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Assessment Report, Revision 1**

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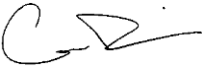

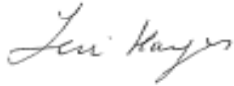
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EXECUTIVE SUMMARY

AWN Consulting Ltd., on behalf of Arxada, has prepared this *updated* Hydrogeological Review as Revision 1 – Technical Assessment for the former Arch Chemicals [Arxada] plant located at Watery Lane, Swords, Co. Dublin (IPC Licence Reg. No. P00060-01). This report follows on from the initial Hydrogeological Review (pre-remedial works) undertaken in 2016. This update is primarily based on monitoring results since the remedial works (i.e. removal of accessible contaminated soil and installation of a containment and collector trench system at the downgradient site boundary) undertaken in 2017/2018 and the installation of an on-going pump and treat system in late 2018.

The site is located within the Swords Groundwater Body and the subcategory Industrial Facility (P001403) Waterbody. The most recent classification (EPA website reviewed - June 2022) is 'Good Status' and 'Poor Status', respectively.

2-Chloropyridine (2-PCI) was identified as the priority contaminant of concern (PCOC). An assessment of 2-PCI was undertaken following the approach outlined in the JAGDAG revised methodology for substances which do not belong to the List I or List II groups. 2-PCI was confirmed as a hazardous substance primarily based on persistence. A compliance concentration of 0.05mg/l has been determined based on eco-toxicity assessment and the minimum threshold at which there is a high degree of laboratory confidence.

Pre-remediation, residual contamination comprised an area of contaminated low permeability clayey till and weathered rock located beneath the former Main Production and Warehouse Building (MPWB) and Boiler House Yard (BHY), extending over an area of c. 30m x 30m x (~2 to 5m deep) with a residual 2-PCI mass [conservatively] estimated in 2016 as ~158kg. This 2016 estimate was based on the available soil quality data. Monitoring showed that the plume extended beyond the site boundary to the Ward River. Post remedial works the residual contaminated soil (which is capped and is not accessible for removal is estimated (based on historical soil testing) as extending over an area of c. 1,130m² (~2m to 4.5m-5m deep) with a residual 2-PCI mass [conservatively] estimated in the region of 63 - 78 kg of 2-PCI (estimated for ~5,085 cubic metres subsoil).

An updated conceptual site model (CSM, refer to Section 3.0, Insert 3.4 below) has been developed for the current status. Monitoring has confirmed that the pathway of concern is through the shallow soils and weathered limestone discharging to the downgradient Ward River (~50 metres from the eastern site boundary). As can be seen from the collated monitoring data since 2018/2019, the concentration of the plume has significantly decreased from pre- to post-remedial works from >10 mg/l to <1 mg/l at its core. For example, the shallow plume has reduced in concentration significantly, with no current concentrations above 1.0 mg/l (refer to Section 4.1, Insert 4.1 below). Similar to the shallow plume, the intermediate plume has reduced significantly with the core of the plume noted to be slightly above 1.0 mg/l (refer to Section 4.1, Insert 4.2 below). The impacted area of the aquifer (c. 100 metres long, c. 12 m deep and c. 50 metres wide) has reduced in concentration since the remedial works were undertaken almost 5 years ago.

The interpreted 2-PCI plume has modified significantly since both the remedial works and commissioning of the pump and treat system in late 2018. The residual plume has reduced in concentration and size due to the removal of contaminated subsoil. Although a shallow plume is conservatively estimated as extending to the Ward River, the concentrations of 2-PCI present in shallow groundwater and groundwater flux is considered not to have an impact on the river water quality. Surface water monitoring has confirmed this to date (Q1 2022). It should also be noted that the impact assessment has not considered the additional significant dilution effect within the river or reduction in concentration due to volatilisation of 2-PCI in surface waters. As such, there is no potential for impact on the

conservation objectives of the downgradient (Malahide Estuary Natura 2000 site located ~1.09 km north-east of the site) or ecological water quality requirements for the Ward River itself.

There is an on-going impact within the shallow localised aquifer (plume area c. 100 metres long, c. 12 m deep and c. 50 metres wide). This small, impacted area of the aquifer is not currently used for potable/ other water supply. Future development of abstractions in this area is also considered to be unlikely due to the availability of a public water supply network and the low potential for a high yielding supply within this limestone. There are no health risks to on-site or off-site users due to the residual contamination on site.

A downward trend of 2-PCI concentrations is evident for groundwater monitoring wells both on site and off site over the period between 2016 and 2022 whilst prior to remedial works an increasing trend was noted in many shallow boreholes within the site and adjacent to the site boundary.

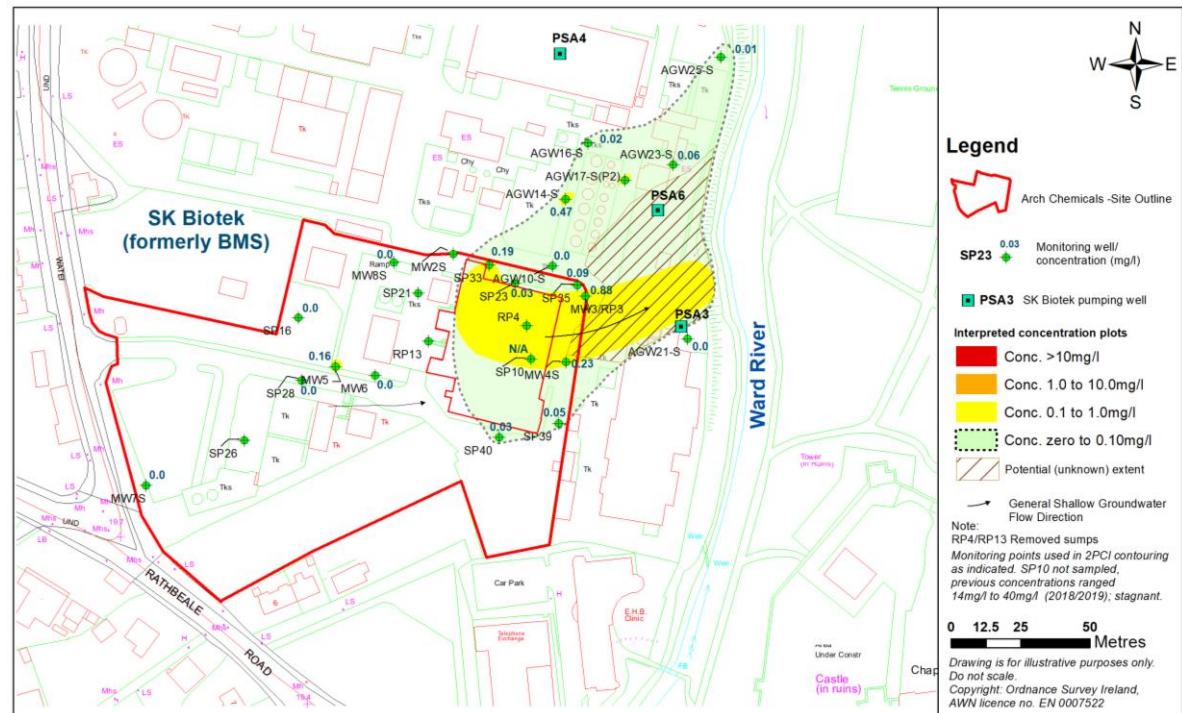
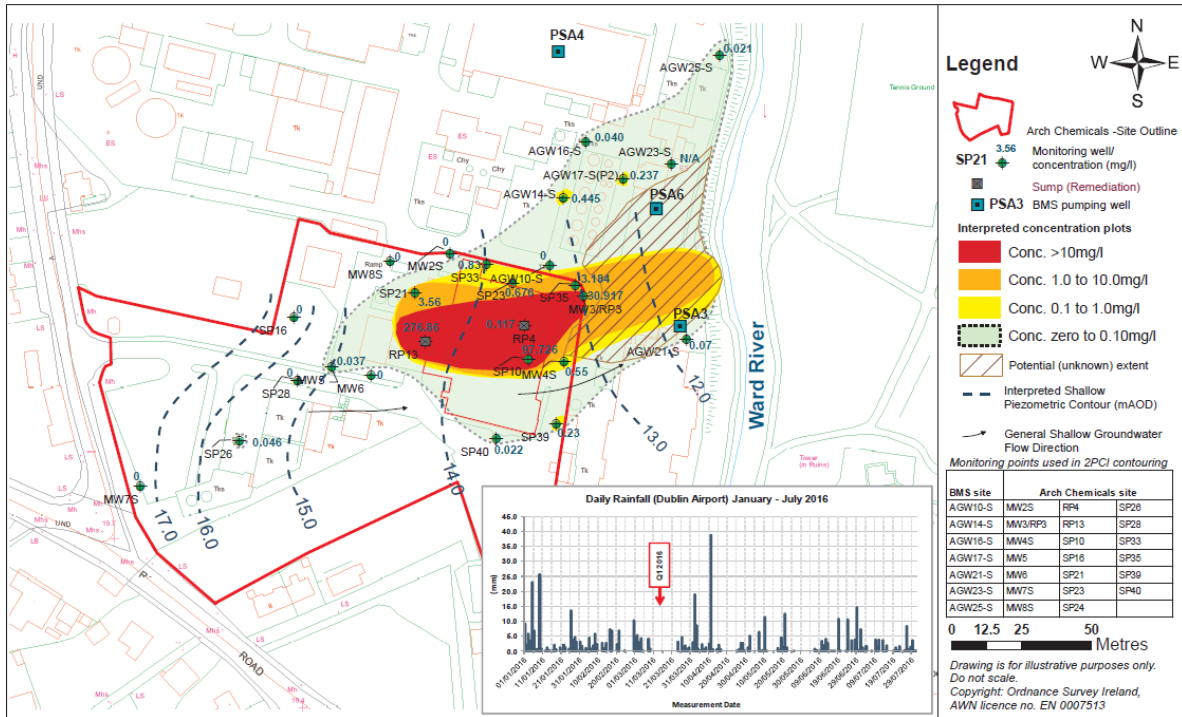
Treatment of extracted water is estimated as having removed approx. 0.11kg of 2-PCI with 2,323.70 m³ of water removed in total since the activation of the pump & treat system in 2018. Following the commencement of the pump and treat system the majority of monthly samples (post treatment at SE-1) were reported below the minimum reporting value (MRV) threshold value of 0.05mg/l for 2-PCI. This abstraction rate and water quality shows that the residual contamination is not being mobilised. This is due to the nature of the host glacial clay and the low level of recharge (site is capped and covered) and shallow hydraulic gradient. As a result of these conditions on site, previous modelling estimated a conservative period of c. 100 years may be needed to reach the proposed remedial target for 2-PCI at the site boundary.

As the plume extent and migration is now better understood, it is recommended that the number of groundwater monitoring locations (which are monitored quarterly) be reduced, i.e. monitoring is further targeted and based on the 'post-remedial works' results for both the Arch Chemicals facility and adjacent property. In addition, it is recommended that operation of the pump and treat system is turned off for 3 no monitoring rounds to confirm that the plume is not migrating in its current undisturbed status.

In summary, the corrective measures initially proposed to the EPA comply with the criteria set out in The Agency's Guidance on the Authorisation of Discharges to Groundwater and comply with the requirements of S.I. No. 9 of 2010 (amended S.I. No. 366/ 2016) as follows:

- As the site is closed and all raw material and waste has been removed, there is no on-going direct discharge of hazardous substances to ground/ groundwater;
- Current trend assessment of selected key groundwater monitoring wells shows a general downward trend profile and the corrective measures have resulted in significant plume reduction;
- Based on the available data, reported 2-PCI concentrations within the shallow and intermediate plume have decreased significantly since 2017/2018 close to/ below the MRV of 0.05 mg/l near the boundary with the Ward River and less than 5 mg/l within the Arch Chemicals (Arxada) site; and
- The extent of contamination both vertically and horizontally is very localised compared with the extent of the Swords Groundwater Body, i.e. not impacting on the overall assessment of status of this water body or on the water requirements of the Ward River and downgradient habitats.

A copy of Insert 4.1 is presented below to show the significant reduction in the interpreted 2-PCI plume within the Shallow horizons.



<p>The Tecpro Building, Clonsillaugh Business and Technology Park, Dublin 17 T: +353 1 847 4220 F: +353 1 847 4257</p>	<p>Project: Arch Chemicals B.V. (Lonza) Swords Groundwater Monitoring 2022</p>	<p>Drawing: SHALLOW Wells - 2-chloropyridine concentration plot Period: Q1 2022 (FEBRUARY)</p>	<p>Reference: 16/6426SR02Rev1 PG/ArcGIS/1:1,500 @A3</p>
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Insert 4.1 Shallow plume (interpreted extent) - March 2016 & February 2022

1. INTRODUCTION

1.1. GENERAL INTRODUCTION AND SITE ASSESSMENT

AWN was requested by Arxada to prepare an updated Hydrogeological Review/ Technical Assessment for the former Arch Chemicals plant in Watery Lane, Swords, Co. Dublin (IPC Licence Reg. No. P00060-01). This report is an updated version of the previous assessment report: *Hydrogeological Review/ Technical Assessment Report prepared by AWN Consulting in December 2016. Report ref - 16_6426SR02.*

A 'Closure, Restoration and Aftercare Management Plan' (CRAMP, August 2013) was also submitted to the Environmental Protection Agency (EPA). The Agency accepted the closure part of the submission, but the restoration and aftercare sections are outstanding including due to completion of the works outlined by AWN in 2016 to identify the most appropriate corrective action. At the time, this comprised removal of contaminated soil, installation of a number of recovery and containment trenches, and a deep collection chamber installed within the weathered rock. These works were fully completed in February 2018 and monitoring of its effectiveness has been on-going since then.

This report (and previous assessments) has been undertaken by the following hydrogeologists at AWN: Teri Hayes, BA (Mod), MSc, PGeo, Pat Groves, BSc, HDip Env Eng, MSc Env. Hydrogeology and Colm Driver, BSc, MSc, PGeo, EurGeol.

1.2. OBJECTIVE & BACKGROUND INFORMATION

In the EPA letter dated February 17, 2020, the Agency requested that *'In accordance with the Agency's letter of 06/09/2016, the EPA still considers the containment and treatment of contaminated groundwater for discharge to sewer through IE Licensed emission point Ref. No. SE-1 (Sampling Chamber Post Remediation System) (corrective measures) as an interim measure, as it will result in a reduction in the source extent, and reduce the local impact on the underlying aquifer and control off-site plume migration.'*

'In order for the matter to be considered further at this time, Arch Chemicals shall review the effectiveness of the corrective measures having regard to the on-going monitoring programme reports and update the hydrogeological assessment in accordance with the EPA's criteria set out in "Guidance on the Authorisation of Discharges to Groundwater and "Guidance on the Management of Contaminated Land and Groundwater at EPA Licensed Sites".'

As requested in the letter from February 2020, this report has now been updated and revised to review the current on-site treatment system (post-remedial works) and the current water quality at the site in terms of the local impact on the underlying aquifer and control of any off-site plume migration. Furthermore, the EPA requested that this review would *present the 'predicted water quality' arising from their activities in 2027 (and / or until such a time that the water quality objectives have been met), following the current and/ or any further proposed corrective actions.* In response to this latter requirement, and in terms of the current corrective action and potential environmental benefit thereof, it is noted that the assessment of water quality to date at key strategic monitoring points has indicated a general downward trend towards the Minimum Reporting Value (MRV) of 0.05mg/l, as agreed. In terms of the reference to the timeline of 2027, it is reasonably clear that the results presented to date, post remedial works, indicate positive results in containing the movement off site of residual 2-PCI with the ultimate aim of meeting target objectives with regard to water quality. In summary, the following is of note:

- As the site is closed and all raw material and waste has been removed, there is no on-going direct discharge of hazardous substances to ground/ groundwater.

- Monitoring to date [and post remedial works] has shown that the historical plume of residual 2-PCI contamination is reducing and that the values reported for both on-site and off-site (SK Biotek) monitoring wells show a decreasing trend over time.
- Review of the current pump and treat system to date.
- The current extent of the residual contamination both on site and off site is outlined within the updated Conceptual Site Model (CSM) described in Section 3. The extent of contamination both vertically and horizontally is very localised compared with the extent of the groundwater body, i.e. not impacting on the overall assessment of status of the Swords Groundwater Body.
- Current trend assessment of selected key groundwater monitoring wells (on-site and off-site shallow, intermediate and deep wells) shows a general downward trend in 2-PCI and the corrective measures have resulted in notable plume reduction.

2. ENVIRONMENTAL SITE SETTING

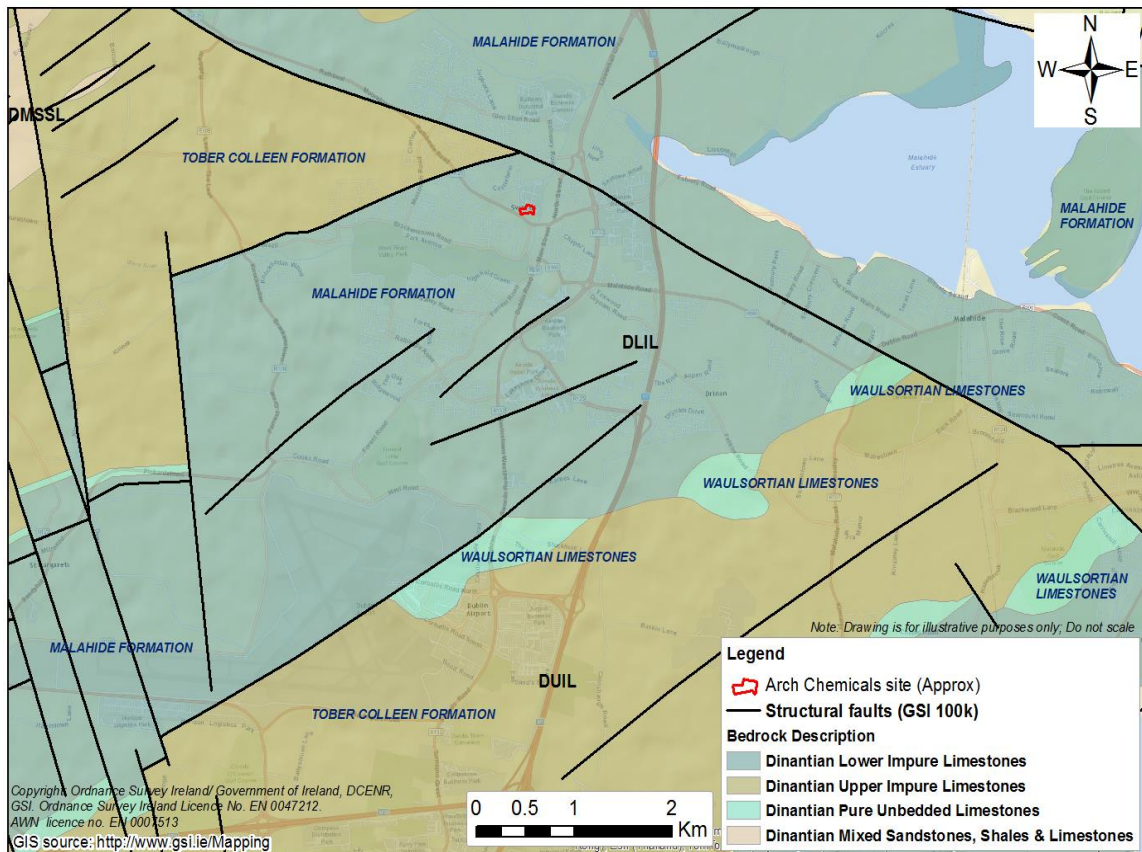
The site is located at Watery Lane, on the edge of the town of Swords, Co. Dublin in an area of mixed residential, commercial, and recreational uses. The SK Biotek (formerly Bristol Myers Squibb (BMS)) facility is located immediately north and east of the plant and these sites were once a single pharmaceutical production site. Residential properties are located up-gradient of the site to the west (approximately 20m) and south-west (approximately 15m up-gradient to nearest adjacent property). Down-gradient residential properties are located farther to the east (approximately 135m to the nearest residential property boundary and approximately 180m to the nearest house). The Ward River is located approximately 50 metres east of the Arch Chemicals property boundary.

The riverbed is approximately +11 metres above OD (mAOD) and approximately 3-4 metres below the elevation of the site at its eastern boundary. Bedrock is evident in the base of the channel. The Ward River flows to the north before its confluence with the Broad Meadow River which then discharges to the Broad Meadow Estuary (an SPA and NHA), located approximately 1 km north-east of the site.

The site is primarily covered in concrete or tarmac surfacing with some small, landscaped areas throughout. The topographic gradient is eastwards towards the Ward River with a shallow gradient. Insert 4.1 to 4.3 below presents the site layout.

