, and storage integrity issues for above-ground leakage and ground contamination. There may also be some important wastewater arisings containing persistent or bio accumulative substances or hard to treat effluents, such as those containing sulphur or amine compounds.

Permitting advice and guidance for installation permits is based around the use of best available techniques (BAT), with most sectors having a sector-specific BAT guide that sets minimum standards on a range of environmental issues. Therefore, when considering options that result in a new effluent or change to existing effluents, the relevant BAT guides should be considered.

BAT conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for common wastewater and waste gas treatment/ management systems in the chemical sector should also be used. This includes techniques for:

- abatement efficiencies
- monitoring – substances, standards, and frequencies
- emissions to water, including best available techniques – associated emissions levels (BAT-AELs) for direct emissions and wastewater treatment strategies

For new discharges, applicants must evaluate and assess any hazardous chemicals and elements they plan to release into surface water. They must then carry out screening tests on the pollutants to check if they are a risk to the environment. This is called a 'specific substances assessment'. For the Humber, potentially hazardous chemicals and elements are in the following tables:

- Estuaries and coastal waters specific pollutants and operational environmental quality standards (EQS).
  Estuaries_and_coastal_waters_specific_pollutants_and_operational_environmental_quality_standards
- Estuaries and coastal waters priority hazardous substances, priority substances and other pollutants environmental quality standards (EQS).
  Estuaries_and_coastal_waters_priority_hazardous_substances__priority_substances_and_other_pollutants_environmental_quality_standards

These reference tables also set the EQS for the listed substances. A series of sequential tests is applied to substances with an EQS to determine potential impact. Depending on the outputs from the screening process, detailed modelling may be required to explore likely risk.

The Lower Humber is most at risk from a combination of factors such as the close location of industry around Saltend and Immingham (existing and proposed sites). These clusters include a mixture of carbon capture and hydrogen production plants that are likely to result in additional effluents. On both banks of the Humber, discharges from several industrial sites are combined and share a common drain that discharges to the Humber. These are Fleet Drain from Saltend and South Killingholme Drain for the major Immingham sites (permitted volume of up 38,000 cubic metres per day). This means that there is a concentration of effluent in this area of the estuary, potentially amplifying the impact at the local level. The tidal nature of the Humber can also mean that effluents discharge over mudflats at low tide, further concentrating potential impacts. Therefore, any changes to the effluent from additional pollutants or an increase in concentration of existing effluent could have a magnified effect on the estuary near these locations unless discharges can be contained to avoid low tide periods.

The concentration of sites proposing hydrogen fuel switching could also result in additional nitrogen oxides (NOx) and ammonia (from the NOx abatement process). There is potential for NOx to result in deposition into the nearby water environment of the estuary (as well as direct deposition at low tide). Air deposition could therefore add to the cumulative impacts from aqueous nitrogen present in the estuary (from multiple sources), potentially affecting important features of the estuary.

The Humber Estuary is one of the main locations of saltmarsh and mudflat habitats. Changes in water quality could pose a significant risk unless priority pollutants are abated by suitable techniques. New effluents can also pose a risk to the main features of the SPA, and with uncertainties about contents of effluents and with the risk from some possible contaminants such as nitrosamines, further impacts are possible.

Planned development on the Trent and Ouse face different challenges. On the Trent, with proposals that include up to four adjacent power stations, there is a clear risk of elevated river temperatures due to additional cooling water needs. Any impacts from these will be complicated by the tidal nature of the Trent, exacerbated by rising river temperatures and periods of lower flow during the summer. The potential risk to priority habitats could include direct damage from elevated temperatures and issues arising from eutrophication and enrichment from algal blooms, with possible increased nitrogen loading from process effluent interacting with estuarine water and thermal plumes. These issues will be compounded by climate changes and impacts from these such as increased levels of phosphate, which could further increase the potential for algal growth and eutrophication.

The influence of an existing effluent discharge or future discharges/changes to existing discharges could have an impact on sensitive features of the estuary. In addition, an effluent could affect future possible improvements that might be desirable under river basin management plan (RBMP) or Natural England’s aspiration to enhance the estuary by restoring natural habitats, increasing biodiversity via the Protected Site Strategy approach. A situation could be envisaged where an area identified for enhancement cannot meet its potential due to the existing influence of industrial discharges.

Protected site strategies for nature’s recovery

Natural England is piloting an approach within the Humber that will consider how it can strategically manage the impact of multiple pressures and aim to address recreational impacts, loss of functionally linked land and the impacts of nutrients on saltmarsh and seagrass beds. While some of these objectives are not directly addressed by this project, the competing demand use requirements of expanding industry needs to be balanced against the use of the same land as functionally linked habitats. A situation could also be envisaged where water needed for ecological enhancement is also needed for an industrial process, leading to potential conflict for resource. Ideally, a compromise or novel approach should be explored that can benefit both. This project has considered the potential impacts of nutrients on saltmarsh and seagrass, and acknowledge that further work to explore potential impacts would be beneficial.

Waste effluent from electrolytic hydrogen production

Recent consultation with industry suggests a water input of 800 to 900 cubic metres per day for a 100MW electrolyser, with around 50% of this being consumptive and the remainder being a waste effluent, the majority of which will be reverse osmosis concentrate. The project can then extrapolate for the likely effluent generation rate from electrolysis for a range of production rates:

- 1GW = approx. 4,000 cubic metres of effluent per day

- 5GW = approx. 20,000 cubic metres of effluent per day
- 10GW = approx. 40,000 cubic metres of effluent per day

Therefore overall, the water quality impacts from green hydrogen production are considered manageable at low scales of production, but these will become more significant as production increases. At a higher rate of production, effluent streams match those of some of the bigger existing industrial effluent streams. Clearly, not all electrolytic hydrogen production will take place around the estuary. But production at scale has implications for effluent capacity, and if effluent reuse is pursued as a water source, this could also impact on receiving waters due to potentially increased concentrations of chemicals within the effluent.

Waste effluent from carbon capture – amine scrubbers

Carbon capture usage and storage (CCUS) installations are expected to present new water stresses due to additional water needs of chemical and physical processes to capture and separate CO_2 as well as abating residual emissions. In addition to these processes, the parasitic energy loads imposed by running carbon capture on power plants will reduce their efficiency and require more water to cool the plant, adding to existing thermal cooling demands.

The main impacts from CCUS will potentially arise from additional water use and associated thermal impacts from reduced power that will need additional cooling capacity. Emission scrubbing will also give rise to additional wastewater, although existing technologies are available to treat it.

One example of complexities posed by potential pollutants from carbon capture technologies relates to sources of environmental nitrosamines. These are diverse in origin and include industrial contributions, food processing/consumption and water treatment. Characterisation and quantification are difficult and understanding contributions from industrial sources in ambient water and air is not comprehensive.

Air dispersion models are used to estimate contributions from industrial sources to ambient air. Estimating contributions of nitrosamines from industrial sources is challenging for several reasons, but not impossible or non-comprehensive.

There are challenges in measuring nitrosamines both at the emission point and in ambient concentrations, mainly because of their very low concentrations, among others. The challenges in monitoring are also a challenge for the validation of the estimation/modelling tools.

The Review of Amine Emissions from Carbon Capture Systems (SEPA 2015) concludes it is not possible to devise a generic environmental quality standard (EQS) for nitramines in the water environment, but N-Nitrosodimethylamine might be a potential representative chemical.

Based on atmospheric studies, rapid degradation of nitrosamines in aquatic environments can be expected, while nitramines are likely to be persistent (Preliminary studies into the environmental fate of nitrosamine and nitramine compounds in aquatic systems).

4.1.3. Air quality – State of the environment

The contributing factors to air quality vary within the Humber, but include traffic, domestic properties, farming, import/export shipping and industry. Industry is concentrated in a few locations around Scunthorpe, east of Kingston upon Hull and Immingham. This is especially significant for those sectors of industry considering carbon capture or hydrogen production and use. Annex 1 displays maps showing background levels of main pollutants associated with industrial activities (sulphur dioxide, oxides of nitrogen, particulate matter).

Emissions to air can have a range of possible impacts, affecting human health and the wider environment in terms of potential damage to sensitive habitats or species. Annex 1 for Humber displays a map showing areas where air quality is affected by air pollution.

The responsibility for achieving good air quality is devolved by the UK government to the devolved administrations in England, Wales, and Northern Ireland. The Department for Environment, Food and Rural Affairs (Defra) co-ordinates assessment of air quality plans for the UK. Defra has drafted a national air quality strategy (AQS) for the UK, setting out air quality standards, objectives and measures for improving ambient air quality required under the Environment Act 1995. The strategy sets out the UK's air quality objectives and considers the action needed to tackle poor air quality at a national and local level.

Part IV of the Environment Act 1995 requires local authorities in the UK to review air quality in their area and designate air quality management areas if improvements are necessary. An air quality action plan describing the pollution reduction measures must then be put in place. These plans contribute to the achievement of air quality limit values at a local level (Defra 2022).

Local authorities are required to keep air quality in their areas under review and assess If there has been an exceedance of an air quality objective. If there has been an exceedance of an air quality objective, then an Air Quality Management Area (AQMA) will be declared. Local authorities then need to review and assess the exceedance and develop an action plan as required under their statutory duties in Part IV of the Environment Act 1995. The action plan enables local authorities to act on improvements to air quality, informing the public of air pollution issues. A set of measures are required to address the exceedance identified.

There are three AQMAs within the Humber industrial cluster; North Lincolnshire, Kingston upon Hull and North East Lincolnshire. The North Lincolnshire AQMA includes Scunthorpe Steel Works and Keadby Power Station. The Scunthorpe AQMA is designated for particulate matter PM10 associated with multiple industrial and transport sources. An air quality action plan has identified that the PM10 issue in Scunthorpe is complex, with multiple stack and fugitive industrial sources. The plan also identifies industry as a source of sulphur dioxide (SO_2) and nitrogen oxides (NOx) impacts in the industrial cluster (North Lincolnshire Council Air Quality Action Plan 2022).

Kingston upon Hull AQMA is designated for NO_2 on the A63 (road adjacent to the Humber and next to the ports and industry), where the primary source at present is road traffic. Targeted work is underway to improve road traffic contributions, so any additional NOx would impact on reduction plans. The AQMA is largely a consequence of the emissions from vehicles on the national trunk road that runs along the southern edge of the city centre. This is being addressed by National Highways. The priority for Kingston upon Hull City Council in the coming year is to continue to support this by reducing annual mean nitrogen dioxide concentrations outside of the existing AQMA.

North-East Lincolnshire Council AQMA is designated for NOx in Grimsby, where industry (power, refineries) producing 5.7% of NOx is the primary source. Plans are in place to reduce NOx levels up to 2025 by targeting road traffic. Any additional NOx not factored into modelling would impact on objectives.

North Lincolnshire Council's Air Quality Action Plan 2020 states that proposals for renewable and low carbon energy generating systems will be supported where any significant adverse impacts are satisfactorily minimised, and the residual harm is outweighed by the public health benefits.

