The Wye & Usk Foundation

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Tremeirchion Quantitative Groundwater Risk Assessment

The Wye & Usk Foundation

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For and on behalf of Wallingford HydroSolutions Ltd.

WHS

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Contents

1 Introduction

1.1 Terms of Reference

Wallingford HydroSolutions Ltd (WHS) has been commissioned by The Wye & Usk Foundation ('the client') to undertake a detailed groundwater risk assessment (GWRA) for the proposed Tremeirchion constructed wetland. The site is located at Tremeirchion, St Asaph, Denbighshire, LL17 0AY, Wales (XY 306863, 372591) (NGR SJ068725).

The client is supporting Dŵr Cymru Welsh Water with the planning application and design of the proposed constructed wetland to treat primary effluent (post-septic tank) from a Wastewater Treatment Works (WwTW). The wetland treatment system will provide secondary and tertiary treatment. The treated effluent will be subsequently discharged into the stream at the south-west corner of the site. Before implementation, Natural Resources Wales (NRW) has requested a groundwater risk assessment to assess risk of the development to groundwater resources and groundwater dependent receptors.

An initial site survey utilising auger drilling (down to 1.05m depth) identified Superficial Deposits (Glacial Till) comprising clay, sand and gravel. The Glacial Till is designated as Secondary (undifferentiated) and the bedrock (Kinnerton Sandstone Formation) as Principal Aquifer. It is a statutory requirement that measures are taken to protect groundwater from potential pollution sources.

The client requires a detailed groundwater risk assessment to evaluate the potential risks associated with the treated discharge into the proposed constructed wetland.

1.2 Client Aim

This document has been produced to support the Dŵr Cymru Welsh Water constructed wetland planning application for submission to local authorities and regulators. This is to include:

- development of an updated conceptual site model and review of any potential polluting substances released within the treated wastewater effluent;
- assessment of the risk to groundwater quality associated with the constructed wetland; and
- assessment of the measures to be implemented to control and mitigate risks associated with constructed wetland operation in relation to groundwater quality impacts.

1.3 Scope

The GWRA report includes a detailed quantitative groundwater risk assessment and assessment of the most appropriate measures to prevent groundwater pollution at the site during the operation phase of the project. It considers the scale and nature of the development in the context of water resources protection and the relevant guidance and legislation. In summary, this report:

- provides an updated site specific hydrogeological conceptual site model;
- identifies the relevant potential source pathway receptor linkages;
- quantifies the potential risk to groundwater; and
- provides appropriate mitigation measures to manage the potential risks to impact on groundwater quality based on best practice guidance.

1.4 Legislative Context and Guidance

The Water Framework Directive (2000/60/EC) (2000)

The Water Framework Directive (WFD) (European Parliament and of the Council, 2000) came into force in 2000. Its primary objective was for all groundwater, surface water and coastal water bodies to achieve 'good' status by 2015 and maintain this status. It includes broader ecological objectives as well as aiming to prevent the deterioration of all water bodies. The framework aims to develop sustainable water use and reduce and eliminate the presence of hazardous substances within water bodies. It must be considered in any development that has the potential to have an impact on any part of the water environment. WFD legislation is applied via The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017.

Groundwater Daughter Directive (2006/118/EC) (2006)

The Groundwater Daughter Directive (European Environment Agency, 2006) classifies groundwater bodies, establishes pollutant threshold values, and identifies trends and starting points for their reversal. Specific measures to control groundwater pollution are described, including good groundwater chemical status criteria and provisions to control groundwater pollutant inputs. The Directive provides further details on groundwater pollution control that are outlined within the WFD (2000/60/EC).

The Environmental Liability Directive (2004/35/EC) (2004)

Environmental Liability Directive (European Parliament and of the Council, 2004) relates to the prevention and remedying of environmental damage. The Directive refers to environmental damage to habitats and protected species, water damage (chemical and ecological) and land damage caused by land contamination. In this instance, damage is defined as "*a measurable adverse change in a natural resource or measurable impairment of a natural resource service which may occur directly or indirectly*". It also establishes a framework based on the 'polluter pays' principle to prevent and remedy environmental damage. Operators are therefore liable for the cost of prevention measures and remediation strategies.

Dangerous Substances Directive (2006/11/EC) (2006)

The Dangerous Substances Directive (European Parliament and of the Council, 2006) sets out the measures of pollution caused by certain dangerous substances discharged into the aquatic environment (inland surface water, territorial waters and internal coastal waters). As part of this Directive, List I and List II substances are described, whereby List I substances should be eradicated, and List II substances should be reduced.

Environmental Protection Act 1990: Part 2A - Contaminated Land Statutory Guidance (1990)

Part 2A of the Environmental Protection Act 1990 (Department for Environment Food and Rural Affairs, 1990) provides a means of dealing with unacceptable risks posed by land contamination to human health and the environment. Enforcing authorities are required to identify and deal with such land.

The Environment Act (2021)

The Environment Act (EA, 2021) makes provision with respect to water (surface and groundwater), waste and improvement of the environment. It provides a legal framework for environmental governance and for specific improvement of the environment, including measures on waste and resource efficiency, air quality and environmental recall, water, nature and biodiversity and nature conservation covenants.

The Water Act (2003)

The Act provides measures with regards to holding and issuing licences for water abstractions. The four broad aims of the Act are to ensure sustainable use of water resources, to strengthen the voice of consumers, to increase competition and to promote water conservation. This Act also considers controlled water pollution and coal mine water discharges and describes provisions for land drainage and flood defence. This was issued to amend the 1991 Water Resources Act (UK Parliament, 1991) and Water Industry Act (UK Parliament, 1991).

The Water Act (2014)

The aim of the Act was to reform the water industry to make it more innovative and responsive to customers and to increase the resilience of water supplies to natural hazards such as droughts and floods. The Act describes provisions for the following: abstraction water licence modifications, waterworks records, flood insurance for households, internal drainage boards, regulations for the water environment and Regional Flood and Coastal Committees.

The Water Resources Act (1991)

The Act gives the EA powers and duties to prevent or remedy the pollution of controlled waters. Previously under the Act and now under the Environmental Permitting (England and Wales) Regulations 2016 (as amended) it is a criminal offence for a person to cause or knowingly permit pollution of controlled waters. Sections within the Act refer to water resources management, pollution of water resources, flood defences, fishery controls, financial provisions, land and works powers and information provisions.

The Environmental Permitting (England and Wales) Regulations (2016) and The Environmental Permitting (England and Wales) (Amendment) (EU Exit) Regulations (2019)

The Regulations set out the measures for those carrying out activities that may cause imminent threats of, or actual 'environmental damage', which require a permit. These Regulations also outline the authorities responsible for enforcing the Regulations. Such Regulations cover environmental permits, discharge into regulated facilities, abstractions of groundwaters, enforcement and offences, public registers and powers/functions of the regulator and authority.

The Nitrate Pollution Prevention Regulations (2015)

The Regulations have the aim to protect designated surface and groundwater waterbodies from nitrate pollution from agricultural sources. Under the Nitrates Directive (91/676/EEC), the UK was required to identify 'polluted water' or water at risk of pollution if no controls were applied. The land draining into these areas and contributing to pollution is designated as a nitrate vulnerable zone (NVZ). Reviews are required every four years and NVZs are updated if grounds can be found to support this. The Environment Agency's role is to identify waters that are polluted by nitrates (through water quality monitoring and land use modelling) and designate land that drains to these waters and is contributing to the pollution of these waters.

National Resources Wales (NRW) Position Statement on Hazardous and Non-Hazardous Substances

Hazardous substances in Wales [and England] are regulated through the Environmental Permitting (England and Wales) Regulations 2016 in accordance with the WG/DEFRA Environmental permitting guidance for groundwater activities, and the approach outlined in GP3.

Natural Resources Wales (NRW) has published an updated list of hazardous substances on the JAGDAG (Joint Agencies Groundwater Directive Advisory Group) section of the UKTAG (UK Technical Advisory Group on the WFD) website[1].

"You must prevent hazardous substances from entering groundwater."

"You must limit non-hazardous pollutants from entering groundwater so that they do not cause pollution."

A non-hazardous pollutant is defined as 'any pollutant other than a hazardous substance'. Non-hazardous pollutants include ammonia (found in sewage) and nitrates. The Water Framework Directive (2000/60/EC) and Groundwater Daughter Directive (2006/118/EC) (GDD) require Member States to prevent inputs of hazardous substances into groundwater subject to various exemptions.

Online UK Government Guidance on Groundwater Protection and Risk Assessment

https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/692989/Envirnment-Agency-approach-to-groundwater-protection.pdf

https://www.gov.uk/guidance/groundwater-risk-assessment-for-your-environmental-permit

1.5 Sources of Information

The main sources used to inform the GWRA are listed below. Sources include public data and site-specific ground investigation and preliminary risk assessment reports.