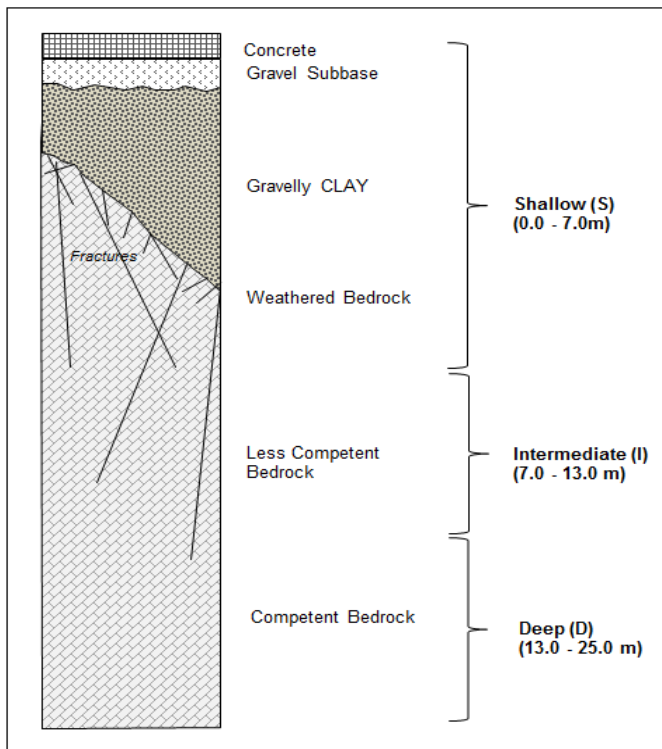
2.1 GEOLOGY

The regional geology comprises Malahide limestones and is presented in Insert 2.1 below.



Insert 2.1 Regional bedrock geology

The geological profile at Arch Chemicals and inferred pathways is presented in Insert 2.2 below and depicts the typical geology associated with the three classification zones used for the site, namely Shallow (S), Intermediate (I) and Deep (D).



Insert 2.2 Geological profile at Arch Chemicals and inferred pathways

Table 2.1 below summarises all the monitoring wells used (for assessment of local geology sampling and/ or groundwater levels). The monitoring wells are classified based on observed hydraulic pathways - Shallow weathered limestone and gravelly Clay (S), Intermediate less competent limestone (I), and Deep competent limestone (D).

The pathways and intervals chosen are in accordance with that of SK Biotek classifications to ensure some consistency in groundwater and plume contouring across both sites - Shallow weathered limestone and overburden with screen interval 1~7m, Intermediate less competent limestone with screen interval 7 to ~12m, and Deep competent limestone with screen >12m to ~25m.

Classification	Arch Chemicals site	SK Biotek (formerly BMS) site
Shallow	MM2S, MW3/RP3, MW4S, MW5, MW6, MW7S, MW8S RP4, RP13 SP10, SP16, SP21, SP23, SP24, SP26, SP28, SP33, SP35, SP39, SP40	AGW01-S, AGW04-S, AGW08-S, AGW10-S, AGW14-S, AGW16-S, AGW19-S, AGW21-S, AGW22-S, AGW25-S, AGW29-S
Intermediate	SP31, SP32, SP34, SP37, SP38, SP41, SP44, SP45, SP46	AGW20-I, AGW21-I, AGW22-I, AGW24-I, AGW25-I, AGW29-I, AGW31-I, AGW32-I, AGW39-I, AGW40-I, AGW43-I, AGW45-I, AGW47-I, AGW48-I, AGW53-I, AGW55-I, AGW59-I
Deep	MW1, MW2D, MW4D, MW7D, SP36, SP43, SP47	AGW22-D, AGW24-D, AGW25-D

Table 2.1 Monitoring well classifications for Arch Chemicals & SK Biotek sites

A summary of the local geology is provided below based on the comprehensive data set available from numerous investigations on both the subject site and adjacent SK Biotek (formerly BMS) site.

Overburden

Glacial drift cohesive deposits constitute the main overburden material at the Arch Chemicals site. Off site, on the SK Biotek site, much of this natural Clay has been removed during site re-development and replaced with more permeable fill.

The generalised downward succession of geology at the Arch Chemicals site can be summarised as consisting of a layer (0.0m to 0.60m) of Made Ground comprising concrete overlying a layer of clayey sandy Gravel subbase and/ or cobbles. Below this, sandy gravelly Clay is generally encountered (~0-6m). This low permeability Clay tends to become stiff to very stiff with depth with occasional bands of cobbles and rare discontinuous sand layers/ lenses. No continuous water table was encountered in the overburden but rather isolated pore water.

The Main Production and Warehouse Building (MPWB) overlies the main residual zone of contamination at the Arch Chemicals site, i.e. the contaminated subsoil beneath the concrete floor and contamination arising from the former leaking UST in the Boiler House Yard area (see Figure 3 in 2016 report which shows the full extent prior to remedial works). The low permeability glacial Clay retards lateral and vertical migration. In-situ field permeability testing in (unsaturated) Clay strata at Arch Chemicals has indicated K values in the order of 0.02m/d with values as low as 0.0004m/d also reported.

It is noted that more extensive fill material is present beneath the SK Biotek facility. Natural Clays were excavated for bund areas, etc. However, there is no available shallow overburden borehole information immediately downgradient of the MPWB plume on the SK Biotek site. Closer to the river boundary glacial till is again noted as present.

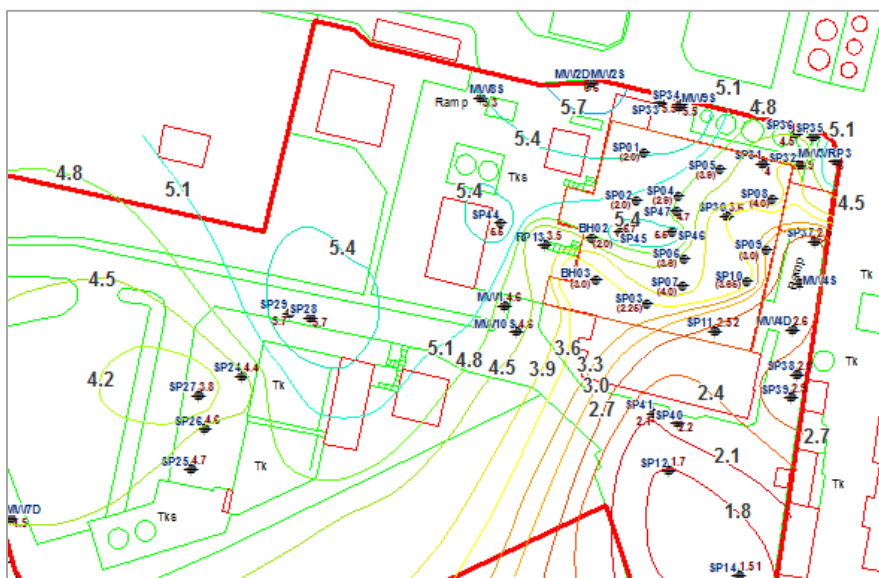
Note: Vertical migration from the upper overburden deposits to the underlying limestone is significantly reduced on the Arch Chemicals site. However, monitoring of 2-PCI contamination at the Arch Chemicals site has shown that contamination has reached the weathered limestone horizon indicating leakage has migrated vertically over a lengthy period (estimated at ca. 15-30 years). More rapid vertical migration will have occurred along localised pathways where these exist and where the protective Clay layer has been removed e.g. at the location of the former underground storage tank which was found directly overlying bedrock (and located immediately up-gradient of the MPWB).

Bedrock

The Clay is underlain by weathered rock head of shaley limestone (of variable thickness) which in turn is underlain by more competent limestone and then competent limestone.

The depth to bedrock varies across the site from 2.6 metres below ground level (mbgl) to ~6.7mbgl with shallower bedrock observed in the southern and western sections of the site. The weathered limestone is part of the Shallow (S) zone while the less competent limestone is referred to as the Intermediate (I) zone. The weathering and low degree of interconnected fracturing within this stratum controls the hydraulic conductivity in the formation.

The weathered and less competent Limestone (I) is potentially hydraulically connected with the underlying more competent Deep Limestone (D). However, an assessment undertaken by AWN of cored bedrock data from this deeper horizon (MPWB and Boiler House Yard areas) and review of cored data presented within SK Biotek reports has confirmed that this deeper stratum is not a significant flow path. This conclusion has been further confirmed by groundwater monitoring over time. **Fracturing observed at the Arch Chemicals site indicates fracture planes with a general dip range from sub-horizontal to ca. 40° dip, with very closely to widely spaced joints** which in turn often exhibit clayey veneer surface coating and clay infill. Insert 2.3 below (see also Figure 5a, 5b and 5c in 2016 report) presents the depth to bedrock profile beneath the MPWB based on site investigation data.



Insert 2.3 Depth to bedrock profile at Arch Chemicals

The thickness of the Clay material is shown to increase (blue) towards the former WWTP to the north of the site, it decreases (red) considerably towards the south of the main production building, i.e. <2.5m thickness. The following image presents the geological profile within the western portion of the MPWB.

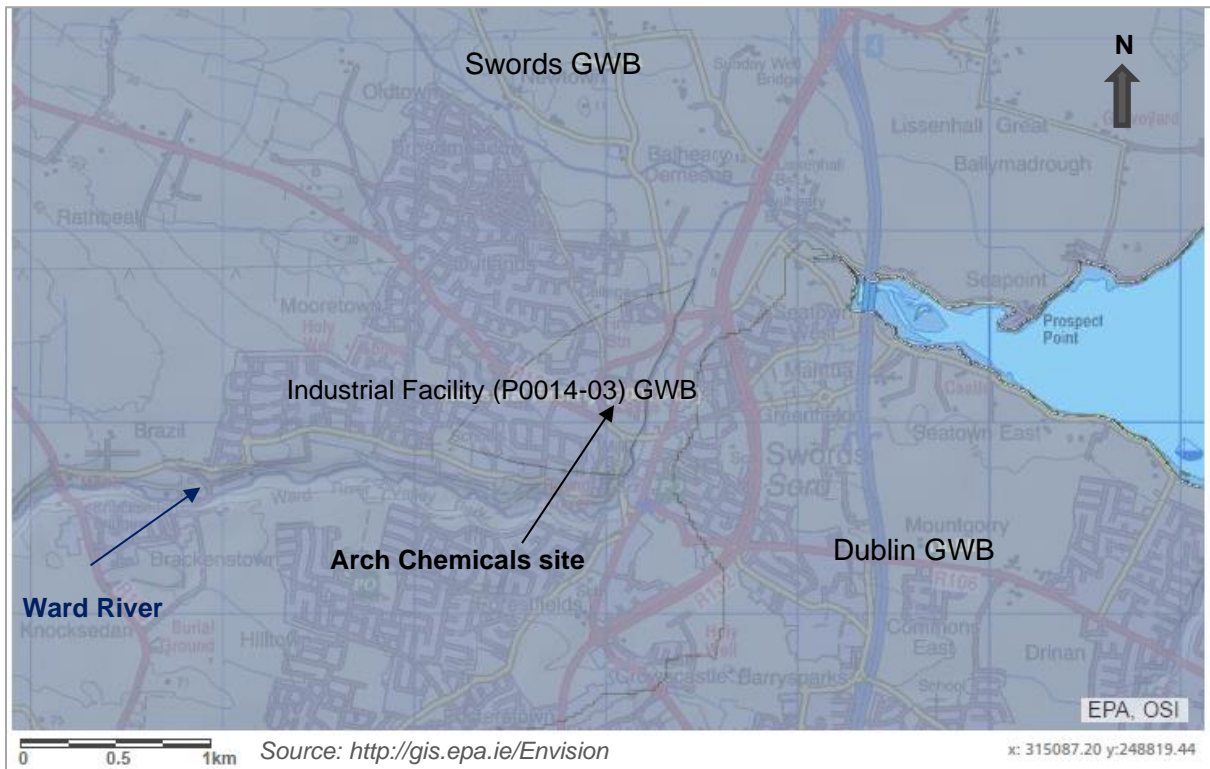


Lithology sequence present within MWPB at Arch Chemicals site. Bedrock encountered in the range of 5.5mbgl to 6.25mbgl.

2.2 REGIONAL HYDROGEOLOGY

The limestone (Malahide Formation) underlying both sites is classified by the Geological Survey of Ireland (GSI) as *‘Locally Important – moderately productive only in local zones’* with High (H) groundwater vulnerability classification. The groundwater forms part of the Swords_CL (IE_EA_G_062) Groundwater Body (GWB). The site is located within a subcategory of this water body highlighted as Industrial Facility (P0014-03) GWB.

Relevant EPA Maps and associate descriptions, [available on-line at <http://gis.epa.ie/Envision>; accessed: November 2016, checked June 2022] are presented below.

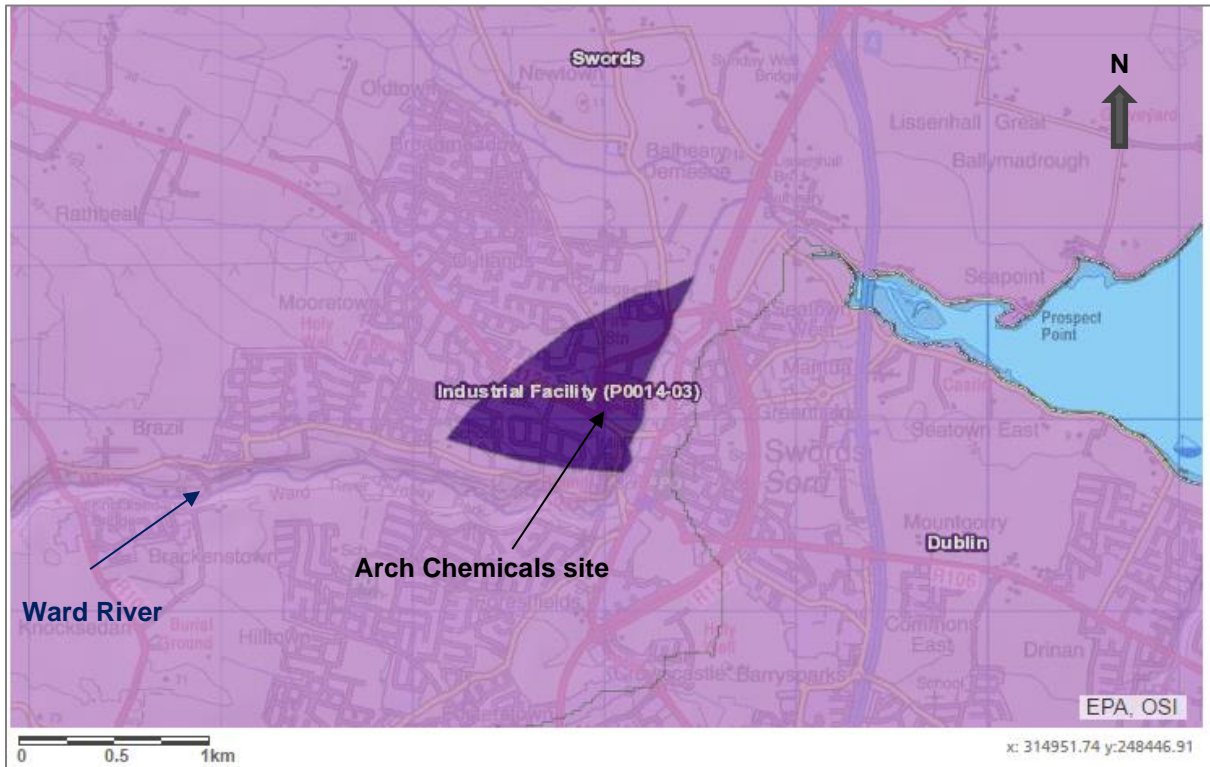


Insert 2.4 Water Features – Groundwater Body (GWB)

Descriptions

Layer Name: Ground waterbodies
 Display value: Industrial Facility (P0014-03)
 OBJECTID: 7591
 European Code: IE_EA_G_062

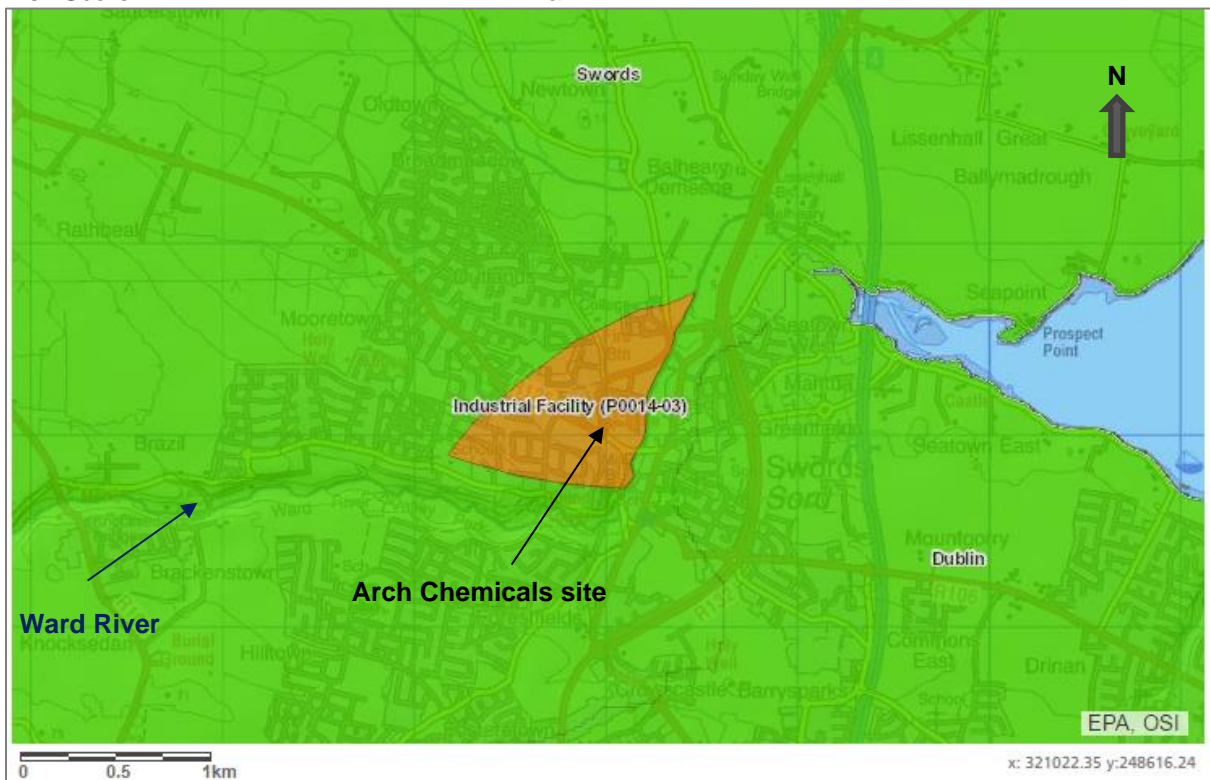
Name: Industrial Facility (P0014-03)
 Description: Poorly productive bedrock
 Display value: Swords
 OBJECTID: 7778
 European Code: IE_EA_G_011
 Name: Swords
 Description: Poorly productive bedrock



Insert 2.5 WFD Risk Scores (GWB Score)

Descriptions

Result for Industrial Facility (P0014-03)	'At risk of not achieving good status'
Risk Score:	1a
Result: Swords	'Expected to achieve a good status'
Risk Score:	2a



Insert 2.6 WFD Status

Descriptions

Layer Name: Ground Waterbody WFD Status 2013-2018
Display Value: Industrial Facility (P0014-03)
OBJECTID: 7591
European Code: IE_EA_G_062
Name: Industrial Facility (P0014-03)
WFD Overall Status: Poor (GW)

Display Value: Swords
OBJECTID: 7778
European Code: IE_EA_G_011
Name: Swords
WFD Overall Status: Good (GW)
Period for WFD Status: GW 2013-2018

There are no known wells used for potable public water supply within a 1 km radius of the site and the area is serviced by public mains supply (Fingal County Council/ Irish Water).

On a regional scale, groundwater flow is expected to be ENE towards the Broad Meadow Estuary.

The [2016 report] description of the Swords water body in which this site is located is included in Appendix A1. In this, it is noted that '*In general, permeability in these rock units are likely to be moderate to low (1-10m²/d) (Creighton et al) apart from where dolomitization is noted*'.

2.3 SITE HYDROGEOLOGY

2.3.1 HYDRAULIC GRADIENT

Local groundwater flow has been regularly mapped based on surveyed groundwater water levels, i.e. elevation to metres Above Ordnance Datum (mAOD) Malin Head datum, made available from both the Arch Chemical and adjacent SK Biotek (formerly BMS) sites. The flow direction is north-east and eastwards towards the Ward River and does not vary significantly over time.

