Environmental Capacity in Industrial Clusters project - Phase 3

Technical Annex 5 – HyNet Evidence baseline and analysis

Date: 27 March 2024

Version: 1.0

Prepared by Water Research Centre, WRc

On behalf of Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH
www.gov.uk/environment-agency

WRc authors

Robert Fairhurst
Senior Scientist
Technical Consulting

Fiona Thompson
Water Supply Consultant
Technical Consulting

Jacob Farrelly
Sustainability Consultant
Senior Consultant
Technical Consulting

Ayash Anwar
Graduate Water Process Engineer
Water and Environment

Amy Jones
Senior Consultant
Technical Consulting

Daniel Pearce
Consultant Scientist
Technical Consulting

Co-authors: Ahmed Khalid (Graduate Water Process Scientist), Abraham Negaresh (Associate Director).

Contents

Appendices

List of Tables

List of Figures

Acronyms

DESNZ	Department for Energy Security and Net Zero
BEIS	Department for Business, Energy & Industrial Strategy
ASU	Air Separation Unit
ATR	Autothermal Reformer
AWE	Alkaline Water Electrolysis
BOD	Biochemical Oxygen Demand
CAMS	Catchment Abstraction Management Strategy
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CHP	Combined Heat and Power
COMAH	Control of Materials, Accidents and Hazards Regulations 2015
COD	Chemical Oxygen Demand
CP	Critical Period
CPI	Corrugated Plate Interceptor
DCWW	Dŵr Cymru Welsh Water
DI	Distribution input
DO	Deployable output
dWRMP24	Draft Water Resource Management Plan 2024
DWMP	Drainage and Wastewater Management Plan
DYAA	Dry Year Annual Average
EA	Environment Agency
ELMS	Environmental Land Management Schemes
EPR	Environmental Permitting Regulations
ERF	Energy Recovery Facility
GHR	Gas-Heated Reformer
HAMP	Highway Asset Management Plans

HD	Hafren Dyfrdwy
HH	Household
HOF	Hands off flow
HRA	Habitat Regulations Assessment
HyNet or HyNet NW	HyNet North West Industrial Cluster
ITS	Isothermal Shift
KO pots	Knockout pots
LCH	Low Carbon Hydrogen
LWEC	Living With Environmental Change
MBR	Membrane Bioreactor
MDO	Minimum Deployable Output
MMO	Marine Management Organisation
NALD	National Abstraction Licensing Database
NAV	New Appointment and Variation
NEP	National Environment Programme
NHH	Non-household
NRW	Natural Resources Wales
NVZ	Nitrate Vulnerable Zones
NWT	North West Transfer
OBH	Observation Borehole
PBDE	Polybrominated Diphenyl Ethers
PCC	Per Capita Consumption
PEM	Proton Exchange Membrane
PFAS	Per- and polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PSA	Pressure Swing Adsorption
PWS	Public water supply
RBMP	River Basin Management Plan
RCP8.5	Representative Concentration Pathway 8.5

rdWRMP24	Revised draft Water Resources Management Plan 2024
RNAG	Reasons for Not Achieving ‘Good’ WFD status
ROG	Reactive Organic Gases
SAC	Special Area of Conservation
SPA	Special Protected Area
SRO	Strategic Resource Option
SSSI	Site of Special Scientific Interest
SSW	South Staffs Water
STT	Severn to Thames Transfer
SVT	Severn Trent Water
TraC	Transitional and Coastal (waters)
TSS	Total Suspended Solids
UKCP18	UK Climate Projections 2018
UU	United Utilities
WAFU	Water Available for Use
WFD	Water Framework Directive
WINEP	Water Industry National Environment Programme
WRGIS	Water Resources Geographical Information System
WRMP	Water Resource Management Plan
WRMP24	Water Resource Management Plan for Price Review 2024
WRSE	Water Resources South East
WRc	Water Research Centre
WRW	Water Resources West
WRZ	Water Resource Zone

1. Background

The HyNet North West Industrial Cluster (HyNet) is a planned network of new infrastructure and existing infrastructure that will capture carbon, and produce, transport and store hydrogen in north-west England and north-east Wales. Water Research Centre (WRc) has been commissioned by the Environment Agency (EA) to complete an evidence review to understand expected emissions to water, water quality impacts, and water demand and availability for HyNet.

Water is an essential raw material for industry and energy production. In the context of the HyNet NW industrial cluster, it is well known that there are significant water requirements for carbon capture and hydrogen production, both in terms of process use and as a mechanism for cooling. This annex also identifies other activities in the cluster which might require water use, or might otherwise impact the water environment, such as hydrogen storage.

The quantity, source, uses, and treatment/discharge of water all affect the environment. For example, power generation involving carbon capture can use water for cooling purposes where much of the water is returned to the environment, albeit at a higher temperature. Water use for hydrogen production can be significant both in terms of process use and cooling requirements, while water is also needed for steam generation and as the basis of the solvents used in carbon capture. It is important to understand these requirements as the impacts have the potential to limit the ability to deploy the technologies at scale.

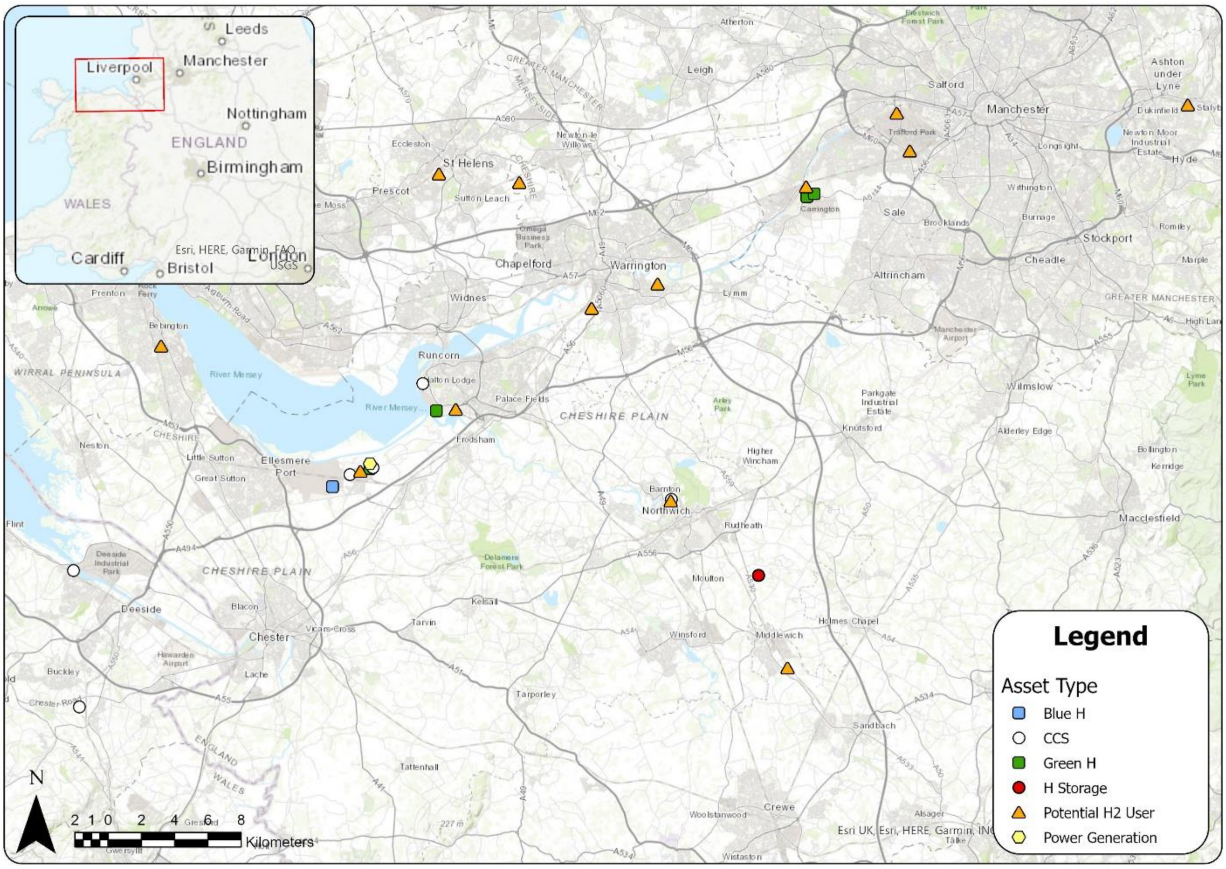
The planned 'HyNet NW' network, illustrated in Figure 1.1 comprises a hydrogen production plant, industrial carbon dioxide capture, underground hydrogen storage and industrial hydrogen users. The network extends across multiple river catchments and crosses the England-Wales border. The network is located in an area with important national heritage and numerous protected sites, such as Sites of Special Scientific Interest (SSSIs) and Special Areas of Conservation (SACs), including some internationally important sites (Environment Agency, 2013; Environment Agency, 2020a).

1.1 Context

1.1.1 Government strategy

The UK government has set a target to have two low carbon industrial clusters deploying hydrogen production and carbon capture and storage by the mid-2020s, and a minimum of four by 2030. HyNet is one of the two planned ‘Track 1’ clusters planned to be deployed by 2025. These clusters seek to *“allow industry and the economy to flourish without the greenhouse gas emissions which have been associated with industrial heartlands by decarbonising carbon-intensive industry and generating cleaner energy”* (Department for Energy Security & Net Zero; Department for Business, Energy & Industrial Strategy, 2021).

Figure 1.1 HyNet asset locations



1.2 Commission Objectives

The WRc commission was made by the EA's Climate Change & Energy Programme which is part of the Environment & Business Directorate. The WRc commission started in November 2023 and completed by 31st March 2024. The objectives set by the EA were as follows:

- To carry out a literature review to understand water quality and water availability, and water demand studies relevant to net zero, focusing on the possible impacts from hydrogen production and carbon capture technology.
- To use knowledge gathered from current studies to inform a stakeholder engagement exercise including Environment Agency water quality and water resource specialists, industry, trade associations, hydrogen and carbon capture research groups.
- To evaluate and interpret the evidence to produce key findings on the water-related environmental impacts of the proposed decarbonisation of the HyNet Industrial Cluster in the near and mid-term future.
- Support EA project write up and production of products such as a final report and infographic by providing evidence. Support the production of a set of key messages to be included in the project products.

The impacts of/on flooding, droughts, and sea level rises are outside the scope of this annex .

2. Methodology

The WRc commission tasks included a literature review, development of an 'evidence baseline' slide pack outlining HyNet and its links to the local water environment, and stakeholder engagement. Evidence from each of these tasks was analysed (Section 3) with results summarised in Section 4 of this annex. The approach for each task is outlined below.

2.1 Literature review

A review of existing literature and available data relevant to water-related environmental risks was undertaken, covering low carbon technologies planned for deployment in the HyNet NW Industrial Cluster. In addition, a review was undertaken of future risks to the natural water environment and for external factors which might affect future water availability or the level of risk. Key sources included:

- project reports from the EA's previous Phase 1 and 2 work on environmental capacity in industrial clusters,
- EA publications such as abstraction licensing strategies and its catchment data explorer,
- EA/Natural Resources Wales (NRW)/UK Government spatial layers and abstraction licensing data,
- publications from the Joint Environment Programme estimating water intensity and demand for hydrogen production,
- water company draft water resource management plans, drainage and wastewater management plans and draft business plans,
- government strategies, plans, and projections,
- UK Climate Risk Assessments.

WRc also appealed for documented evidence via our stakeholder engagement exercise.

This research was used to establish an evidence baseline for the current status of the natural and potable water environments, and the likely future status (availability and quality) given the expected impacts of pressures such as climate change, limits of the environment, demand, potential impacts from low carbon technology, and policy changes.

The literature review can be found in Annex 4.

2.2 Evidence baseline

The evidence baseline was used to inform and guide internal (EA) and external stakeholder engagement to fill knowledge gaps, identify potential issues and risks, and assess water quality and water availability. The evidence baseline was further developed based on the findings of the stakeholder engagement to establish the extent constraints could challenge proposed deployment.

2.3 Stakeholder engagement

The Environment Agency arranged online meetings with stakeholders between December 2023 and February 2024 inclusive. Meetings with multiple stakeholders (i.e. trade associations, regulators, local authorities) comprised a presentation delivered jointly by the EA and WRc, following by a semi-structured interview with questions adapted to the stakeholder(s). The smaller meetings with individual companies were conducted by the EA only and comprised a shorter presentation and semi-structured interview. Annex 6 provides more details of the stakeholders consulted and summarises the key findings from each meeting.

2.4 Analysis

These various information sources were then appraised to identify and direct additional analysis that could be performed to support the project objectives. This is documented in Section 3 of this annex. This technical annex presents an interpretation of the available information and possible impacts of the results, alongside the method used to derive them and the assumptions and limitations which underly these interpretations.

In particular, the analysis task considered gaps in current knowledge, given that there are HyNet projects likely to occur by 2030 that are not yet planned or in the public domain. The analysis synthesises information from the literature and stakeholder engagement and analyses additional data – including abstraction licences and discharge permits – that were sourced through the project. It aims to understand likely water availability for HyNet and potential water quality impacts.

2.5 Results

The results section summarises known projects within HyNet, likely water demand, water availability constraints and potential impacts of HyNet on receiving waters, up to 2080. Gaps in current knowledge are highlighted.

Water availability has been presented as geospatial outputs that highlight where overlap might occur between hydrogen development/low carbon technology and acute water resource constraints.

The results of the study are presented in Section 4 of the final report.

2.6 Time horizons

The EA has asked WRc to assess the impacts of HyNet against three time horizons:

- Short-term future: 2030
- Mid-term future: 2050
- Long-term future: 2080

It was generally found that insufficient data exists to consider impacts in the long-term future. As such, the quantitative analysis in this annex has focussed on the 2030 and 2050 horizons.

The EA asked for future time horizons to be assessed in the context of the high temperature UKCP18, RCP8.5 (high emissions scenario). This scenario is characterised by high rates of temperature change, reaching 5°C above pre-industrial temperatures before the end of the 21st Century (Met Office Hadley

Centre, 2018). However, most water resources planning by regional groups and water companies used RCP6.0 for their preferred plans, therefore RCP6.0 has been assessed where RCP8.5 data were not available. Within other contexts, quantitative data for specific emissions scenarios was not available, therefore only broad statements have been made about the impacts of climate change.

3. Analysis

3.1 Estimated water demand

Two approaches to estimating water demand were used. The bottom-up approach detailed within Section 3.1.1 was calculated based on plans for known HyNet sites whilst the top-down approach (Section 3.1.2) provided an estimate of water demand based on supply/demand projections and targets for both the region and nationally.

3.1.1 Bottom-up estimates of HyNet water demand

The bottom-up approach predicted demand for HyNet by identifying available information on planned HyNet assets. The planned scale and technology for each asset was assessed using information from the literature review and stakeholder engagement. Estimates of water intensity for the identified technologies were used to forecast demand associated with each asset. Assets were grouped according to the following categories: hydrogen producers, carbon capture and storage (CCS) sites, power generation sites, hydrogen storage sites and hydrogen fuel-switchers. Hydrogen fuel switchers were not considered as producing additional water demand, as the water intensity of operations on these sites would not be affected by fuel switching. A summary of the results of this analysis can be found in Table 4.1 and a comparison against headroom in abstraction licenses in Section 4.1.3.

Hydrogen Producers

Hydrogen production has been further categorised by either ‘blue’ or ‘green’ production process.

- Blue hydrogen refers to the process of converting fossil fuels or non-renewable hydrocarbons with a low carbon intensity into hydrogen while implementing carbon capture and storage systems.

- Green hydrogen refers to the creation of hydrogen gas via electrolysis of water powered by renewable energy.

One blue and five green hydrogen production assets have been identified.

Blue Hydrogen

The Essar/Vertex[1] hydrogen plant at the Stanlow Refinery in Ellesmere Port is intended to play a central role in the HyNet NW cluster, generating 3 TWh per year (equating to 350 MW) of blue hydrogen by 2025 and rising to 30 TWh per year (equating to 3500 MW) of production after 2030 (HyNet North West, 2021). Stakeholder consultation has indicated that the first phase of development intends to source surface water from an existing UU abstraction point on the River Dee to meet demand but that the subsequent phase may need to consider alternative sources.

The water intensity of this hydrogen production process has been characterised as 17.4 L of consumptive surface water demand to produce 1 kg of hydrogen following Mbaguta (2021), inclusive of treatment, process and cooling water requirements. This water intensity results in a projected 4.3 Ml/d consumptive demand in 2030 (3TWh per year) and 43 Ml/d consumptive demand in 2050 (30 TWh per year). Water demand met via alternative sources would result in a different water intensity due to the level of treatment required, with the sole use of ground water (18.7 L/kg H_2) or a potable water supply (14.6 L/kg H_2) resulting in the projections shown in Table 3.1. The surface water estimates (shown in bold) have been assumed to be the most likely given the stakeholder engagement.

Table 3.1 Estimates of Blue Hydrogen Water Demand

Asset	2030 Demand Estimate (Ml/d)			2050 Demand Estimate (Ml/d)		
	Ground Water	Surface Water	Potable Water	Ground Water	Surface Water	Potable Water
Essar/Vertex Stanlow Refinery	4.6	**4.3**	3.6	45.9	**42.7**	36.4

---

[1] Essar/Vertex rebranded as EET Essar partway through the project. Essar/Vertex and EET Essar can be considered the same company throughout this annex.

Green Hydrogen

Green hydrogen production has been characterised with a water intensity of 35.4 L of consumptive water demand per kilogram of hydrogen produced, following Mbaguta (2021). This water intensity has been used consistently for ground water, surface water and potable water supplies in the source. Estimated demands are summarised in Table 3.2.

Cheshire Green, Protos, Ince

Plans for a Cheshire Green Hydrogen site at Protos Park, Ince indicate an expected capacity for production of up to 12,940 kg/year, drawing up to 30 MW of electricity (Environment Agency, December 2023). The 12,940 kg of hydrogen equates to 18 MW of hydrogen production (National Academy of Engineering, 2004), showing a 60% efficiency for the transfer between energy vectors. During the stakeholder engagement with Progressive Energy the plant was referred to as a 30 MW electrolytic hydrogen project, demonstrating potential for miscommunication when specifics are not clear. Where the capacity of a production plant has been specified, it has been assumed this is referring to output hydrogen rather than input electricity.

As no timeline for the operation of the site has been seen, it has been assumed that this site will not be producing hydrogen by 2030. The additional demand for 18 MW is estimated at 0.46 Ml/d using the Mbaguta (2021) water intensity. It has been indicated that the electrolysers will require 11,280 L/hr of potable water when operating at full capacity (Environment Agency, December 2023), equating to 21 L/kg H_2 and 0.27 Ml/d potable supply. This value is significantly lower than the Mbaguta (2021) estimate and has been assumed to result from the exclusion of demand for system cooling water.

Stakeholder engagement has shown that Progressive Energy intends to use potable supply to the Protos Park site to meet this demand and that UU have yet to confirm sufficient capacity to meet this demand.

Carlton Power, Trafford Green

Stakeholder engagement with Carlton Power indicated that the proposed capacity at the Trafford site is 15 MW for the first phase with permitting for up to 200 MW. It has been assumed that the first phase will be operational by 2030, and the full permitted capacity operational by 2050. Carlton Power indicated that water for the initial phase was planned to be sourced from a UU potable supply, with abstraction potentially considered for later stages in site development. Using the Mbaguta (2021) green hydrogen water intensity value of 35.4 L/kg H_2, this equates to 0.38 Ml/d demand in 2030 and 5.1 Ml/d demand in 2050.

Stakeholder engagement also provided the following values for water demand: 1300 kg/h for a 5 MW block (8.7 L/kg H_2) and 2.5 l/s for 15 MW (20.0 L/kg H_2). A 15 MW site was described as three modular 5 MW blocks and so it is surprising that these figures produce inconsistent water intensities. 8.7 L/kg H_2 is lower than the minimum stoichiometric requirement of 9L/kg H_2 to produce hydrogen from water with 100% efficiency, and so has not been used as an estimate. The 20.0 L/kg H_2 has been assumed to refer to electrolyser demand exclusive of cooling water requirements.

Ineos Inovyn CV, Runcorn

Stakeholder engagement has clarified that the Ineos Inovyn CV, site at Runcorn identified in the literature review has been producing hydrogen for many years and in its current form is operating at a reduced capacity of 38 MW out of a maximum capacity of 200 MW due to a limiting business model and financial regime in the UK. Most of the hydrogen produced is said to be burnt in boilers on site. As a result of this information, the 38 MW of Inovyn hydrogen generation capacity has been categorised as baseline (i.e. existing) demand, and not included in 2030 additional demand estimates. It has been assumed that by 2050, demand for hydrogen will result in the operation of the plant at full capacity, therefore 162 MW of additional hydrogen generation have been included in the 2050 scenario, resulting in 4.13 Ml/d additional demand (Mbaguta, 2021). Ineos advised that the current demand is met by UU potable water supply.

Kellogg’s, Trafford Park and Pilkington’s Glass, St Helen’s

Progressive Energy shared their intention to develop green hydrogen production at Kellog’s site in Trafford Park and at Pilkington Glass in St. Helen’s. Both sites were listed in the literature review as future fuel-switchers, however little evidence was available on the scale or timeline of hydrogen production at these sites and so they have been omitted from the bottom-up estimates.

Table 3.2 Estimates of Green Hydrogen Water Demand

Asset	2030 Demand Estimate (Ml/d)			2050 Demand Estimate (Ml/d)		
	Ground Water	Surface Water	Potable Water	Ground Water	Surface Water	Potable Water
Cheshire Green, Protos, Ince	Assumed not operational			0.46	0.46	**0.46**
Carlton Power, Trafford	0.38	0.38	**0.38**	5.10	5.10	**5.10**
Inovyn CV, Runcorn	Currently operational, no additional demand.			4.13	4.13	**4.13**

Carbon Capture and Storage (CCS)

Where site specific information is not available, CCS sites have been characterised with water intensities provided in Element Energy (2022). Water intensity of carbon capture is dependent on the cooling technology (detailed in Section 4.1.1) used. Air cooled CCS is reported as 0.01 m^3/tCO_2 consumptive demand, open-loop cooled CCS requires 0.2 m^3/tCO_2 consumptive demand and closed-loop cooled CCS requires 2.63 m^3/tCO_2 consumptive demand. Closed-loop cooling technology has been assumed at identified sites as it is the preference of plant operators in the UK.

Connah’s Quay CCS

Connah’s Quay CCS is a carbon capture facility planned to be built alongside a new power station, replacing an unabated gas-fired power station. Uniper plans for the CCS site to operate at 1,200,000 tCO_2/yr of carbon capture by its first phase of development in 2030, with potential plans to double capacity to 2,400,000 tCO_2/yr in future, with raw water abstraction sourced from the River

Dee (Uniper, n.d.). Completion to final capacity is assumed to take place by 2050, resulting in additional demand of 8.7 Ml/d in 2030 and 17.3 Ml/d by 2050, using closed-loop water intensity.

Protos Encyclis ERF CCS

Protos Encyclis ERF have shared plans to capture 500,000 tCO_2/yr of emissions from the Energy Recovery Facility (ERF) currently on the site, with the aim of operation by 2027. This would require 3.6 Ml/d of consumptive water demand when assuming closed-loop cooling, however Encyclis have informed us that the additional water requirement for the CCS is ‘effectively zero’ as this will be provided through the recycling of water generated in the ERF process. A potable water connection would be required for sanitary facilities and the fire water tank. The additional demand forecast for the Protos Encyclis CCS facility is therefore given as 0 Ml/d for both 2030 and 2050.

Viridor, Runcorn ERF CCS

Viridor, Runcorn ERF have shared plans to capture 900,000 tCO_2/yr of emissions from the ERF currently on the site. This equates to 6.5 Ml/d consumptive demand when closed-loop cooling is assumed. During stakeholder engagement Viridor stated they were looking to make use of condensate generated in the ERF, but that additional water would be required, especially in periods of higher temperature such as summer periods, and that it would look for this supply from Ineos’ River Dee abstraction. Use of generated condensate suggests efficiencies that are not accounted for in the current estimate. It has been assumed that the CCS plant will not be operational before 2030.

Evero EfW/MHI, BECCS, Ince

Evero’s plans for a 250,000 tCO_2/yr capturing CCS plant at Ince are hoped to be operational by 2029. The scale of plant is equivalent to a 1.8 Ml/d consumptive demand from closed-loop cooling. Evero have shared their process water requirements for CCS as 71.98 m^3/hr (1.72 Ml/d), broadly in line with the Element Energy (2022) based estimate. They intend to meet 0.5 Ml/d of this demand with recovered water from the EfW plant operation, leaving a required additional demand of 1.22 Ml/d. Evero anticipate that this demand will be met by UU potable water supply and do not anticipate applying for an abstraction license.

Padeswood Cement Works CCS

Padeswood Cement Works plans for an 800,000 tCO_2/yr CCS plant will require 5.8 Ml/d additional consumptive demand (closed-loop estimate). It has been assumed that this plant will not be operational by 2030, therefore the demand has been added to the 2050 scenario.

Winnington CHP with CCU

Winnington CHP with CCU is currently operational at a scale of 40,000 tCO_2/yr. Using a closed loop water intensity of 2.63 $m^3/tCO2$ (Element Energy, 2022), this amounts to a consumptive demand of 0.29 Ml/d. The demand has not been included as additional HyNet demand as the site is in current operation and permit.

Table 3.3 Estimates of CCS Water Demand

Asset	2030 Demand Estimate (Ml/d)			2050 Demand Estimate (Ml/d)		
	Air Cooled	Open Loop	Closed Loop	Air Cooled	Open Loop	Closed Loop
Connah's Quay CCS	0.03	0.66	**8.65**	0.07	1.32	**17.29**
Protos Encyclis ERF CCS	N/A	N/A	**0**	N/A	N/A	**0**
Viridor, Runcorn ERF CCS	Assumed not operational			0.02	0.49	**6.48**
Evero EfW/MHI, BECCS, Ince	N/A	N/A	**1.22**	N/A	N/A	**1.22**
Padeswood Cement Works CCS	Assumed not operational			0.02	0.44	**5.76**
Winnington CHP with CCU	No additional demand.					

Power Generation

Ince Low Carbon Power Project is at the early development stage of plans to develop two low carbon CCGT generating stations (1700-1800MWe), one or both of which will be hydrogen-fired. The plant is expected to utilise local raw water supply with a demand of 20 Ml/d (Environment Agency, December 2023).

Hydrogen Storage

Stakeholder engagement with Ineos has clarified that plans for a hydrogen storage site in solution mined salt caverns between Rudheath and Middlewich would not produce additional demand outside of currently licensed abstraction for solution mining operations to commercially produce brine. Solution mining caverns intended for hydrogen storage is expected to begin by 2027 by Ineos.

3.1.2 Top-down estimates of HyNet water demand

It was noted during stakeholder engagement that initial (bottom-up) estimates of water demand from HyNet NW were likely to be an underestimate of actual demand as they considered only publicly announced schemes. In particular, some stakeholders alluded to additional water users about which details could not yet be shared. Moreover, it was unknown whether hydrogen production at HyNet would only be used on-site. There therefore existed the possibility for HyNet NW to be used as a hydrogen hub, generating hydrogen power for industry in the area (or wider, as part of a grid). As a result, it was decided additionally to provide plausible upper bounds to the water demand based on how HyNet NW might contribute to regional and national targets and supply/demand projections.

The various water demand estimates for hydrogen and carbon capture are discussed in the context of HyNet NW in Section 4.1.

Demand from hydrogen production

The following sources were identified as providing useful information regarding the water requirements associated with likely demand for / production of hydrogen in the vicinity of HyNet.

- Moores, A., 2021 Electricity and Hydrogen Production to 2050, under the 2020 Future Energy and CCC Scenario – Regional Analysis, Joint Energy Programme, ENV/677/2021

- Water Resources West, 2022, *Draft Regional Plan Appendix K Non PSW planning approach*

- Department for Energy Security and Net Zero, 2024, *2030 potential water demand for hydrogen production*, personal communication 08/02/2024

- Department for Business, Energy & Industrial Strategy, 2021, Analytical Annex to the Hydrogen Strategy, Net Zero Hydrogen Fund consultation, Low Carbon Hydrogen Business Model consultation, and Low Carbon Hydrogen Standards consultation, [Available at https://assets.publishing.service.gov.uk/media/611b34f9d3bf7f63a906871e/Hydrogen_Analytical_Annex.pdf , accessed 20/02/2024]

- Department for Business, Energy & Industrial Strategy & Department for Energy Security and Net Zero, 2021, *Industrial decarbonisation strategy*, Policy paper [Available at https://www.gov.uk/government/publications/industrial-decarbonisation-strategy/industrial-decarbonisation-strategy-accessible-webpage, accessed 20/02/2024]

- Department for Energy Security and Net Zero, 2023, *CCUS Cluster Sequencing Track-2: Market update December 2023,* Notice [Available at https://www.gov.uk/government/publications/cluster-sequencing-for-carbon-capture-usage-and-storage-ccus-track-2/ccus-cluster-sequencing-track-2-market-update-december-2023, accessed 20/02/2024]

- Department for Business, Energy & Industrial Strategy & Department for Energy Security and Net Zero, 2021, *October 2021 update: Track-1 clusters confirmed*, Guidance [Available at https://www.gov.uk/government/publications/cluster-sequencing-for-carbon-capture-usage-and-storage-ccus-deployment-phase-1-expressions-of-interest/october-2021-update-track-1-clusters-confirmed , accessed 20/02/2024]

- Department for Energy Security and Net Zero, 2021 (updated 2023), *UK Hydrogen strategy*, Policy paper [Available at https://www.gov.uk/government/publications/uk-hydrogen-strategy , accessed 20/02/2024]

- Department for Energy Security and Net Zero, 2021 (updated 2023), *Hydrogen strategy delivery update – Hydrogen Strategy Update to the Market: December 2023*, [Available at https://www.gov.uk/government/publications/uk-hydrogen-strategy , accessed 20/02/2024]

- Mbaguta, O., 2021, *JEP21WT07 A Review Of Water Use For Hydrogen Production*, Joint Energy Programme (Mbaguta, 2021)

The first three of these sources provided independently generated estimates directly for the surface water demands associated with hydrogen production in Water Resources West and the West of England (2030 only[2]). The other sources were then used to calculate a separate estimate for the demand from HyNet NW alone. This was combined with water usage estimates from (Mbaguta, 2021) to provide estimated water use if demand were to be met by surface water, groundwater or public supply. The results are presented in Table 3.4. Table 4.3 provides estimated water demand, based on these estimated values for hydrogen production. Where available, values have been provided by low carbon hydrogen types (blue and green). These splits were subsequently combined with the assumed water intensity of blue and green hydrogen to facilitate estimation of national water requirements.

---

[2] No data was available in this study for 2050 or any other future dates.