Public Data

- NRW Surface Water Flood Mapping – to help determine surface water flow paths across the site[2].
- NRW Interactive Map Viewer – to identify groundwater aquifers and source protection zones[3].
- British Geological Society (BGS) Geology of Britain Viewer - to identify bedrock and superficial deposits[4].
- Landis Soilscapes Map - to identify soil types[5].
- Drawings of the proposed scheme provided by the client.
- Met Office weather data.
- Hydrogeology of Wales: Permo-Triassic and Jurassic aquifers – Vale of Clwyd[6].
- Data Map Wales[7].
- National Resources Wales, Interactive Map Viewer[8]

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[1] https://wfduk.org/resources/groundwater-hazardous-substances-standards
[2] NRW Surface Water Flood Maps (2024), https://datamap.gov.wales/maps/new#/
[3] NRW Interactive Map Viewer (2024) https://experience.arcgis.com/experience/dd852f0e12864928973e3e165a1b4631/
[4] BGS Geology of Britain Viewer (2022) https://mapapps.bgs.ac.uk/geologyofbritain/home.html
[5] Landis Soilscapes Map (2022) http://www.landis.org.uk/soilscapes/
[6]https://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Wales:_Permo-Triassic_and_Jurassic_aquifers_-_Vale_of_Clwyd
[7] DataMapWales, https://datamap.gov.wales/maps/new#/
[8] NRW Interactive Map Viewer, https://experience.arcgis.com/experience/dd852f0e12864928973e3e165a1b4631/page/English/?views=Home

Tremeirchion Site Specific Ground Investigation Reports

JBA Consulting (2022), Tremeirchion Groundwater Risk Assessment – Baseline Report.

Erice Wright Group (2024), Tremeirchion ICWT Wetland Trial – Geotechnical Survey Report.

SOCOTEC (2024), Tremeirchion Integrated Constructed Wetland Trial, Denbighshire – Ground Investigation Report (factual account of fieldwork and laboratory testing).

1.6 Report Structure

The report is structured to provide details on the publicly and site specific available hydrogeological and water quality baseline site conditions to support the development of the updated hydrogeological conceptual site model. The report then goes on to describe the groundwater risk assessment approach, the modelling results (without and with mitigation measures) and conclusions drawn from the exercise.

1.7 Limitations

WHS has prepared this report for the sole use of the Client in accordance with generally accepted consulting practices and for the intended purposes as stated in the agreement under which this work was completed. This report may not be relied upon by any other party without the explicit written agreement of WHS Limited. No other third-party warranty, expressed or implied, is made as to the professional advice included in this report. This report must be used in its entirety.

Information provided by third parties has been used in good faith to enable an assessment of the site condition. Whilst we have taken every effort to critically evaluate the data provided to us, WHS takes no responsibility for the quality of the work/data provided to us by any third parties on which our interpretation is based and our warrantee does not extend to the accuracy or completeness of third-party data.

2 Site Description

2.1 Site Location

The Tremeirchion WwTW and proposed constructed wetland are located at Tremeirchion, St Asaph, Denbighshire, LL17 0AY, Wales (XY 306863, 372591) (NGR SJ068725) (Figure 1).

2.2 Proposed Constructed Wetland

The proposed constructed wetland scheme will include:

- 3 integrated constructed wetlands (1650m^2 + 1575m^2+1350m^2);
- 2 septic tanks; and
- associated pipework, tanker access and footpaths.

Operating water depths of the wetland cells have been proposed as 0.2m. The layout of the wetland is confirmed to be in the field southwest of the existing WwTW, with the outfall being on the western boundary of the site, downstream of the current outfall point into the Nant Penisa Waun (local stream).

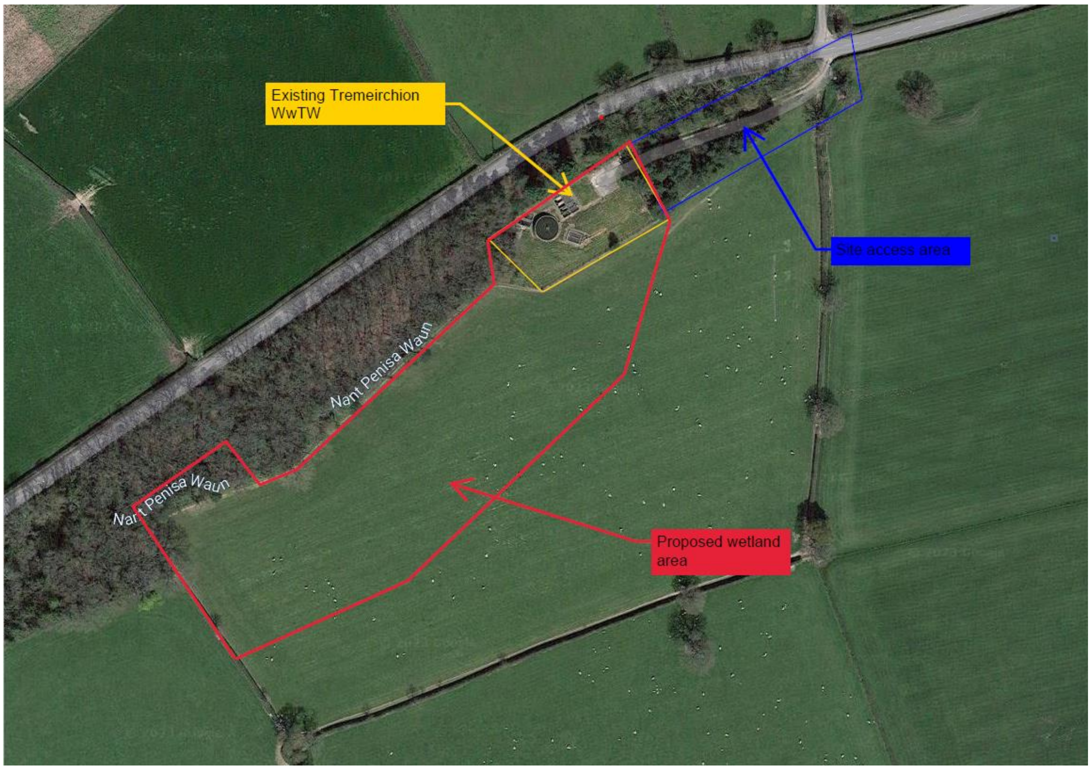


Figure 1 – Aerial image of the Tremeirchion WwTW (Google Maps) (taken from The Wye & Usk Specification for Ground Investigation 2024).

3 Environmental Setting

3.1 Topography

The site is situated on a broad, flat terrace above the floodplain. The ground elevation across the site slopes gently from north-east down to the south-west, with elevations ranging from approximately 39mAOD to 44mAOD. In the wider area ground levels generally dip towards the Afon Bach, which is situated to the west of the site and flows south.

The land of the proposed constructed wetland is currently used as grazing pastureland. Historic land use was identified as undeveloped and agricultural within the baseline assessment report (JBA, 2022).

3.2 Soils

Soil classification by the Soil Landscapes Online Viewer (DEFRA, 2022) has classified the site as containing impeded drainage, slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils.

The auger analysis of Wye and Usk Foundation (April 2022) found that the area is underlain by predominantly clay including 70-80% clay down to at least 1.05 mbgl. There is not a distinctive boundary between the topsoil and superficial deposits. However, it is interpreted that sandy/gravelly clay forms the upper part of the superficial till deposit.

3.3 Hydrology

The nearest watercourse to the site is Nant Penisar Waun which flows south-west past the site's western boundary and has a depth of approximately 0.5m from the bank top to bed (from 2m resolution LiDAR data). The stream is approximately 975m long, with a catchment area of 8.24 km². The watercourse meets the Afon Bach about 590m downstream of the site and is the main waterbody of the area. Afon Bach, which belongs to the Conwy and Clwyd Rivers Catchment, flows south and meets the Afon Clwyd about 450m to the south-west of site.

The WFD classification status of the Nant Penisar Waun overall is 'moderate', with ecology having a status of 'moderate' and chemical status classified as 'good' (2015 and 2018) (JBA 2022).

The WFD classification status (cycle 3) of the Afon Bach (GB110066066059950) overall is 'bad', with ecology having a status of 'bad' and chemical status classified as 'high' (2021 to 2024)[9].

Rainfall

The site has an annual average precipitation of 778mm/yr (GRID_ID AR-73), based on annual averages of precipitation amount (mm) for the 1991-2020 period from HadUK gridded data (v1.1.0.0), provided on a 12km British National Grid (BNG)[10].

At River Clwyd at Pont Dafydd (Station 066025), the historic catchment rainfall statistics are 675 to 700mm/yr; SAAR 1961-1990 rainfall map based on Met Office Standard Average Annual Rainfall[11].

3.4 Geology

Information on the geology of the site and surrounding area has been derived from 1:50,000 BGS mapping, BGS online borehole archive and the auger analysis carried out by the Wye and Usk Foundation (2022). The geology of the site is summarised in Table 1.

Superficial Deposits

The site is dominated by Glacial Till composed of clay, silt, sand and gravel. The nearest BGS borehole record (reference: SJ07SE2) from approximately 0.8km southeast of the site boundary indicates that superficial till deposits have a thickness of approximately 30m. BGS borehole data also indicate that the thickness of till varies between 11.5m approximately 2.37km to the north, and 28.3m approximately 2.28km to the south of the site.

Bedrock

The Kinnerton Formation comprises up to 150m thick, red-brown to yellow, generally pebble-free, fine to medium-grained and cross-stratified sandstone, and is part of the Triassic Sherwood Sandstone Group. At BGS borehole record SJ07SE2 the unit has a thickness of at least 70 m.