Water levels show little seasonal variability. Hydraulic gradient values have been calculated following the completion of many rounds of groundwater level monitoring of the Shallow, Intermediate and Deep classification boreholes. These have been measured at an average range of between:

- 0.020 to 0.025 for the Shallow (S) zone,
- 0.022 to 0.033 for the Intermediate (I) zone, and
- 0.028 to 0.032 for the Deep (D) zone

Pumping has been undertaken as part of the remedial programme at SK Biotek (formerly BMS) which has been observed as having a local influence on the groundwater pattern within their site boundary. Information provided to date by SK Biotek indicated that the average groundwater abstraction rates in 2016 were 8.7m³/day (PSA 4) and 6.0m³/day (PSA 6). The pumping wells are recorded as abstracting from the weathered limestone (typically screened from 7-10mbgl) and drawdown levels range from 6–12mbgl, i.e. top of the competent bedrock). AWN learned that (as at 11/03/2015) PSA6 had been shut down temporarily to observe potential recovery in solvent levels. Farther north-east on the SK Biotek site, shallow flow is also affected by the presence of a cut-off barrier. However, the localised pumping and cut-off barrier did not appear to have had an impact on the flow pattern underling the Arch Chemicals site [in 2016].

3 CONCEPTUAL SITE MODEL (CSM)

A conceptual site model (CSM) has been developed based on extensive site investigation and assessment at the site.

3.1 POTENTIAL SOURCE AREAS (PSA)

3.1.1 SOURCE AUDIT

Summary of Remedial Works in 2017/2018

Remedial works at Arch Chemicals site (Arxada) commenced in October 2017 and lasted for approximately fifteen (15 no.) weeks. These works involved significant volumes of soil removal from within the Boiler House Yard (BHY) area and from within a defined footprint of the Main Production & Warehouse Building (MPWB) of Arch Chemicals. This project was reported under separate cover, however the key field observations are briefly summarised below in the context of the current CSM and site status.

Boiler House Yard (ref: Zone A)

Extensive excavations were undertaken in the boiler house yard, especially at the location of the former UST (Underground Storage Tank). Trial pits were carried out throughout the BHY to examine the horizontal and vertical extent of the contamination within this area. The following is a summary of key observations:

- Contaminated subsoil and [shallow] water was encountered at the former UST location. This was excavated down to 'clean', dry, hard BOULDER CLAY with soil samples taken and tested in order to ensure that the Boulder Clay was not contaminated. The [shallow] contaminated water was pumped to a tanker on site and disposed of off-site by an approved, licenced contractor.
- The gravelly subsoils (fill material) to the immediate west of the former UST tank (i.e. location RP13) and spoil from trial pits completed near sample points B2 and B3 were observed with 'significant' staining/ 2-PCI contamination and notably along the gravel surrounding the former [process] drainage lines. Note: RP13 sump was removed and decommissioned.
- 2-PCI concentrations within the BHY ranged from ~36.98 mg/kg (B2 at 1.10 mbgl) to ~7.17 (excavation zone RZ5 at a depth of 4.70mbgl).
- BOULDER CLAY (i.e. Natural Ground, with low permeability) was encountered in all the trial excavations at depth. This Boulder Clay was observed as 'clean' with the majority of 2-PCI concentrations recorded at between ~0.01 mg/kg to <LOD (laboratory limit of detection).
- The staining/ contamination profile appeared to taper towards sample reference B0, located towards the northern limit of the Zone A Works. As with location B2, the staining/ contamination was observed to lie along the route of the former drainage [process] lines and clayey gravelly fill surrounding these pipes.
- 'Significant' black staining/ contamination was encountered at 0.80mbgl within the excavation at location C9, at the gate entrance to the BHY. (*Note: This appeared to possibly extend southwards and past the southern extent of Zone A Works*)
- The BHY was reinstated with 'clean' stone material which was compacted in layers of 300mm. This was then capped with concrete with a newly installed storm water drainage system.

Main Production & Warehouse Building (Ref: Zone B)

Deep excavations were carried out to the top of rock for the main drainage plan

comprising four (4 no.) main manhole chambers installed as part of the remedial works within the MPWB. Three (3 no.) trenches were constructed with the objective of ensuring hydraulic connection [under natural gradient] between the three up-gradient manholes (MH1-MH3) and the main pumping manhole (MH4), located within the NE corner of the building – taking into account the interpreted groundwater flow orientation across the site. The following is a summary of key observations noted during the main excavation within Zone B:

- Significant subsoil was removed as non-hazardous throughout Zone B during the excavations; contaminated groundwater was also removed for approved disposal off-site.
- The subsoil was made up of Fill material, stiff brown CLAY with strong 2-PCI odour and stiff to hard, black BOULDER CLAY with no obvious 2-PCI contamination.
- Limestone bedrock was encountered at depths of between 5.20 – 6.20mbgl.
- Reported 2-PCI concentrations ranged from between ~4.7mg/kg (location D0 at 4.20mbgl within brown CLAY) to ~3.1mg/kg (near location MH2 at 4.20mbgl, within brown CLAY).
- The hard Boulder Clay was observed as 'clean' with the majority of 2-PCI concentrations reported between 0.17mg/kg to <LOD.
- All manholes were installed within the underlying bedrock with MH4 [the main collection chamber in the NE corner] installed ~1.5 metres into the bedrock. MH4 will be the main pumping chamber for the on-site remedial treatment system.
- Contaminated groundwater was encountered during the installation of the main drainage system in Zone B. This was pumped into the on-site tanker prior to off-site disposal by licenced contractor. Reported contaminated groundwater concentrations ranged from between ~0.53mg/l (MH4) and ~12.47mg/l (MH3).
- Historical monitoring points RP4 (former remedial sump) and the Intermediate well SP31 were removed, during the main excavations within the MPWB.

Summary of subsoil and groundwater removed off site

An approximation of the full subsoil/ water removed off site was compiled based on the waste dockets provided for all waste removed from site during the full extent of the remedial works project. This is outlined as follows:

- *Hazardous waste* *Approx. 728 tonnes*
- *Non-hazardous waste* *Approx. 2,590 tonnes*

An approximate volume of 150.5m³ of [mostly contaminated] water was removed off-site for approved disposal during the full extent of the remedial works.

- *Aqueous waste* *Approx. 150,360 kg*

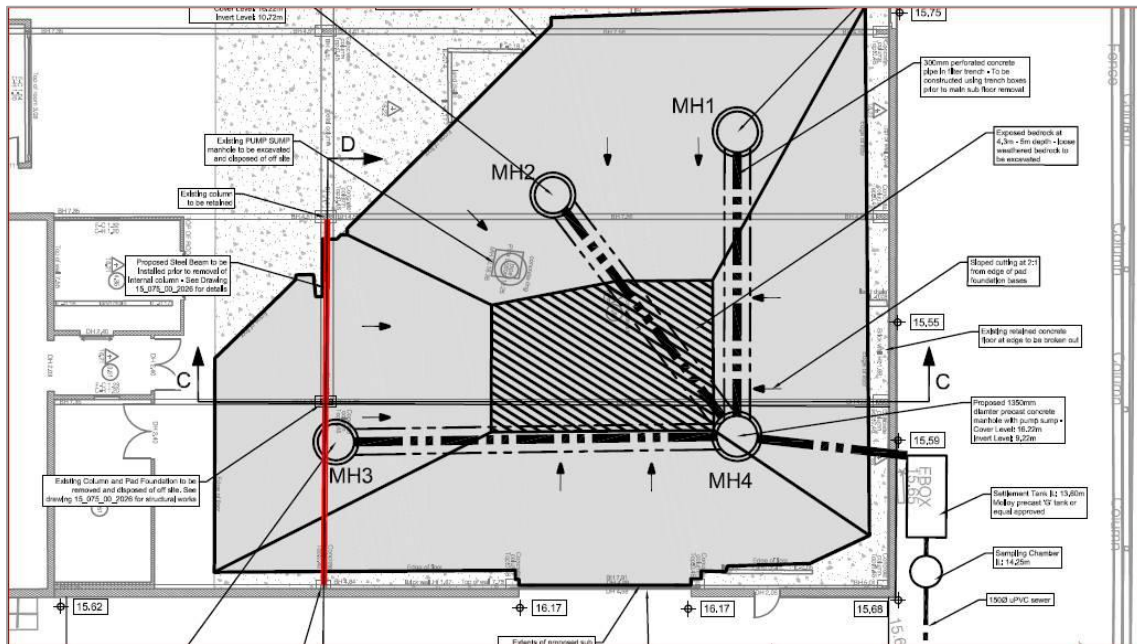
Note: Detailed summary of remedial works is presented in Appendix G in 2016 report.

Installation of Pump and Treat System

In February 2018, as part of the EPA approved Corrective Actions, a pump and treat system was installed during the remedial works phase mentioned above. Deep excavations were carried out to the top of rock for the main drainage plan comprising four (4 no.) main manhole chambers installed within the MPWB. Three (3 no.) trenches were constructed with the objective of ensuring hydraulic connection [under natural gradient] between the three up-gradient manholes (MH1-MH3) and the main collection/pumping manhole (MH4), located within the NE corner of the building – taking into

account the interpreted groundwater flow orientation across the site. MH4 is the deepest manhole with a pumping chamber located at the bottom of this sump.

This pump and treat system has been operational since 2019 in compliance with the appropriate discharge licence as agreed with the EPA and Irish Water (IW). Insert 3.1a presents the plan view of the alignment of manholes MH1 to MH3 with a designed flow direction towards the main collection chamber at MH4, located within the north-eastern corner of the MPWB.



Insert 3.1a Current pump and treat system active within the site

The pump and treat system uses a submersible pump located within the deeper pumping chamber (MH4) to extract water out and into the treatment system and includes carbon filtration which treats the pumped groundwater to the discharge licence limit concentration of 0.05 mg/l. Refer to Insert 3.1b below for the discharge licence limits.

Monthly sampling is carried out for 2-PCI, pH, temperature and flow (m³/hr), with bi-annual sampling carried out on the remaining parameters. However, due to COVID-19 a number of months of monitoring were missed during 2019 & 2020 with construction sites being closed/ made inaccessible.

Yearly sampling for respirometry testing is carried out on the pump and treat system. This measurement is taken at the end of each year to examine the potential (if any) impact on the downgradient receiving municipal wastewater treatment plant (this was Swords Municipal Wastewater Treatment Plant – MWwTP prior to Covid19) where it receives secondary treatment using an activated sludge process with nutrient reduction and tertiary treatment.

Based on the available respirometry data (2019-2021), which has included the use of activated sludge from Ringsend, Dublin 4, under agreement of Irish Water, it is concluded [for 2021 testing] that....

‘Respirometry measurements were taken at the end of every year. The Arxada (formerly Arch Chemicals) SE-1 composite sample tested exhibited no acute toxicity/ biological inhibition to the activated sludge (containing a mixed microbial population of heterotrophic and nitrifying bacteria) from Ringsend municipal wastewater treatment plant at up to 50 % volume/volume concentration in the activated sludge (500 ml of test

sample plus 500 ml of Ringsend WWTP activated sludge). This equates to an EC50 toxicity value (180 minute) of 'greater than' 50 % concentration v/v (less than 2 TU).'

Therefore, there is no impact on the active operational of the Ringsend WWTP from the Arxada site; this conclusion has been consistent to date.

Schedule 2(i) Emissions to Sewer		
Emission Point Reference No.	SE1 (sampling chamber post remediation system)	
Emission Type:	Treated groundwater	
Name of receiving sewer:	Irish Water sewer	
Volume to be emitted:	Maximum in any one day:	11 m ³
	Maximum rate per hour:	2 m ³
Parameter	Emission Limit Value	
pH	6-10	
Temperature	35°C	
	mg/l	kg/day
COD	500	5.5
Suspended Solids	300	3.3
Sulphates (as SO ₄)	800	8.8
Chlorides (as Cl)	1,000	11
2-Chloropyridine	0.05	0.00055

Insert 3.1b Discharge licence limits for the discharge point SE-1

3.1.2 ASSESSMENT OF 2-PCL & COMPLIANCE THRESHOLD CONCENTRATION

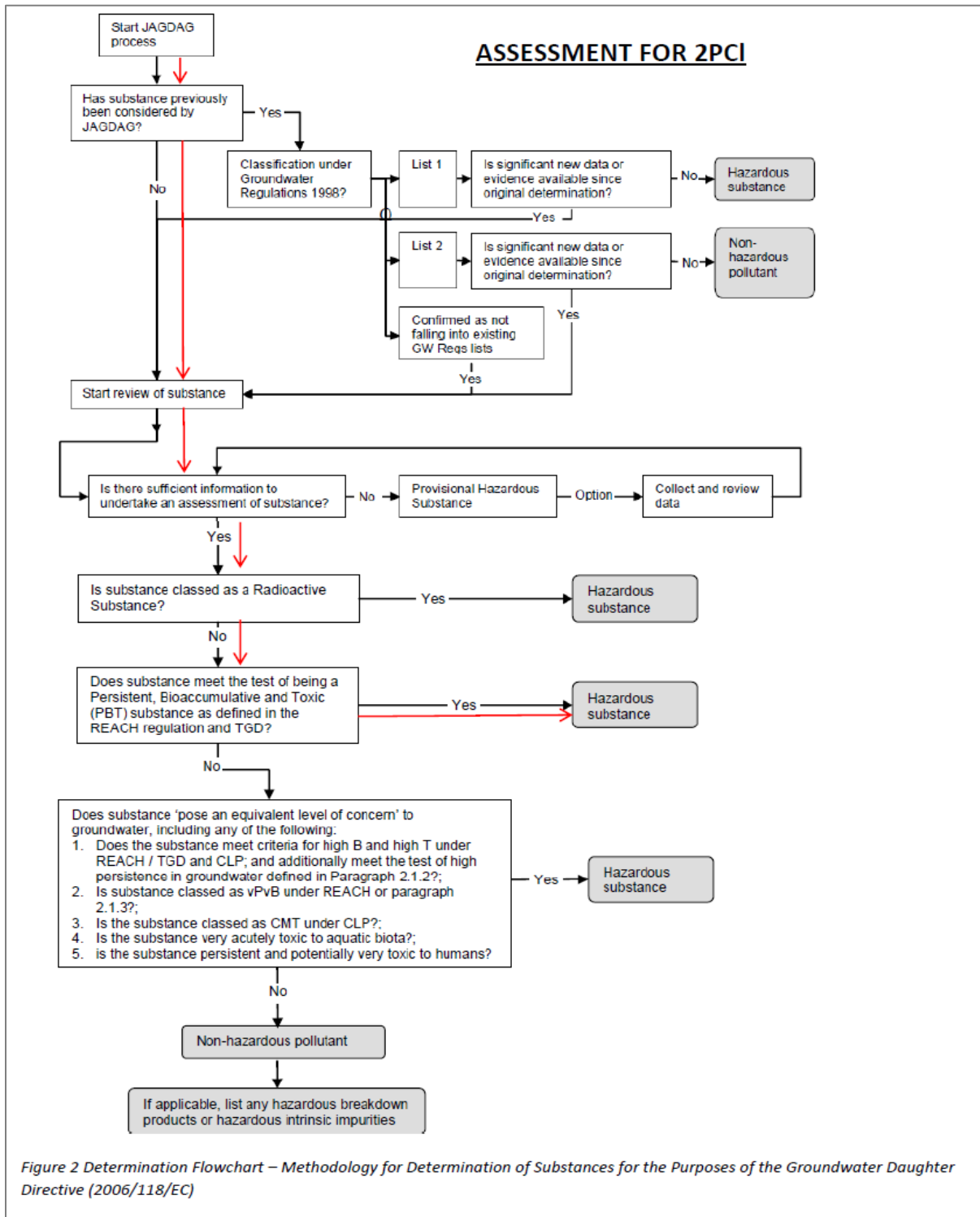
2-Chloropyridine (2-PCI) was identified in the source audit and subsequent monitoring as the priority contaminant of concern (PCOC). An assessment of (2-PCI) was undertaken following the approach outlined in the JAGDAG revised methodology for substances which do not belong in the List I or List II groups. (ref Methodology for Determination of Substances for the Purposes of the Groundwater Daughter Directive (2006/118/EC). 2-PCI is the PCOC present within the soils and shallow aquifer at the Arch Chemicals site.

Appendix C4 (in 2016 report) presents the available SDS information for 2-PCI. As there is little available information on the toxicity to aquatic species for 2-PCI, Awn has undertaken independent analysis and assessment and has proposed a threshold concentration of 0.05mg/l in groundwater as this is a concentration which does not have a detrimental effect on aquatic species and is also a detection limit in which there is a high level of laboratory confidence. Laboratory results for toxicity testing are provided in Appendix C10 (in 2016 report).

In compliance with the JAGDAG approach, with the additional toxicity data collated during this investigation there is adequate data to complete this assessment. 2-PCI is primarily categorised as Hazardous based on its persistence in the environment i.e. the

half-life in soil is > 1E+30 days. The Log Kow value for 2-PCI is less than 4.5 (value of 0.16) and therefore does not bio-accumulate. Although 2-PCI is not carcinogenic or mutagenic, the 'no observable effects concentration' (NOEC) for freshwater is 0.05 mg/l based on toxicity testing. As this is greater than 0.01 mg/l, the substance is considered to be highly toxic following the guideline.

Insert 3.2 below presents our assessment of 2-PCI as a Hazardous Substance following the Determination Flow chart.



Insert 3.2 Assessment for 2-PCI (red arrow indicates assessment for 2-PCI)

A summary of the characteristics of 2-Chloropyridine (2-PCI) is provided below.

2-chloropyridine (CAS Registry number: 109-09-1) is a colourless to pale yellow, clear liquid with a very distinct sharp aromatic amine odour. The compound has a high aqueous solubility and high vapour pressure. Due to aqueous solubility, it is unlikely to form a separate phase in a groundwater setting and have a high mobility in soil.

2-PCI exhibits volatilisation losses from open water and less so from soil (Sims G. K and L.E Somers 1985).

2-PCI in soil does not degrade under anaerobic conditions and is poorly degraded under aerobic conditions. Therefore, no biodegradation is assumed for 2-PCI. Table 3.1 below summarises the key characteristics of 2-PCI.

Chemical	KOC (cm ³ /g)	Kw (mL/g)	HLC (-)	Max Solubility (mg/L)	Half Life	Source and Justification
2-PCI	50.12 (min) 57.0 (max)	16.6	3.3E-04 (max), 1.4E-05 (min) 1.89E-05 (likely)	25,000	1E+30 assume no degradation	USEPA and Arch Chemical data, PhysProp database

Note: HLC=Henry's Law Constant (unit less)

Table 3.1 Characteristics of 2-PCI

There is no on-going direct discharge to ground at the former Arch Chemicals site as it is now closed. Residual concentrations will decrease slowly over time due to natural attenuation and the planned [now implemented] corrective works at the site. This is in accordance with the requirements of *Article 4 and 56 of S.I No 9 of 2010...* 'any proposed threshold value should demonstrate plume reduction and reversal of chemical trends as part of any final corrective action'.

Summary of toxicity testing and minimum reporting value (MRV)

A receptor compliance point threshold of 0.05 mg/l for 2-PCI in groundwater was proposed, as no legislative standard for 2-PCI in water exists. The basis for this threshold is discussed below.

As there are no relevant legislative concentrations for 2-PCI in groundwater or surface water, Awn submitted a number of groundwater samples for independent toxicity testing (Appendix C10 in 2016 report). The objective of this testing was to provide some understanding of the likely impact of 2-PCI concentration on the Ward River surface water quality status. Samples were tested against *Daphnia magna* and *Vibrio fischeri* species which are typical of river fauna in Ireland. The toxicity results recorded for this concentration were 1 and 2 TU (Toxicity Units).

There are no relevant legislative criteria with which to compare the toxicology results. However, the EPA generally imposes a limit of toxicity for discharge to sewer/ IPPC and waste licenced sites of 10 toxic units (TUs). (Note: reference licences for which TU limits have been set at 10 TU include Abbott Ireland IPPC Licence P0847-01, Schering-Plough (Ireland) Company IPPC Licence P0015-04 and Smithkline Beecham (Cork) Limited IPPC Licence P0004-03).

The Shannon Aquatic Toxicity Laboratory (now City Analysts) set out at the SETAC Europe Annual Meeting 2007 in a presentation 'The H14 Criterion and Bioanalytical approaches to Ecotoxicology Waste Characterisation' a description of the relevance of the toxic units. This is summarised in Table 3.2 below.

Toxic Units	Description
<3	Non Toxic
3-10	Slightly Toxic
11-50	Toxic
50-100	Very Toxic
>100	Extremely Toxic

Table 3.2 Toxic units and description

In conclusion, testing of 2-PCI samples at a concentration of 0.05 mg/l adjacent to the Ward River came back as non-ecotoxic when assessed against this wastewater discharge standard. As such, this concentration will not impact water quality requirements of the Ward River as outlined under the Water Framework Directive. There is no current or likely use of the immediate aquifer for a GWDTE or water supply. It is currently overlain by a [live] Pharmaceutical plant and urban area, both serviced by Public Water supply.