Table 3.4 Estimates of UK hydrogen energy production

Year	2030						2050					
Estimate	**Low**	Source	**Mid**	Source	**High**	Source	**Low**	Source	**Mid**	Source	**High**	Source
National demand (GW)	5.0	(HM Government, 2021)	7.5	Estimate	10.0	(Department for Energy Security & Net Zero, August 2023)	28.6	Lower value - (Department for Business, Energy & Industrial Strategy, 2021)	40.5	Estimate - midpoint value (Department for Business, Energy & Industrial Strategy, 2021)	52.5	Upper value - (Department for Business, Energy & Industrial Strategy, 2021)
Blue hydrogen with CCUS supply (GW)	<5.0	Estimate: 5GW national production	<<10.0	Estimate: 10GW national production	<10.0	Estimate: 10GW national production	1.1	Lower value - (Department for Business, Energy & Industrial Strategy, 2021)	19.7	Estimate - midpoint value (Department for Business, Energy & Industrial Strategy, 2021)	38.3	Upper value - (Department for Business, Energy & Industrial Strategy, 2021)
Green hydrogen supply (GW)	-	-	-	-	-	-	2.3	Lower value - (Department for Business, Energy & Industrial Strategy, 2021)	8.9	Estimate - midpoint value (Department for Business, Energy & Industrial Strategy, 2021)	15.4	Upper value - (Department for Business, Energy & Industrial Strategy, 2021)
Hydrogen supply required from HyNet (GW)	0.4	See table notes	0.5	See table notes	0.7	See table notes	3.1	See table notes	4.5	See table notes	5.8	See table notes

Notes: In order to estimate hydrogen production at HyNet from national estimates, it was first estimated how much of national supply in 2030 and 2050 would be provided by the industrial clusters that would become hydrogen production and carbon capture 'hubs'[3]. No quantitative information was found to make this assessment, so an estimate was produced by considering the timeline and vision for decarbonisation of the industrial clusters, descriptive evidence of the current nature of the hydrogen industry, and predictions regarding how hydrogen production will scale in the future and what it will be used for. For example, it is understood that the majority of current hydrogen production is for industrial process use, as opposed to as a fuel. In addition, the vast majority of the production is on-site, and much is produced as a biproduct of another process. Hydrogen produced at industrial clusters would be unlikely to displace biproduct production, or small-scale production located outside of the geographical area of the cluster. As such, it was assumed that by 2030 65% of production would take place outside of industrial clusters, but by 2050, this would only be 45%. The 'track 1[4]' clusters have been announced: at the East Coast (Humberside & Teesside https://eastcoastcluster.co.uk/) and Merseyside (HyNet), while it was also assumed that two 'track 2[5]' clusters would be in place by 2030. While these haven't been announced, literature appeared to indicate that these are likely to include one in Scotland (Grangemouth). The total aim from the industrial decarbonisation strategy is to mitigate 20-30 Mt CO_2e, (Department for Business, Energy & Industrial Strategy & Department for Energy Security & Net Zero, 2021). HyNet contributes 5Mt CO_2e. Taking the midpoint of the national total, this contributes 20%. If hydrogen production scales with emissions (as an indicator of size and demand), we can assign 1/5 of the supply from industrial clusters to HyNet. Multiplying these two numbers by the national demand gave an estimate of the hydrogen production attributable to HyNet. However, the UK Strategy for industrial decarbonisation (Department for Energy Security & Net Zero; Departmet for Business, Energy & Industrial Strategy, 2021) assumed a more widely distributed network of CCUS industrial clusters would be required, assuming a minimum of nine clusters.

---

[3] "Early deployment of CCUS technology and infrastructure will likely be located in industrial clusters. Many of these are in coastal locations, with important links to CO_2 storage sites such as disused oil and gas fields. Government aims to establish CCUS in four industrial clusters by 2030 at the latest, supporting our ambition to capture 10Mt/CO_2 per annum." [https://www.gov.uk/government/publications/industrial-decarbonisation-strategy/industrial-decarbonisation-strategy-accessible-webpage]

[4] https://www.gov.uk/government/publications/cluster-sequencing-for-carbon-capture-usage-and-storage-ccus-deployment-phase-1-expressions-of-interest/october-2021-update-track-1-clusters-confirmed

[5] https://www.gov.uk/government/publications/cluster-sequencing-for-carbon-capture-usage-and-storage-ccus-track-2/ccus-cluster-sequencing-track-2-market-update-december-2023

The 2030 ‘mid’ scenario for hydrogen supply required for HyNet of 0.5 GW is slightly larger than the 0.4 GW of production identified in the bottom-up approach. Similarly, the 4.5 GW of hydrogen supply required from HyNet in the ‘mid’ scenario is slightly larger than the 3.9 GW identified through bottom-up analysis.

Estimates by Joint Environmental Programme (JEP) for WRW

JEP produced a number of estimates for water use by different energy generation sectors for the areas under each of the regional water resource groups. The analysis considered two sets of scenarios:

- Future Energy Scenarios (FES20) by national grid (National Grid ESO, 2020)
- UK’s path to Net Zero (CCC20) by the Climate Change Committee (Climate Change Committee, 2020).

These are discussed in more detail in Appendix A1.

Results were generated using JEP’s power-water model. The model was run many times as part of a Monte Carlo simulation, considering different random combinations of power generators which meet the requirements of the scenario being modelled. The output was therefore a distribution of possible water uses for each scenario. For the purposes of this annex, the median result of each scenario was utilised, and the mean, maximum, and minimum of these across the various scenarios were reported in Table 4.3 (Water required for Hydrogen – WRW area (Ml/d from surface water) - JEP estimate).

In addition to this, analysis was performed for WRW (using the updated WRW boundaries from autumn 2021) with FES21 scenarios. The FES19TD scenario was reported within the results shared with WRc via the EA.[6]

---

[6] *Water needs for power, hydrogen and CCS*, private communication from EA 15/03/2023

Demand from carbon capture

The Government's industrial decarbonisation strategy (Department for Energy Security & Net Zero; Department for Business, Energy & Industrial Strategy, 2021) states the aim to establish CCUS in four industrial clusters by 2030 at the latest. The strategy does not mention plans to capture carbon outside of these industrial clusters. That is, the strategy for carbon capture deployment appears to focus on capture at industrial clusters. The aim is to capture 10Mt CO_2 per annum by 2030. The strategy also notes the plan eventually to capture 20-30Mt CO_2 per annum. It has been assumed that this longer-term target will have been achieved by 2050. If it is further assumed that:

- meeting this target would require essentially all emissions from the HyNet NW region to be captured,
- HyNet NW's emissions are not expected to change from their current 5Mt/CO_2 per annum,
- the actual amount of carbon captured in 2050 is 25Mt CO_2 per annum,
- carbon capture is not introduced at other locations,
- carbon capture in each of the four industrial clusters grows at the same rate.

then HyNet can be estimated to provide 5/25=20% of the carbon capture in the UK. This allows the amount of carbon capture in HyNet NW in 2030 to be estimated as 20% of 10 Mt CO_2 per annum = 2 Mt CO_2 per annum, equivalent to **14.4 Ml/d consumptive demand** when closed-loop cooling is assumed (Element Energy, 2022). This compares well to the bottom-up estimate of 1.9 Mt CO_2 by 2030[7]. The 2050 target of 5Mt/CO_2 (which is almost identical to the bottom-up estimate of 4.9 Mt/CO_2) would correspond to **36.0 Ml/d consumptive demand** for closed loop cooling. For any cases where sites are

---

[7] Top-down estimates were performed without knowledge of the bottom-up estimates. As such, the parameters and estimation methods chosen for the top-down estimates were a reflection of the best available information,

capable of recycling water from existing processes (e.g. Energy Recovery Facilities) much of this consumption will not represent additional demand.

It is noted that other sources suggest that much larger quantities of carbon capture may be required.[8,9] However, as the above calculation assumes 100% utilisation of carbon capture at HyNet, this does not change the 2030 estimate. Achieving higher levels of carbon capture instead would require deployment of carbon capture at additional sites.

3.2 Estimated water availability

The literature review in Annex 4 identified available information on water availability and gaps where information was missing or outdated. Stakeholder engagement and data analysis has been used to improve the understanding of water availability, which are detailed in the following sections.

3.2.1 Abstraction data

Data received

WRc received three datasets from the EA towards the end of 2023. Two of these datasets contained abstraction licence data, which will be referred to as *Ds1* and *Ds2* hereafter, and one dataset contained actual abstraction data, hereafter referred to as *Ds3*. Data was provided for the geographical extent of the following CAMS areas:

- Dee (England)[10]

---

[8] For example, the action plan for ‘Clean Growth The UK Carbon Capture Usage and Storage deployment pathway’ notes *“the CCC state that the scale of CCUS required by 2050 may be between 60-180 $MtCO_2$/ year , whilst ESC modelling shows capacity of ~80 $MtCO_2$/ year by 2045”* (Department for Energy Security and Net Zero; Department for Business, Energy & Industrial Strategy , 2018)

[9] JEP’s analysis for the WRW region predicted zero water demand in 2030, with 2050 estimates varying across scenarios from 0-17.4 Ml/d (mean 5.5 Ml/d)

[10] the EA does not hold information on Welsh abstractions, no data from NRW was used.

- Lower Mersey
- Northern Manchester
- Upper Mersey
- Weaver and Dane.

Ds1 contained a wide array of information concerning water abstraction licenses. It includes essential details such as the license number, original effective date, and expiry date. Additionally, the dataset categorised abstractions based on primary and secondary codes and descriptions, shedding light on the nature and purpose of each abstraction. It provided information on source type (surface water, ground water or tidal water). Cartesian coordinates were included alongside maximum annual and daily quantities.

Ds2 comprised essential information related to water abstraction sites. Each entry included details such as the license number, purpose code, and expiry date. Additionally, the dataset contained information on the sector to which each site belonged, aiding in the categorisation and classification of water usage patterns across various industries. Importantly, the dataset also included hourly, daily, and annual licensed quantities, allowing for a detailed examination of the permitted volume of water abstraction over different time intervals. Cartesian coordinates were also provided. *Ds2* included deregulated abstractions[11], which *DS1* did not.

The information within *Ds1* and *Ds2* were from two separate databases. *Ds1* provided data held on the National Abstraction Licensing Database (NALD) system, and *Ds2* provided data from Water Resources Geographical Information System (WRGIS). Due to this there were differences in the licences within each dataset. The EA was consulted and it was agreed to assess both datasets and report the findings. It should be noted that *DS1* and *DS2* provided

---

[11] Deregulated abstractions are abstractions that are less than or equal to 20 m^3/day.

licence information for those which were active at the time of data provision (December 2023).

Ds3 provided monthly actual abstraction data from annual returns for the period between 2007 and 2023.

Data acceptance

Before analysis, steps were undertaken to prepare the three datasets for analysis. The data underwent routine data quality checks, including assessing:

- Completeness,
- Null values and errors,
- Duplicates,
- Ranges and other forms of statistical summary.

Through these checks a number of issues were identified with DS3 which resulted in the actual abstraction data not being used. The below section describes these issues.

Data quality of *Ds3*

There were two primary issues which resulted in the decision not to use this dataset.

Suspicious/errant data: Multipoint or multi-use licences were within the dataset, which have multiple entries for the volumes of water abstracted. However, there were instances where the volume of water reported for a licence was the same at all points. This was generally assumed to be an error in the reported abstraction volumes the EA had received. However, this would not always the case as it is possible for multiple points to abstract the same volume (either by design or by coincidence).

Missing data: It was assumed that null values were the result of abstraction not being reported through the annual returns process. Reasons for why it may not have been reported were investigated and the following reasons identified:

- Abstraction licence expired,
- Abstraction licence not started,
- Financial Year was 2019/20 or 2020/21 – assumed to be missing due to COVID disruptions,
- No abstraction took place therefore not reported in annual returns,
- Unknown.

WRc was unable to identify all the reasons for the null values, and therefore unable to identify what the value should be. The number of null values with an unknown reason was large enough to impact an assessment of water requirements based on recent actual abstraction. Therefore, when considered alongside the data quality concerns, the decision was taken to not use *Ds3* to identify the current non-public water supply demand.

Data processing: transforming *Ds1* and *Ds2*

Ds1 and *Ds2* passed the initial quality checks and the below transformations were performed to prepare for analysis.

Multi-point licences: Where licences were multi-point, there was a risk of double counting. To prevent this, licences were summarised according to their licence number and duplicates removed creating two new datasets, hereafter referred to as *DS1*-1 and *DS2*-1. Where there were discrepancies between primary use description or other descriptor, the more dominant (mode) description was selected.

Data formatting: To ensure uniformity throughout the dataset, inconsistencies in data formatting were rectified, which encompassed errors such as textual entries within numerical fields or numerical values formatted as text. This step guaranteed smooth execution of subsequent analysis processes.

Sector assignment: To allow for comparison of the sector composition of the HyNet region with the water requirement information presented in WRW emerging plan (Water Resources West, 2022) and the EA's National

Framework for Water Resources (Environment Agency, 2020) the licences needed to be assigned to a sector in line with those used in the aforementioned documents. *Ds1* contained a *Primary Description* parameter which was used to identify the sector to assign to. *Ds2* contained a *Sector* parameter which was used to assign the sectors for the analysis. The sectors used within the analysis are listed below, and the lookups used to assign sectors to *Ds1* and *Ds2* can be found in Appendix B.

Agriculture
Chemicals
Environmental
General Industry
Food & Drink
Other
Hydropower
Minerals
Navigation
Paper & Pulp
Power
Private Water Supply
Public Water Supply

CAMS areas assignment: The abstraction licence Cartesian coordinates were plotted in GIS for *Ds1* and *Ds2*. The CAMS area boundaries (Environment Agency, 2021a) were used to assign CAMS areas to the licences.

Discrepancies between *Ds1* and *Ds2*: As previously stated, the data within *Ds1* and *Ds2* were from separate data storage locations within the EA. While visualising the data it was noted that there were licences within one dataset which were not present in the other (and vice versa). The EA was consulted on this matter and it was agreed to assess and present results from both datasets.

This data was used in Section 3.2.2 and Sector 3.2.3.

3.2.2 Current water availability

In Section 5.1 of the literature review (Annex 4) the abstraction licensing strategies for Upper Mersey (Environment Agency, 2013a), Lower Mersey & Alt (hereafter referred to as Lower Mersey) (Environment Agency, 2013), Weaver and Dane (Environment Agency, 2020a), and Dee (Natural Resources Wales, 2015) were reviewed as part of understanding the current water availability in the HyNet area. The areas covered by the licensing strategies are referred to as Catchment Abstraction Management Strategy (CAMS) areas throughout this annex. The year the abstraction licensing strategies were published was noted in the literature review and raised as a concern by WRc and during engagement with trade organisations. Two strategies were published in 2013, one in 2015 and one in 2020. The EA and Natural Resources Wales (NRW) were consulted to identify if more recent information was available, but they advised that no updates would be ready before the end of this annex. The option of utilising the EA's Water Abstraction Tool was discussed but due to the timescales of the project this was not possible. To identify an indication of changes since publication of the abstraction licensing strategies and their applicability to current water resources, abstraction licence data was analysed.

For each CAMS area governed by the EA (Upper Mersey, Lower Mersey, Weaver and Dane, and Dee (England), the sum of maximum annual abstraction volume was calculated for each sector for both the year prior to the applicable abstraction licensing strategy publication year (e.g. for Lower Mersey the year 2012) and the year of data provision (2023). This was split by source type and the values compared to identify differences in maximum annual abstraction volume.

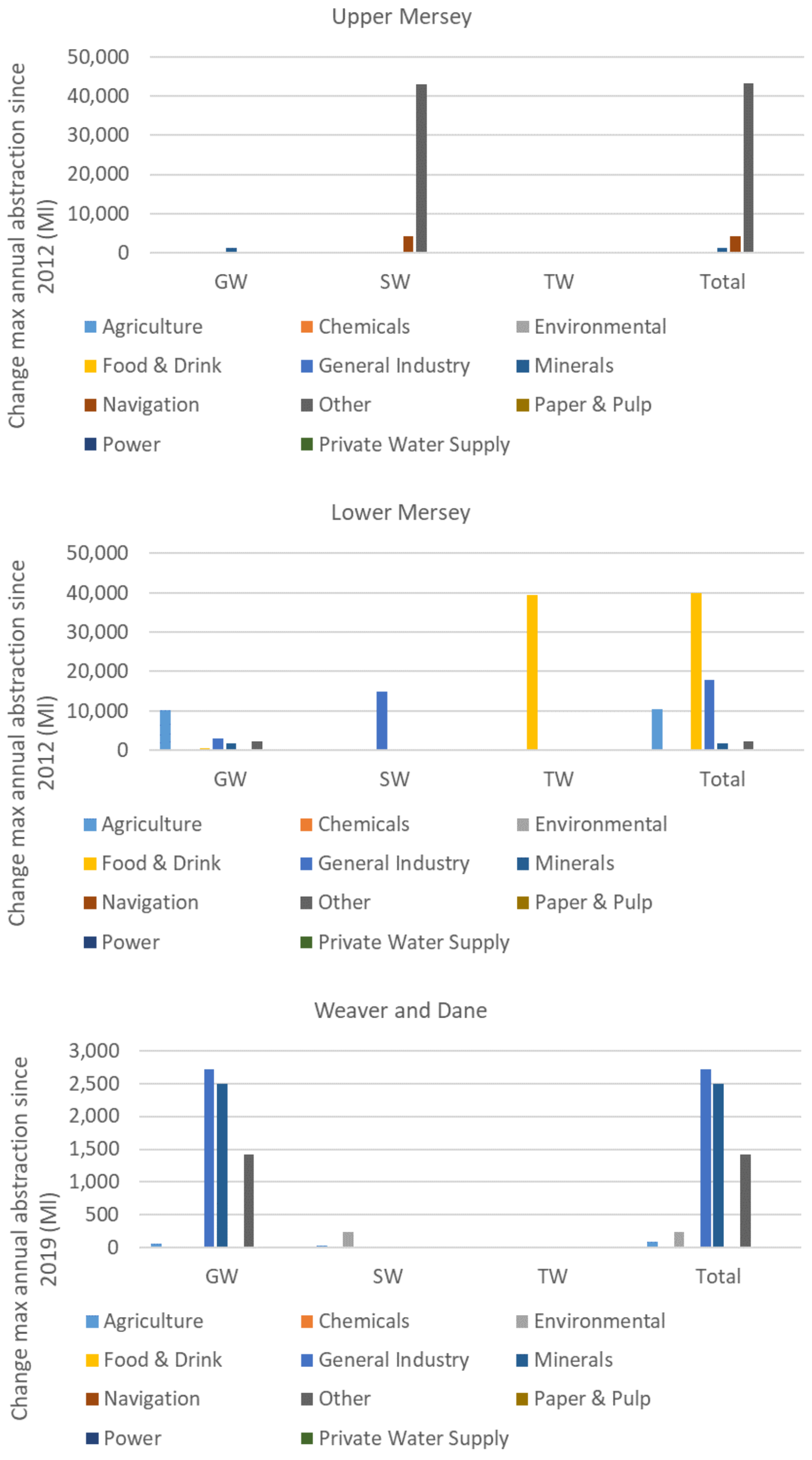
Ds2 does not provide the licence start date so this analysis was performed on *Ds1* only. The data provided did not include licences that had expired at time of data provision (December 2023) which should be considered when interpreting the results. As such, it also does not include licences active in previous years but expired at time of data provision (December 2023) as these are not included in the data provided.

This analysis was not performed for Dee (England) as stakeholder engagement with NRW confirmed there is effectively no water available for licensing in the Dee catchment.

The change in licensed maximum annual abstraction volume is shown in Figure 3.1. It does not include hydropower as this is non-consumptive and so available for use downstream, and the volumes were significantly larger than other sectors. The data (not plotted) shows an increase in licensed surface water maximum annual abstraction for hydropower in Upper Mersey (215,000 Ml), Lower Mersey (330,000 Ml), and Weaver and Dane (1,600 Ml). Most increases for groundwater maximum abstraction were for consumptive use with the exception of 51.1 Ml in Lower Mersey for environmental purposes. The majority of the increase in surface water maximum abstraction was for the hydropower sector; 82% in Upper Mersey, 96% in Lower Mersey and 86% in Weaver and Dane.

From the licensing strategies, the CAMS area with the most available water in locations appropriate to key HyNet assets is currently the Weaver and Dane, whose abstraction licensing strategy was published in 2020. From the analysis of abstraction licences there appears to be a significant increase in licensed maximum groundwater annual abstraction volume since 2019. The abstraction licensing strategy (Environment Agency, 2020a) indicates little groundwater management units under the Weaver and Dane CAMS area, with the closest units having no or restricted water availability. With the increase in maximum groundwater annual abstraction volume, it is assumed that there is now no longer groundwater available for new abstraction licensing. Excluding hydropower, there is a relatively small increase in maximum surface water annual abstraction volume for agricultural use in Weaver and Dane of 234 Ml/year (0.7 Ml/d) which is less than the water available at the most downstream assessment point (AP5), which is stated to have 22.8 Ml/d water available at hands off flow (HOF) restriction (Environment Agency, 2020a).

Figure 3.1 Increase in licensed maximum annual abstraction volume[12] for each sector spit by groundwater (GW) surface water (SW) tidal water (TW) and total for Upper Mersey (top), Lower Mersey (middle) and Weaver and Dane (bottom) between year prior to abstraction licensing strategy publishing year and 2023



The literature review (Annex 4) identified ‘no’ or ‘limited’ groundwater availability for the Lower Mersey with the exception of East Glaze groundwater management unit near Upper Mersey. This management unit was stated as having 14.7 Ml/d available in the Lower Mersey abstraction licensing strategy (Environment Agency, 2013). The assessment of *Ds1* abstraction licensing data indicates the greatest increase in maximum annual groundwater abstraction volume from 2012 to 2023 for the Lower Mersey in the agricultural sector, with notable increases also in the food and drink sector, minerals sector and general industry. There was a total increase in licensed max annual groundwater abstraction volume of 49 Ml/d which is significantly greater than the 14.7 Ml/d stated as available. Therefore, it is considered that groundwater for Lower Mersey is most likely not available for licensing. The Lower Mersey CAMS area covers a large area north of the Mersey Estuary, however most of the key HyNet assets have been identified as sitting on the south bank, where there is ‘no’ to ‘limited’ water available at low flows (Q95).

In other parts of the CAMS area water is stated as available. An increase of 40.5 Ml/d in maximum surface water abstraction volume was identified from the data provided for general industry. There is a relatively large maximum abstraction licence volume for general industry on the south bank of the Mersey estuary near key HyNet assets. Licensing of surface water from the Lower Mersey catchment is considered to be dependent on the specific location of abstraction within the CAMS area. Close to key HyNet assets on the south bank of the Mersey estuary is considered to be unlikely to have water available for licensing, but there may be a relatively small amount of water available east of the Mersey Estuary. Water that is most likely to be available is north of the Mersey Estuary or east of key HyNet assets towards Birkenhead.

Based on the location of known assets (Figure 1.1), the Upper Mersey may be more likely to provide water to industrial users rather than hydrogen production or carbon capture. Groundwater is stated to be ‘available’ to ‘limited’ availability (Environment Agency, 2013a). The majority of the increase in maximum groundwater annual abstraction volume from 2012 to 2023 is attributed to the

---

[12] The data used to calculate this does not include licences active in 2012 but expired at time of data provision as these are not included in the data provided.

Minerals sector. The increase is approximately 4 Ml/d. The abstraction licensing strategy states that there is more than this volume available (Environment Agency, 2013a) therefore groundwater may still be available for licensing. One assessment point (assessment point 17) situated near the western edge of the CAMS area, is stated as having available water (10.4 Ml/d at HOF). The Upper Mersey has seen an increase in maximum surface water annual abstraction for navigation (12 Ml/d) which the other CAMS areas discussed do not. Similar to hydropower, navigation is considered non-consumptive and available for potential abstraction further downstream. Excluding hydropower and navigation increases, the data indicated an increase in maximum annual abstraction volume of 118 Ml/d for the *Other* sector category, the majority of which is used for non-evaporative cooling. It has been assessed that there may be surface water available for licensing in the Upper Mersey but this is highly location dependant.

Where it is unknown whether water use is consumptive or not, consumptive use has been assumed for a conservative assessment. These assessments have been made under the assumption that abstractions will be required every day of the year, including at low flows.

Please note that the data used to create these assessments does not contain licences that were expired at time of data provision (December 2023). Local teams should be consulted regarding water availability, where water availability appears to be particularly location dependant.

KEY POINTS

- There is no surface or groundwater availability in the Dee catchment.
- The Weaver and Dane may have no to limited groundwater available, and available surface water for licensing due to recent increases in maximum abstractable volumes.
- There may be no to limited groundwater available in Lower Mersey. The surface water availability is likely greater north of the Mersey Estuary and west of key HyNet assets towards Birkenhead.
- Upper Mersey may have groundwater available. Surface water availability may be highly dependent upon location.

Water Resources West needs and opportunities assessment

WRW identified licensed volumes that are no longer needed by abstractors (organised by management catchment) (Water Resources West, 2022a). For the areas relevant to HyNet, they identified 67 Ml/d of licensed volume not being used. The breakdown by management catchment can be found in Table 3.5. However, WRW note the age of the data used, 2010-15 for England and 2015-19 for Dee, and that there may have been changes to abstraction since.

Table 3.5 Public water supply and non-public water supply fully licenced volumes with no recent abstraction (2010-2015 England, 2015-2019 Wales) (Water Resources West, 2022a).

Management Catchment	Volume of licence Ml/d (consumptive)
Dee	3
Lower Mersey	22
Upper Mersey	33
Weaver Gowy	9

3.2.3 Future non-public water supply demand

WRW present their assessment of non-public water supply demand by sector per WRZ in Appendix H of their emerging plan (Water Resources West, 2022b), shown here in Table 3.6. An estimation of future power and hydrogen demands, calculated though a JEP model, is included for the entire WRW region rather than per WRZ[13]. The regional freshwater requirements for the power industry (nuclear, combustion, hydrogen) are calculated as 2.4 Ml/d by 2029-30 and 131.9 Ml/d by 2049-50. Note, the volume water required calculated by WRW does not follow a linear progression in the first 6 years. The largest amount of water required for power in the region from 2024 to 2030 is 7.7 Ml/d in 2026-27. These numbers are based on the median value of the 'System Transformation' JEP scenario (Water Resources West, 2022c).

Through the stakeholder engagement session with WRW and Appendix H of their emerging plan, it was identified that they have engaged with the energy sector to identify future water needs but were not aware of all the HyNet assets WRc had identified, likely due to information being released into the public domain after the estimates of water requirements for the regional plan had been modelled.

The largest water requirement in Table 3.6 is for the navigation sector in the Strategic WRZ, with other notable requirements from the chemicals, paper and printing, and general industry sectors. The Strategic WRZ is a large zone stretching far from the HyNet area in the south to Penrith in the north.

---

[13] For map showing extent of WRW's region, see https://waterresourceswest.co.uk/our-region. It extends north to Cumbria, east beyond Birmingham, and south to Cardiff.

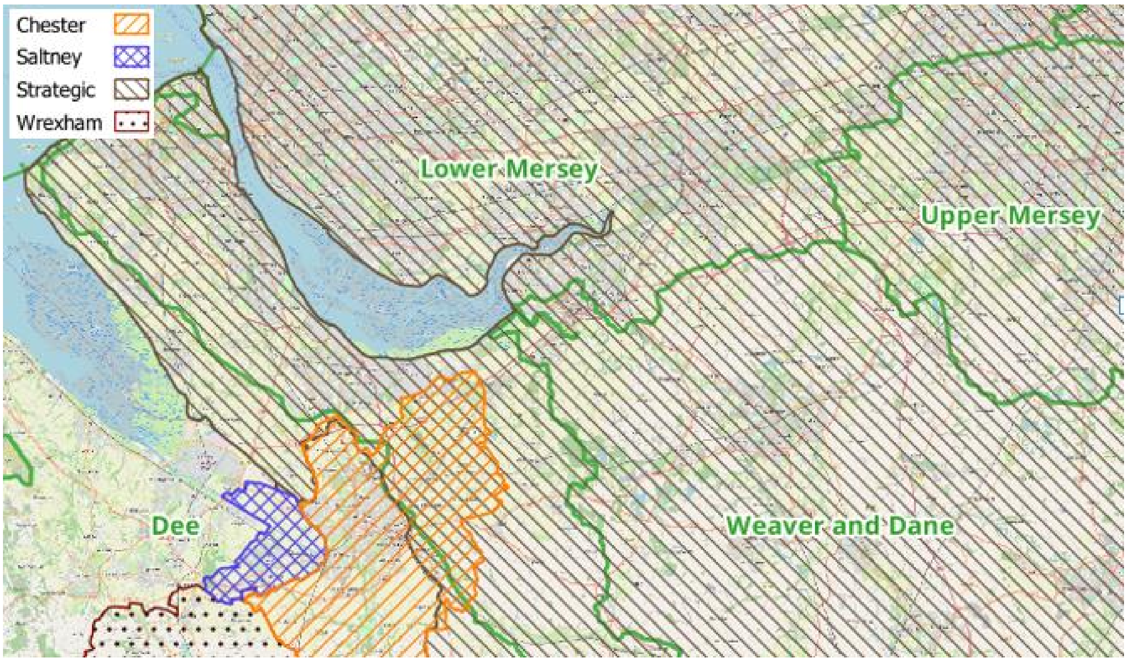
Table 3.6 **Non-public water supply estimated future regional demand, excluding power (Ml/d) (Water Resources West, 2022b).**

	Alwen Dee		Chester		Saltney		Strategic		Wrexham	
Sector	**2029-30**	**2049-50**	**2029-30**	**2049-50**	**2029-30**	**2049-50**	**2029-30**	**2049-50**	**2029-30**	**2049-50**
Aquaculture	0.00	0.00	0.00	0.00	0.04	0.04	0.10	0.10	No data	No data
Agriculture - General	0.01	0.01	0.02	0.02	0.00	0.00	5.26	5.26	No data	No data
Horticulture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Agriculture	0.00	0.00	2.29	2.29	0.00	0.00	0.01	0.01	0.00	0.00
Spray Irrigation	0.00	0.00	0.02	0.02	0.00	0.00	3.37	4.41	0.22	0.29
Navigation	0.00	0.00	0.00	0.00	0.00	0.00	154.63	154.63	0.00	0.00
Chemicals	0.42	0.49	0.00	0.00	0.00	0.00	47.58	55.24	0.00	0.00
Food and Drink	0.00	0.01	0.00	0.00	0.00	0.00	4.31	5.09	0.10	0.11
General Industry	0.00	0.00	0.02	0.02	0.00	0.00	17.26	16.36	1.57	1.45
Minerals	0.00	0.00	0.00	0.00	0.00	0.00	3.71	3.50	0.00	0.00
Paper and Printing	0.00	0.00	0.00	0.00	0.00	0.00	20.20	22.01	0.00	0.00
Private Water Supply	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.83	0.00	0.00
Amenity and Env	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.00	0.00
Other industry / metals	0.03	0.03	0.00	0.00	0.00	0.00	0.62	0.58	0.00	0.00
Total	**0.47**	**0.54**	**2.36**	**2.36**	**0.04**	**0.04**	**257.98**	**268.11**	**1.89**	**1.85**

*Note that totals are as quoted by WRW. Rounding all values in this table to two decimal places means that total does not equal sum of values in each column.

With the large geographical area covered by the WRZs in Table 3.6, particularly the Strategic WRZ, it should not be assumed that these water requirements represent only the HyNet area. To better understand how to relate the values estimated by WRW with the requirements of the HyNet area, the sector composition of the area has been assessed using both *Ds1* and *Ds2*. Sector compositions will be explored within the CAMS areas of the HyNet area: Upper Mersey, Lower Mersey, and Weaver and Dane. How the CAMS areas relate to the WRZs are shown in Figure 3.2.

Figure 3.2 WRZ and CAMS areas



Sector composition in the HyNet region – Ds1

Ds1 contains 622 individual licences. Of these, the majority were assigned to the agricultural sector (184, 30%). The agricultural industry is particularly present in the Weaver and Dane CAMS area (71), accounting for 50% of the total licences in the area. General industry is also dominant in the HyNet area (129, 21%), particularly in Lower Mersey (58) where it accounts for 29% of the total licences. The proportion breakdown for each CAMS area in the HyNet region is shown in Figure 3.3.

The maximum volume that is licensed to be abstracted annually is overwhelmingly dominated by public water supply in the Dee catchment (99%) and dominated by hydropower in the other catchments (proportions shown in

Table 3.7). As this section is interested in non-public water supply water requirements and in consumptive use (hydropower is non-consumptive use), these both have been removed from Figure 3.4. Figure 3.4 shows that while agriculture has the greatest number of licences in the area, it does not represent the greatest potential impact to water availability given that the maximum annual abstraction volume is relatively small with the exception of the Dee (England) area. General industry has the greatest maximum annual abstraction volume in the Lower Mersey area and is significant in the Weaver and Dane area. Also significant in the Weaver and Dane area is the maximum annual abstraction volume for the chemicals industry. For Northern Manchester and Upper Mersey there is no specific sector that is dominant, instead the *Other* categorisation has the greatest maximum annual abstraction volume. Following interrogation of the *Use Description*s for the licences categorised as *Other*, the dominant water use was identified as process water and cooling.

The spatial distribution shows large maximum annual abstraction volumes for *General Industry* and *Chemicals* along the south bank of the Mersey estuary, near key HyNet assets. The Weaver and Dane catchment, which was being considered as a having water available for HyNet in the literature review (Annex 4), has moderate maximum annual abstraction volumes for *Chemicals*, *General Industry*, *Public Water Supply* and *Hydropower*.