[9] https://waterwatchwales.naturalresourceswales.gov.uk/en/
[10] https://climatedataportal.metoffice.gov.uk/datasets/TheMetOffice::annual-precipitation-observations-1991-2020-12km/about
[11] https://nrfa.ceh.ac.uk/data/station/spatial/66025

Table 1 - Geology

Age	Lithostratigraphic Units	Formation	Aquifer Classification
Quaternary	Superficial Deposits.	**Diamicton Till (Glacial Till)** – Mixture of clay, silt, sand and gravel. Sedimentary superficial deposit formed between 116 and 11.8 thousand years ago during the Quaternary period	Secondary (undifferentiated)
Triassic	Bedrock	**Kinnerton Sandstone Formation** - red-brown to yellow sandstone, generally pebble-free, fine to medium-grained, cross-stratified. Dominantly aeolian. Sedimentary bedrock formed approximately 246 to 252 million years ago in the Triassic Period.	Principal Aquifer

3.5 Hydrogeology

The site is situated above the Triassic sandstone bedrock aquifer within the central part of the Clwyd catchment in north Wales. The catchment comprises some 800 km^2 and lies between the River Conwy to the south and the River Dee to the north and east. The sandstone aquifer is partly confined by overlying superficial deposits, causing artesian conditions in the centre of the southern basin. Confinement is not total, since leakage occurs elsewhere through the superficial deposits, which may be in hydraulic contact with some reaches of the river (Lambert et al., 1973[12]).

Superficial Deposits

Groundwater is present in most of the Quaternary deposits in Wales and is stored and transported in useable quantities where sand and gravel deposits are present (Robins and Davies, undated[13]).

The central valley floor in the Vale of Clwyd is covered in thick weakly permeable Glacial Till. Hydraulic conductivities vary by several orders of magnitude depending on clay content. Clay horizons that are larger than 5m in thickness tend to inhibit recharge to the underlaying bedrock aquifer.

The conceptual understanding is that superficial deposits are in hydraulic continuity with surface watercourses and contribute the majority of river baseflow, with a small contribution sourced from upward leakage from the sandstone.

Bedrock Aquifer

The Triassic sandstone bedrock aquifer, underlying the superficial deposits, is designated as a Principal Aquifer. There are three abstraction licences within 2km of the site, for three boreholes located 1.2km south-west of the site (Figure 4). These boreholes abstract from the Kinnerton Sandstone Formation and are known as the Llannerch Park public supply boreholes. They have a collective abstraction licence of 3400 Ml a^{-1}. At Afon Clwyd to the south-west of Llannerch Park are

[12] Lambert, A O, English, K B, Skinner, A, Fleet, M, and Wilkinson, W B. 1973. *Groundwater resources of the Vale of Clwyd*. *Water Resources Board, Reading*, Publication No. 20.
[13] N.S. Robins and J. Davies (undated), Hydrogeology of Wales: Permo-Triassic and Jurassic aquifers – Vale of Clwyd.(https://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Wales:_Permo-Triassic_and_Jurassic_aquifers_-_Vale_of_Clwyd)

five river augmentation boreholes with a collective licence of 2290 Ml a^{-1}, and these are used seasonally as required.

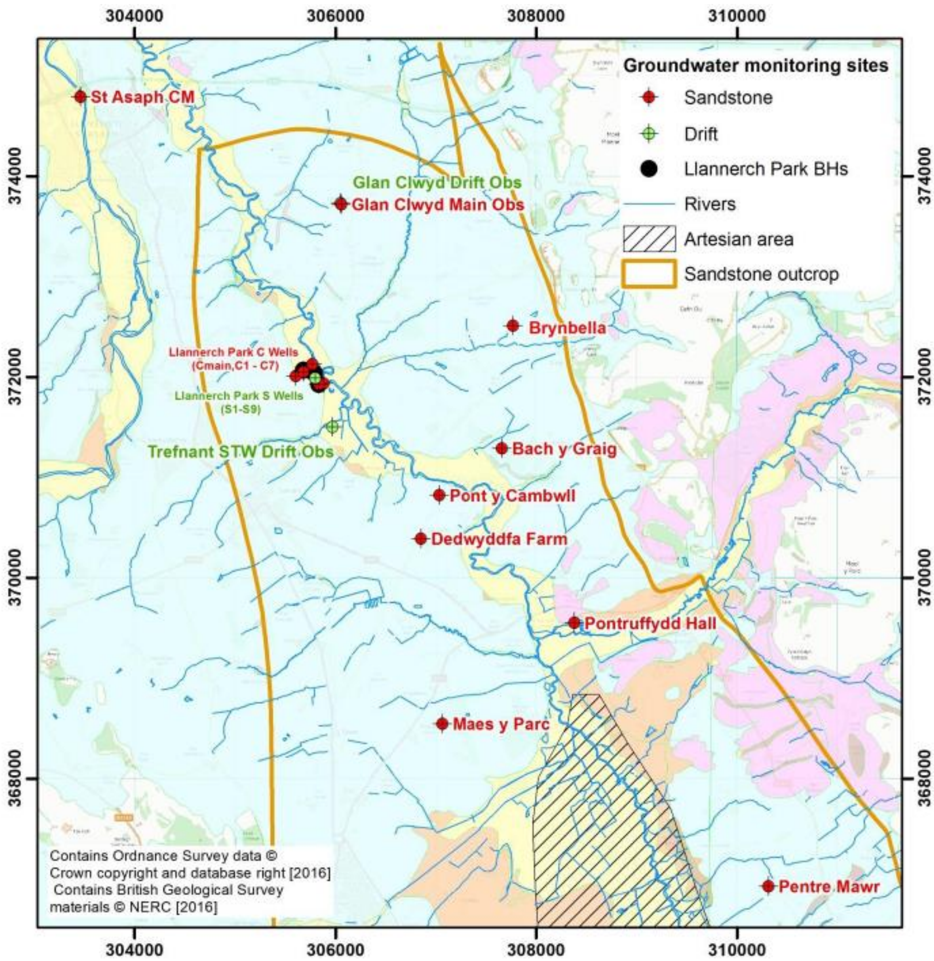


Figure 2 – Location of key Sandstone and Superficial Deposits observation boreholes in the southern sandstone block of the Vale of Clwyd[14].

Based on pump test data, the mean transmissivity is 130 m^2 d^{-1}, but values range from 20 to 1200 m^2 d^{-1} depending on the degree of fracturing penetrated in each borehole. These values equate to bulk hydraulic conductivities of 0.17 m d^{-1} to 20 m d^{-1} with a mean value of 2.4 m d^{-1}. Core porosity data range between 19 to 31%, with a mean of 23.6%. Storage coefficients calculated from six pumping tests range from 1×10^{-4} to 2×10^{-3} with a mean of 3.8×10^{-4}. The higher values reflect seepage from the weakly to moderately permeable superficial strata that overlie the sandstones (Lambert et al., 1973).

Typical groundwater levels in the sandstone around Llannerch are interpolated to range between 10 and 20mAOD (based on the Triassic sandstone GW contour map for the Vale of Clwyd[13]). At monitoring well Brynbella (ref. borehole SJ07SE2), located about 0.8km to the southeast and close

[14] Ricardo Energy & Environment (2019), Environmental Assessment of Llannerch Borehole Drought Permit (8012-5).

to site, groundwater levels have been observed to range between 16.5 and 17.8mAOD (1994 to 2007)[14]. With Glacial Till recorded down to 12mAOD, these water heads represent potentiometric levels and confirm that the sandstone aquifer is confined in this area. Water levels in the shallow Glacial Till are largely unknown; the conceptual understanding is that water levels in the Glacial Till are above sandstone water heads resulting in vertical hydraulic gradient directed downwards. In the south-central part of the Vale of Clwyd the sandstone aquifer is artesian. Here vertical hydraulic gradients through the Glacial Till are directed upwards. In the immediate vicinity of Llannerch (within 200m of the abstraction wells), the 'natural' hydraulic gradient between the bedrock and the superficial deposits hydro stratigraphic units is reversed as a result of abstractions (Figure 3).