Image 8: Map showing location of 2 main habitats in the lower Humber. Data source: QGIS Geographic Information System with Principal Habitat data from ***data.gov.uk*** *(2022) (under open government licence) and OS MiniScale(R) open data.*

The risk to sensitive habitats depends on the location of the potential emission and the existing habitat, but in general the risk consists of the potential for direct deposition (either dry or via moisture in the air) onto the sensitive habitat. In general, mudflats can be considered resistant to such impacts. The main habitats referenced in the Special Protection Area (SPA) designation that could be sensitive to air deposition are saltmarsh and dune systems, these being heavily concentrated in the lower estuary. Annex 1 for Humber lists a selection of the main protected areas or habitats that could be affected by known projects within the cluster. Also discussed here are the main habitats at risk and factors that influence the risk.

Air quality – Low and zero carbon technologies changes to the baseline

From a review of the evidence (Annex 1) in Humber changes in air quality are likely to affect habitat locations along the lower estuary. The pollutants that will be the main challenge to low and zero carbon developments are NO_2 (NO_X), NH_3 and PM_{10} (as direct emissions and potential precursors).

Environmental Standards (ES), toxicity, and environmental fate of many amines/amine degradation substances are unknown, at present there are only two solvents Monothanolamine (MEA) and Nitrosodimethylamine (NDMA) with Environmental Assessment Levels (EALs).

EALs are used in conjunction with the air quality impact risk assessment process (H1), to judge the acceptability of proposed emissions to air from industrial sites, and their contribution to the environment. EALs represent a pollutant concentration in ambient air at which no significant risks to human health or environmental damage are expected. The expected low concentrations of emissions from amine processes, means the risk of impact caused by this process is low. To address the risk, the EA is in the process of developing EALs for carbon capture, solvents, and by-products this work will give us a view of the level of toxicity of the substances.

In 2020, the EA updated our derivation of new EALs to air, based on available toxicological data and information for individual compounds. The approach has been agreed with the UK Health Security Agency (UKHSA). The EA has since been applying the updated method to the derivation by industry of new EALs as part of our commitment to developing permits for new proposed carbon capture and storage (CCS) facilities in England.

Carbon capture techniques will typically involve an amine solvent to capture CO_2 from flue gas. This seems to be the case for the power sector, but this might not be true for other sectors as their CO_2 stream/needs are different. There is a high degree of uncertainty in understanding future impacts on air quality until the technology matures. The Next Generation Carbon Capture Technology (BEIS 2022) study provides examples of how carbon capture will mature from 2025 onwards, and states that despite looking ahead to the next generation technology, there is no current generation of carbon capture technology.

There are environmental standards for protected conservation areas including critical levels and nutrient nitrogen and acid depositions critical loads at conservation areas within a buffer distance defined by EA guidance. These are feature specific.

4.1.4. Flood risk

Large areas of the Humber region are at risk from fluvial (rivers) and tidal flooding (Image 9).

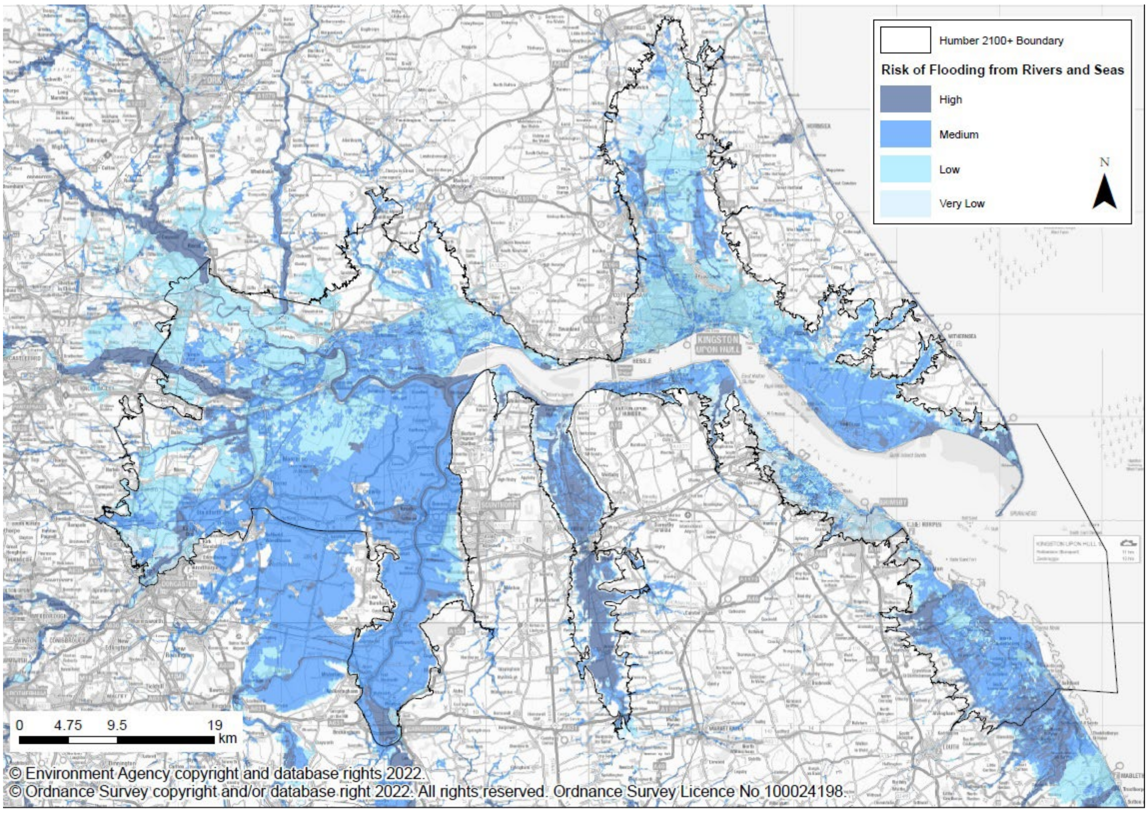

Image 9 - Map of flooding from rivers and sea (Environment Agency, 2023).

This risk will increase with climate change. At a Humber wide scale, while the 'extent' of the area at risk of flooding may not significantly increase with climate change due to ground levels (the extent is already very widespread as the land is low lying), the risk itself will increase. Flooding considered rare and extreme today will become increasingly common over time. This is flooding with greater damage and associated with greater hazard to people and property. Any site already in the flood plain can expect to experience more flooding over time if no action is taken.

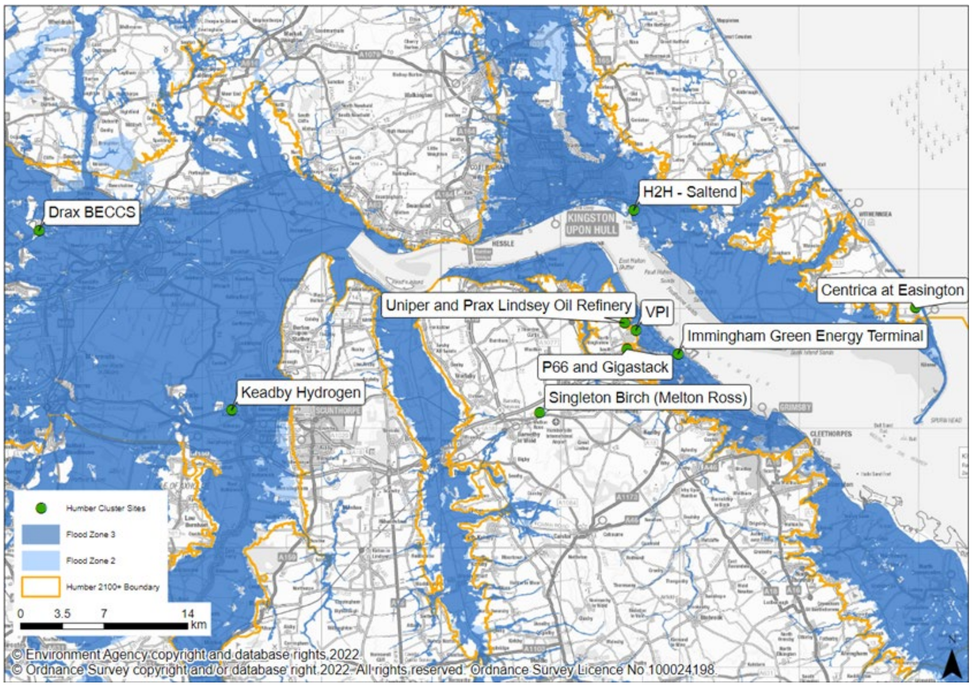

Image 10 - Low and zero carbon projects and 'flood map for planning' (Environment Agency, 2022)

Flood defences reduce the likelihood of flooding very effectively, but they cannot completely stop flooding. Many of the individual industrial locations included in the Humber industrial cluster are already within or close to the flood plain (Image 10). Specifically, they are within an area that has a 0.5% chance or greater in any one year of flooding from the sea, or a 1% or greater chance each year of flooding from rivers.

Flood defences can be overtopped or fail (breach). It is therefore important for industry to plan for residual risk and ensure flood resilient design measures and contingency/emergency plans are in place to reduce their exposure, mitigate risk to life, operation of important infrastructure, and economic performance. Developments must also demonstrate their actions will not increase risk to others. Projects need to build climate adaptation into their designs rather than rely on flood defences.

At a local authority scale, strategic flood risk assessments (SFRAs) provide evidence to support decision-making on proposed developments and steer developments first and foremost away from areas at risk of flooding where possible. Individual industrial locations and their plans for the deployment of low and zero carbon technologies will need to consider their specific risk of flooding now and in the future. An emphasis on flood risk assessments for any proposed infrastructure is an important part of building resilience into design. The EA and local authorities hold significant flood data and modelling. This is a starting point for the more detailed and tailored information site owners/developers need.

There are interdependencies between these industrial locations and the cluster itself that rely on a wide range of third-party infrastructure to operate, for example, road, rail and communications. Alongside this where there is workforce that live in the Humber region within areas at risk of flooding, there are further potential indirect impacts on the operational capability of industry. Consequently, it will be important for the cluster to consider flood risk strategically across the Humber as well as the risk to individual sites, to manage overall impacts and identify any collective resilience priorities.

The environmental capacity for the deployment of low/zero carbon technologies will be determined by the scale of the hazard to the sites now and in the future, and whether a site can show it can mitigate the flood hazards sufficiently to operate safely, in design and operations through its anticipated lifetime and without increasing flood risk elsewhere. An adaptive approach may be needed, where industry shows it is able to respond to additional flood risk, if infrastructure lifetime is longer than expected, or if climate change and sea level rise is faster.

As well as requiring the site-specific adaptive resilience, the reliance of the cluster sites on the existing and future flood risk and drainage infrastructure (for example, flood defences) needed to support the function of the cluster will need to be considered for at least the lifetime of the development. Maintenance and improvement of flood infrastructure is subject to central government spending decisions. Current policy sets an expectation that additional sources of partnership funding are found from beneficiaries of flood management action. Where flood risk infrastructure is needed to continue, or to extend, the existing site operation in a location, proposals should consider how they can support maintenance or make improvements to that infrastructure for at least the lifetime of the development.

Conversations with the risk management authorities are recommended about the need and opportunities for this.