The food and drink industry have the greatest maximum annual abstraction volume from tidal water sources (such as the Mersey Estuary) across all the CAMS areas in the HyNet area.

Figure 3.3 Proportion of licences assigned to each sector per CAMS area

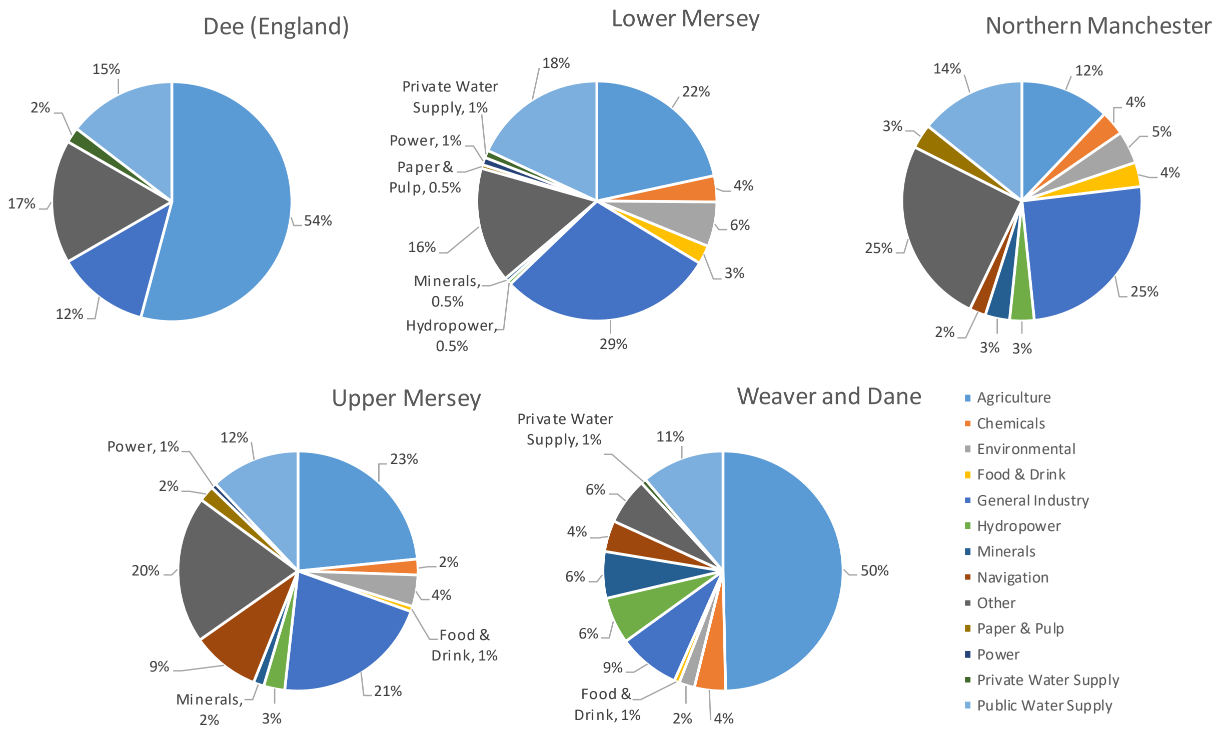
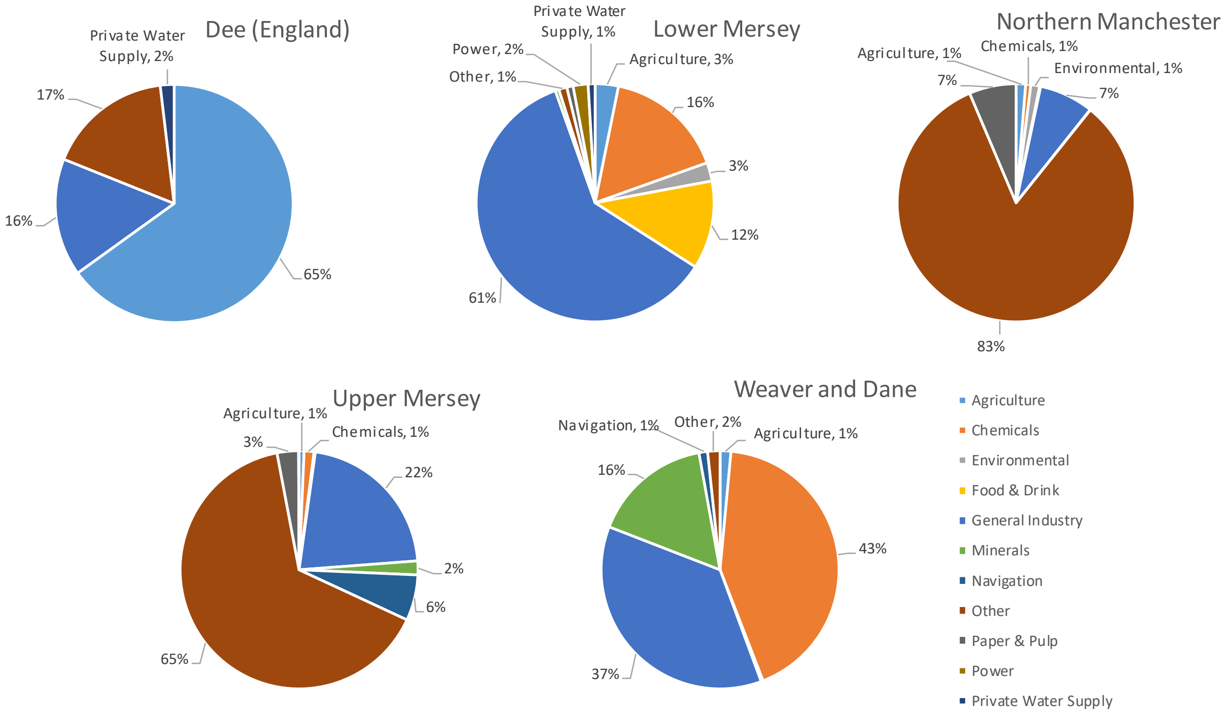


Table 3.7 Proportion of max annual abstraction assigned to public water supply and hydropower per CAMS

CAMS area	Proportion licensed for public water supply	Proportion for hydropower
Dee (England)	99%	0%
Lower Mersey	10%	43%
Northern Manchester	22%	55%
Upper Mersey	22%	65%
Weaver and Dane	5%	82%

Figure 3.4 Proportion of maximum annual abstraction assigned to each sector per CAMS area excluding public water supply and hydropower



Sector composition in the HyNet region – Ds2

This section repeats the analysis using the *Ds2* dataset, which contains 1016 licences: 577 active licences, 8 expired, and 431 deregulated. Deregulated abstractions are those equal to or less than 20 m^3/day. General industry and agriculture are prominent sectors in the area with abstraction licences, at 42% and 49% respectively. However, the greatest max annual abstraction volumes are in the power and general industry sector, 53% and 40% respectively. The proportion breakdown for each CAMS area in the HyNet region is shown in Figure 3.5. Agriculture with an abstraction licence is most prevalent in Weaver and Dane (73%), with general industry prominent in Lower Mersey (62%), Northern Manchester (78%) and Upper Mersey (55%). However, as shown in Figure 3.6, general industry in Lower Mersey has the greatest proportion of total licensed max annual abstraction (83%), with power in Northern Manchester (69%), Upper Mersey (88%) and Weaver and Dane (72%) being prominent. Notable is agriculture licensed max annual abstraction in Dee (England) with (79%).

Deregulated licences are most prominent in the agricultural sector, with 81% of the total max annual abstraction volumes and 344 licences, 174 of which are in the Upper Mersey. Agriculture has the greatest deregulated max annual abstraction in all CAMS areas, as shown in Figure 3.7.

When examining the water sources, in the Dee (England) area, Surface Water (SW) serves as the source for part of agriculture and public water supply. Groundwater (GW) is utilised by the *General Industry* and *Agriculture* sectors. In Lower Mersey, GW and SW are both heavily used in *General Industry*, while SW is used in *Power*. In Northern Manchester CAM, *General Industry* and *Other* rely on GW, while power relies on SW. Lastly, in Weaver and Dane, SW is utilised for the *Power* and *General Industry* sectors, while the *General Industry* sector also relies on GW. Overall, GW is the main source for *General Industry* and SW water is the main source for the *Power* sector.

Figure 3.5 Proportion of of licences assigned to each sector per CAMS area

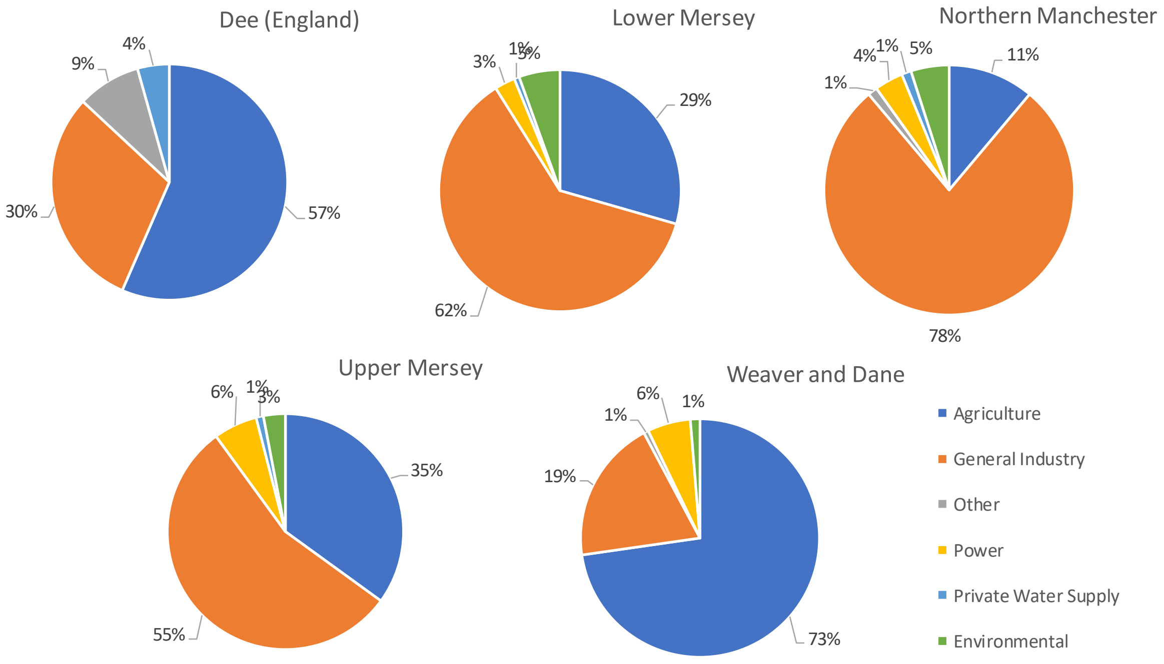


Figure 3.6 Proportion of maximum annual abstraction assigned to each sector per CAMS area

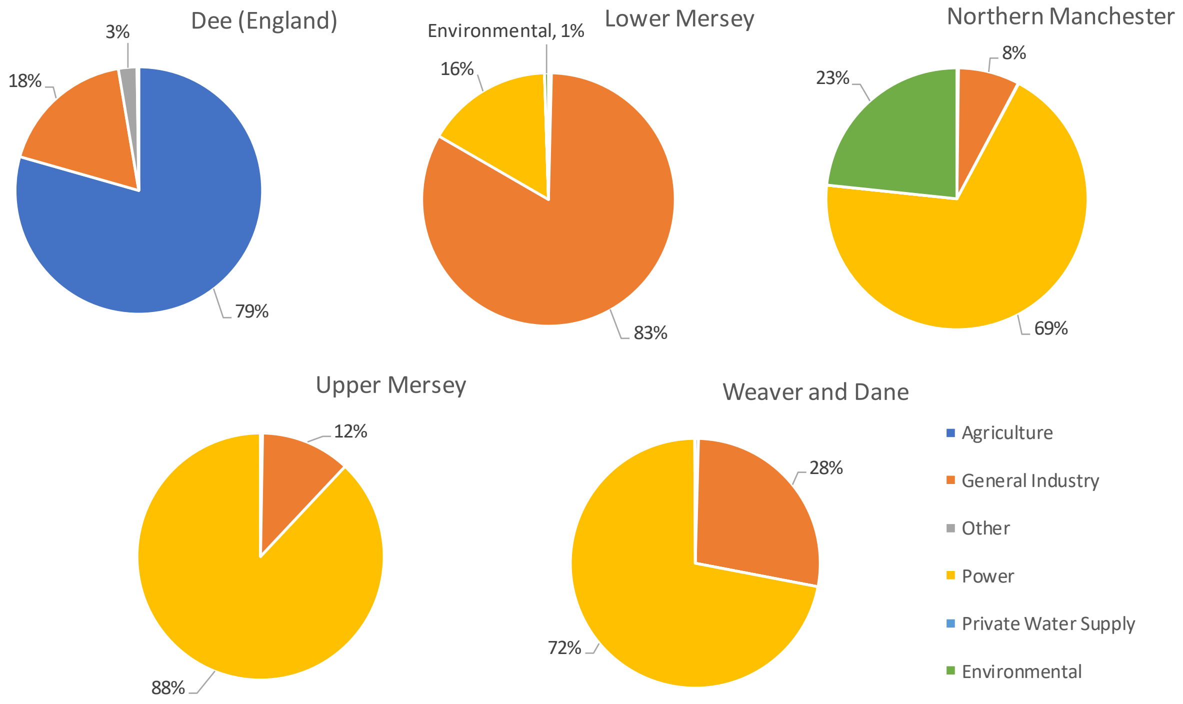
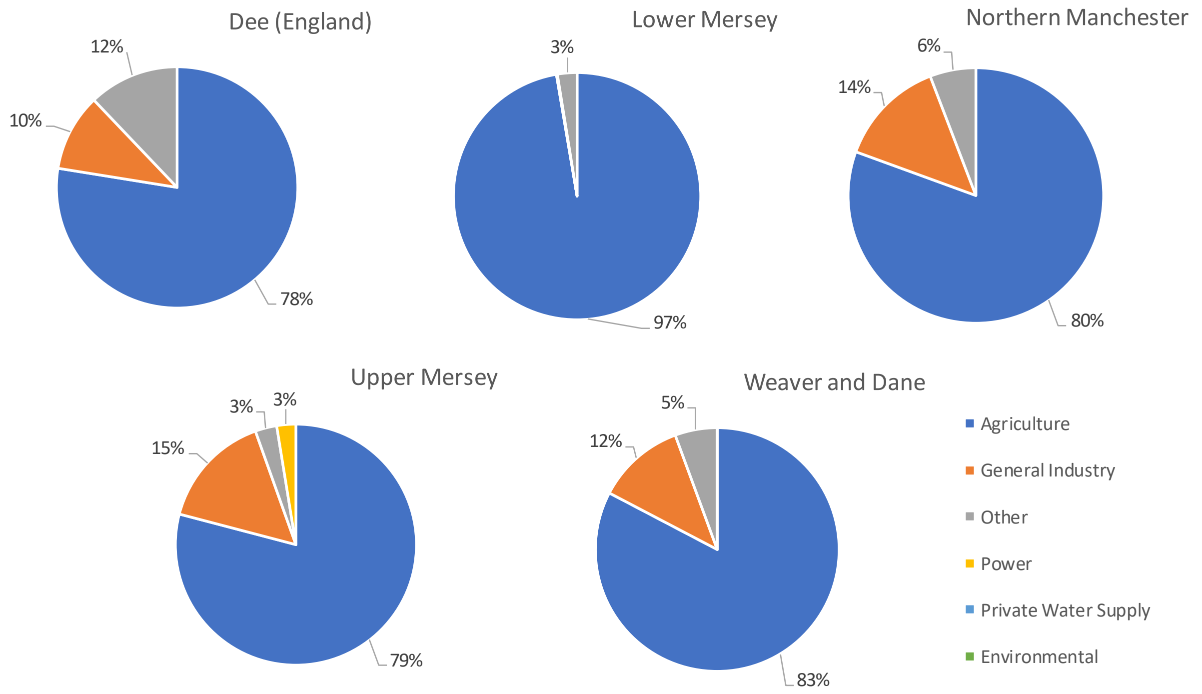


Figure 3.7 Proportion of maximum annual abstraction for deregulated abstractions assigned to each sector per CAMS area



Comparison of findings from Ds1 and Ds2

There are common indications between the two data sets. Both datasets indicate the agricultural sector has the largest reliance on non-public water supply abstractions in the Dee (England) CAMS area. There is also consensus on Lower Mersey non-public water supply being dominated by general industry. *Ds1* had more information on the sector of the licensee, and so abstraction licences for hydropower could be identified, which was a significant amount. *Ds2* indicates significant max annual abstraction volumes for the power sector, which is in line with the significant maximum annual abstraction volumes for hydro power, particularly in Upper Mersey, Northern Manchester, and Weaver and Dane. *General industry* is significant in all the aforementioned CAMS areas, with Northern Manchester having the greatest max annual abstraction for environmental sector.

Conclusions

- Agriculture maintains a significant share of total water abstraction, representing approximately 24% of water abstracted for consumptive use in WRW's region (Water Resources West, 2022), suggesting a continued reliance on water resources for agricultural activities. An increase in consumptive abstraction is estimated for agriculture of 26 Ml/d for the WRW region. WRW estimated that the greatest change to consumptive water abstraction in the agricultural sector is for spray irrigation. In the HyNet area the Dee (England) and Weaver and Dane CAMS areas have the greatest number of licences attributed to the agricultural sector, so these areas are likely to be most impacted by any increase in agricultural water requirements. However, the licenced maximum annual abstraction volume within HyNet region is relatively low at 1% (*Ds1*) - 2.5% (*Ds2*) of total max. abstraction volume. This suggests that although agriculture plays a smaller relative role in HyNet, it could have significant impact on water availability of the WRW region which may impact the water availability of the HyNet area.

- General industry is prevalent within the HyNet area, particularly in Lower Mersey CAMS area. WRW's have estimated no increase in consumptive water requirements for general industry for 2050, so changes to this sector should not impact water availability.

- The chemicals sector has a prominent volume of licenced max annual abstraction in Weaver and Dane CAMS area and is notably present in the Lower Mersey. WRW estimate an increase in consumptive abstraction of 12 Ml/d by 2050 for the whole region, this will likely impact the HyNet area.

- The water use description data in Ds1 was more granular in Ds2, separating out hydropower from other power sources, which is assumed to account for the significant difference in licenced max annual abstraction dominance between the two datasets. HyNet WRW expect an increase in consumptive abstraction by the power sector of 50 Ml/d for the entire region. HyNet will contribute to this increase. WRW engaged with Energy UK, and presumably other stakeholders in the power sector, during the development of the revised draft Regional Plan and so were aware of many HyNet assets this annex had identified at the stakeholder engagement meeting, and had planned for the known assets of HyNet but they are limited by the information they have at time of estimation.

- The "Other" category encompasses various sectors and activities, representing a small but noteworthy share of WRW data. A significant portion of the licensed quantities within this category (19.3% in *Ds1*) are specifically classified under the sub-sector of golf in *Ds1*.

KEY POINTS

- WRW's estimated non-public water supply demand combined with sector prevalence within the HyNet area suggests that the area contributes significantly to the Strategic WRZ's estimated non-public water supply demand for general industry.
- HyNet may also contribute moderately (and possibly even significantly) towards the minerals sector's non-public water supply demand. It also provides a non-negligible contribution to the demand for agriculture and chemicals.
- Further investigation into local water use, potential to reduce local non-household demand, and engagement with industry in the local HyNet area would be useful to provide a more accurate and up to date representation of these contributions.
- WRW may have further information at a more local scale for the HyNet area that was not available for this assessment.

3.2.4 Consideration of sustainability reductions

With the creation of the five water resources 'Regional Groups' in England, the Environment Agency has taken the opportunity to plan for an 'Environmental Destination' for water resources. Each regional group should create an Environmental Destination plan that enables water resources resilience and protection up to at least 2050, taking into account the impacts of climate change and growth[14]. As part of this, reductions in volume of abstractions are expected to be required. These are known as sustainability reductions. Through the stakeholder engagement, particularly with WRW, it was clear that a significant impact upon water availability was expected as a result of the sustainability reductions. The EA will assess each catchment and identify where a reduction in abstraction volume is required. It is expected that this process will start within the next few years, although it is not known how long this process will take. It was noted that many abstraction licences are time limited, meaning that once

---

[14] EA (2020) Long-term water resources environmental destination: Guidance for Regional Groups and water companies. Version 1.

they are up for renewal (which for the catchments of the HyNet NW region will be before 2030) the licences may be reduced.

WRW used the EA National Framework Enhanced environmental protection scenario to estimate the impact of sustainability reductions. The Business as Usual scenario leaves the EA's policy and regulatory approach unchanged by 2050. The Enhanced scenario applies the EA's 'most sensitive flow constraints' to 'offset the impact of climate change and enable these sites to continue to meet their environmental objectives in the future.' They considered 100%, 50% and 25% of the reductions described in the EA's scenario to understand the impact and assumed a straight-line profile to 2050. The sustainability reductions were apportioned across licences and used to assess the impact upon deployable output (DO) of WRZs. Table 3.8 shows this for WRZs relevant to the HyNet (map in Annex 4, Section 3.2.6). The amount being considered within WRW's baseline scenario and Enhanced scenario is shown in Table 3.9.

Table 3.8 Scenarios showing additional deployable output reductions (Ml/d)

WRZ	Environmental destination sustainability reduction scenario (Future Predicted)			
	25% of Enhanced	50% of Enhanced	100% of Business as Usual	100% of Enhanced
Strategic	12.0	0.0	24.0	24.0
Chester	0.2	0.2	0.3	0.3
Saltney	-	-	-	-
Wrexham	-	-	-	-
Alwen Dee	0.0	0.0	0.0	0.0

Table 3.9 WRW 100% Enhanced scenario deployable output sustainability reductions as represented in baseline tables and scenario analysis (Ml/d) per WRZ

WRZ	Baseline 2050	100% Enhanced 2050	Total 2050	% of Enhanced delivery included in Baseline
Strategic	24.0	24.0	48	50%
Chester	0.4	0.3	0.7	57%
Saltney	-	-	-	-
Wrexham	-	-	-	-
Alwen Dee	0.0	0.0	0.0	n/a

Due to the uncertainty around sustainability reductions and limitations on data availability, WRW did not assess the impact of sustainability reductions on non-public water supply abstractions. This also means they did not investigate the impact that a reduction in non-public water supply abstraction would have on the public water supply demand (as users seek alternative supply options).

The impact of sustainability reductions remains a significant uncertainty for water availability within the HyNet NW region. This annex has highlighted the difficulty in predicting future availability given this uncertainty, and the severe impacts on HyNet's feasibility that such reductions could have. This is consistent with the assertion by WRW during stakeholder engagement that sustainability reductions are considered by WRW to be the largest risk to HyNet.

KEY POINTS

Water available for abstraction in future may reduce because of 'environmental destination' plans being developed by regional water resource groups. The impact of these 'sustainability reductions' remains a significant uncertainty for water availability within the HyNet region. This annex has highlighted the difficulty in predicting future availability given this uncertainty, and the severe impacts on HyNet's feasibility that such reductions could have. This is consistent with the assertion by WRW during stakeholder engagement that sustainability reductions are considered by WRW to be the largest risk to HyNet.

3.2.5 Impact of demand management options

The proposed water surplus of WRZs within and near the HyNet NW region was collated within the literature review, and can be found in Table 4.5 in Section 4.2.3. Demand side measures were key to realising these surpluses, alongside the addition of three new local groundwater sources in the Strategic WRZ (UU) as supply side measures. During the stakeholder engagement sessions, scepticism around realising the full benefits stated through demand side measures (also referred to as demand management options) was expressed. Demand management options are typically formed of three main areas:

- Leakage,
- Metering,
- Water efficiency.

Quantifying benefits accurately and precisely can be challenging as many aspects of demand side options are outside of a water company’s control, particularly for water efficiency options. Therefore, there is significant uncertainty around the quantified benefits from demand management options. There is some scepticism in the literature about their effectiveness, particularly in the long-term (Artesia Consulting, 2018). The environmental regulators raised concerns during the stakeholder engagement over the surplus volumes presented in the draft and revised draft WRMP24s that were reviewed during the literature review (Annex 4).

For the purposes of this annex, it has been assumed that the stated supply demand balance surplus in the most recent draft or revised draft documents will be achieved. A mix of draft and revised draft WRMP documents were used based on what was freely available online. Severn Trent and Hafren Dyfrdwy have their draft documents available and United Utilities and Dŵr Cymru Welsh Water have published their revised draft documents online.

3.2.6 Water Resources West water resources planning

WRW is a key stakeholder for water availability in the HyNet area. They are responsible for the creation of the regional water resources plan which should bring together the water resources needs of public water supply, non-public water supply and the environment, ensuring there is a plan that provides sufficient water for all parties. Through the stakeholder engagement it was stated that their assessment had indicated that **overall** across the WRW region there was sufficient water available for all stakeholders (including the environmental and societal requirements) under the future scenarios considered. However, they strongly emphasised the uncertainties around the impact of sustainability reductions (see Section 3.2.4) and identified that the nuances of **local water availability** were not captured in their regional view. WRW adopted a 60-year planning period, with their emerging plan having a planning period of 2025-2085. In addition, there were concerns from trade organisations during the stakeholder engagement that the regional planning focused on public water supply, particularly in the assessment of strategic schemes.

The stakeholder sessions identified that a lot of information regarding HyNet is not in the public domain, and WRW were therefore unable to account HyNet fully when making their assessment.

The WRMP24s from the water companies which are members of WRW contribute significantly to the regional assessment. However, it was raised in the stakeholder engagement that the supply demand balance is expected to change between the draft / revised draft WRMP24 (which was used within the literature review of this annex) and the final WRMP24s (not yet available). This would impact the overall water availability assessment. For the purposes of this annex the values in the most recent draft or revised draft documents have been used.

Sustainability reductions were considered to be the biggest uncertainty for the West region by WRW, followed by carbon capture and storage, industrial growth and hydrogen production and storage. The research conducted over the course of this annex supports this view.

KEY POINTS

Regional water resources groups such as WRW hold a good view of water availability in the region from the current state to the future (approximately 60 years) based on available data which will be refreshed at least every 5 years. Further consultation with applicable Regional Groups for hydrogen and carbon capture hubs would be beneficial. Since Regional Groups provide an overall assessment, combination of their regional view with EA local team's views could provide a strong platform for a centralised, strategic approach to managing water resources for HyNet.

3.2.7 Influence of other regions – raw water transfers

In the literature review for this annex (Annex 4), water transfer Strategic Resource Options (SROs) were discussed. This identified how the water availability challenges in the South East could impact the water availability in the north west, and even the North water resources region. The stakeholder engagement also identified the impacts of water availability limitations outside of the HyNet region (and outside of the WRW region) could impact the water available for HyNet development.

A scheme such as the proposed Severn Trent Transfer (note, not currently selected in WRSE's preferred plan within their revised draft Regional Plan (WRSE, 2023)) may impact overall water availability in WRW region and shift the balance of sources used to feed public supply. It introduces a wider range of considerations and more uncertainties into establishing whether there will be sufficient water to support the development of HyNet. It also provides evidence that there should be a centralised, strategic approach to water allocation for hydrogen production and carbon capture nationally, which was also raised within the stakeholder engagement by a range of stakeholders.

Currently the only large-scale water transfers to bring water into the HyNet region that was identified was the North West Transfer, which is being proposed to offset the water transferred through the Severn Thames Transfer, but as stated previously, this is not selected as part of WRSE's preferred plan currently (WRSE, 2023).

During the stakeholder consultation, it was raised that large water transfers were predominantly, or solely, proposed due to public water supply benefits, and that the energy sector would want the benefits to their industry, and others, included in the SRO screening and selection process for regional plans. Were this change to occur, this would likely alter the SROs selected for Regional Group preferred plans, potentially altering water availability. This could happen as early as the next water industry price review which commences in 2029.

During the assessment of water availability for HyNet NW it was assumed that there would be no large inter-region transfers, and no impact from water scarcity from wider areas such as the South East.

It is worth noting that during stakeholder engagement, concerns were raised by local authorities regarding abstraction from canals (largely the Manchester Ship Canal) and ensuring sufficient water for navigation. This was raised in response to using waterways to transfer water. Water level in canals is important for recreational use as well as transport and for houseboats. In areas with abstraction on a navigation waterway water levels can limit the amount available to abstract.

3.2.8 Dee catchment

‘Limited’ to ‘No’ water availability was identified in the Dee catchment through the literature review (Annex 4, Section 5.1.4). The stakeholder assessment clarified that NRW considered there to be no more water available for licensing within the Dee catchment, and if water was to be used from the Dee catchment water trading would have to occur. At least one of the stakeholders mentioned during engagement that they were operating such a scheme.

There is a potential option to augment river flows within the Dee to free up water for abstraction. This is already performed in some environmentally important locations, such as in the Upper Mersey area (Environment Agency, 2013a). However, it is considered unlikely to be a sustainable solution by NRW given that environmental pressures are likely to increase in the future (HR Wallingford, 2020).

NRW currently do not require sustainability reductions in Wales in the same manner that the EA does for England. Instead they expect stakeholders to work together to promote the environmental health of an area (Dŵr Cymru Welsh Water, 2023). However, this does not mean that NRW will not introduce abstraction reductions in the future, instead it is an additional uncertainty. The English approach to environmental destination is also very different, focussing primarily on reductions in abstraction, whereas the Welsh approach is more holistic, looking for opportunities to improve ecosystems and catchment-level biodiversity on the ground (Hafren Dyfrdwy, 2023). This remains an uncertainty when evaluating future water availability from the Dee catchment.

It was assumed for the purposes of this annex that there is (and will be) no water available in the Dee catchment (with the exception of water trading, see Section 3.2.10).

3.2.9 Pressures impacting water availability

The sections below identify the pressures identified through the literature review, evidence baseline generation, stakeholder engagement and analysis that are impacting water availability. There are a significant number of areas of uncertainty surrounding estimating water availability for HyNet NW, which cannot be quantitatively accounted for within the scope of the current project. It can be beneficial to consider the pressures of a catchment / region when assessing water availability and there is insufficient data / information for a robust quantitative assessment.

Current Pressures

The following pressures currently seen on water resources in the area are acknowledged:

- Population growth
- Industrial water abstraction
- Energy production water requirements
- Environmental requirements
- Recreational / navigational requirements
- Agriculture & livestock

Future Pressures

Future pressures are likely to include the following:

- Population growth
- Climate change
- Environmental Destination – sustainability reductions
- Recreational / navigational requirements
- Agriculture & livestock
- Energy production water requirements – non hydrogen
- Hydrogen production and storage
- Carbon capture and storage
- Industrial growth

Future pressures on the HyNet NW region will also include the impact that such pressures have on other regions in the UK, as further discussed in Section 3.2.7.

3.2.10 Alternative water sources

The following sections evaluate the opportunities for, and challenges of, using alternative water sources. Alternative water sources are defined in this context as any water source that is not traditional groundwater abstraction, direct surface water abstraction, surface water abstraction to reservoir or impounding reservoir, or use of existing water supply. Considering the high quality and quantity of water required for hydrogen production, particularly when produced using electrolysis, seawater desalination and water reuse are likely to be the most suitable alternatives to surface and groundwater sources. Stakeholder engagement with EET Essar and CCSA identified a preference for water reuse over desalination as it was considered easier to clean a plant's effluent.

Water reuse

Water reuse had been considered or was viewed as a potential water source by many stakeholders including NRW, Encyclis, EET Essar, Hydrogen Trade Associations, and CCSA. In particular, Encyclis stated that they will reuse water from their Energy Recovery Facility for use, and EET Essar have commissioned a study into potential water sources which includes effluent reuse.

Water reuse can be on site or centralised. Any type of water can be reused so long as there is sufficient treatment processes to treat it to the required water quality. Generally water that is of a consistent quality is better for reuse as it provides a good baseline for treatment. Common sources of water for reuse are greywater, effluent, and wastewater.

Wastewater reuse involves treating municipal or industrial wastewater to remove contaminants and produce water suitable for various applications, including hydrogen production. The process typically includes the following steps.