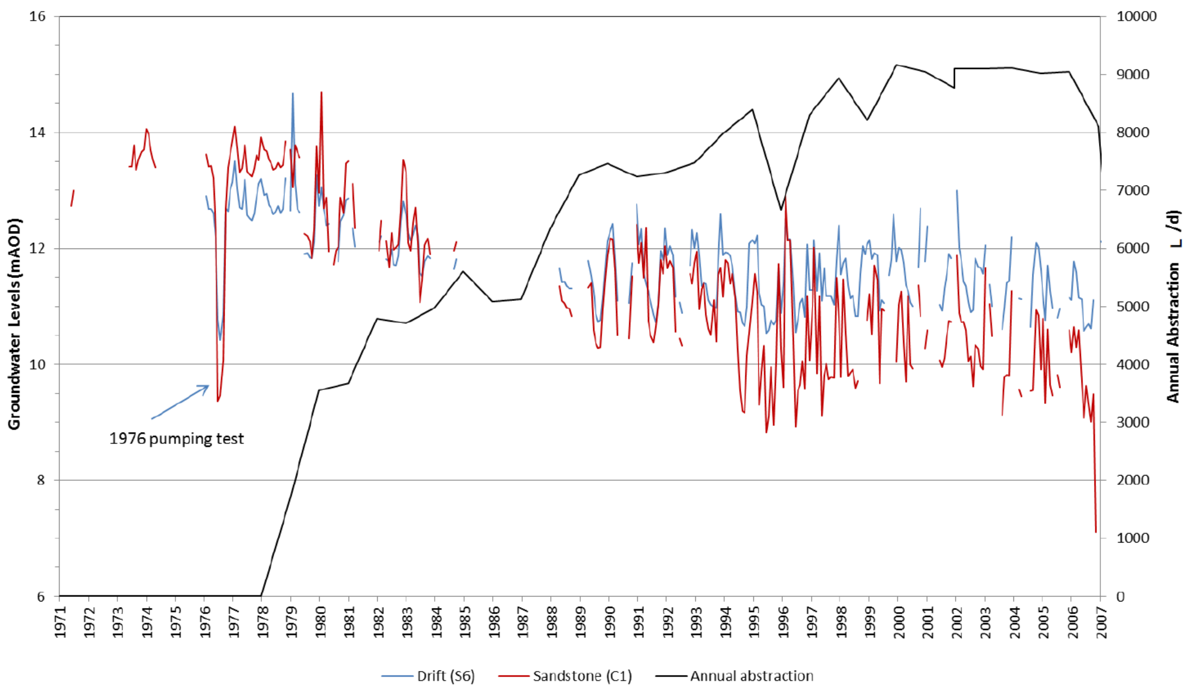


Figure 3 – Comparison of Drift and Sandstone Groudnwater Levels at Llannerch.[14]

The Tremeirchion site is within Source Protection Zone 2 for the Llannerch Park public supply wells (Figure 4).

The WFD classification status (cycle 3) of the Clwyd Permo-Triassic Sandstone groundwater body (GB41001G202100) overall is 'good', with groundwater quantity, abstraction and chemical status all good (2021 to 2024)[9].

3.6 Designated Sites

There is one Site of Specific Scientific Interest (SSSI) within 2km of the site (1.5km east), called "Ffynnon-Beuno and Cae-Gwyn Caves". These caves are the best sites in Clwyd (0.5km south of Tremeirchion) to encompass important palaeontological deposits and also to provide ideal conditions for the hibernation of bats.

There are no Special Areas of Conservation (SAC) or Special Protection Areas (SPA) within 2km of the site boundary.

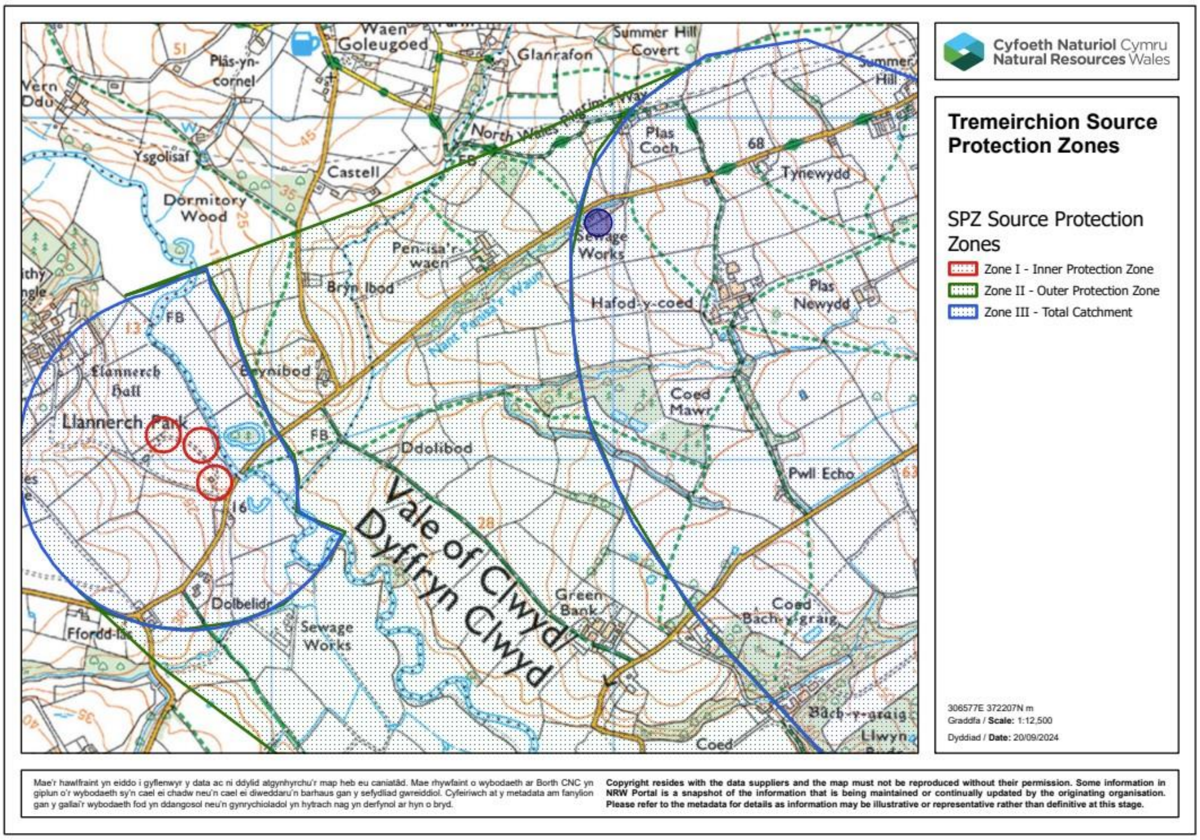


Figure 4 – Llannerch Park public water supply wells and associated Source Protection Zones.

3.7 Tremeirchion Geotechnical Survey Report (Eric Wright Group, 2024) and Ground Investigation Report (SOCPTEC, 2024)

To confirm ground conditions to support the design of foundations, facilitate the design of liners for the wetlands, and perform nutrient test analysis, a number of in-situ soil permeability tests as well as soil samples were collected for laboratory triaxial permeability tests, particle size and composition analysis. In addition, five cable percussion boreholes, two exploratory boreholes down to 10m depth and three boreholes down to 5m depth (for piezometer installation purpose), were completed.

Trial pits excavated down to about 2.0m depth and the six soil samples (0.5 to 2.0mbgl) taken for particle size distribution analysis confirm stiff clay ground conditions across the site (Table 2).

Soil permeability assessed through laboratory falling head tests using the flexible wall permeability methodology within a triaxial cell resulted in vertical permeability ranging between 2.88E-10 and 4.34E-11m/s (Table 3). The results correlate with low permeable, clay-rich ground conditions.

In-situ soil infiltration rates were interpolated from trial pit permeability tests (after BRE) where an excavation of known dimensions is filled with water and changes in water levels are observed over time. The observed changes in water level within three trial pits across the site were very small with just 1 to 5cm water level drop over the total 19-to-24-hour observation time, with less than 5% of the water volume drained. All three tests were therefore incomplete, and the interpolated soil infiltration rates need to be viewed with caution (Table 4).

In the five boreholes down to 5 and 10mbgl no water strikes or groundwater was encountered (June 2024). The Glacial Till is described as stiff brown sandy slightly gravelly CLAY.

Table 2 – Soil Particle Size Distribution Analysis

Trial Pit	Depth (mbgl)	Particle Size Distribution (%)				Soil Description
		Gravel	Sand	Silt	Clay	
TH01	0.5-0.9	2	16	32	50	CLAY, silty, sandy
TH01	1.5-2.0	3	14	40	43	CLAY, silty, sandy
TH02	0.5-1.0	2	13	39	46	CLAY, silty, sandy
TH02	1.5-2.0	2	10	39	50	CLAY, silty, sandy
TH03	0.7-1.0	2	10	46	43	CLAY, silty, sandy
TH03	1.4-1.8	2	12	43	43	CLAY, silty, sandy

Table 3 - Flexible Wall Permeability (Triaxial Cell) Test Results

Trial Pit	Sample Depth (mbgl)	Permeability (m/s)
TH01	0.5-0.9	4.62E-11
TH01	1.4-1.8	2.88E-10
TH02	0.5-1.0	1.12E-10
TH02	1.5-2.0	4.34E-11
TH03	0.7-1.0	6.40E-11
TH03	1.4-1.8	2.66E-10

Table 4 - Soil Infiltration Rates (BRE365)

Trial Pit	WHS review Soil Infiltration Rate		Johnson Jones Soil Infiltration Rate	
	(m/s)	(m/d)	(m/s)	(m/d)
TP4 (next to TP1)	1.17E-07	1.01E-02	1.67E-07	1.44E-02
TP5 (next to TP2)	2.99E-07	2.58E-02	6.67E-08	5.76E-03
TP6 (next to TP3)	6.37E-08	5.51E-03	1.67E-08	1.44E-03
Average	1.60E-07	1.38E-02	8.33E-08	7.20E-03

Piezometer Readings

Shallow perched water levels are encountered across the site within the three monitoring well installations during the wet season. Flooding might indicate that P3 well installation is in direct hydraulic continuity with the ground surface (Table 5).