The scale of the tidal flood challenge expected because of climate change means something different will be needed in the future to enable the Humber to adapt and thrive. The nature and magnitude of the tidal flood risk, and the complexities in how actions to manage flood risk affect elsewhere, means an estuary-wide management approach is required. The Humber 2100+ Partnership of 12 local authorities and the EA is developing a new strategic approach to define how tidal flood risk may be managed into the next century. The partnership will engage with others who operate, live and have interests around the Humber Estuary to inform development of the long-term strategic approach. The ability to provide flood infrastructure, and the pace of this, will depend on the availability of public and private funding and other resources.

There are land needs associated with flood risk management. These include, for example, space for water and flood infrastructure, the land required to manage the impacts on wildlife, and to meet biodiversity net gain requirements. This need will increase in the future, and wider cluster engagement with long-term flood management planning will help to minimise conflict or potentially identify opportunities.

Industry in the Humber industrial cluster should consider the following recommendations:

1. Consider how current and future flood risk may affect the operation of the cluster sites and network as a whole and implement resilience measures. Engage early with the EA and local authorities in relation to flood risk.
2. Individual proposals should also consider how flood risk beyond their site/planning boundary may impact their operations.
3. Consider how they could work with other organisations involved in the cluster, the EA and other risk management authorities to understand and mitigate the risk. This may involve commissioning further modelling for use by the industrial cluster.
4. Agree realistic development lifetimes alongside credible maximum climate change allowances.
5. Work with the Humber 2100+ Partnership and other flood management groups to support alignment of the Humber industrial cluster plans with implementation and maintenance of flood management measures and adaptation of the Humber.
6. A cross-government approach should be sought (including, as a minimum, the Department for Energy Security and Net Zero, the Department for Levelling Up, Housing and Communities (DLUHC), Defra and the Treasury) to consider the wider risks and benefits and funding solutions.

4.2. Stakeholder engagement response – Humber

4.2.1 Water quality

One of the biggest issues for industrial stakeholders is uncertainty. They are unsure what substances will get into their effluent, what types or levels of treatment will be needed, and where they will be able to discharge to.

Stakeholders identified temperature as a potential environmental challenge. As the environment warms, so abstractions are warming, which could be an issue for the discharge of warm effluents. Another consideration is the phosphate levels in abstractions, which has implications for the reuse of wastewater as an alternative to a cleaner potable source.

4.2.2 Air quality

The biggest issue for industrial stakeholders regarding air quality is uncertainty around expected emission limits set in environmental permits. The lack of environmental assessment levels for amines is an important issue. The EA has started a programme of developing environmental assessment levels, but there is debate as to who does that, how long it will take and which species to cover. This uncertainty extends to degradation pathways and the potential cumulative effects from multiple developments.

Industrial stakeholders are also concerned about the possibility of the public being misinformed, for example about substances that are potentially harmful. It is important, therefore, to demonstrate how those emissions are controlled and minimised to provide appropriate reassurance.

Ammonia is also felt to be a major issue. Emission limits are set to control Nox and carbon capture needs NO_x levels to be lowered before it goes into the carbon capture plant. So therefore, some form of NO_x abatement is required which then leads to an ammonia emission.

4.2.3 Flood risk

Stakeholders consider flood risk to be a potential challenge to development and are beginning to think of the wider picture and indirect impacts. Where flood risk had been considered, the focus was on the individual site and not the cluster itself or how flooding elsewhere around the Humber could impact site/facility operation/resilience. Longer term impacts were also not generally considered. Stakeholders themselves did not, have extensive knowledge of the potential future risks from flooding.

5. Tees Industrial Cluster

This section explores potential environmental capacity for new low and zero carbon developments relating to water availability (water demand) and water quality (impacts of industrial discharges). This was the focus of Phase 1 in the Humber included in the final Phase 1 report and extended for water quality in this Phase 2 report (see section 4.2).

The Tees industrial cluster is a tightly packed area with a radius of 7km. It is an energy hub with access to gas and oil from the North Sea and an extensive industrial history alongside planned hydrogen and carbon capture projects.

Image 11 – The Tees industrial cluster area, south of the River Tees. Credit: Tees Valley Combined Authority

Hydrogen production and carbon capture and storage is the focus of this review, but it is recognised that they are part of an array of projects in the Tees cluster, including direct air carbon capture, fuel switching, hydrogen storage in salt caverns, large scale battery energy storage, solar farms, and sustainable aviation fuel production (SAF). This section considers the current and future situation for water use, water quality and wastewater generated by the proposed low and zero carbon technology in the Tees industrial cluster.

5.1. Water resources on the Tees

Water resources in the Tees is set out in our published catchment abstraction management strategies (CAMs) that set out the framework for water available for abstraction. At a regional level water resource regional groups carry out long-term planning. The Water Resource North (WreN) plan, which is currently out for consultation, covers the Tees industrial cluster area. The proposed low and zero carbon projects considered within this project have now been shared with the WreN authors to include in the plan. This will expand the list of sites locating to the Tees industrial cluster area and potentially increase the proposed non-domestic water demand. There is an expectation placed by the water regulator on the water supplier, to reduce non-household demand and increase water efficiency.

The project examined several publicly available reports and publications that quantify and plan current and future water demand in the region. These are summarised in Annex 3, with public water supply and planning information provided by water companies. Direct abstractions by users from surface or groundwater supplies also play an important part in providing supply in certain areas or for certain types of use. This means that planning and supplying water is a complex issue.

The development of new abstraction needs is a complex issue. A significant quantity of water could be provided from storage on the fluvial Tees. However, this is in itself a challenge, plans to exploit those reserves can only be developed reliably within the existing regulated framework.

The Tees ASL shows that most of the Tees area currently holds more water than is required to meet the needs of the environment and water for use by industry.

AP	Name	Water Resource Availability	HOF Restriction (Ml/d)	Number of days per annum abstraction may be available	Approximate volume available at restriction (Ml/d)	Is there a gauging station at this AP?
1	Skerne	Water Available for Licensing - see comment 1 (below)	72.3 (see comment 1, below)	146	84.7	Yes (South Park)
2	Leven	Water Available for Licensing	99.1	146	47.5	No
3	Upper Tees	Water Available for Licensing - see comment 2 (below)	see comment 2 (below)	365	407.3	Yes (Middleton-in-Teesdale)
4	Middle Tees	Water Available for Licensing - see comment 2 (below)	see comment 2 (below)	365	407.3	Yes (Broken Scar)
5	Lower Tees	Water Available for Licensing - see comment 2 (below)	see comment 2 (below)	365	219.2	No

Table 3 – water availability assessments at named abstraction points

Water availability assessment at named abstraction points (Skerne)

There are waterbodies within the Upper Skerne catchment that have no or restricted water available as the ecology within the waterbodies may already have been affected because of abstraction impacts reducing the base flow. Investigations are currently ongoing to determine the degree of impact to surface water flows from ground and surface water abstractions. It is unlikely that we will allow any new abstractions within this area until these impact assessments are completed unless there is sufficient evidence to demonstrate negligible abstraction risks. Proposals for any new abstractions should be discussed with local area staff prior to submission of a formal application. The Lower and Middle Skerne has multiple discharges currently supporting flows. Some of this ‘grey water’ has already been licensed, preventing dilution of poor water quality at low flows. The EA will restrict licensing of grey water in the Skerne in future to prevent further deterioration in the water quality of the River Skerne and its tributaries.

Water availability assessment at Upper, Middle and Lower Tees

Cow Green reservoir is a regulating reservoir as it releases water when required to support low river flows at Darlington. This support ensures that Northumbrian Water Limited's (NWL) public water supply (PWS) abstractions can operate with no restrictions. Cow Green reservoir (River Tees), Grassholme reservoir (River Lune) and Hury reservoir (River Balder) also release compensation flows into the River Tees. Additionally, flows can be supported by releases from the Kielder Transfer tunnel, which discharges at Eggleston, if required. There is limited water available within the Middle and Lower Tees and no water available within the vicinity of the Lune and Balder reservoirs, located in the Upper Tees, catchment at Q30-70. This reflects the impact of the reservoirs on medium to high flows. Compensation flow from the reservoirs is constant, which prevents extremely low flows. The reservoirs also act as a buffer to reduce high flows. The overall impact of any reservoir is therefore a reduction in seasonal flow variability. It is this reduction in naturally high flows that results in the restriction in water availability. The EA are currently working with the water company to assess whether the introduction of flow variability from Grassholme and Hury reservoirs would mitigate their impact and contribute to more natural flow regimes. Due to the large volumes of water and sources of support available throughout the Tees catchment, abstraction for new and existing licences is unrestricted, unless restrictions are locally required on unregulated tributaries.

Groundwater resource availability and reliability

The EA have a good understanding of the Skerne Magnesian Limestone groundwater body and the Tees Sherwood Sandstone aquifer which underlie the Tees industrial cluster.

The Skerne Magnesian Limestone water body has been assessed as having restricted water available. At present, there are no restrictions on water availability in the Tees Sherwood Sandstone although to the south of the river, it may be too saline for current and future industrial use.

There is very little existing abstraction from the sandstone aquifer and little knowledge of potential yields. New abstractions from the sandstone, rather than limestone aquifers would be preferable, providing the risk assessments demonstrate low risk, and testing demonstrates that it is a sustainable water source.

For both the Skerne Magnesian Limestone and Tees Sherwood Sandstone a 5km buffer zone is in place along the coast to manage saline intrusion, which is known to have occurred around Hartlepool, deteriorating the quality of the aquifer, and affecting several existing abstractions. New applications should locate outside of this zone or demonstrate that new abstractions will not result in saline intrusion.

Coast and estuary

Image 12 – the protected coastal habitat at South Gare. Credit: Environment Agency

Abstraction from the tidal and coastal areas is possible where water quality and salinity are not a concern. However, new abstractions will require compliance with The Eels (England and Wales) Regulations 2009, requiring the installation of eels screens to exclude eels from water abstraction and discharge points, and ongoing maintenance costs associated with catch and return systems.

The recent revocation of a Large, historic abstraction licence from the estuary should be considered as one of multiple abstraction options in accordance with a proposed water supply hierarchy of using poorer quality water or treated wastewater effluent initially and only using clean, potable water where necessary, to better conserve water for the environment and public/private water supplies.

Protected habitats

A significant area of the Tees Estuary is designated for conservation purposes.