Primary Treatment: Wastewater undergoes primary treatment to remove large solids and debris through processes such as screening and sedimentation.

Secondary Treatment: Biological processes, such as activated sludge or trickling filters, are used to remove organic matter and nutrients from the wastewater.

Tertiary Treatment: Advanced treatment technologies, including filtration, disinfection (e.g., UV or chlorine), and membrane processes (including Nanofiltration and Reverse Osmosis), are employed to further purify the water to meet quality standards for reuse.

Other types of water (non-wastewater) typically are of a better water quality than wastewater and so will use only the treatment processes required for that water quality. Tertiary treatment may not required. The level of treatment should be optimised based on the water quality requirements of the water users.

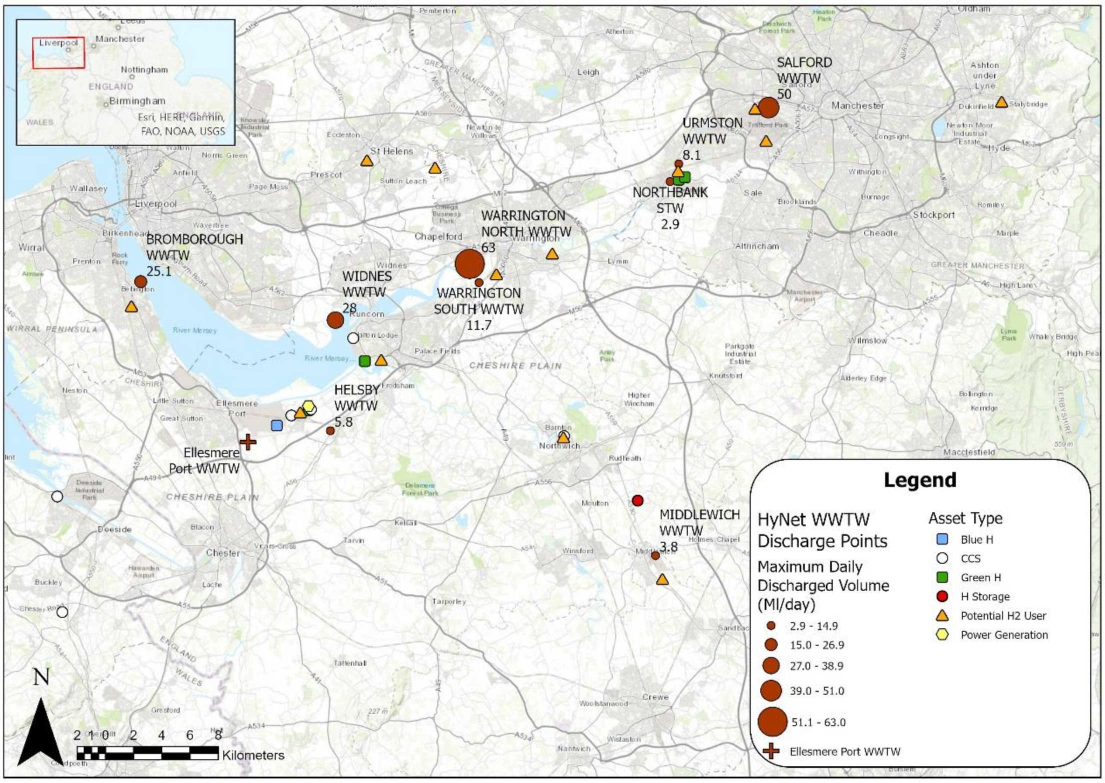
Opportunities for water reuse

Resource Conservation: Water reuse can contribute towards conservation of freshwater resources and can reduce pressure on traditional water sources. The north west of England's network of wastewater treatment facilities provides a decentralised water source for hydrogen production facilities. This would provide flexibility to the hydrogen production facilities to be built away from the coastal areas which cannot easily make us of coastal water.

Previous feasibility studies: UU have given previous consideration to wastewater treatment works (WwTW) effluent reuse and trade effluent reuse within their WRMP process (United Utilities, 2019). They assessed 275 of their WwTWs across all the WRZs and identified eight that fit the criteria, with seven being in the Strategic WRZ. Trade effluent reuse options were not developed as appropriate sites were not identified. Most trade effluent already goes to the WwTWs so can be captured in the wastewater reuse. One of the WwTWs that was identified as an option for wastewater reuse was a 10 Ml/d final effluent reuse scheme from Ellesmere Port WwTW (Figure 3.8) (United Utilities, 2019; United Utilities, 2023). This option did not pass the secondary screening due to the overall cost outweighing the benefits, but it is considered feasible.

Locations of WwTW: Figure 3.8 shows the potential sources of WwTW effluent that could be reused. The EA provided discharge permit details for WwTWs within 2.5 km of a known HyNet asset. It can be seen that there are some WwTWs with significant maximum dry weather flows close to HyNet assets.

Figure 3.8 Location and max. dry weather flow (max. daily discharged volume) of WwTWs within 2.5 km of a known HyNet asset, plus Ellesmere Port WwTW



<u>Cost of water:</u> Water reuse provides clean water at a lower cost than the one produced by seawater desalination systems. The salinity of municipal and industrial wastewater is much lower than that of seawater, which leads to a lower operating cost. In a study, the cost of producing high-quality water through industrial wastewater reuse was compared with the cost of desalinating seawater (Madwar, 2003). It was demonstrated that tertiary treatment of industrial wastewater using RO membranes was 44% cheaper than seawater desalination.

<u>Advanced Treatment Technologies:</u> Advanced treatment technologies, including membrane bioreactors (MBRs) combined with advanced oxidation processes (AOPs) or a combination of various membrane technologies (Microfiltration, Ultrafiltration, Nanofiltration and Reverse Osmosis), enable the production of high-quality water suitable for electrolysis (ASTM Type II). In recent years, there has been improvement in the reliability, performance and resilience of the advanced treatment technologies.

Regulatory Support: The UK government has established regulatory frameworks to promote water reuse. The Water Industry Act 1991 allows for the abstraction and use of treated wastewater for non-potable purposes, including industrial applications.

Challenges

Waste: The waste products from treatment (e.g. sludge) will need to be disposed of.

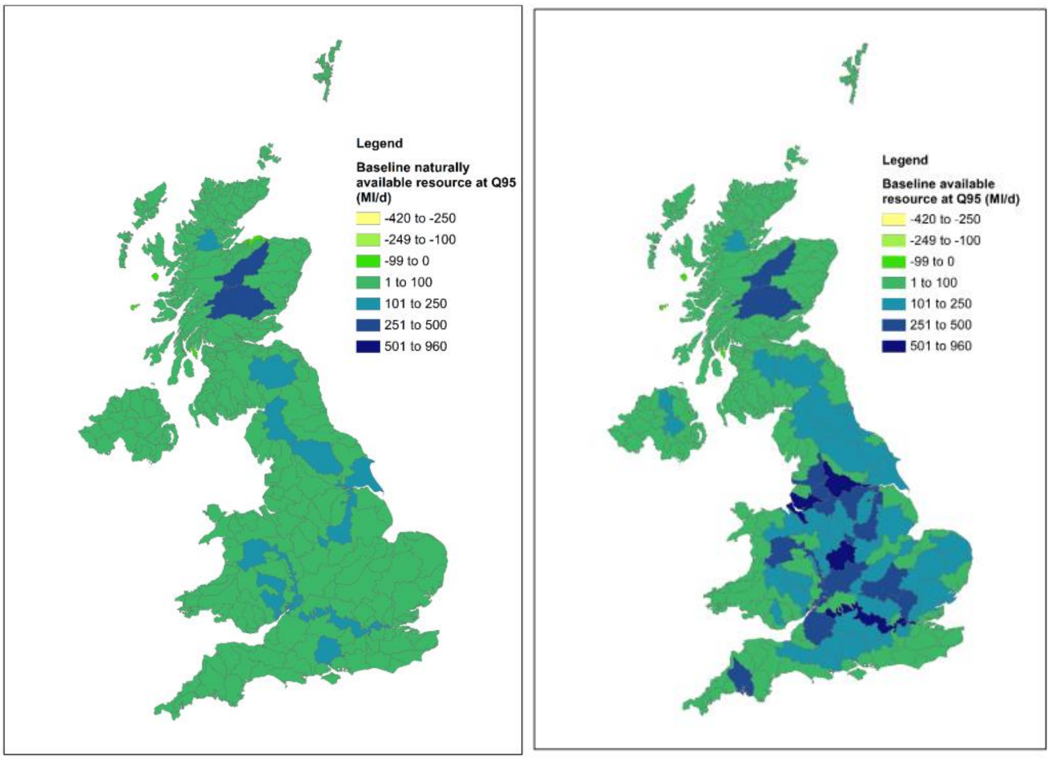
Treatment Complexity: Treating wastewater to meet stringent quality standards requires multiple stages, including biological treatment, filtration, and disinfection.

Regulatory Compliance: Compliance with regulatory standards governing water quality and environmental protection is essential. Wastewater reuse projects must comply with the Water Framework Directive and Environmental Permitting Regulations.

Regulatory mechanisms: During stakeholder engagement with CCSA, it was suggested that WwTW effluent re-use had been explored as a water source by one company, but they had been informed that there was no delivery mechanism for the water company to provide the wastewater to HyNet. CCSA identified the WwTW effluent as a cleaner water source than the Mersey Estuary. Seabank power station, located near Bristol, was identified as a case study where water from a nearby WwTW was used as a water source. Clarity on legitimate delivery mechanisms for the use of WwTW effluent was requested.

Environmental Flows: There would be a need to consider whether streams rely on discharges to meet their environmental flow requirements whilst also provide sufficient water for abstraction. In instances where removing a portion of the effluent discharge will negatively impact the environment and ecology of the waterway, flow augmentation from another source (such as compensation releases from upstream impounding reservoirs) would be required. Figure 3.9 shows that the water resource availability of the HyNet area is significantly impacted by discharges into the area. Baseline naturally available resource include the water availability of a catchment without water being brought into the catchment through transfers or discharges, and the baseline available resource includes these inputs. It is expected that in the long term, if environmental flows remain at their current values, many catchments in England and Wales will not be able to meet their environmental flow requirements without support from discharges (HR Wallingford, 2020).

Figure 3.9 Baseline naturally available resource (left) and baseline available resource (right) at Q95 by catchment (HR Wallingford, 2020)



Desalination

Seawater membrane-based desalination is a process that removes salt and other impurities from seawater or brackish water to produce fresh water suitable for various applications, including hydrogen production. The process typically involves the following steps.

<u>Pre-Treatment:</u> Seawater undergoes pre-treatment processes to remove large particles, debris, and organic matter. This step helps protect the membranes from fouling and extends their lifespan.

Membrane treatment: In this stage, seawater is forced through Reverse Osmosis (RO) membranes under high pressure. The membranes selectively allow water molecules to pass through while rejecting salts and other contaminants, producing fresh water.

Post-Treatment: The clean water produced by the RO membranes undergoes post-treatment processes to adjust pH levels, remineralise, and disinfect the water before it is utilised for hydrogen production or other purposes.

Opportunities for desalination

Coastal Access: In the north west of England the areas around Mersey Estuary could provide a blend of seawater and river water at a lower salinity than seawater. This lower saline water is called brackish water. The lower salinity means that desalinating a brackish water is cheaper than desalinating seawater. Coastal regions offer ideal locations for seawater desalination plants, complementing hydrogen production facilities.

Previous feasibility studies: UU have considered desalination plants in both the Mersey Estuary and the Dee Estuary (United Utilities, 2019; United Utilities, 2023). In both WRMP19 and rdWRMP24 the plans passed the primary screening but were removed from the options list at secondary screening due to the overall cost outweighing the benefits. Due to this it is classed as a feasible option. WRMPs prior to WRMP19 were not reviewed. In stakeholder engagement with Energy UK it was noted that the large strategic water resource options were focusing on public water supply only, and that if a multi-sector cost benefit analysis was undertaken the results may be different; this may be true for desalination.

Technological Advancements: Membrane-based desalination technologies have advanced significantly. Membrane-based desalination capacity has grown globally, reaching 109,200 Ml/d in 2023[15]. There has been significant improvement in membrane design, its efficiency, reliability, and salt removal

---

[15] GWI DesalDara/IDRA

capability. These have contributed to the optimised and more cost-effective operation of the desalination processes.

Integration with Renewable Energy: The UK has made substantial investments in renewable energy, particularly offshore wind. According to RenewableUK, offshore wind capacity reached 10.4 GW in 2020. Integrating desalination plants with renewable energy sources aligns with the UK's green objectives and reduces carbon emissions.

Challenges

Energy Intensity: Desalination remains energy-intensive. Desalination processes, depending on the salinity of the seawater and the efficiency of the system, consume approximately 2.5 to 5 kWh/m^3 of water produced (American Membrane Technology Association, 2016)[16]. Balancing energy consumption with renewable energy integration is crucial to minimise environmental impact. Engagement with NRW raised concerns around the energy requirements and whether overall it would be benefiting or harming the environment.

Brine Disposal: Disposing of brine concentrate generated during desalination processes poses environmental challenges. Implementing responsible brine disposal practices requires adherence to regulatory standards and environmental impact assessments.

Silt: In engagement with CCSA the challenge of silt in the estuary for abstraction and treatment was raised, water reuse was considered easier to treat.

Fish and eel protection: Engagement with CCSA also identified fish and eel protection can make it more difficult to get an abstraction licence, and if a licence is granted it must be ensured that the fish and eels are not being negatively impacted by the abstraction. Abstractions can cause hydrodynamic changes to ecology, including salinity pathways and sediment pattern change (WSP, 2023). The literature review (Annex 4, Section 5.3) identified that there are protected areas near the HyNet area, including for fish and eels, and a

---

[16] (International Renewable Energy Agency, 2012)

native oyster bed in the River Mersey. A Habitat Regulations Assessment and Strategic Environmental Assessment would identify environmental risks.

Capital Investment: The initial capital investment for desalination plants can be significant. Collaboration with local authorities, stakeholders, and initiatives like the HyNet project can facilitate access to funding and achieve economies of scale, ensuring the viability of desalination projects in the North of England.

Governance: If a desalination plant is developed due to potential multi-sector benefits there can be challenges relating to who owns and governs the plant, who manages and operate it, and who is entitled to what amount of water. WRc has witnessed challenges with governance and changes to governance if it has not been clearly set out at the start of the project with each change clearly recorded.

Water trading (licence trading)

Water trading is defined as the legitimate use of water not abstracted by a regulated water company by someone other than the license holder or for something other than the purposes stated on the license. This is typically facilitated through:

- Inter-company agreements to sell raw or treated water abstracted from a licensed point to another company, or,
- the centralised abstraction by a parent or umbrella company for a number of children company or operations.

There is evidence that licence trading schemes can be effective, but equally examples of systems that have been unsuccessful. It should be noted that water trading allows the allocation of water resources to be optimised (and incentivises efficiency) but does not increase supply. As such, to allow for additional demand it is reliant either on there being scope for some users to reduce their water usage or for their being existing headroom in licenses (actual abstractions being less than the permit limit). There may therefore be significant risk to businesses who are be relying on short-term agreements with other users.

While there is not considered to be any water available from the Dee catchment for new licensed surface water abstractions, there are current abstraction licences that can be used to support HyNet through water trading. This was identified through stakeholder engagement as a planned water source for companies in the HyNet area. Unlike in England, Wales have no current planned sustainability reductions in abstraction so maximum annual abstraction volumes in the Welsh part of the Dee catchment are unlikely to be reduced over the next few years. However, NRW have not ruled out sustainability reductions in the future.

Stakeholder engagement found that EET Essar is planning on water trading with UU, from their Dee abstraction, and Viridor is planning on water trading with Ineos (Inovyn) who have a significant existing abstraction licence.

The amount of water available through water trading is dependent upon what the licence holder is willing to trade. The longevity and reliability of water trading as a water source is dependent upon the water trading agreement.

Onsite storage and rainwater harvesting

Our research has indicated that there will be a change in weather patterns in the north west of England, with more rain in the winter and less in the summer, but overall about the same level of precipitation (Section 6.1 of the literature review in Annex 4). Encouraging local industries to capture their own water is starting to become more popular but with the HyNet area being quite flat, this may be restricted to small scale (roof) rainwater harvesting. It has also been suggested that industries work together to develop their own water supply schemes sharing the cost and water between the different industries.

The scale of opportunity for rainwater harvesting has been estimated by assuming rainfall at HyNet equivalent to the average annual rainfall 1991-2020[17] at Hawarden and Woodford weather stations, and at the average of these rainfall values (Table 3.1). It was then assumed that rainwater harvesting would likely take place on the roofs of existing building at the sites. This was

---

[17] https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/

generally performed using satellite map images. Estimating the plan roof area at each site and multiplying by the annual rainfall gave an estimate of the quantity of water that could be easily collected at each site.

Current plans also show potential for incorporating rainwater harvesting, but this is unlikely to significantly address a water availability shortfall. During stakeholder engagement with EET Essar, Tata Chemicals, and Carbon Capture and Storage Association (CCSA) rainwater harvesting was noted as having been / being considered as a potential source. EET Essar are currently undertaking a water study which includes the feasibility of rainwater harvesting as a source. Tata Chemicals have been considering rainwater harvesting as a source, although no indication it is being used currently. CCSA raised concerns over the feasibility of a significant contribution from rainwater harvesting as finding space to store the water was considered challenging. Water availability from rainfall can fluctuate considerably and can be an unreliable water source (Pidou, Jeffrey, Kuin, Valk, & Houwelingen, 2024). This wouldn't mean that rainwater harvesting is not a viable option, only that it most likely would not provide the volumes required and would need to be combined with another water source and on-site storage.

Table 3.10 Estimation of potential for rainwater harvesting at HyNet sites

Site	Estimated roof surface area (m^2)	Comment	Potential based on Hawarden (Ml/d)	Potential based on Woodford (Ml/d)	Potential based on average (Ml/d)
Padeswood	10300	Estimated from satellite image	0.02	0.02	0.02
Runcorn	18400	Estimated from satellite image	0.04	0.04	0.04
Protos	8000	Building not constructed in most recent maps. Estimate based on building site	0.02	0.02	0.02

Site	Estimated roof surface area (m^2)	Comment	Potential based on Hawarden (Ml/d)	Potential based on Woodford (Ml/d)	Potential based on average (Ml/d)
Buxton Lime	5000	Estimated from satellite image	0.01	0.01	0.01
HPP1 (500kNm3/hr unit)	17500	FEED	0.03	0.04	0.04
HPP1 (100kNm^3/hr unit)	3500	No data available. Assumed footprint scales linearly with output	0.01	0.01	0.01
HPP1 (500+100kNm^3/hr option[18])	21000		0.04	0.05	0.05
HPP1 (3x100kNm^3/hr option)	10500		0.02	0.02	0.02

Tidal water (direct)

The abstraction licence analysis undertaken in Section 3.2.2 found that has been an increase in tidal water abstraction in the Lower Mersey CAMS area by the food & drink sector since 2012. This abstraction was taken from the Mersey Estuary. Tidal water can be used directly for cooling systems, depending on the type of system and materials used, which was established in the stakeholder engagement with EET Essar. Tower-cooled cooling systems at coastal

---

[18] The short-term business plan is for the establishment of a single 100 kNm3/hr unit, however the plot has been selected to be expandable […] for either **3x100 kNm3/hr units (9 TWh/yr of hydrogen and captures 1.8 mt/yr of CO2) or 1x100 plus 1x500 kNm3/ hr (18 TWh/yr of hydrogen and captures 3.6 mt/yr of CO2).** The longer-term build-out approach will depend on policy framework and therefore rate of market development as well as operation of the initial unit. (https://assets.publishing.service.gov.uk/media/5e4ac453ed915d4fff2dbf04/HS384_-_Progressive_Energy_-_HyNet_hydrogen.pdf)

(including banks of an estuary) sites are expected to use tidal water (Joint Environmental Programme, 2021). In addition, where tidal water is not suitable for HyNet, they can work with other industries who can use tidal water and combine this with water trading. It should be noted, however, that the increased conductivity and salt content of brackish and other saline waters have been demonstrated to cause fouling and be particularly corrosive, even to materials usually considered to be corrosion resistant (Nowak, 2016; Rajala, 2016).

Other

The following options are less viable than those previously mentioned.

Condensate reuse

During the stakeholder engagement session with Encyclis, it was stated that the water they intend to use for their carbon capture process will come from reusing condensate. The water supply for per tonne of carbon dioxide captured is effectively zero as the water consumed for the carbon capture processes is generated through drops from the flue gas from Encyclis' Energy Recovery Facility or through the wet gas from the combustion. It can then be re-entrained into the carbon capture facility or used as a coolant in the facility's coolers.

Aquifer recharge and storage

Aquifer storage and recharge (ASR) systems are not commonplace in the UK. Additionally, the GW in the area isn't high quality and may not be suitable for most uses. Using ASR, the changes in salinity due to over abstraction and sea level rises can be mitigated, for example by creating a freshwater barrier around the coast to keep the salinity from intruding. Such a venture would require a full feasibility study. Other alternative sources are more likely to be viable.

Sea water transfers

The physical transport of water, for example the use of tankers or ships to transport water or glacial ice across the sea has also been considered as an alternative source of freshwater. Limitations include environmental impact, reliance on supply from another country, and generally prohibitive costs as this requires purchase and transport. Other alternative water sources are more viable.

Air condensation

Air condensation extracts moisture present in the air in the form of water vapour. Condensers can be active, requiring the input of energy, such as air conditioning units, or passive, such as collection of dew and fog. Typical yield factors for conventional passive approaches are 0.13-0.42 $l/m^2/h$. There is evidence that approaches to optimise surfaces for best water droplet formation can harvesting capability to 6 $l/m^2/h$. Other passive approaches include utilising natural dew formation. Examples include. water sorption units that collect dew during the night. The unit then closes to the environment during the day where solar radiation vaporises the dew and re-condenses it on cooler inner wall of case. A further mechanism is ‘Canadian wells’ which provide passive cooling for properties utilising the inertial delay between air temperature and sub-surface temperature by venting air underground where cooling and condensation occurs (Xiaoyi, Beysens, & Bourouina, 2022).

A key limitation of air condensation is that condensation is exothermic, meaning that it raises the temperature of the surface, reducing further condensation. The yield from active devices tends to scale with energy usage as the primary mechanism requires cooling their air to condense out the water. As such, they are very energy intensive to run at scale. Research is also ongoing regarding the use of water harvesting solar panels – can materials be chosen so that they have low emissivity except in atmospheric window so as to remain cool? Such devices are currently achieving 0.04-0.06 $l/m^2/h$ (Xiaoyi, Beysens, & Bourouina, 2022).

Overall, there is no evidence that air condensation can currently provide a practical solution to providing water to large industrial users. Yields from passive means are very low, and active systems are significantly more energy intensive than other sources such as desalination.

Cloud seeding

Cloud seeding is the deliberate introduction into clouds of various substances that act as condensation nuclei or ice nuclei in an attempt to induce precipitation[19]. Scientific opinion remains divided regarding the effectiveness of the system, but it is used at scale in China and has also been adopted in areas of the Middle East. Novel research includes the addition of electricity in the United Arab Emirates[20]

The premise of cloud seeding is transforming small cloud drops into bigger cloud drops. However, in the United Kingdom, when there is drought, that is not due to the fact that there are clouds there that don't rain. Instead droughts in the United Kingdom are typically characterised by a lack of clouds. In such a situation cloud seeding would have no effect. As such, cloud seeding may not be effective within the UK.

If successful, the effectiveness of cloud seeding at increasing water availability relies on the collection of this water. The proximity of HyNet NW to the sea risks much of the collected water entering water course downstream of abstraction points and being washed out to sea. Public opinion would also have to be considered as rainfall isn't desirable for the majority of the population.

Other alternative water sources are more viable.

Technological advances

There is uncertainty around technological developments in the future and how this will impact water availability and water requirements from the HyNet network. There is ongoing development in the water treatment area which may make things like water reuse and desalination more viable. Developments may also assist with improving groundwater quality and making ASR more viable.

---

[19] https://www.britannica.com/science/cloud-seeding

[20] E.g. Rohweter et al., 2010 DOI 10.1038/nphoton.2010.115

3.3 Assessing water quality impacts

3.3.1 How water quality impact can be assessed

To assess the potential water quality impacts from the HyNet development, it is important to understand the quantity and quality of wastewater discharge from each HyNet site, as well as the environmental state of the corresponding receiving water body. An initial assessment of the permit application process applicable to HyNet sites and relevant surrounding environmental legislation was undertaken to provide an insight into the type of data that could be available to help inform the HyNet water quality impact assessment. A high-level understanding of the environmental permitting process also helped highlight potential areas of concern for future HyNet projects, helping ensure that HyNet developments can be delivered within the desired timeframe.

The permit application process summarised in this section of the report focuses on the ‘Discharges to surface water and groundwater: environmental permits’ guidance published by the EA and DEFRA (available at https://www.gov.uk/guidance/discharges-to-surface-water-and-groundwater-environmental-permits). All sites that plan to discharge liquid effluent or wastewater streams must apply for an appropriate permit. The type of permit needed depends on two main factors: the type of effluent that will be released and where the effluent will be discharged to. Excluding ‘clean’ rainfall runoff (i.e. no additional contaminants), wherever possible, wastewater should be discharged into the public foul sewer. To discharge anything other than non-domestic sewage into the public foul sewer, a consent for trade effluent, or a trade effluent agreement, must be obtained from the relevant sewerage undertaker (Water Industry Act 1991, c. 3., 1991).

An environmental permit should only be applied for in instances where connecting to the public foul sewer is not feasible (e.g. distance or geographical obstacles), or the local sewage undertaker has refused to grant a consent for trade effluent (e.g. because the discharge effluent volume is too large). In England and Wales environmental discharge permits allow the release of liquid effluent into surface water regulated by the EA/NRW. There are two main types of environmental discharge permits: a ‘standard rules permit’ or a ‘bespoke permit’. Standard rules permits are only applicable for small sewerage treatment plants, discharging 5-20m^3 of domestic sewage a day. Bespoke permits are applicable for all other types of effluent, including discharges located within designated or protected environmental sites. Consequently, the majority of HyNet sites will require bespoke environmental permits.

The application process for bespoke permits consists of four main sections.

- The development of an appropriate 'management system' (a set of procedures that identify and mitigate risks of pollution).
- The submission of any necessary risk assessments.
- A plan detailing how emissions will be controlled and monitored.
- Permissions from any relevant parties (including the EA).

Further details on each of these four sections can be found within the webpage mentioned previously. During the application process, the EA must also be told if the proposed discharge will contain a 'surface water specific substance'. 'Specific substances' refer to a particular set of hazardous chemicals and elements. The list of priority substances and corresponding environmental standards that must be met differ depending on the type of receiving surface water body (riverine, estuarine or coastal). If a discharge includes any of these specific substances, additional screening tests must be undertaken. Screening tests assess the concentrations of specific substances in both the proposed discharge and upstream receiving water body, to understand the risk posed to the hydrological environment.

When considering the validity and acceptability of new or variations to discharge permits, the EA will consider several different factors. First and foremost, the EA will adhere to the primary objective set out by the Water Framework Directive (WFD) to '*prevent deterioration of the status of all bodies of surface water'*[21] Typically, the proposed discharge must be of similar, or better, quality than that of the receiving waterbody, so that environmental impact of the discharge is minimised. A range of factors may also be considered, that can

---

[21] Available at *https://www.legislation.gov.uk/uksi/2017/407/contents/made)*.

include dilution in the receiving watercourse that would allow a more concentrated effluent. If the proposed discharge location is inside, or within 500m of, a protected site or area, this must also be taken into consideration. For example, both the Mersey and Dee estuaries contain SSSI, Ramsar (an international designation for wetlands under the Convention on Wetlands, which provides a framework for the conservation and use of wetlands and their resources) and SPA sites, indicating the ecological importance of the water bodies. For discharges within or nearby to these waterbodies, discharge permits are likely to be stricter and harder to obtain. As such, any HyNet stakeholders applying for future discharge permits must consider the proximity of protected ecological sites, alongside the WFD water quality classification level. If future HyNet developments have the potential to impact SAC, SPA or Ramsar sites, a habitat regulations assessment (HRA) must be undertaken to ensure that appropriate mitigation and protection measures are implemented (https://www.gov.uk/guidance/habitats-regulations-assessments-protecting-a-european-site).

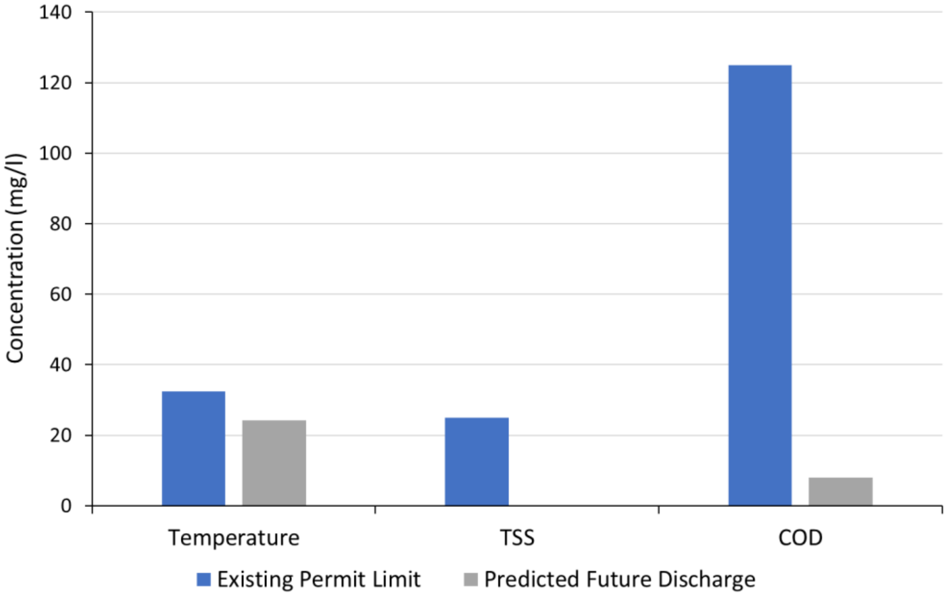
3.3.2 Impacts of individual sites on water quality

The following section utilises details from available EPR permits in the HyNet industrial cluster and stakeholder engagement sessions to provide high-level insights into the possible impacts of different HyNet developments on receiving water quality. A comparison of existing permit discharge limits with expected future wastewater discharge details for each individual HyNet site indicates whether the future HyNet site is likely to have a detrimental or beneficial impact on water quality. If the predicted future discharge falls outside the existing permit limitations, then the receiving water quality could worsen in the future. Conversely, if the predicted future discharge remains within the existing permit limits, the water quality impact is unlikely to be significantly worse. A comparison between current discharge quality and predicted future discharge quality would provide a more definite indication of future receiving water quality impact, but lack of data prohibits such analysis.

Stanlow Essar blue hydrogen production plant was the only site where a quantitative estimate of future wastewater effluent streams could be confidently calculated as part of this annex. The current plant effluent discharges into the Manchester Ship Canal, via the ‘W3’ site discharge point. The permit discharge flow limit for the whole site is 90,000 m^3/day under standard operating conditions. Consequently, an increase in process discharge volume to 413.2 m^3/day by 2030, or 4,132 m^3/day by 2050, would still only account for a negligible part of the current discharge permit limit (roughly 0.5% or 5% respectively). Therefore, unless the site is currently discharging near the 90,000 m^3/day limit or the additional discharge contains significant pollutants, it seems unlikely that this relatively minor additional discharge volume will cause a breach in permit or worsening of receiving water quality.

The concentrations of most hazardous substances in the future discharge are also predicted to remain within the existing permit limits, as shown by Figure 3.10. WRc has assumed that the discharge concentrations referenced will not vary with increased flow volume. The final effluent is currently predicted to have BOD of 25 mg/l, which is not currently accounted for in the existing discharge permit. As such, this may need to be accounted for in a future permit variation. Additionally, it is important to note that whilst TSS concentrations are currently estimated at zero, WRc note this unlikely to be achievable in practice. The predicted pH of the future effluent is 7.6, also falling well within the permitted pH of 6 – 9. Overall, it seems unlikely that future plant effluent streams are unlikely to exceed current permit limitations for the Stanlow Essar site. Consequently, the water quality impact is likely to remain at acceptable levels in the future, unless the background water quality of the Manchester Ship Canal changes significantly, forcing environmental standards to become more stringent.