Table 5 – Tremeirchion Water Level Data

Date	P1	P2	P3
23/09/2024	0.474mbgl (43.426mAOD)	3.624mbgl (37.006mAOD)	1.07mbgl (39.79mAOD)
01/10/2024	0.38mbgl (43.52mAOD)	3.41mbgl (37.22mAOD)	Flooded (40.86mAOD)

4 Hydrogeological Conceptual Site Model

Local Ground Model

Topographic levels range from 39 to 44mAOD at the site, located adjacent to the watercourse Nant Penisa Waun, and slopes from northeast to southwest. Based on BGS borehole records, the site is situated above an approximate 30m thick, low permeable Glacial Till. Site specific exploratory boreholes confirm Glacial Till down to 10mbgl. This stratum is described as brown, stiff, silty, gravelly CLAY or silty, sandy CLAY; and this is confirmed through soil samples and particle size distribution analysis taken from the top 2m.

Depth of the Triassic bedrock sandstone aquifer has not been confirmed during local ground investigations. The interface is inferred at about 10mAOD (Figure 5). The Kinnerton Sandstone Formation is a red-brown to yellow sandstone, generally pebble-free, fine to medium-grained, and cross-stratified.

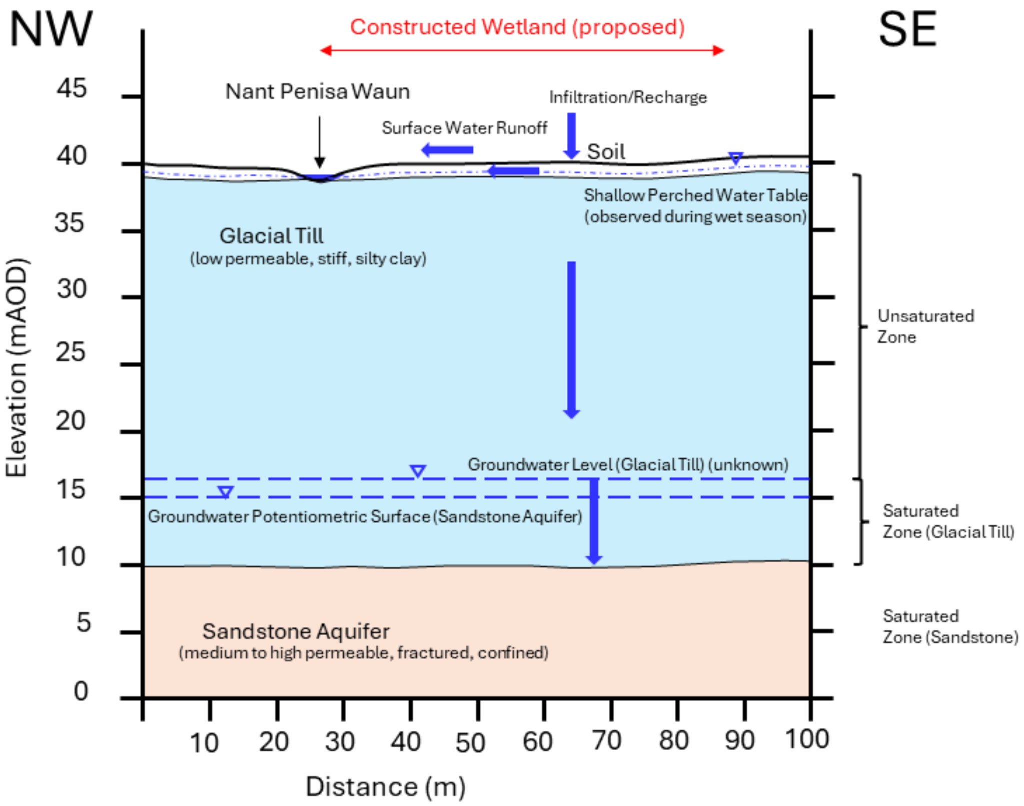


Figure 5 – Conceptual hydrogeological cross section through the central part of the proposed constructed wetland at Tremeirchion WwTW.

Infiltration and recharge through the Superficial Deposits is limited due to the overall low to medium permeable soils and Glacial Till covering the site. Surface watercourses receive water dominantly from surface water runoff and lateral interflow out of the Glacial Till. During the wet season a shallow perched water level is observed. Water percolates through the dominantly unsaturated Glacial Till into the deeper saturated zone. The Glacial Till confines the Sandstone Aquifer, and groundwater levels in the basal Glacial Till are observed in regional monitoring wells to be close to the groundwater potentiometric surface of the Sandstone Aquifer (Figure 5). Groundwater movement within this

Principal Aquifer is from south to north within the River Clywd catchment. Intergranular matrix flow and fracture flow occur.

4.1 Potential Source Pathway Receptor Linkages

In the context of current industry best practice (UK CIRIA report C552[15]), the results of the baseline assessment were reviewed on a qualitative basis, using a "Source-Pathway-Receptor" (SPR) assessment approach. Pollutant linkages (i.e. the relationships between a potential pollutant source, the migration or exposure pathway linking potential pollutants to a receptor) are required for a risk to a receptor to be present.

4.2 Sources

Sewage discharge moving through the constructed wetland system has been identified as the single potential pollutant source. The primary effluent contains potentially hazardous and non-hazardous substances, which are released to ground through the wetland.

Flow Rates

The Tremeirchion WwTW is a small plant (PE 248) that receives domestic sewage, as well as surface water runoff from roads and from agricultural land (rural area). The WwTW does not receive any industrial discharges. The actual average discharge flow rate from the WwTW (monitored between November 2022 and September 2024) is 88m³/d (Table 6).

Table 6 – Theoretical and actual Tremeirchion WwTW discharge flow rates

	Flow Rate	Comments
DWF	52 m^3/d	Theoretical
Theoretical flow	37.2 m^3/d	Theoretical (150l*PE)
Average flow	88 m^3/d	Actual
Average summer flow	87 m^3/d	Actual
Average winter flow	89 m^3/d	Actual
Peak instantaneous flow	2.96 l/s	Actual

Notes:
Actual flow is based on WwTW monitoring data Nov22 to Sep24.
Theoretical flow is based on 248 people equivalent (PE) and 150L water usage per person.

Nutrient Loads

The Tremeirchion WwTW annual average discharge nutrient loads are 30.2mg/l ammoniacal nitrogen as N (AmmN) and 6.5mg/l total phosphorous (TP) (Table 7). These are crude influent water quality values not treated final WwTW discharge.

Table 7 – Tremeirchion WwTW discharge nutrient loads.

	BOD (mg/l)	AmmN (mg/l)	SS (mg/l)	TP (mg/l)
Annual average	169.6	30.2	211.6	6.5
Summer average	170.2	31.5	197.7	6.4
Winter average	173.1	30.7	243.8	6.6

Notes: Based on Tremeirchion WwTW monitoring data Mar21 to Dec23.

[15] D J Rudland, R M Lancefield, and P N Mayell, 2001, Contaminated Land Risk Assessment. A guide to good practice (CIRIA 552).

Hazardous and Non-Hazardous Substances

Tremeirchion WwTW sewage (crude inlet) has been sampled (27/09/2024) and analysed for a basic contaminated water suite plus PFAS to derive potential contaminants of concern (PCoC). The wastewater analytical suite included Total Phenols, Metals, Pesticides, PAHs, VOCs, BTEX, THP CWG, PFOS and PFAS. The laboratory results are presented in Appendix 1. Analytical methodologies and associated Limit of Detection (LOD) allow for screening the data against relevant UK Drinking Water Standards[16] with the exception of three pesticides (Aldin, Heptachlor and Dieldrin). These three pesticides have a UK DWS of 0.03ug/l, below the 0.1ug/l reported LOD.

A small number of determinands were detected above LOD, and these are copper, zinc, fluoranthene, aromatic petroleum hydrocarbon bands between C8 and C35, aliphatic C22-C35, and PFAS compounds. Detections are below relevant UK DWS.

Derived Ammonium concentrations are significantly above the UK DWS. Ammonium is an indicator parameter. Depending on redox conditions in the subsurface, Ammonium might be converted to Nitrite and Nitrate during fate and transport.

Risk Drivers

Following the Tier 1 risk assessment (data screening) against relevant water quality standards, the identified PCoC is Ammoniacal Nitrogen as N (AmmN) (converted to Ammonium). PFAS is detected below the relevant DWI drinking water Tier 2 action value.

Table 8 -Tremeirchion WwTW effluent pollutants and relevant UK water quality standards.

	Wastewater Source (mg/l)	UK DWS[16] (mg/l)	UK EQS (mg/l)	UKTAG[17] (mg/l)
Ammonium ($NH4^+$)	38.8	0.5	-	-
Ammoniacal Nitrogen as N (AmmN)	30.2	-	0.2 (high)* 0.3 (good) 0.75 (moderate) 1.1 (poor)	-
Fluoranthene	0.00001	-	0.0000063**	-
PFAS (sum of 49)	0.00003608	0.0001***	-	0.001****

Notes:

* The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015. Total Ammonia (as N) standard for river and lakes, based on surface water body type.

