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Gyproc and Isover Ireland
Kingscourt
Co. Cavan,
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Attention: John Stapleton

Hydrogeological characterization of the Kingscourt plant site

1. BACKGROUND

At the request of Gyproc and Isover Ireland, Piteau Associates Engineering Ltd. (Piteau) has carried out a hydrogeological assessment of the gypsum plant site at Kingscourt, Co. Meath. Groundwater monitoring and reporting has been carried out at the site by Minerex for over 10 years and a considerable amount of monitoring data are available.

A recent investigation into the drainage systems identified that not all of the surface water was reporting to the lagoons. Some of the stormwater was reporting to one of the local streams. The drainage system at the wet waste end of the board plant was subsequently plugged to help route as much surface water as possible to the lagoon system, and to monitor the water quality at the weir behind the technical academy (the Academy Weir) to assess the impacts of the discharge.

The purpose of this report is to use the currently available monitoring data to characterize the site with respect to movement and quality of water, and to provide recommendations on monitoring going forward.

1.1 Site Location

The Gyproc plant site is located 3.5 km south of Kingscourt, Co. Meath, near the border with Co. Monaghan and Co. Cavan (Figure 1). The factory is on the R162 road, approximately 10 km south of the Knocknacran and Drummond gypsum mines. The factory manufactures plaster and plasterboard products from the gypsum mined at Drummond Mine and opencast Quarry.

1.2 Site Layout

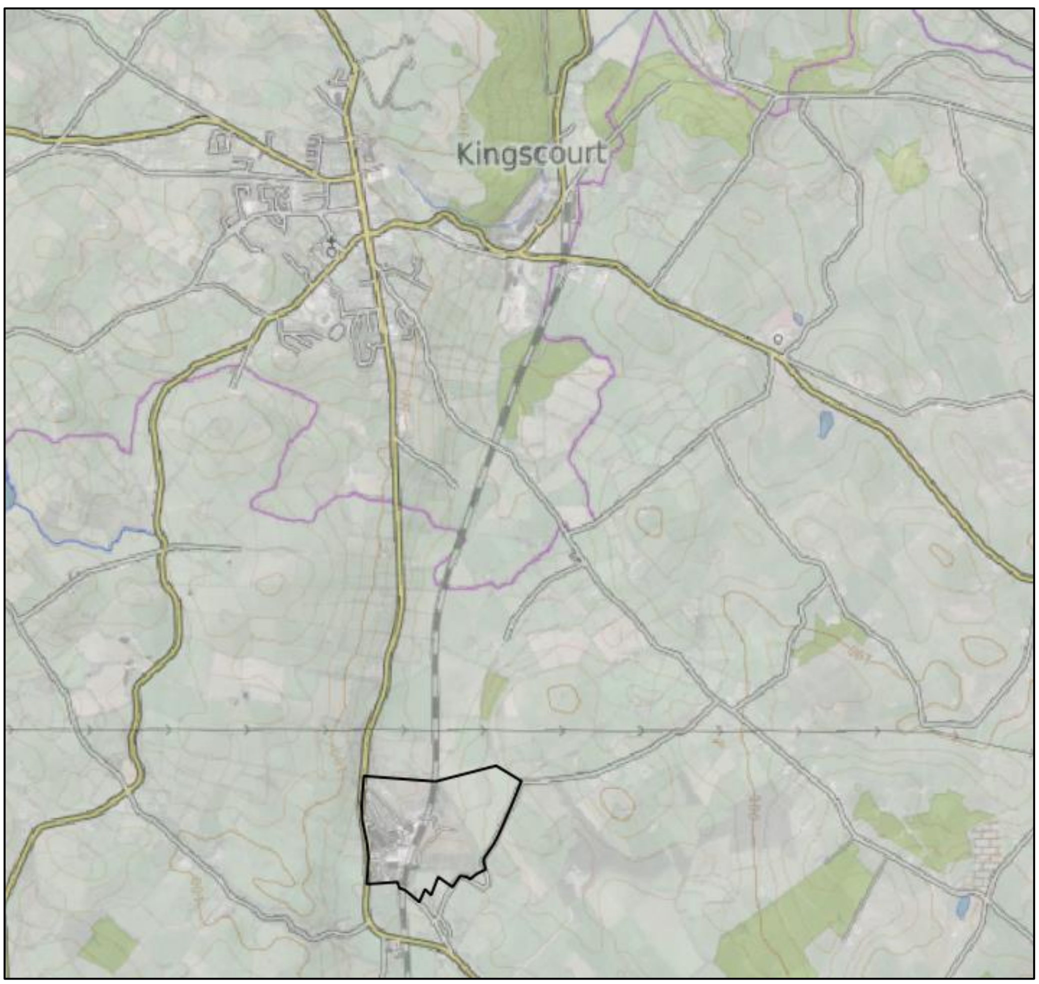
The site layout is shown in Figure 2. The area within the site boundary is approximately 50 ha. The plant itself comprises a 2 ha factory building, concrete yards and multiple outbuildings.

Central to the site is a landfill that has been in use throughout the life of the factory. The footprint area of the landfill is about 6.5 Ha. It was covered with an LLDPE liner and re-vegetated in March 2017. The remaining site area is made up of open fields that are used for agriculture.

There are 5 lagoons north of the landfill. Lagoons 1A, 1B, 2, and 4 are unlined. Lagoon 3 is the furthest to the north and lined with HDPE.

The old Lisnabo Mine workings cover an area of approximately 4 ha and extend underground from the main factory building to near Milltown Cross Roads.

Figure 1 General site location



1.3 Monitoring Points

There are 17 groundwater monitoring wells on the site, listed in Table 1 and shown in Figure 2. Of these, 8 are shallow wells with screened intervals up to 9 m depth. The remaining wells are of varying depths, up to 44 m. The wells are screened in the following units:

- Six in gravel;
- Five in mudstone;
- Two in overburden;
- Two in Dolerite; and
- Two in Gypsum and Mudstone.

The collar elevations vary between 64 and 93 m above Ordnance Datum Poolbeg (maODP).

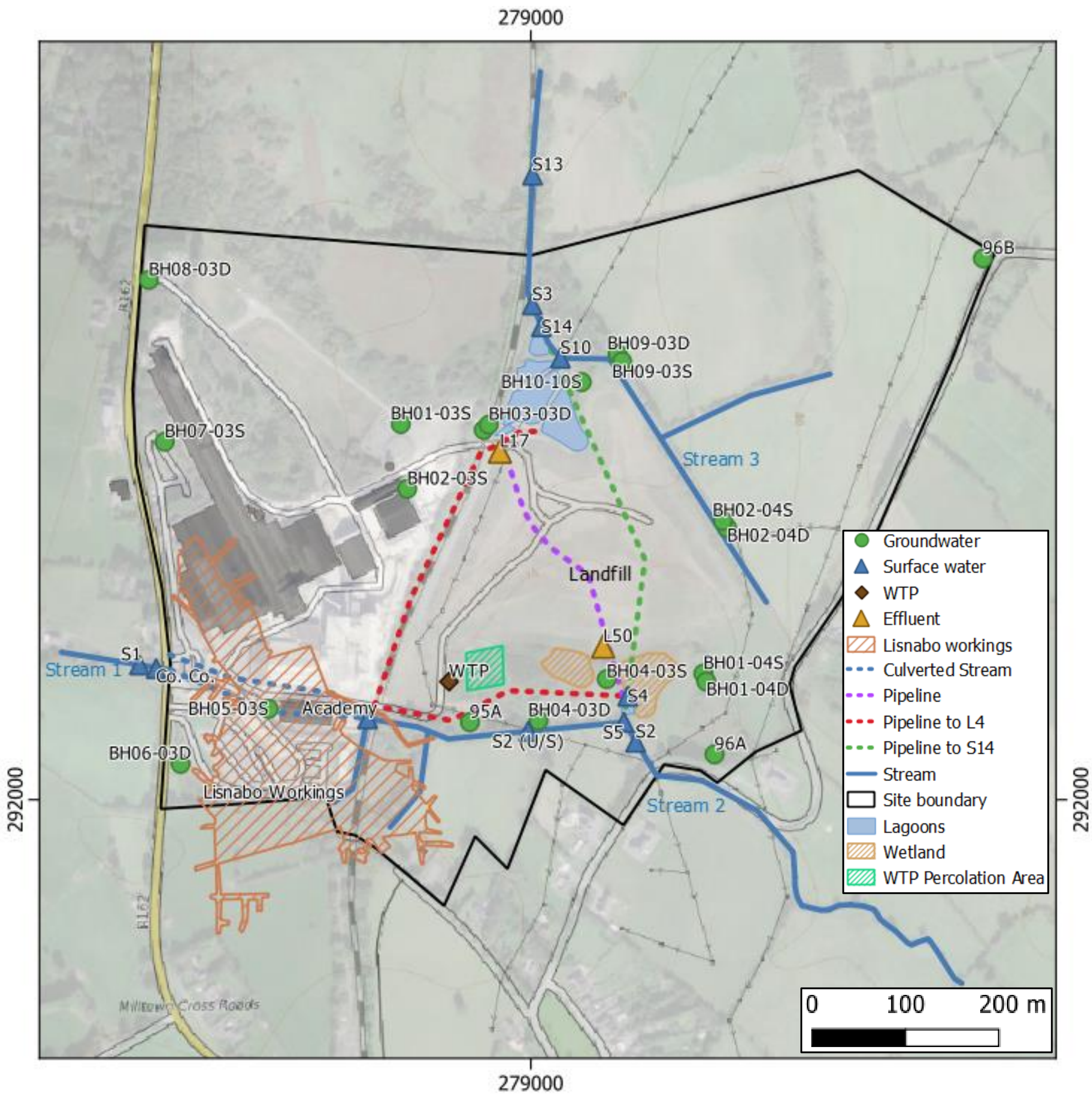
Table 1 Groundwater monitoring points

Well ID	Elevation (top of casing) (maODP)	Screened From	Screened To	Screened Unit
BH03-03S	64.8	4	7	Gravels
BH03-03D	64.8	16.5	25.5	Dolerite
BH04-03S	66.5	4	7	Gravels
BH04-03D	66.3	28	37	Gypsum & Mudstone
BH05-03S	75.6	1.6	5	Overburden
BH06-03D	82.9	23	44.5	Gypsum & Mudstone
BH07-03S	74.1	1.6	4.5	Gravels
BH08-03D	77*	7	19	Mudstone
BH09-03S	65	2.5	5.5	Gravels
BH01-04S	67.3	2	5	Gravels
BH01-04D	67.3	7	12	Mudstone
BH02-04S	80.4	3	9	Overburden
BH02-04D	80.4	11	17	Mudstone
95A	70.2	-	-	Dolerite

Well ID	Elevation (top of casing) (maODP)	Screened From	Screened To	Screened Unit
96A	80.4	-	-	Mudstone
96B	92.6	-	-	Mudstone
BH10-010S	64.2	-	-	Gravels

* estimated from NASA Shuttle Radar Topography Mission (SRTM) data

Figure 2 Site layout



1.4 Drainage Network

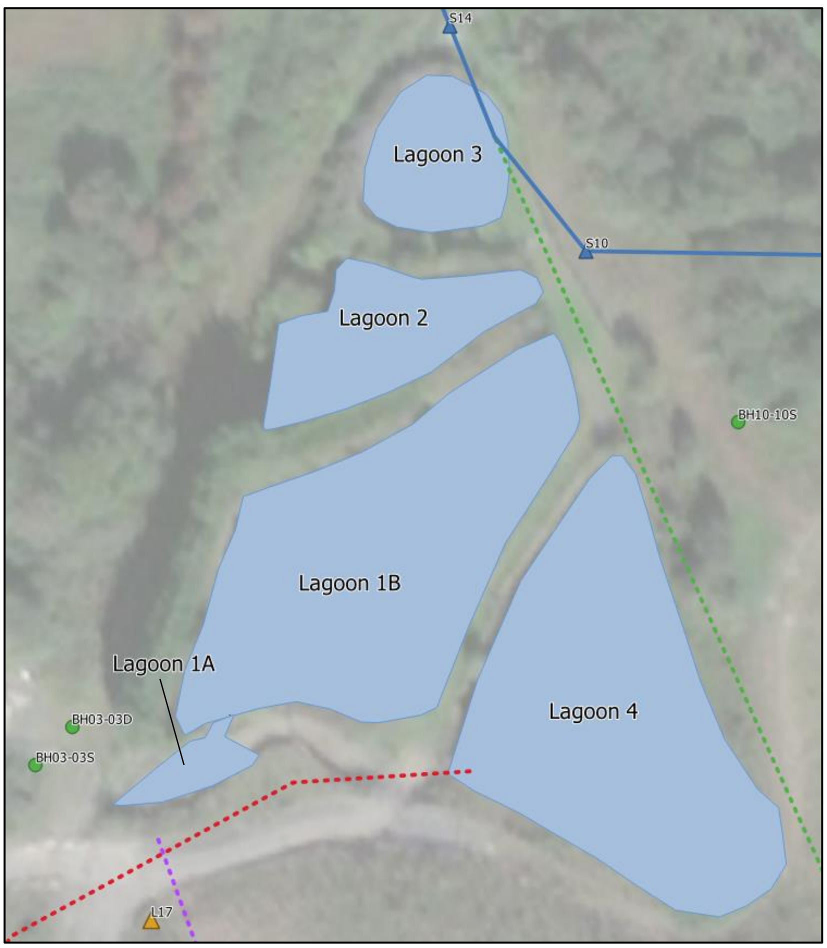
The plant site lies approximately 70 m above sea level (masl) with a gentle overall gradient to the northeast. The topography of the locality is dominated by small hills or drumlins, which are typical of the region.

The 5 lagoons are used to store surface water emanating from part of the roof of the board plant, the wet waste access road of the board plant, the rock road and the gypsum recycling area. The surface water includes rainwater, all washwater from the truck wash and washwater from yard cleaning. The surface water contained in the lagoon system is used as process water in the board plant. Excess surface water is discharged to the Mullantra stream via the S14 discharge point (Figure 3).

The drainage network for the factory and yard area are shown in Figure 4. Drains are typically underground and accessed through various manhole access points. Site runoff enters the drainage network and flows to Lagoon 1A.

A small pond (S4) located near the wetlands south of the landfill provides additional water for process (Figure 2). Water from pond S4 is pumped through a pipeline to Lagoon 4 as required.