Figure 3.10 A comparison between the current discharge permit limits with estimated future discharge quality at the Stanlow Essar blue hydrogen production site (HyNet North West, 2021).



For the remaining HyNet sites, it was not possible to estimate the quality of future wastewater effluent streams due to a lack of data from the literature review and relevant stakeholders. Consequently, a comparison of current permit restrictions and future water discharge data was not feasible for the remaining HyNet sites. Instead, stakeholder assumptions on future wastewater effluent quality and an estimation of future discharge volumes are detailed in Table 3.11. Future discharge volumes have been estimated for green hydrogen production using Mbaguta (2021)’s values of 0.7 l of reject water discharged per litre consumed, whilst CCS assets discharge volume has been estimated using stakeholder insight where possible. The receiving waterbody is also included in Table 3.11, so that the factors currently impacting water quality can be considered.

Table 3.11 Stakeholder comments on future wastewater discharge quality, along with estimated discharge volumes and associated receiving water body.

HyNet Site	Stakeholder Comments on Future Wastewater Discharge	Estimated Future Discharge Volume (m^3/day)	Receiving Waterbody
Runcorn Viridor ERF CCS	Purge effluent from hybrid cooling towers would still be of sufficient quality to discharge into the Manchester Ship Canal.	Volume uncertain as to fluid to be recycled through multiple closed loop cycles	Manchester Ship Canal
Ineos, Potential H Storage	Potential for wastewater effluent to be very saline, so discharge or disposal must be carefully considered.	Unknown	Unknown
Cheshire Green H, Protos	Wastewater will be discharged into Protos SuDS network, until treated to an appropriate standard and discharged into the river.	Estimated 310 m^3/day for 18 MW by 2050 (Mbaguta, 2021).	Unknown
Evero EfW and MHI, BECCS	The process water effluent, discharged at 5 m^3/h, that cannot be further recycled in Evero's water recycling treatment plant, would potentially be discharged into the Manchester Ship Canal. The water quality is thought to be suitable for discharge into a watercourse; at no point do amines come in contact with the process water. Evero intends to advise on temperature or flow impacts. The other option considered is disposing the effluent into a local drain at Protos Park.	121 m^3/day by 2030 (stakeholder disclosed)	Manchester Ship Canal
Ince Low Carbon Power Project	n/a	Estimated 10,700 m^3/day from discharge limit of similar sized plant, (Environment Agency, December 2023).	Manchester Ship Canal

HyNet Site	Stakeholder Comments on Future Wastewater Discharge	Estimated Future Discharge Volume (m^3/day)	Receiving Waterbody
Winnington CHP with CCU, Northwich	Switching to hydrogen fuel would not produce a waste stream. The acid wash wastewater generated would be disposed into United Utilities' sewer network.	914 m^3/day return flow of cooling water (Environment Agency, December 2023).	River Weaver
Inovyn CV, Project Quill 2, Green H	Weak waste brine undergoes pH adjustment at a treatment plant then discharged into western canal, ultimately flowing to the Mersey.	Estimated 650 m^3/day at 38 MW (Current and 2030). 3400 m^3/day at 200 MW (2050). (Mbaguta, 2021)	Mersey Estuary
Trafford Green H, Carlton Power	Small quantities of wastewater discharged from the electrolysis process is suitable to be released into the sewage system in Trafford.	250 m^3/day at 15 MW (2030) and 3400 m^3/day at 200 MW (2050) (Mbaguta, 2021)	n/a
Protos Encyclis ERF CCS	There is no foul wastewater discharge from the carbon capture facility. Only clean surface water is discharged into the drains near the Ince Protos Park. Acid wash is used to control the amines in the emissions from the carbon capture stack. The blowdown from the coolers and the acid wash on site is treated and the polished water is reused in the carbon capture process. Currently Encyclis is looking at options for reverse osmosis (RO) with Electrodeionisation (EDI), in which case the return would be sent to ERF.	n/a	n/a
Keuper Gas Storage, Byley	There is an agreement with the EA regarding the amount of brine allowed to be discharged into	n/a	Mersey Estuary

HyNet Site	Stakeholder Comments on Future Wastewater Discharge	Estimated Future Discharge Volume (m^3/day)	Receiving Waterbody
	Western canal and Mersey and is currently maintained under the limit.		

The majority of receiving water bodies shown in Table 3.11 currently have a moderate or poor WFD ecological status. The reasoning behind the moderate and poor classifications varies between catchments, but common factors include high levels of phosphate, nitrate, zinc, mercury and polybrominated diphenyl ethers (PBDEs). The source of these contaminants also varies between catchments, but generally includes the water industry, agricultural sector, urban pollution, and the navigation industry. Consequently, HyNet sites should consider how water quality will be impacted by these industry sectors in the future and attempt to minimise the discharge of pollutants that will exacerbate ongoing issues. (SEPA , 2013). For the Stanlow Essar site and some CCS sites, the use of amine solvents presents an emissions risk, both to air and wastewater. Reaction (or degradation) products of amine solvents produced within the process and in the environment, such as nitrosamines, are possible carcinogens. These reaction products are poorly understood due to their difficulty to sample and analyse but may produce significant environmental harm if emitted (SEPA , 2013).

KEY POINTS

1.The industry already has a good focus on water re-use, limiting the volume of expected HyNet discharges. Many HyNet stakeholders have suggested that future wastewater discharges will have minimal environmental impact, but there is little quantitative data to support these statements.

KNOWLEDGE GAPS

2.There is a clear lack of data on actual current wastewater discharge volumes/quality and minimal understanding of the expected discharge volume/quality at future HyNet sites.

Without more specific details on expected future discharge quality, it is difficult to provide conclusions on the extent to which each individual HyNet site will impact receiving water environment. Whilst many HyNet stakeholders have emphasised the importance of water re-use technologies to reduce discharge volumes, there is minimal evidence to suggest that each HyNet site has a list of potential hydrological pollutants. As most HyNet sites are yet to receive their discharge permits from the EA, it is important that future discharge pollutants are correctly identified, so that appropriate management strategies can be implemented.

3.3.3 Future receiving water quality

When accounting for the future impacts of wastewater discharges on receiving water quality, it is important to consider how the receiving waterbody will change over time. Climate change is likely to have a significant impact of the water quality of all receiving waterbodies within the HyNet area. However, understanding how climate change will affect the water quality of individual waterbodies is difficult, due to the heterogeneity of different catchments and the complex, multi-dimensional biogeochemical processes governing water quality variables. Future water quality projections can vary significantly across relatively small spatial areas and periods of time, and factors such as catchment runoff and variability in river flows also need to be accounted for. Therefore, it is important that an appropriate level of uncertainty is accounted for when appraising the future impact of climate change on water quality within the HyNet NW region.

Despite these high levels of uncertainty, it seems likely that an increase in water temperature is likely within receiving water bodies around HyNet. For instance, discharged water from the Winnington CCS plant can reach temperatures of up to 40°C (Environment Agency, December 2023). Although the extent of this temperature rise is difficult to quantify at many sites, it is likely to lead to changes in pollutant decay rates and could increase the risk of eutrophication problems. Drops in dissolved oxygen as temperatures increase are a further risk, with impacts to wildlife. As such, HyNet sites should attempt to minimise the discharge of warm, ‘nutrient rich’ effluent, so that these climate change induced impacts are not exacerbated further. During a stakeholder engagement session with NRW, concerns over the impact of warmer discharges in conjunction with climate change were reiterated. Changes in hydrological flow regimes, particularly in relation to hydrological extremes, are also likely to impact the receiving waters around HyNet. In particular, HyNet sites should take into account the risks associated with discharging wastewater during periods of drought or low-flow, as the impact of pollutants can be worsened due to lack of dilution. The majority of HyNet assets are planning on discharging to larger waterbodies (e.g. the Manchester Ship Canal), meaning changes in receiving water quality due to climate change are likely to be less extreme. When considering how receiving water quality may change in the future, it is also important that the impacts associated with human activities are considered.

3.3.4 Contaminated land risk

Potential for HyNet construction works to mobilise contaminated sediments in the region, impacting water quality, was highlighted as a risk during the stakeholder engagement sessions. Whilst it is outside the scope of this annex to do a detailed assessment of contaminated land risk for each site within HyNet and all pipework construction across the cluster, key risks identified by stakeholders are highlighted below. Contaminated land is being considered in more detail for individual HyNet sites through the planning application process.

As noted in the literature review, reports on groundwater in the region provide some insights into contaminated land risk. ‘Galligu’, a waste product that can contain arsenic and heavy metals, was used to reclaim marshy areas alongside the Mersey. Chemical waste products were also used to fill landfill sites in hard rock quarries at Weston and in drift sand deposits (LWRC, n.d.).

The EA provided details of previous permits for two sites within HyNet, which provide some indication of contaminated land risk, albeit restricted to the location of the permitted installations[22]:

- Encyclis, Ince, permit granted 2012 – Installation area had been unchanged for around 100 years, used as agricultural fields. Application

---

[22] Email from EA, 23/01/2024.

recognised that there may be small areas of contamination resulting from fly tipping, use of fertilisers and pesticides, and fuel storage.

- Evero site, Ince, application 12/02/2016 – Decision document recommends that further evidence is provided by the applicant to confirm whether there are signs of existing contamination on site. Decision document also asks applicant to check for pollution incidents, as incidents after 2004 were not outlined in their application. The site was considered rural, with predominantly agricultural land use.

Discussion with staff from the EA’s Greater Manchester Merseyside & Cheshire Groundwater and Contaminated Land Team provided further indications of potential contaminated land risk in the HyNet area. The team has started to be consulted about sites within HyNet, notably the CO_2 pipeline running into the Stanlow site. The team highlighted that the HyNet region has a long industrial legacy, and as such has known contaminated land issues. Near Runcorn, excavations for clay and sandstone have left voids that are thought to have been backfilled with waste. Western Quarries, near Runcorn, is thought to have been filled with waste from Imperial Chemical Industries. Ellesmere Port has been a key development area for the UK petrochemical and refinery industry, therefore is likely to have some areas of contaminated land that would need to be managed. The team were keen to emphasise that companies developing sites as part of HyNet should engage early with the EA and with local authorities to understand contaminated land risk and where mitigation options might be required. Both organisations have datasets and expertise that can be drawn upon.

KEY POINTS

There are known pockets of contaminated land across the HyNet area, notably near Runcorn and Ellesmere Port, linked to the region’s long industrial legacy. Contaminated land is being considered in more detail for individual HyNet sites through the planning application process. Companies planning to develop sites as part of HyNet are encouraged to consult the EA and local authorities early, to understand localised contaminated land risk and potential mitigation measures.

4. Results

4.1 How much water does HyNet need?

4.1.1 Estimating use from known water users (bottom up estimations)

Table 4.1 contains a summary of the bottom-up assessment of HyNet demand, with method detailed in Section 3.1.1. Where scale and demand is listed in (*bracketed italics)*, for example Inovyn CV/ Quill II's 2030 estimate, this is because the demand is not considered additional and is excluded from the total additional demand summary in Table 4.2.

Table 4.1 Summary of bottom-up assessment of HyNet demand

Asset	Asset Type	Assumed Source	2030		2050	
			Scale	Demand (Ml/d)	Scale	Demand (Ml/d)
Essar/Vertex, Stanlow	Blue Hydrogen	Surface Water	350 MW	4.3	3500 MW	42.7
Cheshire Green, Protos	Green Hydrogen	Potable Water	*(Assumed not operational)*		18 MW	0.5
Carlton Power, Trafford	Green Hydrogen	Potable Water	15 MW	0.4	200 MW	5.1
Inovyn CV, Quill II, Runcorn	Green Hydrogen	Surface Water	*(38 MW)*	*(1)*	200 MW*	4.1
Connah's Quay CCS	CCS	Surface Water	1200 kt CO_2/yr	8.7	2400 kt CO_2/yr	17.3
Protos Encyclis ERF CCS	CCS	Potable Water	500 kt CO_2/yr	0	500 kt CO_2/yr	0
Viridor, Runcorn ERF CCS	CCS	Surface Water	*(Assumed not operational)*		900 kt CO_2/yr	6.5
Evero EfW/MHI BECCS	CCS	Potable Water	250 kt CO_2/yr	1.2	250 kt CO_2/yr	1.2
Padeswood Cement Works CCS	CCS	Surface Water	*(Assumed not operational)*		800 kt CO_2/yr	5.8
Winnington CHP with CCU	CCS	Surface WATER	*(2 kt CO_2/yr)*	*(0.3)*	*(2 kt CO_2/yr)*	*(0.3)*
Ince Low Carbon Power Project	Generation	Surface Water	*(Assumed not operational)*		1750MWe	20
*162MW additional demand, 38MW operational currently.						

The planned scale of green hydrogen production plants in the 2050 scenario equals a combined 418 MW of generation, small in comparison to the projected 3500 MW Essar/Vertex blue hydrogen production plant. As such, the water demands associated with each category of hydrogen production by 2050 are of similar differences in scale – blue hydrogen representing 42.7 Ml/d of demand whilst the rest of the green hydrogen generation assets reaching less than a quarter of that demand with 9.7 Ml/d consumptive water use.

The estimates show that two CCS sites total 9.9 Ml/d demand by 2030 for the capture of 1,240 kt CO_2/yr, a figure that rises to 30.8 Ml/d of consumptive demand by 2050 in order to capture 4,890 kt CO_2/yr.

Table 4.2 Total bottom-up estimates of demand at HyNet

2030 hydrogen total (Ml/d)	2030 CCS total (Ml/d)	2050 hydrogen total (Ml/d)	2050 CCS total (Ml/d)
4.7	9.9	52.4	30.8

- Power plants convert one form of energy into another. There will always be ‘losses’ during this process where not all the energy is converted into the desired form (the ‘efficiency’ of the system). Particularly for electrolysis when the input energy for is electricity which is easily quantifiable, it is important to ensure that all parties understand whether the input power or output power of a plant are being discussed. For example, it became evident through following through calculations that at least one stakeholder appeared to be referring to a “X MW” green hydrogen plant when meaning one that consumed X MW of electricity.

- Due to the transience of electricity and heat demand, and of the availability of input energy, power plants typically do not operate at 100% capacity (load) at all times. For example, wind turbines and solar panels operate when the weather conditions are conducive, and other ‘flexible’ forms of electricity production are balanced according to demand and cost of production. By using the nominal output power of hydrogen plants to estimate their water usage, we are assuming 100% load. Various assumptions could be made regarding load/utilisation, but these would be dependent on, amongst others, the hydrogen storage available, end uses of the hydrogen, and the energy source.

- Both ‘typical’ production and maximum production are useful to understand in terms of assessing water impacts (Joint Environmental

Programme, 2021). Consideration of maximum production ensures the environment can cope when the system is under peak load, while typical production allows the total availability, say, over a year, to be compared against the quantity of water required. The same applies to consideration of the impacts of discharges.

- If operation would typically vary within a day, 100% load may never be achieved resulting in our figures being overestimates. Similarly, if operation is designed to vary over a longer timescale, then using a blanket load factor would result in underestimating water demand at some points in the year.

- Surface waters (and to a lesser extent, groundwaters) experience highest flows / recharge rates during winter and spring months when rainfall is higher, evapotranspiration is lower, and snowmelt occurs. Demand for potable water is highest in summer months. Combined, these factors means that water availability for non-PWS users is lowest in summer months.

- Heat and electricity demand (particularly household demand) is highest during winter months. Some forms of electricity production are seasonal, such as reduced solar power during winter months.

- Depending on the purpose and setup of a hydrogen plant, the following impacts could be possible:

    - Green hydrogen production is greatest in summer months, using hydrogen as energy storage to utilise excess green electricity at times of low grid demand.

    - Green hydrogen production is variable according to the variability of the green electricity supply.

    - Insufficient storage is available meaning that blue and/or green hydrogen production is greater in winter months to meet demand.

- Sufficient storage is available to buffer changes in demand, or demand is primarily industrial and does not experience seasonality such that production is constant throughout the year.

KEY POINTS

- Care must be taken to ensure all parties share an understanding of definitions such as ‘power’.
- Both peak hydrogen production and annual average production should be considered in an evaluation of environmental capacity.
- In the absence of average load factors / annual average production, the worst case of 100% utilisation has been assumed in this annex.
- Full analysis should consider the interface between the seasonality and variability of production and water availability.

Pre-treatment

Water losses occur during treatment of water. The lower limit for losses is set by the ratio of pure water to impurities. In practice, losses are determined by a combination of the quality of the influent (the amount of impurities) and the nature of these impurities which determines the treatment processes required to extract the pure water. When considering the suitability of water sources for a particular use, the requirements for the quality of that influent water must be considered alongside the availability of that water source and environmental impacts of using the water. Broadly speaking, when high-grade water is required, as its already undergone treatment and disinfection, water from the public supply will be of higher quality and require less additional treatment than raw water sources.

Following Joint Environmental Program (2021) estimates, losses of 10% from public supply water, 25% from surface water, 30% from groundwater, and 70% from seawater would be expected for process water use in blue hydrogen production. The consumptive demand of green hydrogen production presented is independent of water source (Joint Environmental Programme, 2021).

While the use of dirty water can cause issues with sedimentation and deposition in some cooling systems, it has been assumed that all water available in the

HyNet area would be of sufficient quality for use in cooling systems without additional treatment.

Cooling methods

The type of cooling technology employed in a CCS process is the most significant factor determining water intensity. Post-combustion CO_2 capture systems feed the flue gas from combustion through an absorption column with a solvent, which selectively removes the CO_2. The CO_2-rich solvent is then heated in a desorber column to release CO_2 for storage, after which the regenerated solvent is cooled for reuse (Agbonghae, Hughes, Ingham, & al., 2014). Three cooling configurations may be employed: air-cooled, open-loop and closed-loop.

Air-cooling systems do not use cooling water and instead use air condenser tubes, producing direct cooling by utilising conductive heat transfer from ambient air blown by electric fans. These systems greatly reduce water demand to 0.01 m^3/tCO_2 (Element Energy, 2022), however have relatively higher capital and operating costs in addition to poorer cooling performance (Global CCS Institute, 2016).

Open-loop, or once-through, systems rely on a high volume of raw water abstraction that is discharged back to the source following heat exchange, and so have a relatively low consumptive water demand of 0.2 m^3/tCO_2.

Recirculatory, closed-loop, or evaporative cooling systems recirculate cooling water, lower temperatures are produced as a result of the evaporation of this water. Periodic discharges of blowdown water are required to purge evaporative build-up. These systems have the highest water consumption intensities of the three, at 2.6 m^3/tCO_2 (Element Energy, 2022), but require less abstraction from and return of water to a source than open-loop cooling.

It is important to consider both gross and consumptive water use. This annex focusses on consumptive use as this directly impacts upon water availability. However, non-consumptive use will still affect the water environment. In particular if:

- the discharge location is different to the abstraction point,

- the discharge water is a different temperature to the water in the environment,
- the discharge water is different quality (for example, dissolved oxygen levels, chemical leaching, suspension of sediments),
- the discharge water hydraulically alters the flow regime of the receiving water body.

When used for cooling purposes, it is typical for water from once-through systems to be returned at up to 15°C higher than the abstracted water (Madden, 2013) which, in combination with the larger volume of return flows in once-through systems than recirculatory systems, can produce significant thermal effects in the receiving water.

4.1.2 Upper and lower limits (top down estimates)

Table 4.3 shows the estimated water demand under several different scenarios.

- The water required were WRc’s estimates of the share of national hydrogen supply that might be provided by HyNet to be sourced from groundwater, surface water, and public water supply.
- National-level estimates of water demand from hydrogen supply.
- Two sources of regional estimates of water supply for green, blue, and total hydrogen supply.

Table 4.3 Top-down estimates of water demand for hydrogen production relevant to HyNet NW

Year	2030						2050					
Estimate	Low	Source	Mid	Source	High	Source	Low	Source	Mid	Source	High	Source
Water required for HyNet - base scenario (Ml/d from groundwater)	6.4	See table notes	9.6	See table notes	12.8	See table notes	59.1	See table notes	84.0	See table notes	108.8	See table notes
Water required for HyNet - base scenario (Ml/d from surface water)	6.2	See table notes	9.3	See table notes	12.4	See table notes	55.5	See table notes	78.9	See table notes	102.2	See table notes
Water required for HyNet - base scenario (Ml/d	5.8	See table notes	8.7	See table notes	11.6	See table notes	52.1	See table notes	73.9	See table notes	95.8	See table notes

Year	2030						2050					
Estimate	**Low**	Source	**Mid**	Source	**High**	Source	**Low**	Source	**Mid**	Source	**High**	Source
from potable water)												
Water required - national	-	-	165.8	(Department for Business, Energy & Industrial Strategy, 2021)	323.3	(Department for Energy Security & Net Zero, 2023)	-	-	-	-	-	-
Water required Green - North West	-	-	11.0	(Department for Energy Security & Net Zero, 2023)	-	-	-	-	-	-	-	-
Water required Blue - North West	-	-	19.2	(Department for Energy Security & Net Zero, 2023)	-	-	-	-	-	-	-	-
Water required Hydrogen - North West	-	-	30.1	(Department for Energy Security & Net Zero, 2023) Assume	-	-	-	-	-	-	-	-

Year	2030						2050					
Estimate	**Low**	Source	**Mid**	Source	**High**	Source	**Low**	Source	**Mid**	Source	**High**	Source
				surface water quality since compared to surface water availability								
Water required for Hydrogen – WRW area (Ml/d from surface water) - JEP estimate	2.0	Minimum across scenarios - (Joint Environmental Programme, 2021)	23.0	Average across scenarios - (Joint Environmental Programme, 2021)	73.0	Maximum across scenarios - (Joint Environmental Programme, 2021)	24.7	Minimum across scenarios - (Joint Environmental Programme, 2021)	149.4	Average across scenarios - (Joint Environmental Programme, 2021)	391.8	Maximum across scenarios - (Joint Environmental Programme, 2021)
Alternative estimate for water required for Hydrogen – WRW area	4.0	FES19TD scenario - WRW presentation to EA	5.0	FES19TD scenario - WRW presentation to EA	16.0	FES19TD scenario - WRW presentation to EA	180.8	FES19TD scenario - WRW presentation to EA	275.0	FES19TD scenario - WRW presentation to EA	383.6	FES19TD scenario - WRW presentation to EA

Year	2030						2050					
Estimate	**Low**	Source	**Mid**	Source	**High**	Source	**Low**	Source	**Mid**	Source	**High**	Source
(Ml/d from surface water) - JEP estimate												

Notes: Base scenario water uses were calculated by multiplying the base scenario hydrogen production attributable to HyNet from Table 3.4 by the relevant water intensity factors detailed in Section 3.1.1. As water intensity varies according to hydrogen production method, it was assumed that all production at HyNet would be from blue or green hydrogen, and that the split between the two would be 60% blue, 40% green in 2030, based on the assertion that 6 GW would be produced with CCUS compared to the national target of 10 GW (Department for Business, Energy & Industrial Strategy, 2021). For 2050, actual estimates were provided for hydrogen production with CCUS: 1.1 GW-38.3 GW coming from CCUS. The midpoint of this was attributed to blue hydrogen and divided by the national total prediction and the remainder assumed to be green, giving 55% blue and 45% green.

A number of aspects make it challenging to compare these different estimates.

- The national estimate cannot easily be disaggregated to regional level as it is not known what assumptions were made regarding where the hydrogen would be produced.
- It is difficult to know how much of the regional (and national) estimates can be attributed to HyNet.
- The WRW region is unlikely to match to the ‘north west’ area.

2030 estimates

However, there is an extreme degree of variability both between upper and lower estimates from the same source and across sources and estimation methods. In particular, the DESNZ national estimate for 2023 is almost double that of the BEIS estimate, and that the upper estimate from the JEP study is more than 3x the mean value. Within this context, there is reasonable agreement between the central regional estimates from DESNZ and JEP. The WRc estimates assumed that in 2030 30% of the national hydrogen production would come from industrial clusters, and that HyNet would account for 20% of this 30% (6% of national demand). The assumed national demand is approximately 120 Ml/d, which is significantly less than the DESNZ national estimate of 323 Ml/d, but not far from the BEIS estimate of 166 Ml/d. Given that one of the industrial clusters will sit in the north west/ WRW region, it also seems plausible that 23-31 Ml/d of this total should come from the region, giving credibility to the central JEP regional estimate and DESNZ regional estimate. (However, it should be noted that the DESNZ estimate was based on a very different regional breakdown which attributed <15% of production to the north west.)

KEY POINTS

3. These top-down estimates are **significantly larger** than the 5Ml/d estimated demand from HyNet hydrogen assets in 2030 calculated via the bottom-up estimate.

4. There is **significant variability** in estimates across calculation methods and **significant uncertainty** associated with all estimates.

5. The analysis suggests that known assets will likely account for only a small portion of total HyNet demand, consistent with comments from stakeholders during the engagement exercise. As such, the analysis that could be performed of environmental capacity are **limited**.

6. This can only be improved with **improved information** about the likely scale, nature, and location of HyNet assets.

7. The top-down estimate of water demand from CCC of 14.4Ml/d (Section 3.1.2) is **much larger** than the bottom-up estimate of 0.3Ml/d. This raises concerns about the ability to assess the true environmental impact of HyNet in the short-medium term.

2050 estimates

WRc estimated that 50% of hydrogen supply in 2050 would come from industrial clusters, with HyNet providing 20% of this 50% (10% of national demand). The estimates of 78.9 (55.5-102.2) Ml/d are therefore likely to be significantly higher than the estimates reached by JEP and WRW; using the same attribution would give upper estimates of 39.2 Ml/d and 38.4 Ml/d. However, estimates of 39.2 Ml/d and 38.4 Ml/d are less than the bottom-up estimate of 68 Ml/d. In contrast, WRc's top-down estimates seem plausible in the context of the anticipated demand from known assets. The lower estimates from the JEP models can be partially explained by the fact that these studies estimated actual energy supply as opposed to peak energy supply (capacity of the hydrogen network). For example, assuming an average load factor of 60% would reduce WRc's estimates to 47.3 (33.3-61.3) Ml/d. However, these still significantly exceed 10% of the national central estimates from other sources (14.9 Ml/d-37.5 Ml/d), and indeed WRc's central estimate still exceeds the upper estimate from the JEP models.

KEY POINTS

8.The WRc top-down estimates are comparable to the 68Ml/d estimated demand from known HyNet assets in 2050 calculated via the bottom-up estimate. It is therefore plausible that, accounting for unknowns, **environmental abstraction might be in the vicinity of the 78.9 Ml/d** predicted from the top-down estimate.

9.There is **significant variability** in estimates across calculation methods and **significant uncertainty** associated with all estimates.

10.Estimates from other sources may be too low if the bottom-up estimates for HyNet are accurate, even considering a plausible load factor.

11.The top-down estimate of water demand from CCC of 36 Ml/d (Section 3.1.2) is larger than the bottom-up estimate of 16 Ml/d. This is as expected, as the top-down estimate assumed carbon capture of all emissions from HyNet, while existing plans for carbon capture systems cover only a subset of assets. It is plausible that existing plans account for 44% of the total, giving credibility to the top-down estimate.

4.1.3 Comparing demand to permitted abstractions and environmental capacity (headroom in abstraction licences)

Datasets Ds1 and Ds2 (described in Section 3.2.1) provide details of the maximum annual permitted abstraction under each license, while ds3 provides monthly abstraction data since 2007 for each license. It was determined that 2021 provided the most representative total annual consumption (as 2023 data was only partially complete and a number of omissions were observed in 2022 data). The license numbers for each known HyNet asset were identified and the total annual (2021) abstraction calculated. The coordinates attached to these licenses in Ds1 and Ds2 were plotted and points which were not close to HyNet assets removed. This was then linked via license number to the maximum permitted abstraction for that license. A number of assumptions were then used to draw conclusions by comparing predicted demand at each site to the spare capacity in existing licenses and to compare spare capacity in the environment to predicted demand. These results are presented below.

A dataset was created which compared recent actual abstraction quantities to maximum permitted abstractions for current licences held/used by owners of HyNet assets. To compare these quantities to water demand forecasts, the following assumptions were made.

- All demand estimates provided for 2030 and 2050 are **additional** to existing (business as usual) activities.

- Business as usual water use has not changed significantly since 2021.

- Assets in current operation do not represent additional demand, leading to the exclusion of some assets.

    - Winnington CHP with CCU is in currently in operation with no evidence of future expansion, and so has been excluded as it does not represent additional demand.

    - Connah's Quay CCS abstraction license has not been included due to identification of the site at a late stage in the project. Scoping plans indicate that abstraction at this site would substitute current licensed abstraction at the power plant being replaced.

- Asset demand estimates provided for 2030 and 2050 are **net** water increases taking into account, for example, demand reductions (or increases) from changes to operation or decommissioning of other assets operated by the licensee as a result of decarbonisation.

- Abstraction licenses would not be issued if the environment could not support the additional demand.

    - This statement holds true if all licensees were to maximise use of their permits, abstracting the maximum permitted volume.

    - It has been assumed that this holds true until our time horizons of 2030 and 2050 and that the max annual abstraction volume will not change.

- CAMS assessments provide a view of the availability in an area for additional licenses to be granted or existing licenses increased.

- CAMS assessments are independent. That is, the use of available water in one catchment does not reduce the availability in another catchment.

Table 4.4 Examining headroom in existing abstraction licenses at HyNet

Asset	2030 demand (m^3/year) [Ml/d]	2050 demand (m^3/year) [Ml/d]	Max Annual Quantity (m^3/year) [Ml/d]	Actual abstraction (m^3/year) [Ml/d]	Headroom (m^3/year) [Ml/d]	Headroom after adding 2030 demand (m^3/year) [Ml/d]	Headroom after adding 2050 demand (m^3/year) [Ml/d]
Inovyn CV, Quill II, Runcorn	0 [0]	3,872,650 [11]	36,927,508 [101]	15,761,873 [43]	21,165,635 [58]	21,165,635 [58]	17,292,985 [47]
Winnington CHP with CCU	0 [0]	0 [0]	23,400,000 [64]	6,853,513 [19]	16,546,488 [45]	16,546,488 [45]	16,546,488 [45]
Padeswood Cement Works CCS	0 [0]	210,240 [1]	24,500 [<1]	0 [0]	24,500 [<1]	24,500 [<1]	-185,740 [-1]
Essar/Vertex Stanlow	1,569,500 [4]	15,585,500 [43]	8,997,914 [25]	1,758,958 [5]	7,238,956 [20]	5,669,456 [16]	-8,346,544 [-23]
Other HyNet assets currently using potable supply or currently without license	584,000 [2]	9,774,700 [27]	0 [0]	0 [0]	0 [0]	N/A	N/A
HyNet total (all assets)	2,153,500 [5]	29,443,090 [81]	69,349,922 [190]	24,374,344 [67]	44,975,579 [123]	42,822,079 [117]	15,532,489 [43]
HyNet total (excluding those expecting/known to use potable supply)	1,569,500 [4]	19,668,390 [54]	69,349,922 [190]	24,374,344 [67]	44,975,579 [123]	43,406,079 [119]	25,307,189 [69]

- The anticipated additional demand at 2030 **from known assets** can be accommodated within existing permits, i.e. by the environment at the time of permit issue.

- The Padeswood Cement Works and Stanlow Refinery would likely have to significantly increase their abstraction licenses in order to scale up to the activities planned to be in place by 2050.

The following conclusions can be drawn.

- Considering **only these known assets,** there may be scope for license trading to account for these shortfalls, even if assets currently unlicensed or that are expected to use public supply were required to make use of these existing licenses.

- As of 2013, there was 57,000,000 m^3/yr of additional surface water available across the HyNet area. This would also be sufficient to cover the required increase in abstraction licenses.

- The picture would be **significantly different** were the total demand at HyNet closer to the top-down estimates presented in Section 4.1.2.

There is likely to be sampling bias in that known assets are those which have existing abstraction permits (or have applied for them). For example, the conspicuous absence of large-scale green hydrogen production, expected to be part of the strategy to decarbonise industrial clusters, is likely linked to the fact these would be new assets/sites as opposed to expanding/altering existing assets. **These omissions are likely to be significant**, particularly given the expectation that green hydrogen will be more water intensive than blue hydrogen.