** Fluoranthene annual average UK EQS; not a drinking water standard.

*** Drinking Water Inspectorate (DWI) Guidance specific to PFAS in drinking water (2024). Tier 2 action value. www.dwi.gov.uk

**** PFOS annual mean

4.3 Pathways

Groundwater is present below the site within the Superficial Deposits and within the Kinnerton Sandstone Formation. There is likely some lateral hydraulic connectivity between Nant Penisar Waun

[16] The Water Supply (Water Quality) Regulations (England and Wales) 2016
[17] UK Technical Advisory Group on the Water Framework Directive 2016 – Technical report on Groundwater Hazardous Substances.

and shallow perched groundwater within the topsoil and Superficial Deposits. This interaction may be minimal, but it depends on the local permeability of the Glacial Till in close proximity to the river channel and seasonal variability.

Pollutants released at site have the potential to infiltrate through the ground surface and migrate through the unsaturated zone of the Glacial Till into groundwater. BRE infiltration tests (although incomplete) confirmed that the vertical infiltration pathways through the Glacial Till is considered to be significant.

Dissolved pollutants that have reached the groundwater zone have the potential to migrate laterally within the Sandstone bedrock aquifer, and discharge through groundwater baseflow contribution into nearby watercourses.

The Sandstone Aquifer is a high permeability, dual porosity aquifer with flow through the porous matrix as well as the fracture network. Lateral groundwater flow is generally in a northern direction; however, flow direction is impacted locally by water abstractions.

4.4 Receptors

The following potential receptors are identified:

Nant Pensar Waun – shallow surface watercourse adjacent to site.

Glacial Till – generally low to moderate permeable sandy clay deposits may contain locally higher permeable sand and gravel layers (or lenses). Classified as Secondary Undifferentiated Aquifer.

Kinnerton Sandstone Formation – high permeability sandstone aquifer. Classified as Principal Aquifer.

Llannerch Park public supply wells – abstractions are located about 1.2km south-west of the site and abstract water from the Kinnerton Sandstone Formation.

4.5 Preliminary Qualitative Water Quality Risk Assessment

Table 9 summarises plausible Controlled Waters source pathway receptor linkages and provides a qualitative risk level based on severity and probability (UK CIRIA 552). Plausible pollutant linkages with risk levels low/moderate or higher are considered to require further assessment. Risk descriptors are detailed in Appendix 2.

Table 9 – Risk Matrix with Plausible Source – Pathway – Receptor Linkages

Source	Pathway	Receptor	Risk Level (CIRIA 552)	Comment
Tremeirchion WwTW Operation				
Effluent Discharge into Constructed Wetland (i.e. release of dissolved-phase contaminants to ground, including nutrients, low concentrations of petroleum	Leachate into groundwater (vertical migration into shallow perched groundwater in the superficial deposits)	Groundwater beneath the site (Superficial Deposits)	Low risk	***(Severity - Mild, Probability - Low Likelihood).*** Receptor is the Glacial Till (Secondary Undifferentiated Aquifer). The low to medium permeable Glacial Till is composed of sandy or silty CLAY. Shallow perched groundwater is limited to the wet season. The water is not utilised, however provides baseflow to the local watercourse adjacent to site.

Source	Pathway	Receptor	Risk Level (CIRIA 552)	Comment
hydrocarbons, PAHs, metals, and persistent organic pollutants (POP))	Leachate into groundwater (vertical migration through the superficial deposits and recharge into bedrock aquifer)	Groundwater beneath the site (Kinnerton Sandstone Formation)	Moderate/ low risk	***(Severity - Medium, Probability - Low Likelihood).*** Receptor is the Kinnerton Sandstone Formation (Principal Aquifer). The bedrock aquifer is protected by about 20 to 30m thick, low to medium permeable Glacial Till composed of sandy or silty CLAY. The aquifer is locally utilised for public water supply, farming and domestic use. The site is located within a public water supply SPZ2.
	Vertical migration through the superficial deposits into the bedrock aquifer, followed by lateral groundwater migration	Llannerch Park public supply wells (Kinnerton Sandstone Formation)	Low risk	***(Severity - Medium, Probability - Unlikely).*** Receptors are the Llannerch Park public supply wells, which abstract groundwater from the Kinnerton Sandstone Formation (licenced groundwater abstraction within 1,200m). Based on the distance it is unlikely that the water quality would be impacted due to dilution and plume travel distance within the Kinnerton Sandstone Formation.
	Lateral groundwater migration within Superficial Deposits, and discharge to surface watercourse (baseflow contribution)	Nant Pensar Waun	Low risk	***(Severity - Mild, Probability - Low Likelihood).*** Receptor is a local shallow watercourse. Severity is mild due to pollution of non-sensitive watercourse. The pathway might be limited to the wet season.

4.6 Summary

Pollutant linkages (Table 9) have been identified within the CSM that are considered to represent a potential risk to controlled waters. The pollutant linkage with the highest risk (medium/low risk) is associated with dissolved-phase contaminants released to ground through WwTW effluent discharge into a Constructed Wetland. The key potential contaminant of concern (PCoC) to groundwater is Ammoniacal Nitrogen (as N) (or as Ammonium).

5 Detailed Quantitative Groundwater Risk Assessment

5.1 Model Selection

The controlled waters Detailed Quantitative Risk Assessment (DQRA) has been undertaken in accordance with United Kingdom's Environment Agency methodology (Remedial Targets Methodology, 2006) using regulatory (NRW, Environment Agency, SEPA) endorsed ConSim risk assessment software (Golder Associates, Version 2.5).

Model tool selection is based on ConSim's ability to simulate fate and transport processes through the unsaturated and saturated zone. The unsaturated zone can be composed of multiple layers, allowing the assessment of layers with different physical properties. In addition, cumulative discharges to ground can be delineated as a single polygon source area. Alternatively, multiple discrete source locations can be defined; however, the definition of multiple source locations is limited to a small number and requires significant computational time.

The ConSim DQRA model simulates risks from the transport of contaminants discharged to ground, leaking into and migrating through the unsaturated zone, mixing with groundwater at the unsaturated/saturated interface, and traveling within the aquifer toward identified receptors. The software utilises probabilistic calculations and iterations, therefore allowing for the adoption of a distribution of input values for model parameters. The results are probabilistic in that they assess a range of permutations which more likely reflect the inherent uncertainty associated with a number of the numerical model input parameter values.

Simplifying model assumptions include:

- homogeneous & isotropic transport zones;
- laminar flow, in one direction only with constant velocity;
- no diffusion other than that specifically included;
- constant contaminant and geosphere properties, both those defined and those implicitly assumed (such as water viscosity, temperature, density etc.); and
- sorption approximated by a linear isotherm; desorption can be approximated by a linear isotherm and no geochemical or other processes are restricting this release.

5.2 Model Domain and Conceptualisation

A 'Level 2' (ConSim terminology) model was constructed to calculate the risks to controlled waters from contaminants identified as source concentrations within the Tremeirchion WwTW effluent. The numerical groundwater model will evaluate the migration of these contaminants through the Glacial Till below site and provide an indication whether effluent discharge to ground (into constructed wetland) could present a significant risk to groundwater in the sandstone aquifer.

Model 1 represents natural ground conditions at site with the point of compliance (POC) set at the base of the unsaturated zone, near the base of the Glacial Till / Sandstone interface. Shallow perched groundwater is not represented in the model domain.

Model 2 represents the constructed wetland with a 0.5m low permeable clay liner installed. POCs are set at the base of the clay liner and at the base of the unsaturated zone.

5.3 Active Processes and Simulations

Physical and biological processes occur naturally within groundwater systems. It is considered likely that soil water interaction is taking place, and contaminants are retarded within the unsaturated zone through partitioning (e.g. sorption). Biodegradation has not been activated; providing conservatism in the model.

The models were run using Monte Carlo analysis at 10,000 iterations with a maximum time slice of 1,000 years in Model 1 and 7,000 years in Model 2.

5.4 Model Input Parameters

Appendix 3 details the input parameters of the numerical groundwater model (Model 1 and Model 2).

5.5 Model 1 Results

Groundwater impact is assessed based on the 95th percentile not exceeding the target (giving 95% confidence that the Ammonium concentrations will be lower). This conservative approach provides assurance that the probability of exceeding the target concentration of 0.5mg/L Ammonium at the POC is very low.

The time history chart is most useful for assessing the breakthrough times of the compound of concern at the POC. Time history plots show the predicted contaminant concentrations against time for selected uncertainty levels (probabilities). In summary:

- Ammonium is simulated to exceed the target concentration of 0.5mg/L at the Glacial Till/Sandstone Aquifer interface within the 150 year time-slice (Figure 6 and Table 1010). Breakthrough is approximated with 107 years (based on the 5th percentile retarded travel time).
- Model simulations predict a potentially unacceptable long-term risk to groundwater quality in the Sandstone Aquifer.

Figure 6 – Model 1 predicted contaminant concentrations against time for selected uncertainty levels (probabilities) at the base of the unsaturated zone.