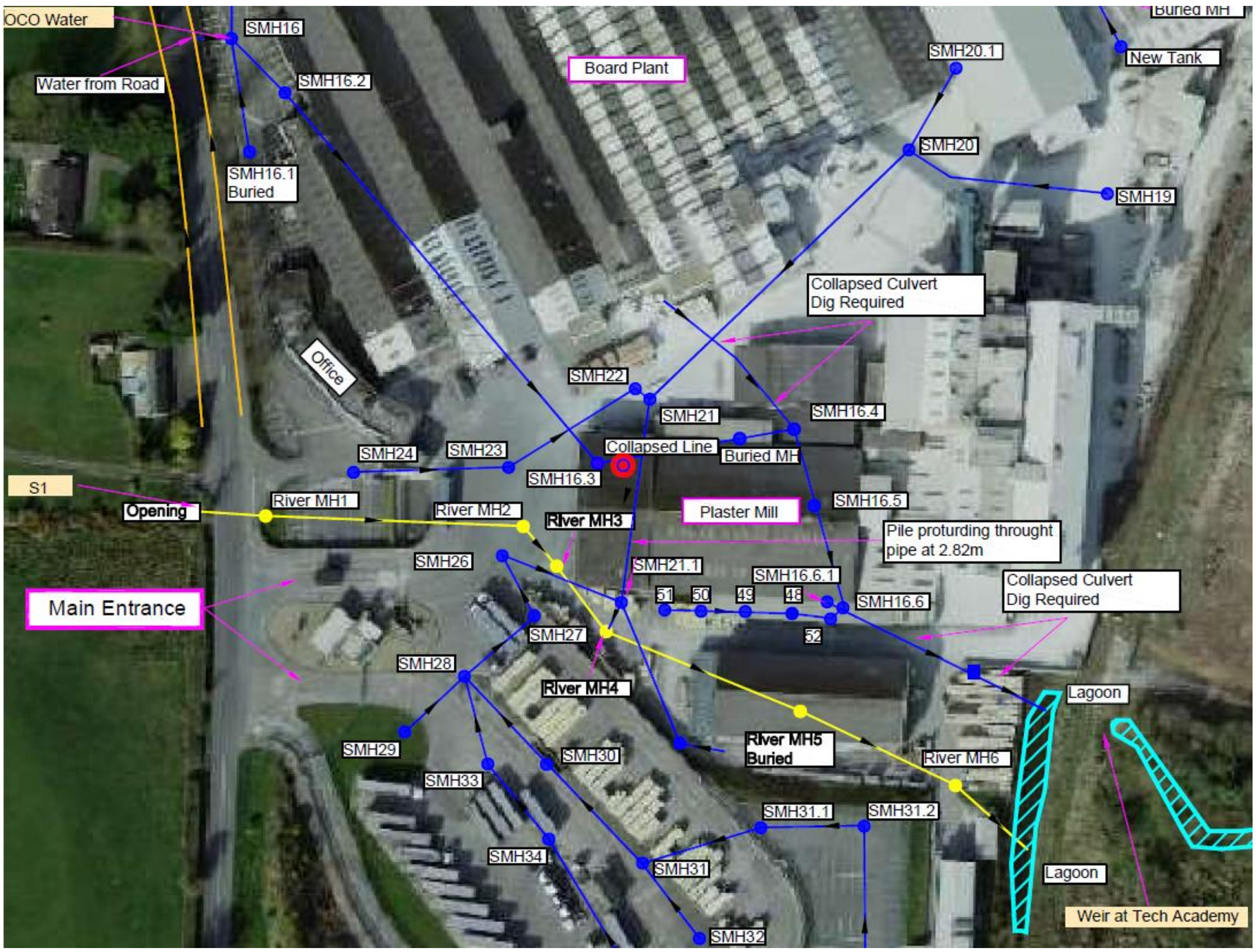
Figure 3 Configuration of the lagoons



The broader scale drainage network for the site and surrounding area is shown on Figure 2. The site drainage is typically from southwest to northeast. Natural streams flow into the site from the west and south.

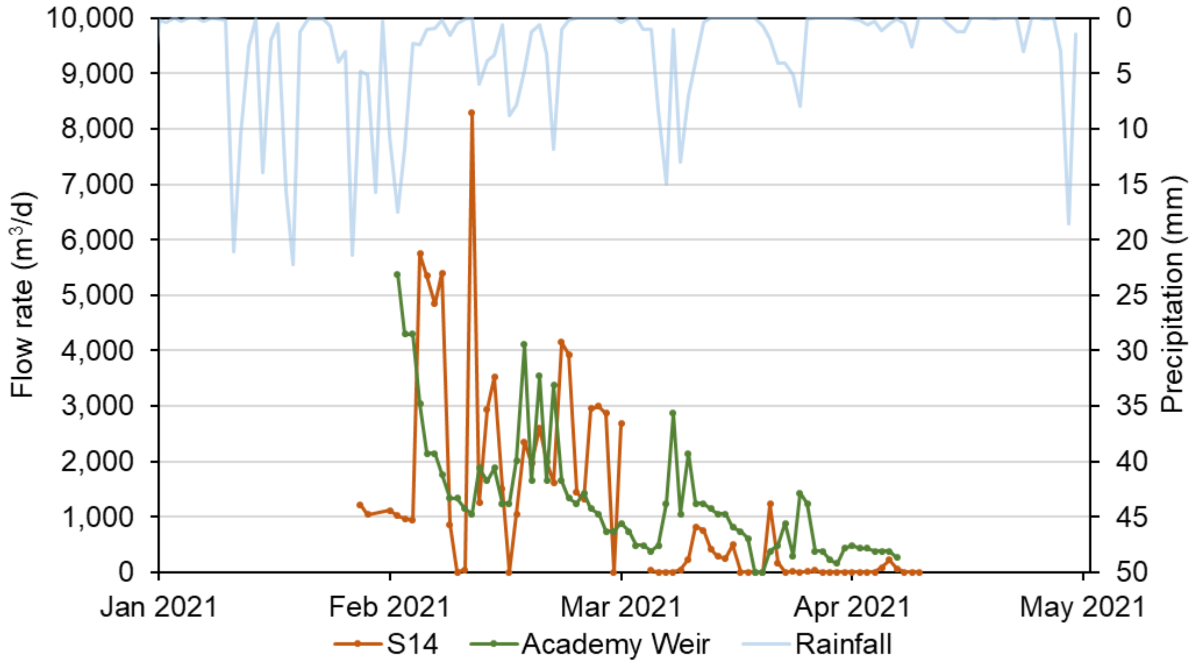
Figure 4 shows River MH4 (RMH4) which drains the portion of site runoff that does not drain to the lagoons. This equates to approximately 80% of the surface water from the yards and roofs of the site. RMH4 also receives flow from the R162 road (Co. Co. water). The RMH4 water discharges to Stream 1.

Figure 4 Drainage network focussed on discharge to Stream 1



Stream 1 flows into the site from the west. Where it enters the site, it is culverted beneath the yards and emerges at Academy Weir. Flow at Academy Weir is measured using a V-notch weir (Figure 5). Flow has varied between 260 m^3/day (3 L/s) and 5,382 m^3/day (62 L/s) throughout the monitoring period. Peaks in flow are correlated with precipitation events.

Figure 5 Flow at Academy Weir and S14



Below Academy Weir, Stream 1 continues to flow east and joins Stream 2 at monitoring point S5. The stream is then culverted beneath the landfill through a large diameter pipe where it then emerges beside S14. S14 is the compliance point for site discharge.

Three flows meet at this location: (i) the S14 overflow from the lagoons via a pipe from Lagoon 4, (ii) Stream 1 water, and (ii) Stream 3 water (Figure 6). S3 is the monitoring point 10 m downstream (to the north) of the S14 flow on the Mullantra Stream.

Figure 6 Flows contributing to the Mullantra Stream

Flow is measured at S14 using a flow gauge (Figure 5). The flow rate at S14 shows some correlation to the rainfall record. Flows tend to increase with precipitation and therefore higher rainfall directly on the lagoons, and higher runoff to the lagoons.

A water treatment plant (WTP) for site sewage is located southwest of the landfill.

2. CONCEPTUAL HYDROGEOLOGICAL MODEL

2.1 Climate

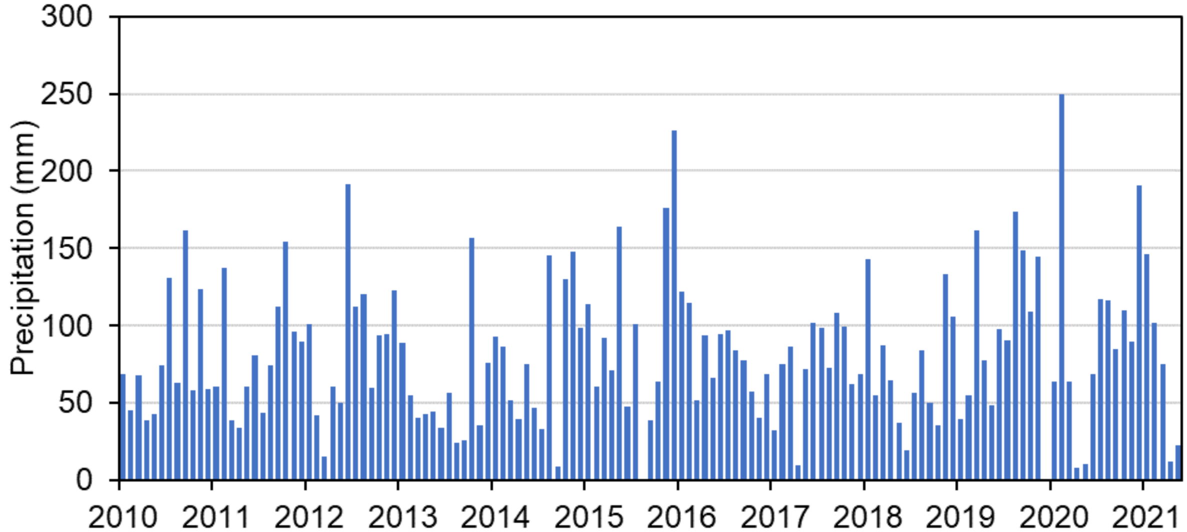
Met Éireann maintain the Dunsany synoptic weather station in Boycetown, Co. Meath. The station is approximately 38 km from the plant site and records data on temperature, evaporation, precipitation and solar radiation. A summary of climate data at Dunsany is shown in Table 2. Rainfall is typically highest between October and January. Mean annual precipitation is 870 mm, mean annual evaporation is 757 mm and mean annual temperature is 9.3 ºC.

Table 2 Summary of climate data at Dunsany synoptic station

Month	Mean Monthly Precipitation (mm)	Mean Monthly Evaporation (mm)	Mean Monthly Temperature (ºC)
Jan	80.2	16.7	4.6
Feb	59.7	27.5	4.9
Mar	63.4	50.8	6.2
Apr	61.1	80.1	7.8
May	65.1	119.4	10.5
Jun	71.5	120.5	13
Jul	61.4	117.8	15.2
Aug	77.7	93.3	14.7
Sep	71.8	65.9	13
Oct	90.6	35.8	9.6
Nov	84	16.6	6.7
Dec	83.2	12.7	5.1
Annual	**870**	**757**	**9.3**

In addition, a rain gauge has been monitored at the plant site on a daily basis since the late 1950s. Monthly total rainfall at the plant site gauge are shown in Figure 7.

Figure 7 Monthly precipitation record at plant site rain gauge from 2010 to present



2.2 Surface water

The plant site straddles a broad valley. Local drainage is to the north (Figure 8). The watershed boundary of the River Dee basin lies to the south, and the River Glyde basin to the north.

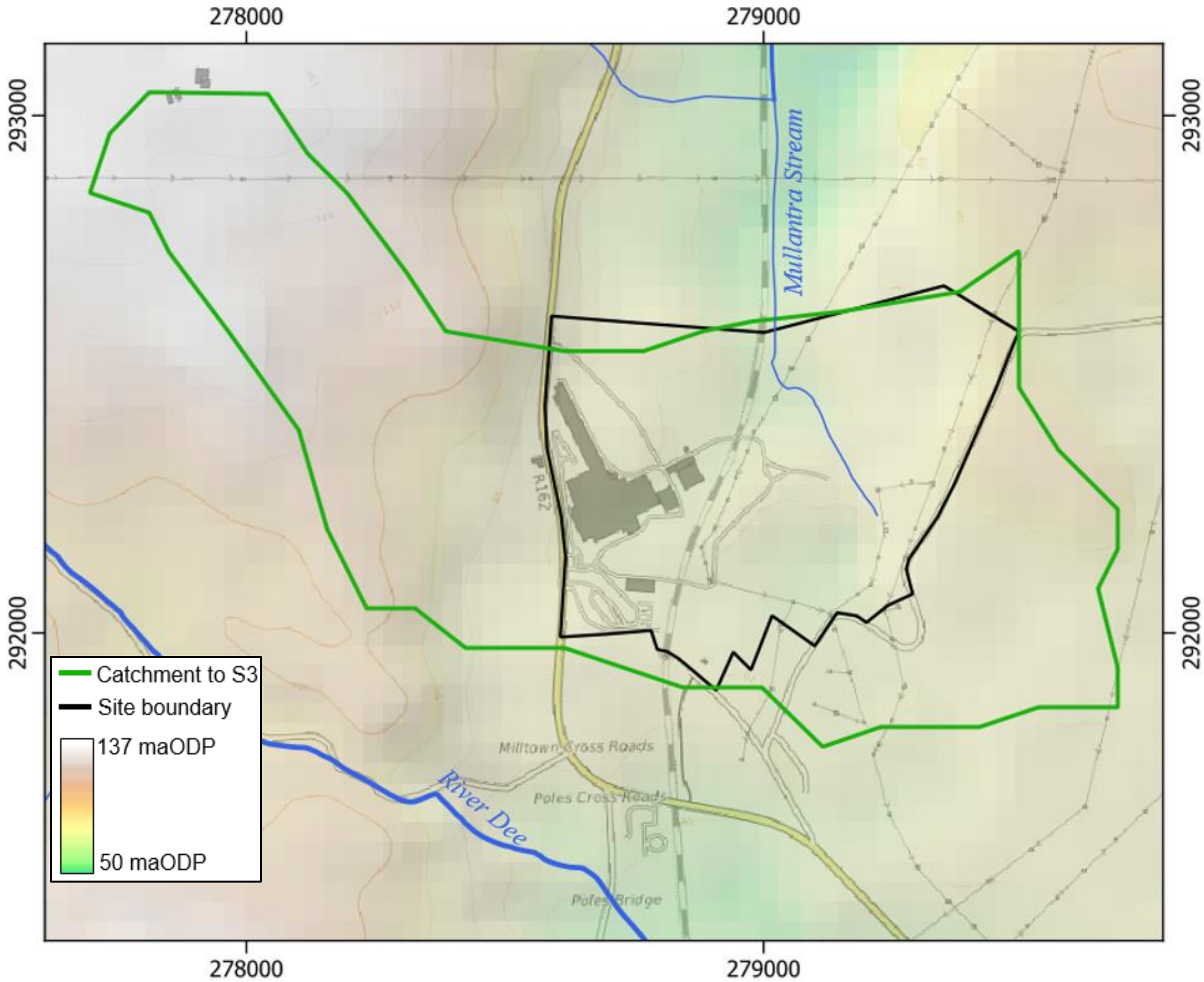
A small watercourse flows from the northern boundary of the site at monitoring point S14 and is a tributary to the Mullantra Stream. The Mullantra Stream flows north through Kingscourt then joins the River Glyde.

The catchment to S3 was calculated using NASA Shuttle Radar Topography Mission (SRTM) 1-arcsecond (30 m) resolution data. The catchment is approximately 121 ha in area and includes most of the site boundary itself and land to the west, east, and a small portion to the south (see Figure 8). The catchment is rural and comprised mostly of pastureland to the west and east, with some dwellings and agricultural buildings present.

A 600 m long stretch of the R162 road runs centrally through the catchment and forms the western border of the plant site. The maximum land elevation within the catchment is 137 maODP at the western boundary.

Using the Rational Method (Dooge, 1974), an estimation of the water volume reporting to S3 can be calculated. The equation uses the catchment area, a runoff coefficient (determined by catchment land use and slope) and rainfall intensity. The estimated average flow reporting to S3 is 1,030 m^3/day or 12 l/s.