4.2 Where could that water come from?

4.2.1 Current

From the stakeholder engagement with hydrogen and carbon capture companies, evidence was collected on where they would source their water from, which has been discussed in Section 4.1. No new abstractions were identified as being needed by hydrogen and carbon capture companies in the HyNet area currently or in the short term.

Current water sources identified were water trading, existing abstraction licences (increasing abstraction up to max licensed or repurposing water use), third party suppliers (assumed to be part of water trading agreement), onsite water reuse, condensate reuse, and public water supply.

These current water sources identified by HyNet companies are considered to have a minimal impact on the environment. Existing licences are assumed to be suitable for the environment, having been previously assessed when the licence was granted. However, it is noted that catchments change with time which may result in a previously sustainable abstraction becoming not sustainable. It is also noted that sustainability reductions will be enforced in England where the environmental sustainability of abstraction licences will be reassessed, the impact of this on water availability for HyNet is discussed further in Section 3.2.4.

All sources listed above are considered suitable water sources for companies within HyNet. The impact of using public water supply as a water source is assessed by the relevant water company. UU was consulted as part of stakeholder engagement and confirmed that they have permitted some hydrogen and carbon capture companies to use water supplied by them for current requirements (see Annex 6 for details). However, there were conditions for future requirements which are further discussed in Section 4.2.2.

In addition to the sources listed above, there are other water sources to consider if further water is required, for example by a company with plans not in the public domain. These are discussed below.

New surface water abstraction

From the evidence identified in the literature review (Annex 4) and stakeholder engagement with NRW (Annex 6) there is no surface water availability in the Dee catchment, therefore new licensed surface water abstractions from the Dee catchment are not considered a possible water source for HyNet.

From the most recent published abstraction licence strategies (Environment Agency, 2013; Environment Agency, 2013a; Environment Agency, 2020a) there appears to be some surface water available for licensing. However, the abstraction licence strategies represent water availability at time of assessment with some strategies being published over 10 years ago. In the stakeholder engagement with the EA concerns were raised about using data that was this age as it does not represent the current state. These concerns were echoed by other stakeholders including NRW and the Hydrogen Trade Associations. Catchments change frequently and keeping information up to date can be time consuming and challenging. Access to more up to date licence strategies was not possible for this annex. However, to estimate changes from licensing strategy publication, abstraction licence data was analysed (Section 3.2.2). From the assessment of abstraction licences in 2012 and 2023 from the data provided by the EA it was found that surface water may be available for licensing at volumes required for HyNet up to 2030, particularly in Weaver and Dane CAMS area (see Sections 3.2.1, 3.2.2 and 4.2).

Local EA water resources teams would need to be consulted for any new abstraction licences to ensure the most up to date information is used.

New groundwater abstraction

From the evidence identified in the literature review (Annex 4) and stakeholder engagement with NRW there is effectively no groundwater availability in the Dee catchment that can be licensed. NRW noted that there is an area in the Dee catchment that has restricted water availability but that licensing of that water was very unlikely to occur to protect the groundwater and catchment health, particularly if there are other sources available.

The literature review (Annex 4) identified no or limited groundwater availability around the Lower Mersey and Weaver and Dane CAMS areas with the exception of East Glaze groundwater management area near Upper Mersey catchment. This management unit was stated as having 14.7 Ml/d available in the Lower Mersey abstraction licensing strategy (Environment Agency, 2013). The assessment of *Ds1* abstraction licensing data provided by the EA (see Section 3.2.1) indicates the greatest increase in max annual groundwater abstraction volume from 2012 to 2023 for the Lower Mersey in the agricultural industry, with notable increases in the food and drink industry, minerals industry and general industry. There is a total increase in licensed max annual groundwater abstraction volume of 49 Ml/d which is greater than the 14.7 Ml/d stated as available in the Lower Mersey abstraction licensing strategy (Environment Agency, 2013). Therefore, it is considered that there may not be available groundwater currently for new abstractions. Note the data may not contain licences that were active in 2012 and expired in 2023.

The reasons for restricted water availability are historic over licensing and saline intrusion (Environment Agency, 2013).

Alternative water sources

In section 3.2.10 rainwater harvesting was discussed as an alternative source and it was noted that EET Essar and Tata Chemicals both stated they are or have considered it as a water source. Rainwater harvesting often does not provide water in large quantities and is dependent on rainfall, this may change as seasonal variations in rainfall events change due to climate impacts. CCSA noted in the engagement sessions that storage of rainwater can be difficult due to lack of space. Rainwater harvesting is a viable option, but it probably would need to be combined with other sources to provide sufficient water volumes.

Section 3.2.10 also notes that wastewater treatment works final effluent re-use could be a viable future water source for HyNet assets, although one that requires further investigation. Desalination was also explored as a future option.

KEY POINTS

Current proposed water sources for HyNet put minimal pressure on the environment, assuming that existing licences have considered environmental capacity.

Where UU are the water source preferred by HyNet companies, there is an agreement between parties that UU will provide the current required volume but will not be obliged to provide any increase in required water.

There may be some surface water availability in the Weaver and Dane CAMS area.

Surface water may be available north of the Mersey estuary for industrial HyNet users. In addition, there may be groundwater available and limited surface water in Upper Mersey.

There is no additional water available in the Dee catchment.

Rainwater harvesting is unlikely to significantly address a water availability shortfall but could supplement other sources. Wastewater reuse could contribute a proportion of the water needed by HyNet but requires further investigation.

4.2.2 Future

WRW have performed an assessment of water availability for their region, which includes the HyNet area, as part of their emerging water resources plan (Water Resources West, 2022). From reviewing this emerging plan and engaging with them through the stakeholder engagement process, it is considered that there may be sufficient water to go around up to 2050. However, there are limitations to this regional view raised by WRW during stakeholder engagement. The assessment does not represent local variation which may limit local water availability. In addition, WRW can only make an assessment based on information available at time assessment. This annex has identified through stakeholder engagement with hydrogen production and carbon capture storage companies and trade associations that asset development plans may be withheld from the public domain until a suitable point due to commercial sensitivity, impacting the data available to complete an assessment.

The largest risk to water availability for HyNet that WRW had identified were the sustainability reductions that will be enforced over the coming years, which they communicated during the stakeholder engagement. Section 3.2.4 talks about the sustainability reductions and the scenarios considered by WRW in their emerging plan (Water Resources West, 2022). However, it is acknowledged that the impact of sustainability reductions has large uncertainty surrounding it, and the impact of reducing the licensed maximum annual abstraction volumes could have upon public water supply demand has not been assessed, as identified by WRW in stakeholder engagement.

Time horizon 2030

As detailed in Section 3.2.2, if licensed maximum annual abstraction volumes are not reduced sufficient water could be available to support HyNet based on the information currently in the public domain (the bottom-up estimation). This assessment is based on the assumptions detailed in Section 4.1.3. The following sections will outline potential changes to water availability due to key pressures.

Climate change

Research into impacts of climate change tend to be high level (regional) with a minimum time horizon of 2050, leaving an evidence gap relating to the impact of climate change for 2030. Public water supply companies have calculated the yearly impact of climate change upon the WRZ DO as part of their WRMP process. However, this does not account for seasonal variations in water availability. Evidence identified through the literature review (Annex 4) indicates that the greatest impact of climate change on the north west will be changes in seasonality rather than overall water availability. Since seasonal impacts of climate change for 2030 is an evidence gap, and other pressures are considered more significant impacts upon water availability in the north west by WRW and identified through the literature review, impact of climate change has not been considered in our assessment of water availability for 2030. This evidence gap could be addressed in future work by the EA.

Public water supply

The hydrogen and carbon capture companies that stated public water supply as their water source in the stakeholder engagement sessions stated the supplier to be United Utilities (UU). UU stated in their engagement session that they are providing conditional agreements for the supply of water to the HyNet companies that require a water supply. The essence of the agreement, as communicated by UU during stakeholder engagement, is that UU can provide the volume a company is currently requesting but alternative sources will need to be used if further water is required and UU cannot provide it. UU is not agreeing to provide a supply above that which is currently requested in the future. They stated that the volume of water that HyNet would require is greater than the estimated surplus of the Strategic WRZ, where many HyNet assets are located.

UU's rdWRMP24 indicates 11.1 Ml/d surplus water in the Strategic WRZ during 2030-31 (United Utilities, 2023), delivered through primarily demand management options which stakeholder engagement, particularly with the EA and NRW, identified are not always reliable for their water saving benefits. The engagement session with NRW also indicated that surplus values are expected to change from the revised draft table for the final WRMP24, but this information was not available for this annex. From the bottom-up estimated requirements, this would be sufficient to cover potable water requirements in 2030, but not total requirements. From the top-down estimate this would not be sufficient to cover the total water requirements.

Environmental requirements – sustainability reductions

Sustainability reductions are being considered as the required abstraction licence reduction for a catchment to reach its Environmental Destination. WRW's consideration of sustainability reductions is discussed in Section 3.2.4. During the stakeholder meeting with WRW the uncertainty around sustainability reduction volumes was discussed with it being considered the greatest water availability risk to HyNet because of the unknown scale of impact and unknown time of impact. From the stakeholder engagement, sustainability reductions are expected to be established and enforced from the next few years onwards. The specific timeframe is unknown.

WRW have planned for the 'Mid' environmental destination scenario, which has an estimated sustainability reduction impact on UU's Strategic WRZ public water supply DO of -15 Ml/d for 2029-30, where most of the planned HyNet assets are located. For 2031-35 this increases to an impact on DO of -18.99 Ml/d, with the estimate for the High scenario -21.87 Ml/d. If the High scenario occurred this would reduce the Strategic WRZ's surplus to 8.22 Ml/d, which is potentially impactful for HyNet development.

There are significant uncertainties around sustainability reductions which has resulted it challenging water resources planning.

Estimations of how sustainability reductions impact non-public water sector were not performed.

Non-public waters supply requirements

The power sector is estimated by WRW to require 2.4 Ml/d by 2029-30 across the WRW region (Water Resources West, 2022b). Due to the modelling method used to calculate these estimates WRW does not provide a WRZ or more local breakdowns of power water requirements. . However, the sector breakdown in Section 3.2.1 indicated that this navigation requirement most likely is not within the HyNet area but would be in upstream areas. Removing navigation requirements from WRW's estimation of non-public water supply demand for UU's Strategic WRZ leaves a requirement of 103.35 Ml/d, an increase of 2.53 Ml/d from the recent actual daily water abstracted. This additional volume is available in the existing licences (Water Resources West, 2022b). Therefore, it is assumed that if there are no reductions in licensed max annual abstraction volumes, non-public water supply requirements will not be a significant limitation for HyNet.

Water trading

Water trading is already occurring in the HyNet area and can be a useful way to use existing licences which are not being fully utilised. However, these licences are likely to be impacted by sustainability reductions and may result in water trading being less feasible. It is unknown when this impact may occur, whether before or after 2030.

KEY POINTS

12. With the current planning assumptions and known water requirements of HyNet there could be sufficient water available in 2030. However, there are large uncertainties around HyNet water requirements and sustainability reductions which may prevent there being sufficient water in 2030.

13. Reducing the uncertainty around HyNet water requirements and sustainability reductions will allow for more effective water resource planning by WRW, who engage with trade organisations and stakeholders in their plan development.

Time horizon 2050+

As detailed in Section 4, even if licensed maximum annual abstraction volumes are not reduced it is likely there will not be sufficient water available to support HyNet based on the information currently in the public domain (the bottom-up estimation). This assessment is based on the assumptions detailed in Section 4.

There are many uncertainties for the 2050 and beyond horizon[23] which make it challenging to assess whether water availability would be sufficient for HyNet. An overall high-level view assumes that any required sustainability reductions will be known prior to 2050 and so water resource plans will be incorporating these reductions and any required alternative water sources will have been developed or be in development. Therefore, it is assumed that there could be sufficient water for HyNet in 2050, providing it is considered early and fully in water resource planning. The following sections explains some key areas of consideration for water availability in 2050 and beyond.

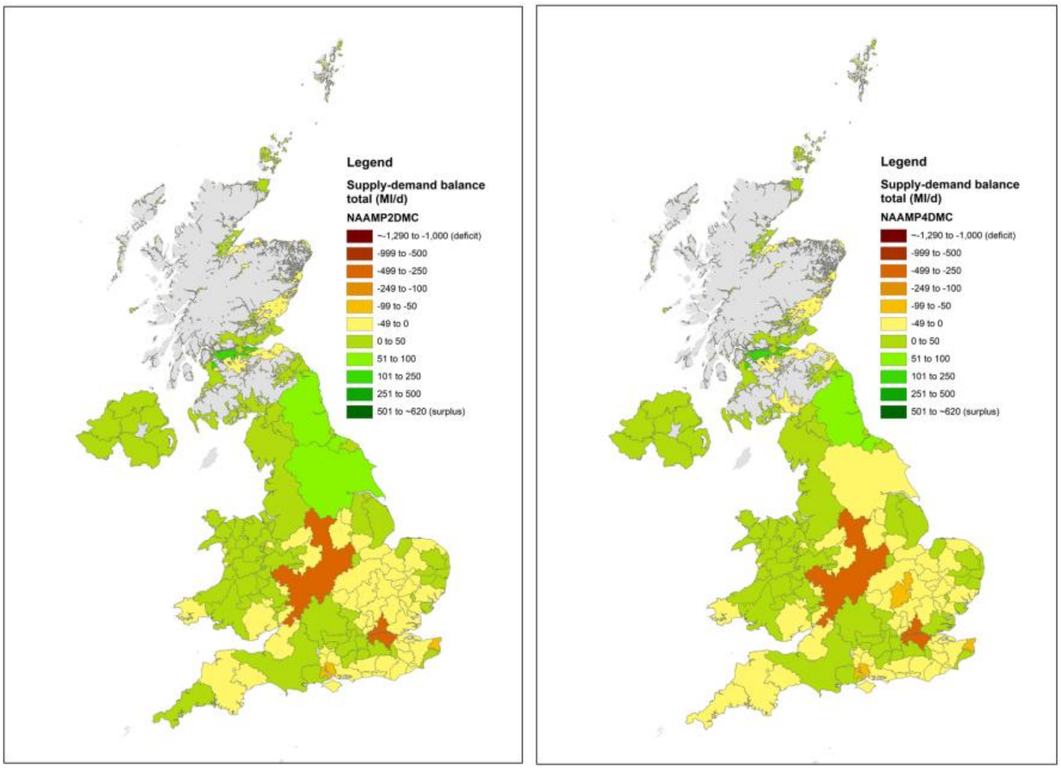
---

[23] Also looked at 2080, but available information was insufficient to draw a significant conclusion in water availability.

Climate change, impact of other areas, and seasonality

The literature review (Annex 4) undertaken as part of this annex explored climate change literature for the HyNet area. Figure 4.1 shows that there is an expected surplus between 0 Ml/d and 50 Ml/d in the four WRZs near the HyNet region. However it also shows a deficit of between -100 Ml/d and -249 Ml/d in Severn Trent's Strategic Grid WRZ, which is within the WRW region. This may have an impact on the water available in the HyNet area due to the potential for large in-region transfers. Transfers already exist within the WRW region and by 2050 may have increased in size, having an impact on the HyNet area. In addition, Thames Water's London WRZ shows a deficit of between -100 Ml/d and -249 Ml/d. This may impact the water availability for the HyNet area due to the potential Severn-Thames Transfer and North-West Transfer options, which are not currently selected as part of the preferred plans (Water Resources West, 2022), but may be by 2050.

Figure 4.1 Supply-demand balance in the mid-century, in a 2°C world (left) and 4°C world (right), central population projection and assuming no additional adaptation action (HR Wallingford, 2020)



From the literature review (Annex 4) it was identified that the expectations for precipitation in the north west are for similar overall precipitation, but increased seasonality, with more rainfall in the winter and less in the summer. Water requirements for HyNet assets may vary throughout the day and seasonally depending upon trends in energy use. In the UK, more energy is typically used in the winter, which is when there is a greater volume of water available in the HyNet area. An increased understanding of the seasonality of water requirements of HyNet assets may present some water availability opportunities such as variable abstraction licences.

Public water supply

As stated previously, stakeholder engagement with UU identified that they are conditionally agreeing to providing water to some HyNet assets (see Annex 6 for details). The condition is that they will provide the amount agreed now but will not be obligated to provide more in the future as they understand that the requirements of HyNet will be greater than their surplus.

UU's rdWRMP24 indicates 129.7 Ml/d surplus water in the Strategic WRZ during 2049-50 (United Utilities, 2023), delivered through primarily demand management options which stakeholder engagement, particularly with the EA and NRW, identified are not always reliable for their water saving benefits. There are 5 planning periods prior to 2050 which could significantly change the surplus amount and options selected to ensure a resilient public water supply. It is not considered that public water supply could provide all the water required by HyNet, from both the estimations identified in Section 4.1 and from the perspectives of UU during the stakeholder engagement sessions.

Environmental requirements – sustainability reductions

Sustainability reductions are being considered as the required abstraction licence reduction for a catchment to reach its 'Environmental Destination'. WRW's consideration of sustainability reductions is discussed in Section 3.2.4. It is assumed that by 2050 the scale of impact of sustainability reductions will be better understood. With the uncertainties removed the challenges in water resources planning for sustainability reductions are assumed to be removed. Therefore, it is assumed that suitable alternative water sources have been or will be developed and sustainability reductions will no longer be a risk to water availability for HyNet. This will, however, be dependent on large schemes being identified, designed, built and commissioned if required, within the next 25 years.

Non-public waters supply requirements

The power sector is estimated by WRW to require 131.90 Ml/d for 2049-50 across the WRW region (Water Resources West, 2022b). Due to the modelling method used to calculate these estimates WRW does not provide a WRZ or more local break down of power water requirements. Navigation requirements are estimated to remain the same in the Strategic WRZ, at 154.63 Ml/d for 2049-50. The greatest change in water requirements is for the chemicals sector (+9.96 Ml/d), which the sector breakdown (Section 3.2.3) indicated had a moderate presence in the HyNet area. The impact this will have upon water availability for HyNet is dependent upon the impact of other pressures such as sustainability reductions and climate change.

Water trading

The potential for water trading may decrease by 2050 with reduction in max. annual abstraction volumes, as the licences would be using a greater proportion of the reduced licence. However, there are many uncertainties and the potential for abstraction licencing governance to significantly change impacting potential of water trading.

KEY POINTS

14. If uncertainties in water requirement estimates and water availability limitations are reduced with sufficient time for an alternative water source to be developed, water availability could be sufficient for HyNet with limited environmental impact by 2050.

15. Regional planning could improve resilience of the area by including the costs and benefits to all sectors in the options assessment process rather than a focus on the costs and benefits to the public water supply sector.

4.2.3 Interpreting results - commentary/conclusions

This section presents a series of maps illustrating bottom-up estimates of water demand for each asset within HyNet overlain with estimated water availability in each surface water catchment, ground water catchment or water resource zone (public supply) for 2030 and 2050. The maps reinforce the conclusions drawn in sections 4.2.1 and 4.2.2.

The following should be considered when interpreting the maps.

- Polygons were unavailable for groundwater bodies in Wales[24]. A label has been added to show that there is no water available in the Dee groundwater catchment.
- The commissioning date of several HyNet assets is unknown, in addition to how the production might scale through time. Based on the available information, it was considered reasonable to assume that water demand in 2030 for the assets listed below would be zero, but that they would be operating at capacity by 2050. These have been listed as ‘evidence gap’ in the 2030 map.
  - Protos, Cheshire Green, Ince
  - Viridor, Runcorn ERF CCS
  - Padeswood Cement Works CCS
  - Ince Low Carbon Power Project.
- Stakeholder engagement suggested that the following fuel switching sites were also considering green hydrogen production, however sufficient information to understand potential water demand and scale of generation

---

[24] NRW report on the entire Dee groundwater catchment meaning that polygons are unavailable also for the part of the Dee catchment that sits in England.

at the sites was unavailable. They are not shown on the 2030 and 2050 maps.

  - Kellogg’s, Trafford Park
  - Pilkington Glass, St Helens

- As current information suggests that there will only be a one-off water demand associated with the Inovyn, Keuper Gas Storage (and that the time, quantity, and water demand are unknown), ‘evidence gap’ has been shown on the map.

- Water demand values are estimates associated with significant uncertainty. In particular, the accuracy of the estimates is highly dependent on the quality and quantity of information which was received from stakeholders.

- Water availability data is from datasets published in 2024, but is not considered to represent the water availability of 2024, rather the water availability of the most recent published abstraction licensing strategy for that CAMS area. Water availability changes regularly making keeping the water availability records up to date challenging. Local water resources teams should be consulted regarding local water availability where appropriate, especially where water availability appears to be particularly location dependant.

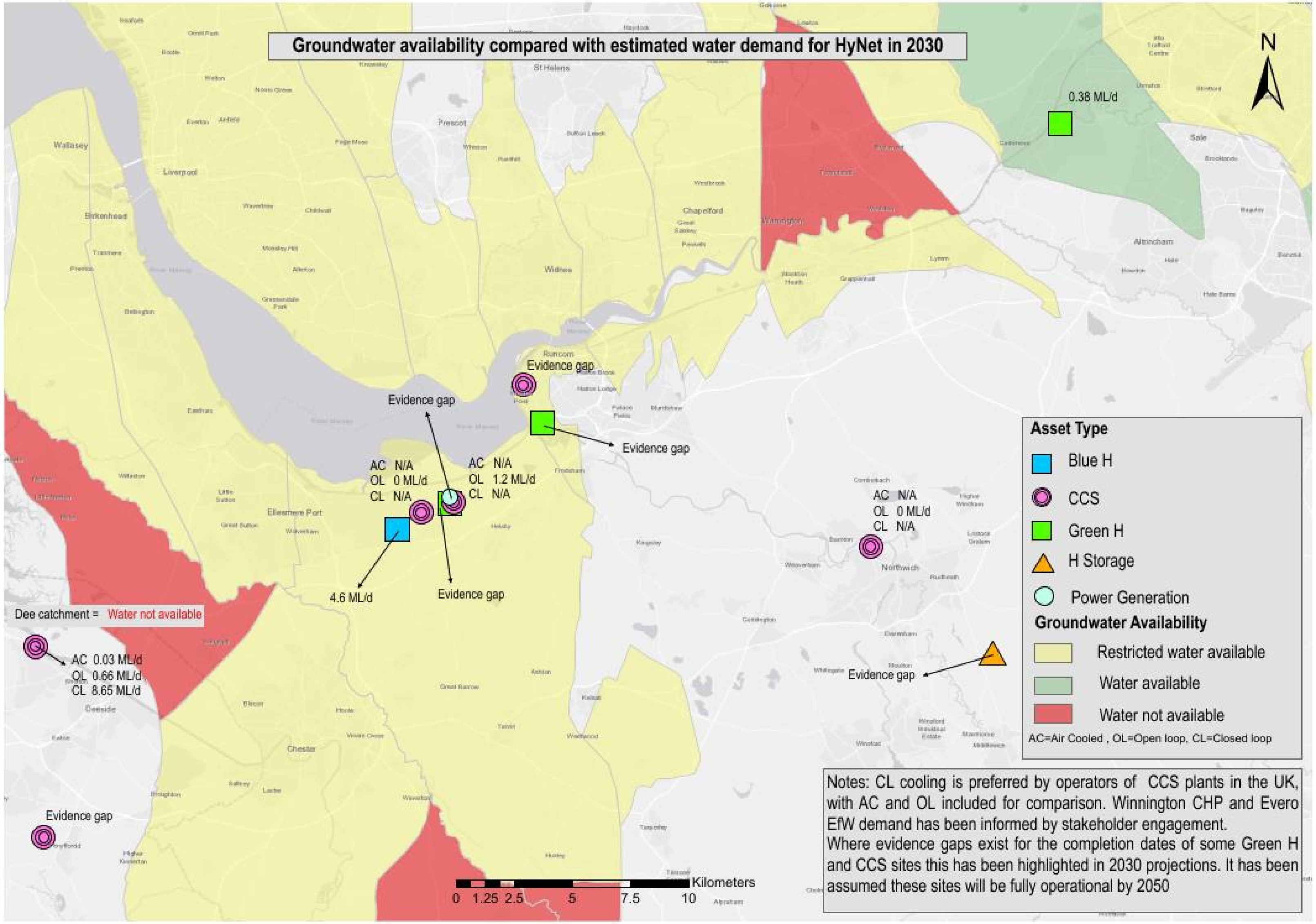
- Surface water availability has been assigned from the resource reliability assessment (i.e. proportion of time that water may be available), with the assumption that HyNet will require water all year (at least 90%).

- The maps provide an unrealistic worst-case scenario whereby all assets utilise exclusively a single type of water source (groundwater, surface water, or public supply). While, in reality, availability, logistics, quality requirements, and cost will determine which source is most suitable (or is possible) for a given process stream, the maps allow the water footprint of HyNet to be put into the context of the amount of water available in the environment.

Groundwater sources

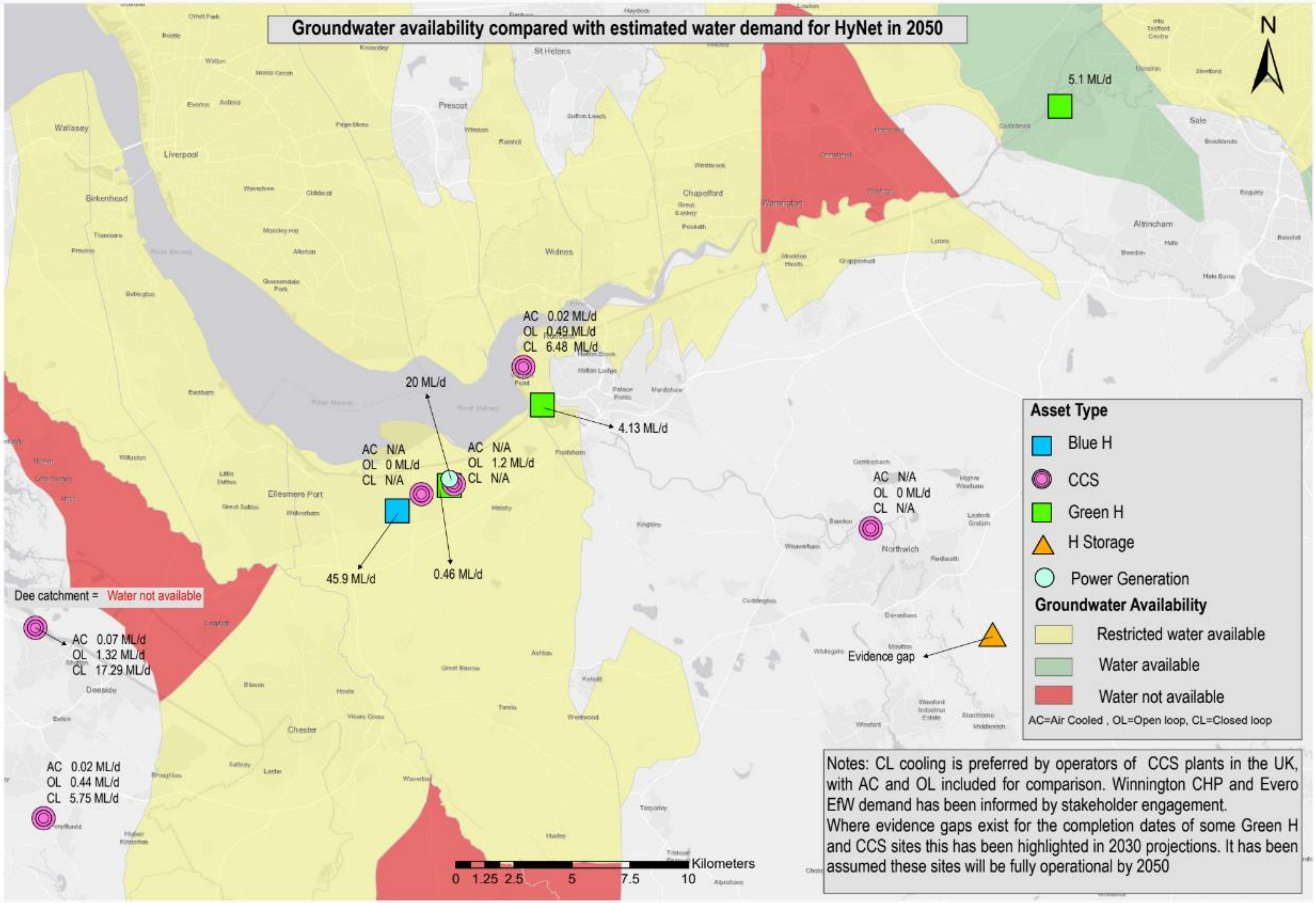
Figure 4.2 and Figure 4.3 show a map of the HyNet area overlaid with the current groundwater availability from the EA’s freely available *Groundwater Management Units coloured according to water resource availability colours* shapefile (Environment Agency, 2024). A points layer is also plotted showing the expected location and water demand of HyNet assets in the respective years **assuming that all the water demand from these assets was sourced from groundwater.**

Figure 4.2 Groundwater availability and estimated water demand for the HyNet NW area in 2030



Notes: CL cooling is preferred by operators of CCS plants in the UK, with AC and OL included for comparison. Winnington CHP and Evero EfW demand has been informed by stakeholder engagement.
Where evidence gaps exist for the completion dates of some Green H and CCS sites this has been highlighted in 2030 projections. It has been assumed these sites will be fully operational by 2050

Figure 4.3 Groundwater availability and estimated water demand for the HyNet NW area in 2050



Notes: CL cooling is preferred by operators of CCS plants in the UK, with AC and OL included for comparison. Winnington CHP and Evero EfW demand has been informed by stakeholder engagement.
Where evidence gaps exist for the completion dates of some Green H and CCS sites this has been highlighted in 2030 projections. It has been assumed these sites will be fully operational by 2050

Figure 4.2 shows no or restricted groundwater at all assets except one green hydrogen plant which has been estimated as requiring 0.38 Ml/d in 2030, which may be available from groundwater. In 2050, Figure 4.3 shows that this water requirement has been estimated as increasing to 5.1 Ml/d. From the review of changes in abstraction licences and comparison with water availability in the applicable abstraction licencing strategy undertaken in Section 3.2.2 this water may not be available from a groundwater source.

Surface water sources

Figure 4.4 and Figure 4.5 show a map of the HyNet area overlaid with the current surface water availability from the EA’s freely available *Water Resource Availability and Abstraction Reliability Cycle 2* shapefile (Environment Agency, 2024). A points layer is also plotted showing the expected location and water demand of HyNet assets in the respective years **assuming that all the water demand from these assets was sourced from surface water.**

Figure 4.4 and the analysis undertaken in Section 3.2.2 shows more surface water availability than groundwater availability shown in Figure 4.2 above. However, there are more evidence gaps for the amount of water required, particularly at 2030. With these evidence gaps an assessment of whether surface water may be available has not been undertaken for 2030. Figure 4.5 shows potential water availability relatively close to the key HyNet assets. However, there remains some assets that are not near areas of potential water availability such as the blue hydrogen production plant that would require 42.7 Ml/d of surface water. Transporting the surface water the distance from available water to asset may be less sustainable than other water sources.