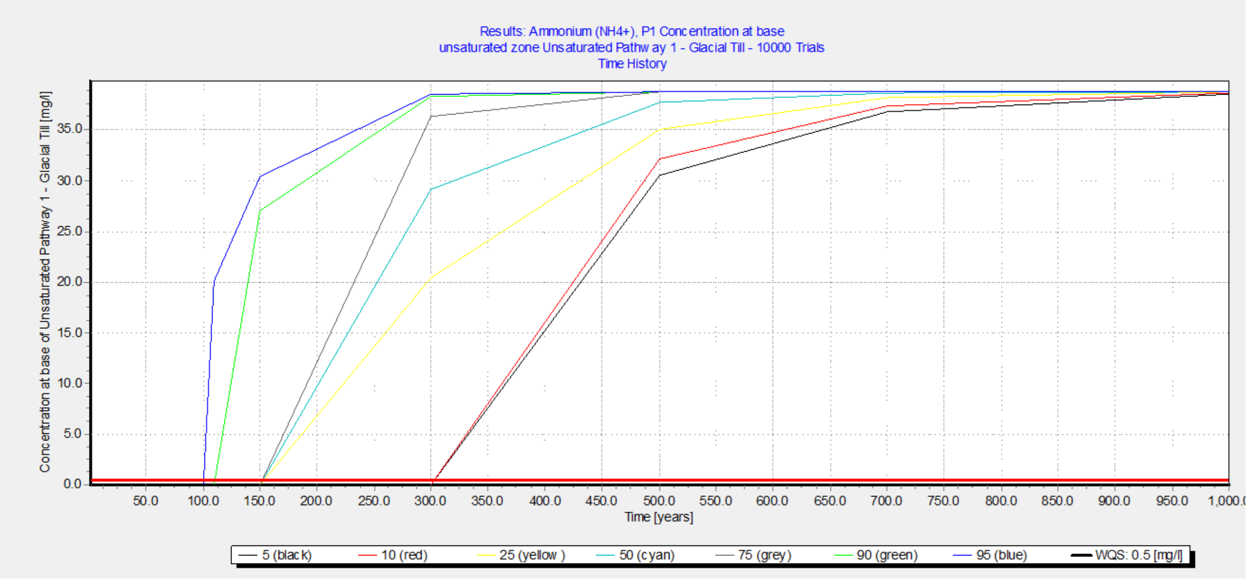


Table 10 - Ammonium Impact at Base of the Unsaturated Zone for the 95th Percentile (mg/L)

Time slices (years)						
50	100	110	150	300	500	1000
0.00E+00	0.00E+00	**20.1**	**30.4**	**38.6**	**38.8**	**38.8**

Sensitivity Analysis

The effect of parameter uncertainty has been taken into account by the use of a probabilistic model within which the parameter values are defined by a distribution or range. In addition, ConSim sensitivity analysis has been used to assess which model parameters have the most control over the model results.

The sensitivity analysis results vary between -1 and +1. A value of 1 indicates a perfect linear positive correlation between the input value and the result. A result of -1 indicates a perfect negative linear correlation between the input and the result. The results from the sensitivity analysis are sorted in decreasing order with the most sensitive model input first regardless of whether this is a positive or negative correlation. The parameters with the greatest influence are listed below (Table 111).

Table 11 – Model 1 Input Parameters with the greatest Influence.

Model 1 Input Parameter	Sensitivity
Unsaturated Pathway 1 – Glacial Till, Partition Coefficient [ml/g]	0.951
Infiltration [mm/yr]	-0.251
Unsaturated Pathway 1 – Glacial Till, Thickness [m]	0.172
Unsaturated Pathway 1 – Glacial Till, Water filled porosity [frac.]	0.019
Unsaturated Conductivity [m/s]	0.015
Source Thickness [m]	0.011

5.6 Model 2 Results

Groundwater impact and travel times are assessed through a 0.5m thick clay liner; installed to provide a low permeable hydraulic barrier at the base of the constructed wetland. The clay liner is simulated with an effective porosity ranging between 1 and 7% and vertical hydraulic conductivity (K_v) of 1.37E-10m/s (average Triaxial Cell test results, Table 3).

Time history plots show the predicted contaminant concentrations against time for selected uncertainty levels (probabilities) (Figure 7 and Figure 8). In summary:

- Ammonium is simulated to not exceed the target concentration of 0.5mg/L at the Glacial Till/Sandstone Aquifer interface within the 1000-year time-slice. Breakthrough is approximated with 3962 years (based on the 5th percentile retarded travel time).
- Based on travel times, simulations predict no significant risk to groundwater quality in the Sandstone Aquifer.
- Model simulations with variable clay liner K_v values identified that travel times through the clay liner increase from 87 to >1000 years when lowering the K_v value to 1.5E-11m/s.

Figure 7 - Model 2 predicted contaminant concentrations against time for selected uncertainty levels (probabilities) at the base of the clay liner.

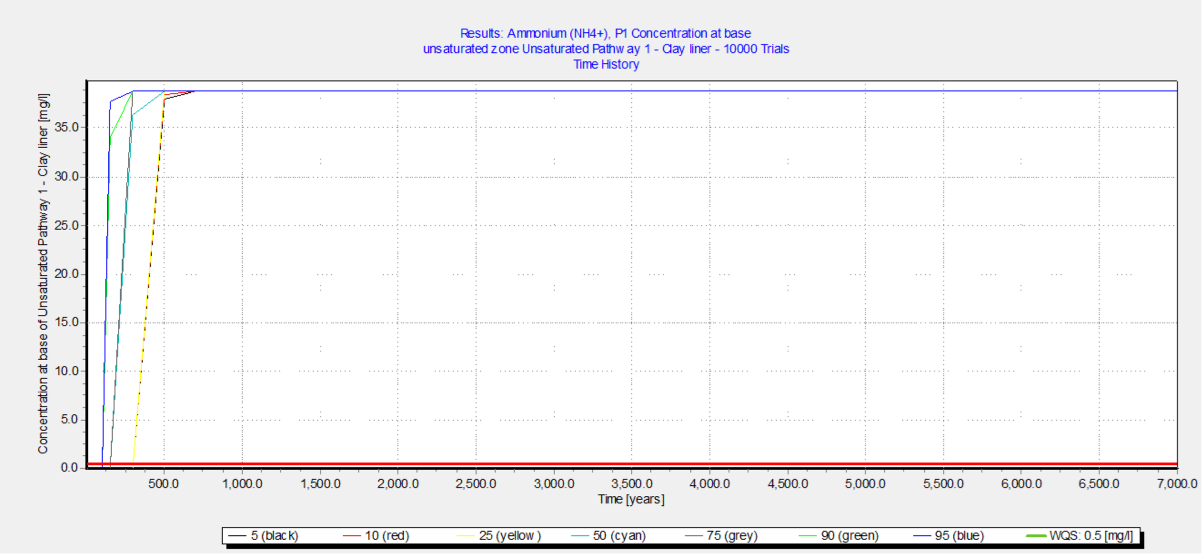
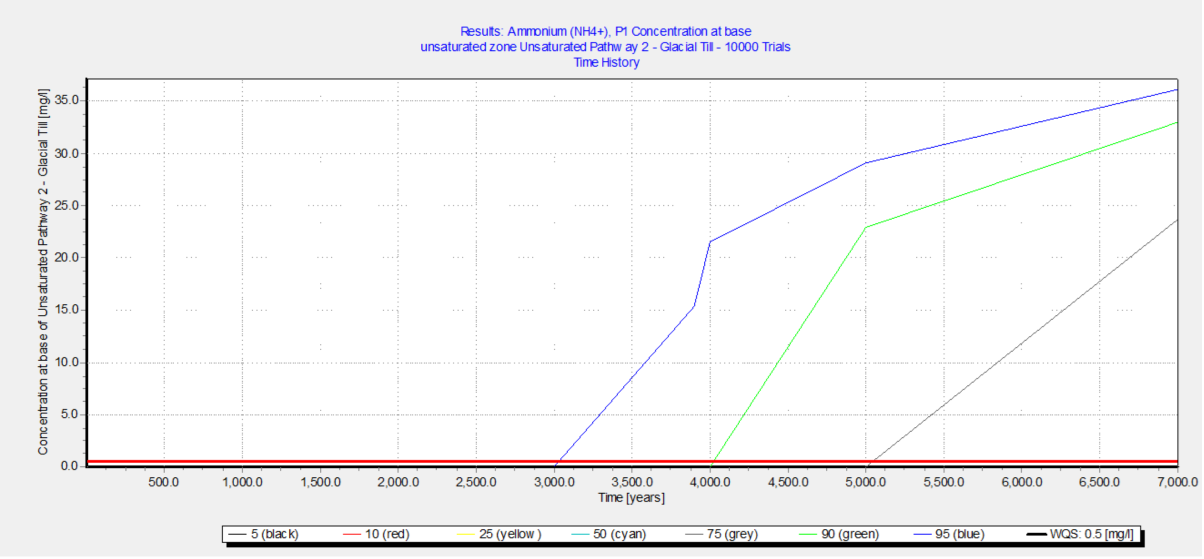


Figure 8 - Model 2 predicted contaminant concentrations against time for selected uncertainty levels (probabilities) at the base of the unsaturated zone.



Sensitivity Analysis

Input parameters with the greatest influence on the model outcome are listed below (Table 12). Infiltration rate, unsaturated hydraulic conductivity, and soil water partition coefficient for clay liner as well as Glacial Till are the most influencing model parameters on Ammonium fate and transport.