AWN notes the following extract from the *EPA Guidance on the Authorisation of Discharges to Ground*: 'For hazardous substances, minimum reporting values (MRVs) are used where standards do not yet exist. An MRV is the lowest concentration of a substance that can be determined with a known degree of confidence using commonly available laboratory analytical methods but is not equivalent to a limit of detection'. The laboratory detection limit for 2-PCI using HPLC methodology (EMT, formerly Jones Environmental laboratory) is 0.005 mg/l. However, further conversation with the laboratory (see also Appendix C10, email correspondence) has confirmed low confidence in a detection limit of 0.005 mg/l ('± 30% would be expected') while with a detection limit of 0.05 mg/l they state:

"We would confirm that we would have a high degree of confidence in detecting a concentration of 0.05mg/l (50ppb) of 2-chloropyridine. Furthermore, we use this concentration as part of our standard calibration for this method of analysis".

AWN therefore concluded that 0.05mg/l 2-PCI be used as the MRV based on both toxicity testing and laboratory detection limit.

This threshold value demonstrates the requirement for plume reduction and reversal of chemical trends as part of any final corrective action as required under Article 4 and 56 of S.I. No. 9. of 2010 (amended S.I. 366 of 2016). The 2016 trends and plume within the shallow and intermediate borehole showed a localised plume with 2-PCI concentrations exceeding 0.05 mg/l on site therefore a reduction to 0.05 mg/l at the site boundary would conform with the requirement of S.I. No. 9 of 2010 (amended S.I. No. 366 of 2016) for a reversal of chemical trend and plume reduction. Currently, the reported concentrations have been trended up to Q1 2022 with a noticeable reduction in 2-PCI concentrations and interpreted plume characteristics. Based on the available data, reported 2-PCI concentrations within the shallow and intermediate plume have decreased significantly since 2017/2018 close to/ below the MRV of 0.05 mg/l near the boundary with the Ward

River and less than 5 mg/l within the Arch Chemicals (Arxada) site. Trends of the reported 2-PCI spatially are further discussed in Section 4.1 below.

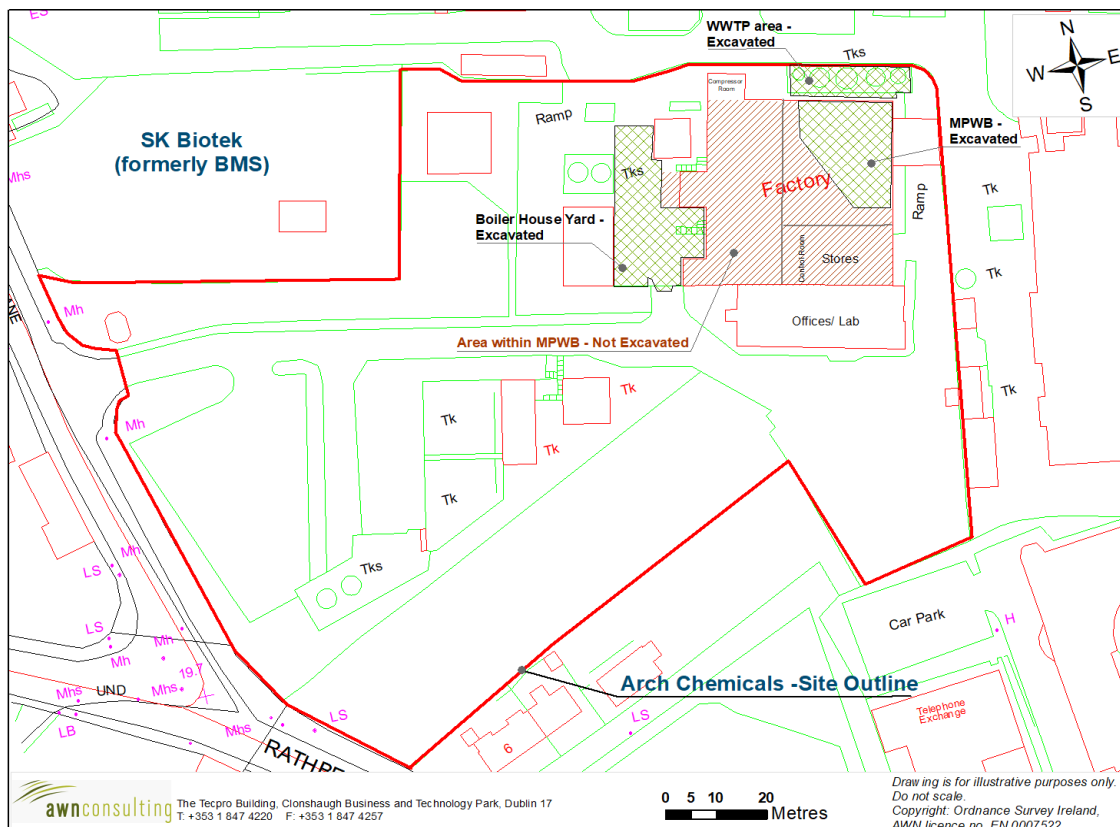
3.1.3 SUMMARY OF RESIDUAL CONTAMINATION ON SITE

Residual Soil Contamination

The residual mass of 2-PCI beneath the source area (MPWB) was estimated at ~158Kg in 2016 prior to remedial works. This estimation was based on the depth to bedrock (Insert 2.1 above) and measured 2-PCI concentration for the subsoil within the source area including for subsoil near the former UST below ground structure as well as other ‘hot spots’ as identified from site investigations and groundwater monitoring. This was a conservative estimate in 2016 which overcompensated for the hotspots across the site. In 2017/ 2018, bulk excavation was undertaken and a pump and treat system installed as part of the objective remedial works. The removal of subsoils led to approx. 25.5 kg of 2-PCI being taken off site with the removal of approx. 3,607,640 kg of subsoil material. However, all 2-PCI contaminated subsoil could not be removed due in large to structural constraints with the MPWB footprint.

The subsoil that is left *in situ* and which could not be excavated is highlighted in Insert 3.3 below. This area contains hotspot areas of elevated concentrations of 2-PCI from 1 metre below ground level to ~4.5-5.0 metres below ground level. Available soil quality results from each metre were used in order to estimate the amount of 2-PCI (kg) remaining within this areal extent. (The data used is presented in the previous version of this report issued in December 2016 as Table 3.3 in Section 3.0, Sub Section 3.1.3).

Therefore, it is estimated that approx. 63 - 78 kg (based on an area of 1,130m²) of 2-PCI may be left in-situ as residual subsoil contamination. There is approx. 5,085 m³ of subsoil within this extent which contains minor hotspots of elevated concentrations of 2-PCI. Insert 3.3 below presents the ‘unexcavated’ area mainly within the MPWB outline.



Insert 3.3 Residual subsoil contamination area as at May 2022

It should be noted that the 'unexcavated area' presented in Insert 3,3 above is directly up-gradient of the pump and treat system with no impact to the downgradient Ward River. Furthermore, this area is covered by concrete and a large warehouse building which indicates that there is no possible infiltration of surface water (recharge) within this footprint.

Residual Plume

The current residual [contaminated] plume is significantly reduced in terms of 2-PCI concentrations spatially at and beyond the subject site since the main remedial works were undertaken and following the operation of the pump and treat system at manhole chamber MH4. In general, there is an overall downward trend in reported 2-PCI concentrations at the Arch Chemicals facility and for groundwater monitoring wells located within the [hydraulically downgradient] off-site SK Biotek facility (refer to Section 4.0 below).

Furthermore, the size of the plume is decreasing with concentrations at/ below the MRV and often below the respective laboratory LOD at the SK Biotek. It is noted that the testing laboratory for 2-PCI has remained unchanged for the past number of years (i.e. from 2013 to 2022) with EMT, a UKAS accredited laboratory, continuing to be used.

3.2 PATHWAYS

A pollutant linkage exists between the historical contaminated soils beneath the former production building (MPWB), the underlying weathered limestone aquifer, and the down-gradient Ward River (~50 metres from the eastern site boundary).

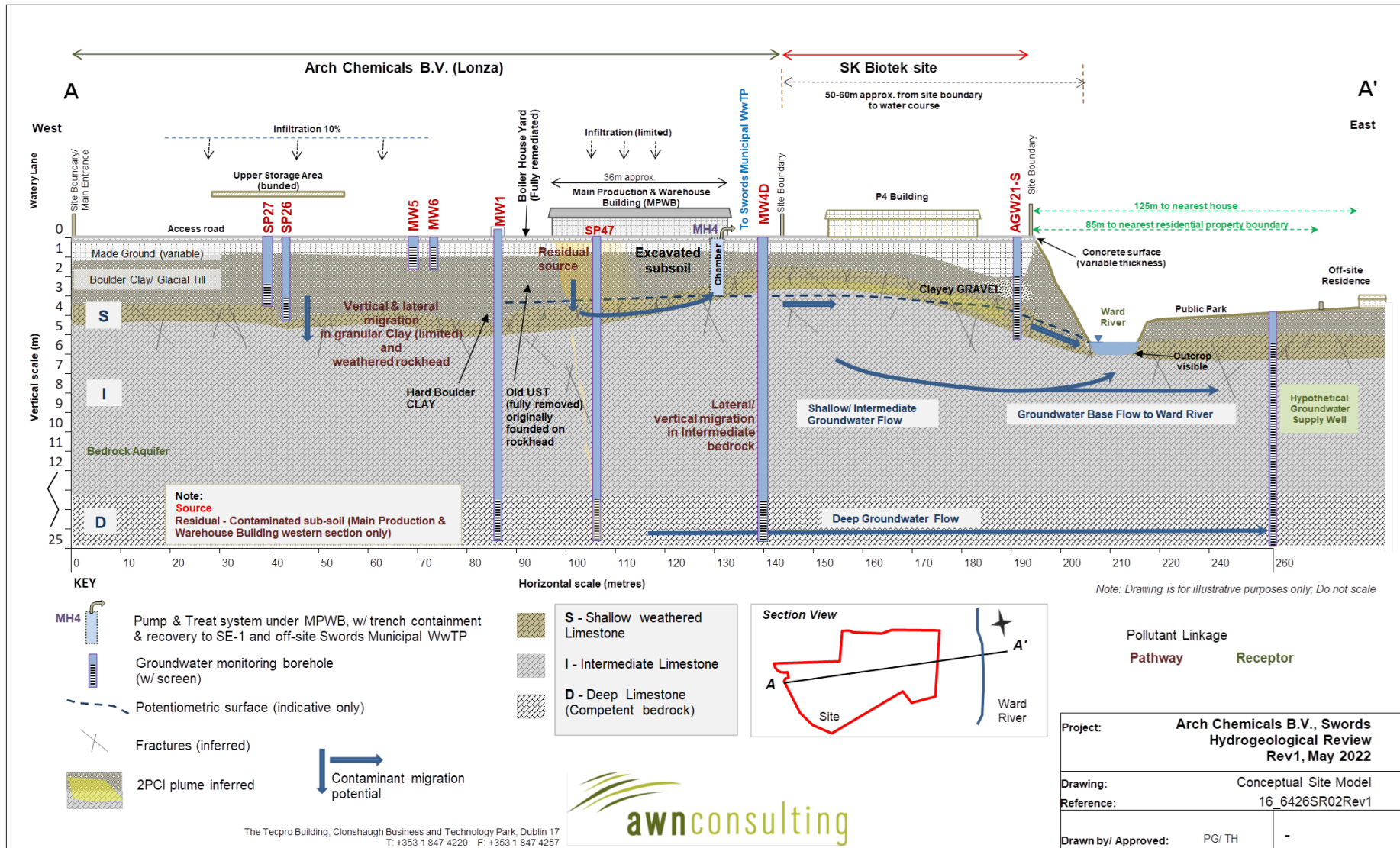
The primary pathway is leakage from residual contaminated soil through the weathered limestone (shallow pathway) and underlying less competent limestones (Intermediate pathway). The competent limestone (D) encountered beneath the site does not show evidence of karstification or interconnected fissures in bedrock cores both on and off site. Monitoring results support the view that this is not a pathway for off-site migration. Insert 3.4 below presents an *updated* schematic (CSM) cross section for the site.

The site and off-site pathway is generally capped with concrete/ tarmacadam surfacing and the main contaminant area is also roofed therefore infiltration potential is low, reducing the potential for mobilisation of contaminants. In addition, mobilisation is reduced due to the clayey nature of the soils present, the discrete weathering and fracturing within the shallow limestone, and the shallow hydraulic gradient observed.

The residual 2-PCI mass was conservatively estimated [in 2016] at ~158kg and modelling has shown that, without intervention, 2-PCI would continue to leach slowly over time and migrate off site. As 2-PCI does not degrade in groundwater, the only factor in plume migration is attenuation and dilution.

Bedrock is visible within the river located 50 metres down-gradient of the site and it is understood that this is the main discharge for groundwater migrating in the shallow and intermediate horizons. However, a conservative view was taken in considering the potential for groundwater also migrating beneath the base of the river i.e. off site, extending to an open parkland behind Swords Castle. Monitoring within the river itself for over a decade (i.e. up-gradient (RS1) and down-gradient (RS2)) has consistently shown no detection of 2-PCI.

The CSM cross section is presented in schematic form below in Insert 3.4.



Insert 3.4

Updated Conceptual Site Model (CSM) as of May 2022

Although the plume size generally remained stable over the monitoring periods covered between 2012 and 2016, it was shown to extend beyond the Arch Chemicals site boundary line. Consequently, a strategic remedial approach was planned to limit/ prevent the potential off-site migration to the neighbouring SK Biotek (former BMS) facility.

3.3 RECEPTORS

The primary receptors identified in relation to the residual contamination include:

- (i) Limestone aquifer (on site and off site);
- (ii) Ward River which subsequently discharges to the Broad Meadow Estuary (an SPA and NHA) located approximately 1 km north-east of the site; and
- (iii) The SK Biotek (former BMS) facility is located north and east of the plant. Residential properties are located up-gradient of the site to the west (approximately 20m) and south-west (approximately 15m up-gradient to nearest adjacent property). Down-gradient residential properties are located to the east (approximately 135m to the nearest residential property boundary and approximately 180m to the nearest house). A separate risk assessment has been undertaken to show that there was no potential human health risk during uncovering and excavation of any contaminated soil. Further assessment and confirmation of any required mitigation measures for contractors will be undertaken prior to works commencing.

There are no down-gradient potable or industrial water abstractions within the general vicinity of the plume. Public mains water supply services the general Swords area.

The Ward River discharges to the Broad Meadows Estuary which is an SAC. The Ward River is the primary surface water receptor. However, to date there have been no detections of 2-PCI above the laboratory detection limit of 0.005mg/l in river water samples. Toxicity sampling indicates that a concentration of <0.05mg/l in groundwater discharging to the river will not have a deleterious effect on the river ecology.

3.4 SPR LINKAGES -RISK SCREENING

Table 3.3 presents the plausible pollutant linkages considered as part of the assessment.

Source	Pathways	Receptors considered	Risk of Impact
<p>Historical Leakage of 2-PCI from a former UST, incidental spills, plant wash down and leaking drains in Main Production and Warehouse Building, Boiler House Yard area and former WWTP has resulted in the following:</p> <p><u>Residual Sources</u></p> <p>Clayey subsoil and weathered limestone contaminated with 2-PCI and Chloride beneath parts of the Main Production and Warehouse Building and former drainage system within this footprint (Note: Since 2016 the residual source within the Boiler House Yard (including former UST area) has been removed)</p> <p>Vapour emissions during exposure of contaminated soil</p>	<p>Lateral migration via shallow groundwater flow within the weathered Limestone (S) to the SK Biotek Site and Ward River</p> <p>Vertical migration via shallow groundwater flow to underlying partially competent Limestone (I) bedrock</p>	<p>Limestone bedrock aquifer</p>	<p>High – localised shallow weathered and less competent limestone. The residual contamination within the Arxada facility is contained by the pump and treat system (installed to weathered rock).</p>
	<p>Lateral migration via groundwater flow in the intermediate Limestone (I) bedrock discharging to the Ward River</p> <p>Vertical migration from intermediate Limestone to underlying competent bedrock (D) via isolated/ discrete fractures</p>	<p>Ward River</p>	<p>Low – although a residual off-site 2-PCI plume exists, the concentrations present are not significant enough to result in an impact on the river quality. Lack of detections of 2-PCI above LOD generally reported to date.</p>
	<p>Lateral migration via groundwater flow in the intermediate limestone (I) bedrock beneath the Ward River to off-site aquifer</p>	<p>Broad Meadow Estuary</p>	<p>Low – As above, the risk of impact is insignificant based on 2-PCI concentrations (below detection level) discharging from the facility and distance to the estuary. Low - As the plume is present in the shallow less competent limestones will discharge to the river and less likely extend below the river bed to the downgradient aquifer.</p>
	<p>Lateral migration via groundwater flow in the competent limestone (D) bedrock to the Ward River (not applicable)</p>	<p>Off -site bedrock aquifer</p>	<p>Low (modelling undertaken to confirm no likely impact).</p>
		<p>On site contractors and off-site occupants</p>	

Table 3.3 Pollutant linkages

A risk assessment was undertaken by AWN to assess the likely impact of the residual

contamination on the aquifer and Ward River. The potential impact of the contaminated soils beneath the manufacturing building on the water environment was assessed in 2016 using ConSim (version 2.2) and RISC 4 (refer 2016 Hydrogeological Review).

In brief, the modelled results predicted that a period of c.100 years is required to reach the proposed remedial threshold at the river boundary even with the then planned soil removal. The lengthy period is due to the lack of any breakdown of 2-PCI and the slow migration rate for the residual plume in the soil and shallow limestone to reach the river boundary. Even without the cut-off and recovery trenches in place to reduce off-site migration, the modelled 2-PCI concentration at the river boundary well (I) never reaches twice the threshold target (0.005 mg/l). Higher concentrations may be present in the shallow horizon (S), however there is no existing monitoring point to confirm this. The installation of the cut-off trench would contain the shallow off-site plume going forward, therefore the likely impact on the Ward River was concluded as low, even discounting the additional effect of dilution in the river.

Modelling of a residual pulse down-gradient of a fully contained boundary showed reduction to below the remedial threshold at the river boundary well within 50 years. However, it should be noted that 100% engineered containment is not feasible.

4 ASSESSMENT OF HISTORICAL & CURRENT GROUNDWATER IMPACTS

This section considers the requirements of Regulation 56 of the Groundwater Regulations and the need to assess the impact of the plume at the Arch Chemicals [Arxada] facility. A comprehensive dataset has been collected leading up to Q1 2022 and assessed at the subject site in order to develop a robust CSM for the former [now closed] facility in Swords, Co. Dublin.

There is no current or potential unlicensed discharge of hazardous substances to ground as the plant is closed and all above ground raw material and waste materials have been fully removed from the site. As such, there is only indirect discharge to groundwater due to leaching which is limited by the extensive capping (including existing and new concrete surfacing) at the site which further reduces direct infiltration from rainfall events.