Figure 4.4 Surface water availability and estimated water demand for the HyNet NW area in 2030

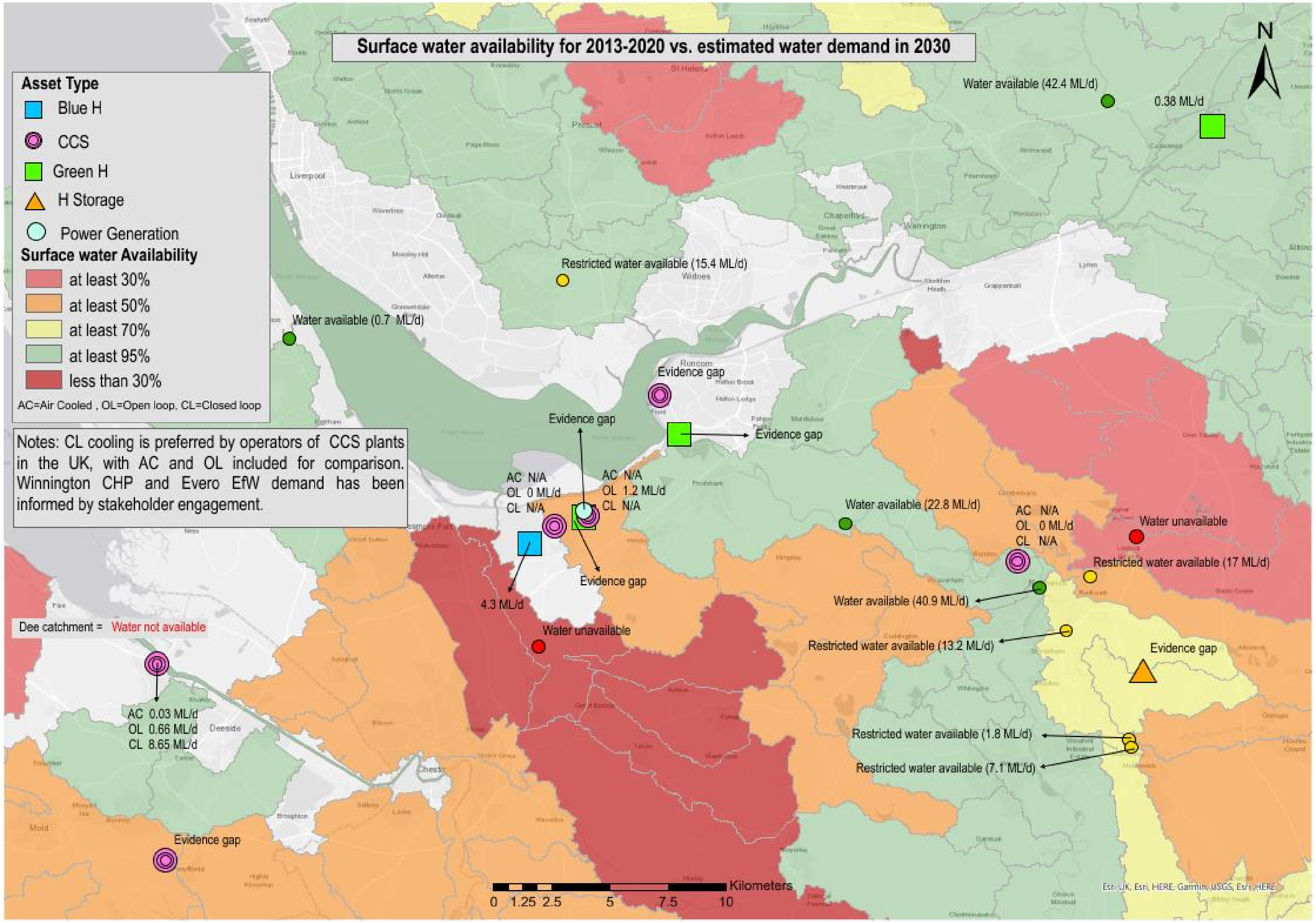
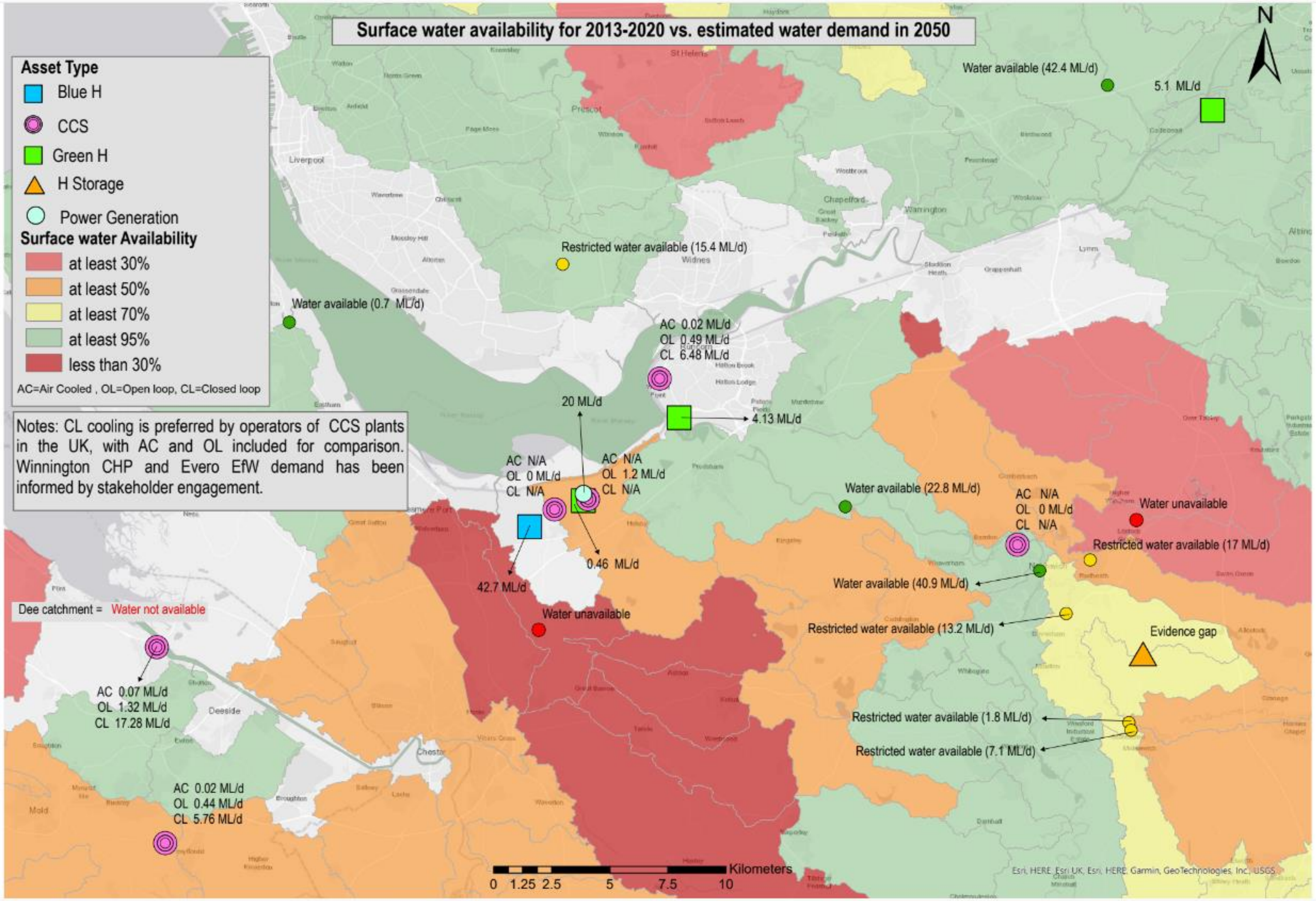


Figure 4.5 Surface water availability and estimated water demand for the HyNet NW area in 2050



Sourcing from public supply

Figure 4.6 and Figure 4.7 show a map of the HyNet area overlaid with the WRMP19 WRZs, freely available from the relevant water company's website under water resources market information (United Utilities, 2019; Severn Trent Water, 2019; Dwr Cymru Welsh Water, 2019; Hafren Dyfrdwy, 2019). No known significant changes to these WRZs have occurred in the HyNet area for WRMP24. The expected surplus from draft/revised draft WRMP24 documents is shown in Table 4.5. A points layer is also plotted showing the expected location and water demand of HyNet assets in the respective years **assuming that all the water demand from these assets was sourced from public water supply.**

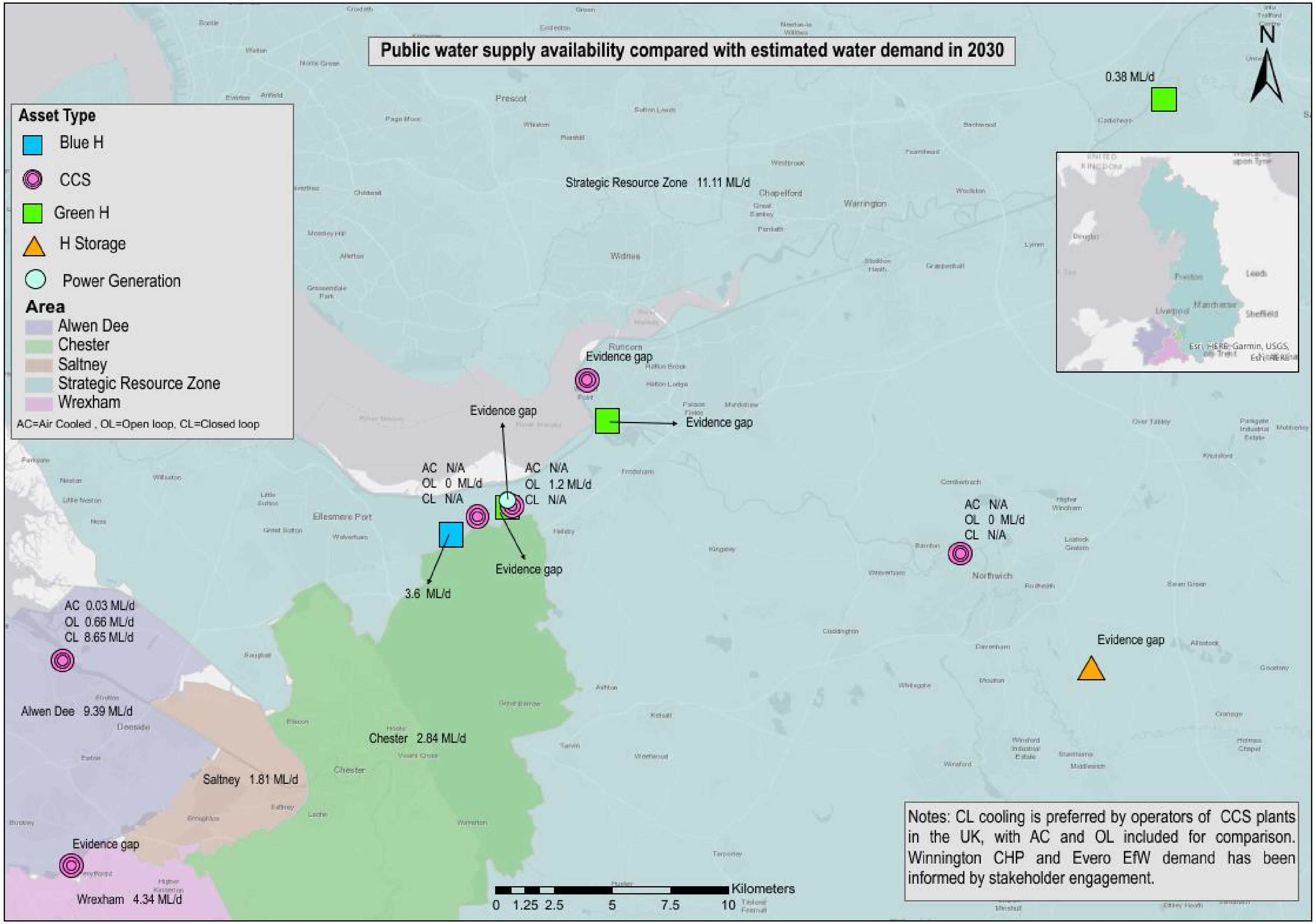
Figure 4.6 shows one asset (blue hydrogen plant) close to Chester WRZ requires 3.6 Ml/d, which is greater than Chester's estimated surplus. The relatively small value of 0.38 Ml/d may be able to be supplied by UU. Annex 4 indicates that the Strategic Zone may have sufficient water to provide HyNet; however, engagement with UU indicates that they are of the opinion the water requirements will be greater than they can provide.

It has been acknowledged that this annex did not identify all planned HyNet assets as some are not in the public domain and are considered commercially sensitive, therefore information about them could not be shared. Based on top-down estimates (Section 3.1.2), this increase in assets would increase the water requirements and could raise the maximum estimated demand from ~83 Ml/d in 2050 to over the surplus in the Strategic WRZ.

Table 4.5 Quoted surplus expected at 2030-31, 2050-51, and 2080-81 in draft and revised draft WRMP24 documents

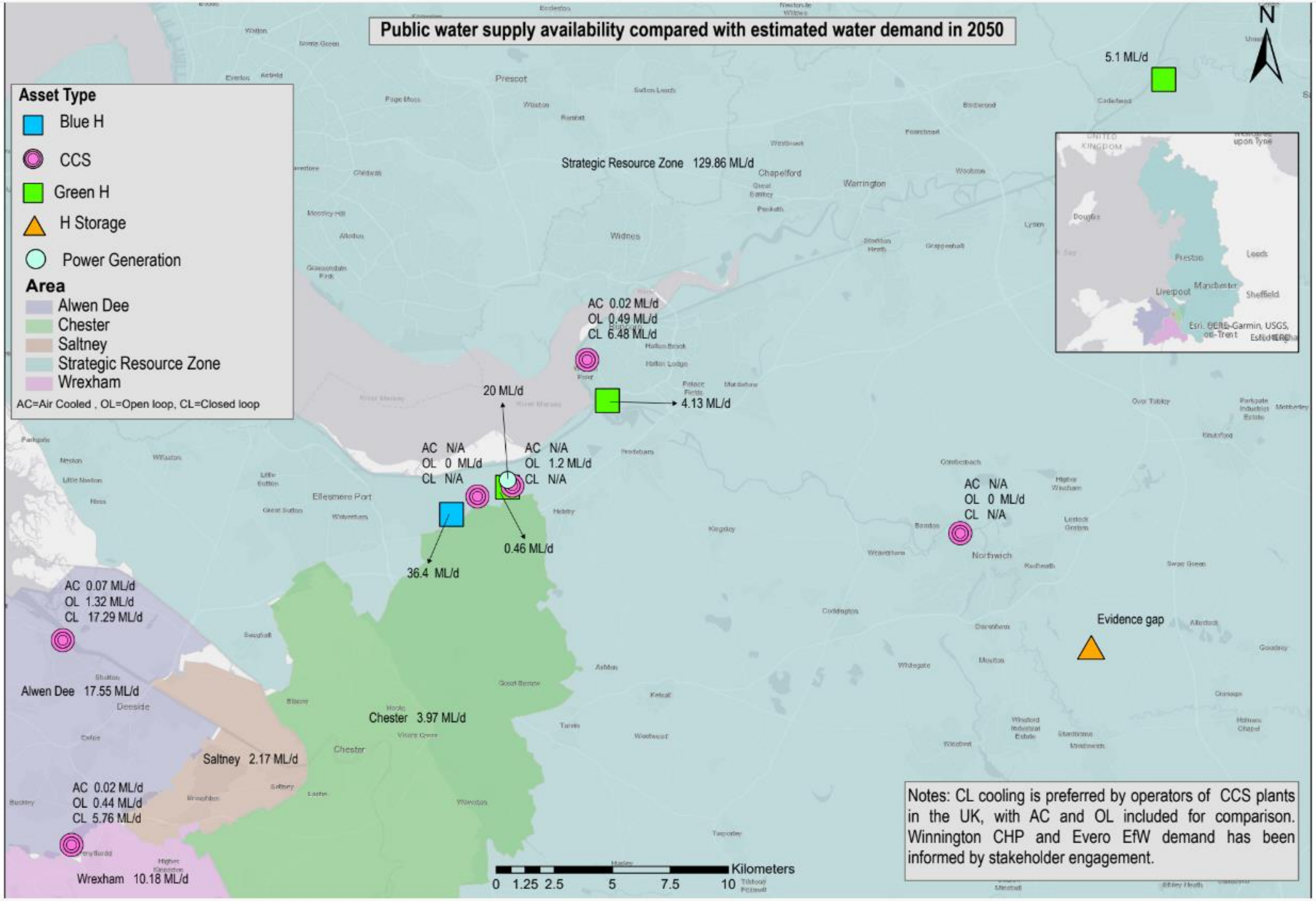
WRZ	Company	Surplus in 2030-31 (Ml/d)	Surplus in 2050-51 (Ml/d)	Surplus in 2080-81 (Ml/d)
Strategic	United Utilities	11.11	129.86	36.49
Chester	Severn Trent	2.84	3.97	1.21
Saltney	Hafren Dyfrdwy	1.81	2.17	2.28
Wrexham	Hafren Dyfrdwy	4.34	10.18	8.63
Alwen Dee	Dwr Cymru Welsh Water	9.39	17.55	16.74

Figure 4.6 Availability in the public supply water resource zones and estimated water demand for the HyNet NW area in 2030



Notes: CL cooling is preferred by operators of CCS plants in the UK, with AC and OL included for comparison. Winnington CHP and Evero EfW demand has been informed by stakeholder engagement.

Figure 4.7 Availability in the public supply water resource zones and estimated water demand for the HyNet NW area in 2050



Notes: CL cooling is preferred by operators of CCS plants in the UK, with AC and OL included for comparison. Winnington CHP and Evero EfW demand has been informed by stakeholder engagement.

KEY POINTS

- From the assessment in Section 4.2.3 it is evident that there are several data gaps that prevent a purely quantitative assessment of water availability and constraints.
- From the data that is available, it appears that to ensure sufficient water for HyNet, multiple water sources will be required.
- A strategic coordination of water sources may be beneficial in ensuring the environmental capacity does not prevent development at HyNet.

4.2.4 Alternative water sources

Water resources planning is important to ensure all stakeholders have sufficient water available. Through this process it is identified whether there is sufficient water available from existing sources, and if not then options (demand side and supply side) are planned. This includes the use of alternative supplies, here referring to sources other than traditional groundwater or surface water abstraction or impoundment. These alternative sources are discussed in Section 3.2.10.

It is important that water requirements and challenges are known in advance to allow for the development of infrastructure and / or assets required to allow for these alternative water sources. There may be a risk to HyNet where there is insufficient time to develop alternative water sources prior to reduction in existing water sources.

4.3 How might HyNet impact receiving water environment?

Current state of the environment. The majority of surface water bodies within the HyNet area currently have WFD ecological classification of ‘moderate’ or ‘poor’. The reasoning behind the ‘moderate’ and ‘poor’ classifications varies significantly between different water bodies and there is no clear, over-arching reason for the current environmental state. Analysis of the ‘reasons for not achieving good’ (RNAGs) for different water bodies in the HyNet region suggests that a combination of industry sectors and legacy pollution issues are often responsible for the underlying water quality issues, making it difficult to highlight a specific area of concern for all future HyNet assets. Instead, HyNet sites must undertake site-specific risk assessments, to determine which pollutants pose the greatest risk to the hydrological environment.

Future state of the environment. When attempting to understand how HyNet may impact the water environment in the future, it is important to consider how factors such as climate change and urban development may impact the quality of receiving waters. An increase in water temperature and hydrological extremes seems likely across the HyNet region. As several of the proposed HyNet facilities are likely to discharge warm effluent into receiving waters, it is likely that the impact of these discharges will worsen over time. Consequently, continual efforts should be made to minimise warm wastewater discharges, utilising new water re-use approaches for process usage and cooling wherever possible. Further in-depth, localised catchment studies assessing the possible effects of climate change on water quality are needed in order to provide more definitive risks associated with each individual HyNet site.

Risks posed to the water environment by HyNet. Overall, it remains difficult to quantify the extent to which HyNet developments will impact receiving waters in the future, particularly when quantitative data on discharge volumes and quality are not readily available (Sections 3.3.1 and 3.3.2). Future efforts should be made to collate current discharge details, so that comparisons can be made with future estimations of water usage and corresponding discharge rates. In doing so, more extensive integrated catchment modelling could be undertaken to better understand the combined risk that HyNet development poses to the water environment.

There are known pockets of contaminated land across the HyNet area, notably near Runcorn and Ellesmere Port, linked to the region’s long industrial legacy. Contaminated land is being considered in more detail for individual HyNet sites through the planning application process. Companies planning to develop sites as part of HyNet are encouraged to consult the EA and local authorities early, to understand localised contaminated land risk and potential mitigation measures.

How will environmental capacity challenge HyNet’s development? Overall, it is difficult to provide a conclusion on how environmental capacity will impact HyNet’s development. Very limited details are known about the expected wastewater volume and quality from each future HyNet site. Consequently, it is impossible to ascertain whether current discharge permits will be sufficient for future HyNet developments. This has the potential to cause delays to the implementation of future HyNet developments, if additional permit applications or permit variations are required. Further studies should be undertaken to determine and collate a more quantitative database on future HyNet discharge quantity and quality, so that risks associated with permit applications can be minimised. This could also allow for an integrated catchment modelling study to be undertaken, providing a better estimation of the impact of HyNet discharges on receiving water quality.

5. Conclusions and Recommendations

5.1 Background

The HyNet north west Industrial Cluster (HyNet) is a planned network of new infrastructure and existing infrastructure that will capture carbon, and produce, transport and store hydrogen in north-west England and north-east Wales. Water Research Centre (WRc) was commissioned by the Environment Agency (EA) to complete an evidence review to understand expected emissions to water, water quality impacts, and water demand and availability for HyNet. The work aims to support Government's Net Zero Strategy and facilitate successful development of low carbon industrial clusters in a way that is environmentally responsible and sustainable.

The project involved a literature review (Annex 4) and stakeholder engagement exercise (Annex 6). Around 250 stakeholders from companies planning hydrogen or carbon capture infrastructure as part of HyNet, from key trade organisations (Hydrogen Trade Associations, Energy UK and the Carbon Capture and Storage Association), from other regulators, water companies and local authorities were consulted.

This annex has presented analysis of the literature and stakeholder engagement, and analysis of additional datasets gathered for the project, including abstraction licences and discharge permits. Key findings are outlined below. In line with the project scope set by the EA, the project has explored short-term (2030), and mid- to long-term (2050-2080) water environment capacity for HyNet.

5.2 Current state of the water environment

Water availability

Catchment Abstraction Management Strategies (CAMS) indicate availability of surface water and groundwater in a catchment. The CAMS for catchments closest to HyNet were last updated in 2013 (Lower Mersey and Alt.), 2015 (Dee) and 2020 (Weaver and Dane). Abstraction licence data was therefore analysed as part of this annex, to try to understand changes in abstractions since the

CAMS were published and therefore develop a more current picture of surface water and groundwater availability.

Based on the CAMS and abstraction licence analysis, there is no surface water or groundwater available in the Dee Catchment. The Weaver and Dane may have no to limited groundwater available, and available surface water for licensing due to increases in maximum abstractable volumes. There may be no to limited groundwater available in Lower Mersey. The surface water availability is likely greater north of the Mersey Estuary and west of key HyNet assets towards Birkenhead. Upper Mersey may have groundwater available, and surface water availability may be highly dependent upon location. There is water available in the public supply.

Public water supply requires most water of all uses in Water Resources West’s region, with navigation the second-largest abstractor. There are large industrial users across the WRW region, including power, agriculture (dairy) and chemicals. The HyNet area is thought to contribute significantly to estimated non-public water supply for general industry within the WRW region. It is also thought to include a not insignificant proportion of water demand from the minerals sector, agriculture and chemical sector demand.

Receiving water quality and the water environment

The majority of surface water bodies in the HyNet area currently have WFD ecological classification of ‘moderate’ or ‘poor’. The reasons behind the ‘moderate’ and ‘poor’ classifications vary between different water bodies and are often complex; there is no clear, over-arching reason for the current environmental state. Analysis of the ‘reasons for not achieving good’ (RNAGs) for different water bodies in the HyNet region suggests that a combination of industry and legacy pollution issues are often responsible for the underlying water quality issues.

Both the Mersey and Dee estuaries are designated Sites of Special Scientific Interest, Ramsar sites and Special Protected Areas, with the Dee estuary also classed as a Special Area of Conservation (SAC). These reflect the estuaries’ importance to sea birds and wildfowl including little tern, red-throated diver and whooper swan. They are also important for smelt, eel, trout and salmon, and are breeding grounds for commercially important fish species. This includes native oyster beds, which occur in the river Mersey.

Four areas near HyNet have been identified as SACs requiring nutrient neutrality assessments for new developments. At present, these are not likely to be impacted by discharges from HyNet assets, with the potential - albeit unlikely - exception of the River Dee where phosphorus is a concern.

In addition to statutory investigations under the WFD, Per- and polyfluoroalkyl substances (PFAS) concentrations and loads in the River Mersey were investigated in recent research. PFAS are a class of chemical compounds that persist in the environment and have been linked to harmful health impacts in humans and animals. Although limited data are available for other water bodies, Perfluorooctanesulfonic acid (PFOS) yields (i.e. load divided by catchment area) in the River Mersey were found to be 2-28 times higher than those observed in the Rhone, Seine and Danube rivers. Perfluorooctanoic acid (PFOA) yields were 25 times higher than those observed in the Danube. PFAS yields in the River Mersey were found to be exceeded only by Cape Fear River, USA, and in the Tokyo Basin, Japan (Byrne, P., et al., 2024).

There are known pockets of contaminated land across the HyNet area, notably near Runcorn and Ellesmere Port, linked to the region’s long industrial legacy. Contaminated land is being considered in more detail for individual HyNet sites through the planning application process. Companies planning to develop sites as part of HyNet are encouraged to consult the EA and local authorities early, to understand localised contaminated land risk and potential mitigation measures.

5.3 Future pressures on the water environment

Water availability

Climate change is one of several elements impacting water availability in the north west, impacting through changes to seasonal weather patterns and rainfall. Other aspects such as environmental water requirements (sustainability reductions), water requirements of the energy sector, growth in industry and population growth are also impactful on water availability. The following pressures on future water availability are explored further in section 5.5:

- ‘Environmental Destination’ plans are likely to reduce water available for abstraction in future.

- Climate change is likely to lead to more rainfall in winter, but less in summer.

- Plans to reduce water demand through reduced leakage, metering or improved water efficiency measures. WRMPs show a significant reliance upon demand management for creating surplus water in public water supply.

Receiving water quality

Although it is likely that climate change will have a significant impact on the water quality of UK riverine, estuarine and coastal environments during the next century, it is difficult to accurately and reliably quantify these changes. The impacts of climate change on water quality are complex, but there is a consensus that changes in water temperature and hydrological regimes are the two most significant issues facing freshwater ecosystems in the UK, due to climate change (Watts, et al., 2015). In line with the rest of the UK, the Mersey Estuary and surrounding river catchments can expect to experience a rise in average water temperature, relating primarily to the projected increase in average ambient air temperature. The extent to which water temperature will rise in water bodies within the HyNet project area is difficult to predict at a local level, particularly without any in-depth, catchment-specific research.

Predicting future water quality is further complicated by plans to invest in improving water body health. Both United Utilities (UU) and Dŵr Cymru Welsh Water (DCWW) have developed their draft business plans for the 2025-2030 (PR24) period. UU proposes 26.8% fewer storm overflows by 2030, and no more than 10 spills per year in 2050, in line with the government’s Storm Overflow Discharge Reduction Plan for England. UU further plans to ‘protect and enhance 386km of rivers’ across its region, including spending £340 million at three wastewater treatment works discharging into the Manchester Ship Canal. This work, and that of local Catchment Partnerships, aims to improve future water quality, though no data has been found to quantify the water quality benefits of this planned work.

5.4 Pressures of HyNet on the water environment

Water demand

One blue hydrogen plant, three to five green hydrogen plant, six carbon capture and storage (CCS) plants and one hydrogen-fired low carbon power (combined-cycle gas turbine) project are known to be planned as part of HyNet. Hydrogen storage is being considered in salt caverns in Cheshire, near Middlewich. Companies that intend to switch to hydrogen as a fuel have been identified throughout the region (Figure 1.1) but are not expected to have additional water demands.

Water demand has been estimated for each of these facilities, and the totals are presented in the first row of Table 5.1. The low carbon power project has an estimated demand of 20 Ml/d but is not included in the totals shown in Table 5.1.

Hydrogen generation and CCS sites will be unlikely to operate at full capacity year-round in order to cater to factors such as energy demand and availability that vary across seasonal and daily timescales. Water requirements will vary based on the capacity sites are operating at. The bottom-up calculations have been performed at a 'worst case' scenario for water demand with the loading being at 100%. Realistic average annual loading has been reported as 60 - 80% by the Carbon Capture and Storage Association (CCSA) stakeholders.

Table 5.1 Total estimated water demand for HyNet

Estimation method	2030 hydrogen total (Ml/d)	2030 CCS total (Ml/d)	2050 hydrogen total (Ml/d)	2050 CCS total (Ml/d)
Bottom-up estimate	4.7	9.9	52.4	30.8

Top-down estimate	9.3 (6.2-12.4)[25]	14.4	78.9 (55.5-102.2)[26]	36.0

Stakeholder engagement revealed that many planned HyNet elements that are not in the public domain as they are either considered commercially sensitive or not sufficiently advanced in their development. As a result, the total demand figures from the bottom-up estimate are likely to be underestimates. To better understand this risk, this annex derived ‘top-down’ estimates for water demand from HyNet, based on government strategy documents, and other organisations’ estimates for national or regional demand, including the Joint Energy Programme and Water Resources West (Section 3.1.2).

Although many assumptions underly the top-down estimate (detailed in Section 3.1.2 and 4.1.2), Table 5.1 shows that the total water demand for HyNet may be larger than the bottom-up estimate based on known schemes. The biggest difference is for 2050 hydrogen production, where the top-down estimate is 26.5 Ml/d greater than the bottom-up estimate.

Wastewater impacts

Limited quantitative data on the likely wastewater arisings, or effluent, from planned developments within HyNet were found. The likely concentrations for some parameters and effluent volumes from the planned blue hydrogen plant were available, however this data was not available for other planned HyNet sites.

Most companies involved in developing sites within HyNet indicated that they had considered wastewater arisings and planned to discharge effluent either into a nearby sewer network or water body (Table 3.11). Some companies indicated that they planned to treat effluent – with SuDS or their own treatment

---

[25] Assuming sources from surface water. Alternative estimates of 9.6 (6.4-12.8) Ml/d for groundwater and 8.7 (5.8-11.6) Ml/d if sourced from public supply.

[26] Assuming sources from surface water. Alternative estimates of 84.4 (59.1-108.8) Ml/d for groundwater and 73.9 (52.1-95.8) Ml/d if sourced from public supply.

plant. Potential environmental impacts include the high salinity of brine from the potential hydrogen storage in salt caverns near Middlewich. Carbon capture plants using amine solvents require a final stage of acid wash to minimise emissions of amines and breakdown products (ammonia and nitrosamines) to air. This acid scrubbing liquid becomes a waste and will need treatment before discharge (on or off-site). This causes potential for nutrient (N), ammonia and new pollutants in receiving waters. Emissions to air could also impact water bodies, through deposition. The temperature of effluent, particularly when used for cooling, is another potential impact.

Limited consideration has been given to future wastewater arisings and how these might impact receiving waters. Notably, future impacts of climate change and other pressures on receiving waters do not yet appear to have been considered.

5.5 How could capacity of the water environment challenge development of HyNet?

Water availability

Stakeholder engagement indicated than many HyNet companies have considered and identified suitable water sources for their short-term requirements. Some companies indicated that they were able to abstract sufficient water under their existing licence terms, and others have agreed water supply from United Utilities (UU) or by trading with another licence holder. No concerns around short-term (pre-2030) availability of water were identified by stakeholders or through the analysis undertaken as part of this annex.

An assessment of abstraction licences in 2012 and 2023 found that surface water may be available for licensing at volumes required for HyNet up to 2030, particularly in the Weaver and Dane CAMS area. However, future water availability for HyNet (2030+) is less certain. Some HyNet companies indicated that they were considering new abstractions in the future and others had not started to consider future water sources. Companies involved in HyNet had started to consider alternative water sources, including re-use of wastewater and industrial effluent. EET Essar is undertaking a study of potential water sources, the results of which will be published following conclusion of this annex. It is not clear whether water will be available to support HyNet in future, due to a number of uncertainties:

- Each regional water resources group is now required to produce an ‘Environmental Destination’ plan that enables water resources resilience and protection up to at least 2050. The EA will assess each catchment and identify where a reduction in abstraction volume is required. As these plans are still under development, it is not yet clear how this will impact the HyNet region. However, reductions in water available for abstraction are likely as some areas are considered ‘over abstracted’ in the abstraction licensing strategies.

- Whilst the impacts of climate change are assessed by public water supply companies, this is done for full years. Seasonal variations are therefore not well understood. Evidence in the literature review indicates that the greatest impact of climate change will be seasonal variations, rather than changes to overall yearly water availability.