Figure 8 Topography and hydrology of the site area



2.3 Geology

The plant site is located on the western boundary of the Kingscourt Outlier (Figure 9), which is a north-south striking band approximately 1.2 km wide and 12 km long extending from near Carrickmacross in the north to Carlanstown in the south.

The Kingscourt Outlier is a half-graben structure formed of Carboniferous and Permo-Triassic rocks, bounded to the west by the Kingscourt Fault (Figure 10). The fault is mapped approximately 75 m east of the R162 road (GSI, 2019) but the geology in wells BH08-03D, BH07-03S and BH07-03D (gypsum and mudstone) suggest that the fault is west of the wells. The Kingscourt Outlier is comprised of:

- Castlerahan Formation;
- Kingscourt Sandstone Formation;
- Kingscourt Gypsum Formation
- Lower Mudstone;

- Lower Gypsum;
- Middle Mudstone;
- Upper Gypsum;
- Upper Mudstone;
- Westphalian shales and siltstones;
- Namurian sandstones;
- Carrickleck Sandstone;
- Milverton group; and
- Dolerite and basalt sills.

Figure 9 Geology of the plant site area

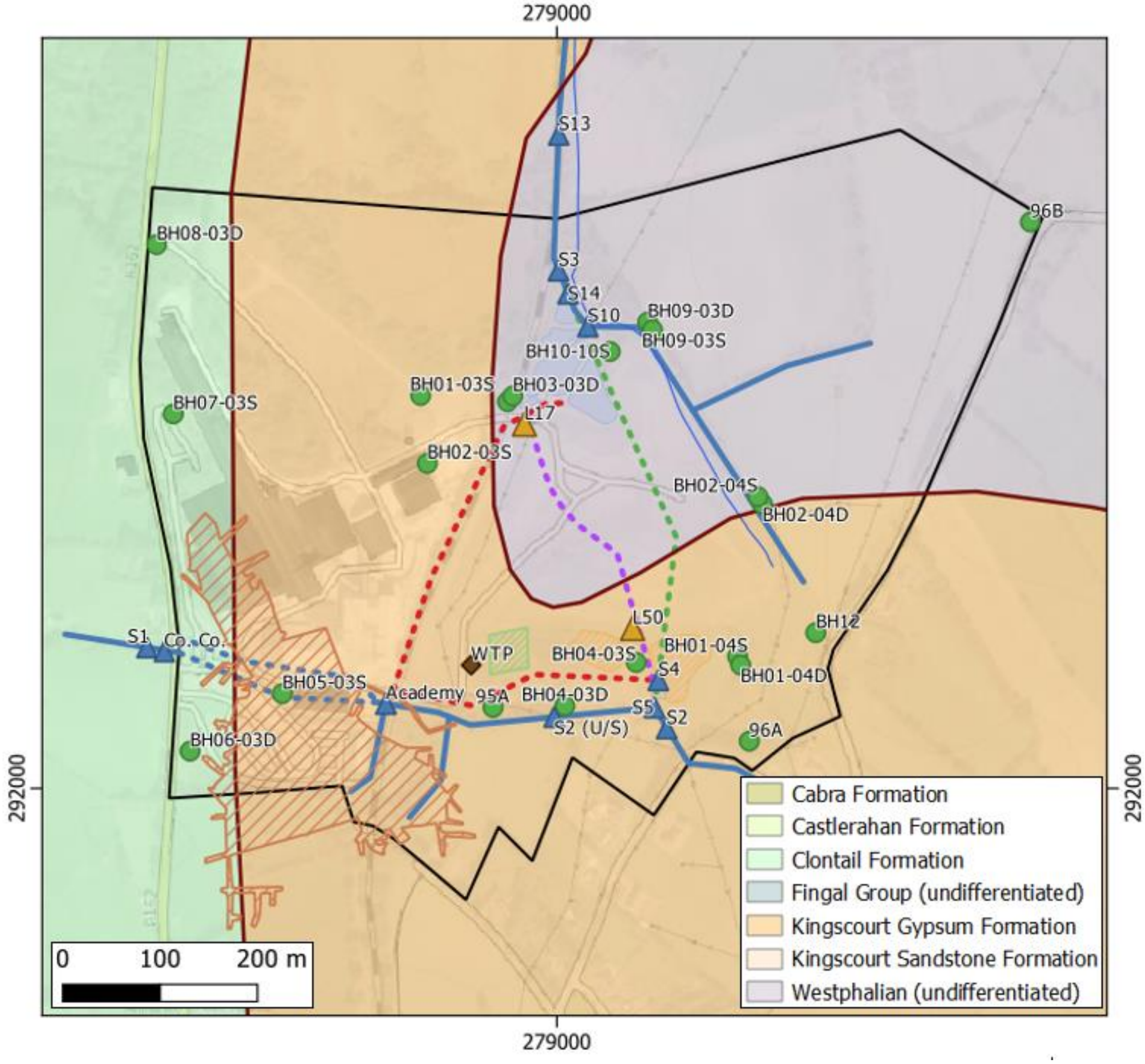
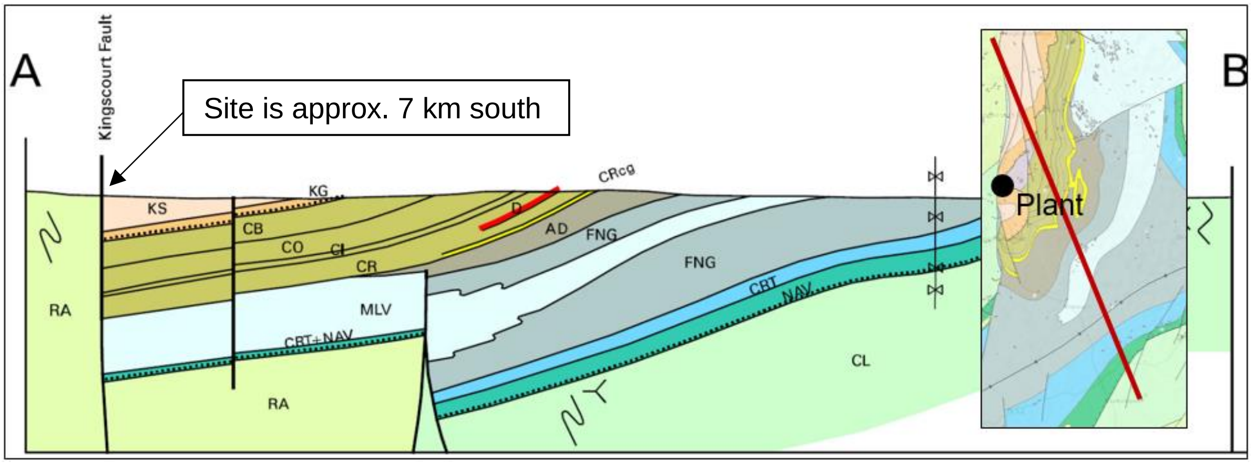


Figure 10 Geological cross-section through the Kingscourt Outlier (GSI, 2019)



To the west of the Kingscourt Fault near the plant site, the Clontail and Castlerahan formations dominate and are composed of greywackes and conglomerate rocks.

The dominant structural trend is north-south, with strata dipping with angles between 10º and 30º towards the Kingscourt Fault. Other faults in the locality have opposite throws but also trend north-south. There is a “Caledonoid” subordinate structural direction that is oriented northeast-southwest.

According to GSI mapping (Figure 11), a thickness of up to 10 m of Quaternary sediments overlies the bedrock in the plant site area. Locally, the Quaternary deposits are predominantly gravels and tills derived from Lower Palaeozoic sandstones and shales, with an area of cut over raised peat occuring through the centre of the site area. Another peat area is mapped near the Academy Weir. From study of borehole logs, superficial deposits are believed to range in thickness between 0.5 m and 12 m.

The factory itself lies on the Kingscourt Gypsum Formation and is built upon the historical Lisnabo Mine. The landfill and lagoons are primarily located on Westphalian group rocks.

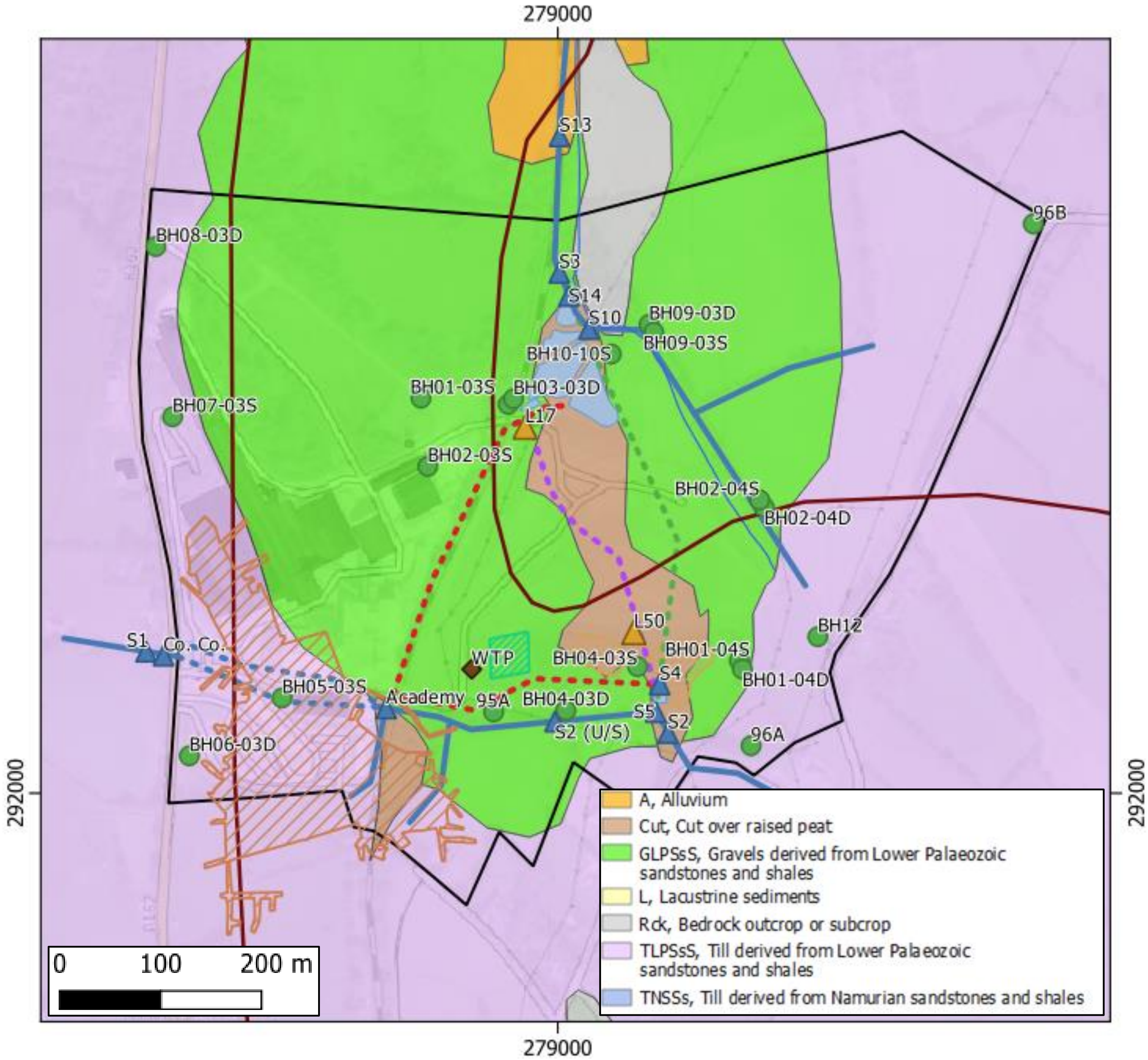
2.4 Hydrogeological Units

Superficial deposits

The superficial deposits beneath the plant site area mostly consist of boulder clay and gravel. The gravel lenses are not mapped as a “Gravel Aquifer” according to the GSI. However, they could locally influence the movement of surficial groundwater.

Distribution of wells screened in the surficial deposits show areas of sand and gravel near S4, around the lagoons and to the west of the main factory building.

Figure 11 Quaternary sediments around the plant site area



Kingscourt Gypsum Formation

The Kingscourt Gypsum Formation is comprised of layered gypsum and mudstone. It is considered a "Poor Aquifer". These rocks are relatively impermeable and will not readily transmit groundwater over a wide area.

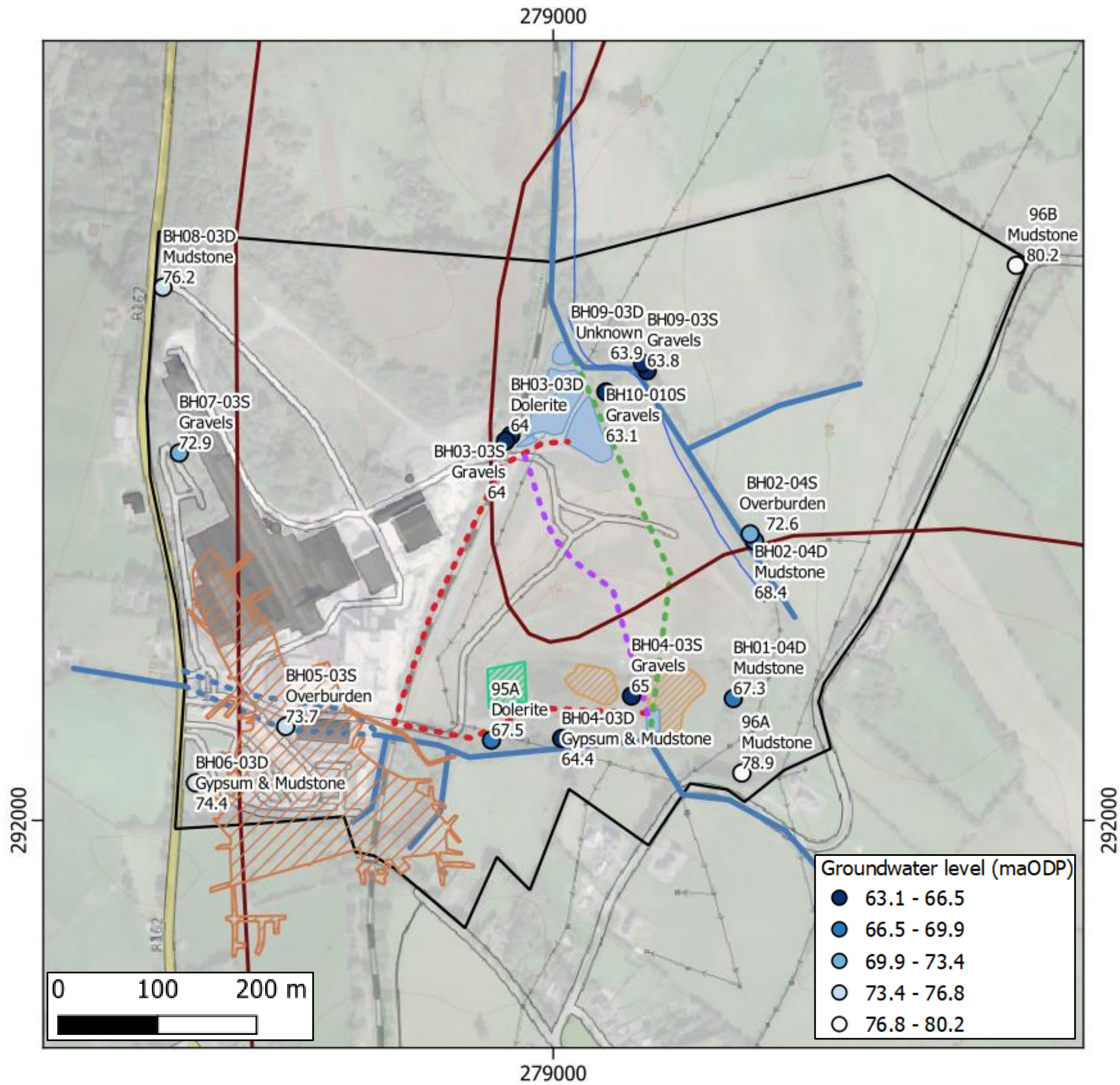
Clontail Formation

The Clontail Formation forms the western-most portion of the site boundary and is also considered a "Poor Aquifer" and is generally unproductive. The Clontail Formation and Kingscourt Fault form an impermeable boundary to the west of the site.