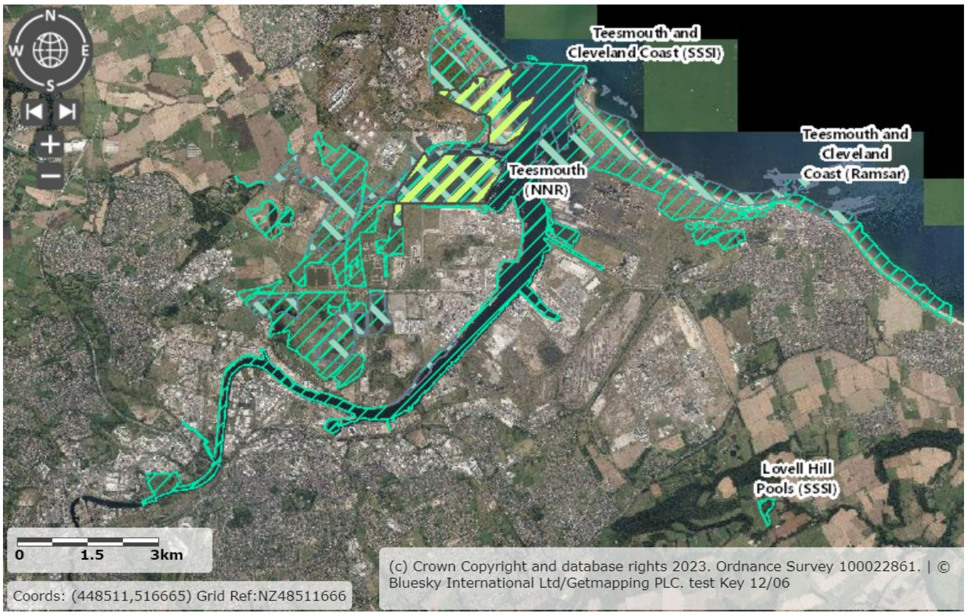

Image 13 – the protected habitats in the Tees industrial cluster area

An extension to the existing Teesmouth and Cleveland Coast SPA and Ramsar site was classified on 16 January 2020. The Teesmouth and Cleveland Coast SSSI Tees Lower and Estuary comprise distinct areas of riverine environment. Applications for surface water abstractions in these locations, if eligible, would require a more restrictive assessment than that described in previous sections.

Heavily modified water bodies and the Kielder Operating Agreement

The Tees abstraction licensing strategy area has artificial connectivity with Kielder reservoir located on River North Tyne, via the Kielder Transfer Tunnel. This can discharge into the River Tees at Egglestone. Kielder Water is northern Europe's largest manufactured lake; it has a surface area of 1,086 hectares and a capacity of 200,000Ml. Water from Kielder Water is released into the North Tyne and then, via the water abstraction at Riding Mill pumping station and the connection with the Kielder Tunnel, transferred into the River Wear and River Tees. Releases are made so that river flows below major abstraction points on the River Wear and River Tees are kept above a prescribed minimum known as the Minimum Maintained Flow (MMF).

The Kielder Operating Agreement (KOA) is a legally binding agreement created by the Secretary of State in 1989. It requires the EA to pay Northumbrian Water 100% of the operating costs and an index linked annual sum based on the capital value of the assets comprising the Kielder Reservoir and the Transfer Scheme. We are required to fully recover all our costs for water resources, including the KOA payments, through abstraction charges. The cost of water supported by Kielder is therefore much higher than water not supported by Kielder.

There is capacity to increase the volume of water available to the Tees through the Kielder Operating Agreement.

Transfers of water-to-water storage reservoirs are subject to significantly lower 'supported sources' charges, so there is also the opportunity for the Tees industrial cluster to consider local water storage options, supplied from the River Tees, that could significantly reduce the unit costs of the water supplied.

The EA is assessing the sustainability of water availability from Kielder Reservoir based on the forecasts available for future needs including decarbonising industry. This includes Northumbrian Water's future needs, potable supplies outside of Northumbrian Water's supply network and the industrial cluster.

Since 2001, under the provisions of Section 66 Water Resources Act 1991, the Canal & River Trust (CRT), previously known as British Waterways, has held management responsibility for a 17km stretch of the River Tees upstream from the Tees Barrage. Only CRT can apply to us for abstraction licences in this stretch of river. As a result, third party proposals to abstract water from this part of the River Tees need to be administered through CRT. Due to the large volumes of water and sources of support available throughout the Tees catchment, abstraction for new and existing licences is unrestricted, unless restrictions are locally required on unregulated tributaries.

Nutrient pressure in the Tees Estuary

The Tees Estuary includes the Teesmouth and Cleveland Coast Special Protection Area (SPA). It is a wetland of European importance. The SPA comprises a wide variety of habitats, including intertidal sand and mudflats, rocky shore, saltmarsh, freshwater marsh, saline lagoons, sand dunes and estuarine and coastal waters on and around the Tees Estuary, which has been considerably modified by human activities. The saltmarsh and mudflat habitats of the Teesmouth and Cleveland Coast SPA are of great importance to a diverse assemblage of bird species.

Currently, the SPA is in ‘unfavourable condition’ for nutrient pressure from excess nitrogen. There is an urgent need to prevent harm to internationally protected habitat sites through elevated nutrient levels.

In the Conservation Objectives supplementary advice for Teesmouth and Cleveland Coast SPA the target for the site related to nutrients is to ‘restore water quality to mean winter dissolved inorganic nitrogen levels where biological indicators of eutrophication (opportunistic macroalgal and phytoplankton blooms) do not affect the integrity of the site and features’.

The Teesmouth and Cleveland Coast SPA/Ramsar has been assessed as at risk of eutrophication. This considered assessments of the WFD dissolved inorganic nitrogen levels, which are high within the industrial cluster, combined with opportunistic macroalgae and phytoplankton quality. Other potential causes require further investigation, including tidal dynamics (limited scour), mussel beds and accretion of coarse sediments. According to our National Marine Monitoring team’s dynamic Combined Phytoplankton Macroalgal (dCPM) model for Seal Sands, which only focused on reducing nutrients to a level where macroalgae is no longer an issue, this would require setting permit limits beyond BAT for relevant industrial sites and Bran Sands STW (sewage treatment works). This would be very costly, could lead to industrial site closures, and prevent new developments.

To manage the nutrient pressures on the SPA in the short term, Natural England requires a nutrient neutrality strategic solution across the whole Tees catchment (Natural England, 2022). In autumn 2023, a new statutory duty will be placed on water and sewerage companies in England, to upgrade wastewater treatment works to the highest technically achievable limits by 2030 in nutrient neutrality areas. (Chief Planner Letter, 2022).

Engagement with Northumbrian Water and Water Resources Management Plans (WRMPs)

Current water demand for the Tees industrial area is met by river extraction at Broken Scar, Blackwell, Low Worsall and supported by the Kielder Transfer. The operating environment for the Kielder Transfer is vastly different to when it was constructed. There is a current 25 Ml/d water surplus in the area following industrial decline over the past few decades. The proposed sudden increase in low and zero carbon projects may require investment in the 50-year-old water supply network to reinforce the pipelines and secure ongoing availability. Northumbrian Water has stated industrial users should contribute to these costs.

Abstraction licence number	Licence holder	Sub-purpose description	Max annual quantity (m^3)	Max daily quantity (m^3)	Point name	Source of supply description	Abstraction name
1/25/02/103	Northumbrian Water Ltd	Public water supply	107,675,000	295,000	Broken Scar	Surface water	River Tees
1/25/02/109	Northumbrian Water Ltd	Public water supply	41,975,000	159,110	Blackwell	Surface water	River Tees
1/25/04/136	Northumbrian Water Ltd	Public water supply	11,000,000	150,000	Low Worsall	Surface water	River Tees

Table 4 – table showing river abstraction details

Discussions with Northumbrian Water confirmed that the Low Worsall abstraction point is currently out of use. It is expected to return to use as local water requirements increase.

Northumbrian Water's Water Resources Management Plan 2019 covered the period 2020 to 2045 and was confident of excess water availability based on a flatline prediction of 7 large, existing industrial users. The draft Water Resources Management Plan 2024 contains a potable water demand forecast for existing and new large industrial users. The forecast assumes a slight increase in demand based on the average of the 5 years prior to the Covid pandemic, adjusted to account for population growth, economic and employment forecasts. Nine new large industrial users were identified using data gathered in June 2021.

There will be a step change increase in demand starting in 2025/26 with the construction of Net Zero Teesside, the BP hydrogen plant and the development of sites in the Teesside Freeport area. Of the sites listed above, the Sembcorp 7200MWth CCGT and the Millennium EfW projects have been replaced with plans for an oxy-combustion plant and a sustainable aviation fuels production plant, of similar scale and similar high-water demand. The GE Turbine Development has been superseded by the new SeAH Wind's facility and is currently under construction, with similar low water demand.

Northumbrian Water has high and low scenarios for demand forecasts, which increases/ decreases the large new user demand by 50%. Desalination or use of aquifers is not currently being considered (Northumbrian Water, 2022).

WRMP 2019 considered plans for a new 140Ml/day pipeline transfer from the River Tees to the Yorkshire area, to be operational by 2050. However, if the Tees industrial cluster develops as proposed and water demand increases quickly and significantly, the pipeline transfer to the Yorkshire region is at risk.

Wastewater treatment capacity

A significant quantity of industrial effluent from the Tees industrial cluster is discharged to Northumbrian Water's Bran Sands facility for treatment. Bran Sands is a hazardous and non-hazardous waste effluent treatment facility and regional sludge treatment centre. The installation involves the aerobic treatment of hazardous and non-hazardous wastes in several dedicated processes or 'trains', as well as anaerobic treatment of non-hazardous wastes. The advanced anaerobic process integrates a sludge digestion and biological treatment process. All aerobic treatment processes are activated sludge processes, with aerobic digestion (AD) followed by sludge settlement. The effluents from these processes then combine prior to discharge to Dabholme Gut and the Tees Estuary. The AD plants generate electricity from approximately 30,000,000m^3 of biogas a year. 100% of Northumbrian Water's sludge passed through these plants, ensuring enhanced treated product status is achieved for use in agriculture as fertiliser. This means it meets the Sludge Use in Agriculture Regulations 1989 that limit the number of microorganisms in the fertiliser to an almost negligible level. Changes to this legislation covering sewage sludge for agricultural benefit would impact all producers (Total Water Solutions).

Northumbrian Water stated it has water treatment capacity to treat to current standards. The Tees Estuary is already sensitive to nutrient loading and additional treatment may be required under nutrient neutrality and sensitive waters objectives in Price review PR24. Northumbrian Water is confident that Bran Sands is a modern asset, with available footprint space, capable of investing in new treatment processes to meet the demands of the low and zero carbon industry and potential future stricter nutrient loading limits. The affordability of these new stricter standards may affect new low and zero carbon projects.

Engagement with Anglian Water Services

The project engaged with Anglian Water Services to jointly discuss the Humber and Tees water supply and wastewater challenges. Anglian Water Services has limited exposure within the Tees industrial cluster, covering only a small northern section of the cluster area. Hartlepool Water, a subsidiary of Anglian Water, provides the sole groundwater supply to the Hartlepool area with industrial customers, Venator and Hartlepool Nuclear Power Station. Northumbrian Water provides wastewater services in this area.

Anglian Water/Hartlepool Water and Water Resources East (WRE) are factoring into the draft water resources management plan (WRMP) a reduction in non-household demand target driven by Ofwat. There is an expectation placed on the water supplier by the water regulator, to reduce non-household demand and increase water efficiency.

Anglian Water/Hartlepool Water has not yet been able to quantify the water demand from low and zero carbon projects. Currently, it would consider any non-household customer that requires between 0.5 and 1Ml/day of additional water to be a significant amount and challenging to supply. This extra demand would need careful consideration. A demand of 40Ml/day would be extreme and require a lead time of approximately 10 years to plan supply in the WRMP. It would not immediately be able to supply a large project with water if a request was received in 2 years (by 2025).

Anglian Water/Hartlepool Water supports studies such as our environmental capacity work to help plan for future demand from non-household customers decarbonising. Large-scale water reuse is not currently considered in the current WRMP (2019). This may be factored into the draft WRMP24 to ease the supply demand challenge for non-household supply.