- Water company draft WRMPs indicate surplus water will be available in the five water resource zones closest to HyNet in 2050 and 2080. However, this is heavily dependent on reductions in demand, which are not guaranteed to be effective. WRW also indicated that it may not have taken full account of HyNet in its plans, as some HyNet projects are still under development or not yet in the public domain. It is also noted that other water resource zones do not have sufficient water and transfers to these deficient zones from the HyNet region could impact water available. There are five planning periods prior to 2050 which could significantly change the surplus amount and options selected to ensure a resilient public water supply. It is not considered that public water supply could provide all the water required by HyNet, from both the estimations identified in Section 4.1 and from the perspectives of UU during the stakeholder engagement sessions.

A number of recommendations were made by stakeholders relating to water resource policy. Concerns were raised around common end dates placed on abstraction licenses, which can mean that abstraction licenses expire before the end of an asset’s operational life, or at worse before assets start to operate. Stakeholders also noted that water resource planning, notably strategic water transfers, are focused on public supply needs and can neglect the needs of industry. Outdated Catchment Abstraction Management Strategies were also raised as a concern, and whilst this has been mitigated to some extent through analysis of abstraction licences as part of this annex, updated CAMS would increase confidence in the findings. Some stakeholders also questioned the ‘first come, first served’ approach to abstraction licence allocation. Stakeholders were, however, supportive of the EA’s early engagement and collaborative working to understand water resource challenges for HyNet.

Receiving water quality

It is not yet feasible to assess whether the water environment has capacity for wastewater arisings from HyNet. Assuming they are unable to discharge to a sewer network (currently unconfirmed), most HyNet sites are likely to require bespoke discharge permits as they are discharging close to designated or protected environmental sites, or as they exceed the daily volume limit for a ‘standard rules permit’.

Very limited details are known about the expected wastewater volume and quality from each future HyNet site. Consequently, it is difficult to ascertain whether current discharge permits for each site will be sufficient for future HyNet developments. This has the potential to cause delays to the implementation of future HyNet developments, if additional permit applications or permit variations are required. The existing discharge permit for the blue hydrogen plant site may be adequate, based on data gathered for this study.

Further studies should be undertaken to determine and collate a more quantitative data on future HyNet discharge quantity and quality, so that risks associated with permit applications can be minimised. This could also allow for an integrated catchment modelling study to be undertaken, providing a better estimation of the combined impact of HyNet discharges on receiving water quality.

5.6 Recommendations

- Evidence gaps have been identified throughout this annex, including:
  - Likely volume and concentration of wastewater arisings.

  - Amine/ammonia/nitrosamines sources – still an evidence gap on CCS amine solvents and related emissions to wastewater and/or impacts on water environment.

  - Climate change impacts at local scale and seasonally.

  - Scale of water demand for HyNet is still uncertain, though we have tried to mitigate this risk through a ‘top-down’ demand estimate. There are a number of unknowns which make it challenging to estimate national or regional hydrogen production or CCS, and significant uncertainties which make it even more challenging to estimate water demand from these. The wide variability across those who have tried, and the significant uncertainty bands which sit around these estimates is testament to this fact.

  Research or further investigations are recommended to address these gaps.

- New data is available regularly – e.g. with the imminent publication of new CAMS, final WRMPs, final WRW Regional Plan, and submission of new planning applications for projects forming part of HyNet. Regular updates or a ‘live’ approach should be considered to make use of new data when available. Stakeholder engagement indicated that WRMP estimates of water availability are likely to change when the plan moves from draft to final, also impacting the final Regional Plan.

- The water availability assessment in this annex has not accounted for any impacts of water quality limitations to water abstraction. This is a common approach to water resources planning and management in the UK water industry and an acknowledged limitation. This limitation largely exists due to the lack of data and proven robust process of incorporation.

- English regional water resources groups such as WRW hold a good view of water availability in the region from the current state to the future (approx. 60 years) based on available data which will be refreshed at least every 5 years and which is more granular. Further consultation with applicable Regional Groups for industrial clusters would be beneficial for successful development of the hubs. Since, as previously mentioned, Regional Groups provide an overall assessment, combination of their regional view with the EA local team's views could be a good source of information for use in a centralised, strategic approach.

- The stakeholder engagement conducted through this annex raised questions around current policies surrounding water resources. It is suggested that these questions are reviewed by the EA, potentially in collaboration with Defra and Natural England where appropriate, to provide clarification and/or identify opportunities to update policies.

- The incorporation of non-public water supply requirements into assessment of Strategic Resource Options would be beneficial in ensuring sufficient water availability for HyNet without compromising the environment. The Regional Groups are relatively new and this incorporation may occur in the next round of planning. Similar development has been seen at regional groups formed before WRW, therefore this progression is expected to occur, particularly if the EA promotes this.

- Continue the collaborative, strategic approach to understanding and mitigating the effects of HyNet on the water environment. We recommend a centralised, strategic view of the hydrogen production and carbon capture network, working with the regional water resources groups to understand and establish the sustainable level of national and local hydrogen network with the water available.

6. References

Department for Energy Security and Net Zero; Department for Business, Energy & Industrial Strategy . (2018). *The UK carbon capture, usage and storage (CCUS) deployment pathway: an action plan .* UK Government: Policy Paper.

Agbonghae, E., Hughes, K., Ingham, D., & al., e. (2014). Optimal Process Design of Commercial-Scale Amine-Based CO2 Capture Plants. *Industrial and Engineering Chemistry Research, 53*(38), 14815-14829.

American Membrane Technology Association. (2016). *Membrane Desalination Power Usage Put in Perspective, .* AMTA.

Artesia Consulting. (2018). *The Long Term Potential for Deep Reductions in Household Water Demand.*

Artesia Consulting. (2018). *The potential role of NHH water use benchmarking in encouraging business water efficiency.*

Babcock & Wilcox. (n.d.). *Boiler Water and Steam Chemistry.* Retrieved 2023

CH2M. (2018). *Wirral Coastal Processes Report 2017.* Birmingham.

Chen, F. e. (2023). Capacity assessment and cost analysis of geologic storage of Hydrogen: A case study in Intermountain-West Region USA. *International Journal of Hydrogen Energy,, 48*(24), 9008-9022.

Climate Change Committee. (2020). *The Sixth Carbon Budget.* Committee on Climate Change: The UK's path to Net Zero.

Defra. (2021). *Climate change allowances for peak river flow in England*. Retrieved November 2023, from https://environment.data.gov.uk/hydrology/climate-change-allowances/river-flow

Defra. (2021, June). *North West Inshore and North West Offshore Marine Plan .* Retrieved November 2023, from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1004490/FINAL_North_West_Marine_Plan__1_.pdf

Defra. (2021, September). *River basin planning guidance.* Retrieved December 2023, from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1019774/River_basin_management_planning_ministerial_guidance.pdf

Defra. (2021). *Water abstraction plan.* Policy paper: Department for Environment, Food & Rural Affairs.

Defra. (2022). *Flood risk and coastal change*. Retrieved November 2023, from https://www.gov.uk/guidance/flood-risk-and-coastal-change

Defra. (2022). *Storm overflows discharge reduction plan .* Policy Paper: Department for the Environment, Food & Rural Affairs.

Department for Business, Energy & Industrial Strategy & Department for Energy Security & Net Zero. (2021). *Industrial decarbonisation strategy.* BEIS, DESNZ: Policy paper.

Department for Business, Energy & Industrial Strategy. (2021). *Hydrogen Analytical Annex.* UK Government: Analytical Annex to the Hydrogen Strategy, Net Zero Hydrogen Fund consultation, Low Carbon Hydrogen Business Model consultation, and Low Carbon Hydrogen Standards consultation.

Department for Communities & Local Governments. (2017, January). *Factsheet: Local Plans (clause 6 – 11) .* Retrieved December 2023, from https://assets.publishing.service.gov.uk/media/5a749f88ed915d0e8bf19cf8/Local_Development_Documents_policy_factsheet.pdf

Department for Energy Security & Net Zero. (2023). *2030 potential water demand for hydrogen production.* DESNZ: Private communication.

Department for Energy Security & Net Zero. (August 2023). *Hydrogen Strategy Update Update to the Markey.* UK Government: DESNZ.

Department for Energy Security & Net Zero; Department for Business, Energy & Industrial Strategy. (2021). *Industrial decarbonisation strategy.* Policy paper.

Department for Energy Security & Net Zero; Departmet for Business, Energy & Industrial Strategy. (2021). *Industrial decarbonisation strategy.* Policy paper.

Dŵr Cymru Welsh Water. (2019). *Draft Drought Plan 2020: Annex 1c - Alwen Dee WRZ.*

Dwr Cymru Welsh Water. (2019). *Ofwat Market Tables.* Retrieved March 24, 2024, from Dwr Cymru Welsh Water: https://www.dwrcymru.com/en/our-services/water/water-resources/ofwat-market-tables

Dwr Cymru Welsh Water. (2023). *Draft PR24 Business Plan.* Cardiff: DCWW.

Dŵr Cymru Welsh Water. (2023). *Revised Draft Water Resources Management Plan 2024.* Cardiff: DCWW.

Element Energy. (2022, October). *HICP Water Study.* Retrieved November 2023, from https://humberindustrialclusterplan.org/files/221208_HICP_Water_study_Final_report.pdf

Environment Agency. (2010, December). *Environmental Permitting Guidance Water Discharge Activities.* Retrieved December 2023, from https://assets.publishing.service.gov.uk/media/5a78afd940f0b632476995e7/pb13561-ep2010waterdischarge-101220.pdf

Environment Agency. (2013). *Lower Mersey and Alt abstraction licensing strategy.* Bristol: EA.

Environment Agency. (2013a). *Upper Mersey abstraction licensing strategy.* Bristol: EA.

Environment Agency. (2018). *Storm Overflow Assessment Framework.* Version 1.6: EA.

Environment Agency. (2020). *Meeting our future water needs: a national framework for water resources.* Policy Paper: EA.

Environment Agency. (2020a). *Weaver and Dane Abstraction Licensing.* Bristol: Environment Agency.

Environment Agency. (2021). *European site protected areas: challenges for the water environment*. Retrieved December 2023, from https://www.gov.uk/government/publications/european-site-protected-areas-challenges-for-the-water-environment

Environment Agency. (2021a). *Catchment Abstraction Management Strategy (CAMS) Reference boundaries.* Retrieved March 22, 2024, from https://www.data.gov.uk/dataset/e89f134c-f335-48e5-8d02-a1d467ce6996/catchment-abstraction-management-strategy-cams-reference-boundaries

Environment Agency. (2022, December). *North West River Basin District Flood Risk Management Plan 2021 to 2027.* Retrieved November 2023, from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1120229/North-West-FRMP-2021-2027.pdf

Environment Agency. (2022). *Notice of variation and consolidation with introductory note.* EPR/FP3139FN/V012: The Environmental Permitting (England & Wales) Regulations 2016.

Environment Agency. (2022). *River basin management plans: updated 2022*. Retrieved December 2023, from https://www.gov.uk/guidance/river-basin-management-plans-updated-2022

Environment Agency. (2023). *Catchment Partnership Pages*. Retrieved December 2023, from https://environment.data.gov.uk/catchment-planning/v/c3-plan/CatchmentPartnerships

Environment Agency. (2023). *Check if you need a licence to abstract water*. Retrieved January 2023, from https://www.gov.uk/guidance/check-if-you-need-a-licence-to-abstract-water#when-you-do-not-need-an-abstraction-licence

Environment Agency. (2023). *Measures data for England*. Retrieved December 2023, from https://environment.data.gov.uk/catchment-planning/v/c3-plan/England/measures

Environment Agency. (2023). *Monthly Water Situation Report: North West England (October 2023).* Environment Agency.

Environment Agency. (2023a). *Catchment Data Explorer: Mersey Estuary Operational Catchment*. Retrieved December 05, 2023, from https://environment.data.gov.uk/catchment-planning/OperationalCatchment/3306

Environment Agency. (2023b). *Catchment Data Explorer: Weaver Gowy Management Catchment*. Retrieved December 05, 2023, from https://environment.data.gov.uk/catchment-planning/ManagementCatchment/3111

Environment Agency. (2023c). *Permitting Decisions - Variation: EPR/FP3139FN/V013.* Environment Agency.

Environment Agency. (2024). *Groundwater Management Units coloured according to water resource availability colours.* Retrieved March 24, 2024, from Environment Angency - Data: https://www.data.gov.uk/dataset/54181453-b5bd-4694-96b2-a1b5d40985b5/groundwater-management-units-coloured-according-to-water-resource-availability-colours

Environment Agency. (2024). *Water Resource Availability and Abstraction Reliability Cycle 2.* Retrieved March 24, 2024, from Environment Angency - Data: https://www.data.gov.uk/dataset/b1f5c467-ed41-4e8f-89d7-f79a76645fd6/water-resource-availability-and-abstraction-reliability-cycle-2

Environment Agency. (December 2023). *Known Information on Water Demand at Hynet.*

Global CCS Institute. (2016, September). *Water Use in Thermal Power Plants Equipped with CO2 Capture Systems.* Retrieved November 2023, from https://www.globalccsinstitute.com/archive/hub/publications/200603/Water%20use%20in%20thermal%20power%20plants%20equipped%20with%20CO2%20capture%20systems.pdf

Greater Manchester CA. (2023, June). *Integrated Water Management Plan.* Retrieved December 2023, from https://www.greatermanchester-ca.gov.uk/media/8082/integrated-water-management-planv14.pdf

Griffiths, K., Shand, P., & Ingram, J. (2002). *Baseline Report Series: 2. The Permo-Triasic Sandstons of West Cheshire and the Wirral.*

Griffiths, K., Shand, P., & Ingram, J. (2003). *Baseline Report Series: 8. The Permo-Triassic Sandstones of Manchester and East Cheshire .*

Hafren Dyfrdwy. (2019). *Plan and Strategy: Market Information.* Retrieved March 24, 2024, from Hafren Dyfrdwy: https://www.hdcymru.co.uk/about-us/plan-and-strategy/water-resource-planning/market-information-tables/

Hafren Dyfrdwy. (2023). *Draft Water Resources Management Plan 2024.*

Hafren Dyfrydwy. (2023a). *Draft WRMP24: Appendix A Supply - How much water we have.*

Hannaford, J. (2016). *Working Technical Paper 2. Observed long-term changes in UK river flow patterns: a review.* Centre for Ecology & Hydrology: A climate change report card for water.

Herzog, R. a. (2016). Comment on ‘Reassessing the Efficiency Penalty from Carbon Capture in Coal-Fired Power Plants. *Environmental Science and Technology, 50*, 6112-6113.

HM Government. (2021). *UK Hydrogen Strategy.* CP 475: Secretary of State for Business, Energy & Industrial Strategy.

HR Wallingford. (2020). *Updated projections of future water availability for the third UK Climate Change Risk Assessment.* RT002: UKCRA, Committee on Climate Change.

HyNet North West. (2021, July). *HyNet North West Production Plant Environmental Permit Application Supporting Document.* Retrieved November 2023, from https://consult.environment-agency.gov.uk/psc/ch65-4hb-essar-oil-uk-limited/supporting_documents/Application%20Supporting%20Document%20%20Redacted.pdf

HyNet North West. (2021). *Phase 2 Report for BEIS, HyNet Low Carbon Hydrogen Plant.*

International Renewable Energy Agency. (2012). *Water Desalination Using Renewable Energy.* Technology Brief 112: IEA-ETSAP and IRENA.

Jackson, C., Mackay, J., & Bloomfield, J. (2016). *Working Technical Paper 4. Changes in groundwater levels in the UK over the 21st centrury: an assessment of evidence of impacts from climate change.* UKCRA: A climate change report card for water.

Joint Environmental Programme. (2021). *Projections of Water Use in Electricity and Hydrogen Production to 2050, under the 2020 Future Energy and CCC Scenarios - Regional Analysis.* ENV/677/2021: JEP.

Kovats, R. a. (2016). *UK Climate Change Risk Assessment Evidence Report: Chapter 5, People and the Built Environment.* London: Adaptation Sub-Committee of the Committee on Climate Chang.

Lemieux, A., Sharp, K., & Shkarupin, A. (2019). Preliminary assessment of underground hydrogen storage sites in Ontario, Canada. *International Journal of Hydrogen Energy, 44*(29), 15193-15204.

Living With Environmental Change. (2016). *Report Card 2016.* LWEC: Water Climate Change Impacts.

LWRC. (n.d.). *Wirral and West Cheshire Aquifer Study - Volume 1.*

Madden, L. D. (2013). Thermal effluent from the power sector: an analysis of once-through cooling system impacts on surface water temperature. *Environmental Research Letters*.

Madwar, T. (2003). Desalination techniques for industrial wastewater reuse. *Desalination, 152*(1-3), 325-332.

Mbaguta, O. (2021). *JEP21WT07 A Review Of Water Use For Hydrogen Production.* JEP: Joint Energy Programme.

Met Office Hadley Centre. (2018). *UKCP18 National Climate Projections.* Defra, BEIS: Crown Copyright.

Met Office. (n.d.). *Historic Station Data*. Retrieved 02 15, 2024, from https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data

Moss, B. (2011, July). Allied attack: climate change and eutrophication. *Inland Waters, 1*, 101–105. doi:10.5268/iw-1.2.359

National Academy of Engineering. (2004). *The Hydrogen Economy: Opportunities,Costs, Barriers, and R&D Needs.* Washington, DC: The National Academies Press. doi:https://doi.org/10.17226/10922.

National Grid ESO. (2020). *Future Energy Scenarios.* https://www.nationalgrideso.com/document/173821/download: nationalgridESO.

Natural Course. (2023). *Natural Course*. Retrieved December 2023, from https://naturalcourse.co.uk/

Natural England. (2004, May). *EC Directive 79/409 on the Conservation of Wild Birds.* Retrieved December 05, 2023, from https://publications.naturalengland.org.uk/publication/5790848037945344

Natural England. (2014, October 28). *Site Improvement Plan: Mersey Estuary (SIP138).* Retrieved December 05, 2023, from https://publications.naturalengland.org.uk/publication/6273450410770432

Natural England. (2014a, August 22). *European Site Conservation Objectives for Dee Estuary SPA (UK9013011).* Retrieved December 05, 2023, from https://publications.naturalengland.org.uk/publication/6557770283220992

Natural England. (2023). *Designated Sites View*. Retrieved December 05, 2023, from https://designatedsites.naturalengland.org.uk/SiteSearch.aspx

Natural Resources Wales. (2015). *Dee Catchment Abstraction Management Strategy.* Cardiff: NRW.

Nowak, E. B. (2016). Key Issues Related to Corrosion Protection of Brackish Water and Seawater Bearing Components in Cooling Water Systems. *Proceedings of the 15th International Conference on Environmental Degradation of Materials in Nuclear Power Systems—Water Reactors*, 2303-2319.

Office for National Statistics. (2023). *Local Planning Authorities (April 2022) UK BUC*. Retrieved December 2023, from https://geoportal.statistics.gov.uk/datasets/4bc5a98dda0c410b9f2f0caaed64b220/explore?location=53.277778%2C-2.631775%2C9.00

Ofwat. (2023). *Business plans*. Retrieved December 2023, from https://www.ofwat.gov.uk/regulated-companies/price-review/2024-price-review/business-plans/

Ofwat. (2023). *Water company performance report: 2022-23.* Ofwat.

Pidou, K. C., Jeffrey, P., Kuin, P., Valk, S. D., & Houwelingen, G. V. (2024). *Dual Pipe Water Recycling Systems and Risks to Water Quality.* Cranfield University. Retrieved March 24, 2024, from https://dwi-content.s3.eu-west-2.amazonaws.com/wp-content/uploads/2024/02/20160530/DWI70_2_346.pdf

Rajala, P. B.-S. (2016). Influence of chlorination and choice of materials on fouling in cooling water system under brackish seawater conditions. *Materials*, 9(6), p.475.

RPS Environmental Management Limited. (2013). *Impact of Climate Change on Water Demand.* Sub-Contractors: HR Wallingford Limited, WRc plc, Lancaster Environment Centre, Callidus : UKWIR.

Sayers, P. H.-R. (2020). *Third UK Climate Change Risk Assessment (CCRA3): Future flood risk.* London: Committee on Climate Change.

SEPA . (2013). *Review of Amine Emissions from Carbon.*

Severn Trent Water. (2019). *Water Resources Management Plan.* Retrieved March 24, 2024, from Severn Trent: https://www.severntrent.com/about-us/our-plans/water-resources-management-plan/

Severn Trent Water. (2023). *Draft Water Resources Management Plan 2024: Main Narrative.*

Severn Trent Water. (2023a). *Draft WRMP24: Appendix A - Supply - how much water do we have?*

Severn Trent Water. (2023b). *Draft WRMP24: Appendix G - Our Preferred Plan and Adaptive Pathway.*

Simões, S et al. (2021). Assessing water availability and use for electrolysis in Hydrogen production. doi:10.13140/RG.2.2.18531.27685.

Source magazine. (2023, 12 20). *Who saved the Mersey?* Retrieved from Mersey Basin.org: https://www.merseybasin.org.uk/archive/assets/176/original/Who_Saved_the_Mersey.pdf

UK Climate Change Committee. (2021). *Independent Assessment of UK Climate Risk*. Retrieved December 2023, from https://www.theccc.org.uk/publication/independent-assessment-of-uk-climate-risk/

UKCEH. (2023). *Enhanced Future Flows and Groundwater (eFLaG) Portal*. Retrieved 01 30, 2024, from https://eip.ceh.ac.uk/hydrology/eflag/

Uniper. (n.d.). *Connah's Quay Low Carbon Power*. Retrieved March 2023, from https://www.uniper.energy/connahs-quay-low-carbon-power

United Utilities. (2019). *Final Water Resources Management Plan 2019: Technical Report - Options identification.* Retrieved March 24, 2024, from https://www.unitedutilities.com/globalassets/z_corporate-site/about-us-pdfs/wrmp-2019---2045/final-wrmp19-technical-report---options-identification.pdf

United Utilities. (2019). *Water resources.* Retrieved March 24, 2024, from United Utilities: https://www.unitedutilities.com/corporate/about-us/our-future-plans/water-resources/

United Utilities. (2023). *Draft PR24 Business Plan.* Available at https://pr24.unitedutilities.com/: UU.

United Utilities. (2023). *Revised Draft Water Resources Management Plan 2024.* Main Report: UU.

United Utilities. (2023). *Revised Draft WRMP24 Technical Report - Demand for Water.*

United Utilities. (2023). *Revised Water Resources Management Plan 2024: Technical Report - Options Identification.* Retrieved March 24, 2024, from https://www.unitedutilities.com/globalassets/z_corporate-site/about-us-pdfs/wrmp24-drafts/revised-draft-wrmp24-technical-report----options-identification.pdf

United Utilities. (2023a). *Revised draft WRMP24: Technical Report - Supply Forecast.*

Wade, A. J., Whitehead, P. G., Hornberger, G. M., & Snook, D. L. (2002, January). On modelling the flow controls on macrophyte and epiphyte dynamics in a lowland permeable catchment: the River Kennet, southern England. *Science of The Total Environment, 282–283*, 375–393. doi:10.1016/s0048-9697(01)00925-1

Wang, T. C. (2022). PEM water electrolysis for Hydrogen production: fundamentals, advances, and prospects. . *Carb Neutrality, 21*, 1.

Water Industry Act 1991, c. 3. (1991). Retrieved 03 26, 2024, from https://library-guides.ucl.ac.uk/harvard/act-parliament

Water Resources West. (2022). *Draft Regional Plan: for consultation.*

Water Resources West. (2022a). *Appendix J: Non-PWS water needs and opportunities.* Retrieved March 23, 2024, from https://static1.squarespace.com/static/5e67889204d86850e1fdcece/t/6373e82c4330fd24062ac30d/1668540462324/Appendix+J+-+Non-PWS+planning+approach+v1.1.pdf

Water Resources West. (2022b). *Appendix H: Supporting Data Tables.* Retrieved March 23, 2024, from Draft Water Resources Wst Regional Plan documents: https://waterresourceswest.co.uk/s/Appendix-H-Supporting-data-tables-WRW-draft-plan-public-version.xlsm

Water Resources West. (2022c). *Appendix J: Non-PWS water needs and.* Retrieved March 23, 2024, from https://static1.squarespace.com/static/5e67889204d86850e1fdcece/t/6373e82c4330fd24062ac30d/1668540462324/Appendix+J+-+Non-PWS+planning+approach+v1.1.pdf

WaterSMART Solutions. (2020). *Water for the Hydrogen Economy.*

Watts, G., Battarbee, R. W., Bloomfield, J. P., Crossman, J., Daccache, A., Durance, I., . . . Wilby, R. L. (2015, February). Climate change and water in the UK – past changes and future prospects. *Progress in Physical Geography: Earth and Environment, 39*, 6–28. doi:10.1177/0309133314542957

Whitehead, P. G., Wilby, R. L., Butterfield, D., & Wade, A. J. (2006, July). Impacts of climate change on in-stream nitrogen in a lowland chalk stream: An appraisal of adaptation strategies. *Science of The Total Environment, 365*, 260–273. doi:10.1016/j.scitotenv.2006.02.040

Wirral Council. (2016, July). *Local Flood Risk Management Strategy 2016-2019.* Retrieved December 2023, from https://www.wirral.gov.uk/files/wirral-local-flood-risk-management-strategy.pdf/download?inline

WRc. (2024, 03 28). Environmental Capacity in HyNet Industrial Cluster. *Water – Evidence Baseline*. [Powerpoint Presentation provided to EA].

WRSE. (2023). *Revised Draft Regional Plan Water Resources South East.*

WSP. (2023). *Water Resources Management Plan: Water Framework Directive compliance assessment.* Retrieved March 24, 2024, from https://www.unitedutilities.com/globalassets/z_corporate-site/about-us-pdfs/wrmp24-drafts/revised-draft-wrmp24-wfd-redacted.pdf

Xiaoyi, L., Beysens, D., & Bourouina, T. (2022). Water Harvesting from Air: Current Passive Approaches and Outlook. *ACS Materials Letters*, 1003–1024.

Appendix A Estimating national and regional water demand from hydrogen and carbon capture

A1 Assumptions and supplementary data to JEP's regional estimates

A1.1 Climate scenarios

The following (italic text) is an extract from (Joint Environmental Programme, 2021) explaining the climate scenarios that were considered in JEP's modelling.

"FES21 are the four Future Energy Scenarios produced by National Grid ESO in 2021. Each of the four scenarios represents a credible pathway for the development of energy from today to 2050. No probabilities are attached to the scenarios.

1. *Two of the four FES20 (Consumer Transformation and System Transformation) are consistent with an achievement of net zero in 2050.*

2. *The other two illustrate a faster (Leading the Way) and a slower (Steady Progression) decarbonisation timescale. These are interpreted by NG-ESO as 'fastest' and the 'slowest credible decarbonisation' pathway and representative of those scenarios that do not meet the net zero target in 2050.*

The CCC20 scenarios […] consist of four explorative and a balanced scenario:

- *in the Headwinds (HW in the text & figures that follow) scenario: people change their behaviour and new technologies develop, but we do not see widespread behavioural shifts or innovations that significantly reduce the cost of green technologies ahead of our current projections. This scenario is more reliant on the use of large hydrogen and carbon capture and storage (CCS) infrastructure to achieve Net Zero.*

- *the Widespread Engagement (WE) scenario is more optimistic than Headwinds on developments regarding societal and behavioural changes (people and businesses are willing to make more changes to their* *behaviour). This reduces demand for the most high-carbon activities and increases the uptake of some climate mitigation measures.*

- *the Widespread Innovation (WI) scenario is more optimistic than Headwinds on developments regarding improvements in technology costs and performance (greater success in reducing costs of low-carbon technologies). This allows more widespread electrification, a more resource and energy efficient economy, and more cost-effective technologies to remove CO2 from the atmosphere.*

- *Tailwinds (TW), the last exploratory scenario, assumes instead that a considerable success on both innovation and societal/behavioural change can be achieved, and goes beyond the 'Balanced Net Zero Pathway' to achieve Net Zero before 2050.*

- *A fifth scenario the 'Balanced Net Zero Pathway' that reaches net zero by 2050 was then construed as a 'recommended pathway' being a scenario where progress is driven through the 2020s, while creating options in a way that seeks to keep the exploratory scenarios open. JEP modelled the four underlying scenarios. "*

A1.2 Modelling approach

This is done by ranking all available sites (in accordance with a prescribed set of rules) and sequentially selecting the top ranked plant until the generation capability prescribed by the energy scenario (used as input by the model) at the given time is reached.

The adopted rates depend on the (station-specific) cooling system (once-through, wet or hybrid towers or dry cooling) and are derived through 'random extraction' from probability distributions that are consistent with those derived by JEP on the basis of reported data, in recent years (Booth & Edwards, 2019) or from the literature.

Distribution of water uses sampled.

Maximum daily water uses are also estimated by the model, using the same rates, but in doing this:

− for each site where electricity is produced they are estimated under the assumption that (for the 24 hours of interest) the site will be running at its full capacity,

− for the sites where hydrogen is produced no difference is instead assumed to occur between daily maximum and daily averaged water uses as, contrary to electricity, hydrogen can provide potential long-term (seasonal) storage capabilities and, consequently, its production would not have to ramp up during short term stresses. Under this simplifying assumption, the daily maximum water uses are estimated by simply re-scaling the annual ones.

A1.3 Assumptions and limitations

The infrastructure development envisaged in Sunny (2020) would have more CCUS nodes inland and hence could allow more dispersed SMR production than is currently modelled under the assumption of JEP (2021) (where CCUS plant are constrained to be 'in the vicinity' of one of the industrial CCUS clusters presently identified by Government and located in coastal zones).

Alternative options for the 'deployment rules' (portraying alternative dynamics in future market and policy drivers) have been developed and implemented in the modelling reported by JEP (2021) who undertook an analysis of the sensitivity of the model to these assumptions. They found that for a range of seven rules which varied between favouring freshwater to favouring saltwater sites as well as changing the number of CCUS clusters that for GB as a whole there was a 60% difference in the freshwater consumption between the highest and lowest within a single scenario.

In the model, it has been assumed that a plant might be fitted with CCUS, in the future, if 'sufficiently close' to one of these five clusters (JEP 2021, Appendix B.3). As it is based on 'straight line' distance only, the rule strongly simplifies the likely operator actual decision process, which will be based on the pipeline infrastructure and the pipeline corridors needed to transport carbon to where it can be utilized and stored. It should therefore be regarded as illustrative only.

In the model, the H_2-producing plant is assumed:

− for electrolysis - to be spatially distributed (analogously to the electricity-generating plant),

− for SMR - to be located 'linked' to one of the CCUS industrial clusters, to allow, under a Net Zero future, the capture and storage of the carbon released in the hydrogen production process.

Appendix B Sector assignment

Table 0.1 Assigned sector for *Ds1*

Primary Description	Secondary Description	Use Description	Assigned Sector
Agriculture	All	All	Agriculture
Amenity	All	All	Other
Environmental	All	All	Environmental
Industrial, Commercial And Public Services	Chemicals	All	Chemicals
Industrial, Commercial And Public Services	Breweries/wine, Business parks, Construction, Dairies, Extractive, Machinery and electronics, Metal, Other industrial/commercial/public services, Petrochemicals, Refuse and Recycling, Rubber, Slaughtering, Textiles & leather	All	General Industry
Industrial, Commercial And Public Services	Food & drink	All	Food & Drink
Industrial, Commercial And Public Services	Mineral Products	All	Minerals
Industrial, Commercial And Public Services	Navigation	All	Navigation
Industrial, Commercial And Public Services	Paper And Printing	All	Paper & Pulp
Industrial, Commercial And Public Services	All other	All	Other
Production Of Energy	Electricity	Hydroelectric Power Generation	Hydropower
Production Of Energy	Electricity	All other	Power
Water Supply	Private Water Supply	All	Private Water Supply
Water Supply	Private Water Undertaking	All	Private Water Supply
Water Supply	Public Water Supply	All	Public Water Supply

Table 0.2 Assigned sector for *Ds2*

Primary Description	Assigned Sector
AGRICULTURE	Agriculture
AMENITYENVIRONMENTAL	Other
INDUSTRY	General Industry
OTHER	Other
OTHERPOTABLEUSES	Private Water Supply
POWERGENERATION	Power
PUBLICWATERSUPPLY	Public Water Supply