2.5 Groundwater Levels

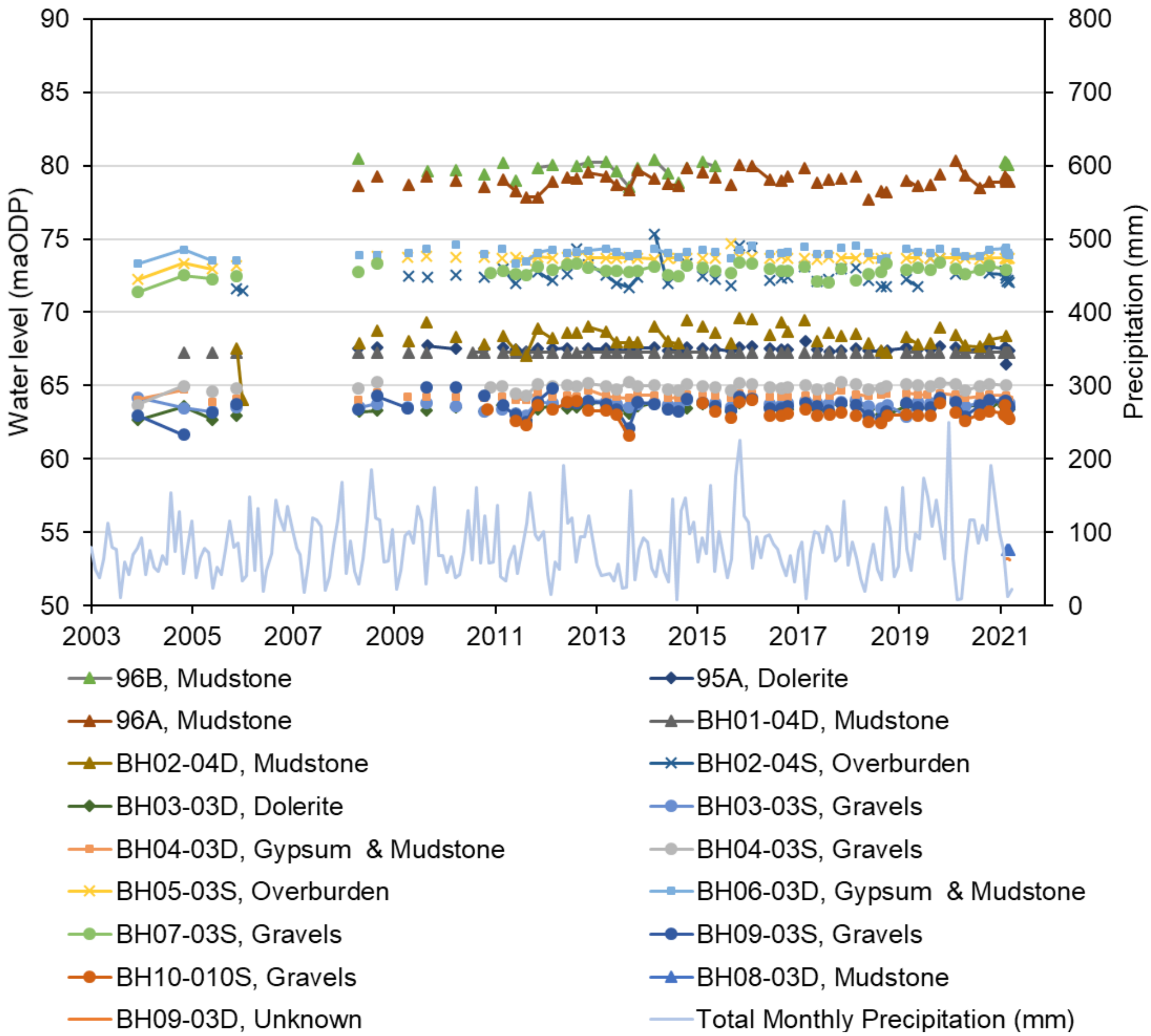
There are 15 standpipe monitoring wells for which water level data are available, from 2003 to present. Wells are dipped and sampled by Minerex on a quarterly basis. Groundwater levels measured in April 2021 are mapped in Figure 12. The entire monitoring record for all wells is shown in Figure 13, along with the monthly precipitation record at the site rain gauge.

Figure 12 Distribution of groundwater levels across the site (April 2021)



Throughout the entire period of monitoring, groundwater levels have ranged between 61 and 80 maODP. Groundwater levels are generally higher to the west and east of the project area; and fall to the north in the superficial deposits in the central part of the site area. Water levels are generally highest in the confined mudstones and lowest in the superficial deposits in the northern part of the plant site area. Within the superficial deposits, groundwater levels fall from 65 maODP in the southern part of the plant site to about 63 maODP in the north, around the lagoons. Groundwater in the surficial deposits is close to surface, between 0.3 m and 1.5 m below topography. Generally, levels fluctuate seasonally with higher groundwater levels in the wetter winter months, and lower levels during the summer (Figure 13).

Figure 13 Hydrographs for wells in all geological units



BH02-04S and BH05-03S are wells screened in overburden. Since records began, groundwater levels in both wells have remained stable through time. BH02-04S shows fluctuations of up to 3.5 m seasonally, but levels typically remain at around 72 maODP. This well is located to the east of the landfill. BH05-03S is located near the Technical Academy on the plant site yard and directly overlies mapped Lisnabo workings. Groundwater levels at this well show minimal variation and have remained at around 73 maODP throughout the entire monitoring record.

BH04-03S, BH03-03S, BH09-03S and BH10-010S are wells screened in superficial deposits. Groundwater levels for these wells show similar trends through time with levels between 62 and 65 maODP. In BH07-03S, groundwater levels are higher at approximately 73 maODP. BH07-03S is at a higher elevation than the other wells. BH03-03S is located 18 m west of Lagoon 1A and it has been noted that the groundwater level in the well corresponds to the level in the lagoon. BH04-03S is in the wetland area south of the landfill mound near the S4 pond, and both BH09-03S and BH10-010S are east of the lagoons.

All wells screened in surficial deposits show increases in level correlating to precipitation events. Seasonal fluctuation in the wells can reach up to 1 m, with the greatest variation occurring in response to high rainfall following a dry period in 2013.

There are two wells screened in dolerite. Groundwater levels in BH03-03D are between 63 and 64 maODP and vary slightly seasonally. Well 95A is 45 m to the southeast of the water treatment plan and shows quite stable groundwater levels at about 67 maODP.

Wells 96A, 96B, BH01-04D and BH02-04D are the four wells screened in mudstone. Groundwater level trends in wells 96A and 96B are similar, varying between 78 and 80 maODP, with stronger seasonal fluctuations than wells screened in other units (up to 3 m). Well 96B is at the furthest northeastern boundary of the plant site area and is around 27 m higher in elevation than 96A, which is around 700 m to the south. The high groundwater levels in these wells suggest that they are screened in the confined Lower Mudstone layers. BH01-04D and BH02-04D typically show groundwater levels between 67 and 69 maODP, with BH02-04D showing a greater variance in response to precipitation events. BH01-04D is noted as being an artesian well.

Wells BH04-03D and BH06-03D are screened in gypsum and mudstone. BH04-03D is near the stream at the south of the site. BH06-03D is near the southwest boundary of the site near the R162 road. Groundwater levels in BH06-03D range between 73 and 75 maODP and show similar variation in response to precipitation events as other wells. BH04-03D groundwater levels are lower, at approximately 64 maODP and show smaller seasonal fluctuations than BH06-03D.

Generally, wells screened in deeper, confined Mudstone and Gypsum units show higher groundwater levels than those screened in the surficial deposits. Water from the deeper bedrock groundwater is likely recharging the shallow groundwater system in the plant site area. The surficial groundwater can therefore be expected to show an influence of calcium, sulphate and other parameters that are characteristic of the Kingscourt gypsum strata.

2.6 Groundwater Recharge

Groundwater recharge is primarily derived from infiltration of precipitation and local runoff, predominantly between the months of October and March.

Local groundwater recharge is low according to GSI mapping. The available groundwater level monitoring data mostly show upward hydraulic gradients, indicating that the site is predominantly a local area of groundwater discharge.

2.7 Groundwater Movement

The geological strata underlying the site area are not considered good aquifers and do not support the widespread flow of groundwater in their natural state. Gravel lenses present on the site may provide a pathway for localized site-scale superficial groundwater flow.

The local geological setting indicates that the site is well-contained hydrogeologically, with flow to the north, east and south limited by the relatively impermeable geological formations, the dip of the strata to the west, and the higher bedrock groundwater elevations. The Kingscourt Fault bounds the site to the west and likely prevents flow of groundwater westwards into the Clontail Formation.

The Lisnabo Mine workings underlie the west side of the plant site and some of the land south of the site boundary (Figure 12). They may provide pathways for the rapid movement of water beneath the site. The depth of the workings is unknown, but if they extend to the depth of the Lower Gypsum, they may be up to 200 m in depth (Minerex, 2019). Groundwater elevations in the area of the Lisnabo Mine area typically about 10 m higher than surficial groundwater in the plant site area. Therefore, some discharge of water from the historic workings to the plant site area may also be expected, with elevated levels of calcium, sulphate and other parameters characteristic of the gypsum strata.

2.8 Groundwater/Surface Water Interaction

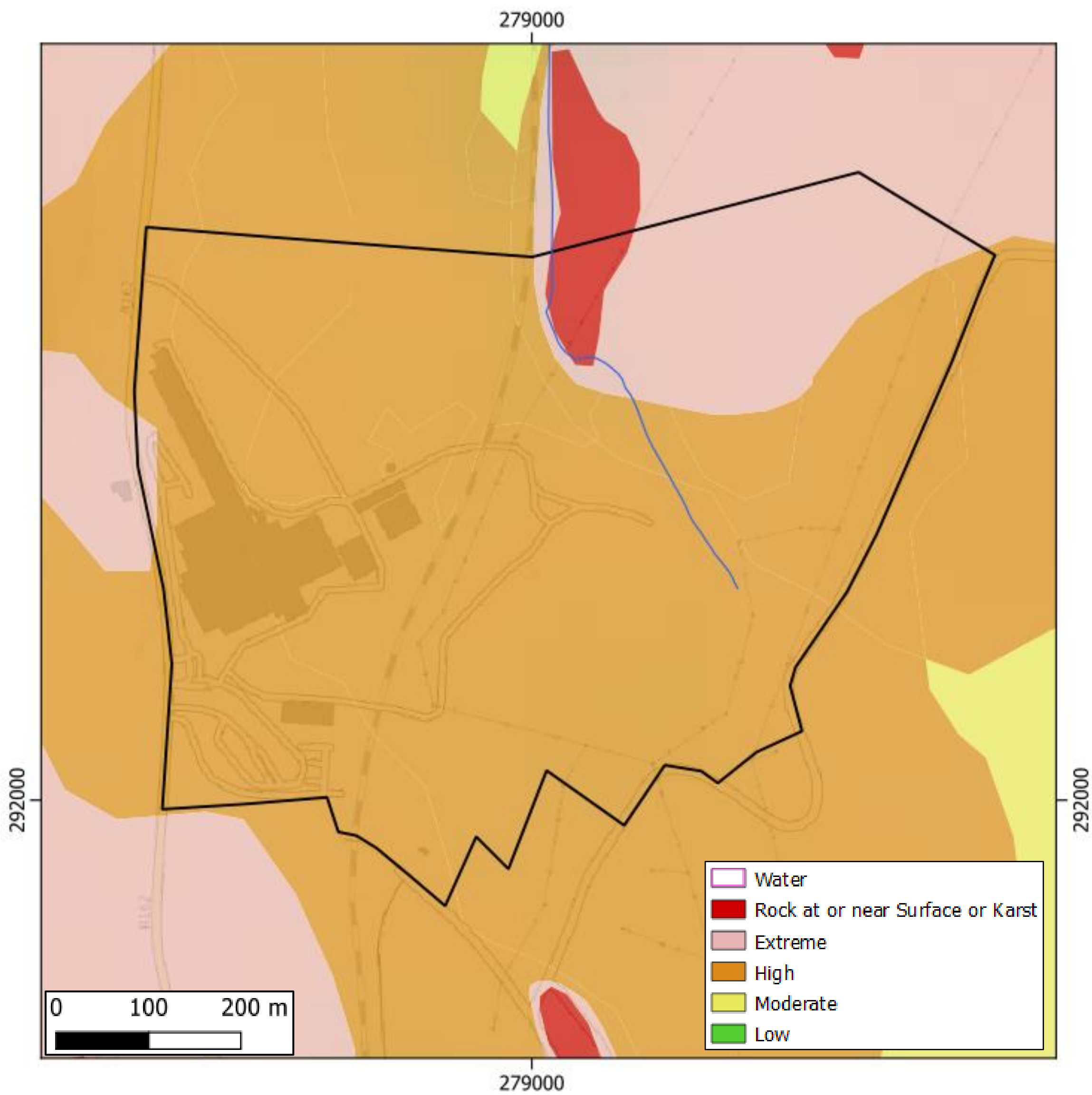
The surface monitoring point “Co. Co.” is likely a groundwater seep. The flow emerges from a pipe beneath the R162 road. It is not believed to be surface runoff because of its continuous flow, including during dry periods. The groundwater levels in proximity to the seep are near ground surface in BH06-03D, which is screened in gypsum and mudstone. It appears that groundwater is being forced to the surface by the impermeable strike of the Kingscourt Fault.

According to GSI vulnerability mapping for the region (Figure 14), most of the site is designated as “high vulnerability”, with a depth to bedrock of between 5–10 m. However, local conditions on site do not support this designation for the immediate area. Past the lagoons to the northwest of the site, the GSI applies a designation is “extreme vulnerability”, with an estimated depth to bedrock of between 1–3 m. A small area (less than 1 ha) within the site boundary is designated with “rock at or near surface or karst”. This area extends about 200 m beyond the site boundary to the north along the Mullantra Stream.

Groundwater levels in BH03-03S are similar in elevation to the water levels in Lagoon 1A suggesting some connectivity between the lagoons and the superficial deposits, as would be expected.