Hartlepool Water has a total supply volume of 25Ml/day sourced from 3 boreholes. There is a potential risk of saline intrusion to groundwater as an example of climate impact. Hartlepool Water has not planned for non-household demand growth. This is a reasonable assumption at this stage as its main industrial user is considering switching fuel to hydrogen, which is not predicted to increase its water demand. Early discussions with the proposed new green hydrogen plant in its area are, however, recommended.

Water Resources North (WreN) – Water resources plan for the North of England

Water is a critical resource for industrial processes and cooling. The draft water resources plan for the North of England, WreN, has been issued for consultation and is due to be published in autumn 2023 (WreN, 2022). The WreN covers a large area of England, encompassing both the Humber and Tees industrial clusters.

WreN considers that a strategic approach to the supply of water is needed to meet demand for a cluster of low and zero carbon industrial projects and has consulted with non-household customers on water efficiency as part of WRMP24.

In the Tees industrial cluster area, a wide range of existing and new industries are planning to decarbonise by 2027 to 2030, sooner than stated in the 2050 WreN. Many of these projects are directly linked to the construction of new hydrogen production plants and the Tees-wide carbon capture gathering network of pipes providing captured CO_2 to the Endurance aquifer for long-term storage.

The Tees cluster area is predicted to construct the following new projects, with high water demand:

- 4 green hydrogen plants (H2Teesside 500MW, EDF 500MW, Protium 70MW)
- 2 new blue hydrogen plants (H2North East 1GW, Hy Green 1GW)
- 9 carbon capture plants (NZT, CF Fertiliser, BOC North Tees, Greenergy, H2North East, 8River/Whitetail oxy-combustion, Suez EfW, TV ERF and/or Redcar EfW)

The Joint Environment Programme (JEP) (Joint Environmental Programme, 2021) predicts the water demand from the WreN area power sector to be 296Ml/day by 2050 from a baseline of 60.1Ml/day. While not insignificant, the additional 250Ml/d non-public water demand is approximately 31% of the overall demand for the region (including public water supply) and comprises 2 large industrial clusters both rapidly expanding into low and zero carbon technology. Over a similar timeframe, public water supply is expected to decrease from 2,084 to 1,710 Ml/day (WreN, 2022).

Although, these figures do not assume that water is taken from one source, they show the water intensity of these projects.

The new resilience standard for severe droughts, updated climate change projections and increased demand are putting extra pressure on water resource systems in the Kielder zone, an area which incorporates the Tees cluster. WreN predicts that by 2025, the Kielder Water Resources Zone (WRZ) will be in deficit by 24Ml/day, with the Hartlepool WRZ still in surplus. The draft plan outlines measures for metering and leakage reduction (demand measures) to reduce demand and restore a surplus, with an aspiration to reduce leakages by 50% by 2050. Water companies operate on a first come first served basis for water supply to non-household customers, which may become an obstacle to development.

The WReN forecasts are based on consumptive use only. Non-consumptive use is considerably larger, dominated by the power sector's use of non-evaporative cooling processes which return a substantial proportion of abstracted water to the environment directly and locally, with little or no treatment. This type of cooling known as once-through cooling is described as BAT in the post-combustion CO_2 capture guidance.

Operators considering a once-through cooling option must factor in compliance with The Eels (England and Wales) Regulations 2009 and modelling the impact of heat on the receiving environment and protected local habitats.

Water companies are encouraging operators to install air cooling to eliminate raw water demand, contrary to the hierarchy of water use in the BAT for cooling guidance.

A framework of third-party water suppliers has been factored into WRMP24 that allows the production and supply of water via third parties.

The South Tees Development Corporation and Sembcorp Utilities at Wilton International both have an existing potable water connection with Northumbrian Water. Both companies resell water to their customers on a first come, first served basis. An increase in extraction to meet predicted increased demand will have an impact on abstraction levels in the Tees.

Water retailers are incentivised to sell water to maximise their profits. Northumbrian Water stated retailers in the Tees cluster area are good at driving water minimisation projects.

Draft water resources management plan 2024

Northumbrian Water and Anglian Water both have draft WRMP24s under public consultation, with the final reports due to be published in autumn 2023. They predict the level of resilience needed for these new plans is different to previous years. This means less water is available than stated in the WRMP19. Their current plans do not include the new power sector water demand predictions developed by Energy UK, providing a forecast by 2050 (Anglian Water, 2022).

Image 14 – proposed low and zero carbon projects within the Tees industrial cluster. Sites shown to be located within the River Tees have not yet announced their preferred location (Anglian Water, 2022).

Phased approach to new builds

The production of hydrogen within the Tees industrial cluster is linked to the construction of the Endurance offshore storage facility, the East Coast cluster Tees network of CO_2 gathering pipelines, the CO_2 high pressure compressor station, and growing demand. A Development Consent Order (DCO) for the hydrogen transmission pipelines is due in 2023/24. The DCO for the CO_2 gathering pipeline and the CO_2 high pressure compressor is already under examination. The Endurance carbon store lease and licences are in place (The Planning Inspectorate, 2020).

The two main technologies for hydrogen production being considered in the Tees industrial cluster are:

- electrolysis proton exchange membrane or polymer electrolyte membrane (PEM)
- steam methane reforming

The roll-out of projects within the Tees industrial cluster will start with the addition of small-scale carbon capture plants to the existing steam methane reforming plants to generate blue hydrogen. Blue hydrogen production will increase as full-scale carbon capture technology becomes tried and tested, and the offshore storage facilities come online. Operators will then fuel switch from natural gas to blue hydrogen as supply increases, and then possibly move to green hydrogen as costs decrease. Green hydrogen production will increase considerably over the next 30 years as that technology develops, costs reduce, and renewables become more available.

Image 15 – Renewables in Tees Bay. Large wind farms are proposed with direct wire to a green hydrogen plant and battery energy storage on Teesside. Credit Chloe Harvey-Walker

5.2. Water requirements of low and zero carbon technologies

Green hydrogen

BP, EDF Renewables, Protium and EDF Nuclear are proposing or considering green hydrogen within the Tees cluster. Questionnaires were not sent to these applicants as they are at a very early stage of seeking funding, developing this new technology and/or agreeing an Environment Impact Assessment (EIA) scoping report for the planning permission application process. BP has held an initial enhanced pre-application discussion with the EA to introduce the project. Protium has held a local stakeholder engagement event which the EA attended.

The following table was extracted from the Humber Pathfinder Phase 1 report and used to estimate water demand from green hydrogen production plants in the Tees industrial cluster.

		Litres Water/Kg H2		
Source of Water	**Use**	**Total**	**Consumptive**	**Returned**
Demineralised*	H2 production	10.5	10.5	0
Potable*	H2 production	20	10	10
Saline (seawater)**	H2 production	30	13	17
		M3/hr		
Saline (seawater)**	Cooling	60	20	40

* Hydrogen supply chain evidence base. Prepared by Element Energy Ltd for the Department for Business, Energy & Industrial Strategy November 2018
** Response from Uniper Hydrogen UK Limited to the EA questionnaire

Table 6 – Evidence provided to the Humber phase 1 report indicating water use for green hydrogen production.

Using the above table, if a 1GW green H2 plant produces 400tpd of hydrogen, (GHD, 2020) it requires 20 litres of potable water/kg of green H2 produced, of which 10 litres is consumed and 10 litres returned. Each 1GW plant produces 400,000kg H2 per day x 20 litres water/kg H2 = 8.0Ml/day potable water, half of which is consumed.

		Total potable water requirement		
		2025	2027	2030
EDF Renewables	500MWe by 2030			4Ml/d
EDF Renewables	50MWe by 2027		0.4Ml/d	
BP	80MWe by 2025	0.64Ml/d		
BP	500MWe by 2030			4Ml/d
Protium	17MWe by 2025	0.136Ml/d		
Protium	70MWe by ~2030			0.56Ml/d
	Totals	0.776Ml/d	1.176Ml/d	9.736Ml/d

Table 7 – Estimated water demand of green hydrogen production in the Tees industrial cluster.

Predicted water use for green hydrogen production is developing and increasing over time. Commonly overlooked water supply and wastewater issues include:

- significant electrolyser cooling load which can require an additional 30 to 40kg water per kg hydrogen of make-up water in evaporative systems
- multi-stage compressors with intercooling to compress the produced hydrogen to a suitable pressure for storage or use
- depending on the quality of the incoming raw water 20 to 40% may be wasted to achieve the required purity in the electrolysers
- increased concentration of impurities in the wastewater require treatment prior to discharge

These loads can lead to as much as an additional 60 to 95kg water required per kg of green hydrogen produced. Of this demand, approximately 60 to 70% is for cooling water makeup, assuming full evaporative cooling (EA, 2023).

Green hydrogen operators are exploring opportunities to reuse wastewater from Bran Sands, which provides an innovative way of recycling effluent from a wastewater treatment plant.

Green hydrogen wastewater generated

The following is the predicted wastewater generated from green hydrogen production used in the Humber's phase 1 report:

Technology	Units	MEP	GEP
System Size	MWe	2.0	5.0
System Efficiency	%(HHV)	68	73
Hydrogen Production Capacity	kgH2/hr/system	34.5	92.6
Wastewater	Litres/kg H2	20	17

MEP = Megastack Electrolyser Platform
GEP = Gigastack Electrolyser Platform

Table 8 – Predicted green hydrogen wastewater production rates in the Humber area

Assuming a 500MW electrolyser produces 400tp hydrogen, or 400,000kg/d hydrogen. Using the above table and multiples of the 5.0Mwe arrays, the wastewater generated is 17 litres/kg H_2 produced x 400,000 = 6.8Ml/d, and as follows:

		Wastewater produced		
		2025	2027	2030
EDF Renewables	500MWe by 2030			6.8Ml/d
EDF Renewables	50MWe by 2027		0.68Ml/d	
BP	80MWe by 2025	1.09Ml/d		
BP	500MWe by 2030			6.8Ml/d
Protium	17MWe by 2025	0.23Ml/d		
Protium	70MWe by ~2030			0.95Ml/d
	Totals	1.32Ml/d	2Ml/d	16.55Ml/d

Table 9 – Predicted green hydrogen wastewater production rates in the Tees industrial cluster

A review of literature showed predicted green hydrogen production wastewater generation data of 1kg hydrogen produced generates 25kg of effluent. [Ref Tees 28] If the water is brackish, seawater or industrial wastewater, the volume of raw water will increase dramatically and so will the wastewater/brine produced from the water treatment process.

If 1kg hydrogen produced generates 25kg of effluent. [Ref Tees 29] and 1GW electrolyser produces 400tpd hydrogen [Ref Tees 30]], 1GW PEM produces 400,000kg/d H2 = 10Ml/d.

Wastewater generated by green hydrogen using the above assumptions are comparable to that proposed by the Humber's Phase 1, Megastack Electrolyser Platform.

Wastewater can also contain polymer electrolyte membrane (PEM) sludge, PEM washings, and possibly bacterial levels depending on the exit temperatures and concentrated brine, if saline is used.

Blue hydrogen water demand

There are 2 proposed blue hydrogen production plants within the Tees industrial cluster. H2North East has claimed commercial confidentiality, so its data has not been used here. BP and H2North East have both engaged with the EA to introduce their projects and discuss the application of BAT. The plant designs are at an early stage therefore their water demand information is not available currently.