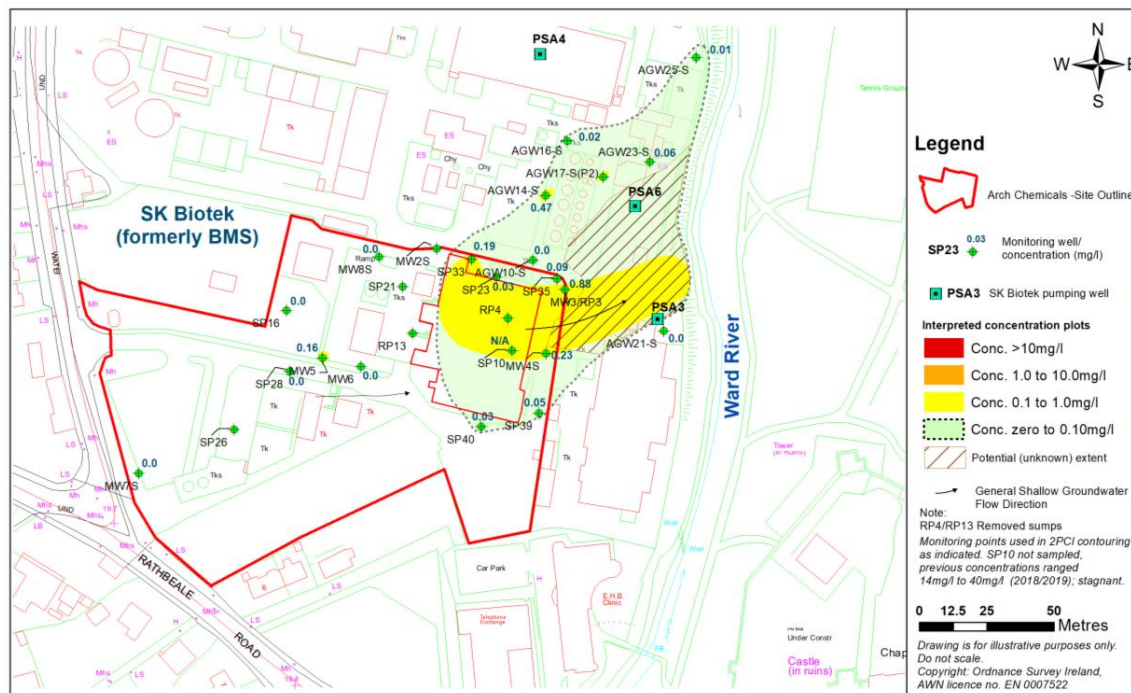
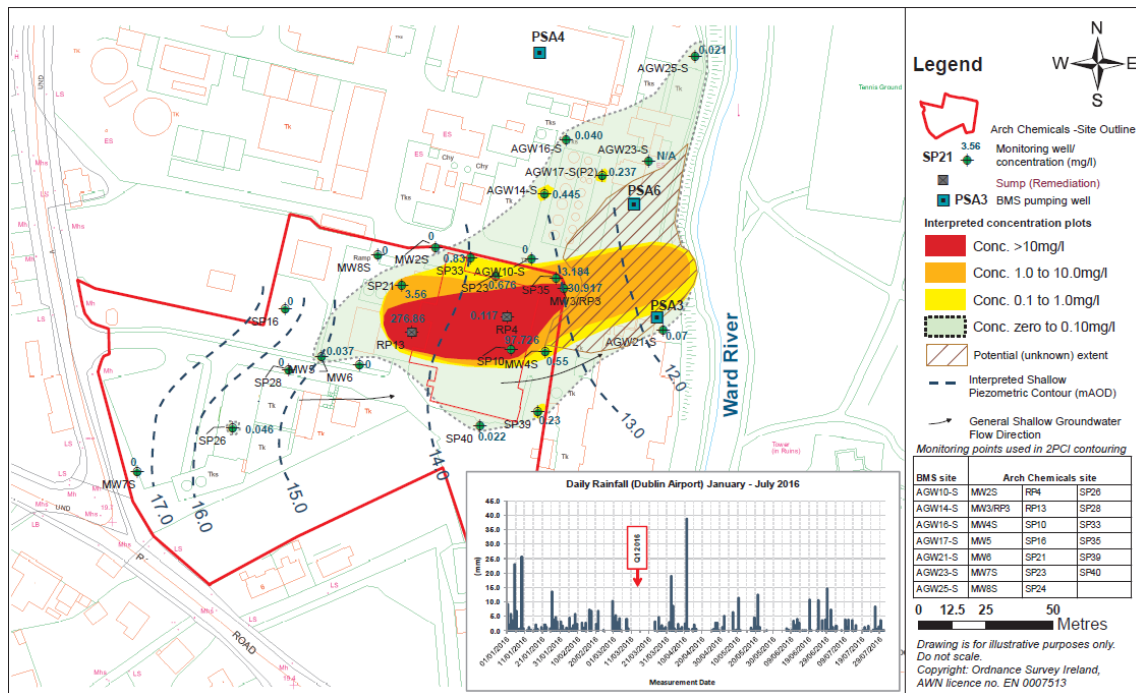
4.1 EXTENT OF PLUME AND TRENDS

This section discusses the residual source on site and the interpreted off-site contaminant plume, both historically and as of Q1 2022.

The interpreted groundwater flow (and plume extent) for the shallow overburden and weathered zone (S), intermediate and less competent limestone (I) and deeper competent limestone (D) is included on the 2-PCI plots below, as Insert 4.1, Insert 4.2 and Insert 4.3, respectively, and relate to Q1 2016 (March), i.e. pre-remedial works at the Arch Chemicals site and Q1 2022 (February), i.e. post-remedial works and following the operation of the pump and treat system now on-going at the subject site.

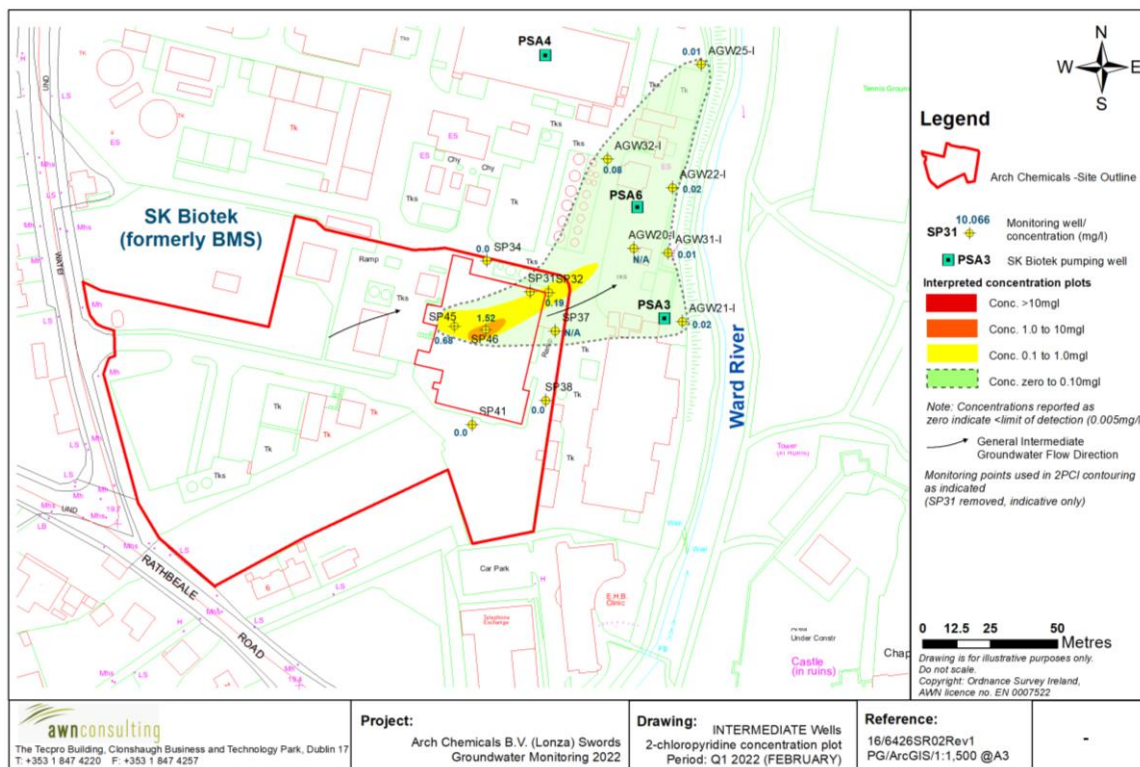
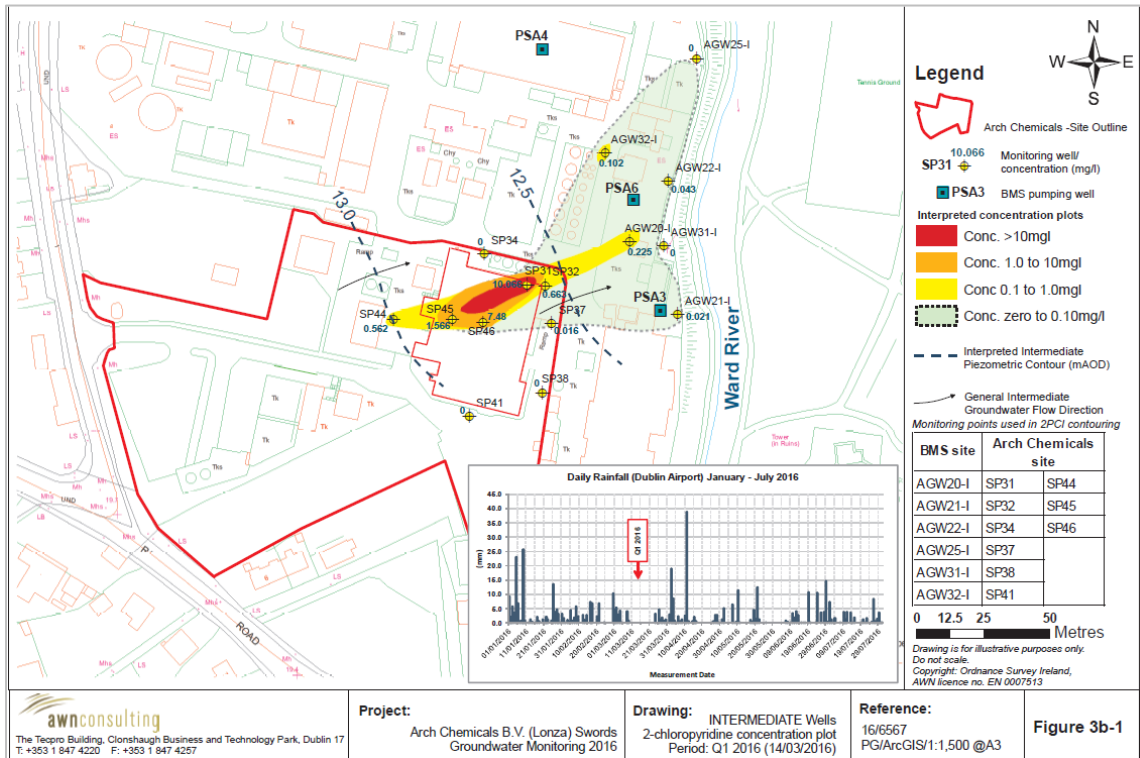
Groundwater elevations presented are relative to Malin Head datum and the interpreted 2-PCI plots are based on reported concentrations to date and sub-categorised into concentration ranges including:

- Zero to 0.1 mg/l (GREEN polygon)
- 0.1 to 1.0 mg/l (YELLOW polygon)
- 1.0 to 10 mg/l (ORANGE polygon)
- > 10 mg/l (RED polygon)

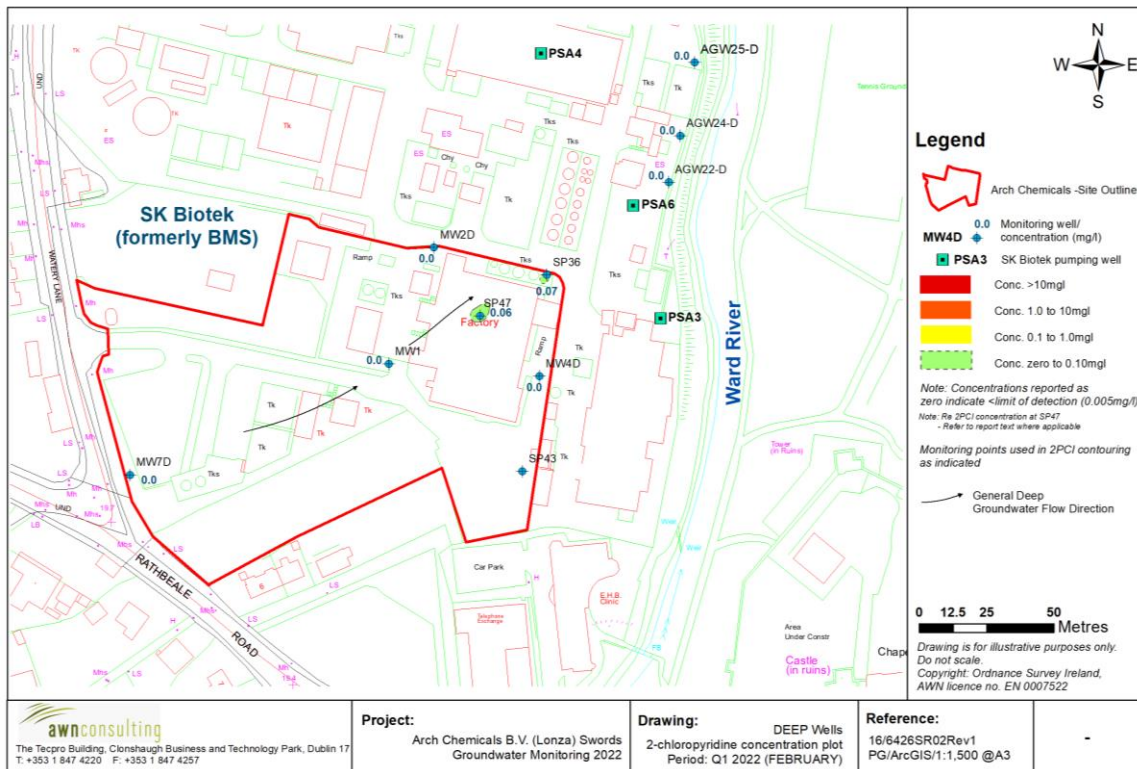
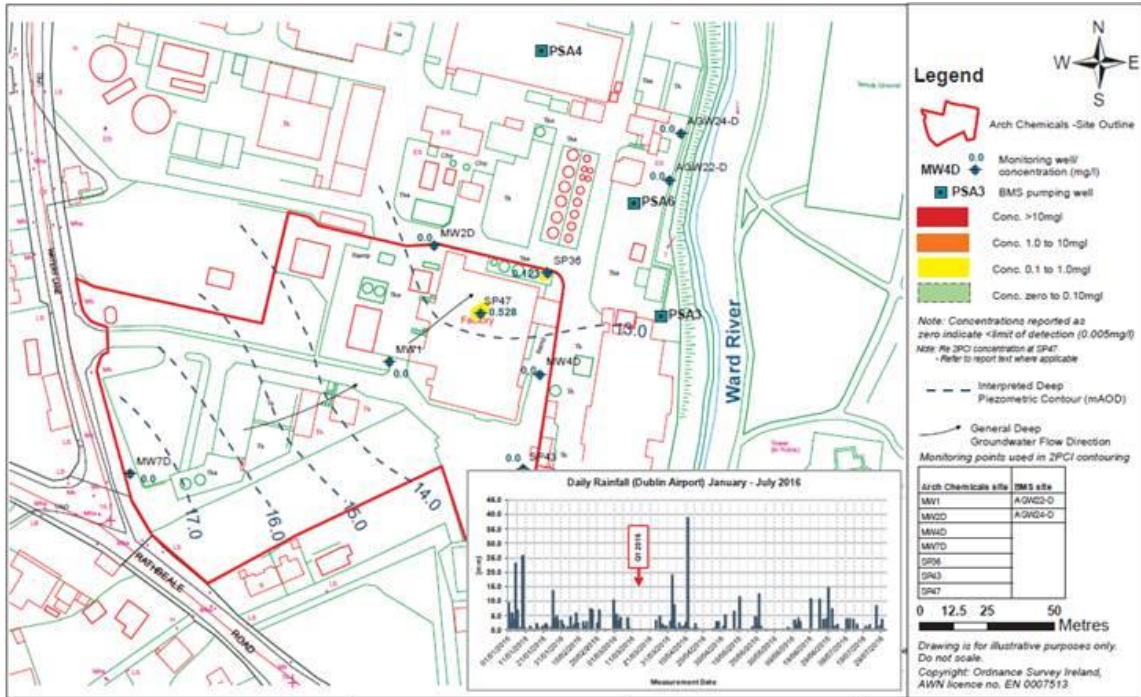


<p>The Tecora Building, Clonsilla Business and Technology Park, Dublin 17 T: +353 1 847 4220 F: +353 1 847 4257</p>	Project: Arch Chemicals B.V. (Lonza) Swords Groundwater Monitoring 2022	Drawing: SHALLOW Wells - 2-chloropyridine concentration plot Period: Q1 2022 (FEBRUARY)	Reference: 16/6426SR02Rev1 PG/ArcGIS/1:1,500 @A3
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Insert 4.1 Shallow plume (interpreted extent) - March 2016 & February 2022



Insert 4.2 Intermediate plume (interpreted extent) - March 2016 & February 2022



Insert 4.3 Deep plume (interpreted extent) - March 2016 & February 2022

4.1.1 2-PCL PLUME

Long-term monitoring using an extensive range of boreholes both on and off site has allowed determination of the plume extent both vertically and horizontally. The plume extent had not changed significantly over time prior to the significant remedial works undertaken in 2017-2018. Insert 4.1, Insert 4.2 and Insert 4.3 above present the [pre-remedial works] interpreted extent of 2-PCI contamination within in the Shallow,

Intermediate and Deep geological horizons, respectively as well as the current (Q1 2022) interpreted plume extent. The interpreted plume has changed significantly due to the bulk excavation works and on-going groundwater pump and treat system in place (refer to Section 4.1.2 below).

A number of (on-site & off-site) groundwater monitoring wells - targeted at Shallow, Intermediate and Deep response zones - were selected for trend analysis in order to examine the evolving 2-PCI plume within the site as well as potential for off-site migration of the contaminant over time and post remediation works completed to date at the Arch Chemicals (Arxada) site. The intervening years since remedial works have centred on active pumping and treatment of groundwater (intercepted along the inferred flow path) prior to authorised discharge (via reference monitoring point SE-1). The key representative groundwater monitoring wells used for contaminant trending include the following:

On-site well points (Arch Chemicals):

Shallow	MW4S
Shallow	MW3/RP3
Shallow	SP33
Shallow	SP35
Intermediate	SP32
Intermediate	SP45
Intermediate	SP46
Deep	SP34
Deep	SP36
Deep	SP47 (borehole with subvertical fracturing at depth)

Off-site well points (SK Biotek):

Shallow	AGW14-S
Shallow	AGW21-S
Shallow	AGW25-S
Intermediate	AGW22-I
Intermediate	AGW24-I
Intermediate	AGW31-I
Intermediate	AGW32-I
Deep	AGW22-D
Deep	AGW24-D

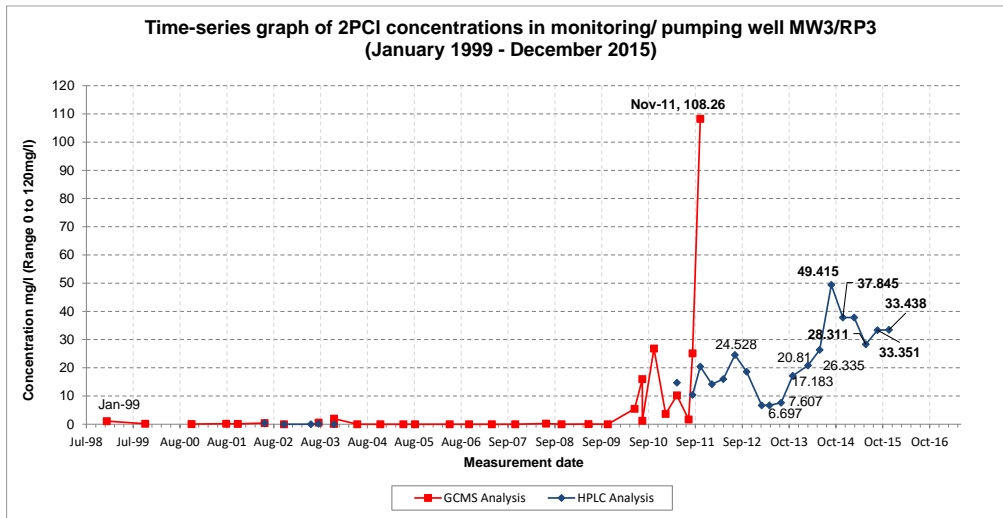
These groundwater monitoring wells were selected based on their location in relation to the historical interpreted groundwater flow orientation from south-west to north-east as well as the interpreted [reducing] 2-PCI contaminant plume crossing the subject site towards the adjacent property i.e. SK Biotek.