Pond S4 is small pond in the wetland area in the topographic low to the south of the landfill (Figure 15). It is situated towards the south of the area of mapped peat deposits (Figure 11). Vegetation surrounding S4 includes sedge and mosses, typical of bog areas. Water from S4 is pumped to Lagoon 4 to provide water for process. The edges of S4 appear to be engineered and not lined.

Figure 14 GSI groundwater vulnerability map (GSI, 2019)



During a site inspection in April 2021, the pump was turned on for approximately 1 minute which caused a drawdown in the pond of approximately 1 cm. When the pump was turned off, the water level in the pond rebounded within 1 minute. In nearby shallow well BH04-03S, water levels are consistently near surface around 1.6 m below top of casing (mbTOC).

Around 30 m south of S4 is stream monitoring point S5 where the main watercourse along the southern boundary of the site meets a small tributary. The stream is around 3 m lower in elevation than the area of wetland where S4 is located. This indicates a poor connection between the wetland and the stream potentially due to the geology.

Figure 15 S4 pond (foreground) and landfill (background)

2.9 Groundwater Abstractions

According to GSI mapping, there are 10 groundwater abstractions mapped within 1 km of the site boundary (Table 3). Of these, 6 are dug wells and 4 are boreholes. Most of these are for domestic use, with one designated as a public water supply (PWS). This is likely a mis-label as satellite imagery shows a single dwelling at this location.

The nearest known PWS are Kingscourt Mullantra PWS and Kingscourt Descart PWS, approximately 8 km and 7 km north of the site respectively.

There are no pumping wells on the plant site itself.

Table 3 Wells and boreholes within 1 km of the plant site boundary

GSI Well Code	Source Type	Source Use	Shortest Distance from Site Boundary (m)
2629SEW020	Dug well	Domestic use	1000
2629SEW019	Borehole	Domestic use	377
2629SEW016	Dug well	Public supply (Co. Council) *	148
2629SEW036	Borehole	Domestic use	733
2629SEW017	Dug well	-	323
2629SEW018	Dug well	Domestic use	909
2629SEW072	Dug well	Domestic use	846
2629SEW074	Dug well	Other	797
2629SEW009	Borehole	-	579
2629SEW015	Borehole	Domestic use	243

* believed to be a domestic supply mis-labelled as a public supply

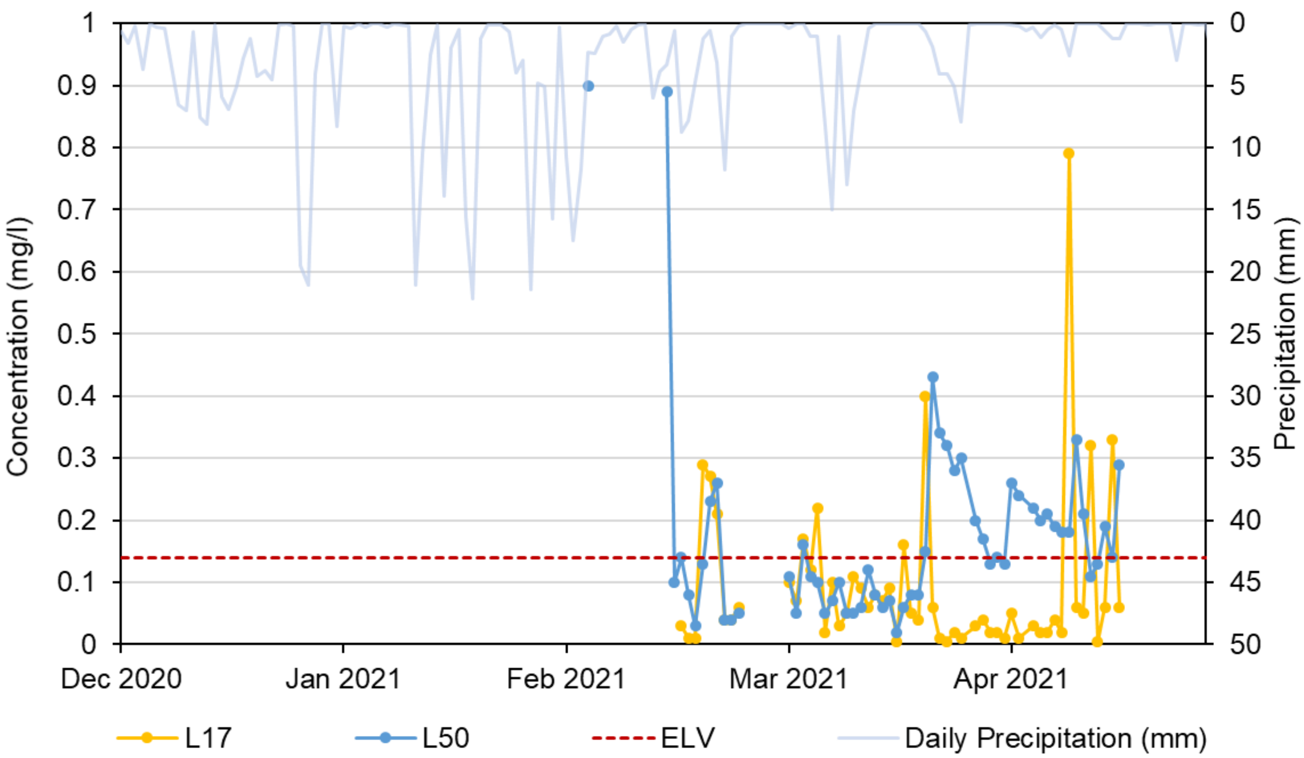
3. WATER QUALITY

3.1 Site Leachates and Lagoons

L50 is a sampling point for effluent from the landfill site. Ammonia concentrations at this point vary between 0.02 and 0.9 mg/l (Figure 16). Flow rates are noted to be low.

L17 is the manhole close to Lagoon 1A. Leachate from the landfill and surface runoff from the yard flow through this point to Lagoon 1A. Ammonia concentrations are between 0.02 and 0.8 mg/l. At these points, there appears to be some increase in ammonia correlation with the rainfall, particularly in L50 where peaks in ammonia correspond to rainfall events in March, with a lag time of approximately 7 days.

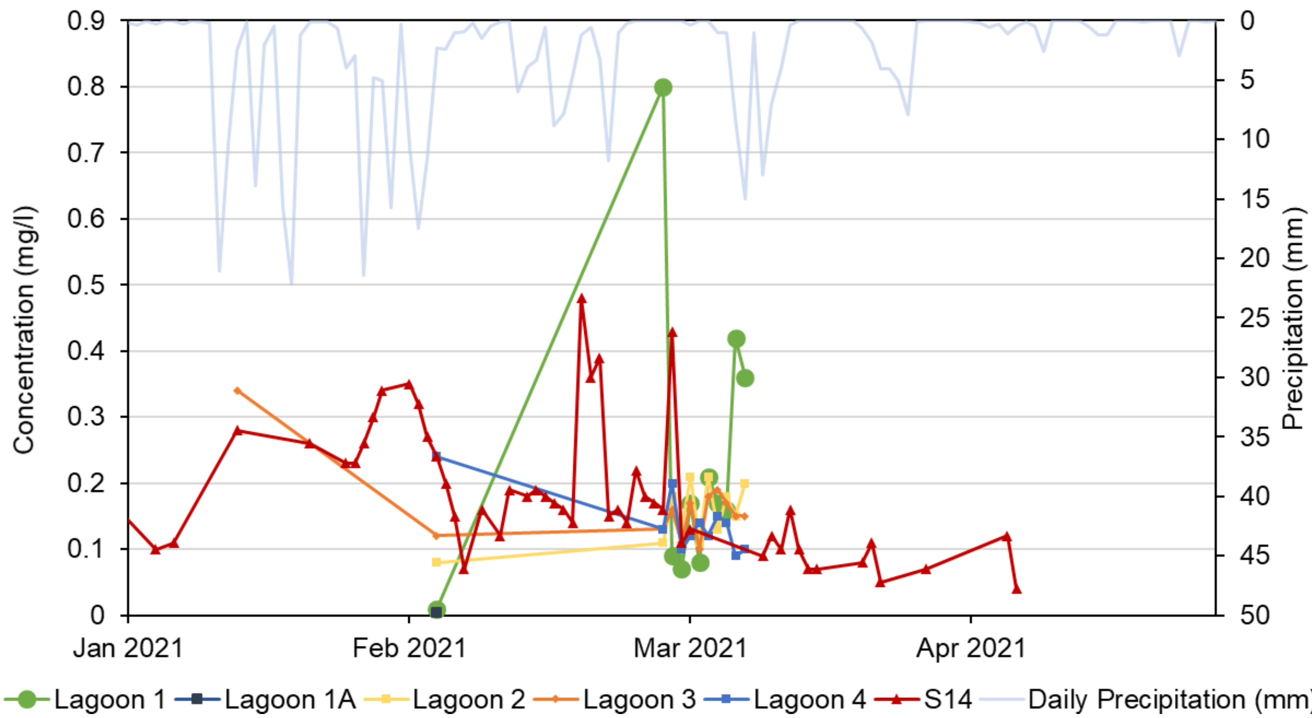
Figure 16 Ammonia concentrations in site leachates



Ammonia concentrations in the site lagoons are shown in Figure 17. Concentrations in 2021 have typically fluctuated between 0.07 and 0.21 mg/l. A peak in ammonia occurred in Lagoon 1 at the beginning of March. Similar but smaller peaks were observed in the other lagoons.

Concentrations in Lagoon 4 have decreased during the period of monitoring, while concentrations in Lagoon 2 and Lagoon 3 have slightly increased. There does not appear to be a correlation between rainfall and ammonia concentrations in the lagoons.

Figure 17 Ammonia concentrations in site lagoons



3.2 Surface Water

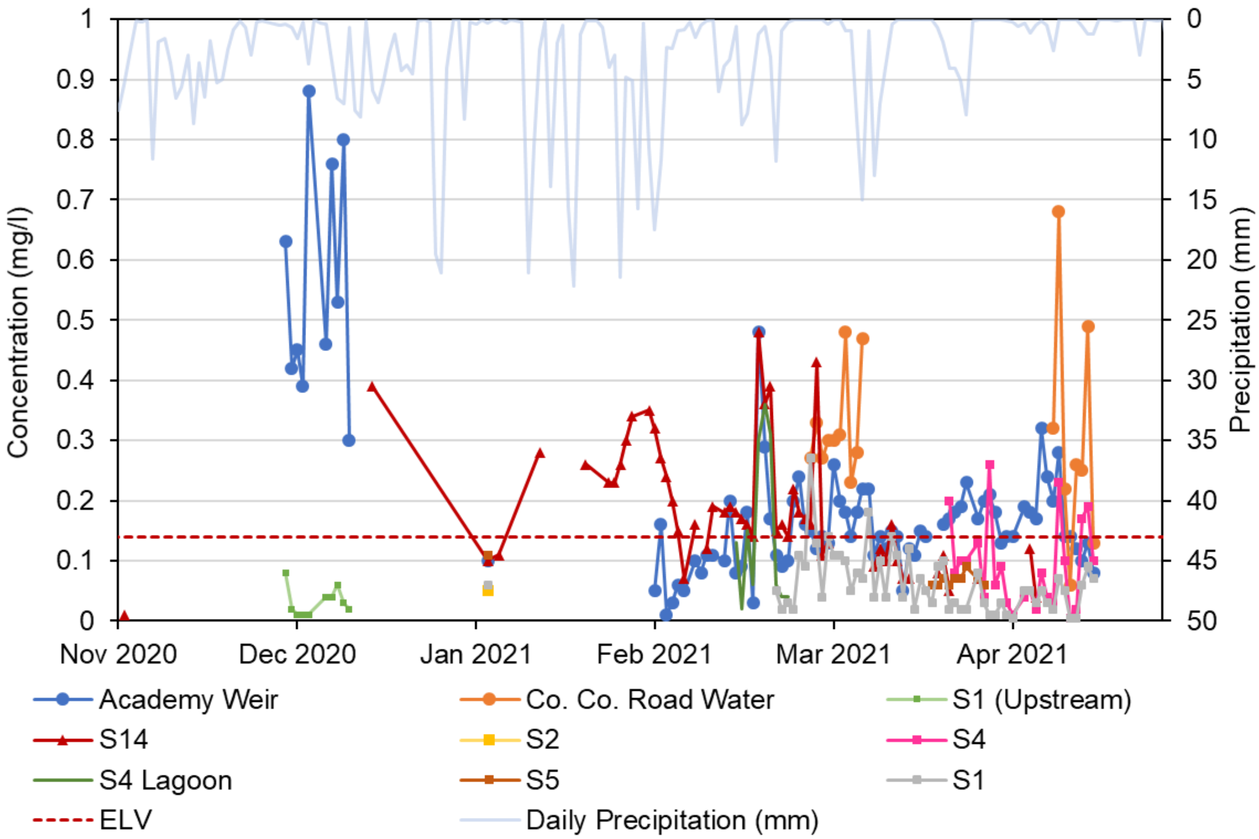
Figure 18 shows concentrations of ammonia in site surface water monitoring points south of the landfill. Figure 20 shows concentrations of ammonia in monitoring points north of the landfill, near S14. The ELV for ammonia at S14 is 0.14 mg/l ammonia as N.

Monitoring point S1 is on Stream 1, around 20 m from the plant site on the opposite side of the R162 road, outside the site boundary. Ammonia concentrations in S1 vary between 0.005 and 0.27 mg/l and fluctuate with rainfall.

The Stream 1 enters the site along with a flow known as “Co. Co. Road Water”. The “Co. Co.” water is potentially a groundwater seepage (see Section 2.8 above). Where monitoring data for ammonia in Co. Co. water exist, the concentrations are the highest of all surface water monitoring points, ranging between 0.06 and 0.68 mg/l.