Blue hydrogen typically consumes less water than green hydrogen.

In response to Humber's questionnaire, Uniper Hydrogen UK Limited provided the following information for its proposed 720MW blue hydrogen plant. This information was used to generate predicted water demand for the 2 proposed blue hydrogen plants within the Tees industrial cluster:

Source of Water	Annual Water Requirement Mm³/year
Demineralised – H2 production	1.53[a]
Non-potable – H2 production	2.10
Saline – H2 production	2.10[a]
Cooling	1.53[a]

a: Consumptive amount

Table 10 – Blue hydrogen predicted water demand

A 720Mwe blue H_2 plant is predicted to use 2.10Mm^3/year non-potable water in hydrogen production, plus 1.53Mm^3/year cooling water = total water demand of 3.63Mm^3 water/year = 9,945m^3 per day = 9.95Ml/day. This information was used to estimate water demand for the following sites in the Tees industrial cluster:

	Non-potable process water demand	
	2027	2030
bp 500MW	6.91Ml/d	
bp 1GW		13.82Ml/d
H2North East 355MW	4.91Ml/d	
H2 North East 1GW		13.82Ml/d
Total water demand	11.82Ml/d	39.46Ml/d

	Demin process water plus cooling water demand by:	
	2027	2030
bp 500MW	5.808MLD	
bp 1GW		11.506MLD
H2North East 355MW	4.109MLD	
H2 North East 1GW		11.506MLD
Total water demand	9.956MLD	32.968MLD

Table 11 – Estimated water demand for the two proposed blue hydrogen production plants in the Tees industrial cluster.

Predicted wastewater from blue hydrogen production

By-products of the hydrogen production process, such as methanol and ammonia, are expected in the condensed water from the process, and dissolved CO_2. A large proportion of condensate can be reused following appropriate treatment (EA, 2023).

No predicted wastewater quantity data was found in a review of recent literature.

Despite only gaining a limited understanding of the water requirements for proposed green and blue hydrogen technologies to be deployed in the Tees industrial cluster, the information provided or obtained confirms our understanding that significant amounts of water will be required both to produce hydrogen and capture the CO_2.

5.3. Carbon capture

Information on the amount of water required for carbon capture is generally limited. However, the Tees industrial cluster does benefit from the information submitted in support of an EPR permit for the advanced Net Zero Teesside (NZT) project. NZT will be a new 860Mwe (assuming ~1,440MWth) H-Class combined cycle gas turbine (CCGT) with amine-based post-combustion carbon capture, designed for rapid start-up and eventually operating in dispatchable mode to balance the renewables market. Cooling options being considered have a range of water demand from 1,100 to >100,000t/hr, with the mechanical wet draught cooling option preferred by the applicant requiring 1,200t/hr of water from Northumbrian Water Limited.

Based on the above information, Net Zero Teesside's water requirement could be 28.8Ml/day. This is for cooling demand only. Demineralised water for the amine system would be an additional demand. The EA cannot predetermine the assessment of the environmental permit application, therefore the final cooling method may change.

It is important to note a carbon capture plant can be a net producer of clean water following appropriate treatment of condensed gas and blowdown. This water can be in sufficient quantities to supply the amine regeneration system.

BOC North Tees and CF Fertiliser operate existing hydrogen plants. CF Fertiliser did not respond to a questionnaire, and no recent decarbonising announcements have been made on its website. Both were early partners in the East Coast cluster carbon capture project. The SUEZ Wilton 11 EfW plant has not announced any decarbonising plans.

The following table assumed the same water demand assumptions as the Humber report to help comparisons.

		Water demand	
VPI Immingham CHP using 0.023 Ml/d to capture 3.3MtCO2/year	~2,100MWth	2025-27	2035
NZT CCGT capturing 2MtCO2/yr	~1,440MWth	0.014Ml/d	
MGT biomass	730MWth		0.008Ml/d
Greenergy	unknown		
TV ERF	~100MWth	0.001Ml/d	
Redcar Energy Centre	~100MWth	0.001Ml/d	
Suez Haverton Hill	~60MWth	0.0007Ml/d	
Suez Wilton 11 EfW	unknown		
BOC	unknown		
	Totals	0.0167Ml/d	0.025Ml/d

Table 12 – This table shows the predicted water demand for the proposed carbon capture plants in the Tees industrial cluster using source data provided in the Humber Pathfinder Phase 1 report.

Possible water emissions from carbon capture plants

The origin of the blowdown water for Net Zero Teesside may be untreated water from the River Tees containing contaminants typical of a large lowland river draining a diverse catchment with extensive farming and industrial use, including dissolved inorganic nitrogen (DIN). These contaminants will be concentrated by up to 5 times during the on-site processes. The condensed water flows are significantly smaller, but this water may contain concentrations of ammonia up to 5mg/l (AECOM Ltd, 2022). The following are possible pollutants, known or potentially associated with the use of amine-based scrubbers and air pollution abatement equipment: ammonia – unionised, dissolved inorganic nitrogen, chlorine; metals: cadmium, copper, mercury, zinc, methyl di-ethanolamine, nitric acid, N-Nitroso-di-methylamine, ketones, temperature, formaldehyde, nitrates, nitrites and persistent organic pollutants (POPs). This information was obtained from chemical safety data sheets, EA guidance ‘Estuaries and coastal waters specific pollutants and operational environmental quality standards (EQS)’ and the Tees 3D model project.

5.4. Summary of predicted water demand

	Water demand by 2025/27	Water demand by 2027	Water demand by 2030-2035
Green hydrogen, potable water, with no cooling	0.776Ml/d	1.176Ml/d	9.736Ml/d
Blue hydrogen: non-potable process water demand		11.82Ml/d	39.46Ml/d
Carbon capture with cooling, total potable and non-potable.	0.0167Ml/d		0.025Ml/d
Totals	0.793Ml/d	13.79Ml/d	63.01Md/l

Table 13 – An indication of total water demand in the Tees industrial cluster

For both green and blue hydrogen production, the data shows the significant increase in water demand due to scaling-up, by 2030. Green hydrogen users are considering reusing wastewater to reduce their water consumption. Note this uses the Humber carbon capture water demand information, not that provided by NZT.

By 2030, alternative sources of water may be required for cooling to allow non-potable water to be used preferentially for demineralised water use, reducing wastewater generated. In addition to the above, there may be additional, currently unknown water demand, from the following sites:

- By 2025: Circular Fuels, New carbon capture at Greenergy, Nova Pangaea Technologies, Clean Planet Energy and Whitetail/8Rivers.
- By 2030: EDF AMR and hydrogen production and ReNew ELP supercritical steam requirement.

The following will generate new wastewater streams in currently unknown quantities and polluting potential:

- By 2025: Circular Fuels will be generating a new concentrated effluent stream containing trace ranges of suspended solids, volatile organic compounds (VOCs), heavy metals, heavy hydrocarbons, sulphur and chlorine compounds. Greenergy may generate additional post-carbon capture amine and cooling wastewater. BOC North Tees may generate carbon capture effluent with additional NW treatment at Bran Sands. Protium green hydrogen wastewater may require treatment and Clean Plant Energy.
- By 2027: Suez Haverton Hill new carbon capture plant.
- By 2030: EDF hydrogen production at existing nuclear power station and ReNew ELP new wastewater effluent stream.

Projection of water requirements for the Teesside industrial cluster through to 2050

As outlined above, hydrogen production and carbon capture can use potable, non-potable, saline, and wastewaters for cooling, as well as a raw material in the generation of electricity; production of hydrogen; and capture of CO_2.

The long-term energy transformation towards low and zero carbon industries by 2050 may result in considerably higher freshwater demands for power production than in recent history (Energy UK, 2021).

All power plants need access to high quality water (HQW) or demineralised water (for non-cooling uses). This is often supplied by public water (potable) supply. The amount of HQW annually consumed by electricity producers (95%ile) in 2050 is modelled to be up to 7Mm^3/year for the entire Water Resources North (WreN) area (Energy UK, 2021). The Humber Phase 1 report stated its HQW consumption is predicted to be 5Mm^3/year by 2050, therefore 2Mm^3/year for the remainder of the area. This appears to drastically underestimate predicted water use following the post-Covid interest in low and zero carbon technologies within the Tees industrial cluster area.

A review of publicly available JEP documents showed modelling of freshwater use for energy production (generation plus hydrogen) increases after a period between 2025 to 2030. While the rates of increase vary between scenarios, for all scenarios the use is much greater than the 2018 baseline (Energy UK, 2021). This is confirmed by our data.

In the JEP document CCC20 scenario, the production of hydrogen by electrolysis begins around 2025 to 2030 and either continues to increase or reaches a peak around 2048. Consumption of freshwater for the steam methane reforming production of hydrogen is predicted to begin in the period 2025 to 2030 and reach a peak between 2035 and 2045 before reducing in the period to 2050 (Energy UK, 2021). This is confirmed by our data.

- Alternative cooling methods can be used to reduce reliance on the local water sources. However, water cooling is normally preferred by industry and is considered best available technique (BAT) under the following hierarchy (EA, 2021).and most thermally efficient. It uses by far the greatest gross volume of water, but with little consumed in the process (less than 1%). Recently, designing, installing and

operating once-through cooling systems to ensure compliance with The Eels (England and Wales) Regulations 2009, has increased costs drastically.
- Tower and hybrid (indirect) cooling facilities involve the evaporation of water to remove waste heat. Less water is required compared to a once-through system, but indirect cooling has the highest consumptive demand. Almost 50% of the abstracted water required for cooling on a combined cycle gas turbine (CCGT) is lost to the atmosphere. These systems are typically 0.5% to 2% less efficient than direct cooling.
- Dry/air cooling requires only small amounts of water in a closed, re-circulating water circuit. The heat generated is transferred to the atmosphere as hot air by motor driven fans. This system is 2% to 3% less efficient than direct cooling (EA, 2013).

5.5 Stakeholder engagement response -Teesside

5.5.1. Water quality

Many industrial stakeholders have recently accelerated their plans to decarbonise but are generally at the pre-FEED stage and therefore were unable to give the level of detailed requested by this project.

New and existing stakeholders were confident of a sustained water supply in the Tees cluster area.

Water companies are encouraging new operators to consider air cooling technology to reduce water demand, which may contradict the best available techniques (BAT) for cooling hierarchy.

New operator, Circular Fuels proposes to reuse more than 60% of its treated effluent. This is an encouraging example of site-specific effluent treatment prior to discharge for third party treatment by Northumbrian Water. The extraction of cleaner water for reuse reduces raw water demand but also concentrates the final effluent to Bran Sands.

The rapid development of low and zero carbon projects across many brownfield sites may affect the environment because of ground conditions and potential mobilisation of historical contaminants. There is a once-in-a-generation opportunity to clean contaminated land prior to construction, to protect and improve surface water and groundwater quality.

The Tees industrial cluster area is already designated for nutrient neutrality to protect the Special Protection Area (SPA). The nitrogen capacity of the environment may affect new low and zero carbon projects because of stricter limits on potential water quality impacts. New processes must prevent or limit emissions of dissolved inorganic nitrogen (DIN) to the water environment.

Treatment capacity is available at Bran Sands, although stricter nitrogen nutrient loading limits in the river may require the installation of additional treatment.