Table 12 – Model 2 Input Parameters with the greatest Influence.

Model 2 Input Parameter	Sensitivity
Infiltration [mm/yr]	-0.673
Unsaturated Pathway 2 – Glacial Till, Unsaturated Conductivity [m/s]	-0.673
Unsaturated Pathway 1 – Clay liner, Unsaturated Conductivity [m/s]	-0.663
Unsaturated Pathway 1 – Clay liner, Partition Coefficient [ml/g]	0.630
Unsaturated Pathway 2 – Glacial Till, Partition Coefficient [ml/g]	0.611

6 Conclusions

The Tremeirchion WwTW primary effluent discharge to ground within a constructed wetland, without clay lining installed, represents a potentially unacceptable long-term risk to groundwater within the bedrock Sandstone Aquifer.

Ammonium is simulated to exceed the target concentration of 0.5mg/L at the Glacial Till/Sandstone Aquifer interface within the 150-year time-slice. Breakthrough is approximated at 107 years (based on the 5th percentile retarded travel time).

The recommended mitigation measure is to install a low permeability clay barrier at the base of the constructed wetland. Conservative fate and transport simulations (allowing soil water partitioning, without biodegradation activated) confirm that a 0.5m thick clay liner constructed with clay material obtained from site is suitable to prevent pollutant breakthrough into the Sandstone Aquifer within a model timeframe of 1,000 years.

The current wetland design with 0.5m thickness of compacted clay won from site will be suitable and meets the requirements as set out in the report. The installation of a synthetic liner might be an alternative.

Appendix 1 Laboratory Analysis

Appendix 2 Risk Descriptors

The identification of potential "pollutant linkages" is a key aspect of the evaluation of potentially contaminated land. An approach based on the UK CIRIA report C552 (Contaminated Land Risk Assessment: A Guide to Good Practice, 2001) has been adopted within this report. For each of the pollutant linkages, an estimate is made of:

- the potential severity of the risk; and
- the likelihood of the risk occurring.

Table A-1 presents the classification of the severity of the risk:

Table A-1: Severity of Risk

Severe	Acute risks to human health; Major pollution of controlled waters (watercourses or groundwater)
Medium	Chronic (long-term) risk to human health; Pollution of sensitive controlled waters (surface waters or aquifers)
Mild	Pollution of non-sensitive water resources.
Minor	Requirement for protective equipment during site works to mitigate health effects; Damage to non-sensitive ecosystems or species

The probability of the risk occurring is classified by criteria given in Table A-2.

Table A-2: Probability of Risk Occurring

High Likelihood	Pollutant linkage may be present, and risk is almost certain to occur in the long term, or there is evidence of harm to the receptor.
Likely	Pollutant linkage may be present, and it is probable that the risk will occur over the long term.
Low Likelihood	Pollutant linkage may be present and there is a possibility of the risk occurring, although there is no certainty that it will do so.
Unlikely	Pollutant linkage may be present but the circumstances under which harm would occur are improbable.

An overall evaluation of the level of risk is gained from a comparison of the severity and probability as presented in Table A-3.

Table A-3: Comparison of Severity and Probability

		Severity			
		Severe	**Medium**	**Mild**	**Minor**
Probability	**High Likelihood**	Very high risk	High risk	Moderate risk	Moderate / low risk
	Likely	High risk	Moderate risk	Moderate/ low risk	Low risk
	Low Likelihood	Moderate risk	Moderate/ low risk	Low risk	Very low risk
	Unlikely	Moderate / low risk	Low risk	Very low risk	Very low risk

Table A-4 then provides a description of the typical consequences and potential actions required following each risk definition.

Table A-4: Qualitative Risk Assessment - Classification of Consequence

Classification	Definition
Very High Risk	Severe harm to a receptor may already be occurring, or a high likelihood severe harm will arise to a receptor, unless immediate remedial works / mitigation measures are undertaken.
High Risk	Harm is likely to arise to a receptor, and is likely to be severe, unless appropriate remedial actions / mitigation measures are undertaken. Remedial works may be required in the short-term, but likely to be required over the long-term.
Moderate Risk	Possible that harm could arise to a receptor, but low likelihood that such harm would be severe. Harm is likely to be mild. Some remedial works may be required in the long-term.
Moderate / Low Risk	Possible that harm could arise to a receptor, but where a combination of likelihood and consequence results in a risk that is above low but is not of sufficient concern to be classified as mild. Limited further investigation may be required to clarify the risk. If necessary, remediation works are likely to be limited in extent.
Low Risk	Possible that harm could arise to a receptor. Such harm, at worst, would normally be mild.
Very Low Risk	Low likelihood that harm could arise to a receptor. Such harm is unlikely to be any worse than mild.

Appendix 3 ConSim Model Input Parameters

Model 1 Input Parameters

Parameter	Input Values	Probability Distribution
Source		
Constant Source Term		
Thickness [m]	(0.4, 0.6, 0.8)	TRIANGULAR
Ammonium (NH4+) leachate Concentration [mg/L]	(25.7, 38.8, 64.3)	TRIANGULAR
Infiltration		
Infiltration [mm/year]	(155.6, 194.5, 233.4)	TRIANGULAR
Unsaturated Pathway 1 – Glacial Till		
Porous Medium		
Thickness [m]	(20, 24)	UNIFORM
Dry Bulk Density [g/cm3]	(1.67)	SINGLE
Vertical Dispersivity [m]	(2.0)	SINGLE
Water Filled Porosity [fraction]	(0.05, 0.10, 0.15)	TRIANGULAR
Unsaturated Conductivity [m/s]	(6.37E-08, 1.6E-07,2.99E-07)	TRIANGULAR
Unsaturated Pathway Contaminants		
Ammonium Partition Coefficient [ml/g]	(0.5, 2)	UNIFORM
No Degradation in Dissolved and sorbed phases		
Half-life [years]	-	-
Aquifer Pathway		
Thickness [m]	(100)	SINGLE
Dry Bulk Density [g/cm³]	(1.75)	SINGLE
Calculated Mixing Zone Thickness		
Hydraulic Conductivity [m/s]	(1.97E-06, 2.31E-04, 2.78E-05)	TRIANGULAR
Effective Porosity [fraction]	(0.19, 0.236, 0.31)	TRIANGULAR
Hydraulic Gradient	(0.001, 0.005, 0.01)	TRIANGULAR
Groundwater Flow Direction (degrees)	0	
Longitudinal Dispersivity [m]	(5)	SINGLE
Lateral Dispersivity [m]	(0.5)	SINGLE
Contaminant Inventory		
Ammonium Partition Coefficient [ml/g]	(0.5, 2)	UNIFORM
No Degradation in Dissolved and sorbed phases		
Half-life [years]	-	-

Model 2 Input Parameters

Parameter	Input Values	Probability Distribution
Source		
Constant Source Term		
Thickness [m]	(0.4, 0.6, 0.8)	TRIANGULAR
Ammonium (NH4+) leachate Concentration [mg/L]	(25.7, 38.8, 64.3)	TRIANGULAR
Infiltration		
Infiltration [mm/year]	(155.6, 194.5, 233.4)	TRIANGULAR
Unsaturated Pathway 1 – Clay Liner		
Porous Medium		
Thickness [m]	(0.5)	SINGLE
Dry Bulk Density [g/cm3]	(1.67)	SINGLE
Vertical Dispersivity [m]	(0.005)	SINGLE
Water Filled Porosity [fraction]	(0.01, 0.05, 0.07)	TRIANGULAR
Unsaturated Conductivity [m/s]	(4.34E-11, 1.37E-10,2.88E-10)	TRIANGULAR
Unsaturated Pathway 1 – Glacial Till		
Porous Medium		
Thickness [m]	(20, 24)	UNIFORM
Dry Bulk Density [g/cm3]	(1.67)	SINGLE
Vertical Dispersivity [m]	(2.0)	SINGLE
Water Filled Porosity [fraction]	(0.05, 0.10, 0.15)	TRIANGULAR
Unsaturated Conductivity [m/s]	(6.37E-08, 1.6E-07,2.99E-07)	TRIANGULAR
Unsaturated Pathway Contaminants		
Ammonium Partition Coefficient [ml/g]	(0.5, 2)	UNIFORM
No Degradation in Dissolved and sorbed phases		
Half-life [years]	-	-
Aquifer Pathway		
Thickness [m]	(100)	SINGLE
Dry Bulk Density [g/cm^3]	(1.75)	SINGLE
Calculated Mixing Zone Thickness		
Hydraulic Conductivity [m/s]	(1.97E-06, 2.31E-04, 2.78E-05)	TRIANGULAR
Effective Porosity [fraction]	(0.19, 0.236, 0.31)	TRIANGULAR
Hydraulic Gradient	(0.001, 0.005, 0.01)	TRIANGULAR
Groundwater Flow Direction (degrees)	0	
Longitudinal Dispersivity [m]	(5)	SINGLE
Lateral Dispersivity [m]	(0.5)	SINGLE
Contaminant Inventory		
Ammonium Partition Coefficient [ml/g]	(0.5, 2)	UNIFORM
No Degradation in Dissolved and sorbed phases		
Half-life [years]	-	-