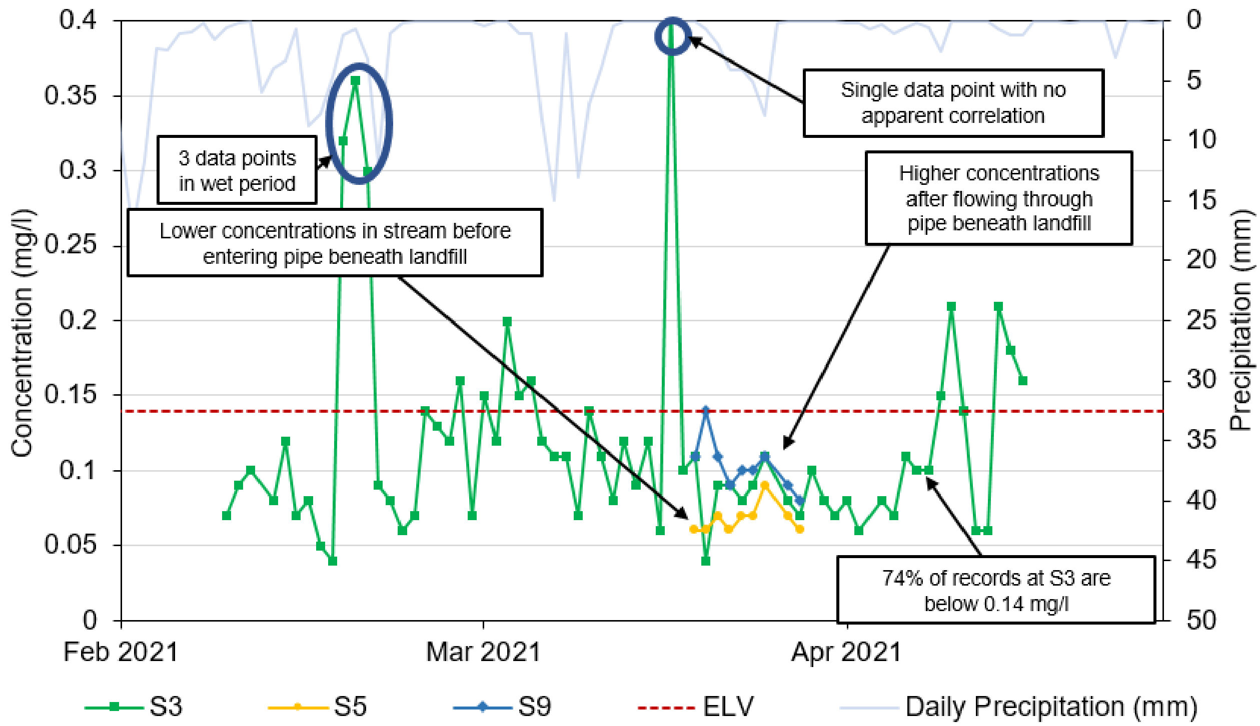
Stream 1 then flows to the Academy Weir, where ammonia concentrations fluctuate between 0.01 mg/l and 0.88 mg/l. Stream 1 then continues to flow east parallel to the southern site boundary where it joins Stream 2 at S5. There is little monitoring data available for Stream 2 (at monitoring point S2), but ammonia concentrations in January 2021 were 0.06 mg/l. Ammonia concentrations at S5 are between 0.06 mg/l and 0.11 mg/l. The inflow of water from Stream 2 at the confluence of at S5 is likely reducing the ammonia concentrations observed in Stream 1 at Academy Weir.

Figure 18 Ammonia concentrations in site surface water monitoring points on south side (upgradient) of the landfill



From S5, the watercourse then flows beneath the landfill and lagoons through a large diameter pipe to S3. Ammonia concentrations in the stream before and after flowing through the pipe are shown in Figure 19. Concentrations in the stream are up to 0.08 mg/l higher after flowing beneath the landfill. The majority of reported values for S3 are below 0.14 mg/l. There are four main periods in time when the reported values exceed 0.14 mg/l, of which one is a single data point. Section 4 discusses the potential to carry out synoptic (snapshot) surveys to improve the understand of which data points may correlate.

Figure 19 Ammonia concentrations in stream upstream and downstream of pipe beneath landfill



Ammonia concentrations at S14 vary between 0.01 and 0.48 mg/l. The ELV was exceeded throughout January 2021, with further exceedances during February. One exceedance was noted in March. The exceedances typically correspond to peaks in ammonia concentrations at Academy Weir and in the Co. Co. water.

The trend in ammonia concentrations at S1, Co. Co. road, Academy Weir and S14 are similar and show highs and lows almost simultaneously. S1 has shown naturally elevated ammonia at some points during the record, but ammonia concentrations jump when the Co. Co. road water joins the watercourse via the site drainage system at RMH4.

Water sampled at S4 (the pond in the wetland south of the landfill) shows similar peaks in ammonia concentrations to Academy Weir and Co. Co. road water, but with lower overall concentrations.

S3 is the final monitoring point on site where S14 water, Stream 1 and Stream 3 (monitoring point S10 water) mix and flow out of the site boundary as the Mullantra Stream. Ammonia concentrations at S3 are generally lower than at S14, but show peaks at similar times.

Figure 20 Ammonia concentrations in site surface water monitoring points on north side (downgradient) of the landfill

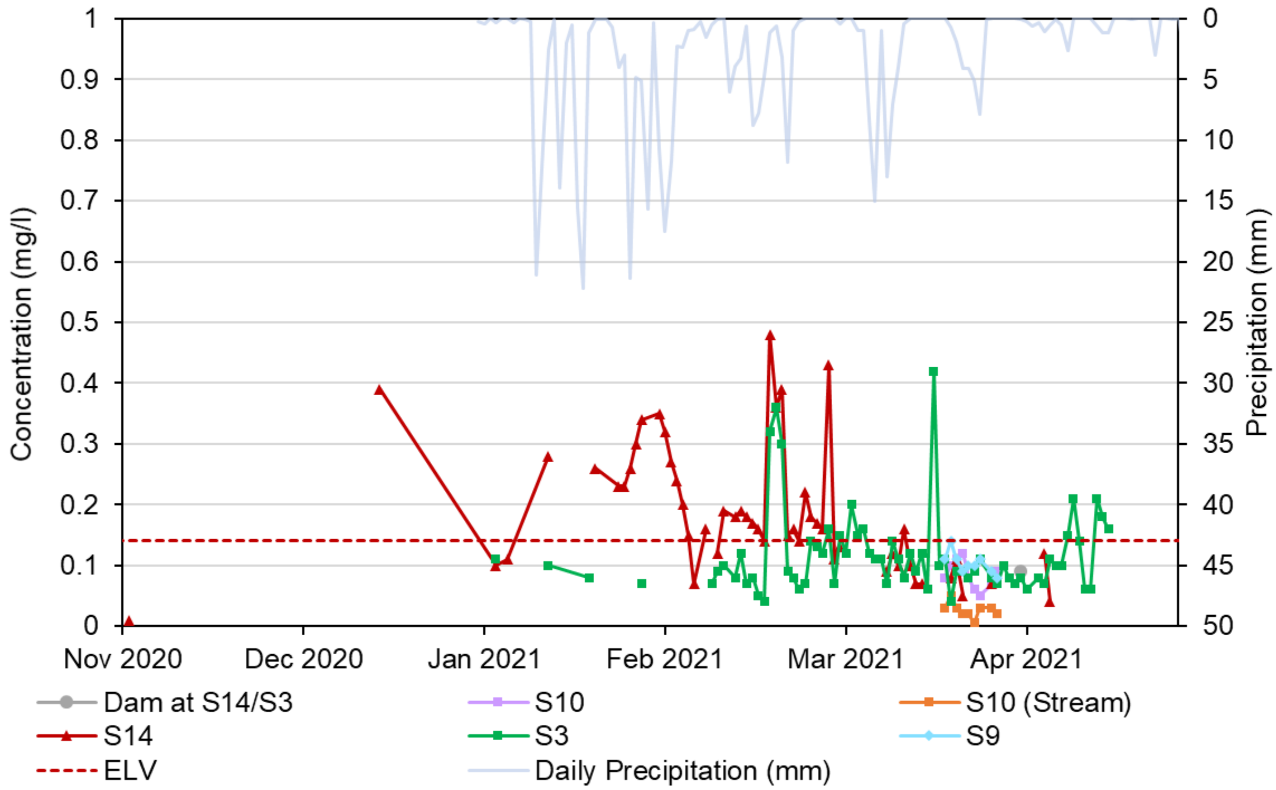
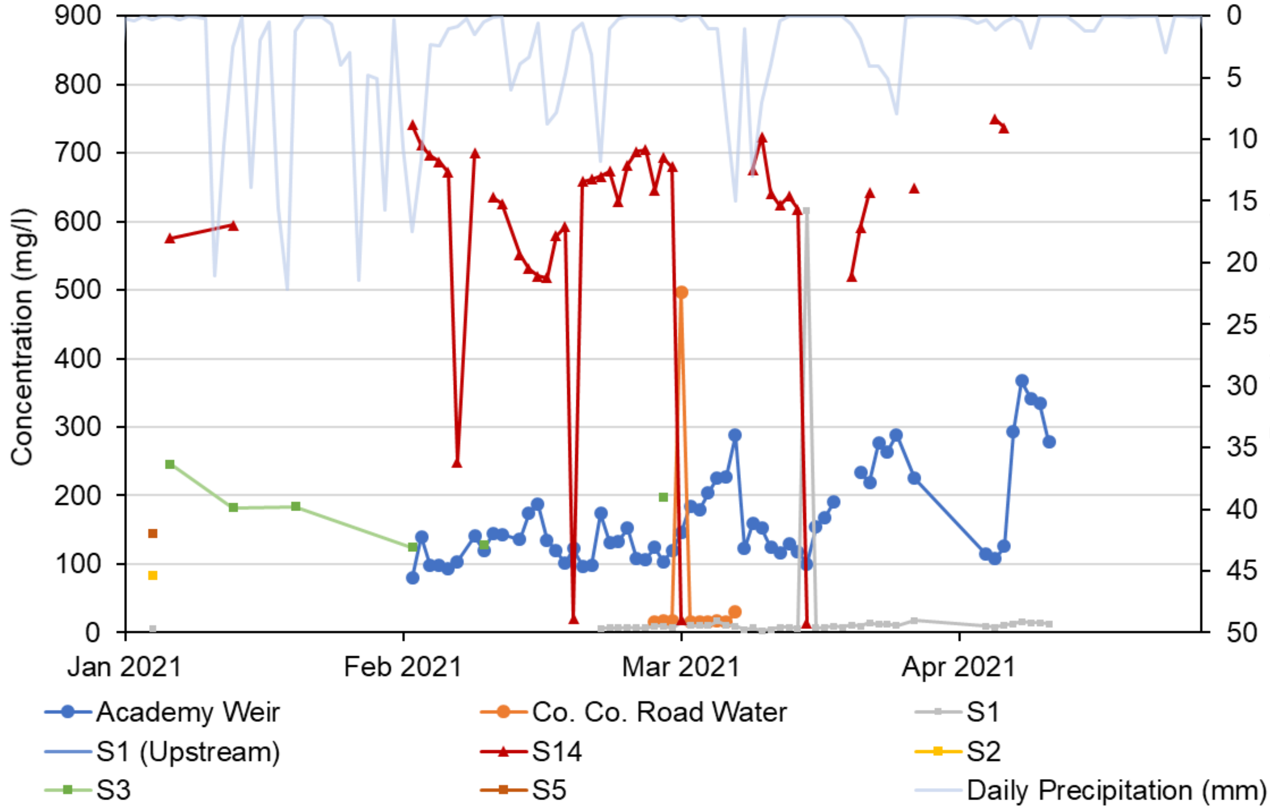


Figure 21 shows sulphate concentrations at site surface water monitoring points. Sulphate is lowest at S1, upstream of the site, with concentrations around 10 mg/l. Sulphate is highest in S14 and peaks occur following precipitation events. At S14, sulphate ranges between 14 and 749 mg/l. Concentrations at Academy Weir are typically between 100 and 400 mg/l during the monitoring period, with peaks in concentration occurring approximately 3 days before they are observed at S14.

Figure 21 Sulphate concentrations in site surface water monitoring points



3.3 Groundwater

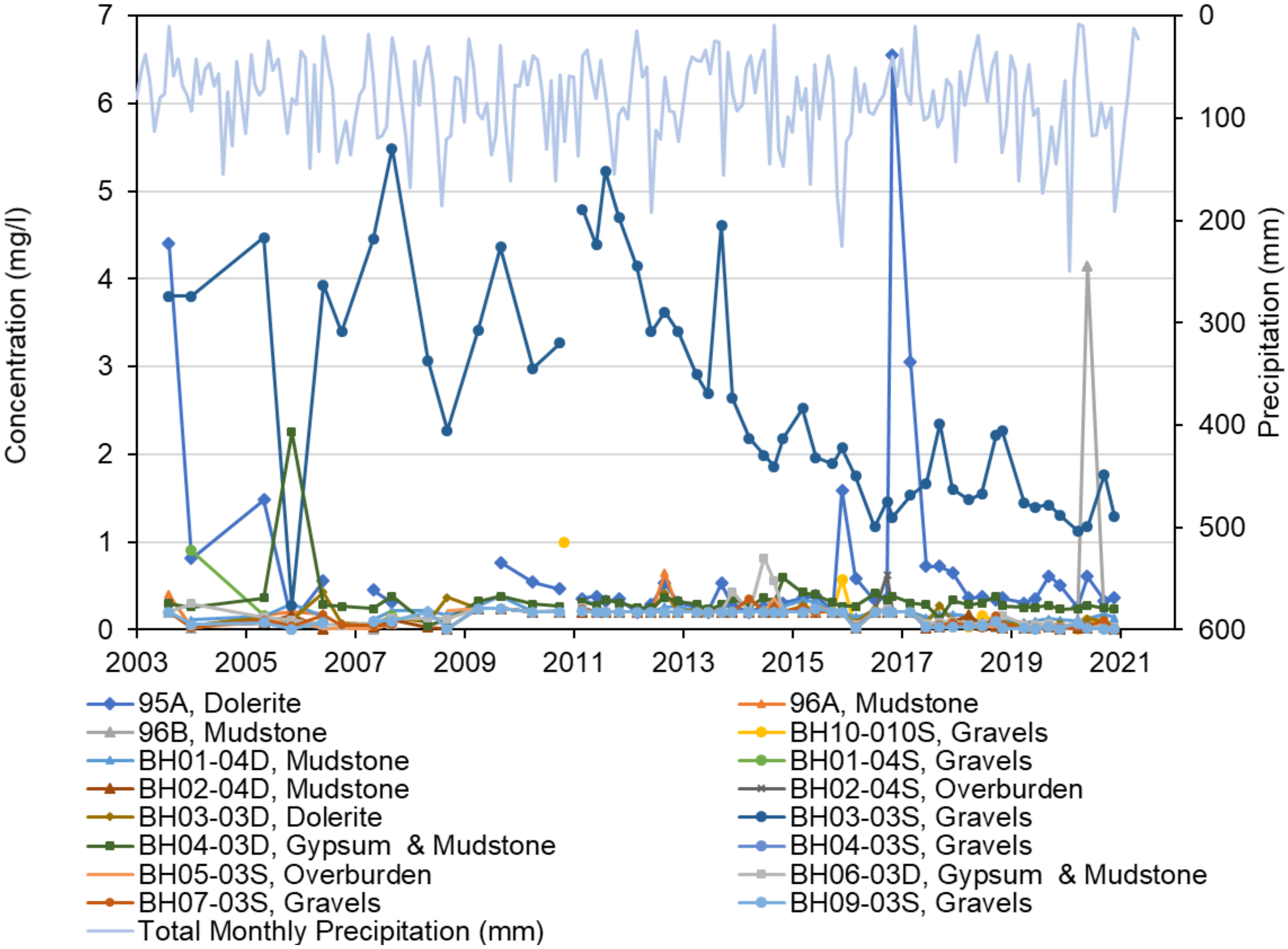
Ammonia concentrations in groundwater are shown in Figure 22. BH03-03S is a shallow well screened in superficial deposits, located near Lagoon 1A. This well has historically shown the highest ammonia concentrations of all wells, reaching approximately 5.5 mg/l in 2007.

Concentrations have since reduced to around 1.3 mg/l in 2020. Wells 95A and BH04-03D are south of the WTP and downgradient of the landfill near the peat deposits and wetlands. The wells are screened in dolerite, and gypsum and mudstone, respectively, and have shown elevated ammonia concentrations.

Occasional peaks were also observed in wells 96B during 2020. 96B is at the northeastern site boundary and is upgradient of the plant and landfill. Ammonia at this location would be expected to be of agricultural origin.