Changes to the use of effluent sludge for agricultural benefit may have an impact on the treatment capacity at Bran Sands.

Potential investors in low and zero carbon industries are investigating wastewater reuse.

5.5.2. Water availability

There is uncertainty around the industrial water demand data figures. There is an interdependency between the cooling method agreed during the environmental permit determination process and abstraction sources.

Desalination or abstraction from aquifers is not a focus of attention.

Potential investors in low and zero carbon industries are investigating wastewater reuse.

There is a current 25Ml/day surplus of water to supply planned deployments in the Tees industrial cluster area. To achieve the range of volumes required by new low and zero carbon technologies, there will likely be a need to reinvest in the transfer infrastructure and to review the Kielder Operating Agreement.

For most of the Tees cluster area there are no water abstraction restrictions.

5.5.3. Water company and water resource management engagement

Two water supply undertakers, Northumbrian Water and Anglian Water provide public water supply around the Tees industrial cluster. The government asks water companies to provide a secure supply of water to their customers over a minimum 25-year period, at an affordable price without damaging the environment.

Water companies in England and Wales must produce a water resources management plan (WRMP) every 5 years to show how they will achieve this. If a WRMP forecasts a deficit, then the water company must consider both supply-side options to increase the amount of water available and demand side options which reduce the amount of water required.

6. Humber and Teesside – Climate change impact projections

Climate impact projections were previously reviewed in the Phase 1 pathfinder project. For the purposes of Phase 2, we have provided a more in-depth review of climate impacts.

Climate change will affect the Humber and Northumbria River Basin Districts (RBD) and the Humber and Tees Estuaries in several ways. It is expected to have severe physical, chemical, and biological effects on the Humber Estuary, although consensus on the magnitude of these impacts varies.

Although there are differences between the 2 estuaries, the headline climate change and impacts messages are:

- Air temperature could increase by up to about 8°C in the summer by the end of the century.
- Winter rainfall is projected to increase (by up to about 45%) and summer rainfall to decrease (by about 65%).
- Peak rainfall may increase by up to 45%.
- Peak river flows are variable by management catchment but may increase by over 60%.
- Low flows may decrease for rivers in the basin by as much as 60 to 80 % depending on the flow metric.
- Large reductions (of about 60%) in summer groundwater recharge are projected, with relatively small increases projected in winter.
- Groundwater levels could decrease by between about 1 and 14%.
- Phosphorus concentrations could increase by mid-century, especially in the summer, by as much as 60%.
- The maximum median monthly chalk stream water temperature is projected to increase by over 4°C in some streams in the Humber basin.
- Allowances suggest assessing and planning for impacts of over 1.5m of sea level rise by 2121. Climate science indicates we are locked into significant sea level increase, with credible maximum scenarios suggesting 1.9m by 2100. Sea levels will continue rising beyond the 2100s. The speed of sea level change depends on the pace of carbon emission reductions.

These results are indicative, represent high-end impacts and suggest the need for more detailed, locally specific climate change impacts assessments. They are consistent however with the planning assumptions recommended by the EA for risk screening. While the climate change projections cover the Humber (and Tees) Estuary themselves, much of the impacts information (river flows, water temperature, phosphorus concentrations) is derived from river locations across the Humber (and Northumbria) river basin districts, at different scales and for different time periods.

Estuaries are dynamic environments influenced to varying degrees by the interaction of coastal and fluvial processes. Sea level rise has already affected UK estuaries, increasing the impact of storm surges, and increased winter rainfall may have increased fluvial flows to estuaries (Watts and Anderson, 2016). There is clear evidence that warming seas, reduced oxygen, ocean acidification and sea-level rise are already affecting UK coasts (MCCIP, 2020). Several risks have been identified in relation to future climate change (Watts and Anderson, 2016):

- Changing patterns of river flow: lower summer flows increase the risk of eutrophication.
- In some estuaries, higher sea levels will lead to saltwater intruding further inland above and below ground.
- Increased temperatures may increase risks to human health through pathogens in water.
- Habitat loss from rising sea levels may have a serious impact on some protected areas.

Recently, Lonsdale et al (2022) provided a comprehensive summary of climate change impacts on estuarine environments, using the Humber Estuary as a case study. Recognising that in addition to local pressures, climate change is having a range of severe impacts on estuarine ecosystem functions and services, they focused on how current legislation and management addresses the potential physical, chemical and biological impacts of climate change. They highlighted that a major gap is the availability of data to understand the magnitude of the effects of climate change and what can be done about it.

For the Humber river basin district, under the high emissions scenario from the UKCP18 probabilistic projections (from the UKCP18 Key Results Spreadsheet) mean annual temperature can be up to 1.8 to 6.2°C warmer for the period 2080 to 2099 relative to the period 1981 to 2000. In the summer (when we expect water and pollution related impacts to be greater), mean temperature can be up to 2.0 to 8.2°C higher for the same periods. Although mean winter rainfall is generally expected to increase (change between -6 and +46%), summer rainfall is expected to see significant reductions (change between -66 and +10%) under Representative Concentration Pathway (RCP) 8.5 (a high emissions scenario). Rainfall and temperature changes from UKCP18 are quite similar for the Tees (Northumbria RBD).

UKCP18 also provides estimates of future sea level rise as part of the marine projections (Palmer and others, 2018). These have been processed to provide epoch rates and cumulative levels for the river basin districts in England for the Flood risk assessments: climate change allowances). Using the higher central and upper end rates provides an estimate of sea level rise of between 0.8 and 1.0m in 2095 relative to 2000 for the Humber and slightly lower at between 0.7 and 0.9m for the Tees. However, a credible maximum scenario for 2100 is 1.9m, which nationally significant infrastructure projects should assess the impact of. This is so they can ensure that they are able to adapt to higher rates of change if needed over the lifetime of the project. Sea levels will continue to rise beyond 2100, and how quickly we experience higher rates will depend on the pace of global carbon reductions[1]. (Met Office, 2019)

In general, it is expected that flow estimates will be broadly consistent between projections using UKCP18 and the previous UKCP09 projections. The UK Centre for Ecology & Hydrology's Future Flows and Groundwater Levels project developed flow projections using UKCP09 (Prudhomme and others, 2013). Future Flows Hydrology (FFH) consists of daily flow time series between 1951 and 2098 for 282 catchments across the UK. There are some important differences between the production (different climate projections, sites, scenarios, hydrological models and time periods) of the sets of flow projections that may produce specific differences between the 2 data sets. In particular, the newer eFLaG: Enhanced Future Flows and Groundwater data set is based on a newer and higher emissions scenario (RCP8.5) than that used in Future Flows (Medium emissions). This will likely suggest greater flow reductions towards the end of the century. Future Flows Hydrology (FFH) has been used in water resources management planning and the National Framework for Water Resources.

For stations across the Humber between the 1989 to 2018 baseline and 2050 to 2079 for future periods, low flows (Q90, Q70) show that consistent decreases in flow between less than -60 to -10% are projected.

For groundwater, levels statistics consistently show small decreases, although these are greatest at the lowest levels. Winter recharge is projected to increase, while summer recharge is projected to significantly decrease.

As part of the PR19 water resources management plans, Future Flows was used to develop monthly flow change factors, which were aggregated by river basin district and included in the current Climate impacts tool. Winter monthly change factors for the north-east region (covering both the Humber and Tees) tend to suggest flow increases (by up to 30%) between the 1961 to 1990 baseline and 2070 to 2098 future period. Summer monthly change factors tend to suggest flow decreases (up to 50%). The greatest reduction in monthly flows for the north-east region could see decreases of as much as 70%. These appear consistent with the magnitudes derived from eFLaG, despite the differences in data set production and chosen flow metrics. It is important to note that for both eFLaG and FFH flow projections are derived at stations on rivers away from the estuary itself.

For the Humber, groundwater levels statistics consistently show small decreases, although these are greatest at the lowest levels. Decreases in groundwater levels for the Tees are higher than for the Humber. Winter recharge is projected to increase (by up to about 10%) and summer recharge is projected to significantly decrease (by almost 60%) for the Humber. Winter recharge is projected to increase by a similar amount for the Tees, but the decreases in summer recharge are less.

Future Flows was used to produce estimates of changes in phosphorus concentrations in English rivers (EA, 2016; Charlton and others, 2018). It shows increases in summer phosphorus concentrations in the north-east region of up to +60%, with some reductions (of about 5%) between the 1961 to 1990 climate baseline period and the 2050s (2040 to 2069).

This was driven by reduced dilution under reduced flows in summer. Similar dilution effects might be expected for other pollutants. An extension of this work (EA, 2019b) demonstrated the importance of water temperature in influencing future algal bloom risk in English rivers. Recently, water temperature projections for chalk streams have been published (EA, 2022) using the UKCP18 regional (12km) projections. They indicate that the maximum monthly water temperatures could be up to 4.6°C warmer by the 2070s.

The climate change impacts outlined indicate some substantial changes in rainfall and temperature into the future because of climate change. In turn, these produce changes in risks to the water environment, which will impact ecology. To ensure that the risks can be planned and prepared for, there is a need for a greater understanding of the risks to water quality and ecology both now and in the future from pressures such as climate change, land use change, and industrial emissions.

7. Conclusions and recommendations

Phase 2 of this project reviewed environmental capacity for the deployment of carbon capture usage and storage and hydrogen production in the Humber and Teesside industrial clusters due to their sizeable contribution of 12.4Mt and 3.9Mt respectively to the UK's 33.2Mt total annual industrial carbon dioxide emissions. The focus of Phase 2 is a deeper assessment of water quality, a review of air quality and flood risk in the Humber. In Teesside the project considered water availability and water quality to provide an overview of water capacity across the whole East Coast Industrial Cluster. The project worked with local and national EA specialists, and leading industrial and place-maker stakeholders to gather knowledge, compile and interpret the evidence and canvas opinion.

In conclusion, water quality in both Humber and Teesside is already negatively affected by multiple factors and suffers challenges to ecological and chemical statuses that need to be addressed. River basin management plans (RBMP) include a programme of measures, including proposed and ongoing water company investments to achieve good chemical and ecological status in inland and coastal waters by 2027 at the latest. This target needs to be kept on track, while keeping to the timetable of low and zero carbon deployments.

Water availability forecasts in the Tees show that current demand can be met, but forecasts for future availability are uncertain. Looking to the future, climate change projections for the Humber and Tees (UKCP18) indicate that this situation will be worsened by climate change; rainfall will significantly reduce over the summer months (34%), and we can expect greater incidence of droughts and low river flows by 2050.

Developers need to provide realistic estimates of their water needs and commit to this in writing as part of the Water Resource Management Plan (WRMP) consultation process. They should not rely solely on surface and groundwater sources. There will be limitations on supply in specific areas within a region, both now and in the future. Wastewater reuse is being actively investigated by potential investors in low and zero carbon projects.

The draft WRMP for Water Resources North (WreN) envisages a potential need for future water transfers from Northumbrian Water into Yorkshire to provide public water supply and a secure supply for industrial use. For this to happen, appropriate funding mechanisms would need to be in place, suggesting the need for greater collaboration between water companies and industry.