4.1.2 TREND ASSESSMENT PRE-REMEDIAL WORKS

Long-term monitoring has allowed determination of the stability of/ reduction in the interpreted 2-PCI plume. An example of the historical monitoring data (2015) is included in Appendix B (in 2016 report) with sampling methodology summarised in Appendix C7 (in 2016 report). Representative trends (from the 2016 report) - which show the 'pre-remedial works' scenario - are presented here to indicate the extent of 2-PCI (mg/l) spatially at the site and off site at the time. These include:

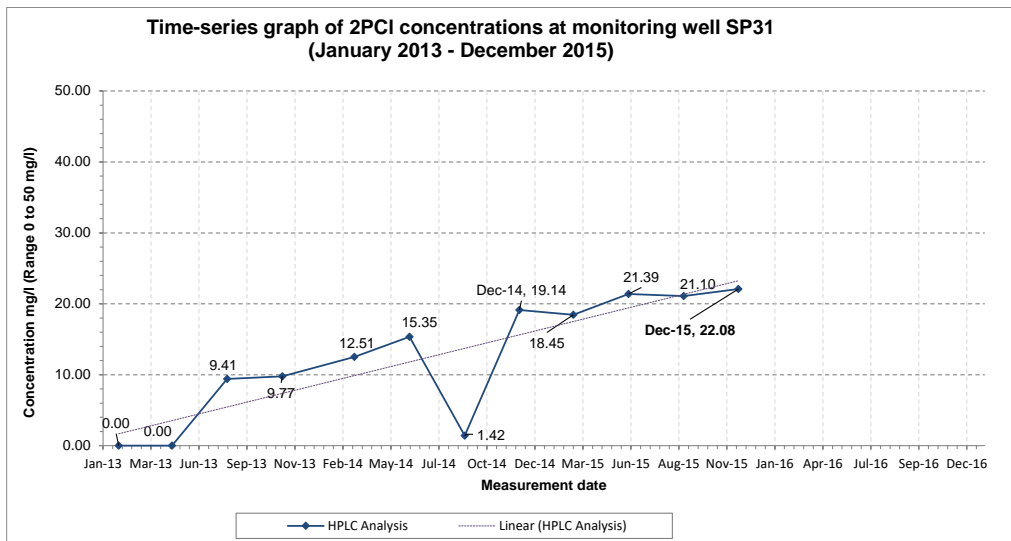
- On-site (S) Shallow well (MW3/RP3) screened in overburden and weathered limestone - located in the NE perimeter of the site and within the interpreted plume profile. A general upward trend [in the Shallow horizon] is evident in the graph

presented leading up to September 2014.



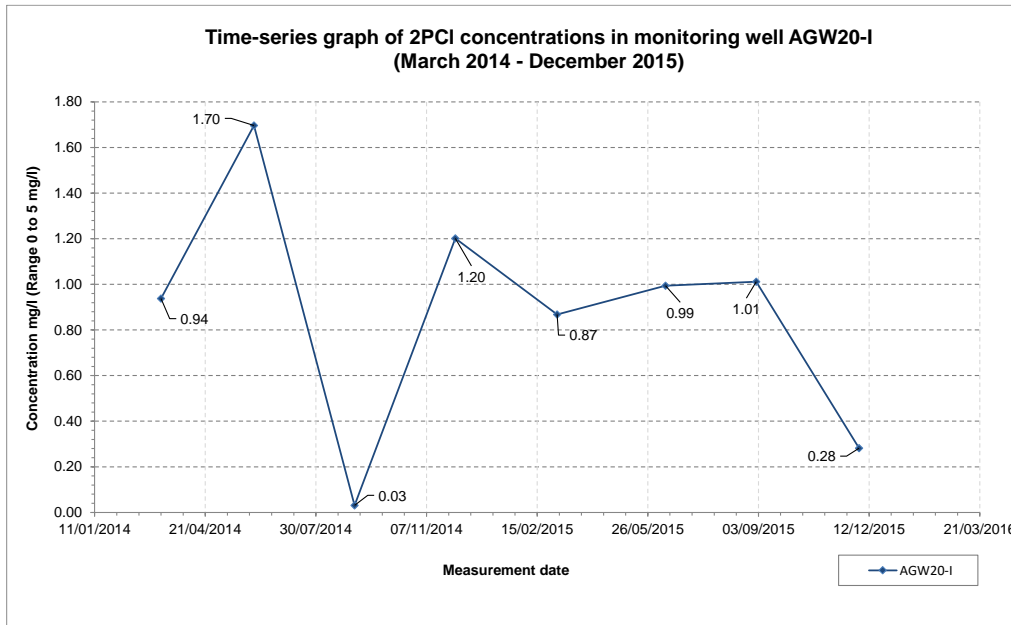
Insert 4.4 Shallow well (MW3/RP3) trend graph 1999-2015

- On-site (I) Intermediate well (SP31) screened in less competent limestone – historically located beneath the MPWB [since removed during excavation works] and within the interpreted plume profile. An upward trend [in the Intermediate horizon] is evident in the graph presented below.

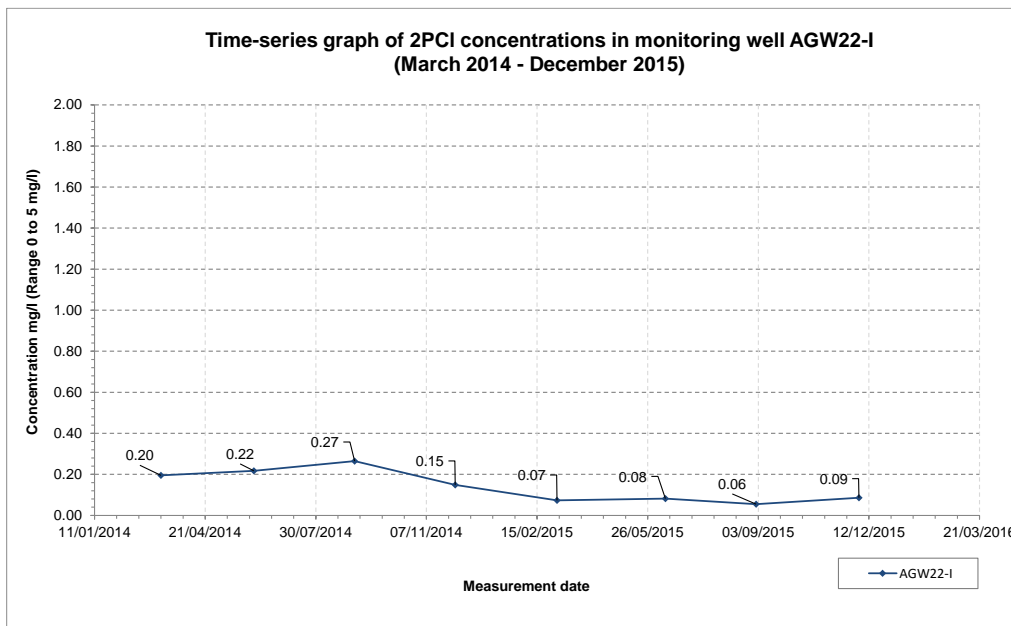


Insert 4.5 Intermediate well (SP31) trend graph 2013-2015

- Off-site (I) Intermediate wells AGW20-I and AGW22-I (below) which are screened in less competent limestone - located at the SK Biotek (formerly BMS site) and within the interpreted plume profile, downgradient.



Insert 4.6 Intermediate well (AGW20-I) trend graph 2014-2015

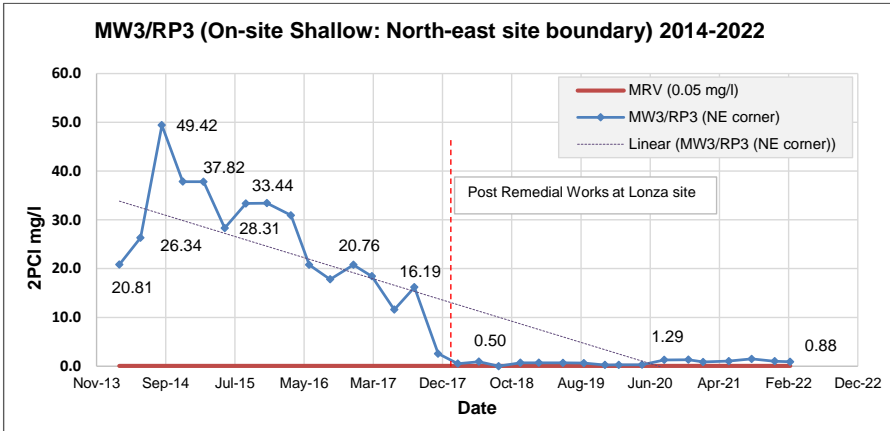
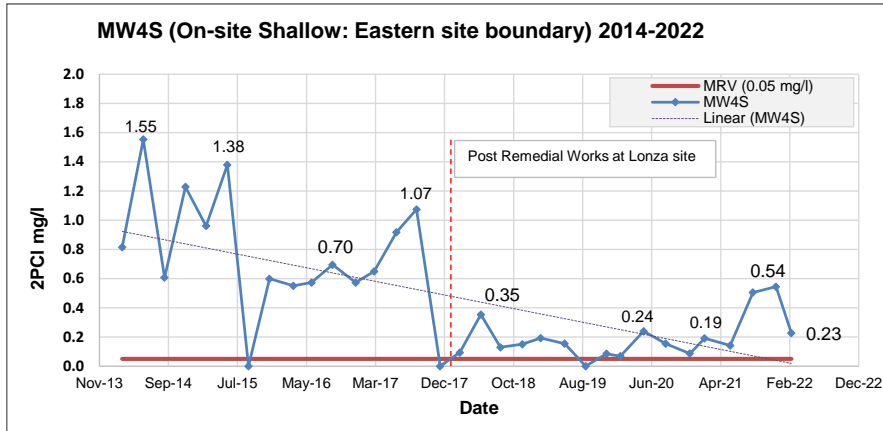


Insert 4.7 Intermediate well (AGW22-I) trend graph 2014-2015

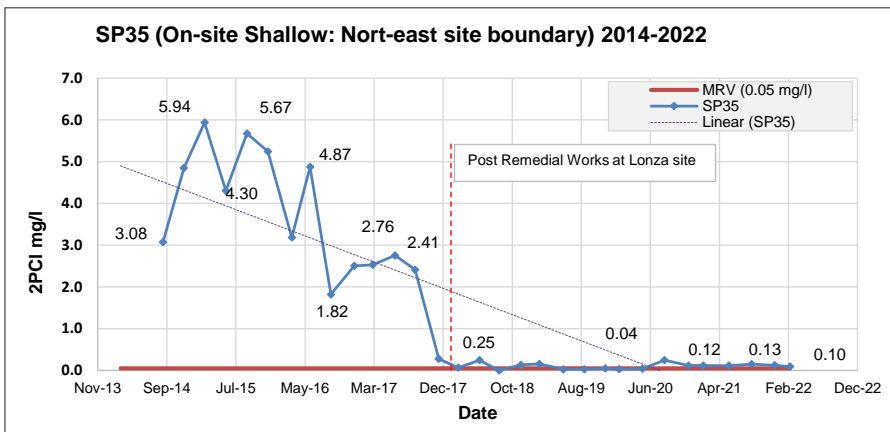
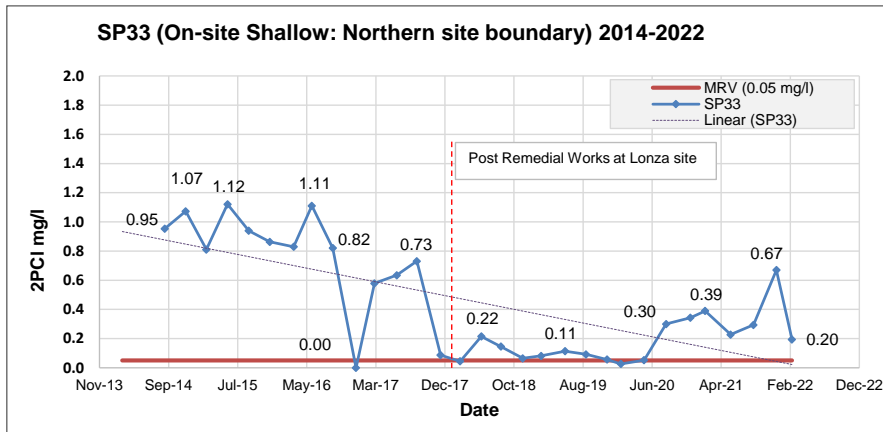
From the trends presented in Insert 4.6 and 4.7 above, it is noted that within the Intermediate (I) horizon the reported laboratory concentrations tend to decrease notably off site and over a relatively short distance (<50 metres) from the residual source at the Arch Chemicals site.

4.1.2.1 On-Site Groundwater Monitoring Wells Trends Post Remediation

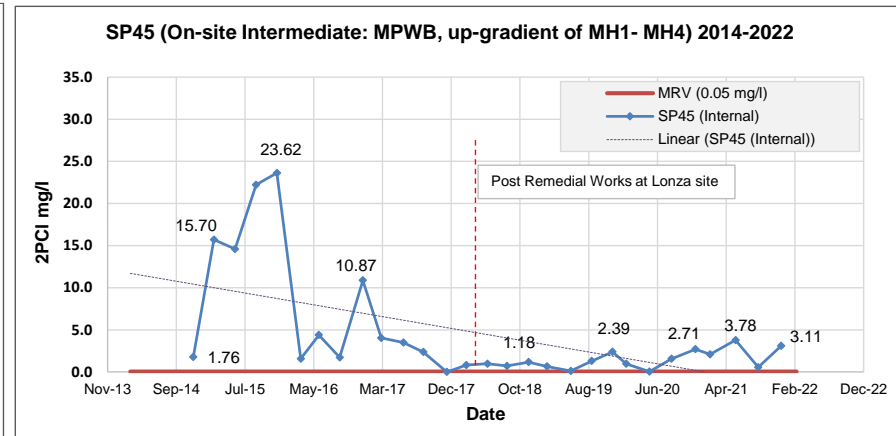
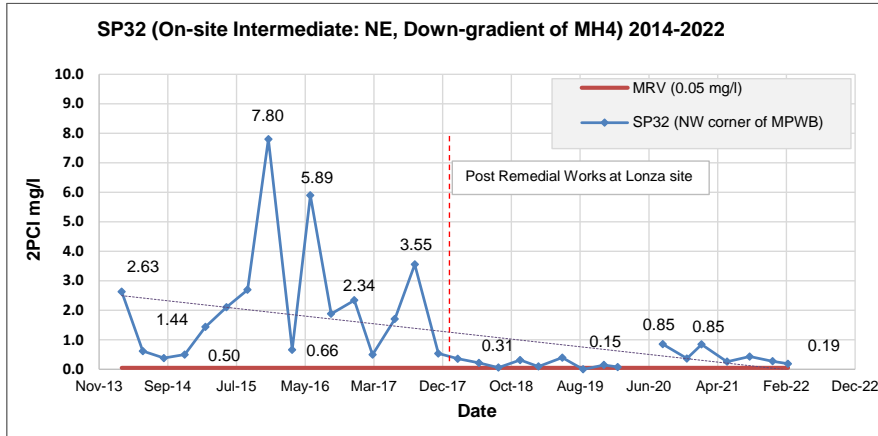
A number of groundwater monitoring wells were selected in order to examine the trends in 2-PCI within the Arch Chemicals boundary as well as the trend off site i.e. downgradient of the pump and treat system. The wells presented below are included based on the key location of same across the subject site and in terms of the local groundwater flow orientation both at the Arch Chemicals site and crossing the adjacent property towards the Ward River.



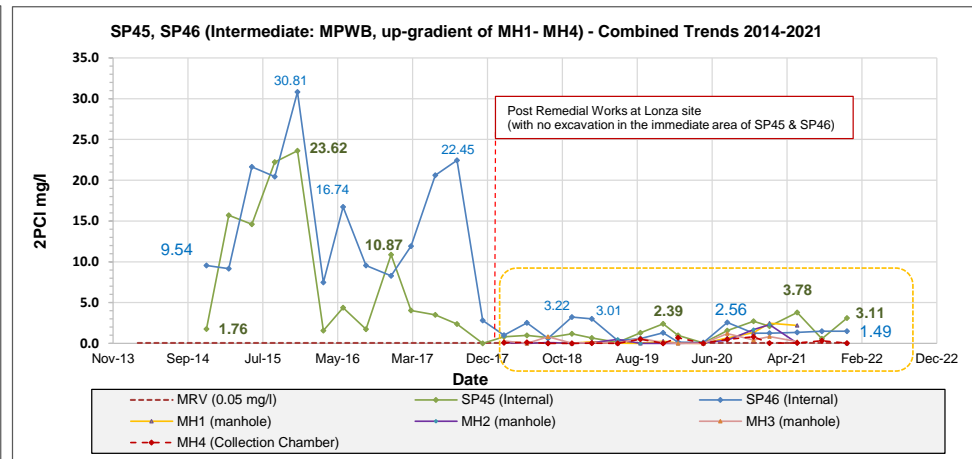
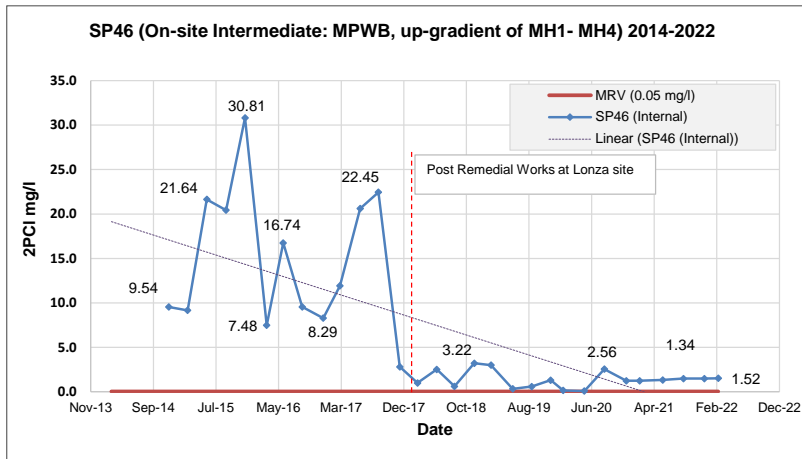
Insert 4.8 Shallow wells MW4S and MW3/RP3 trend graphs



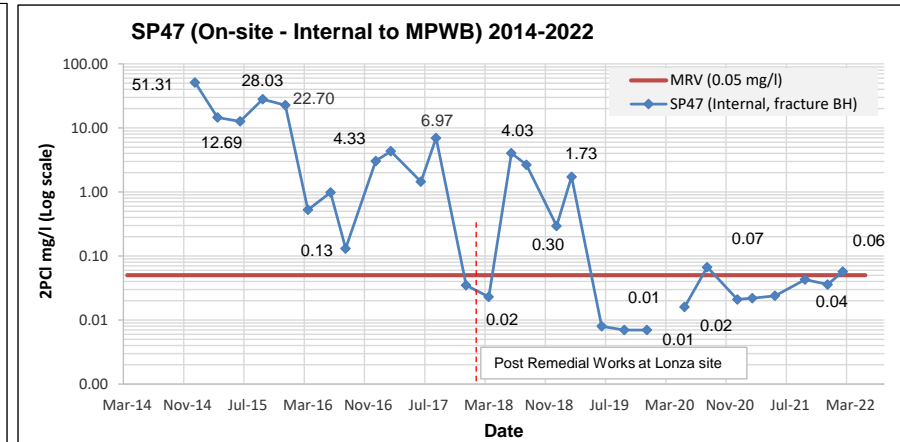
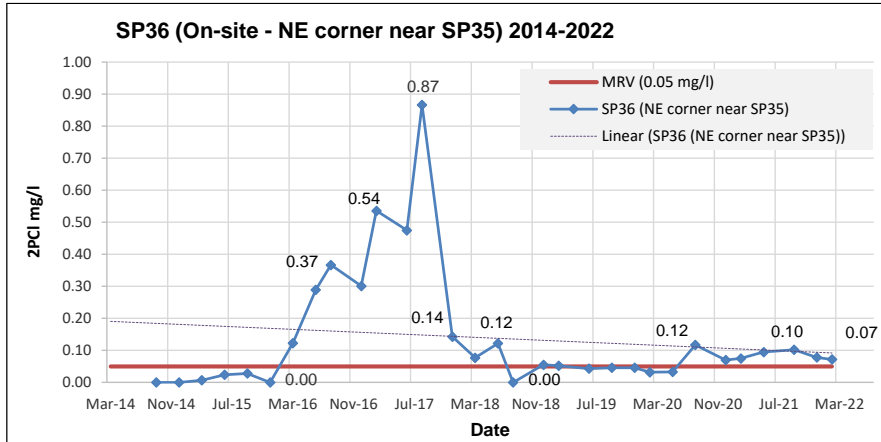
Insert 4.9 Shallow wells SP33 and SP35 trend graphs