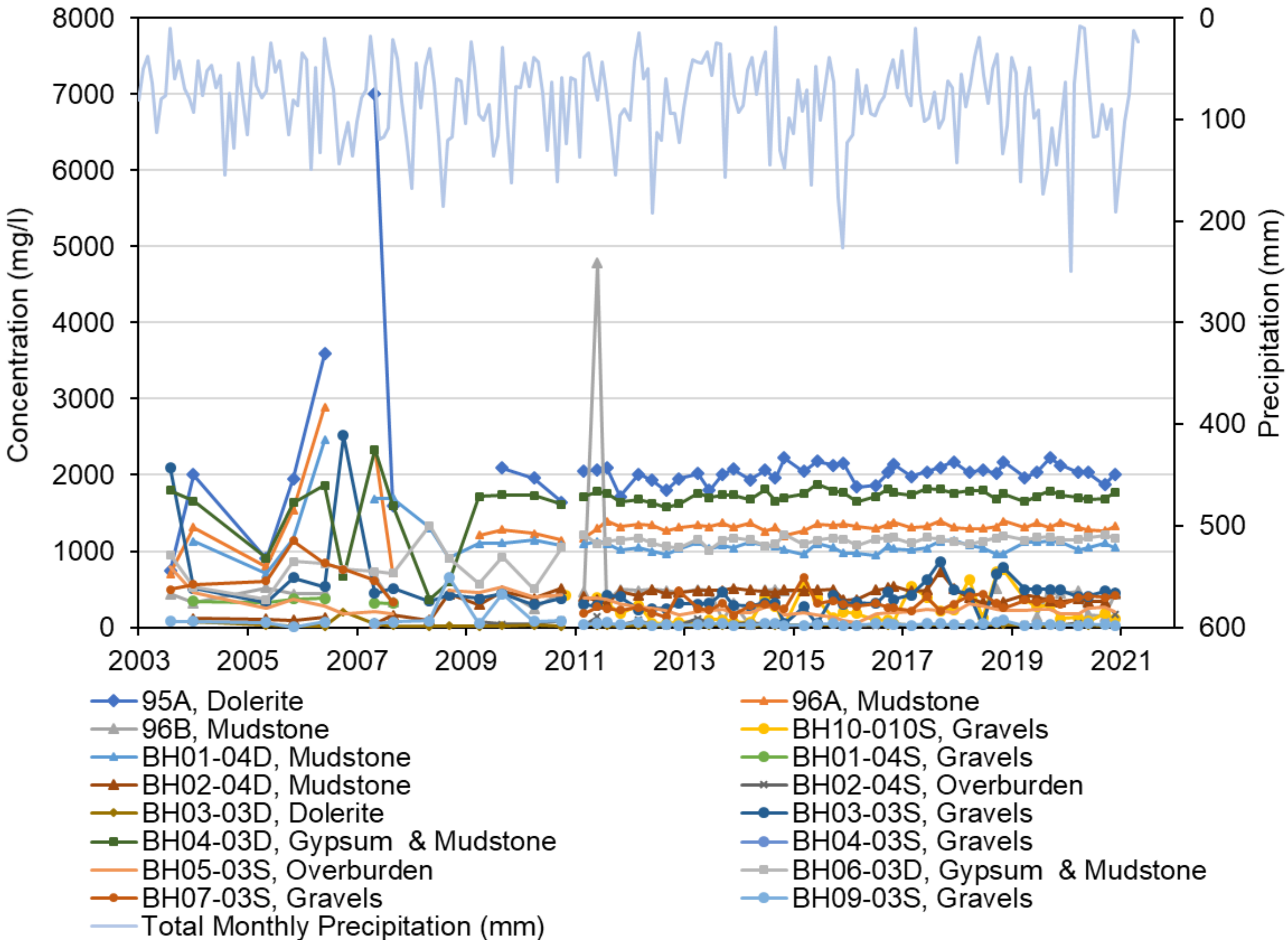
The other 12 wells showed ammonia concentrations of below 0.175 mg/l during 2020, which is the SI 366 of 2016 upper threshold limit (Irish Statute Book, 2016).

Figure 22 Ammonia concentrations in groundwater



Sulphate concentrations in groundwater are shown in Figure 23. Concentrations are highest in wells screened in gypsum, dolerite and mudstone. Sulphate typically ranges between 900 and 2,220 mg/l in these wells. Such concentrations are expected in this geological setting as gypsum dissolves in contact with water that is unsaturated with respect to gypsum, resulting in elevated sulphate. Observed sulphate concentrations in superficial overburden wells are typically below 1,000 mg/l. This is likely due to mixing of fresh water from precipitation in the surficial deposits with the higher sulphate bedrock groundwater that upwells at the site.

Figure 23 Sulphate concentrations in groundwater



3.4 Discussion

The distribution of observed ammonia concentrations in site leachates, lagoons, surface water and groundwater during March 2021 are shown in Figure 24. The highest concentrations (0.5 mg/l to 1.29 mg/l) are observed in monitored Landfill Leachate, and shallow gravel wells BH03-03S and BH04-03S. Both wells are in close proximity to mapped peat deposits (see Figure 11) which may be influencing the observed ammonia concentrations. The presence of ammonia in the surficial wells may also indicate some local influence of historical landfill leachate.

Other elevated ammonia concentrations (0.09 to 0.5 mg/l) occur at the site lagoons, L50, Co. Co. road water, Academy Weir, 95A, BH04-03D and BH01-04D. Except for BH01-04D, these wells are downgradient of the landfill and all are close to mapped peat deposits. These deeper wells typically have higher groundwater heads than the surficial wells and may also be contributing some of the ammonia loading to the plant site area.

Co. Co. road water is likely a groundwater seep, where groundwater with elevated ammonia from peat deposits and potential landfill leachate has been forced to surface by the Kingscourt Fault. This water may also be influenced by discharge from the Lisnabo workings. The Co. Co. seep joins Stream 1 and results in elevated ammonia at Academy Weir. Concentrations of ammonia appear to increase in Stream 1 after it flows through the concrete pipe beneath the landfill. Water has been noted to drip from the joints in the concrete pipe. This suggests there is some residual seepage entering the stream beneath the landfill.

Other monitoring boreholes hydraulically upgradient of the site (BH09-03S, BH10-10S, BH02-04S, BH02-04D, 96B and 96A) all show low (non-detect to 0.05 mg/l) concentrations of ammonia. The data indicate that the hydrogeological system of the site is well constrained to the east and south by the topographic gradient and the westward dip of the geological strata.

Figure 24 Distribution of ammonia concentrations in site surface water and groundwater

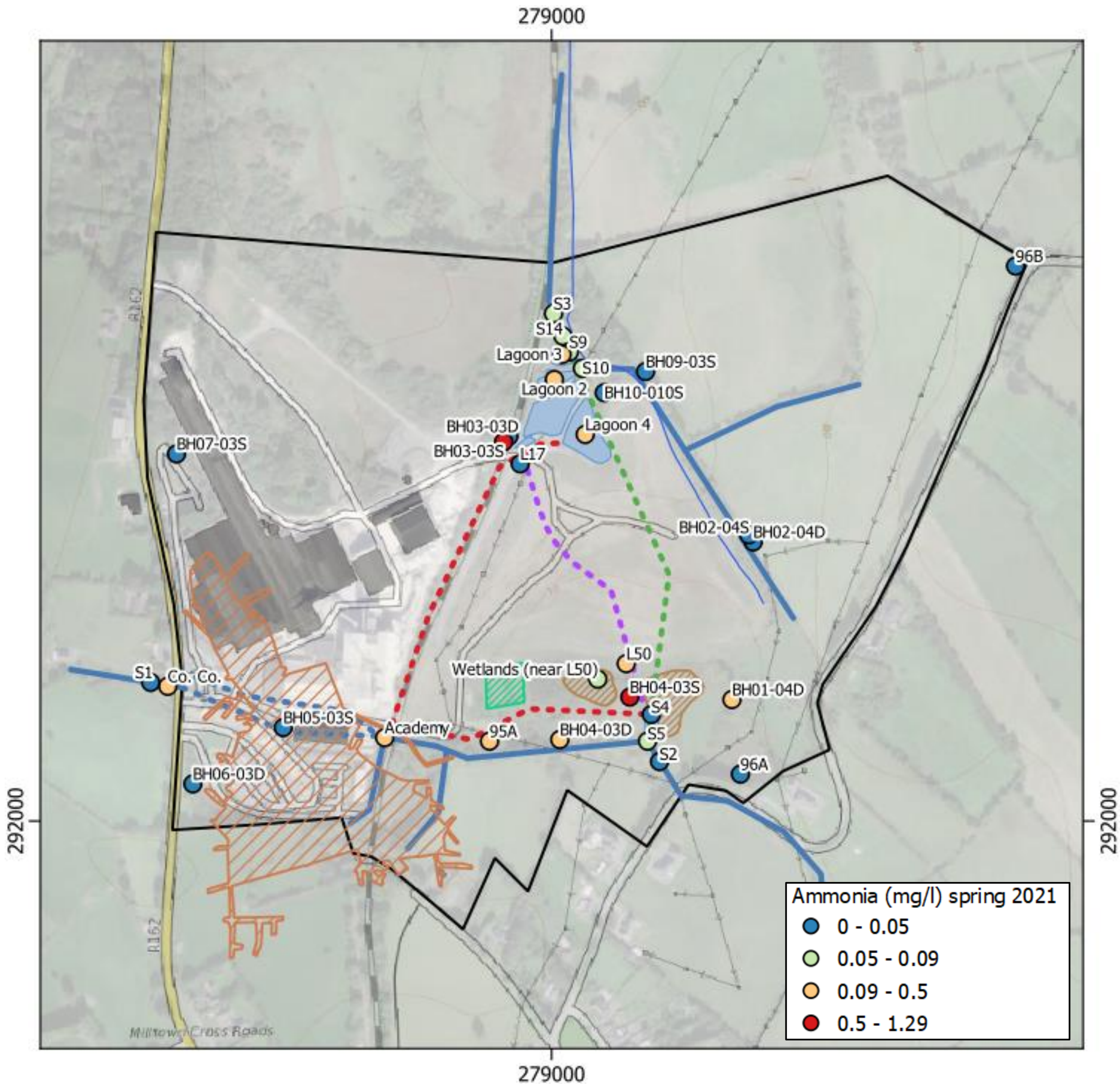
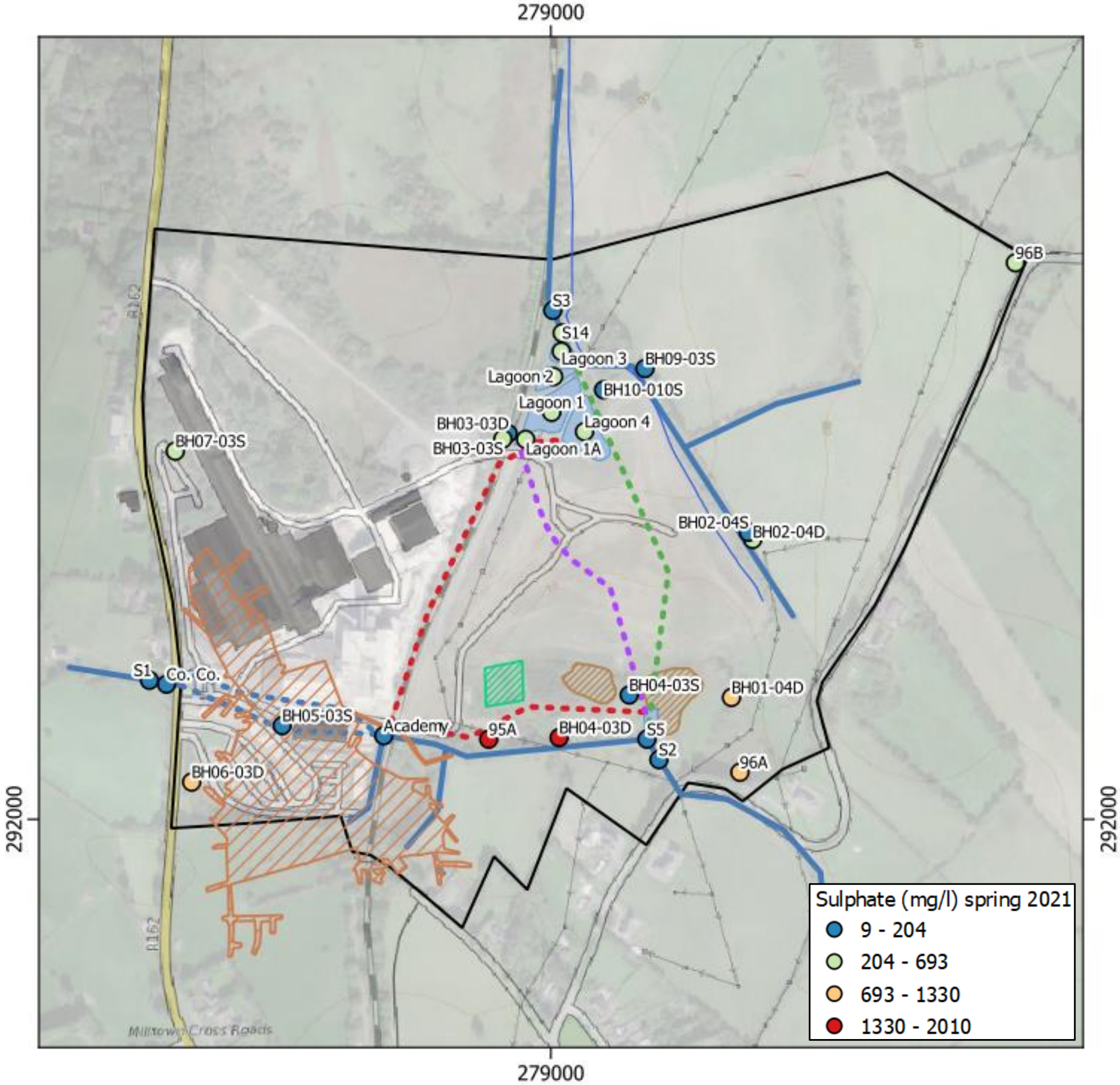


Figure 25 shows the distribution of sulphate across the site during March 2021. Sulphate is highest (1,330 mg/l to 2,010 mg/l) in deep wells 95A and BH04-03D. In contrast, sulphate is lower in deep borehole BH02-04D (9–204 mg/l). This may indicate some gypsum dissolution occurring, as fresh water that is unsaturated with gypsum enters the deeper groundwater system near 95A and BH04-03D.

Observed sulphate in the lagoons is between 693 mg/l and 1,330 mg/l likely due to a combination of runoff from site and circulation of water that is naturally high in sulphate.

Figure 25 Distribution of sulphate concentrations in site surface water and groundwater



3.5 Sources, Pathways and Receptors of Ammonia and Sulphate

The conceptual understanding for the movement of ammonia and sulphate through the site is illustrated in Figure 26 and 27. It appears the loading of both ammonia and sulphate in the waters is a combination of the local geological setting, the site topography (which causes bedrock groundwater discharge) and plant site activity. Key observations are as follows:

- Some of the groundwater monitoring wells appear to be influenced by the local peat deposits which likely contain elevated ammonia.
- The landfill leachate contains ammonia, but the volume and loading of this has reduced since the landfill was covered in March 2017. Nonetheless, there remains a correlation between ammonia at L50 (the landfill leachate sump located under a manhole cover just south of the landfill mound) and the downstream sampling location S3 (Figure 28).
- Agricultural products and effluent from local surface waters influence run off entering the site.
- Some site effluents (heat exchanger effluent) are known to contain up to 33 mg/l ammonia as N but are now no longer part of the discharge to the lagoon system and S14, as they are recycled back into the process directly.
- There may also be some influence of the on-site sewage treatment plant.