While the large scale inter-regional transfer of water from areas of surplus to areas with deficit could be a solution to longer term water supply issues, there are potential environmental impacts that would need to be considered. Removing water from a resource could have an impact on overall water quality, leading to ecosystem decline and habitat degradation. These issues should be addressed at the earliest opportunity with the correct planning and design approach.

Large-scale water transfers have been discounted from previous stages of water resource planning due to cost and potential environmental impact. If they are to be a viable future option, then further work to better understand potential environmental impacts of water transfers that involve rivers or canals as either transfer conduits or receiving bodies is recommended.

A significant risk to the decarbonisation of the Humber and Teesside industrial clusters is the lack of certainty over the timing, scale and location of proposed projects. Planning with such uncertainty is difficult for many reasons, which makes it challenging for investment in infrastructure to support decarbonisation, including the provision of water.

Investment is only possible where clear decisions and agreed needs and targets are available. For example, generation capacity output required by 2030 at Humber Industrial Cluster. From a statutory water resource planning perspective, the strategic water company plans are not nimble enough to respond to sudden 'new' demands, and the financial regulator is currently not able to support companies delivering against unknown demands as this presents a significant risk to customers and bills.

The availability of water, both from the environment and public water supply companies, is difficult to assess. Water availability is a significant challenge, but with certainty over the scale and timing of future water needs, options can be developed either by the developers, the incumbent water company or third parties. This also enables existing asset owners to better plan for future requirements, enabling efficient investment decisions.

The benefit of working as an 'industrial cluster', where multiple industrial complexes are co-located in a strategic spatial hub, is to facilitate the join-up needed between sectors and local and national stakeholders (including government). However, the cluster approach must be extended to the whole system, and not just the carbon capture and storage and hydrogen systems, for this to be effective. There are existing water quality concerns, so permitting additional discharges are likely to be challenging. The Humber's conservation designations may limit what development is permissible in the immediate vicinity. The evaluation of available evidence suggests that salt marsh and sea grass habitat are most at risk from water quality issues, while sand dunes and sensitive groups such as lichen and bryophytes are at risk from air quality issues. These are at the highest risk in certain geographical areas and vulnerable to cumulative impacts if not managed correctly.

Sewer capacity may also limit the extent of what is permissible without improvements in infrastructure and treatment. It's important to remember that wastewater arisings, including heat discharges coupled with climate change impacts, can lead to further decline in water quality.

Capacity to treat wastewater is available in the Humber and Tees, although stricter nitrogen nutrient loading limits in the Tees will require the installation of additional treatment. Areas of the Tees already designated for nutrient neutrality to protect the special protection area (SPA) may affect new low and zero carbon projects, requiring stricter limits to address potential water quality impacts from nitrogen nutrient loading, and nitrogen capacity.

With the rapid development of low and zero carbon infrastructure expected in Teesside, there is the potential for impact from brownfield sites during construction, due to ground conditions and potential mobilisation of historic contaminants. There is an opportunity to reduce river pollution in the Tees by cleaning contaminated land prior to construction, to protect and improve surface water and groundwater quality.

There is uncertainty around the potential impacts on air quality in the Humber. This is due to the lack of information available on expected emissions from planned deployments. There is also an increased risk of impact on habitats due to high nutrification, coupled with unknown background levels of amine solvents used in carbon capture and storage. Work is needed to further understand ambient levels of new pollutants and by-product cumulative impacts, with early disclosure of emissions profiles from industry. As such, our permit approaches for these technologies are less well developed. Challenges to effective regulation and authorisations include our understanding of the impact of new pollutants, and the availability of baseline data. Early disclosure of emissions profiles from industry is crucial to our understanding of their impact on air quality and ecology.

A significant proportion of the Humber and the cluster is already at risk of flooding, and this risk will only increase due to climate change. To minimise vulnerability and provide resilience to flooding and coastal change, individual projects must assess and plan for current and future flood risk. They should extend their review of flooding impacts beyond their site, to assess possible disruption to their activities, such as transportation routes or critical off-site infrastructure. Ultimately design standards need to take account of unpredictable extremes the future climate will bring. The connected deployments should understand the risk of flooding to the whole cluster and its ability to operate and achieve the benefits expected. This will complement site-specific implications and may identify main collective risks and actions. There are opportunities to positively support adaptation to flooding across the region by working with established flood risk partnerships.

This project provides an overview of potential environmental capacity for the deployment of carbon capture and hydrogen production in Humber and starts to review challenges in Teesside, providing an overview of current and future water needs and potential impacts in Humber and Tees for the whole East Coast cluster. The value of this work is taking a cumulative view of industry needs and environmental capacity within the context of the current and future environment. Without this cumulative advance view of deployment in clusters we risk an individual project approach that will not deliver collective deployment of carbon capture and hydrogen production in clusters.

To continue the approach used in Phase 1, this current Phase 2 and provide a representative overview of environmental capacity for industrial clusters, it is recommended that this project continues, to extend to one additional industrial cluster. This would allow us to explore the full spectrum of environmental capacity across a representation of clusters in England, to help decision-makers, industry, and regulators, and help avoid costly delays in collective and effective deployment.

Project recommendations:

- Expand the technical scope of environmental capacity, to review updated water demand and availability information, further consider air quality and flood risk in Teesside.
- Conduct a review of water availability and water quality (and later air quality and flood risk) in the North-west (Hynet) industrial cluster.

- Incorporate these factors and results into advice for all industrial clusters that include carbon capture and hydrogen production.
- Compare findings between industrial clusters to identify commonalities that may challenge deployments across England.

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9. Glossary

Term	Meaning
Abstraction	Removal of water from a source of supply (surface or groundwater).
Abstraction licence	The authorisation granted by the Environment Agency to allow the removal of water.
Amine degradation by-products	The most known about carbon capture technologies use a range of amine containing solvents to capture CO2 from waste gases and then release them following a heating process. Due to the volatility of amines, their reaction with mixtures of flue gas contaminants and heat the amines can react to form new compounds. These are degradation by-products.
APIS	UK Air Pollution Information System. This site provides a searchable database and information on pollutants and their impacts on habitats and species.
AQMA	Air Quality Management Areas: Since December 1997 each local authority in the UK has been carrying out a review and assessment of air quality in their area. The aim of the review is to make sure that the national air quality objectives will be achieved throughout the UK by the relevant deadlines. If a local authority finds any places where the objectives are not likely to be achieved, it must declare an Air Quality Management Area.
Blow down	The steam cycle used in boilers to transfer heat results in the concentration of contaminants such as limescale and metals within the water used to make steam. Blowdown is the intentional purging of some of the boiler water/steam to reduce impurities in the water system via replenishment using new water, with the associated benefit of flushing through contaminants during the purge process.
CAMS	Catchment abstraction management strategies, set out the framework for water availability for abstraction. These strategies explain if there is water available or not. They are underpinned by extensive and detailed work to establish the extent of water resource. Our critical work to satisfy the Water Framework Directive (WFD) drives the indication of water availability and water quality. We consider applications for abstractions from surface and groundwater resources.
Consumptive abstraction	Abstraction where a considerable proportion of the water is not returned either directly or indirectly to the source of supply after use. For example, for the use of spray irrigation.
Contract for Difference	The Contracts for Difference (CfD) scheme is the government’s main mechanism for supporting low-carbon electricity generation
Discharge	The release of substances (for example, water, treated sewage effluent) into surface waters.

Emission scrubbing	This is the intentional removal of selected pollutants from emissions arising from an industrial process. The technology varies according to the industrial process and emission limit target.
Environmental capacity	This is the potential of the natural environment to provide resources necessary for decarbonisation or to accommodate emissions from such processes. For example, the adequate supply of water without compromising other users or the environment.
Epoch rates	There are allowances for different climate scenarios over different epochs, or periods of time, over the coming century. They include figures for extreme climate change scenarios. Climate change allowances are predictions of anticipated change for factors such as sea level rise and peak river flow. These change between different epochs so projects will need to consider the changing risks between epochs.
Future Flows Hydrology	**A projection of daily river flow and monthly groundwater levels for climate change impact assessments in Great Britain.**
Industrial cluster	Industrial clusters are a concentration of related industries or several industrial sites that are grouped within proximity to one another.
Kielder Operating Agreement	In 1989 the National Rivers Authority, predecessor body to the Environment Agency, and Northumbrian Water Limited entered into a legally binding agreement made under section 20 Water Resources Act 1991 for payment of the Kielder Reservoir and transfer scheme. This is called the Kielder Operating Agreement (KOA). The Environment Agency is legally obliged to pay NWL an annual payment for the Kielder Reservoir and transfer scheme. It is also obliged to pay 100% of the operating costs. The Environment Agency must recover these costs from charge payers in line with HMT guidelines for managing public money.
Kielder Transfer	A major piece of water transfer infrastructure underpinned by Kielder Reservoir on the North Tyne. Originally designed for anticipated industrial growth on Teesside. Water can be transferred to the Wear and the Tees rivers, to meet shortfalls in those areas
Natural England	They are the government's adviser for the natural environment in England and are an executive non-departmental public body, sponsored by DEFRA.
Net zero	Net zero means that the UK's total greenhouse gas (GHG) emissions would be equal to or less than the emissions the UK removed from the environment.
Nutrient neutrality	Nutrient neutrality is a means of ensuring that a development plan or project does not add to existing nutrient burdens within catchments, so there is no net increase in nutrients as a result of the plan or project.
Once-through cooling	The purpose of cooling is to remove waste heat from a thermal process. Once through cooling is also known as direct cooling and involves the singe use circulation of water extracted from the environment for cooling purposes which is then returned after only one use.

Pathfinder project	This was phase 1 of the environmental capacity project and considered water supply to and future demand from the Humber industrial cluster.
Place-maker	Place-makers are organisations, communities and individuals involved in creating quality places that people want to live, work, play and learn in. For this report we are referring to local authorities.
PWS	Public Water Supply.
RBMP	River basin management plan.
Surface water	A general term used to describe all water features such as rivers, streams, springs, ponds and lakes.
Trac	Transitional and coastal water body
Water body	Units of either surface water or groundwater which we use to assess water availability**.**
WRE	Water Resources East.
YWS	Yorkshire Water Services.

List of abbreviations

AD	Anaerobic digestion
AEL	Associated emissions levels
ALS	Abstraction licensing strategy
AQS	Air quality strategy
BAT	Best available techniques
BEIS	(Department for) Business, Energy and Industrial Strategy
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CCUS	Carbon capture usage and storage
CHP	Combined heat and power
CO_2	Carbon dioxide
COMAH	Control of Major Accident Hazards
CRT	The Canal & River Trust
DIN	Dissolved inorganic nitrogen
DLUHC	Department for Levelling Up, Housing and Communities
EfW	Energy from waste
EIA	Environmental impact assessment
EQS	Environmental quality standard

ESNZ	(Department for) Energy Security and Net Zero
FFH	Future Flows Hydrology
GEP	Good ecological potential
GES	Good ecological status
Ml/d	Megalitres per day, one million litres per day
MMF	Minimum maintained flow
MoU	Memorandum of understanding
PEM	Polymer electrolyte membrane
POP	Persistent organic pollutants
SAC	Special Area of Conservation
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
TRL	Technology readiness level
VOC	Volatile organic compound
WFD	Water Framework Directive
WReN	Water Resources North
WRMP	Water resources management plan