Insert 4.10 Intermediate wells SP32 and SP45 trend graphs



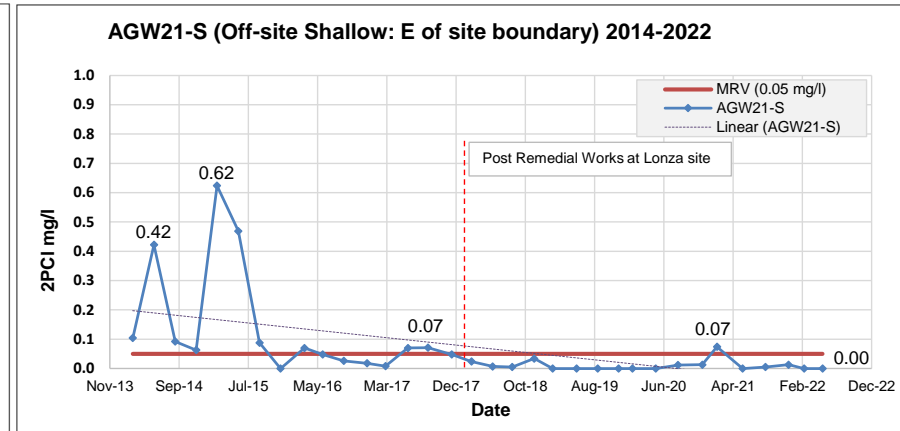
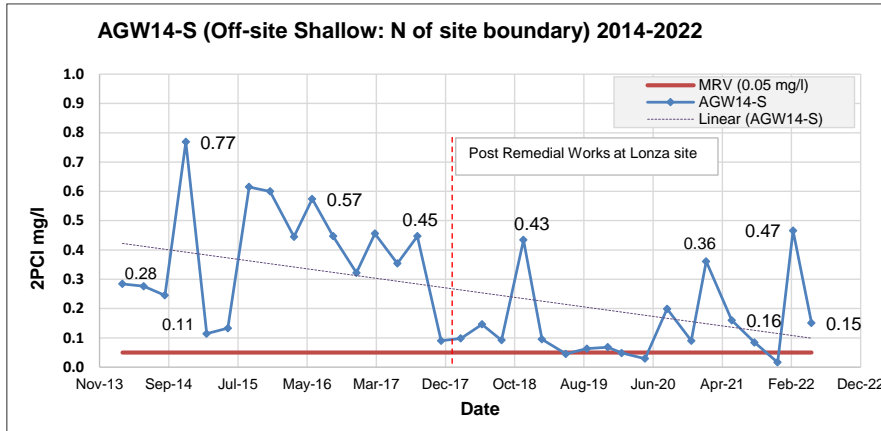
Insert 4.11 Intermediate well SP46 & Combined SP45/ SP46 trend graphs



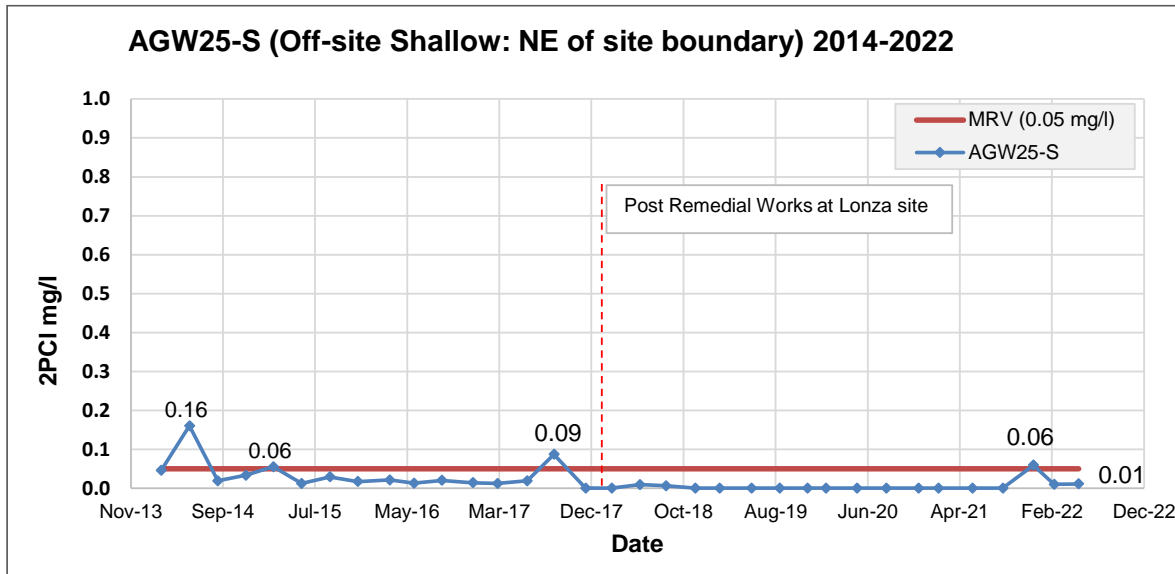
Insert 4.12 Deep wells SP36 and SP47 trend graphs

4.1.2.2 Off-site Groundwater monitoring wells post remediation

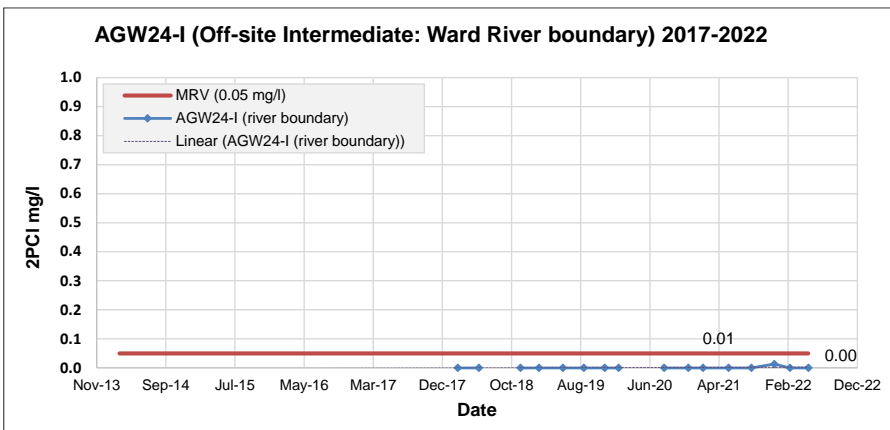
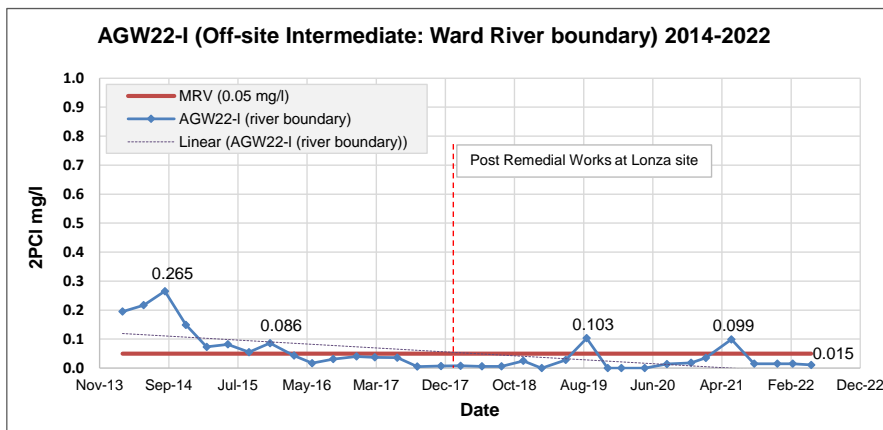
A number of off-site groundwater monitoring wells were selected in order to examine the extent of the plume migration beyond the north-eastern/ eastern site boundary line with the adjacent SK Biotek property.



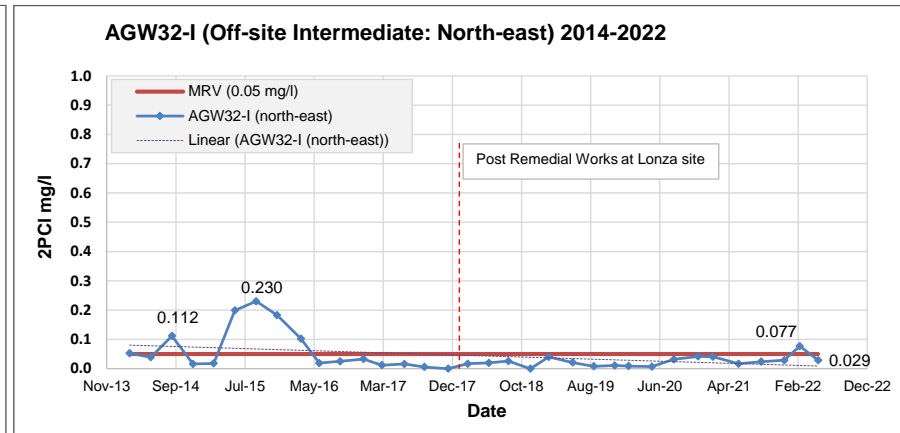
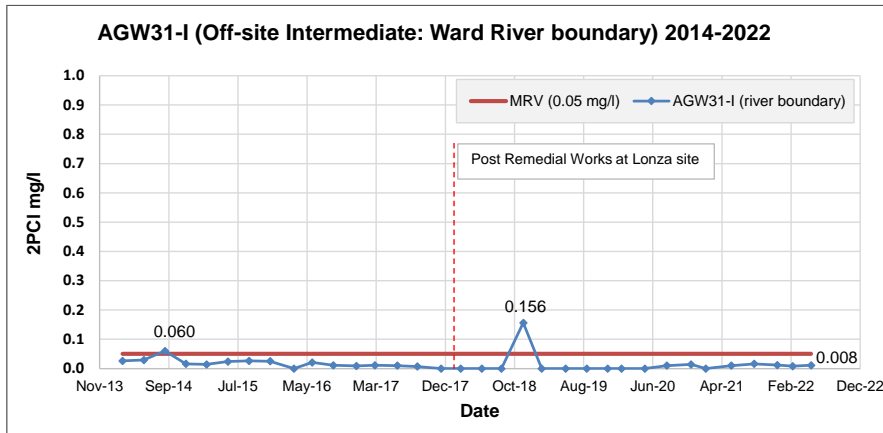
Insert 4.13 Shallow wells AGW14-S and AGW21-S trend graphs. Note AGW14-S is located approx. 70 metres west from the Ward River, while AGW21-S is located approx. 15 metres west from the waterbody.



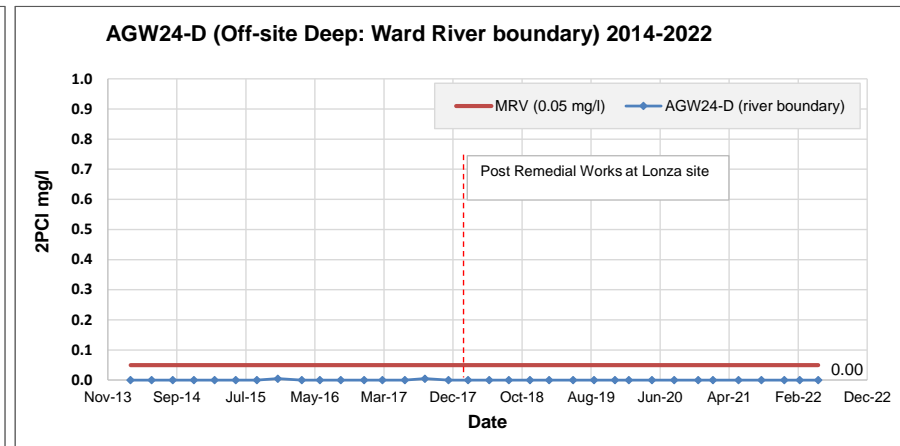
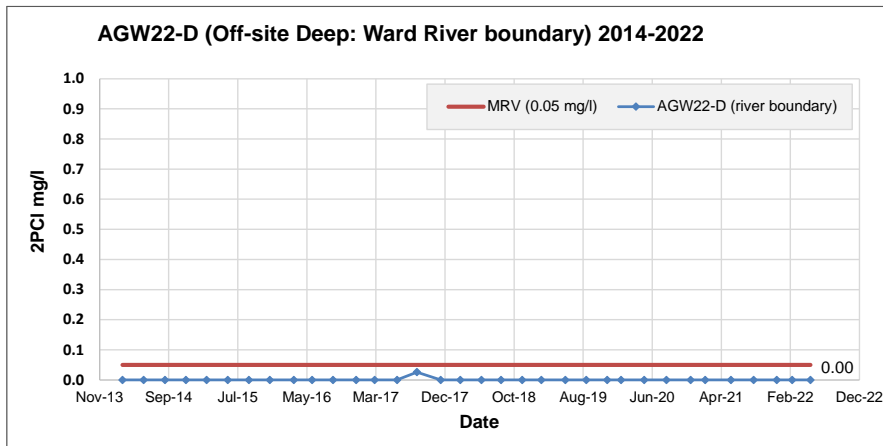
Insert 4.14 Shallow well AGW25-S trend graph



Insert 4.15 Intermediate wells AGW22-I and AGW24-I trend graphs



Insert 4.16 Intermediate wells AGW31-I and AGW32-I trend graphs



Insert 4.17 Deep wells AGW22-D and AGW24-D trend graphs

Overall, the trend analysis for both on-site and off-site shallow and intermediate groundwater monitoring wells is generally recorded as downward with the plume extent decreasing over time due to the recently installed, and continuously operating pump and treat system as well as the mass removal of contaminated soil in 2017/2018 as discussed.

Specifically, some minor fluctuations in reported 2-PCI concentrations continue to be observed at on-site shallow wells MW4S and SP33 at the eastern and northern site boundary lines, respectively, and at the off-site well AGW14-S for which the general profile, albeit with a downward trend, indicates some continued fluctuations at both the pre- and post-remedial system installation. This may be due to localised stagnant/ limited groundwater movement at this [off-site] well point. However, there are no exceedances noted at AGW21-S, AGW25-S, AGW22-I, AGW24-I, and AGW31-I which are located at the Ward River boundary within the SK Biotek facility.

With regard to Intermediate wells, there are continued minor fluctuations in reported 2-PCI values for on-site wells SP45 and SP46 located within the Arxada site (beneath the MPWB and down-gradient of the external remediated [BHY] area). Notwithstanding this, a general downward trend is recorded for both wells and a significant decrease in the contaminant is noted following the installation of the pump and treat system nearby which taps into the shallow limestone rock here.

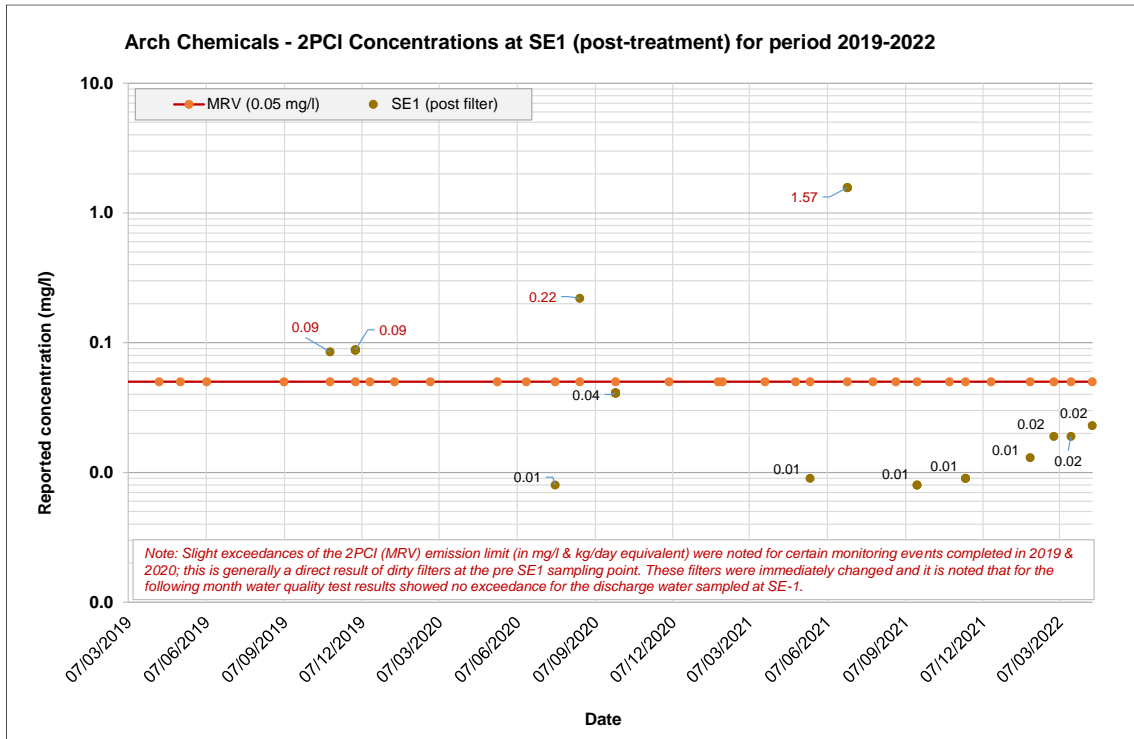
Finally, in terms of monitored values at deep wells on site, a significant decrease in reported concentrations for 2-PCI at SP47 (up to three orders of magnitude reduction with recent values reported below/ very slightly above the MRV 0.05mg/l) and the hydraulically down-gradient well SP36 is noted following installation of the pump and treat system. Although a downward trend is observed for both, some minor fluctuations in reported 2-PCI are shown for SP36 and, as highlighted to data as part of the overall CSM, this well may continue to pick up groundwater passing from SP47 due to sub-vertical fracturing recorded at this particular deep borehole. Furthermore, based on the available data that there is no evidence of off-site migration in the deep bedrock groundwater monitoring location (both on-site and off-site). This confirms as part of the CSM that the deep bedrock is not a pathway.

4.1.2.3 Discharge Licence Monitoring (Pump & Treat System)

The approved discharge to sewer at monitoring point SE-1 is on-going with treated water emanating from the pump and treat system via carbon filtration. Four (4) no. slight exceedances of the 2-PCI emission limit (0.05 mg/l) were recorded since the activation of the system. This was due to the filters getting dirty/ clogged with fines in pumped groundwater. On each occasion, the filter was immediately changed and for the following month's water quality sampling no exceedance was once more reported for SE-1 samples. It is noted, however, that despite the water quality exceedances discussed here, the discharge limit in terms of volume equivalent (kg/day) was not exceeded.

In terms of the remaining monthly sampling events, all recorded 2-PCI concentrations were either below the respective laboratory LOD which is 0.005 mg/l or below the discharge licence concentration limit of 0.05 mg/l. Insert 4.18 below presents data collated for SE-1 to date for 2-PCI.

The pump and trench system provides some level of containment but based on the low pumping rates as shown since 2018/2019 (c. 2.11 m³/day [770.15 m³/day], recovery of 2.48 mg/L/year [0.11 kg/year]), the main control is the low permeability nature of the clay in which the residual contaminant is contained and the fact that the recharge rate is very low.



Insert 4.18 Pump & Treat System for period 2019-2022

4.2 IMPACT ON RECEPTORS

Table 3.3 above presents the plausible pollutant linkages considered as part of the GQRA. Pre-remedial works, groundwater monitoring has confirmed that localised contamination of the shallow limestone aquifer was present (Insert 4.1, Insert 4.4). Completion of the DQRA has confirmed that a long-term localised impact on the shallow aquifer will occur despite the planned corrective action. This is due to the very slow migration of the plume in the aquifer due to natural condition present at the site and persistence of 2-PCI in the environment.

However, as the plume is very localised, it is not likely to impact on the ability of the Swords Water Body to achieve ‘Good Status’. A comparison of the extent of the [historical, 2015] plume at the Arch Chemicals site against the subcategory Industrial Facility (P0014-03) (see Insert 2.6 above) indicates an impact spatially of c. 1/8 of this subcategory body. This is significantly less when compared against the entire Swords Water Body.

Groundwater currently discharging from the shallow aquifer (S) may marginally exceed the threshold of 0.05 mg/l 2-PCI based on a conservative estimate of the off-site plume (see Insert 4.1 above) rather than a direct borehole measurement as there is no representative shallow (S) borehole available at the immediate downgradient river boundary. Monitoring shows there is generally no/ limited current exceedance in the intermediate limestones (I) or deeper more competent limestones (D). In addition, monitoring within the Ward River over time has not shown any exceedances of 2-PCI above detection limit (refer also surface water quality data within the monitoring report, Appendix B in 2016 report). As such, there is no measure of any water quality impact due to any localised discharge of 2-PCI contamination. Furthermore, the flow in the river has been estimated to provide a 40-fold dilution effect. Depletion of 2-PCI would also be more rapid within the river due to volatilisation occurring in surface water.

Following the installation of the trench and recovery system, it was estimated [in 2016]

that there would be a slow reduction in the off-site shallow plume and over time a corresponding reduction in the impact on the local aquifer and subsequently the potential for impact on the Ward River; this is further addressed under Section 6.0 and Section 7.0.

Flux Assessment

Mass flux calculations were determined from groundwater quality data at the Arch Chemicals site, in addition to permeability (k) and hydraulic gradient values derived on-site. For the modelling exercise, the natural movement of 2-PCI within the groundwater (i.e. saturated zone) was treated as a 'conservative tracer' and its concentration plume movement was monitored over time.

2-PCI concentrations over time were obtained from the quarterly (borehole) groundwater quality sampling events. Total mass flux across one or more transects of the tracer plume were calculated using a mass flux toolkit developed by GSI Environmental Inc. (2013, USA, in 2016 report). Each transect was divided into grids, each of which was assigned an average tracer concentration.