Most bedrock groundwater levels across the site area are observed to be higher than groundwater levels in the surficial deposits. The lower lying parts of the site are therefore a groundwater discharge location. Even though the bedrock groundwater units are not described as significant aquifers, it is clear they contribute groundwater flow and chemical mass loading. The presence of historical Lisnabo Mine workings also provides an interconnected pathway for movement of groundwater in the southwest part of the site.

The surficial glacial deposits in the plant side area support groundwater flow, with local groundwater flow pathways created by the sand and gravel lenses. As surficial groundwater moves downgradient to the north, it progressively discharges and enters the surface water system. The primary receptor of water from the site is the Mullantra Stream. Previously this was a water source for cattle. Borehole 96B has been provided for this purpose as an alternative.

Because the site is primarily a groundwater discharge location, groundwater movement away from the site area is limited. Based on the data available, there are no local groundwater sources that are likely to be affected by the site.

Figure 26 Conceptual figure for transport of ammonia and sulphate

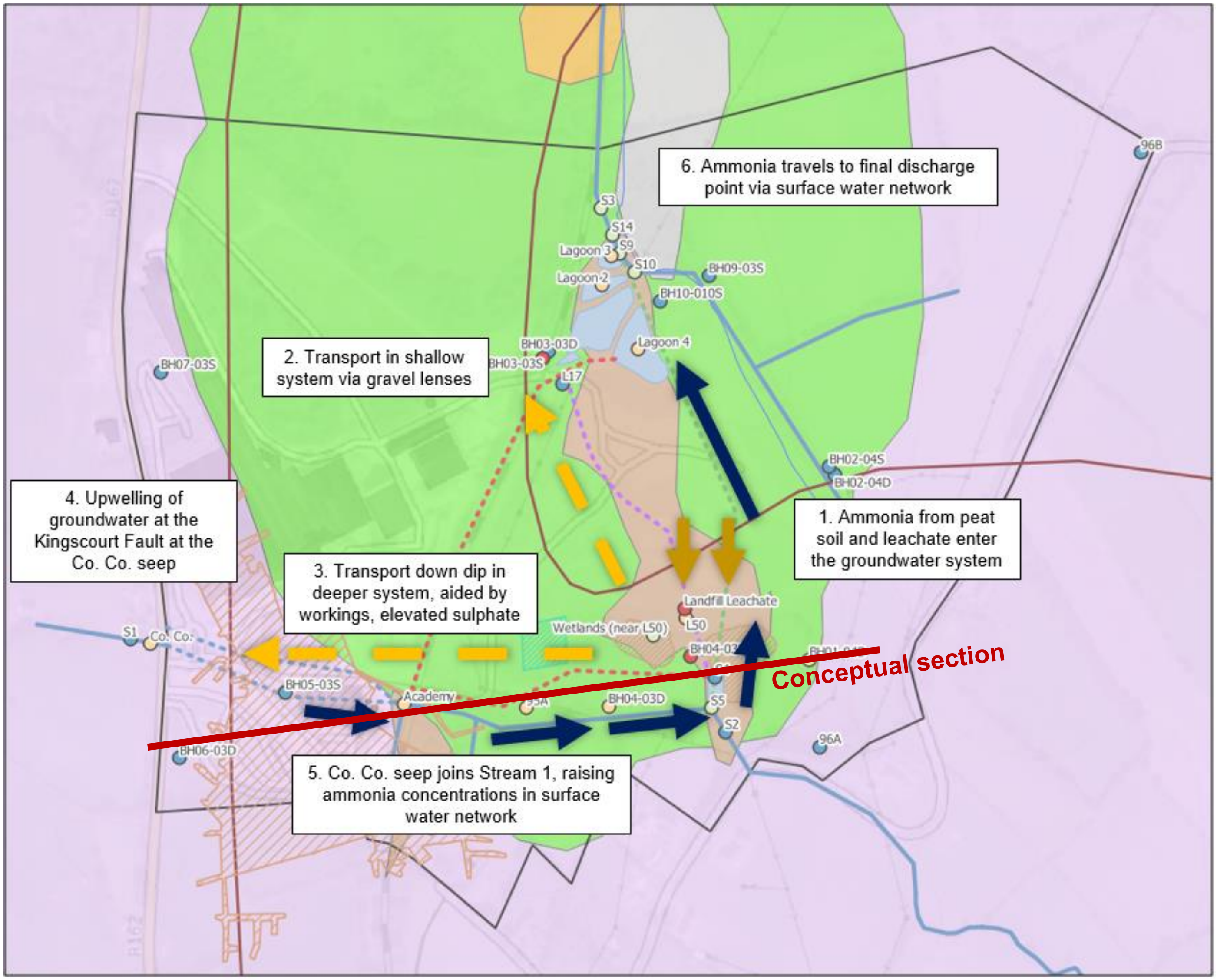


Figure 27 Conceptual section

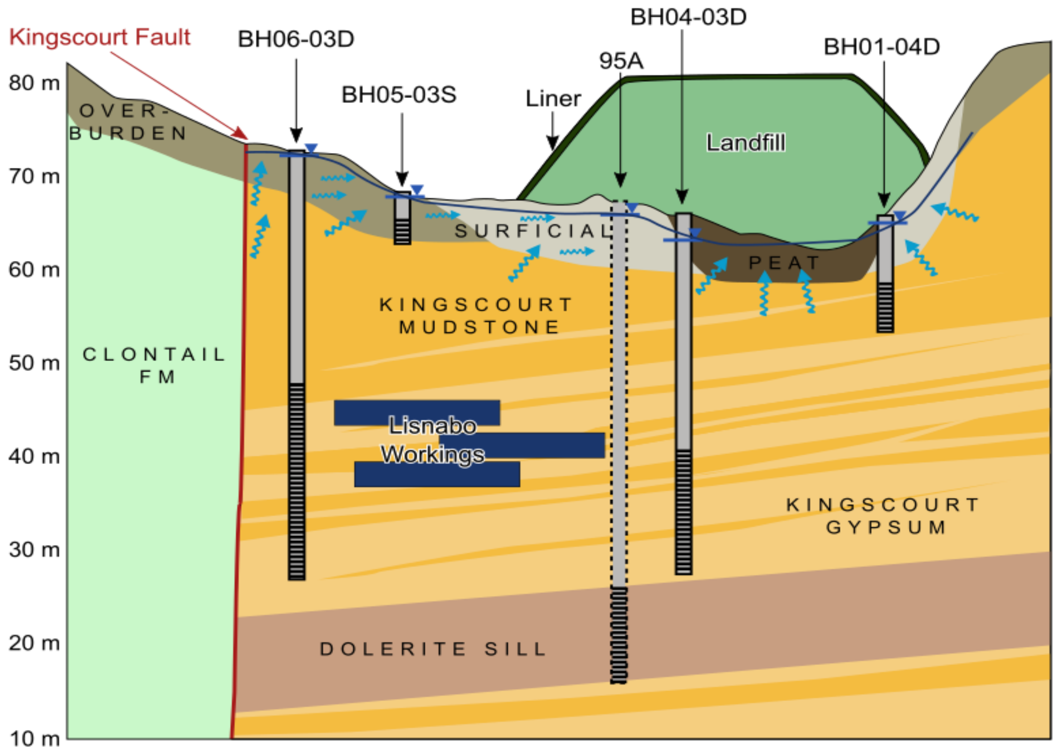
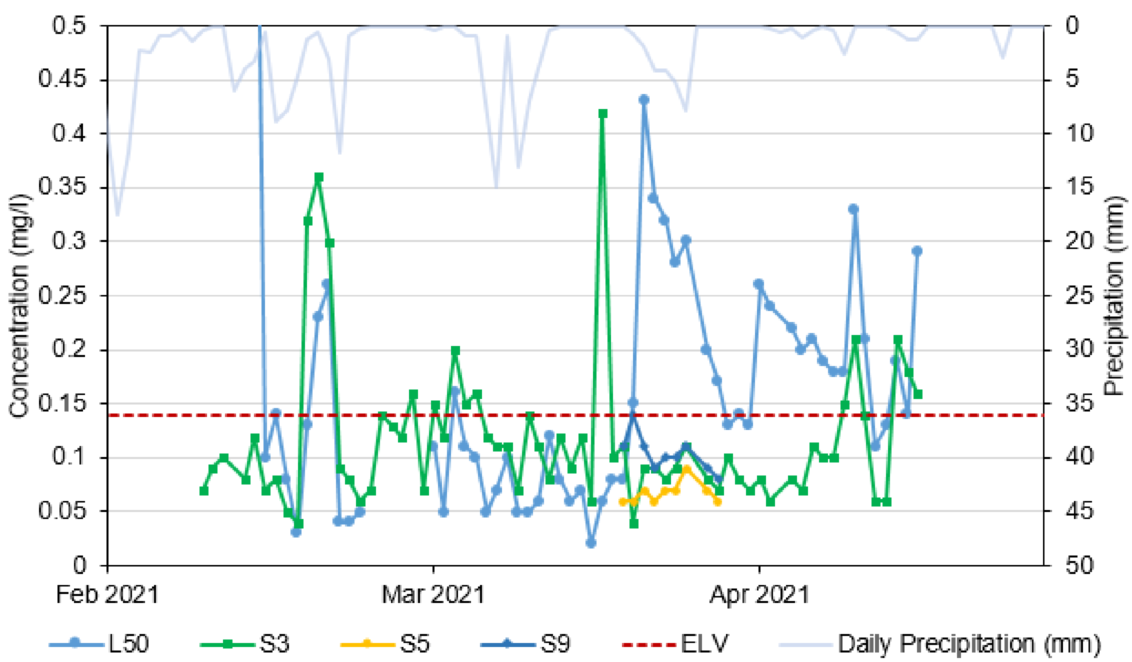


Figure 288 Correlation of ammonia at L50 with the downstream flows at S3



4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The key conclusions of the current study are as follows:

Conceptual hydrogeological model

- The site occurs in a groundwater discharge area. Consequently, groundwater is hydrogeologically well-contained and there is low potential for outward groundwater flow to the area surrounding the site.
- The local hydrogeology is dominated by mostly low permeability rocks, which supports that there is low potential for widespread lateral flow of groundwater.
- The hydrogeology is bounded to the west by the impermeable Kingscourt Fault and to the north and south by low permeability gypsum, mudstone and Westphalian rocks. The east of the site is geologically up dip, so eastward groundwater flow is unlikely.
- The location of the “Co. Co.” road water seep is coincident with the north-south trending Kingscourt Fault which appears to be forcing bedrock groundwater to surface.
- The historical Lisnabo Mine workings provide local continuity of groundwater levels and may be partly contributing to the spring at “Co. Co.” road (the “Co. Co. road water seep”).
- Most bedrock groundwater discharges into the local surficial glacial deposits in the lower lying parts of the site. Sand and gravel lenses within the surficial deposits are providing a medium for shallow groundwater flow.
- The ultimate discharge point for all site waters is the Mullantra stream. Some surficial groundwater also emerges at the wetlands around S4 pond.

Ammonia

- There appears to be several sources contributing to the observed ammonia distribution at the site, including local peat deposits, agriculture in the upgradient areas, bedrock groundwater, treated sewage effluent, historical leakage of leachate from the landfill and other plant site activities
- The dataset indicates that some ammonia is present in surface water upgradient of site. The source could potentially be natural (peat soils) or from agriculture. It is apparent that the surface water catchment both to the east and to the west has the potential for ammonia and nitrate sources (silage, slurry pits). GSI surficial deposit mapping shows several locations where peat horizons are present which may also be a source of ammonia.
- Some groundwater enters the surface water system through Stream 1 from the Co. Co. road water. The seep appears to be a prominent source of the observed ammonia at

Academy Weir and S3 downstream, as evidenced by correlation between ammonia trends at these sampling locations. The similar signature of ammonia between Co. Co. road water (groundwater) and S14 suggest that the water is from the same origin.

- Some residual seepage from the landfill is likely entering the groundwater network as the base of the landfill is unlined. Some residual landfill seepage is also observed to be entering the stream within the concrete pipe below the landfill. The movement of residual landfill seepage leachate may be influenced by the old mine workings and local gravel lenses. The landfill has been capped with an LLDPE liner since March 2017. It is expected the volume of landfill leachate will reduce through time due to the installation of the cover.
- Ammonia levels at the surface water S14 compliance point vary between 0.01 and 0.48 mg/l. The ELV (0.14 mg/l) was exceeded throughout January 2021, with further exceedances during February. One exceedance was noted in March. The exceedances typically correspond to peaks in ammonia concentrations at Academy Weir and in the Co. Co. water, as the origin of ammonia is likely from the same shallow groundwater source.
- Downstream of the site, 74% of the recently reported values for S3 are below 014 mg/l. Ammonia levels further reduce in the Mullantra stream as it flows downgradient of the site boundary.

Sulphate

- Elevated sulphate concentrations are expected in areas dominated by gypsum deposits due to dissolution of gypsum when in contact with fresh water.
- Much of the bedrock groundwater discharging at the site, from both the gypsum and mudstone strata, is naturally high in sulphate, creating a natural loading in the site groundwaters.
- There are other sources of gypsum due to activities at the site, notably in the lagoons and runoff from product storage yards, but it appears that the reported concentrations are typically lower than the observed concentrations in the natural strata.

4.2 Recommendations

The results of the study support the following recommendations:

- Continue monitoring of the leachate to quantify the future benefit of the landfill cover.
- Streamline the monitoring system by defining those parameters that are identified as constituents of concern and focussing the future monitoring on those parameters. This would make the hydrogeological dataset more manageable.
- Carry out an investigation into the site-scale ammonia loading. This should include several synoptic (snapshot) surveys of all watercourses and flows across and upgradient of the site. This will help to assess the background ammonia concentrations in water entering the

site, quantify the proportions of ammonia loading that are natural or derived from site activities or landfill, and ultimately help to establish the assimilative capacity of the Mullantra stream to receiving site discharge in excess of the background ammonia concentrations.

- Continue monitoring flow rates and water quality throughout the year to capture any seasonal variation, at locations including:
- Stream 1 before it enters the site at S1;
- Stream 1 at Academy Weir;
- Stream 2 at S2 before confluence with Stream 1;
- Confluence of Stream 1 and Stream 2 at S5;
- Stream 3 (Mullantra stream) at S10;
- Downstream of the point where Stream 1, Stream 3 (Mullantra) and S14 discharge merge at S3;
- S14 discharge point; and
- Any leachate flows (including L17 and L50).
- Consider diversion of the Co. Co. water for use in process as a means to help reduce the overall ammonia load entering the Mullantra stream at S3.

5. REFERENCES

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J. C.I. Dooge, 1974. The development of hydrological concepts in Britain and Ireland between 1674 and 1874, Hydrological Sciences Journal, 19:3, 279-302, DOI: 10.1080/02626667409493917.

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6. LIMITATIONS

This investigation has been conducted using a standard of care consistent with that expected of scientific and engineering professionals undertaking similar work under similar conditions in BC. No warranty is expressed or implied.

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Respectfully submitted,

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