The calculated mass flux (g/ day) for both zones was also tabulated for individual transects at different time periods. A summary of the key results from mass flux calculations completed is included in *Stage 2.1 – Outline Corrective Action Strategy; September 2015*. A summary of the derived [modelled] flux is as follows:

- Shallow Horizon (S) - up to ~1g/d leaving the site boundary. No accurate estimate was available adjacent to the Ward River due to lack of monitoring data in this horizon along the river boundary.
- Intermediate Horizon (I) - up to ~1g/d leaving the site boundary and ~0.04g/d observed at the Ward River boundary.
- No mass flux assessment was undertaken for the Deep zone as generally no concentrations of 2-PCI were detected within the Deep pathway.

In summary, the source area was estimated [conservatively] at ~158Kg residual 2-PCI and assessment of off-site contaminant flux indicated <1kg/yr. This supports the conclusion that there would be no likely impact on the Ward River receptor.

Summary of impact on groundwater body status in relation to S.I. No. 9 of 2010 (amended S.I. No. 366/ 2016)

Based on the extent of the 2-PCI plume and concentration present, the residual contamination at the Arch Chemicals site was considered unlikely to impact on the Groundwater Body status as outlined in S.I. No. 9 of 2010 (amended S.I. No. 366/ 2016).

The most relevant test to determine impact on the groundwater body as described by *Craig, M. and Daly, D. (2010)*¹ is the General Chemical Assessment test. An extract from the assessment approach is described below and based on our understanding of the local area of contamination at Arch Chemicals compared to the full extent of the Swords Water body, there is no likely impact on the water body status due to the localised nature of the plume.

'Test 5: The General Chemical Assessment Test identifies groundwater bodies where widespread deterioration in quality has, or will, compromise strategic use of groundwater.'

¹ Ref: Craig, M. and Daly, D. (2010). *Methodology for establishing groundwater threshold values and the assessment of chemical and qualitative status of groundwater, including an assessment of pollution trends and trend reversal*. Environmental Protection Agency.

The status of the groundwater body is Poor if there is a widespread exceedance of relevant groundwater TVs or quality standards (UKTAG, 2008a). Key concept: Status is determined through an assessment of the areal extent of a groundwater body exceeding a TV for a pollutant. It is only conducted for determinands for which: an EU prescribed standard is set; or the risk characterisation process has indicated that pollutants may cause significant impairment of human uses of groundwater. Threshold Values: An appropriate percentage of the EU prescribed standards for nitrates and pesticides or a use-related standard that is appropriate for existing or planned use of the groundwater body. The conditions for good chemical status are not met when: Threshold Values are exceeded at individual monitoring points, and a representative aggregation of the monitoring data at the groundwater body scale indicates that there is a significant environmental risk or a significant impairment of human uses of the groundwater body. (UKTAG, 2008a).

For known contaminated areas an assessment is undertaken to determine whether the extent of the pollution is significant enough to impact on the status of the groundwater body.

An area weighted aggregation of the contaminant plume is calculated from using monitoring data from the site:

Area Weighted Average Concentration = $((\text{Polluted area} \times \text{Estimated average concentration in polluted area}) + (\text{area of the remainder of the GWB} \times \text{Estimated average concentration in this area})) / \text{Total GWB area}$

4.3 CHEMICAL STATUS OF GROUNDWATER BODY

The site is located within the Swords Groundwater body and the subcategory Industrial Facility (P0014-03). Section 2.2 presents the relevant mapping and current status (see also Insert 2.5 above). This is further summarised below.

WFD Risk Scores (GWB Score)

- Industrial Facility (P0014-03) 'At risk of not achieving good status' Risk Score:1a
- Swords 'Expected to achieve a good status' Risk Score: 2a

WFD Status

- Industrial Facility (P0014-03)
- European Code: IE_EA_G_062
- Name: Industrial Facility (P0014-03)
- WFD Overall Status: Poor (GW)
- Swords
- European Code: IE_EA_G_011
- Name: Swords
- WFD Overall Status: Good (GW)

A robust CSM has been prepared based on a detailed site assessment and is included in Section 3.0 above. As indicated in Insert 3.4, concentrations of 2-PCI which were >100 times the compliance concentration of 0.05 mg/l were present within the Shallow (S) soils beneath the MPWB on site and were conservatively estimated to extend off site and downgradient for c. 50 metres. However, in the less competent limestone aquifer, concentrations of 2-PCI, which were >100 times the compliance concentration of 0.05 mg/l, were present beneath the MPWB on site but did not extend beyond the eastern site boundary. The EPA guideline considers that if the PCOC concentrations in groundwater are greater than 100 times the GAC, or higher, then this could result in one or more of the WFD objectives not being met in the respective GWB. However, as the extent of the elevated contamination in the bedrock aquifer is very localised, it was not considered that the overall status of the GWB would be impacted by this historical impact. In addition, as there is no longer a direct discharge of 2-PCI to ground -as the site remains

closed – and significant excavation works have been undertaken to date, then the 2-PCI trends in concentration have subsequently decreased over time and will continue to decrease in both on-site and off-site groundwater monitoring locations.

As stated in Section 4.1 above, the overall trend analysis for both on-site and off-site groundwater monitoring wells is generally recorded as ‘downward’ post-remedial works with the plume extent decreasing over time due to the recently installed [on-going] pump and treat system as well as the mass removal of contaminated soil in 2017/2018 as discussed. The reported 2-PCI concentrations are decreasing below the minimum reporting value (MRV) which is being used as the remedial target value. Notwithstanding this, although a limited number of wells on site and off site show some [intermittent] minor fluctuations in reported 2-PCI concentrations as presented and discussed in Section 4.1, in general there is a notable difference in current reported values when compared with the ‘pre-remedial works’ scenario.

The chemical status of a body of groundwater which meets all the conditions for Good Chemical Status is set out in the Groundwater Regulations 2010, Regulations 39 to 43. The Arch Chemicals facility has remained closed since 2013 which indicates that the residual source is limited and finite. The majority of the bulk contaminated subsoil was removed during the large-scale remediation works in 2017/ 2018. Furthermore, the pump and treat system which has been active since late 2018 is treating the contaminated groundwater flowing under gradient to the main collection manhole (MH4). Unfortunately, there is a localised area under the MPWB which cannot be accessed due to structural constraints within the [MPWB] building.

In summary, there is no deterioration in the overall chemical status of the Groundwater Body as well as no short- or long-term risk to human health and the environment.

5 REMEDIAL STRATEGY

A report entitled ‘*Corrective Action Feasibility & Design Report, Stage II, Stage 2, 1*’ AWN, September 2015 was provided to The Agency. This report outlined the review of remedial options and the planned remedial approach to the Arch Chemicals site at the time. Further assessment of the remedial approach is outlined in a second report, also issued to The Agency, entitled ‘*Corrective Action Feasibility & Design Report, Stage II, Step 2.2*’, April 2016.

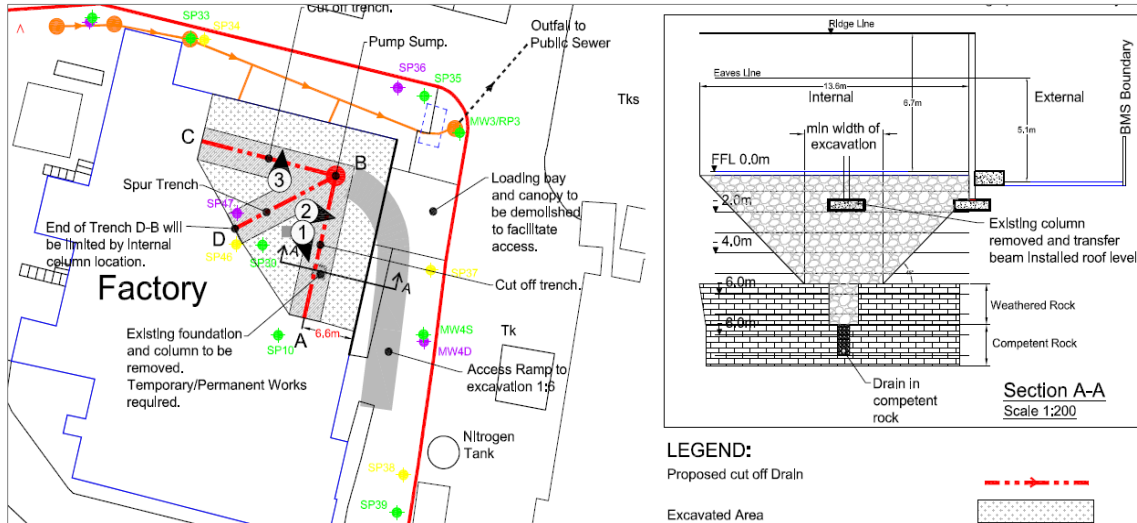
The programme for remedial works was scheduled to commence (subject to contract approval) in February 2017. However, works commenced in October 2017 due to the tender process and the availability of the construction contractor. Works were completed fully in February 2018 with the pump and treat system active from late 2018.

The remedial strategy proposals discussed to date are to continue with quarterly groundwater monitoring across the Arch Chemicals (Arxada) facility in addition to the collection of representative water quality data from the off-site downgradient (SK Biotek) facility. This will allow the examination of the plume reduction spatially and over time. It is recommended that the number of groundwater monitoring locations be reduced, i.e. further targeted and based on the ‘post-remedial works’ results for both the Arch Chemicals facility and adjacent property (see also Section 4.1.2).

Currently, the pump and treat system (via carbon filtration) although performing well, provides only some level of 2-PCI containment. The system is pumping contaminated groundwater for treatment and collects groundwater from the interpreted flow direction across site and therefore is tapping directly into the interpreted contaminant plume. Since the operation of the pump and treat system (2019-2022) the majority of monthly SE-1 samples tested at EMT laboratory were below the MRV threshold value of 0.05mg/l for 2-PCI (refer Insert 4.18 above). However, four (4) no. slight exceedances of the 2-PCI

emission limit (0.05 mg/l) were recorded since the activation of the system. This was due to the filter getting dirty and clogging up rather than a reflection of any shortcoming in terms of the remedial strategy, i.e. once the filter was immediately changed typically the following test result showed no exceedance for the water sample collected at SE-1.

Insert 5.1 depicts the original trench profile (plan and section) towards the main collection chamber (i.e. MH4, at location B in the insert). This insert should be read in conjunction with Insert 3.1a above.



Insert 5.1 Current Pump and Treat system (via carbon filtration) at Arch Chemicals

6 GROUNDWATER COMPLIANCE MONITORING

As part of the original report (2016) Figure 6 and Figure 6a presented the groundwater monitoring programme and proposed compliance boreholes, respectively, at the time. A table showing the boreholes monitored in 2016 and analysis undertaken at the time is included in Appendix B [of the 2016 report version]. However, following review of contaminant trends to date and spatially across both the Arch Chemicals and adjacent property, a further review of the monitoring well locations is proposed -refer Section 7.0 below.

On-going monitoring as per the existing monitoring programme was planned for 5 years post remedial works to confirm the expected reduction in 2-PCI discharge off site within the shallow soil and weathered rock (S) and overall impact on the plume within the intermediate less competent limestone (I). Post remediation, monitoring data over two years could be used to update the model estimates of ‘time to reach 0.05 mg/l within the off-site aquifer’.

Figure 6a (in 2016 report) presented the proposed compliance monitoring boreholes back in 2016. These were chosen to be protective of the groundwater quality discharging to the Ward River. It is not best practice to locate compliance boreholes within the site plume, however there are no available compliance boreholes screened in the shallow soils and weathered rock horizon between the site and the river boundary. The downgradient available boreholes on the SK Biotek (former BMS) are mostly installed in the (I) intermediate less competent limestones, located 30-50 metres down-gradient of the Arch site. It was therefore also proposed to use the shallow and intermediate boreholes outside of the trench area (as shown above) as well as the intermediate boreholes adjacent to the river for compliance monitoring.

As there is such a long delay in impact at the down-gradient river boundary for the (S) shallow horizon (c.100 years to reach 0.05 mg/l) due to the natural conditions present, it

was proposed to set a threshold concentration at the site boundary. Based on the RISC4 model results (see Table 6.1 below), a concentration of 10 mg/l 2-PCI at the site will result in a concentration at the river boundary of 0.092 mg/l after 100 years based on an off-site K value of 0.1 m/day or <0.05 mg/l after 30 years based on an off-site K value of 1 m/day. *Note: the variation in K is presented based on lack of available data on the shallow horizon off site as there is no shallow borehole data present in the direction of the down-gradient plume (on the SK Biotek/ BMS site).*

Timeslice (years)	Well located at river boundary (S Horizon)			
	Post remedial works (K = 0.1 m/day) mg/l	Post remedial works (K = 1 m/day) mg/l	Do nothing scenario (95% <) mg/l (K = 0.1 m/day) mg/l	Do nothing scenario (50% <) mg/l (K = 0.1 m/day) mg/l
10	0.0021	1.9	1.998	0.174
50	0.82	0.00014	1.717	0.152
100	0.092	0	1.180	0.101
200	0.0003	0	0.379	0.025

Table 6.1 Risk Assessment: Concentration at river boundary well for the post remedial scenario compared with the 'Do Nothing' scenario based on a concentration of 10 mg/l in groundwater immediately downgradient of the trench

It was therefore proposed to use a trigger concentration of 10 mg/l within the shallow horizon wells (S) at the site boundary. However, a review of threshold concentrations would be undertaken following a review of monitoring data post remedial works as [it was concluded that subsoil] removal may result in a greater reduction in the residual mass on site -this has been presented in this updated Hydrogeological Review. Based on the current data of c. 1 mg/l at the site boundary after 5 years (post remediation) we are closer to the scenario of K = 1 m/day (1.9mg/l) and the likely achievement of remediation within 50 years.

Following 5 years of post-remedial monitoring and confirmation of model findings, a reduced monitoring programme was proposed to be agreed with the EPA. This is also presented in the recommendations below.

7 SUMMARY, CONCLUSIONS & RECOMMENDATIONS

A comprehensive CSM has been developed for the site based on extensive site assessment completed to date. The assessment has followed the *EPA Guidance on Assessment of Discharges to Ground and Contaminated Land & Groundwater Risk Assessment Methodology*. The primary pathway is the overburden and shallow limestone (weathered). Monitoring has confirmed that there is no evidence of an off-site pathway within the deeper more competent limestone.

2-PCI is the priority contaminant of concern. This has been determined to be hazardous due to its persistence in the environment. A compliance concentration of 0.05 mg/l has been determined based on eco-toxicity assessment and the minimum threshold at which there is a high degree of laboratory confidence.

There is no on-going direct discharge of 2-PCI as the Arch Chemicals facility which formally ceased operations back in 2013. Leaching of residual contamination is reduced at the site as the contaminated area is covered and the down-gradient plume is mostly capped with impermeable surfacing, thereby minimising infiltration potential.

Post remedial works in 2016, residual contamination at this closed facility comprises an area of contaminated low permeability clayey till and weathered rock located beneath the former Main Production and Warehouse Building (MPWB) extending over an area of c. 30m x 30m x (~2-5m deep) with a residual 2-PCI mass of ~63 - 78 kg (estimated for ~5,085 cubic metres subsoil).

Monitoring since 2018/2019 has shown that the concentration of the plume on site has significantly reduced. The off-site plume appears to be close to, if not less than 0.05 mg/l at the Ward River showing that there is no evidence of current or long-term risk to the Ward River. Monitoring within the Ward River over time has shown no exceedance of 2-PCI concentration above detection limit, i.e. no measurable impact on the receiving water quality. As such, there is no potential for impact on the conservation objectives of Malahide Estuary Natura 2000 site located ~1.09 km north-east of the site. It should also be noted that the impact assessment has not considered the significant dilution effect within the river or reduction due to volatilisation of 2-PCI in surface waters.

The pump and treat system provides some level of containment but based on the low pumping rates as shown since 2018/2019 (c. 2.11 m³/day) recovery of 2.48 mg/L/year [0.11 kg/year], the main control is the low permeability nature of the Clay in which the residual contaminant is contained and the fact that the current recharge rate is very low. The modelling undertaken in 2016 (Table 6.1) indicated that a period of c.100 years would be required for remediation of the site based on a migration rate of 0.1m/day. Based on the monitoring to date and the understanding, the characteristics of the residual soil in which the contamination is contained and the fact that recharge is low due to capping, there is no change anticipated in terms of the period for the whole site to be mitigated to 0.05 mg/l. However, the monitoring results and assessment of flow rates since 2017 does indicate that there is no perceptible risk to the off-site aquifer and Ward River while the site remains undisturbed.

The corrective measures undertaken comply with the criteria set out in The Agency's *Guidance on the Authorisation of Discharges to Groundwater* and comply with the requirements of S.I. No. 9 of 2010 (amended S.I. No. 366, 2016) as follows:

- As the site is closed and all raw material and waste has been removed from site, there is no on-going direct discharge of hazardous substances to ground;
- Current trend assessment of selected key groundwater monitoring wells (on-site and off-site shallow, intermediate and deep wells) are showing a notable] downward trend profile and the corrective measure have resulted in significant 2-PCI plume reduction; Concentrations have decreased close to or below the MRV threshold value of 0.05 mg/l.
- The extent of contamination both vertically and horizontally is very localised compared with the extent of the Swords Groundwater Body, i.e. it is not impacting on the overall assessment of status of this water body; and
- It is concluded that groundwater monitoring and post-treatment sampling will continue until otherwise directed by the Agency.

The following recommendations are proposed and are based on the current trend assessment and the findings with regard to water quality spatially at the site and in the context of the post-remedial works stage:

- It is recommended that the current analytical suite used for the site-wide groundwater quality monitoring be continued however at a reduced number of strategic monitoring wells on site (see further below). To date the following key analytes, which relate directly to the remedial strategy, have been tested for:

- Metals, dissolved [Arsenic, Cobalt, Copper, Nickel, Phosphorus, Zinc]
 - Other [2-Chloropyridine, Sulphate as SO₄, Chloride, Ortho Phosphate as PO₄, Ortho Phosphate as P]
 - Field [pH, Electrical Conductivity, Temperature, ORP]
- It is proposed that these analytes be monitored quarterly (Q1-Q4) as per the IE licence for the [closed] facility.
 - It is recommended that the number of groundwater monitoring locations, both on-site and off-site and Shallow - Intermediate - Deep type, be reduced based on the remedial works completed back in 2017/ 2018, historical and current [positive] water quality data for the site and the on-going pump and treat system (via carbon filtration) and the significant reduction of 2-PCI concentration within the shallow and intermediate plumes at the Arch Chemicals B.V. site.

Arch Chemicals site: It is proposed to monitor key groundwater monitoring wells based on their location in relation to the interpreted contaminant plume and [unchanging] groundwater flow direction (i.e. upgradient and downgradient of the remedial works area and MWPB as well as at strategic points along the eastern and northern boundary lines of the [inactive] site).

SK Biotek site: It is proposed to reduce the number of [off-site] groundwater monitoring wells located within the [active] SK Biotek facility. This reduction is based on water trend assessment for the key contaminant 2-PCI over time and location in terms of the Ward River (potential receptor) and interpreted groundwater flow direction to the north-east.

In summary, the following groundwater monitoring wells are recommended for future monitoring until further discussed with the Agency:

On-site well points (Arch Chemicals):

Shallow	MW7S (upgradient, control)
Shallow	MW4S
Shallow	MW3/RP3
Shallow	SP33
Shallow	SP35
Intermediate	SP32
Intermediate	SP34
Intermediate	SP45
Intermediate	SP46
Deep	MW7D (upgradient, control)
Deep	SP36
Deep	SP47 (borehole with subvertical fracturing at depth)

Off-site Monitoring points (SK Biotek and Ward River):

Shallow	AGW14-S
Shallow	AGW19-S
Shallow	AGW21-S
Shallow	AGW23-S
Shallow	AGW25-S
Intermediate	AGW21-I
Intermediate	AGW22-I
Intermediate	AGW24-I
Intermediate	AGW25-I
Intermediate	AGW31-I

Intermediate	AGW32-I
Deep	AGW22-D
Deep	AGW24-D
Deep	AGW25-D
Ward River	RS1, upgradient
Ward River	RS2, downgradient

Note: The above groundwater monitoring wells are selected based on their location in relation to the historical interpreted groundwater flow orientation from south-west to north-east as well as the interpreted contaminant plume crossing the subject site towards the adjacent property i.e., SK Biotek, and significant water quality data collected to date for 2-PCI.

- As the pump and treat system currently in place is resulting in minimal 2-PCI removal, it is recommended that pumping be ceased in August 2022 for an initial period of approx. 9 months to assess if the plume remains unchanged. The equipment will remain in and can be turned ON in the event of any observed increase of note measured in off-site monitoring wells over the three subsequent monitoring rounds dated December (Q4 2022), March (Q1 2023) and June (Q2 2023).

8 REFERENCES

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